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: Chlordane

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.

TABLE OF CONTENTS

	Page
PREFACE	i
1. INTRODUCTION..	1-1
2. PRELIMINARY CONCLUSIONS FOR CHLORDANE IN MUNICIPAL SEWAGE SLUDGE..	2-1
Landspreading and Distribution-and-Marketing	2-1
Landfilling	2-2
Incineration	2-2
Ocean Disposal	2-2
3. PRELIMINARY HAZARD INDICES FOR CHLORDANE IN MUNICIPAL SEWAGE SLUDGE..	3-1
Landspreading and Distribution-and-Marketing	3-1
Effect on soil concentration of chlordane (Index 1)	3-1
Effect on soil biota and predators of soil biota (Indices 2-3)	3-2
Effect on plants and plant tissue concentration (Indices 4-6)	3-4
Effect on herbivorous animals (Indices 7-8)	3-7
Effect on humans (Indices 9-13)	3-10
Landfilling	3-18
Index of groundwater concentration resulting from landfilled sludge (Index 1)	3-18
Index of human cancer risk resulting from groundwater contamination (Index 2)	3-25
Incineration	3-27
Index of air concentration increment resulting from incinerator emissions (Index 1)	3-27
Index of human cancer risk resulting from inhalation of incinerator emissions (Index 2)	3-29
Ocean Disposal	3-31
Index of seawater concentration resulting from initial mixing of sludge (Index 1)	3-31
Index of seawater concentration representing a 24-hour dumping cycle (Index 2)	3-35

TABLE OF CONTENTS
(Continued)

	Page
Index of hazard to aquatic life (Index 3)	3-36
Index of human cancer risk resulting from seafood consumption (Index 4)	3-37
4. PRELIMINARY DATA PROFILE FOR CHLORDANE IN MUNICIPAL SEWAGE SLUDGE	4-1
Occurrence	4-1
Sludge	4-1
Soil - Unpolluted	4-2
Water - Unpolluted	4-4
Air	4-5
Food	4-6
Human Effects	4-7
Ingestion	4-7
Inhalation	4-8
Plant Effects	4-9
Phytotoxicity	4-9
Uptake	4-9
Domestic Animal and Wildlife Effects	4-10
Toxicity	4-10
Uptake	4-10
Aquatic Life Effects	4-10
Toxicity	4-10
Uptake	4-11
Soil Biota Effects	4-11
Toxicity	4-11
Uptake	4-11
Physicochemical Data for Estimating Fate and Transport	4-11
5. REFERENCES	5-1
APPENDIX. PRELIMINARY HAZARD INDEX CALCULATIONS FOR CHLORDANE IN MUNICIPAL SEWAGE SLUDGE	A-1

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. Chlordane 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 chlordane 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.

---

* 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 CHLORDANE 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 Chlordane

Landspreading of sludge may slightly increase soil concentrations of chlordane (see Index 1).

B. Effect on Soil Biota and Predators of Soil Biota

Landspreading of sludge is not expected to result in soil concentrations of chlordane which pose a toxic hazard for soil biota (see Index 2). The toxicity of chlordane concentrations in tissues of organisms inhabiting sludge-amended soil to predators of soil biota could not be evaluated due to lack of data (see Index 3).

C. Effect on Plants and Plant Tissue Concentration

Landspreading of sludge is not expected to result in soil concentrations of chlordane which pose a phytotoxic hazard (see Index 4). The concentrations of chlordane in tissues of plants in the animal and human diet are expected to increase when sludge is landspread (see Index 5). Whether these increased tissue concentrations would be precluded by phytotoxicity could not be determined due to lack of data (see Index 6).

D. Effect on Herbivorous Animals

Plants grown in sludge-amended soil are unlikely to concentrate sufficient amounts of chlordane in their tissues to pose a toxic hazard to herbivorous animals (see Index 7). A toxic hazard due to chlordane is unlikely for grazing animals that incidentally ingest sludge or sludge-amended soil (see Index 8).

E. Effect on Humans

Landspreading of sludge may substantially increase the cancer risk due to chlordane, above the risk posed by pre-existing dietary sources, for humans who consume plants grown in sludge-amended soil (see Index 9). Substantial increases in cancer risk due to chlordane are also expected for humans who consume animal products derived from animals given feed grown on sludge-amended soil (see Index 10); and who consume animals products derived from grazing animals that incidentally ingest sludge or sludge-amended soil (see Index 11). Landspreading of sludge may moderately increase the cancer risk due to chlordane for toddlers who ingest sludge-amended soil. For adults who ingest sludge-amended soil, an increase in cancer risk due to chlordane above the risk posed by pre-existing dietary sources is not expected to occur except possibly when sludge with a high concentration of chlordane is applied at 50 mt/ha (see Index 12). The aggregate amount of chlordane in the human diet resulting from landspreading of sludge may substantially increase the cancer risk due to chlordane above the risk posed by pre-existing dietary sources (see Index 13).

II. LANDFILLING

Landfilling of sludge is expected to increase groundwater concentrations of chlordane at the well; this increase may be large at a disposal site with all worst-case conditions (see Index 1). Groundwater contamination resulting from landfilled sludge may slightly increase the human cancer risk due to chlordane above the risk posed by pre-existing dietary sources. This increase may be substantial when all worst-case conditions prevail at a disposal site (see Index 2).

III. INCINERATION

Incineration of sludge is expected to increase the air concentration of chlordane above background levels (see Index 1). Inhalation of emissions resulting from incineration of sludge is expected to increase the human cancer risk due to chlordane above the risk posed by background urban air concentrations of chlordane. This risk may be substantial when sludge containing a high concentration of chlordane is incinerated at a high feed rate and a large fraction of chlordane is emitted through the stack (see Index 2).

IV. OCEAN DISPOSAL

This assessment shows that a slight incremental increase of chlordane occurs both at the "typical" and "worst" disposal sites after initial mixing. Even calculating the index using the worst sludge concentration results in only a slight increase (see Index 1). This assessment indicates that over a 24-hour period the seawater concentration of chlordane does increase slightly (see Index 2).

This analysis indicates that potentially a tissue residue hazard may exist with the dumping of sludges with "typical" and "worst" concentrations of chlordane at the worst site. A hazard potentially exists for sludges containing "worst" concentrations of chlordane at the typical site (see Index 3).

This assessment indicates that in all scenarios evaluated, there is an increase in the human cancer risk resulting from seafood consumption. Significant risk is apparent in the evaluation of sludges containing high concentrations of chlordane at the "worst" site (see Index 4).

SECTION 3

PRELIMINARY HAZARD INDICES FOR CHLORDANE IN MUNICIPAL SEWAGE SLUDGE

I. LANDSPREADING AND DISTRIBUTION-AND-MARKETING

A. Effect on Soil Concentration of Chlordane

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 pre-existing 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 x 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	3.2 μg/g DW
Worst	12.0 μg/g DW

The above values are the mean and maximum concentrations of chlordane in sludge reported in the currently available literature, obtained from a survey of sludge from 74 wastewater treatment plants in Missouri (Clevenger et al., 1983). (See Section 4, p. 4-1.)

ii. **Background concentration of pollutant in soil (BS) = 0.0 μg/g DW**

A background concentration of zero is assumed based on the suspension of chlordane for agricultural use in 1975, a soil half-life of 14.3 months, and a pre-1975 mean concentration in agricultural soils of 0.003 μg/g DW (Carey et al., 1979b). (See Section 4, p. 4-3.)

iii. **Soil half-life of pollutant ($t_{\frac{1}{2}}$) = 1.19 years**

The half-life of chlordane is 14.3 months (Onsager et al., 1970). If first order of decay is assumed, 95 percent of chlordane will disappear from soil in approximately 5 years. These values are comparable to data reported by Matsumura (1972). (See Section 4, p. 4-12.)

d. **Index 1 Values (μg/g DW)**

Sludge Concentration	Sludge Application Rate (mt/ha)			
	0	5	50	500
Typical	0	0.0080	0.078	0.018
Worst	0	0.030	0.29	0.068

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

f. **Preliminary Conclusion** - Landspreading of sludge may slightly increase soil concentrations of chlordane.

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) = 2.8 μg/g DW**

Since soil molds and bacteria are important for soil fertility, they are chosen as the soil biota of interest. Chlordane in concentrations of 2.8 μg/g in fine sandy loam yields a 43 percent reduction in soil molds, although only a 3 percent reduction in soil bacteria occurs at this level. At approximately the same concentration in other soils, e.g., peat, the impact on soil molds is substantially less, but 19 and 24 percent reductions in soil bacteria counts occur. Doubling the soil concentration of chlordane in fine sandy loam yields approximately a doubling of the effect on soil molds. Assuming soil molds and bacteria to be equally important, the lowest concentration of chlordane in soil at which deleterious effects on soil biota begin to occur is 2.8 μg/g. Data on this relationship between chlordane levels in soil biota counts are from Bollen et al. (1954). (See Section 4, pp. 4-17 and 4-18.)

d. **Index 2 Values**

Sludge Concentration	Sludge Application Rate (mt/ha) 0	5	50	500
Typical	0.0	0.0028	0.028	0.0064
Worst	0.0	0.011	0.10	0.024

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 result in soil concentrations of chlordane which pose a toxic hazard for soil biota.

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)** - Data not immediately available.

iii. **Feed concentration toxic to predator (TR)** - Data not immediately available.

d. **Index 3 Values** - Values were not calculated due to lack of data.

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

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

Immediately available information on the phytotoxicity of chlordane is limited to the research of Eno and Everett (1958). They found that soil concentrations of chlordane of 12.5 µg/g resulted in a 19 percent reduction in the weight of bean roots and an 11 percent reduction in the weight of bean tops. Quadrupling the soil concentrations of chlordane resulted in less than a doubling of the effect on roots and only an additional 3 percent reduction in the weight of bean tops. The level of 12.5 µg/g, then, represents the lowest concentration of chlordane in soil at which a sufficient degree of phytotoxicity begins to be manifested. (See Section 4, p. 4-13.)

d. **Index 4 Values**

Sludge Concentration	Sludge Application Rate (mt/ha) 0	5	50	500
Typical	0	0.00064	0.0062	0.0014
Worst	0	0.0024	0.023	0.0054

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 chlordane 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)**

Animal Diet:
Corn (silage)
0.63 µg/g tissue DW (µg/g soil DW)$^{-1}$

Human Diet:
Sugar beets
2.28 µg/g tissue DW (µg/g soil DW)$^{-1}$

In view of the limited information available on chlordane uptake in plants, sugar beets and corn silage are taken as representative of plants in the human and animal diet, respectively. When sugar beets are grown in (loam) soils amended with chlordane at various application rates, the highest uptake factor observed in the root is 0.29 µg/g in wet weight and ∼2.28 µg/g in dry weight (Onsager et al., 1970). For corn (silage) grown in chlordane treated soils, the highest uptake factor is ∼0.63 µg/g DW (Fairchild, 1976). (See Section 4, p. 4-14.)

d. **Index 5 Values (µg/g DW)**

Diet	Sludge Concentration	Sludge Application Rate (mt/ha) 0	5	50	500
Animal	Typical	0.0	0.0050	0.049	0.011
	Worst	0.0	0.019	0.18	0.043
Human	Typical	0.0	0.018	0.18	0.041
	Worst	0.0	0.068	0.67	0.15

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** - The concentrations of chlordane in tissues of plants in the animal and human diet are expected to increase when sludge is landspread.

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.

d. **Index 6 Values (µg/g DW)** - Values were not calculated 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** - Conclusions were 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)**

The pollutant concentration values used are those Index 5 values for an animal diet (see Section 3, p. 3-6).

ii. **Feed concentration toxic to herbivorous animal (TA) = 2.5 μg/g DW**

Information on the dietary concentration of chlordane toxic to herbivorous animals is not immediately available. In lieu of more pertinent data, the lowest dietary concentration at which deleterious effects are observed in any animal species is used. This level is 2.5 μg/g which results in liver damage in rats (National Academy of Sciences (NAS), 1977). (See Section 4, p. 4-15.)

d. **Index 7 Values**

Sludge Concentration	Sludge Application Rate (mt/ha)			
	0	5	50	500
Typical	0	0.002	0.020	0.0046
Worst	0	0.0075	0.074	0.017

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** - Plants grown in sludge-amended soil are unlikely to concentrate sufficient amounts of chlordane in their tissues to pose a toxic hazard to herbivorous animals.

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	3.2 μg/g DW
Worst	12.0 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)** = 2.5 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	0.064	0.064	0.064
Worst	0	0.24	0.24	0.24

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** - A toxic hazard due to chlordane is unlikely for grazing animals that incidentally ingest sludge-amended soil.

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)**

The pollutant concentration values used are those Index 5 values for a human diet (see Section 3, p. 3-6).

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 (1984). 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	0.011 μg/day
Adult	0.079 μg/day

Food and Drug Administration (FDA) (1980a,b) Total Diet Studies found levels of chlordane infrequently. Total relative daily intake (μg/kg body weight/day) of chlordane or its related compounds, trans-nonachlordane and oxy-chlordane, are reported to range from 0.0009 to 0.0014 for the 1975-78 period; the median value is 0.00113 μg/kg body weight/day (FDA, no date). Assuming adult and toddler body weights of 70 and 10 kg, respectively, the level of intake is estimated as 0.011 μg/day for children and 0.079 μg/day for adults. (See Section 4, p. 4-6.)

iv. **Cancer potency** = 1.61 $(mg/kg/day)^{-1}$

The cancer potency is estimated by the U.S. EPA (1980) from data relating oral dosage of chlordane to the occurrence of liver carcinomas in mice. In this document it will be assumed that the persistent metabolites of chlordane such as oxychlordane are equally potent. This potency estimate will therefore be applied to total residues of chlordane and its metabolites in foods. (See Section 4, p. 4-7.)

v. **Cancer risk-specific intake (RSI)** = 0.0435 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**

Group	Sludge Concentration	Sludge Application Rate (mt/ha) 0	5	50	500
Toddler	Typical	0.26	31.0	300.0	71.0
	Worst	0.26	120.0	1100.0	260.0
Adult	Typical	1.8	86.0	840.0	200.0
	Worst	1.8	320.0	3100.0	730.0

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** - Landspreading of sludge may substantially increase the cancer risk due to chlordane, above the risk posed by pre-existing dietary sources, for humans who consume plants grown in sludge-amended soil.

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)**

The pollutant concentration values used are those Index 5 values for an animal diet (see Section 3, p. 3-6).

ii. **Uptake factor of pollutant in animal tissue (UA) = 0.48 μg/g tissue DW (μg/g feed DW)$^{-1}$**

The uptake factor value applies to cattle body fat for total chlordane isomers as determined by the experimental work of Dorough and Hemken (1973). This value is the highest available for herbivorous animals. (See Section 4, p. 4-16.)

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 (1984) 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	0.011 μg/day
Adult	0.079 μg/day

See Section 3, p. 3-11.

v. **Cancer risk-specific intake (RSI)** = 0.0435 µg/day

See Section 3, p. 3-11.

d. **Index 10 Values**

Group	Sludge Concentration	Sludge Application Rate (mt/ha) 0	5	50	500
Toddler	Typical	0.25	2.7	24.0	5.7
	Worst	0.25	9.3	89.0	21.0
Adult	Typical	1.8	6.7	50.0	13.0
	Worst	1.8	20.0	182.0	44.0

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

f. **Preliminary Conclusion** - Substantial increases in cancer risk due to chlordane are expected for humans who consume animals products derived from animals given feed grown on sludge-amended soil.

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 3.2 μg/g DW
Worst 12.0 μg/g DW

See Section 3, p. 3-1.

iii. **Background concentration of pollutant in soil (BS)** = 0 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)** = 0.48 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 0.011 μg/day
Adult 0.079 μg/day

See Section 3, p. 3-11.

viii. **Cancer risk-specific intake (RSI)** = 0.0435 μg/day

See Section 3, p. 3-11.

d. **Index 11 Values**

Group	Sludge Concentration	Sludge Application Rate (mt/ha) 0	5	50	500
Toddler	Typical	0.25	70.0	70.0	70.0
	Worst	0.25	260.0	260.0	260.0
Adult	Typical	1.8	150.0	150.0	150.0
	Worst	1.8	550.0	550.0	550.0

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

f. **Preliminary Conclusion** - Substantial increases in cancer risk due to chlordane are expected for humans who consume animal products derived from grazing animals that incidentally ingest sludge or sludge-amended soil.

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 an 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, 1984.

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

Toddler 0.011 µg/day
Adult 0.079 µg/day

See Section 3, p. 3-11.

iv. **Cancer risk-specific intake (RSI)** = 0.0435 µg/day

See Section 3, p. 3-11.

d. **Index 12 Values**

Group	Sludge Concentration	Sludge Application Rate (mt/ha) 0	5	50	500
Toddler	Typical	0.25	1.2	9.2	2.3
	Worst	0.25	3.7	34.0	8.0
Adult	Typical	1.8	1.8	1.8	1.8
	Worst	1.8	1.8	2.0	1.8

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

f. **Preliminary Conclusion** - Landspreading of sludge may moderately increase the cancer risk due to chlordane for toddlers who ingest sludge-amended soil. For adults who ingest sludge-amended soil, an increase in cancer risk due to chlordane above the risk posed by pre-existing dietary sources is not expected to occur except when sludge with a high concentration of chlordane is applied at 50 mt/ha.

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**

Group	Sludge Concentration	Sludge Application Rate (mt/ha) 0	5	50	500
Toddler	Typical	0.25	100.0	410.0	150.0
	Worst	0.25	390.0	1500.0	550.0
Adult	Typical	1.8	240.0	1000.0	350.0
	Worst	1.8	890.0	3900.0	1300.0

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

f. **Preliminary Conclusion** - The aggregate amount of chlordane in the human diet resulting from land-spreading of sludge may substantially increase the cancer risk due to chlordane above the risk posed by pre-existing dietary sources.

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 3.2 mg/kg DW
Worst 12.0 mg/kg DW

(b) **Soil half-life of pollutant ($t_{\frac{1}{2}}$) = 434 days**

See Section 3, p. 3-2.

(c) **Degradation rate (μ) = 0.0016 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:

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

(d) **Organic carbon partition coefficient (K_{oc}) = 170,000 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 (ø)**

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** - Landfilling of sludge is expected to increase groundwater concentrations of chlordane at the well; this increase may be large at a disposal site with all worst-case conditions.

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. 3-2.

   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) = 0.079 μg/day**

   See Section 3, p. 3-11.

   d. **Cancer potency = 1.61 $(mg/kg/day)^{-1}$**

   See Section 3, p. 3-11.

   e. **Cancer risk-specific intake (RSI) = 0.0435 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:

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

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 pre-existing dietary sources.

6. **Preliminary Conclusion** - Groundwater contamination resulting from landfilled sludge may slight increase the human cancer risk due to chlordane above the risk posed

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)

	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)	0.044	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).

by pre-existing dietary sources. This increase may be substantial when all worst-case conditions prevail at a disposal site.

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.

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	3.2 mg/kg DW
Worst	12.0 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 $\mu g/m^3$
Worst	16.0 $\mu g/m^3$

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

f. **Background concentration of pollutant in urban air (BA)** = 8.8 x 10^{-4} $\mu g/m^3$

Ambient urban air concentrations of chlordane for Columbia, SC, Boston, and Denver ranged between 0.04 and 5.9 ng/m^3 for the 1980-81 period. Because of the skewed distribution, the median value of 0.88 ng/m^3 is used as a first approximation of ambient urban air levels of chlordane. The data are from Bidleman (1981) and Billings and Bidleman (1983). (See Section 4, p. 4-5.)

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	1.4	9.09
	Worst	1.0	2.7	31.0
Worst	Typical	1.0	2.8	33.0
	Worst	1.0	7.8	120.0

[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** - Incineration of sludge is expected to increase the air concentration of chlordane above background 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}. For non-carcinogens, levels typically were derived from the American Conference of Government Industrial Hygienists (ACGIH) threshold limit values (TLVs) for the workplace.

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. 3-1.

b. **Background concentration of pollutant in urban air (BA) = 8.8×10^{-4} μg/m³**

See Section 3, p. 3-28.

c. **Cancer potency** = 1.61 $(mg/kg/day)^{-1}$

This potency estimate was derived from that for ingestion assuming 100% absorption for both the ingestion and inhalation routes. (See Section 4, p. 4-7.)

d. **Exposure criterion (EC)** = 2.17×10^{-3} μg/m³

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	0.41	0.59	3.7
	Worst	0.41	1.1	13.0
Worst	Typical	0.41	1.1	14.0
	Worst	0.41	3.2	49.6

[a] The typical (3.4 μg/m³) and worst (16.0 μg/m³) 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 resulting from incineration of sludge is expected to increase the human cancer risk due to chlordane above the risk posed by background urban air concentrations of chlordane. This risk may be substantial when sludge containing a high concentration of chlordane is incinerated at a high feed rate and a large fraction of chlordane is emitted through the stack.

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 7.5×10^6 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 described 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	3.2 mg/kg DW
Worst	12.0 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 m + 1 cm/sec x 4 hours x 3600 sec/hour x 0.01 m/cm
= 184 m = approximately 200 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	0.0064	0.0064
	Worst	0.0	0.0024	0.0024
Worst	Typical	0.0	0.054	0.054
	Worst	0.0	0.20	0.20

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

7. **Preliminary Conclusion** - This assessment shows that a slight incremental increase of chlordane occurs both at the "typical" and "worst" disposal sites after initial

mixing. Even calculating the index using the worst sludge concentration results in only a slight increase.

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. 3-32 to 3-33.

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

   See Section 3, p. 3-35.

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	0.0017	0.003
	Worst	0.0	0.006	0.013
Worst	Typical	0.0	0.015	0.030
	Worst	0.0	0.057	0.11

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

7. **Preliminary Conclusion** - This assessment indicates that over a 24-hour period the seawater concentration of chlordane does increase slightly.

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

1. **Explanation** - Compares the effective increased concentration of pollutant in seawater around the disposal site (Index 2) expressed as a 24-hour TWA concentration with the marine ambient water quality criterion of the pollutant, or with another value judged protective of marine aquatic life. For chlordane, this value is the criterion that will protect the marketability of edible marine aquatic organisms.

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 2)**

See Section 3, p. 3-35.

b. **Ambient water quality criterion (AWQC) = 0.004 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 chlordane.

The 0.004 µg/L value chosen as the criterion to protect saltwater organisms is expressed as a 24 hour average concentration (U.S. EPA, 1980). This concentration, the saltwater final residue value, was derived by using the FDA action level for marketability for human consumption of chlordane in edible fish and shellfish (0.3 mg/kg), the geometric mean of normalized bioconcentration factor (BCF) values (4702) for aquatic species tested and the 16 percent lipid content of marine species. To protect against acute toxic effects, chlordane concentration should not exceed 0.09 µg/L at any time.

4. **Index 3 Values**

Disposal Conditions and Site Characteristics	Sludge Concentration	Sludge Disposal Rate (mt DW/day) 0	825	1650
Typical	Typical	0.0	0.43	0.86
	Worst	0.0	1.6	3.2
Worst	Typical	0.0	3.8	7.5
	Worst	0.0	14.3	29.0

5. **Value Interpretation** - Value equals the factor by which the expected seawater concentration increase in chlordane exceeds the marine water quality criterion. A value >1 indicates that a tissue residue hazard may exist for aquatic life. Even for values approaching 1, a chlordane residue in tissue hazard may exist thus jeopardizing the marketability of edible saltwater organisms. The criterion value of 0.004 µg/L is probably too high because on the average, the chlordane tissue residue concentration in 50 percent of species similar to those used to derived the criterion value will exceed the FDA action level (U.S. EPA, 1980).

6. **Preliminary Conclusion** - This analysis indicates that potentially a tissue residue hazard may exist with the dumping of sludges with "typical" and "worst" concentrations of chlordane at the worst site. A hazard potentially exists for sludges containing "worst" concentrations of chlordane at the typical site.

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:

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

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

For the worst (near shore) site:

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

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

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:

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

For the worst (near shore) site:

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

d. **Bioconcentration factor of pollutant (BCF) =** 14,100 L/kg

The value chosen is the weighted average BCF of chlordane for the edible portion of all freshwater and estuarine aquatic organisms consumed by U.S. citizens (U.S. EPA, 1980). 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 chlordane induced by ingestion of contaminated water and aquatic organisms. The weighted average BCF is calculated by adjusting the mean normalized BCF (steady-state BCF corrected to 1 percent lipid content) to the 3 percent lipid content of consumed fish and shellfish. 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)** = 0.079 μg/day

See Section 3, p. 3-11.

f. **Cancer risk-specific intake (RSI)** = 0.043 μg/day

See Section 3, p. 3-11.

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	1.8	1.8	1.8
	Worst	Worst	1.8	12	21
Worst	Typical	Typical	1.8	1.8	1.8
	Worst	Worst	1.8	33	64

[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** - This assessment indicates that in all scenarios evaluated, there is an increase in the human cancer risk resulting from seafood consumption. Significant risk is apparent in the evaluation of sludges containing high concentrations of chlordane at the "worst" site.

SECTION 4

PRELIMINARY DATA PROFILE FOR CHLORDANE IN MUNICIPAL SEWAGE SLUDGE

I. OCCURRENCE

The use and production of chlordane has decreased extensively since the U.S. EPA registration suspension notice in 1975. Significant termite control usage continues.

A. Sludge

1. Frequency of Detection

Chlordane observed in the influent/effluent of 40 POTWs but not in the sludges. — U.S. EPA, 1982 (p. 36-42)

Chlordane not observed in influent/effluent and sludges of 10 POTWs. — U.S. EPA, 1982 (p. 45-50)

2. Concentration

Composite sludge samples - Metro Denver: — Baxter et al., 1983 (p. 315)

Digested: 1345 ng/g WW
Waste-activated: 636 ng/g WW

Sludge from 88 POTWs (μg/g DW): — CDM, 1984d (p. 8)

Min	Max	Wt. Mean
0.017	12	3.01

Sludge from 74 cities (μg/g DW): — Clevenger et al., 1983 (p. 1471)

Min	Max	Mean	Median
0.46	12	3.2	2.75

<10 μg/L in sludges from five sludge sources in Chicago — Jones and Lee, 1977 (p. 52)

B. Soil - Unpolluted

1. Frequency of Detection

69 out of 356 urban soil samples (19%) from 14 U.S. cities contained chlordane in 1970. Detected in all cities.	Carey et al., 1976 (p. 56-58)
105 out of 380 urban soil samples (28%) from 5 U.S. cities contained chlordane in 1971. Detected in all cities.	Carey et al., 1979a (p. 19)
22 out of 37 states and 119 out of 1,468 cropland soil samples (8%) contained chlordane in 1971.	Carey et al., 1978 (p. 120-8)
24 out of 37 states and 117 out of 1,483 cropland soil samples (7.9%) contained chlordane in 1972.	Carey et al., 1979b (p.214-20)
1.1% of 90 hayfield soil samples from 9 states contained chlordane in 1971.	Gowen et al., 1976 (p. 115)
21 out of 99 soil samples (21.2%) from rice growing areas in 5 states contained chlordane. The 21 samples were all from 2 out of the 5 states in 1972.	Carey et al., 1980 (p. 25)
Residues in soil from randomly selected sites on six U.S. Air Force bases with histories of pesticide use:	Lang et al., 1979 (p. 231)

Soil Use	% Pos. Sites 1975	1976
Residential Soils -	65	9.5
Non-use Soils -	24	14
Golf Course Soils -	58.8	35.3

2. Concentration

Control and sludge-applied soils: <125 ng/g	Baxter et al., 1983 (p. 315)
Range of geometric means in urban soil samples from 14 U.S. cities (1970): 0.0015 to 0.0705 µg/g	Carey et al., 1976 (p. 56-58)

Total Range (μg/g)	Mean of Arithmetic Means (μg/g)	Mean of Geometric Means (μg/g)
<0.04-13.90	0.35	0.0194

0.0008 to 0.0131 μg/g (DW) in cropland soils from 12 states (1970)	Carey et al., 1976 (p. 59)
1.1% of hayfield soils from 9 states contained chlordane at a maximum level of 0.04 μg/g (DW) and an arithmetic mean of <0.01 μg/g (1971 data)	Gowen et al., 1976 (p. 115)

Chlordane Levels in Various Soils

Soil use	Total Range (μg/g DW)	Arithmetic Mean (μg/g DW)	Geometric Mean (μg/g DW)	Reference
Urban (1971)	0.01-140.69	0.904	0.0208	Carey et al., 1979a (p. 19)
Cropland (1971)	0.01-6.98	0.06	0.003	Carey et al., 1978 (p. 120)
Cropland (1972)	0.01-7.89	0.05	0.003	Carey et al., 1979b (p. 212)
Rice Growing (1972)	0.01-0.27	0.02	--	Carey et al., 1980 (p. 25)

Residues in soils (μg/g DW) from U.S. Air Force bases: — Lang et al., 1979 (p. 231)

Soil Use	Levels: Range	Average
	1975	
Residential	N.D.-52.11	5.43
Non-use	N.D.-1.76	0.09
Golf Course	N.D.-4.57	0.67
	1976	
Residential	N.D.-1.20	0.16
Non-use	N.D.-3.44	0.18
Golf Course	N.D.-3.05	0.56

C. Water - Unpolluted

1. Frequency of Detection

% occurrence in surface water — Matsumura, 1972 (p. 59)

1966	1967	1968
5%	2.5%	2.5%

No chlordane found in samples from 33 sites in the Upper Great Lakes in 1974 (D.L. = 0.01 μg/L). — Glooschenko et al., 1976

20% of 500 samples of drinking and river water from the Mississippi and Missouri Rivers in 1968 contained chlordane. — NAS, 1977 (p. 557-8)

2. Concentration

a. Freshwater

0.1 ng/L (mean) 76.0 ng/L (max) for major U.S. rivers (1967)
7.0 ng/L (mean), 13.0 ng/L (max) for drinking water (Hawaii, 1971). — Edwards, 1973 (p. 440-1)

b. Seawater

Data not immediately available.

c. Drinking Water

20% of 500 samples of drinking and river water from the Mississippi and Missouri Rivers containing chlordane at up to 0.5 μg/L (1968) — NAS, 1977 (p. 557-558)

Suggested standard limit for drinking water: 52 μg/L — NAS, 1977 (p. 794)

Highest observed concentration in finished water: 0.1 μg/L — NAS, 1977 (p. 794)

In a chlordane contamination incident, uncontaminated water levels of chlordane ranged from 0.1 to 4.6 μg/L. — Harrington et al., 1978 (p. 157)

D. Air

1. Frequency of Detection

In 880 samples from 9 localities in the U.S. in 1968, no samples contained chlordane. — Stanley et al., 1971 (p. 434)

Only 2 out of 2,479 samples collected at 45 sites in 16 states contained chlordane. — U.S. EPA, 1980 (p. C-4)

2. Concentration

a. Urban

Mean Concentrations (ng/m^3) in Urban Air Samples — Billings and Bidleman, 1983 (p. 388-89); Bidleman, 1981 (p. 623)

Location	1980	1981
Boston, MA	0.72	--
Columbia, SC	5.9	1.04
Denver, CO	--	0.04

b. Rural

Wheatley, 1973 (p. 391)

Florida	Range of Concentrations (ng/m^3)
6 small communities in usage area	0.1-6
1 rural area during usage	1-31

Two out of 2,479 samples collected at 45 sites in 16 states contained chlordane with concentrations of 84 and 204 ng/m^3. — U.S. EPA, 1980 (p. C-4)

Chlordane levels in air samples collected in 1979: — Atlas and Giam, 1980 (p. 164)

Location	Concentration (ng/m^3)
Enewtak Atoll (North Pacific)	0.012
North Atlantic	0.03
College Station, TX	1.26

E. Food

1. Total Average Intake

FDA Total Diet Studies - FY75-FY78 — FDA, No date, (Attachment G)

Fiscal Year	Total Relative Daily Intake (μg/kg body wt/day)
FY75	N.D.
FY76	0.0009
FY77	0.0011
FY78	0.0014

2. Concentration

Chlordane occurred in one out of 20 potato samples and one out of 20 leafy vegetable samples in 1978. The residue range for both samples together was 0.0009 to 0.010 μg/g. — FDA, No date, (Attachment E)

Out of 420 composite samples representing 35 market baskets from 32 cities, one grain and cereal samples contained chlordane at a level of 0.05 μg/g (1971-1972). — Manske and Johnson, 1975 (p. 99)

Out of 360 composite samples representing 30 market baskets from 30 cities, one garden fruits sample contained a trace level of chlordane. — Johnson and Manske, 1976 (p. 165)

Chlordane in cow's milk (μg/g) - Illinois, 1971-76, Summary (1,169 samples):	Wedberg et al., 1978 (p. 164)

% Pos. Samples	Avg. μg/g	% Samples 0.01-0.10	% Samples 0.11-0.10
69	0.03	94	6

II. HUMAN EFFECTS

A. Ingestion

1. Carcinogenicity

a. Qualitative Assessment

Chlordane is suspected of being a human carcinogen.	U.S. EPA, 1980 (p. C-20)

b. Potency

Daily intake resulting in estimated upper-bound cancer risk of 10^{-6} = 4.35×10^{-2} μg/day	U.S. EPA, 1980 (p. C-31)
Cancer potency is 1.61 $(mg/kg/day)^{-1}$	U.S. EPA, 1980 (p. C-31)

c. Effects

Liver tumors in mice	U.S. EPA, 1980 (p. C-15)

2. Chronic Toxicity

a. ADI

70 μg chlordane/day: Based on FAO and WHO values of 0.001 mg chlordane/kg body weight	FAO/WHO, 1968, in U.S. EPA, 1980 (p. C-19)

b. Effects

Seizures, electroencephalographic dysrhythmia, convulsions and twitching	U.S. EPA, 1980 (p. C-8)

3. **Absorption Factor**

10 to 15% absorption for small daily doses	U.S. EPA, 1980 (p. C-5)

4. **Existing Regulations**

Ambient Water Quality Criteria	U.S. EPA, 1980 (p. C-21)

Exposure Assumptions (per day)	Risk Levels and Corresponding Criteria (ng/L) 0	10^{-7}	10^{-6}	10^{-5}
2 liters of drinking water and consumption of 6.5 g fish and shellfish	0	0.046	0.46	4.6
Consumption of fish and shellfish only	0	0.048	0.48	4.8

U.S. EPA drinking water regulations, the Canadian standards and National Technical Advisory Committee suggest 3 µg/L for drinking water.	U.S. EPA, 1980 (p. C-19)

B. **Inhalation**

1. **Carcinogenicity**

A cancer potency of 1.61 $(mg/kg/day)^{-1}$ is used and is derived from that for ingestion, assuming equivalent absorption for both inhalation and ingestion routes.	U.S. EPA, 1980

2. **Chronic Toxicity**

Data not assessed since evaluation based on carcinogenicity.

3. **Absorption Factor**

Data not immediately available.

4. **Existing Regulations**

Time weighted average of chlordane in air should not exceed 0.5 mg/m^3. Short-term (15 min.) exposure limit = 2 mg/m^3.	U.S. EPA, 1980 (p. C-18)

III. PLANT EFFECTS

A. Phytotoxicity

See Table 4-1.

B. Uptake

1. Normal range of concentrations in edible tissue

Residue in crops, 1972	Carey et al., 1979b (pp. 222 to 225)

Crop	Range (µg/g DW)	Arithmetic Mean	Geometric Mean
Alfalfa	0.04-0.24	0.02	0.005
Clover	0.07-0.10	0.02	0.008
Field corn kernels	0.01-0.15	<0.01	<0.001
Grass hay	0.09	0.01	0.003
Mixed hay	0.05-0.44	0.03	0.008
Rye	0.08	0.08	--
Soybeans	0.07	<0.01	

2. Concentration factor for edible tissue concentration versus application rate to soil

See Table 4-2.

Sugar beets: residues in tissue averaged 9.6% of the amount in the soil in which they were grown	Edwards, 1973 (p. 420)
0.12 µg/g in sugar beets following soil application of 11.2 kg/ha	Finlayson and MacCarthy, 1973 (p. 63)
Chlordane residues in fresh cut alfalfa 21 days after field treatment:	Dorough et al., 1972 (p. 46)

Treatment Level	Residue (µg/g DW)
1 lb/acre	2.4±0.60
2 lb/acre	4.02±1.07

IV. DOMESTIC ANIMAL AND WILDLIFE EFFECTS

A. Toxicity

See Table 4-3.

B. Uptake

See Table 4-4.

Residues in 168 bald eagles from 29 states: 1975-77 — Kaiser et al., 1980 (p. 147)

Year	Carcass (μg/g WW) Median	Carcass (μg/g WW) Range	Brain (μg/g WW) Median	Brain (μg/g WW) Range
1975	0.32	0.11-4.5	0.19	0.07-1.3
1976	0.24	0.05-1.7	0.09	0.05-1.2
1977	0.22	0.07-2.2	0.19	0.06-6.4

Residues of chlordane in livestock and poultry fat tissue: 1967-1974 — Fairchild, 1976 (p. 61)

Year	Number of Samples	No. of Samples With Residues	% of Samples With Residues	Residue Range (μg/g) 0.01-0.10	0.11-0.50	0.51-1.50	>1.50
Livestock							
1967	2785	11	0.4	2	8	0	1
1970	3500	2	0.06	0	0	2	0
1973	1070	7	0.7	4	2	1	0
1974	2256	398	17.7	393	2	1	2
Poultry							
1967	No Report						
1970	2972	0	0	0	0	0	0
1973	1142	7	0.6	0	7	0	0
1974	1916	38	2.8	38	0	0	0

V. AQUATIC LIFE EFFECTS

A. Toxicity

1. Freshwater

Criterion to protect freshwater aquatic organisms is 0.0043 μg/L as a 24-hour — U.S. EPA, 1980 (p. B-7) average concentration, not to exceed 2.4 µg/L at any time.

2. **Saltwater**

Criterion to protect saltwater aquatic organisms is 0.0040 µg/L as a 24-hour average concentration, not to exceed 0.09 µg/L at any time.	U.S. EPA, 1980 (p. B-8)

B. Uptake

Average weighted BCF for the edible portion of all freshwater and estuarine aquatic organisms consumed by U.S. citizens is 14,100 L/kg.	U.S. EPA, 1980 (p. C-3)

VI. SOIL BIOTA EFFECTS

A. Toxicity

See Table 4-5.

Chlordane is reported to be "very toxic" to earthworms relative to other pesticides.	Edwards, 1973 (p. 430)

B. Uptake

Data not immediately available.

VII. PHYSICOCHEMICAL DATA FOR ESTIMATING FATE AND TRANSPORT

Molecular weight: 410 Physical state: Colorless, odorless, viscous fluid Specific gravity: 1.57 to 1.67 Soluble in many organic solvents Solubility in water: 9 µg/L at 25°C Chemical name: 1,2,4,5,6,7,8,8-Octachloro-4,7-methano-3a,4.7,7a-tetrahydroindane Chemical formula: $C_{10}H_6Cl_8$ Vapor pressure: 0.00001 mm Hg at 20°C .67 Organic carbon partition coefficient: 170,000 mL/g	NRC, 1982 (p. 51)
Water solubility at 20 to 30°C: 0.1 mg/L	Edwards, 1973 (p. 447)
"Relatively immobile" in soil R_f (Relative to fructose) = 0.09 to 0.00	Lawless et al., 1975 (p. 51)
Persistence in soil = 5 years	Lawless et al., 1975 (p. 52)

Vapor pressure = 1×10^{-5} mm Hg at 25°C	Finlayson and MacCarthy, 1973 (p. 67)
Half-life of chlordane in soil = 14.3 months	Onsager et al., 1970 (p. 1145)
95% disappearance of chlordane from the soil requires 3 to 5 years	Matsumura, 1972 (p. 39)

TABLE 4-1. PHYTOTOXICITY OF CHLORDANE

Plant/Tissue	Chemical Form Applied	Growth Medium	Control Tissue Concentration (μg/g DW)	Soil Concentration (μg/g DW)	Application Rate (kg/ha)	Experimental Tissue Concentration (μg/g DW)	Effects	References
Black valentine bean/seed	chlordane	loamy sand (pot)	NR[a]	12.5	NA[b]	NR	4% increased germination	Eno and Everett, 1958 (p. 236)
Black valentine bean/seed	chlordane	loamy sand (pot)	NR	50	NA	NR	4% increased germination	Eno and Everett, 1958 (p. 236)
Black valentine bean/seed	chlordane	loamy sand (pot)	NR	100	NA	NR	8% increased germination	Eno and Everett, 1958 (p. 236)
Black valentine bean/root	chlordane	loamy sand (pot)	NR	12.5	NA	NR	19% reduced weight	Eno and Everett, 1958 (p. 236)
Black valentine bean/root	chlordane	loamy sand (pot)	NR	50	NA	NR	30% reduced weight	Eno and Everett, 1958 (p. 236)
Black valentine bean/root	chlordane	loamy sand (pot)	NR	100	NA	NR	19% reduced weight	Eno and Everett, 1958 (p. 236)
Black valentine bean/top	chlordane	loamy sand	NR	12.5	NA	NR	11% reduced weight	Eno and Everett, 1958 (p. 236)
Black valentine bean/top	chlordane	loamy sand (pot)	NR	50	NA	NR	14% reduced weight	Eno and Everett, 1958 (p. 236)
Black valentine bean/root	chlordane	loamy sand (pot)	NR	100	NA	NR	12% reduced weight	Eno and Everett, 1958 (p. 236)

[a] NR = Not reported.
[b] NA = Not available.

TABLE 4-2. UPTAKE OF CHLORDANE BY PLANTS

Plant	Tissue	Soil Type	Chemical Form Applied	Soil Concentration (µg/g)	Control Tissue Concentration (µg/g)	Uptake Factor[a]	References
Corn	plant	agricultural	chlordane	0.053	<0.008	<0.15	Fairchild, 1976 (p. 58)
Corn	silage	agricultural	chlordane (alpha and gamma)	0.18	0.034 0.116[b]	0.19 0.63	Fairchild, 1976 (p. 58)
Corn	grain	agricultural	chlordane (alpha and gamma)	0.17	0.008	0.05	Fairchild, 1976 (p. 58)
Corn	stalk	agricultural	chlordane (alpha and gamma)	0.17	0.020	0.12	Fairchild, 1976 (p. 58)
Soybean	plant	agricultural	chlordane (alpha and gamma)	0.02	<0.0001 <0.0003[b]	<0.01 <0.015	Fairchild, 1976 (p. 58)
Sugar beet	plant	agricultural	chlordane (alpha and gamma)	1.233	0.224	0.18	Fairchild, 1976 (p. 58)
Sweet potato	plant	agricultural	chlordane (alpha and gamma)	0.28	0.001	<0.01	Fairchild, 1976 (p. 58)
Sugar beet	root	loam (field)	chlordane	0.18	0.02 0.16[b]	0.11 0.89	Onsager et al., 1970 (p. 1144)
Sugar beet	root	loam (field)	chlordane	0.67	0.08 0.63[b]	0.12 0.94	Onsager et al., 1970 (p. 1144)
Sugar beet	root	loam (field)	chlordane	1.28	0.37 2.91[b]	0.29 2.28	Onsager et al., 1970 (p. 1144)
Sugar beet	root	loam (field)	chlordane	2.90	0.61 4.80[b]	0.21 1.66	Onsager et al., 1970 (p. 1144)
Sugar beet	root	loam (field)	chlordane	4.42	0.73 5.75[b]	0.17 1.30	Onsager et al., 1970 (p. 1144)
Sugar beet	root	loam (field)	chlordane	4.14	1.12 8.82[b]	0.27 2.13	Onsager et al., 1970 (p. 1144)

[a] Uptake factor = tissue concentration/soil concentration.

[b] Tissue concentration in DW; adjustment assumes the raw sugar beet has the same water content as raw common red beets which is 87.3%, while corn silage is taken as 70% water (Barnes, 1976), raw soybeans (immature) are 69.2% water (USDA, 1963).

TABLE 4-3. TOXICITY OF CHLORDANE TO DOMESTIC ANIMALS AND WILDLIFE

Species (N)[a]	Chemical Form Fed	Feed Concentration (μg/g)	Water Concentration (mg/L)	Daily Intake (mg/kg)	Duration of Study	Effects	References
Mallard	chlordane	NR[b]	NR	1,200	8 days	LD_{50}	Tucker and Crabtree, 1970 (p. 35)
Rat	chlordane	NR	NR	283	NR	LD_{50}	Lawless et al., 1975 (p. 37)
Rat	chlordane	2.5	NR	NR	NR	Slight liver damage	NAS, 1977 (p. 564)
Mice (55)	chlordane	5	NR	NR	80 weeks	No effect	U.S. EPA, 1980 (p. C-14)
Mice (52)	chlordane	25	NR	NR	80 weeks	64-79% increase in cancer rate	U.S. EPA, 1980 (p. C-14)

[a] N = Number of animals per treatment group.
[b] NR = Not reported.

TABLE 4-4. UPTAKE OF CHLORDANE BY DOMESTIC ANIMALS AND WILDLIFE

Species	Chemical Form Fed	Range (N)[a] of Feed Concentrations (μg/g DW)	Tissue Analyzed	Range of Tissue Concentration (μg/g DW)[b]	Uptake Factor[c]	References
Cattle	chlordane	1-100 (3)	milk fat	0.11-0.78	<0.01-0.11 for chlordane	Dorough and Hemken, 1973 (p. 213-15)
Cattle	chlordane	1-100 (3)	milk fat	0.48-4.85	<0.05-0.48 for total isomers	Dorough and Hemken, 1973 (p. 213-15)
Cattle	chlordane	1-100 (3)[c]	body fat	0.11-0.60	<0.01-0.11 for chlordane	Dorough and Hemken, 1973 (p. 213-15)
Cattle	chlordane	1-100 (3)[c]	body fat	0.47-3.97	<0.04-0.47 for total isomers	Dorough and Hemken, 1973 (p. 213-15)
Rat	chlordane	1-25 (3)	fat	3-75	3	U.S. EPA, 1980 (p. C-5)

[a] N = Number of feed rates.
[b] At 60 days on feed with chlordane.
[c] Uptake factor = tissue concentration/feed concentration.

TABLE 4-5. TOXICITY OF CHLORDANE TO SOIL BIOTA

Species	Chemical Form Applied	Soil Type	Control Tissue Concentration (µg/g)	Soil Concentration (µg/g)[a]	Application Rate (kg/ha)	Experimental Tissue Concentration (µg/g)	Effects	References
Soil bacteria	chlordane	fine sandy loam	NR[b]	2.8	5.6	NR	3% reduction total count	Bollen et al., 1954 (p. 303)
Soil bacteria	chlordane	fine sandy loam	NR	5.6	11.2	NR	24% reduction total count	Bollen et al., 1954 (p. 303)
Soil bacteria	chlordane	fine sandy loam	NR	11.2	22.4	NR	6% reduction total count	Bollen et al., 1954 (p. 303)
Soil mold	chlordane	fine sandy loam	NR	2.8	5.6	NR	43% reduction total count	Bollen et al., 1954 (p. 303)
Soil mold	chlordane	fine sandy loam	NR	5.6	11.2	NR	81% reduction total count	Bollen et al., 1954 (p. 303)
Soil mold	chlordane	fine sandy loam	NR	11.2	22.4	NR	48% reduction total count	Bollen et al., 1954 (p. 303)
Soil mold	chlordane	silty clay loam	NR	5.6	11.2	NR	55% reduction total count	Bollen et al., 1954 (p. 303)
Soil mold	chlordane	silty clay loam	NR	5.6	11.2	NR	36% reduction total count	Bollen et al., 1954 (p. 303)
Soil mold	chlordane	peat soil	NR	2.25	4.5	NR	3% reduction total count	Bollen et al., 1954 (p. 303)
Soil mold	chlordane	peat soil	NR	3.35	6.7	NR	2% reduction total count	Bollen et al., 1954 (p. 304)

TABLE 4-5. (continued)

Species	Chemical Form Applied	Soil Type	Control Tissue Concentration (μg/g)	Soil Concentration (μg/g)[a]	Application Rate (kg/ha)	Experimental Tissue Concentration (μg/g)	Effects	References
Soil bacteria	chlordane	peat soil	NR	2.25	4.5	NR	24% reduction total count	Bollen et al., 1954 (p. 304)
Soil bacteria	chlordane	peat soil	NR	3.35	6.7	NR	19% reduction total count	Bollen et al., 1954 (p. 304)
Soil fungus	chlordane	loamy sand	NR	12.5	NA[c]	NR	11% reduction total count	Eno and Everett, 1958 (p. 237)
Soil fungus	chlordane	loamy sand	NR	50	NA	NR	28% reduction total count	Eno and Everett, 1958 (p. 237)
Soil fungus	chlordane	loamy sand	NR	100	NA	NR	21% reduction total count	Eno and Everett, 1958 (p. 237)
Soil bacteria	chlordane	sandy clay loam	NR	11.2, 5.6 for 2 years	33.6, 11.2 for 2 years	NR	0% reduction total count, 11 months following 2nd application	Martin et al., 1959 (p. 335)
Soil bacteria	chlordane	sandy clay loam	NR	16.8, 5.6 for 3 years	33.6, 11.23 for 3 years	NR	4% reduction, 11 months following 3rd application	Martin et al., 1959 (p. 335)
Soil bacteria	chlordane	sandy loam	NR	22.4, 5.6 for 4 years	44.8, 11.2 for 4 years	NR	22% reduction, 2 weeks following 4th application	Martin et al., 1959 (p. 335)

TABLE 4-5. (continued)

Species	Chemical Form Applied	Soil Type	Control Tissue Concentration (μg/g)	Soil Concentration (μg/g)[a]	Application Rate (kg/ha)	Experimental Tissue Concentration (μg/g)	Effects	References
Fungi	chlordane	sandy clay loam	NR	11.2, 5.6 for 2 years	22.4, 11.2 for 2 years	NR	7% reduction total count, 11 months following 2nd application	Martin et al., 1959 (p. 335)
Fungi	chlordane	sand clay loam	NR	16.8, 5.6 for 3 years	33.6, 11.2 for 3 years	NR	5% reduction total count, 2 weeks following 2nd application	Martin et al., 1959 (p. 335)
Fungi	chlordane	sand loam	NR	16.8, 5.6 for 3 years	33.6, 11.2 for 3 years	NR	5% reduction total count, 11 months after 3rd application	Martin et al., 1959 (p. 335)
Fungi	chlordane	sandy loam	NR	22.4, 5.6 for 4 years	44.8, 11.2 for 4 years	NR	7% increase total count, 2 weeks following 4th application	Martin et al., 1959 (p. 335)

[a] Estimated soil concentration assuming the pollutant is incorporated into the upper 15 cm of soil which has an approximate dry matter mass of 2 x 10^3 mt/ha. The formula is: experimental soil concentration (μg/g) = (y kg/1 ha) x (1 ha/2 x 10^3 mt) x (1 mt/1 x 10^3 kg) x (1 x 10^6 μg/1 g) where y is the application rate.

[b] NR = Not reported.

[c] NA = Not applicable.

SECTION 5

REFERENCES

Abramowitz, M., and I. A. Stegun. 1972. Handbook of Mathematical Functions. Dover Publications, New York, NY.

Atlas, E., and C. Giam. 1980 Global Transport of Organic Pollutants: Ambient Concentrations in the Remote Marine Atmosphere. Science 211:163-65.

Barnes, R. Chapter 48: Mechanization of Forage Harvesting and Storage. In: Heath, M., D. S. Metcalfe and R. Barnes (eds.), Forages: The Science of Grassland Agriculture. 3rd Edition.

Baxter, J. C., M. Aquilar, and K. Brown. 1983. Heavy Metals and Persistent Organics at a Sewage Sludge Disposal Site. J. Environ. Qual. 12(3):311-315.

Bertrand, J. E., M. C. Lutrick, G. T. Edds, and R. L. West. 1981. Metal Residues in Tissue, Animal Performance and Carcass Quality with Beef Steers Grazing Pensacola Bahiagrass Pastures Treated with Liquid Digested Sludge. J. Ani. Sci. 53:1.

Bidleman, T. 1981. Interlaboratory Analyses of High Molecular Weight Organochlorines in Ambient Air. Atmos. Env. 15:619-624.

Billings, W., and T. Bidleman. 1983. High Volume Collection of Chlorinated Hydrocarbons in Urban Air Using Three Solids Absorbents. Atmos. Env. 17(2):383-391.

Bollen, W. B., H. E. Morrison, and H. H. Crowell. 1954. Effects of Field Treatments of Insecticides on Numbers of Bacteria Streptomyces and Molds in the Soil. J. Econ. Ent. 47(2):302-306.

Boswell, F. C. 1975. Municipal Sewage Sludge and Selected Element Applications to Soil: Effect on Soil and Fescue. J. Environ. Qual. 4(2):267-273.

Camp Dresser and McKee, Inc. 1984a. Development of Methodologies for Evaluating Permissible Contaminant Levels in Municipal Wastewater Sludges. Draft. Office of Water Regulations and Standards, U.S. Environmental Protection Agency, Washington, D.C.

Camp Dresser and McKee, Inc. 1984b. Technical Review of the 106-Mile Ocean Disposal Site. Prepared for U.S. EPA under Contract No. 68-01-6403. Annandale, VA. January.

Camp Dresser and McKee, Inc. 1984c. Technical Review of the 12-Mile Sewage Sludge Disposal Site. Prepared for U.S. EPA under Contract No. 68-01-6403. Annandale, VA. May.

Camp Dresser and McKee, Inc. 1984d. A Comparison of Studies of Toxic Substances in POTW Sludges. Prepared for U.S. EPA under Contract No. 68-01-6403. Annandale, VA. January.

Carey, A., G. B. Wiersma, and H. Tai. 1976. Pesticide Residues in Urban Soils from 14 United States Cities, 1970. Pest. Monit. J. 10(2):54-60.

Carey, A., J. A. Gowen, H. Tai, et al. 1978. Pesticide Residue Levels in Crops, 1971 - National Soils Monitoring Program (III). Pest. Monit. J. 12(3):117-136.

Carey, A. 1979. Monitoring Pesticides in Agricultural and Urban Soils of the U.S. Pest. Monit. J. 13(1):23-27.

Carey, A., R. Douglas, H. Tai, et al. 1979a. Pesticide Residue Concentrations in Soils of Five United States Cities, 1971 - Urban Soils Monitoring Program. Pest. Monit. J. 13(1):17-22.

Carey, A., J. A. Gowen, H. Tai, et al. 1979b. Pesticide Residue Levels in Soils and Crops from 37 States, 1972. Pest. Monit. J. 12(4):209-229

Carey, A., H. S. Yang, G. B. Wiersma, et al. 1980. Residual Concentrations of Propanil, TCAB and Other Pesticides in Rice-Growing Soils in the United States, 1972. Pest. Monit. J. 13(1):23-25.

Chaney, R. L., and C. A. Lloyd. 1979. Adherence of Spray-Applied Liquid Digested Sewage Sludge to Tall Fescue. J. Environ. Qual. 8(3):407-411.

City of New York Department of Environmental Protection. 1983. A Special Permit Application for the Disposal of Sewage Sludge from Twelve New York City Water Pollution Control Plants at the 12-Mile Site. New York, NY. December.

Clevenger, T. E., D. D. Hemphill, K. Roberts, and W. A. Mullins. 1983. Chemical Composition and Possible Mutagenicity of Municipal Sludges. Journal WPCF 55(12):1470-1475.

Donigian, A. S. 1985. Personal Communication. Anderson-Nichols & Co., Inc., Palo Alto, CA. May.

Dorough, H., R. F. Skrentny, and B. C. Pass. 1972. Residue in Alfalfa and Soils Following Treatment with Technical Chlordane and High Purity Chlordane for Alfalfa Weevil Control. J. Agri. Food Chem. 20(1):42-47.

Dorough, H., and R. Hemken. 1973. Chlordane Residues in Milk and Fat of Cows Fed HCS3260 (High Purity Chlordane) in the Diet. Bull. Env. Contam. & Tox. 10(4):208-16.

Edwards, C. A. 1973. Pesticide Residues in Soil and Water. In: Edwards, C. A. (ed.), Environmental Pollution by Pesticides. Plenum Press, New York, NY.

Eno, C. F., and P. H. Everett. 1958. Effects of Soil Applications of 10 Chlorinated Hydrocarbon Insecticides on Soil Microorganisms and the Growth of Stringless Black Valentine Beans. Soil Sci. Amer. Proc. 22:235-238.

Fairchild, H. 1976. Chlordane and Heptachlor in Relation to Man. 1972-1975. EPA 540/4-76/005.

Farrell, J. B. 1984. Personal Communication. Water Engineering Research Laboratory. U.S. Environmental Protection Agency, Cincinnati, OH. December.

Finlayson, D. G., and H. R. McCarthy. 1973. Pesticide Residues in Plants. In: Edwards, C. A. (ed.), Environmental Pollution by Pesticides. Plenum Press, New York, NY.

Food and Drug Administration. 1980a. FY77 Total Diet Studies - Infants and Toddlers (7320.74). FDA; Bureau of Foods. Washington, D.C. October.

Food and Drug Administration. 1980b. FY77 Total Diet Studies - Adult (7320.73). FDA; Bureau of Foods. Washington, D.C. December 11.

Food and Drug Administration. No date. FY78 Total Diet Studies Adult (7205.003).

Freeze, R. A., and J. A. Cherry. 1979. Groundwater. Prentice-Hall, Inc., Englewood Cliffs, NJ.

Gelhar, L. W., and G. J. Axness. 1981. Stochastic Analysis of Macrodispersion in 3-Dimensionally Heterogeneous Aquifers. Report No. H-8. Hydrologic Research Program, New Mexico Institute of Mining and Technology, Soccorro, NM.

Gerritse, R. G., R. Vriesema, J. W. Dalenberg, and H. P. DeRoos. 1982. Effect of Sewage Sludge on Trace Element Mobility in Soils. J. Environ. Qual. 2:359-363.

Glooshenko, W., W. M. Strachan, and R. C. Sampson. 1976. Distribution of Pesticides and Polychlorinated Biphenyls in Water, Sediments, and Seston. Pest. Monit. J. 10(2):61-67.

Gowen, J., G. B. Wiersma, H. Tai, and W. G. Mitchell. 1976. Pesticide Levels in Hay and Soil from Nine States, 1971. Pest. Monit. J. 10(3):114-116.

Griffin, R. A. 1984. Personal Communication to U.S. Environmental Protection Agency, ECAO - Cincinnati, OH. Illinois State Geological Survey.

Harrington, J., E. L. Baker, D. S. Folland, et al. 1978. Chlordane Contamination of a Municipal Water System. Env. Res. 15:155-159.

Hassett, J. J., W. L. Banwart, and R. A. Griffin. 1983. Correlation of Compound Properties with Sorption Characteristics of Non-Polar Compounds by Soils and Sediments: Concepts and Limitations. Chapter 15. In: The Environment and Solid Waste Characterization, Treatment and Disposal - Proc. 4th Oak Ridge National Laboratory Life Science Symposium, October 4, 1981, Gatlinburg, TN. Ann Arbor Science Pub.

Johnson, R., and D. Manske. 1976. Pesticide Residues in Total Diet Samples (IX). Pest. Monit. J. 9(4):157-169.

Jones, R. and G. Lee. 1977. Chemical Agents of Potential Health Significance for Land Disposal of Municipal Wastewater Effluents and Sludges. pp. 27-60. In: Sagik, B. and C. Sorber (eds.), Risk Assessment and Health Effects of Land Application of Municipal Wastewater and Sludges. University of Texas, San Antonio, TX.

Kaiser, T., W. L. Reichel, L. N. Locke, et al. 1980. Organochlorine Pesticide, PCB, and PBB Residues and Necropsy Data for Bald Eagles from 29 States - 1975-77. Pest. Monit. J. 13(4):145-149.

Lang, J., L. L. Rodriquez, and J. M. Livingston. 1979. Organochlorine Pesticide Residues in Soils from Six U.S. Air Force Bases, 1975-76. Pest. Monit. J. 12(4):230-233.

Lawless, E., T. C. Ferguson, and A. F. Meiners. 1975. Guidelines for the Disposal of Small Quantities of Unused Pesticides. EPA-670/2-75-057. EPA National Environmental Research Center, Office of Research and Development, Cincinnati, OH.

Manske, D., and R. Johnson. 1975. Pesticide Residues in Total Diet Samples - VIII. Pest. Monit. J. 9(2):94-105.

Martin, J. P., R. B. Harding, G. H. Gaunell, and L. D. Anderson. 1959. Influence of Five Annual Field Applications of Organic Insecticides on Soil Biological and Physical Properties. Soil Sci. 87:334-338.

Matsumura, F. 1972. Current Pesticide Situation in the United States. In: F. Matsumura, (ed.), Environmental Toxicology of Pesticides. Academic Press, New York, NY.

National Academy of Sciences. 1977. Drinking Water and Health. NAS; National Review Council Safe Drinking Water Committee. Washington, D.C.

National Oceanic and Atmospheric Administration. 1983. Northeast Monitoring Program 106-Mile Site Characterization Update. NOAA Technical Memorandum NMFS-F/NEC-26. U.S. Department of Commerce National Oceanic and Atmospheric Administration. August.

National Research Council. 1982. An Assessment of the Health Risks of Seven Pesticides Used for Termite Control. Rept. P 901.

Onsager, J. A., H. W. Rusk, and L. I. Butler. 1970. Residues of Aldrin, Dieldrin, Chlordane and DDT in Soil and Sugar Beets. J. Econ. Ent. 63(4):1143-1146.

Pennington, J. A. T. 1983. Revision of the Total Diet Study Food Lists and Diets. J. Am. Diet. Assoc. 82:166-173.

Pettyjohn, W. A., D. C. Kent, T. A. Prickett, H. E. LeGrand, and F. E. Witz. 1982. Methods for the Prediction of Leachate Plume Migration and Mixing. U.S. EPA Municipal Environmental Research Laboratory, Cincinnati, OH.

Ryan, J. A., H. R. Pahren, and J. B. Lucas. 1982. Controlling Cadmium in the Human Food Chain: A Review and Rationale Based on Health Effects. Environ. Res. 28:251-302.

Sikora, L. J., W. D. Burge, and J. E. Jones. 1982. Monitoring of a Municipal Sludge Entrenchment Site. J. Environ. Qual. 2(2):321-325.

Stanford Research Institute International. 1980. Seafood Consumption Data Analysis. Final Report, Task II. Prepared for U.S. EPA under Contract No. 68-01-3887. Menlo Park, CA. September.

Stanley, C., J. E. Barney, M. R. Helton, and A. R. Yobs. 1971. Measurement of Atmospheric Levels of Pesticides. Env. Sci. & Tech. 5(5):430-435.

Thornton, I., and P. Abrams. 1983. Soil Ingestion - A Major Pathway of Heavy Metals into Livestock Grazing Contaminated Land. Sci. Total Environ. 28:287-294.

Tucker, R., and D. Crabtree. 1970. Handbook of Toxicity of Pesticides to Wildlife. Bureau of Sport Fisheries and Wildlife, Denver Wildlife Research Center, Resource Pub. No. 84.

U.S. Department of Agriculture. 1975. Composition of Foods. Agricultural Handbook No. 8.

U.S. Environmental Protection Agency. 1977. Environmental Assessment of Subsurface Disposal of Municipal Wastewater Sludge: Interim Report. EPA/530-SW-547. Municipal Environmental Research Laboratory, Cincinnati, OH.

U.S. Environmental Protection Agency. 1978. Environmental Assessment of Subsurface Disposal of Municipal Sludge: Interim Report. EPA/530/SW-547. Municipal Environmental Research Laboratory, Cincinnati, OH.

U.S. Environmental Protection Agency. 1979. Industrial Source Complex (ISC) Dispersion Model User Guide. EPA 450/4-79-30. Vol. I. Office of Air Quality Planning and Standards, Research Triangle Park, NC. December.

U.S. Environmental Protection Agency. 1980. Ambient Water Quality Criteria for Chlordane. EPA 440/5-80-027.

U.S. Environmental Protection Agency. 1982. Fate of Priority Pollutants in Publicly-Owned Treatment Works. Vol. I. EPA 440/1-82/303. U.S. Environmental Protection Agency. Washington, D.C.

U.S. Environmental Protection Agency. 1983a. Assessment of Human Exposure to Arsenic: Tacoma, Washington. Internal Document. OHEA-E-075-U. Office of Health and Environmental Assessment, Washington, D.C. July 19.

U.S. Environmental Protection Agency. 1983b. Rapid Assessment of Potential Groundwater Contamination Under Emergency Response Conditions. EPA 600/8-83-030.

U.S. Environmental Protection Agency. 1984. Air Quality Criteria for Lead. External Review Draft. EPA 600/8-83-028B. Environmental Criteria and Assessment Office, Research Triangle Park, NC. September.

Wedberg, J., S. Moore, F. J. Amore, and H. McAvory. 1978. Organochlorine Insecticide Residues in Bovine Milk and Manufactured Milk Products in Illinois, 1971-76. Pest. Monit. J. 11(4):161-164.

Wheatley, G. 1973. Pesticides in the Atmosphere. In: C. A. Edwards (ed.), Environmental Pollution by Pesticides. Plenum Press, New York, NY.

APPENDIX

PRELIMINARY HAZARD INDEX CALCULATIONS FOR CHLORDANE IN MUNICIPAL SEWAGE SLUDGE

I. LANDSPREADING AND DISTRIBUTION-AND-MARKETING

A. Effect on Soil Concentration of Chlordane

1. Index of Soil Concentration (Index 1)

a. Formula

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

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

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

$$0.007980 \text{ μg/g DW} = \frac{(3.2 \text{ μg/g DW} \times 5 \text{ mt/ha}) + (0 \text{ μg/g DW} \times 2000 \text{ mt/ha})}{(5 \text{ mt/ha DW} + 2000 \text{ mt/ha DW})}$$

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

$$0.018 \text{ μg/g DW} = 0.007980 \text{ μg/g DW} \; [1 + 0.5^{(1/1.19)} + 0.5^{(2/1.19)} + \ldots + 0.5^{(99/1.19)}]$$

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

$$0.002850 = \frac{0.007980\ \mu g/g\ DW}{2.8\ \mu g/g\ DW}$$

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

a. Formula

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

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 - Values were not calculated due to lack of data.

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**

$$0.000638 = \frac{0.007980\ \mu g/g\ DW}{12.5\ \mu g/g\ DW}$$

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

a. **Formula**

Index 5 = I_1 x 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**

0.005027 μg/g DW = 0.007980 μg/g DW x

0.63 μg/g tissue DW (μg/g soil DW)$^{-1}$

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

a. **Formula**

Index 6 = PP

where:

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

b. **Sample Calculation** - 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**

$$0.002010 = \frac{0.005027\ \mu g/g\ DW}{2.5\ \mu g/g\ DW}$$

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

$$\text{If } AR \neq 0;\ 0.064 = \frac{3.2\ \mu g/g\ DW \times 0.05}{2.5\ \mu g/g\ DW}$$

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)**

$$31.41 = \frac{(0.018194 \ \mu g/g \ DW \times 74.5 \ g/day) + 0.011 \ \mu g/day}{0.0435 \ \mu g/day}$$

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)**

$2.68 = [(0.005027 \ \mu g/g \ DW \times 0.48 \ \mu g/g$ tissue DW

$[\mu g/g$ feed DW$]^{-1} \times 43.7$ g/day DW) + 0.011 μg/day] ÷

0.0435 μg/day

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)**

$$69.81 = [(3.2 \ \mu g/g \ DW \times 0.05 \times 0.48 \ \mu g/g \ tissue \ DW \ [\mu g/g \ feed \ DW]^{-1} \times 39.4 \ g/day \ DW) + 0.011 \ \mu g/day] \div 0.0435 \ \mu g/day$$

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)**

$$1.17 = \frac{(0.007980 \ \mu g/g \ DW \times 5 \ g/day) + 0.011 \ \mu g/day}{0.0435 \ \mu g/day}$$

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)

$$104.3164 = (31.41 + 2.68 + 69.81 + 1.17) - \left(\frac{3 \times 0.011 \ \mu g/day}{0.0435 \mu g/day} \right)$$

II. LANDFILLING

A. Procedure

Using Equation 1, several values of C/C_o 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, 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

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

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

where:

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

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

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

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

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)
χ = h = Depth to groundwater (m)
$D^* = \alpha \times V^*$ (m^2/year)
α = Dispersivity coefficient (m)

$$V^* = \frac{Q}{\Theta \times R} \text{ (m/year)}$$

Q = Leachate generation rate (m/year)
Θ = Volumetric water content (unitless)

$$R = 1 + \frac{P_{dry}}{\Theta} \times K_d = \text{Retardation factor (unitless)}$$

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)
$\chi = \Delta \ell$ = Distance from well to landfill (m)
$D^* = \alpha \times V^*$ (m^2/year)
α = Dispersivity coefficient (m)

$$V^* = \frac{K \times i}{\phi \times R} \text{ (m/year)}$$

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

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

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)

ϕ = Aquifer porosity (unitless)

B = Thickness of saturated zone (m) where:

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

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 ($\chi = h$) as determined by the following equation:

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

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

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

0.044156733 μg/L = 0.044156733 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

$$3.8462866 = \frac{(0.044156733\ \mu g/L \times 2\ L/day) + 0.079\ \mu g/day}{0.0435\ \mu g/day}$$

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**

$$1.457133 = [(2.78 \times 10^{-7} \text{ hr/sec} \times \text{g/mg} \times 2660 \text{ kg/hr DW} \times 3.2 \text{ mg/kg DW} \times 0.05 \times 3.4 \ \mu g/m^3) + 8.8 \times 10^{-4} \ \mu g/m^3] \div 8.8 \times 10^{-4} \ \mu g/m^3$$

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**

$$0.590911 = \frac{[(1.457133 - 1) \times 8.8 \times 10^{-4} \ \mu g/m^3] + 8.8 \times 10^{-4} \ \mu g/m^3}{2.17 \times 10^{-3} \ \mu g/m^3}$$

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**

$$0.0064\ \mu g/L = \frac{3.2\ mg/kg\ DW \times 1600000\ kg\ WW \times 0.04\ kg\ DW/kg\ WW \times 10^3\ \mu g/mg}{200\ m \times 20\ m \times 8000\ m \times 10^3\ L/m^3}$$

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**

$$0.001736\ \mu g/L = \frac{825000\ kg\ DW/day \times 3.2\ mg/kg\ DW \times 10^3\ \mu g/mg}{9500\ m/day \times 20\ m \times 8000\ m \times 10^3\ L/m^3}$$

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

1. **Formula**

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

where:

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 (μg/L)

2. **Sample Calculation**

$$0.434210 = \frac{0.001736\ \mu g/L}{0.004\ \mu g/L}$$

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

1. Formula

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

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

$$1.84 = \frac{(0.001736\ \mu g/L \times 14{,}100\ L/kg \times 10^{-3}\ kg/g \times 0.000021 \times 14.3\ g\ WW/day) + 0.079\ \mu g/day}{0.0435\ \mu g/day}$$

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)	3.2	12.0	3.2	3.2	3.2	3.2	12.0	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, ∅ (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)	800	3000	800	800	800	800	3000	N
Peak concentration, C_u (μg/L)	0.331	1.24	15.3	800	0.331	0.331	3000	N
Pulse duration, t_o (years)	6200	6200	164	5.00	6200	6200	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)	0.331	1.24	15.3	800	0.331	0.331	3000	N
Saturated zone assessment (Equations 1 and 3)								
Maximum well concentration, C_{max} (μg/L)	0.0442	0.166	0.0547	0.0870	0.204	0.331	69.4	N
Index of groundwater concentration resulting from landfilled sludge, Index 1 (μg/L) (Equation 4)	0.0442	0.166	0.0547	0.0870	0.204	0.331	69.4	0
Index of human cancer risk resulting from groundwater contamination, Index 2 (unitless) (Equation 5)	3.85	9.43	4.33	5.82	11.2	17.0	3190	1.82

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