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

PREFACE

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

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

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SECTION 1

INTRODUCTION

This preliminary data profile is one of a series of profiles dealing with chemical pollutants potentially of concern in municipal sewage sludges. Toxaphene 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 toxaphene poses an actual hazard to human health or the environment when sludge is disposed of by these methods.

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

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

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

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

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

SECTION 2

PRELIMINARY CONCLUSIONS FOR TOXAPHENE 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 Toxaphene

Landspreading of sludge may be expected to result in increased concentrations of toxaphene in soil above the background concentration (see Index 1).

B. Effect on Soil Biota and Predators of Soil Biota

Landspreading of sludge is not expected to result in concentrations of toxaphene in soil that are toxic to soil biota (see Index 2). The potential toxic hazard for predators of soil biota posed by the increased soil concentrations of toxaphene could not be determined 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 concentrations of toxaphene in soil that are toxic to plants (see Index 4). The tissue of plants grown in sludge-amended soil may be expected to have increased concentrations of toxaphene (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

Landspreading of sludge is not expected to result in plant tissue concentrations of toxaphene that pose a toxic threat to herbivorous animals (see Index 7). Incidental ingestion of sludge-amended soil by grazing animals is not expected to exceed dietary concentrations of toxaphene which are toxic (see Index 8).

E. Effect on Humans

Landspreading of sludge may be expected to result in an increase in potential cancer risk due to toxaphene for humans consuming plants grown in sludge-amended soil (see Index 9). Consumption of animal products derived from animals fed crops grown on sludge-amended soil may increase the potential cancer risk to humans (see Index 10). Consumption of animal products derived from animals that have inadvertently ingested sludge-amended soil may be expected to increase the potential cancer risk to humans (see Index 11). The inadvertent ingestion of sludge-amended soil by toddlers may result in an increase in potential cancer risk due to toxaphene. Adults that inadvertently ingest sludge-amended soil are not expected to have any increase in potential cancer risk due to toxaphene (see Index 12). Landspreading of sludge may be expected to increase the potential risk of cancer to humans as a result of the aggregate amount of toxaphene in the human diet (see Index 13).

II. LANDFILLING

Landfilling of sludge may be expected to increase concentrations of toxaphene in groundwater at the well (see Index 1). Landfilling of sludge may be expected to increase the potential cancer risk to humans due to an increase in concentration of toxaphene in groundwater (see Index 2).

III. INCINERATION

Incineration of sludge may be expected to increase the concentration of toxaphene in air above background urban air concentrations, especially when sludge is incinerated at a high feed rate (see Index 1). Inhalation of emissions produced by sludge incineration is expected to increase the human cancer risk due to toxaphene above the risk posed by background urban air concentrations. This increase may be large when sludge is incinerated at a high feed rate (see Index 2).

IV. OCEAN DISPOSAL

Ocean disposal of sludge may be expected to increase concentrations of toxaphene in seawater around the disposal site after initial mixing of sludge and seawater (see Index 1). Ocean disposal of sludge may be expected to increase concentrations of toxaphene in seawater around the disposal site over a 24-hour period (see Index 2). A potential residue hazard exists for aquatic life for sludges disposed at the worst sites at a rate of 1650 mt/day. The marketability of edible saltwater organisms may be jeopardized by sludges disposed at a rate of 825 mt/day containing both typical and worst concentrations of the pollutant at the worst site (see Index 3). Ocean disposal of sludge may result in increased potential in cancer risk to humans consuming seafood, except possibly for a typical disposal site with typical sludge concentrations and with typical seafood intake (see Index 4).

SECTION 3

PRELIMINARY HAZARD INDICES FOR TOXAPHENE IN MUNICIPAL SEWAGE SLUDGE

I. LANDSPREADING AND DISTRIBUTION-AND-MARKETING

A. Effect on Soil Concentration of Toxaphene

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	7.88 μg/g DW
Worst	10.79 μg/g DW

The typical and worst sludge concentrations are the weighted mean and maximum concentrations, respectively, from a summary of sludge data for publicly-owned treatment works (POTWs) in the United States. Toxaphene was detected in sludges from 2 of 61 POTWs sampled (Camp Dresser and McKee, Inc. (CDM), 1984a). (See Section 4, p. 4-1.)

ii. **Background concentration of pollutant in soil (BS)** = 0.003 μg/g DW

Carey (1979) reported geometric means for toxaphene concentrations in agricultural soils from 34 states for the years 1968 to 1973. The geometric means ranged from 0.001 to 0.005 μg/g with an average of 0.003 μg/g. Geometric means were selected because they provide a measure of central tendency, taking into account the zero values when toxaphene is not present or is below the detectable level. (See Section 4, p. 4-3.)

iii. **Soil half-life of pollutant ($t_{\frac{1}{2}}$)** = 11 years

Reported soil half-lives for toxaphene range from 100 days to 11 years (U.S. EPA, 1979a). The half-life of 11 years was selected as the most conservative value, since it represents the longest persistence of toxaphene in the environment. (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	0.0030	0.023	0.20	0.37
Worst	0.0030	0.030	0.27	0.49

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

f. **Preliminary Conclusion** - Landspreading of sludge may be expected to result in increased concentrations of toxaphene in soil above the background concentration.

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) = 16.8 µg/g DW**

Hopkins and Kirk (1957) reported 76 percent survival of adult red worms in soil treated with toxaphene at an application rate of 30 lbs/acre. Although this decrease in survival was not significant, no young worms were found in the soil, possibly indicating an effect on reproduction or on survival of the young worms. Converting the application rate to 33.6 kg/ha and assuming that the toxaphene was evenly distributed in the top 15 cm of soil having a mass of 2000 mt/ha, the soil concentration of toxaphene was 16.8 µg/g. Among the data immediately available, no other toxic effects to soil biota were reported. Eno and Everett (1958) found no adverse effects on fungal counts or CO_2 evolution when soil concentration was as high as 100 µg/g. (See Section 4, p. 4-18.)

d. **Index 2 Values**

Sludge Concentration	Sludge Application Rate (mt/ha)			
	0	5	50	500
Typical	0.00018	0.0013	0.012	0.022
Worst	0.00018	0.0018	0.016	0.029

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 concentrations of toxaphene in soil that are toxic to 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) = 30 μg/g DW**

A soil concentration of 30 μg/g DW was associated with phytotoxic effects in corn, peas and oats (U.S. EPA, 1979a). In corn, stem length, root length and dry matter content of the root tip were decreased; in peas, the root length/stem length ratio and respiration of excised root tips were decreased; and in oats, dry matter content of the root tip was decreased. Because the plants were grown in sand, which does not possess any insecticide retention qualities, the exposure of the plants to toxaphene was considered to be extreme (U.S. EPA, 1979a) and, thus, provides a conservative estimate of the phytotoxic concentration. The only other data indicating phytotoxicity were reported as application rates rather than soil concentrations. In a study by Eno and Everett (1958), soil concentrations of toxaphene were reported; however, beans were not significantly affected by concentrations of up to 100 μg/g. (See Section 4, p. 4-13.)

d. **Index 4 Values**

Sludge Concentration	Sludge Application Rate (mt/ha) 0	5	50	500
Typical	0.00010	0.00075	0.0065	0.012
Worst	0.00010	0.0010	0.0089	0.016

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 concentrations of toxaphene in soil that are toxic to plants.

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:
Potato 0.88 μg/g tissue DW $(\mu g/g \text{ soil DW})^{-1}$

Human Diet:
Potato 0.88 μg/g tissue DW $(\mu g/g \text{ soil DW})^{-1}$

The uptake factor for toxaphene in plants was difficult to determine because all data immediately available were reported as toxaphene residues. These residue values generally did not distinguish between toxaphene adhering to the surface of plants after application and that taken up by the plant. The value selected was calculated from the residue in potatoes grown in soil receiving preplanting treatment of toxaphene (Muns et al., 1960). The potatoes were washed with a spray of water prior to analysis. This value was considered the most representative because the plants received some washing, and because toxaphene was applied to the soil prior to planting, rather than being applied directly to foliage. (See Section 4, p. 4-14.)

Data for uptake of toxaphene in plants normally found in animal diet are not immediately available. It is therefore assumed that the uptake for potatoes is analogous to the uptake of plants normally found in the animal diet.

d. **Index 5 Values (μg/g DW)**

Diet	Sludge Concentration	Sludge Application Rate (mt/ha) 0	5	50	500
Animal	Typical	0.0026	0.020	0.17	0.33
	Worst	0.0026	0.026	0.23	0.43
Human	Typical	0.0026	0.020	0.17	0.33
	Worst	0.0026	0.026	0.23	0.43

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 tissue of plants grown in sludge-amended soil may be expected to have increased concentrations of toxaphene.

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

D. **Effect on Herbivorous Animals**

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

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

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

c. **Data Used and Rationale**

i. **Concentration of pollutant in plant grown in sludge-amended soil (Index 5)**

The pollutant concentration values used are those Index 5 values for an animal diet (see Section 3, p. 3-7).

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

Rats fed 50 μg/g of toxaphene in the diet for 2 years exhibited slight liver changes. No effects were observed in rats fed 25 μg/g, and distinct liver changes were observed in rats fed 200 μg/g (Pollock and Kilgore, 1978). The value selected was the lowest concentration at which toxic effects in herbivorous animals were observed. Also, this value was obtained from the most representative species for which data were available. Dogs, which are carnivores, showed slight liver degeneration when fed 40 μg/g for 2 years. (See Section 4, pp. 4-15 and 4-16.)

d. **Index 7 Values**

Sludge Concentration	Sludge Application Rate (mt/ha) 0	5	50	500
Typical	0.000053	0.00040	0.0034	0.0065
Worst	0.000053	0.00053	0.0047	0.0086

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** - Landspreading of sludge is not expected to result in plant tissue concentrations of toxaphene that pose a toxic threat 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 7.88 µg/g DW
Worst 10.79 µg/g DW

See Section 3, p. 3-1.

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

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

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

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

See Section 3, p. 3-8.

d. **Index 8 Values**

Sludge Concentration	Sludge Application Rate (mt/ha) 0	5	50	500
Typical	0.0	0.0079	0.0079	0.0079
Worst	0.0	0.011	0.011	0.011

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** - Incidental ingestion of sludge-amended soil by grazing animals is not expected to exceed dietary concentrations of toxaphene which are toxic.

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. 3-7).

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	0.346 μg/day
Adult	3.402 μg/day

The Food and Drug Administration (FDA) reported daily intakes of toxaphene based on annual market basket surveys of foods in the United

States for various age groups. The relative daily intake of toxaphene by toddlers was 0.0346 µg/kg body weight/day. This value is an average of the annual means for fiscal years (FY) 1975 to 1977 reported by FDA (1980). Assuming a toddler weighs 10 kg, the daily intake is estimated to be 0.346 µg/day. For adults, the relative daily intake of toxaphene averaged 0.0486 µg/kg of body weight/day for FY75 to FY78 (FDA, 1979). Assuming an adult weighs 70 kg, the daily intake is calculated to be 3.402 µg/day. (See Section 4, p. 4-5.)

iv. **Cancer potency** = 1.13 $(mg/kg/day)^{-1}$

The cancer potency was derived by U.S. EPA (1980) based on data from a carcinogenicity study by Litton Bionetics (1978 as cited in U.S. EPA, 1980). In the Litton Bionetics study, incidence of hepatocellular carcinomas and neoplastic nodules was significantly increased among male mice fed diets containing 50 µg/g of toxaphene for 18 months. (See Section 4, p. 4-6.)

v. **Cancer risk-specific intake (RSI)** = 0.0619 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	8.8	30	210	400
	Worst	8.8	37	290	520
Adult	Typical	64	120	620	1100
	Worst	64	140	830	1500

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 be expected to result in an increase in potential cancer risk due to toxaphene for humans consuming 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. 3-7).

ii. **Uptake factor of pollutant in animal tissue (UA)** = 2.5 μg/g tissue DW (μg/g feed DW)$^{-1}$

The uptake factor selected was the highest uptake factor calculated from the data immediately available. The factor represents uptake of toxaphene in the abdominal fat of steers (Pollock and Kilgore, 1978). The uptake factor for subcutaneous fat from steers was slightly lower at 2.02. For sheep, uptake factors for abdominal and subcutaneous fat were much lower than those for steers, at 1.03 and 0.53, respectively. The value selected represents the most conservative choice. (See Section 4, p. 4-17.) 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 0.346 μg/day
Adult 3.402 μg/day

See Section 3, p. 3-11.

v. **Cancer risk-specific intake (RSI)** = 0.0619 μg/day

See Section 3, p. 3-12.

d. **Index 10 Values**

Group	Sludge Concentration	Sludge Application Rate (mt/ha) 0	5	50	500
Toddler	Typical	10	41	310	580
	Worst	10	52	420	760
Adult	Typical	64	130	670	1200
	Worst	64	150	890	1600

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

f. **Preliminary Conclusion** - Consumption of animal products derived from animals fed crops grown on sludge-amended soil may increase the potential cancer risk to humans.

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** = Abdominal fat - steer.

See Section 3, p. 3-13.

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

Typical	7.88 µg/g DW
Worst	10.79 µg/g DW

See Section 3, p. 3-1.

iii. **Background concentration of pollutant in soil (BS)** = 0.003 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)** = 2.5 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	0.346 μg/day
Adult	3.402 μg/day

See Section 3, p. 3-11.

viii. **Cancer risk-specific intake (RSI)** = 0.0619 μg/day

See Section 3, p. 3-12.

d. **Index 11 Values**

Group	Sludge Concentration	Sludge Application Rate (mt/ha) 0	5	50	500
Toddler	Typical	5.8	630	630	630
	Worst	5.8	860	860	860
Adult	Typical	55	1400	1400	1400
	Worst	55	1900	1900	1900

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

f. **Preliminary Conclusion** - Consumption of animal products derived from animals that have inadvertently ingested sludge-amended soil may be expected to increase the potential cancer risk to humans.

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

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

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

c. **Data Used and Rationale**

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

See Section 3, p. 3-2.

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

Pica child	5 g/day
Adult	0.02 g/day

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

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

Toddler	0.346 μg/day
Adult	3.402 μg/day

See Section 3, p. 3-11.

iv. **Cancer risk-specific intake (RSI)** = 0.0619 μg/day

See Section 3, p. 3-12.

d. **Index 12 Values**

Group	Sludge Concentration	Sludge Application Rate (mt/ha) 0	5	50	500
Toddler	Typical	5.8	7.4	21	35
	Worst	5.8	8.0	27	45
Adult	Typical	55	55	55	55
	Worst	55	55	55	55

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

f. **Preliminary Conclusion** - The inadvertent ingestion of sludge-amended soil by toddlers may result in an increase in potential cancer risk due to toxaphene. Adults that inadvertently ingest sludge-amended soil are not expected to have any increases in potential cancer risk due to toxaphene.

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**

		Sludge Application Rate (mt/ha)			
Group	Sludge Concentration	0	5	50	500
Toddler	Typical	14	690	1200	1600
	Worst	14	940	1600	2200
Adult	Typical	74	1500	2500	3600
	Worst	74	2000	3500	4800

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

f. **Preliminary Conclusion** - Landspreading of sludge may be expected to increase the potential risk of cancer to humans as a result of the aggregate amount of toxaphene in the human diet.

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, 1984b).

(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, 1984b.

(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	7.88 mg/kg DW
Worst	10.79 mg/kg DW

See Section 3, p. 3-1.

(b) **Soil half-life of pollutant ($t_{\frac{1}{2}}$)** = 4015 days

See Section 3, p. 3-2.

(c) **Degradation rate (μ)** = 0.0001726 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})** = 964 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 U.S. EPA, 1982.

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 may be expected to increase concentrations of toxaphene in groundwater at the well.

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)** = 3.402 μg/day

See Section 3, p. 3-11.

d. **Cancer potency** = 1.13 $(mg/kg/day)^{-1}$

See Section 3, p. 3-12.

e. **Cancer risk-specific intake (RSI)** = 0.0619 μg/day

See Section 3, p. 3-12.

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

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

6. **Preliminary Conclusion** - Landfilling of sludge may be expected to increase the potential cancer risk to humans due to an increase in concentration of toxaphene in groundwater.

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, 1984b). 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, 1979b). 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	7.88 mg/kg DW
Worst	10.79 mg/kg DW

See Section 3, p. 3-1.

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

Typical	0.05 (unitless)
Worst	0.20 (unitless)

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

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

Typical	3.4 μg/m^3
Worst	16.0 μg/m^3

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

f. **Background concentration of pollutant in urban air (BA)** = 0.0012 μg/m^3

Reported ambient air concentrations of toxaphene vary from 0.00004 to 2.52 μg/m^3 depending on season and proximity of application. In a study of pesticide concentrations in 9 urban and rural sites (Stanley et al., 1971), toxaphene was detected at 3 sites. Only maximum concentrations were reported; these were 0.068, 1.34 and 2.52 μg/m³. Assuming that concentrations at the other 6 sites were one-half the detection limit of 0.0001 μg/m³, a geometric mean concentration of 0.0012 μg/m³ is calculated for all 9 sites. (See Section 4, p. 4-4.)

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	1.8	16
	Worst	1.0	2.1	21
Worst	Typical	1.0	4.3	59
	Worst	1.0	5.5	81

[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 equals factor by which expected air concentration exceeds background levels due to incinerator emissions.

6. **Preliminary Conclusion** - Incineration of sludge may be expected to increase the concentration of toxaphene in air above background urban air concentrations, especially when sludge is incinerated at a high feed rate.

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

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

2. **Assumptions/Limitations** - The exposed population is assumed to reside within the impacted area for 24 hours/day. A respiratory volume of 20 m³/day is assumed over a 70-year lifetime.

3. **Data Used and Rationale**

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

See Section 3, p. 3-28.

b. **Background concentration of pollutant in urban air (BA)** = 0.0012 μg/m^3

See Section 3, p. 3-27.

c. **Cancer potency** = 1.13 (mg/kg/day)$^{-1}$

The cancer potency for inhalation was derived from the cancer potency for ingestion, assuming 100 percent absorption for both ingestion and inhalation routes of exposure. Data used to derive this value are from a study in which mice fed toxaphene in the diet developed hepatocellular carcinomas and neoplastic nodules (U.S. EPA, 1980). (See Section 4, p. 4-8.)

d. **Exposure criterion (EC)** = 0.0031 μg/m^3

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

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

4. **Index 2 Values**

Fraction of Pollutant Emitted Through Stack	Sludge Concentration	Sludge Feed Rate (kg/hr DW)[a] 0	2660	10,000
Typical	Typical	0.39	0.71	6.0
	Worst	0.39	0.82	8.1
Worst	Typical	0.39	1.7	23
	Worst	0.39	2.1	31

[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 > 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 produced by sludge incineration is expected to increase the human cancer risk due to toxaphene above the risk posed by background urban air concentrations. This increase may be large when sludge is incinerated at a high feed rate.

IV. OCEAN DISPOSAL

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

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

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

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

3. Data Used and Rationale

a. Disposal conditions

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

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

The assumed disposal practice to be followed at the model site representative of the typical case is a modification of that proposed for sludge disposal at the formally designated 12-mile site in the New York Bight Apex (City of New York, 1983). Sludge barges with capacities of 3400 mt WW would be required to discharge a load in no less than 53 minutes traveling at a minimum speed of 5 nautical miles (9260 m) per hour. Under these conditions, the barge would enter the site, discharge the sludge over 8180 m and exit the site. Sludge barges with capacities of 1600 mt WW would be required to discharge a load in no less than 32 minutes traveling at a minimum speed of 8 nautical miles (14,816 m) per hour. Under these conditions, the barge would enter the site, discharge the sludge over 7902 m and exit the site. The mean path length for the large and small tankers is 8041 m or approximately 8000 m. Path length is assumed to lie perpendicular to the direction of prevailing current flow. For the typical disposal rate (SS) of 825 mt DW/day, it is assumed that this would be accomplished by a mixture of four 3400 mt WW and four 1600 mt WW capacity barges. The overall daily disposal operation would last from 8 to 12 hours. For the worst-case disposal rate (SS) of 1650 mt DW/day, eight 3400 mt WW and eight 1600 mt WW capacity barges would be utilized. The overall daily disposal operation would last from 8 to 12 hours. For both disposal rate scenarios, there would be a 12 to 16 hour period at night in which no sludge would be dumped. It is assumed that under the above 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	7.88 mg/kg DW
Worst	10.79 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, 1984c).

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, 1984d).

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	0.016	0.016
	Worst	0.0	0.022	0.022
Worst	Typical	0.0	0.13	0.13
	Worst	0.0	0.18	0.18

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

7. **Preliminary Conclusion** - Ocean disposal of sludge may be expected to result in increased concentrations of

toxaphene in seawater around the disposal site after initial mixing.

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

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

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

3. **Data Used and Rationale**

See Section 3, pp. 3-31 to 3-32.

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

See Section 3, p. 3-34.

5. **Index 2 Values (µg/L)**

Disposal Conditions and Site Characteristics	Sludge Concentration	Sludge Disposal Rate (mt DW/day) 0	825	1650
Typical	Typical	0.0	0.0043	0.0086
	Worst	0.0	0.0059	0.012
Worst	Typical	0.0	0.038	0.075
	Worst	0.0	0.052	0.10

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

7. **Preliminary Conclusion** - Ocean disposal of sludge may be expected to result in increased concentrations of toxaphene in seawater around the disposal site over a 24-hour period.

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 toxaphene, 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. 3-34.

b. **Ambient water quality criterion (AWQC)** = 0.071 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 toxaphene.

The 0.071 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 toxaphene in edible fish and shellfish (5 mg/kg), the geometric mean of normalized bioconcentration factor (BCF) values (4,372) for aquatic species tested, and the 16 percent lipid content of marine species. This value will also protect against acute toxic effects.

4. **Index 3 Values**

Disposal Conditions and Site Characteristics	Sludge Concentration	Sludge Disposal Rate (mt DW/day) 0	825	1650
Typical	Typical	0.0	0.060	0.12
	Worst	0.0	0.082	0.16
Worst	Typical	0.0	0.53	1.1
	Worst	0.0	0.73	1.5

5. **Value Interpretation** - Value equals the factor by which the expected seawater concentration increase in toxaphene 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 toxaphene residue in tissue hazard may exist thus jeopardizing the marketability of edible saltwater organisms. The criterion value of 0.071 µg/L is probably too high because on the average, the concentration in 50 percent of species similar to those used to derive the value will exceed the FDA action level (U.S. EPA, 1980).

6. **Preliminary Conclusion** - A potential residue hazard exists for aquatic life for sludges disposed at the worst sites at a rate of 1650 mt/day. The marketability of edible saltwater organisms may be jeopardized by sludges containing both typical and worst concentrations of toxaphene disposed at the worst site at a rate of 825 mt/day.

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. 3-34.

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, 1984c). Near-shore area 612 has an area of approximately 4300 km^2 and constitutes approximately 24 percent of the total seafood landings (CDM, 1984d). 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) =** 18,450 L/kg

The value chosen is the weighted average BCF of toxaphene for the edible portion of all freshwater and estuarine aquatic organisms consumed by U.S. citizens (U.S. EPA, 1980 as revised by Stephan, 1981). 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 toxaphene 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)** = 3.402 µg/day

See Section 3, p. 3-11.

f. **Cancer potency** = 1.13 $(mg/kg/day)^{-1}$

See Section 3, p. 3-12.

g. **Cancer risk-specific intake (RSI)** = 0.0619 μg/day

See Section 3, p. 3-12.

4. **Index 4 Values**

Disposal Conditions and Site Characteristics	Sludge Concentration[a]	Seafood Intake[a,b]	Sludge Disposal Rate (mt DW/day) 0	825	1650
Typical	Typical	Typical	55	55	55
	Worst	Worst	55	63	71
Worst	Typical	Typical	55	56	58
	Worst	Worst	55	81	110

[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 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** - Ocean disposal of sludge may result in increased potential in cancer risk to humans consuming seafood except possibly for a typical disposal site with typical sludge concentration and with typical seafood intake.

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

Site Characteristics	Condition of Analysis[a,b,c] 1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value (μg/L)	0.20	0.27	0.20	0.21	1.1	8.0	62	0.0
Index 2 Value	61	64	62	62	89	310	2100	55

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

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

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

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

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

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

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

SECTION 4

PRELIMINARY DATA PROFILE FOR TOXAPHENE IN MUNICIPAL SEWAGE SLUDGE

I. OCCURRENCE

Toxaphene is currently (1980) the most heavily used chlorinated hydrocarbon insecticide in the United States. Annual production of toxaphene exceeds 100 million pounds, with primary usage in agricultural crop application, mainly cotton. — U.S. EPA, 1980 (p. A-1)

A. Sludge

1. Frequency of Detection

Toxaphene was detected in sludges from 2 of 61 POTWs analyzed (3%). Data were obtained from several surveys of POTWs in the United States — CDM, 1984a (p. 8)

2. Concentration

Weighted mean	7.88 mg/kg DW	CDM, 1984a (p. 8)
Maximum	10.79 mg/kg DW	
Minimum	4.69 mg/kg DW	

<10 μg/L in Chicago Metropolitan sludge — Jones and Lee, 1977 (p. 52)

B. Soil - Unpolluted

1. Frequency of Detection

Toxaphene use is limited to a few crops and is not a widespread contaminant as are other chlorinated hydrocarbons. Toxaphene is rarely detected in soil, water, or sediment samples that have not received direct or nearby applications. — U.S. EPA, 1979a (pp. 1-3 and 1-4)

Occurrence (percent) of toxaphene in agricultural soils of 34 states: — Carey, 1979 (p. 25)

Year				
1968	1969	1971	1972	1973
4.8	2.0	6.6	5.4	2.7

Frequency of detection of toxaphene in soils from 14 U.S. cities, 1970: Not detected in 27 samples from Augusta, ME Not detected in 27 samples from Charleston, SC Not detected in 19 samples from Cheyene, WY Not detected in 23 samples from Grand Rapids, MI Detected in 3 of 28 samples from Greenville, MS Not detected in 21 samples from Honolulu, HI Not detected in 28 samples from Memphis, TN Not detected in 29 samples from Mobile, AL Not detected in 26 samples from Philadelphia, PA Not detected in 25 samples from Portland, OR Not detected in 27 samples from Richmond, VA Detected in 1 of 27 samples from Sikeston, MO Not detected in 23 samples from Sioux City, IO Not detected in 27 samples from Wilmington, DE	Carey et al., 1976 (pp. 55 to 57)
Frequency of detection of toxaphene in soils from 5 U.S. cities, 1971: Not detected in 156 samples from Baltimore, MD Not detected in 55 samples from Gadsen, AL Not detected in 48 samples from Hartford, CT Detected in 11 of 43 samples from Macon, GA Not detected in 78 samples from Newport News, VA	Carey et al., 1979a (p. 19)
5.1% (76 of 1,483 samples) frequency of detection of toxaphene in agricultural soils from 37 states, 1972.	Carey et al., 1979b (p. 212)
Toxaphene was not detected in agricultural soils adjacent to or within soils of Everglades National Park.	Requejo et al., 1979 (p. 934)

2. **Concentration**

Geometric mean (μg/g DW) of toxaphene in agricultural soils in 34 states:	Carey, 1979 (p. 25)

1968	1969	1971	1972	1973
0.003	0.001	0.005	0.004	0.002
Mean for 1968 to 1973 = 0.003				

1.94 μg/g (DW) arithmetic mean, range of 7.73 to 33.40 μg/g for 28 samples from Greenville, MS	Carey et al., 1976 (p. 56)
0.24 μg/g (DW) arithmetic mean, range of 0.23 to 4.95 μg/g in 11 samples from Macon, GA (1971)	Carey et al., 1979a (p. 19)
0.24 μg/g (DW) arithmetic mean 0.003 μg/g geometric mean 0.22 to 46.58 μg/g range for 76 of 1,483 cropland soil samples from 37 states, 1972	Carey et al., 1979b (p. 212)

C. **Water - Unpolluted**

1. **Frequency of Detection**

Not detected in U.S. surface waters prior to 1975 except in contaminated areas	U.S. EPA, 1980 (p. C-1)

2. **Concentration**

a. **Freshwater**

0.02 μg/L (0 to 32 μg/L) in U.S. lake	Edwards, 1970 (p. 22)

b. **Seawater**

Data not immediately available.

c. **Drinking water**

No detectable levels found in 58 samples in 1975-6 (limit of detection was 0.05 μg/L)	U.S. EPA, 1980 (p. C-3)

D. Air

1. Frequency of Detection

Toxaphene observed in 75 of 880 total air samples (1970 data) from rural areas; not detected in urban areas.	Stanley et al., 1971 (p. 435)

2. Concentration

a. Urban

Toxaphene not observed in samples collected in urban areas of Baltimore, MD; Fresno, CA; Riverside, CA; or Salt Lake City, UT.	Stanley et al., 1971 (p. 435)

b. Rural

Maximum toxaphene concentrations (number of positive detections): Dothan, AL (rural) 68 ng/m^3 (11) Orlando, FL (rural) 2520 ng/m^3 (9) Stoneville, MS (rural) 1340 ng/m^3 (55) Toxaphene was not detected in air samples from rural areas near Buffalo, NY, or Iowa City, IA.	Stanley et al., 1971 (p. 435)
Mean monthly air concentration in Stoneville, MS over 3 year sampling period (1972-1974) = 167 ng/m^3.	Arthur et al., 1976 in U.S. EPA, 1980
Highest concentrations were reported in August: 1,540.0 ng/m^3 (1972), 268.8 ng/m^3 (1973), 903.6 ng/m^3 (1974).	
Lowest concentrations were reported in January: 0.0 ng/m^3 (1972), 0.0 ng/m^3 (1973), 10.9 ng/m^3 (1974).	
Mississippi Delta 258 ng/m^3, 1972 82 ng/m^3, 1973 160 ng/m^3, 1974	Pollock and Kilgore, 1978 (p. 115)
11.1 ng/m^3 Univ. South Carolina, Columbia, SC (1978 data)	Bidleman, 1981 (p. 623)
Sapelo Island, GA $\bar{x}$ = 2.8 ng/m^3 Bermuda $\bar{x}$ = 0.79 ng/m^3 Open ocean $\bar{x}$ = 0.53 ng/m^3	U.S. EPA, 1980 (p. C-13)

Toxaphene residues in air samples at five North American sites: U.S. EPA, 1980 (p. C-14)

Location and Date	Number of Samples	Range (ng/m^3)
Kingston, RI, 1975	6	0.04-0.4
Sapelo Island, GA, 1976	6	1.7-5.2
Organ Pipe Cactus National Park, AZ, 1974	6	2.7-7.0
Hays, KS, 1974	3	0.083-2.6
Northwest Territories, Canada, 1974	3	0.04-0.23

E. Food

1. Frequency of Detection

Frequency out of 20 composite samples and range of toxaphene residues in food groups (1978 data): FDA, 1979 (Attachment E)

Food Group	Frequency
Dairy	-
Meat and Fish	2
Grains and Cereals	-
Potatoes	-
Leafy vegetables	-
Legumes	-
Root vegetables	-
Garden fruit	1
Fruit	-
Oil and Fats	1
Sugars	-
Beverages	-
Range (positive samples)	0.030-0.469 µg/g

2. Total Average Intake

Relative Daily Intake in the Diet (µg/kg body weight (bw)/day)

	FY75	FY76	FY77	FY78	
Toddlers	0.0467	0.0127	0.0443	N/A*	FDA, 1980 (p. 8)
Adults	0.0072	not detected	0.0802	0.1071	FDA, 1979 (Attachment G)

*Not available

Mean for toddlers - 0.0346 μg/kg bw/day for FY75 to FY77, assuming toddler weighs 10 kg, daily intake = 0.346 μg/day.

Mean for adults - 0.0486 μg/kg bw/day for FY 75 to FY78, assuming adult weighs 70 kg, daily intake = 3.402 μg/day.

3. **Concentration**

<0.03 μg/g mean, N.D. to 0.34 μg/g range in sugar beet pulp Toxaphene not detected in molasses, soybean oil, or tallow (1971 data)	Yang et al., 1976 (p. 43)
0.45 μg/g toxaphene in processed food 0.18 μg/g toxaphene in vegetables (1967 data)	Pollock and Kilgore, 1978 (p. 111)
Out of 1,120 samples of food composites from 32 cities (1971-72) toxaphene was found in only 1 sample of leafy vegetables with 0.1 μg/g residue	Manske and Johnson, 1975 (p. 100)

II. HUMAN EFFECTS

A. Ingestion

1. Carcinogenicity

a. Qualitative Assessment

Carcinogenic responses have been induced in mice and rats by toxaphene. Toxaphene was also mutagenic for <u>Salmonella typhimurium</u> strains TA98 and TA100 without metabolic activation. The carcinogenic responses, together with the positive mutagenic response, constitute substantial evidence that toxaphene is likely to be a human carcinogen.	U.S. EPA, 1980 (p. C-74)

b. Potency

Cancer potency = 1.13 $(mg/kg/day)^{-1}$	U.S. EPA, 1980 (p. C-76)
The cancer potency was derived from carcinogenicity data presented by Litton Bionetics (1978 as cited in U.S. EPA, 1980a). A dose-related increase in incidence of hepatocellular carcinomas and neoplastic nodules	U.S. EPA, 1980 (pp. C-43 to C-46, and C-76)

occurred in male $B6C3F_1$ mice fed 7, 20 or 50 μg/g of toxaphene in the diet (0.91, 2.6 or 6.5 mg/kg bw/day, respectively) for 18 months. The following incidences were used to calculated the cancer potency:

Dose (mg/kg/day)	Incidence (number responding/number tested
0.0	10/53
0.91	11/54
2.6	12/53
6.5	18/51

2. **Chronic Toxicity**

a. **ADI**

1.25 μg/kg/day — NAS, 1977 (p. 603)

b. **Effects**

Long-term exposure to dietary concentrations ranging from 25 to 200 μg/g resulted in liver pathology and degeneration in rats and dogs. — U.S. EPA, 1980 (p. C-49)

3. **Absorption Factor**

Elevated toxaphene blood levels in an individual due to consumption of toxaphene-contaminated fish indicated significant absorption after oral exposure. — U.S. EPA, 1980 (p. C-15)

No direct information available on absorption of toxaphene. Absorption across alimentary tract, skin and respiratory tract is indicated by the adverse effects elicited by toxaphene following oral, dermal, and inhalation exposures in animals. Vehicle used in administration of toxaphene has a marked influence on lethality, which is probably attributable to differences in extent and/or rate of absorption. Oral LD_{50} much lower when administered in readily absorbed vehicle such as corn oil. — U.S. EPA, 1979a (p. 6-4)

4. **Existing Regulations**

National interim primary drinking water standard for toxaphene 5 μg/L	U.S. EPA, 1980 (p. C-48)
ADI recommended by NAS 1.25 μg/kg bw/day	NAS, 1977 (p. 603)
FDA tolerances for toxaphene residues range from 0.1 mg/kg in sunflower seeds to 7 mg/kg in various meat fats, nuts and vegetables	U.S. EPA, 1980 (p. C-50)
Tolerance for toxaphene in citrus fruits in Canada is 7.0 mg/kg. The Netherlands' and West Germany's corresponding standard is 0.4 mg/kg.	U.S. EPA, 1980 (p. C-49)

B. **Inhalation**

1. **Carcinogenicity**

a. **Qualitative Assessment**

Data not immediately available; however, it is assumed that toxaphene is carcinogenic when inhaled based on effects observed following ingestion.

b. **Potency**

Cancer potency = 1.13 $(mg/kg/day)^{-1}$ — U.S. EPA, 1980 (p. C-76)

The cancer potency was derived from that for ingestion, assuming 100 percent absorption for both ingestion and inhalation. This slope is based on incidence of hepatocellular carcinomas and neoplastic nodules in mice following chronic feeding studies (see Section 4, p. 4-6).

2. **Chronic Toxicity**

a. **Inhalation Threshold or MPIH**

American Conference of Governmental and Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs) for — ACGIH, 1983

toxaphene in the working environment:
Time-weighted average (TWA) - 500 μg/m^3
Short-term exposure limit (STEL) - 1,000 μg/m^3

b. **Effects**

Humans exposed to toxaphene mists of 500,000 μg/m^3 in air for 30 minutes daily for 10 days, followed by 3 daily exposures, 3 weeks later showed no adverse effects based on physical examination and blood and urine tests.	Shelanski, 1974 in U.S. EPA, 1980 (p. C27)
Two cases of acute bronchitis with miliary lung shadows attributed to inhalation of toxaphene during applications of toxaphene formulation spray. Carriers for toxaphene during spraying not specified. Pulmonary insufficiency and lung lesions resulted but were reversible within 3 months.	Warraki, 1963 in U.S. EPA, 1980 (p. C-27)

3. **Absorption Factor**

Qualitative information on absorption was not immediately available. Absorption across respiratory tract is indicated by adverse effects elicited by toxaphene following inhalation exposure.	U.S. EPA, 1979a (p. 6-4)

4. **Existing Regulations**

ACGIH TLVs TWA - 500 μg/m^3 STEL - 1,000 μg/m^3	ACGIH, 1983

III. PLANT EFFECTS

A. Phytotoxicity

Toxaphene is not phytotoxic to most crop plants at concentrations recommended to kill insects (15-20 kg/ha).	U.S. EPA, 1979a (p. 4-1)
See Table 4-1.	
0.04 to 462.3 μg/g toxaphene in plants with no reported effects.	Carey et al., 1979b (pp. 222-225)

No data immediately available on tissue concentrations causing toxicity.

Toxaphene concentrations in standing agricultural crops, 1972 (μg/g DW) — Carey et al., 1979b (pp. 222 to 225)

Crop	Arithmetic Mean	Geometric Mean	Range
Alfalfa	0.01	0.002	0.17-0.19
Corn stalks	0.04	0.002	0.19-4.14
Cotton stalks	25.44	1.078	0.66-462.30
Cotton seed	0.49	0.082	0.20-3.71
Grass hay	0.15	0.020	0.30-1.19
Milo	0.04	-	0.04
Pasture forage	0.15	0.014	0.59-0.86
Peanuts	0.25	0.100	0.17-0.65
Soybeans	0.01	0.002	0.14-0.38

B. Uptake

The uptake and metabolism of toxaphene by plants has not received much investigation — U.S. EPA, 1979a (p. 1-6)

Toxaphene residues in crops following application of 3 pounds toxaphene per acre (3.36 kg/ha) — Muns et al., 1960

Crop	Concentration in μg/g WW*
Pre-planting soil treatment	
Sugar beet root	N.D.
Table beet root	N.D.
Potato	0.3 (1.48)
On-surface treatment at seedling stage	
Potato	0.3 (1.48)
Table beet root	N.D.
Sugar beet root	0.3 (2.36)
Radish	0.4 (7.27)

N.D. = Not Detectable

* Values in parentheses are the concentrations converted to dry weight using percent water for foods given in USDA (1975). Water content for potatoes, beets (common red), and radishes are 79.8, 87.3 and 94.5 percent, respectively.

See Table 4-2.

IV. DOMESTIC ANIMAL AND WILDLIFE EFFECTS

A. Toxicity

See Table 4-3.

B. Uptake

1.0 µg/g toxaphene in fat of swine feeding in field sprayed with 16 lb/acre of toxaphene	Pollock and Kilgore, 1978 (p. 110)
32.2 (10.3-88.9) µg/g in tissues of quail living in field sprayed with toxaphene	Pollock and Kilgore, 1978 (p. 112)

See Table 4-4.

V. AQUATIC LIFE EFFECTS

A. Toxicity

1. Freshwater

0.013 µg/L as a 24-hour average concentration, not to exceed 1.6 µg/L at any time.	U.S. EPA, 1980 (p. B-8)

2. Saltwater

Concentration should not exceed 0.071 µg/L at any time. No data available regarding chronic toxicity.	U.S. EPA, 1980 (p. B-8)

B. Uptake

For the edible portion of all freshwater and estuarine aquatic organisms consumed by U.S. citizens, BCF is 18,450.	U.S. EPA, 1980 (p. C-11) as revised by Stephan, 1981

VI. SOIL BIOTA EFFECTS

A. Toxicity

See Table 4-5.

Toxaphene is not toxic to soil bacteria and fungi or to the microbiological process important to soil fertility at concentrations even higher than those used for controlling insects.	U.S. EPA, 1979a (p. 1-5)

B. Uptake

Data not immediately available.

VII. PHYSICOCHEMICAL DATA FOR ESTIMATING FATE AND TRANSPORT

Chemical name of toxaphene: chlorinated camphene containing 67-69% chlorine	
Molecular weight: 414 Melting point: 65-90°C Density: 1.64 at 25°C Partition coefficient: 3,300 Solubility in H_2O: 0.4 to 3.0 mg/L	U.S. EPA, 1980 (p. A-1)
Solubility of toxaphene: 3 mg/L at room temp. Vapor pressure: 0.2 to 0.4 ppm at 25°C	Finlayson and MacCarthy, 1973 (p. 67)
Toxaphene is immobile in soils R_f = 0.00-0.09	Lawless et al., 1975 (p. 51)
Toxaphene most persistent of 9 insecticides tested with a half-life of 11 years	Nash and Woolson, 1967 in Pollock and Kilgore, 1978 (p. 116)
Reported half-lives range from 100 days to 11 years (maximum value).	U.S. EPA, 1979a (p. 1-5)
Organic carbon partition coefficient (K_{oc}) = 964 mL/g	U.S. EPA, 1982

TABLE 4-1. PHYTOTOXICITY OF TOXAPHENE

Plant/Tissue	Chemical Form Applied	Soil Type	Control Tissue Concentration (μg/g DW)	Soil Concentration (μg/g DW)	Application Rate (kg/ha DW)	Experimental Tissue Concentration (μg/g DW)	Effects	References
Black valentine beans	Toxaphene	fine sand	NR[a]	12.5-100	NR	NR	No significant change in germination rate, root weight or top weight from the controls	Eno and Everett, 1958 (p. 236)
Table beets, potatoes, cucumbers	Toxaphene	sandy clay loam	NR	NR	22.4[b]	NR	Injury to table beets, serious injury to potatoes and cucumbers	Martin et al., 1959 (p. 337)
Cotton/plant	Toxaphene emulsion	sandy	NR	NR	72.3	NR	"Some toxicity" to growth	U.S. EPA, 1979a (p. 4-17)
Cotton/plant	Toxaphene powder	sandy	NR	NR	101.5	NR	No effect	U.S. EPA, 1979a (p. 4-21)
Corn/stem	Toxaphene	sandy	NR	30	NR	NR	Length 88% of control	U.S. EPA, 1979a (p. 4-21)
Corn/root	Toxaphene	sandy	NR	30	NR	NR	Length 87% of control	U.S. EPA, 1979a (p. 4-21)
Peas/stem	Toxaphene	sandy	NR	30	NR	NR	Length 114% of control	U.S. EPA, 1979a (p. 4-21)
Peas/root	Toxaphene	sandy	NR	30	NR	NR	Dry matter 88% of control	U.S. EPA, 1979a (p. 4-21)
Peas/root and stem	Toxaphene	sandy	NR	30	NR	NR	Slight reduction over control in root length: Stem/length ratio = 0.63	U.S. EPA, 1979a (p. 4-20)
Oats/root	Toxaphene	sandy	NR	30	NR	NR	Dry matter 88% of control	U.S. EPA, 1979a (p. 4-21)
Cucumber/root	Toxaphene	sandy	NR	30	NR	NR	Dry matter 104% of control	U.S. EPA, 1979a (p. 4-21)
Cauliflower/seedling	Toxaphene	NR	NR	NR	1.57	NR	No effect	U.S. EPA, 1979a (p. 4-20)
Tomato/seedling	Toxaphene	NR	NR	NR	1.57	NR	No effect	U.S. EPA, 1979a (p. 4-20)
Cabbage/seedling	Toxaphene	NR	NR	NR	1.57	NR	Significant reduction in size of seedlings	U.S. EPA, 1979a (p. 4-20)

[a] NR = Not reported.
[b] Annual applications applied for 5 years prior to planting.

TABLE 4-2. UPTAKE OF TOXAPHENE BY PLANTS

Plant/tissue	Chemical Form Applied	Soil type	Soil Concentration (μg/g DW)	Application Rate (kg/ha)	Tissue Concentration (μg/g DW)	Uptake Factor[a]	References
Potato/tuber	Toxaphene (pre-planting treatment)	sandy loam	1.68[b]	3.36[c]	1.48 (0.3)[d]	0.88	Muns et al., 1960

[a] Uptake factor = y/x: y = μg/g plant tissue DW; x = μg/g soil DW.
[b] Soil concentration was calculated from the application rate of 3.36 kg/ha assuming toxaphene was evenly distributed in 2000 mt soil/ha in the top 15 cm.
[c] Converted from lbs/acre to kg/ha using a factor of 1.1209.
[d] Value in parentheses is wet weight concentration (μg/g) reported by original author. Dry weight calculated assuming potatoes contain 79.8 percent water (USDA, 1975).

TABLE 4-3. TOXICITY OF TOXAPHENE 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
Dog	Toxaphene	10	NR[b]	1.7	NR	No effect dosage	U.S. EPA, 1976 (p. 175)
Dog	Toxaphene	40-200	NR	NR	2 years	Slight degeneration of liver at 40 μg/g Moderate degeneration of liver at 200 μg/g	NAS, 1977 (p. 175)
Dog (4)	Toxaphene	160	NR	4.0	44 days	Degenerative changes in kidney tubules and liver parenchyma	NAS, 1977 (p. 603)
Pheasant	Toxaphene	100-300	NR	NR	NR	Increased mortality of hatched young	Pollock and Kilgore, 1978 (p. 96)
Rat	Toxaphene	50	NR	NR	2 years	Slight liver change in 25% of rats	Pollock and Kilgore, 1978 (p. 97)
Rat	Toxaphene	200	NR	NR	2 years	Distinct liver change in 50% of rats	Pollock and Kilgore, 1978 (p. 97)
Rat	Toxaphene	25	NR	NR	2 years	No effect level	Pollock and Kilgore, 1978 (p. 98)
Monkey	Toxaphene	NR	NR	0.7	NR	No effect level	Pollock and Kilgore, 1978 (p. 98)

TABLE 4-3. (continued)

Species (N)[a]	Chemical Form Fed	Feed Concentration (µg/g)	Water Concentration (mg/L)	Daily Intake (mg/kg)	Duration of Study	Effects	References
Dog	Toxaphene	20	NR	NR	2 years	No effect level	Pollock and Kilgore, 1978 (p. 98)
Rat	Toxaphene	NR	NR	25	lifetime	No effect level	U.S. EPA, 1980 (p. C-29)
Rat	Toxaphene	NR	NR	100	lifetime	Liver pathology	U.S. EPA, 1980 (p. C-29)
Pelican (5)	Toxaphene	10	NR	NR	3 months	No effect	U.S. EPA, 1979a (p. 5-123)
Pelican (5)	Toxaphene	50	NR	NR	29-48 days	Lethal	U.S. EPA, 1979a (p. 5-123)

[a] N = Number of experimental animals when reported.
[b] NR = Not reported.

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

Species	Chemical Form Fed	Feed Concentration (N)[a] (μg/g DW)	Tissue Analyzed	Tissue Concentration (μg/g DW)	Uptake Factor[b]	References
Steer	Toxaphene in hay	306	Abdominal fat	772	2.5	Pollock and Kilgore, 1978 (p. 109)
Steer	Toxaphene in hay	306	Subcutaneous fat	618	2.02	Pollock and Kilgore, 1978 (p. 109)
Steer	Toxaphene in hay	306	Lean meat	18-35	0.06-0.11	Pollock and Kilgore, 1978 (p. 109)
Sheep	Toxaphene in hay	306	Abdominal fat	317	1.03	Pollock and Kilgore, 1978 (p. 109)
Sheep	Toxaphene in hay	306	Subcutaneous fat	162	0.53	Pollock and Kilgore, 1978 (p. 109)
Sheep	Toxaphene	306	Lean meat	22-51	0.07-0.17	Pollock and Kilgore, 1978 (p. 109)
Cow	Toxaphene in feed	130	Fat	88	0.68	Pollock and Kilgore, 1978 (p. 110)
Mammals	Toxaphene in feed	NR[c]	NR	NR	0.3-0.5	Pollock and Kilgore, 1978 (p. 110)
Dairy cow	Toxaphene in hay	250	Milk	13	0.05	Pollock and Kilgore, 1978 (p. 111)
Dairy cow	Toxaphene in feed	10-20 (2)	Milk	0.11-0.18	0.01	Pollock and Kilgore, 1978 (p. 111)
Cow	Toxaphene	2.5-20 (5)	Milk fat	0.02-0.34	<0.01-0.04	U.S. EPA, 1979a (p. 5-135)
Cow	Toxaphene	60-140 (3)	Fat	8.4-24.3	0.14-0.17	U.S. EPA, 1979a (p. 5-135)

[a] N = Number of feed rates.
[b] Uptake Factor = y/x: y = μg/g feed DW, x = μg/g tissue DW.
[c] NR = Not reported.

TABLE 4-5. TOXICITY OF TOXAPHENE TO SOIL BIOTA

Species	Chemical Form Applied	Soil Type	Soil Concentration (µg/g DW)	Application Rate (kg/ha)	Effects	References
Soil microbes	toxaphene	fine sand	12.5-100	NR[a]	Slight increase in numbers of fungi, evolution of carbon dioxide and nitrate/ nitrogen production	Eno and Everett, 1958 (p. 237)
Soil microbes	toxaphene	silty loam	NR	11.2	42% increase in number of molds	Bollen et al., 1954 (p. 304)
					27% increase in number of bacteria	
		peat	NR	11.2	62% increase in number of molds	
					20% decrease in number of bacteria	
				22.4	8% decrease in number of molds	
					50% decrease in number of bacteria	
Red worm	toxaphene	sandy loam	16.8[b]	33.6[c]	76% survival of adults, no young worms found two months after treatment	Hopkins and Kirk, 1957 (p. 699)
Soil microbes	toxaphene	sandy clay	NR	22.4	After 5 annual applications, no significant difference from control in numbers of fungi or bacteria	Martin et al., 1959 (p. 335)

[a] NR = Not reported.
[b] Calculated from application rate assuming toxaphene was evenly distributed in the top 15 cm of soil with a mass of 2000 mt/ha.
[c] Converted from 30 lbs/acre to 33.6 kg/ha usng a conversion factor of 1.1209.

SECTION 5

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APPENDIX

PRELIMINARY HAZARD INDEX CALCULATIONS FOR TOXAPHENE IN MUNICIPAL SEWAGE SLUDGE

I. LANDSPREADING AND DISTRIBUTION-AND-MARKETING

A. Effect on Soil Concentration of Toxaphene

1. Index of Soil Concentration (Index 1)

a. Formula

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

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

where:

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

b. Sample calculation

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

$$0.023 \ \mu g/g \ DW = \frac{(7.88 \ \mu g/g \ DW \times 5 \ mt/ha) + (0.003 \ \mu g/g \ DW \times 2000 \ mt/ha)}{(5 \ mt/ha \ DW + 2000 \ mt/ha \ DW)}$$

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

$$0.37 \ \mu g/g \ DW = 0.023 \ \mu g/g \ DW \left[1 + 0.5^{(1/11)} + 0.5^{(2/11)} + \ldots + 0.5^{(99/11)}\right]$$

B. Effect on Soil Biota and Predators of Soil Biota

1. Index of Soil Biota Toxicity (Index 2)

a. Formula

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

where:

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

b. Sample calculation

$$0.0013 = \frac{0.023\ \mu g/g\ DW}{16.8\ \mu g/g\ DW}$$

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

a. Formula

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

where:

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

b. Sample calculation - 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**

$$0.00075 = \frac{0.023 \ \mu g/g \ DW}{30 \ \mu g/g \ DW}$$

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

a. **Formula**

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

where:

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

b. **Sample Calculation**

0.020 μg/g DW =

0.023 μg/g DW x 0.88 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**

$$0.00040 = \frac{0.020 \ \mu g/g \ DW}{50 \ \mu g/g \ DW}$$

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

$$\text{If AR} \neq 0; \ 0.0079 = \frac{7.88 \ \mu g/g \ DW \times 0.05}{50 \ \mu g/g \ DW}$$

E. **Effect on Humans**

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

a. **Formula**

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

where:

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

b. **Sample calculation (toddler)**

$$30 = \frac{(0.020\ \mu g/g\ DW \times 74.5\ g/day) + 0.346\ \mu g/day}{0.0619\ \mu g/day}$$

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)**

$$41 = [(0.020\ \mu g/g\ DW \times 2.5\ \mu g/g\ tissue\ DW\ [\mu g/g\ feed\ DW]^{-1} \times 43.7\ g/day\ DW) + 0.346\ \mu g/day] \div 0.0619\ \mu g/day$$

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)

$$630 = [(7.88\ \mu g/g\ DW \times 0.05 \times 2.5\ \mu g/g\ tissue\ DW\ [\mu g/g\ feed\ DW]^{-1} \times 39.4\ g/day\ DW) + 0.346\ \mu g/day] \div 0.0619\ \mu g/day$$

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)

$$7.4 = \frac{(0.023\ \mu g/g\ DW \times 5\ g/day) + 0.346\ \mu g/day}{0.0619\ \mu g/day}$$

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

a. Formula

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

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)

$$690 = (30 + 41 + 630 + 7.4) - \left(\frac{3 \times 0.346 \ \mu g/day}{0.0619 \ \mu g/day} \right)$$

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

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

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

where:

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

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

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

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

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^* = α x 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} x 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)
χ = $\Delta \ell$ = Distance from well to landfill (m)
D^* = α x V^* (m^2/year)

α = Dispersivity coefficient (m)

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

K = Hydraulic conductivity of the aquifer (m/day)

i = Average hydraulic gradient between landfill and well (unitless)

$\emptyset$ = Aquifer porosity (unitless)

$R = 1 + \frac{P_{dry}}{\emptyset} \times K_d$ = 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

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

where:

C_o = Initial concentration of pollutant in the saturated zone as determined by Equation 1 (µg/L)

C_u = Maximum pulse concentration from the unsaturated zone (µg/L)

Q = Leachate generation rate (m/year)

W = Width of landfill (m)

K = Hydraulic conductivity of the aquifer (m/day)

i = Average hydraulic gradient between landfill and well (unitless)

$\emptyset$ = Aquifer porosity (unitless)

B = Thickness of saturated zone (m) where:

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

D. Equation 3. Pulse Assessment

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

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

where:

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

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

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

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

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

1. **Formula**

$$\text{Index 1} = C_{max}$$

where:

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

2. **Sample Calculation**

0.20 μg/L = 0.20 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**

$$61 = \frac{(0.20\ \mu g/L \times 2\ L/day) + 3.402\ \mu g/day}{0.0619\ \mu g/day}$$

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**

$$1.8 = [(2.78 \times 10^{-7} \text{ hr/sec} \times \text{g/mg} \times 2660 \text{ kg/hr DW} \times 7.88 \text{ mg/kg DW} \times 0.05 \times 3.4 \ \mu g/m^3) + 0.0012 \ \mu g/m^3] \div 0.0012 \ \mu g/m^3$$

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**

$$0.71 = \frac{[(1.8 - 1) \times 0.0012 \ \mu g/m^3] + 0.0012 \ \mu g/m^3}{0.0031 \ \mu g/m^3}$$

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**

$$0.016\ \mu g/L = \frac{7.88\ mg/kgDW \times 1600000\ kg\ WW \times 0.04\ kg\ DW/kg\ WW \times 10^3\ \mu g/mg}{200\ m \times 20\ m \times 8000\ m \times 10^3\ L/m^3}$$

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**

$$0.0043\ \mu g/L = \frac{825000\ kg\ DW/day \times 7.88\ mg/kg\ DW \times 10^3\ \mu g/mg}{9500\ m/day \times 20\ m \times 8000\ m \times 10^3\ L/m^3}$$

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**

$$0.060 = \frac{0.0043\ \mu g/L}{0.071\ \mu g/L}$$

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**

$$55 = \frac{(0.0043\ \mu g/L \times 18450\ L/kg \times 10^{-3}\ kg/g \times 0.000021 \times 14.3\ g\ WW/day) + 3.402\ \mu g/day}{0.0619\ \mu g/day}$$

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)	7.88	10.79	7.88	7.88	7.88	7.88	10.79	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, Ø (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)	1970	2700	1970	1970	1970	1970	2700	N
Peak concentration, C_u (μg/L)	217	298	1860	1970	217	217	2700	N
Pulse duration, t_o (years)	42.0	42	5.02	5.00	42.0	42.0	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)	217	298	1860	1970	217	217	2700	N
Saturated zone assessment (Equations 1 and 3)								
Maximum well concentration, C_{max} (μg/L)	0.198	0.272	0.203	0.214	1.05	7.95	62.4	N
Index of groundwater concentration resulting from landfilled sludge, Index 1 (μg/L) (Equation 4)	0.198	0.272	0.203	0.214	1.05	7.95	62.4	0
Index of human cancer risk resulting from groundwater contamination, Index 2 (unitless) (Equation 5)	61.4	63.7	61.5	61.9	89.0	312	2070	55.0

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