United States
Environmental Protection
Agency

Office of Water
Regulations and Standards
Washington, DC 20460

Water

June, 1985

EPA

Environmental Profiles and Hazard Indices for Constituents of Municipal Sludge: 2,4-Dichlorophenoxyacetic Acid

PREFACE

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

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

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

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. 2,4-Dichlorophenoxyacetic acid (2,4-D) was initially identified as being of potential concern when sludge is placed in a landfill.* This profile is a compilation of information that may be useful in determining whether 2,4-D poses an actual hazard to human health or the environment when sludge is disposed of by this method.

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 → groundwater → 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 landfilling practices are included in this profile. The calculation formulae for these indices are shown in the Appendix. The indices are rounded to two significant figures.

---

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

SECTION 2

PRELIMINARY CONCLUSIONS FOR 2,4-DICHLOROPHENOXYACETIC ACID 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

Based on the recommendations of the experts at the OWRS meetings (April-May, 1984), an assessment of this reuse/disposal option is not being conducted at this time. The U.S. EPA reserves the right to conduct such an assessment for this option in the future.

II. LANDFILLING

Landfilled sludge will produce a maximum groundwater concentration of 2,4-D at the well which varies over three orders of magnitude depending upon the soil type, site parameters, and chemical-specific parameters (see Index 1). The 2,4-D groundwater contamination produced by landfilled sludge is not expected to pose a human health risk under any of the site conditions analyzed (see Index 2).

III. INCINERATION

Based on the recommendations of the experts at the OWRS meetings (April-May, 1984), an assessment of this reuse/disposal option is not being conducted at this time. The U.S. EPA reserves the right to conduct such an assessment for this option in the future.

IV. OCEAN DISPOSAL

Based on the recommendations of the experts at the OWRS meetings (April-May, 1984), an assessment of this reuse/disposal option is not being conducted at this time. The U.S. EPA reserves the right to conduct such an assessment for this option in the future.

SECTION 3

PRELIMINARY HAZARD INDICES FOR 2,4-DICHLOROPHENOXYACETIC ACID IN MUNICIPAL SEWAGE SLUDGE

I. LANDSPREADING AND DISTRIBUTION-AND-MARKETING

Based on the recommendations of the experts at the OWRS meetings (April-May, 1984), an assessment of this reuse/disposal option is not being conducted at this time. The U.S. EPA reserves the right to conduct an assessment for this option in the future.

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, 1983). 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 (Camp Dresser and McKee, Inc. (CDM), 1984a).

(c) Volumetric water content (θ)

Typical	0.195 (unitless)
Worst	0.133 (unitless)

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

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

Typical	0.005 (unitless)
Worst	0.0001 (unitless)

Organic content of soils is described in terms of percent organic carbon, which is required in the estimation of partition coefficient, K_d. Values, obtained from R. Griffin (1984) are representative values for subsurface soils.

ii. Site parameters

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

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

(b) Leachate generation rate (Q)

Typical	0.8 m/year
Worst	1.6 m/year

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

(c) Depth to groundwater (h)

Typical	5 m
Worst	0 m

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

(d) Dispersivity coefficient (α)

Typical	0.5 m
Worst	Not applicable

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

iii. Chemical-specific parameters

(a) Sludge concentration of pollutant (SC)

Typical	4.64 mg/kg DW
Worst	7.16 mg/kg DW

Of over 200 publicly-owned treatment works (POTWs) surveyed in the United States, analyses for 2,4-D were conducted only at two Phoenix, Arizona plants (CDM, 1984b). The mean and maximum concentrations of 2,4-D in the sludge at these two POTWs is used for the typical and worst concentration, respectively. Although these concentrations may be biased due to unique local conditions, they were used because they are the only specific values available. (See Section 4, p. 4-1.)

(b) **Soil half-life of pollutant ($t_{1/2}$) = 135 days**

The value selected represents the longest (worst-case) half-life for 2,4-D reported in a study which compared degradation rates under aerobic and anaerobic conditions (Liu et al., 1981). (See Section 4, p. 4-6.)

(c) **Degradation rate (μ) = 5.13 x 10^{-3} day^{-1}**

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

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

(d) **Organic carbon partition coefficient (K_{oc}) =** 20 mL/g

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

b. **Saturated zone**

i. **Soil type and characteristics**

(a) **Soil type**

Typical	Silty sand
Worst	Sand

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

(b) **Aquifer porosity (Ø)**

Typical 0.44 (unitless)
Worst 0.389 (unitless)

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

(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 (1983).

(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** - Landfilled sludge will produce a maximum groundwater concentration of 2,4-D at the well which varies over three orders of magnitude depending upon the soil type, site parameters, and chemical-specific parameters.

B. Index of Human Toxicity Resulting from Groundwater Contamination (Index 2)

1. **Explanation** - Calculates human exposure which could result from groundwater contamination. Compares exposure with acceptable daily intake (ADI) 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. 3-10.

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) = 2.81 µg/day**

Although no 2,4-D residues were reported in market basket surveys from FY75 to FY78 (Food and Drug Administration (FDA), 1979), a worst-case average daily human dietary intake was calculated with prior food concentration data (Johnson and Manske, 1976; Manske and Johnson, 1975) and average daily consumption data for adults (FDA, 1980). The concentration of 2,4-D reported for potatoes and leafy vegetables was multiplied by the respective average daily adult consumption (159 g/day potatoes and 58 g/day leafy vegetables; FDA, 1980) and summed to obtain the total average daily human dietary intake of 2,4-D reported above. (See Section 4, p. 4-3).

d. **Acceptable daily intake of pollutant (ADI) =** 8750 µg/day

Using an uncertainty factor of 100, the U.S. EPA (1982) calculated an ADI of 0.125 mg/kg/day (see Section 4, p. 4-4). Assuming the average adult weights 70 kg (U.S. EPA, 1982), the value given was calculated by multiplying 0.125 mg/kg/day by 70 kg and converting mg to µg (1000 µg/mg).

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

5. **Value Interpretation** - Value equals factor by which pollutant intake exceeds ADI. Value >1 indicates a possible human health threat. Comparison with the null index value indicates the degree to which any hazard is due to landfill disposal, as opposed to preexisting dietary sources.

6. **Preliminary Conclusion** - The 2,4-D groundwater contamination produced by landfilled sludge is not expected to pose a human health risk under any of the site conditions analyzed.

III. INCINERATION

Based on the recommendations of the experts at the OWRS meetings (April-May, 1984), an assessment of this reuse/disposal option is not being conducted at this time. The U.S. EPA reserves the right to conduct such an assessment for this option in the future.

IV. OCEAN DISPOSAL

Based on the recommendations of the experts at the OWRS meetings (April-May, 1984), an assessment of this reuse/disposal option is not being conducted at this time. The U.S. EPA reserves the right to conduct such an assessment for this option in the future.

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

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

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

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

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

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

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

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

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

SECTION 4

PRELIMINARY DATA PROFILE FOR 2,4-DICHLOROPHENOXYACETIC ACID IN MUNICIPAL SEWAGE SLUDGE

I. OCCURRENCE

2,4-D was introduced as a plant growth-regulator in 1942. It is registered in the United States as an herbicide for control of broadleaf plants and as a plant growth-regulator. Domestic use is estimated at 40 to 50 million lbs/yr, approximately 84% of which is used agriculturally and about 16% non-agriculturally (mainly for forest brush control).	NAS, 1977 (p. 493)

A. Sludge

1. Frequency of Detection

Data not immediately available.

2. Concentration

Concentrations in sludges from five sludge sources in Chicago were <1000 μg/L.	Jones and Lee, 1977 (p. 52)
In 4 composite samples from two Phoenix, Arizona treatment plants, 2,4-D ranged from 2.12 to 7.16 mg/kg DW with a mean of 4.64 mg/kg DW.	CDM, 1984b (pp. 43-56)

B. Soil - Unpolluted

1. Frequency of Detection

Out of 188 samples from soils where 2,4-D had been applied, 1.6% contained 2,4-D residues (1969).	U.S. EPA, 1981 (p. 7-6)
No 2,4-D detected in soil samples from the corn belt in 1970.	U.S. EPA, 1981 (p. 7-7)
2,4-D detected in 20% of soil samples from wheat fields in 1969.	U.S. EPA, 1981 (p. 7-7)

2. Concentration

In 1.6% of 188 soil samples from 2,4-D application sites, 2,4-D had a mean concentration of <0.01 μg/g (1969).	U.S. EPA, 1981 (p. 7-7)

In 20% of soil samples from wheat fields in 1969, 2,4-D was detected with a maximum value of 0.2 µg/g DW.	U.S. EPA, 1981 (p. 7-7)

C. Water - Unpolluted

1. Frequency of Detection

No detectable 2,4-D found in monthly water-suspended samples from 11 rivers in the western United States in 1965-66.	U.S. EPA, 1981 (p. 7-5)
2,4-D detected in 14 out of 20 stations on 19 rivers in 1967-68.	U.S. EPA, 1981 (p. 7-5)
No measurable levels of 2,4-D detected in Texas surface waters in 1970.	U.S. EPA, 1981 (p. 7-6)

2. Concentration

a. Freshwater

In a two-year study of 19 western U.S. rivers, the highest 2,4-D concentration found was 0.35 µg/L in the James River at Huron, SD, in 1968.	U.S. EPA, 1981 (p. 7-5)
The highest concentration of 2,4-D detected in a three-year study (1968-1971) of 19 western U.S. streams was 0.97 µg/L.	U.S. EPA, 1981 (p. 7-6)

b. Seawater

Data not immediately available.

c. Drinking Water

Data not immediately available.

D. Air

1. Frequency of Detection

In a one-year monitoring study of air in 16 U.S. cities, three samples contained detectable 2,4-D levels.	U.S. EPA, 1981 (p. 7-4)
The isopropyl ester of 2,4-D was found in 20 out of 22 samples of air in northeastern Oregon in 1962. In eastern Washington, 2,4-D esters were present in 60 to 70% of the samples.	U.S. EPA, 1981 (p. 7-1)

2. **Concentration**

a. **Urban**

In a one-year monitoring study of air in 16 U.S. cities, three samples contained 2,4-D as follows:	U.S. EPA, 1981 (p. 7-5)

Jordan, NY	0.00115 $\mu g/m^3$
Rome, NY	0.00154 $\mu g/m^3$
Salt Lake City, UT	0.004 $\mu g/m^3$

b. **Rural**

Out of 434 samples from Oregon and Washington in 1962 to 1964, the concentration range for most 2,4-D esters was from trace levels to 5.12 $\mu g/m^3$.	U.S. EPA, 1981 (p. 7-2)

E. **Food**

1. **Total Average Intake**

In market basket surveys from FY75 to FY78, no 2,4-D residues were reported.	FDA, 1979
Total diet samples detailing residues in infant and toddler food and tap water (1974-75) did not contain any detectable 2,4-D residues.	U.S. EPA, 1981 (p. 7-10)

2. **Concentration**

2,4-D occurred in 1 out of 30 composite potato samples in 1972-73 at a level of 0.014 µg/g.	Johnson and Manske, 1976
2,4-D occurred in 1 out of 35 composite leafy vegetable samples in 1971-72 at a level of 0.01 µg/g.	Manske and Johnson, 1975 (p. 100)

II. **HUMAN EFFECTS**

A. **Ingestion**

1. **Carcinogenicity**

a. **Qualitative Assessment**

No conclusive evidence of 2,4-D carcinogenicity exists when administered orally to animals.	NAS, 1977 U.S. EPA, 1982

b. **Potency**

Not derived.

c. **Effects**

No carcinogenic effects demonstrated.

2. **Chronic Toxicity**

a. **ADI**

0.3 mg/kg/day	FAO/WHO cited in NAS, 1977
0.0125 mg/kg/day - safety factor of 1000 used.	U.S. EPA, 1982
0.125 mg/kg/day - safety factor of 100 used (or 8.75 mg/man/day)	

b. **Effects**

Fibrillary twitching, muscular paralysis, hemoglobinuria, myoglobinuria, general hyporeflexia.	NAS, 1977

3. **Absorption Factor**

75 to 90 percent absorption of ingested 2,4-D.	Kohli et al., 1974, cited in U.S. EPA, 1980

4. **Existing Regulations**

Quality criteria for a domestic water supply set for 2,4-D at 0.1 mg/L	U.S. EPA, 1976

B. **Inhalation**

1. **Carcinogenicity**

Data not immediately available.

2. **Chronic Toxicity**

Data not assessed since no evaluation of incineration was performed.

3. **Absorption Factor**

Data not immediately available.

4. **Existing Regulations**

10 mg/m^3	Time weighted average	ACGIH, 1983
20 mg/m^3	Short-term exposure limit	

III. PLANT EFFECTS

A. Phytotoxicity

See Table 4-1.

When combined with captan or dichlone, 2,4-D exhibited synergistic phytotoxicity on cucumbers but not on oats. — Nash and Harris, 1973 (p. 495)

Applications of 2,4-D resulted in poor germination and malformed root tips in cotton plants and reduced germination of poinsetta. — NAS, 1968 (p. 6)

B. Uptake

Data not immediately available.

IV. DOMESTIC ANIMAL AND WILDLIFE EFFECTS

A. Toxicity

See Table 4-2.

B. Uptake

Data not immediately available.

V. AQUATIC LIFE EFFECTS

Data not immediately available.

VI. SOIL BIOTA EFFECTS

A. Toxicity

See Table 4-3.

Gram positive and aerobic bacteria were inhibited at lower concentrations than gram negative and anaerobic bacteria. — Newman and Downing, 1958 (p. 352)

Very high levels of 2,4-D cause inhibition of nitrification and ammonification. — Newman and Downing, 1958 (p. 352)

B. Uptake

Data not immediately available.

VII. PHYSICOCHEMICAL DATA FOR ESTIMATING FATE AND TRANSPORT

Persistence of 2,4-D in soils has been reported to be between 4 weeks and 3 years.	Liu et al., 1981 (p. 788)
Under aerobic conditions, half-lives of 2,4-D were 1.8 to 3.1 days. Under anaerobic conditions, half-lives were 69 to 135 days.	Liu et al., 1981 (p. 792)
For low application rates (<100 μg/g) 2,4-D degradation is favored by moisture and soil organic matter.	Ou et al., 1978 (p. 246)
Bacteria are the major organisms responsible for 2,4-D degradation in soils, and low soil pH will significantly reduce 2,4-D degradation rates.	Ou et al., 1978 (p. 246)
Solubility: 540 mg/L at 20°C (in water)	NAS, 1977 (p. 493)
2,4-D is chemically stable, but its esters are rapidly hydrolyzed to the free acid.	NAS, 1977 (p. 493)
From the available data, 2,4-D does not appear to be persistent in the environment. 2,4-D is rapidly photolytically degraded in both air and water and does not sorb significantly to soils or sediments.	U.S. EPA, 1981 (p. 1-1)
Molecular weight: 221.04 Melting point: 104-141°C Boiling point: 106°C Density: 1.57 at 30°C Formula: $C_8H_6Cl_2O_3$	U.S. EPA, 1981 (p. 3-2)

TABLE 4-1. PHYTOTOXICITY OF 2,4-DICHLOROPHENOXYACETIC ACID

Plant/tissue	Chemical Form Applied	Growth Medium	Experimental Concentration[a] (mg/L)	Effects	References
Tomato	2,4-D	soil	5-300	Stem bending, increased cell division adventitious roots, parthenocarpy	U.S. EPA, 1981 (Table 9-1)
Kidney beans	NH_4 2,4-D	soil	66-1000	Stomatal closure	
Lagenaria sp.	2,4-D	soil	500	Reduction of chlorophyll a and b	
Pea seedlings	2,4-D	paper	1.5-50	tumor-like formations in radicle and hypocotyl	
Wheat seedlings	2,4-D	petri dish	0.01-100	21-98% reduction in root growth 19-71% reduction in shoot growth	U.S. EPA, 1981 (Table 9-15)

[a] Solution concentration to soil or to germination substrate (paper).

TABLE 4-2. TOXICITY OF 2,4-DICHLOROPHENOXYACETIC ACID TO DOMESTIC ANIMALS AND WILDLIFE

Species	Chemical Form Fed	Feed Concentration (μg/g)	Daily Intake (mg/kg)	Duration of Study	Effects	References
Cattle	2,4-D	2,000	NR	28 days	Anorexia and weight loss	U.S. EPA, 1981 (Table 10-1)
Cattle	2,4-D	NR[a]	<10	106 doses	Normal post mortem	U.S. EPA, 1981 (Table 10-1)
Sheep	2,4-D	NR	300-500	9 doses 28 days	Lethal Anorexia and weight loss	U.S. EPA, 1981 (Table 10-1)
Chickens	2,4-D	NR	900	single dose 21 days	LD_{50}. No adverse effects	U.S. EPA, 1981 (Table 10-1)
Pheasant	2,4-D	NR	NR	single dose	LD_{50}	Tucker and Crabtree, 1970 (p. 40)
Quail	2,4-D	NR	668	single does	LD_{50}	Tucker and Crabtree, 1970 (p. 40)
Mule Deer	2,4-D	NR	400-800	single does	LD_{50}	Tucker and Crabtree, 1970 (p. 40)
Dog	2,4-D 2,4-D 2,4-D	NR NR NR	8 100 20	NR NR 18-49 days	No adverse effects LD_{50} 75% mortality	NAS, 1977 (p. 496)
Rat Rat	2,4-D 2,4-D	NR NR	30 300	4 weeks 4 weeks	No effect Gastrointestinal irritation	NAS, 1977 (p. 496)

[a]NR = Not reported.

TABLE 4-3. TOXICITY OF 2,4-DICHLOROPHENOXYACETIC ACID TO SOIL BIOTA

Species	Chemical Form Applied	Soil Type	Soil Concentration (μg/g)	Application Rate (kg/ha)	Effects	References
Breeder earthworms	2,4-D	lab	0.1-1000[b]	--	0.1-100 no effect, at 1000 ug/g 100% mortality	U.S. EPA, 1981 (p. 11-9)
Nematodes	2,4-D	lab	100[c]	--	LD_{50}	U.S. EPA, 1981 (p. 11-9)
Coccinellid beetles	2,4-D	NR[a]	--	1.68	Sluggish behavior	Pimentel and Goodman, 1974 (p. 42)
Soil bacteria	2,4-D	Thornton's Medium	125	--	Inhibited soil bacteria at pH 5.6 but not at pH 6.4	Newman and Downing, 1958 (p. 352)
Soil fungi	2,4-D	soil	100	--	Increased fungi population	
Rhizobium	2,4-D	soil	2	--	Inhibited some species	
Soil microbes	2,4-D	sandy loam	10-200	--	No inhibition of electron transport system	Trevors and Starodub, 1983 (p. 596)
Soil microbes	2,4-D	loam	10-200	--	Significantly inhibited electron transport system at all levels	

[a] NR = Not reported.
[b] In solution - immersed for 2 hours.
[c] In solution - immersed for 48 hours.

SECTION 5

REFERENCES

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

American Conference of Governmental Industrial Hygienists. 1983. Threshold Limit Values for Chemical Substances and Physical Agents in the Work Environment with Intended Changes for 1983-84. Second Printing. Cincinnati, OH. 93 pp.

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

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

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

Food and Drug Administration. 1979. Compliance Program Report of Findings FY78 Total Diet Studies-Adult (7305-003). Bureau of Foods, Washington, D.C.

Food and Drug Administration. 1980. Compliance Program Report of Findings FY77 Total Diet Studies-Adult (7320.73). Bureau of Foods, Washington, D.C.

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

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

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

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

Hassett, J. J., W. L. Banwart, and R. A. Griffin. 1983. Correlation of Compound with Sorption Characteristics of Non-polar Compounds by Soils and Sediments: Concepts and Limitations. Chapter 15. In: Francis, C. W. and I. Auerbach (eds.). The Environment and Solid Waste Characterization, Treatment and Disposal. Butterwork Publishers, Boston, MA.

Johnson, R., and D. Manske. 1976. Pesticide Residues in Total Diet Samples (IX). Pest. Monit. J. 9(4):157-159.

Jones, A., and G. F. Lee. 1977. In: Risk Assessment and Health Effects of Land Application of Municipal Wastewater and Sludges. Sagik, B., and C. Sorber, (eds). Center for Applied Technology, University of Texas at San Antonio. p. 52.

Lui, D., W. M. Strachan, K. Thomson, and K. Kwasniewska. 1981. Determination of the Biodegradability of Organic Compounds. Env. Sci. & Tech. 15(7):788-793.

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

Nash, R., and W. Harris. 1973. Screening for Phytotoxic Pesticide Interactions. J. Env. Qual. 2(4):493-497.

National Academy of Sciences. 1968. Effects of Pesticides on Fruit and Vegetable Physiology. Vol. 6 of Principles of Plant and Animal Pest Control. Publication 1968.

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

Newman, A., and C. Downing. 1958. Herbicides and the Soil. J. Agric. Food Chem. 6(5):352-3.

Ou, L., D. F. Rothwell, W. B. Wheeler, and J. M. Davidson. 1978. The Effect of High 2,4-D Concentration of Degradation and Carbon Dioxide Evolution in Soils. J. Env. Qual. 7(2):241-246.

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

Pimentel, D., and N. Goodman. 1974. Environmental Impact of Pesticides. In: Khan, M., (ed.). Survival in Toxic Environments. Academic Press, NY.

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

Trevors, J., and M. Starodub. 1983. Effect of 2,4-D on Electron Transport System (ETS) Activity and Respiration in Soil. Bull Env. Contam. Toxicol. 31:595-598.

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

U.S. Environmental Protection Agency. 1976. Quality Criteria for Water. Washington, D.C.

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

U.S. Environmental Protection Agency. 1980. 2,4-Dichlorophenoxyacetic Acid (2,4-D): Hazard Profile. Revised by Environmental Criteria and Assessment Office, Cincinnati, OH. Prepared by Center for Chemical Hazard Assessment, Syracuse Research Corp., Syracuse, NY. 14 pp.

U.S. Environmental Protection Agency. 1981. Criteria Document for 2,4-Dichlorophenoxyacetic Acid. SRC TR-81-586. Cincinnati, OH. Prepared by Syracuse Research Corporation, Syracuse, NY.

U.S. Environmental Protection Agency. 1982. Draft Interim Criterion Statement: Chlorophenoxy Herbicides. Ambient Water Quality Criterion for the Protection of Human Health. Internal Review Draft CIN-82-D005. Prepared for Criteria Standards Division Office of Water Regulation and Standards. Environmental Criteria and Assessment Office, Cincinnati, OH. 44 pp.

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

APPENDIX

PRELIMINARY HAZARD INDEX CALCULATIONS FOR 2,4-DICHLOROPHENOXYACETIC ACID IN MUNICIPAL SEWAGE SLUDGE

I. LANDSPREADING AND DISTRIBUTION-AND-MARKETING

Based on the recommendations of the experts at the OWRS meetings (April-May, 1984), an assessment of this reuse/disposal option is not being conducted at this time. The U.S. EPA reserves the right to conduct such an assessment for this option in the future.

II. LANDFILLING

A. Procedure

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

B. Equation 1: Transport Assessment

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

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

where:

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

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

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

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

and where for the unsaturated zone:

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

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

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

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

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

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

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

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

μ = Degradation rate (day^{-1})

and where for the saturated zone:

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

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

K = Hydraulic conductivity of the aquifer (m/day)
i = Average hydraulic gradient between landfill and well (unitless)

ϕ = Aquifer porosity (unitless)

$R = 1 + \frac{\rho_{dry}}{\phi} \times K_d$ = Retardation factor = 1 (unitless)

since $K_d = f_{oc} \times K_{oc}$ and f_{oc} is assumed to be zero for the saturated zone.

C. **Equation 2. Linkage Assessment**

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

where:

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

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

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

$$0.0186 \text{ μg/L} = 0.0186 \text{ μg/L}$$

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

1. Formula

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

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)
ADI = Acceptable daily intake of pollutant (μg/day)

2. Sample Calculation

$$3.254 \times 10^{-4} = \frac{(0.0186 \text{ μg/L} \times 2 \text{ L/day}) + 2.81 \text{ μg/day}}{8750 \text{ μg/day}}$$

III. INCINERATION

Based on the recommendations of the experts at the OWRS meetings (April-May, 1984), an assessment of this reuse/disposal option is not being conducted at this time. The U.S. EPA reserves the right to conduct such an assessment for this option in the future.

IV. OCEAN DISPOSAL

Based on the recommendations of the experts at the OWRS meetings (April-May, 1984), an assessment of this reuse/disposal option is not being conducted at this time. The U.S. EPA reserves the right to conduct such an assessment for this option in the future.

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)	4.64	7.16	4.64	4.64	4.64	4.64	7.16	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, $\emptyset$ (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, $\Delta \ell$ (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)	1160	1790	1160	1160	1160	1160	1790	N
Peak concentration, C_u (μg/L)	170.8	263.6	295.0	1160	170.8	170.8	1790	N
Pulse duration, t_o (years)	5.001	5.001	4.999	5.000	5.001	5.001	5.000	N
Linkage assessment (Equation 2)								
Aquifer thickness, B (m)	126.0	126.0	126.0	253.0	23.80	6.320	2.380	N
Initial concentration in saturated zone, C_o (μg/L)	171.0	264.0	295.0	1160	171.0	171.0	1790	N
Saturated zone assessment (Equations 1 and 3)								
Maximum well concentration, C_{max} (μg/L)	0.0186	0.0287	0.0321	0.1261	0.0987	0.7435	41.43	N
Index of groundwater concentration resulting from landfilled sludge, Index 1 (μg/L) (Equation 4)	0.0186	0.0287	0.0321	0.1261	0.0987	0.7435	41.43	0
Index of human toxicity resulting from groundwater contamination, Index 2 (unitless) (Equation 5)	0.0003254	0.0003277	0.0003285	0.00035	0.0003437	0.0004911	0.009791	0.0003211

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