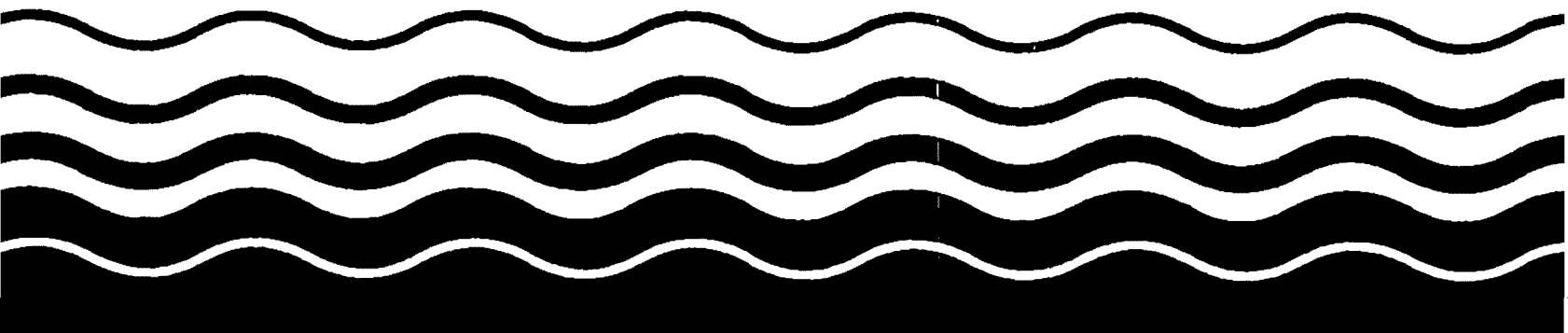




Environmental Profiles and Hazard Indices for Constituents of Municipal Sludge: Malathion



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. Malathion 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 malathion 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 MALATHION 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

The maximum groundwater concentrations of malathion produced by landfilled sludge are expected to be less than one part per trillion for all scenarios evaluated, except for disposal sites with worst-case parameters for the unsaturated zone. For these exceptions, malathion concentrations are expected to be in the part per billion and part per million range (see Index 1). Disposal of sludge in a landfill is not expected to pose a health threat to humans due to malathion contamination of well water (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 MALATHION 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. 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 (CDM, 1984a).

(c) Volumetric water content (θ)

Typical	0.195 (unitless)
Worst	0.133 (unitless)

The volumetric water content is the volume of water in a given volume of media, usually expressed as a fraction or percent. It depends on properties of the media and the water flux estimated by infiltration or net recharge. The

volumetric water content is used in calculating the water movement through the unsaturated zone (pore water velocity) and the retardation coefficient. Values obtained from CDM, 1984a.

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

Typical	0.005 (unitless)
Worst	0.0001 (unitless)

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

ii. Site parameters

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

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

(b) Leachate generation rate (Q)

Typical	0.8 m/year
Worst	1.6 m/year

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

(c) Depth to groundwater (h)

Typical	5 m
Worst	0 m

Eight landfills were monitored throughout the United States and depths to groundwater below

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

(d) Dispersivity coefficient (α)

Typical	0.5 m
Worst	Not applicable

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

iii. Chemical-specific parameters

(a) Sludge concentration of pollutant (SC)

Typical	0.045 mg/kg DW
Worst	0.63 mg/kg DW

The worst sludge concentration is the only reported sludge concentration from a summary of sludge data for publicly-owned treatment works (POTWs) in the United States (CDM, 1984b). Malathion was detected in sludge from only 1 of 14 POTWs sampled. The typical sludge concentration was obtained by calculating the mean for the 14 POTWs sampled, assuming 0 mg/kg for the POTWs where malathion was not detected. Data on the detection limit of malathion in sludge were not immediately available. (See Section 4, p. 4-1.)

(b) Soil half-life of pollutant ($t_{1/2}$) = 20 days

The half-life for malathion in natural soils ranges from 0.5 to 20 days (U.S. EPA, 1982). The longest half-life was selected as a conservative estimate since it represents longer persistence of the chemical in the environment. (See Section 4, p. 4-8.)

(c) Degradation rate (μ) = 0.03465 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}) = 1796 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 ($K_{oc} \times f_{oc}$) 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 Rao and Davidson (1980).

b. Saturated zone

i. Soil type and characteristics

(a) Soil type

Typical	Silty sand
Worst	Sand

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

(b) Aquifer porosity (ϕ)

Typical	0.44 (unitless)
Worst	0.389 (unitless)

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

(c) Hydraulic conductivity of the aquifer (K)

Typical	0.86 m/day
Worst	4.04 m/day

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

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

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

ii. Site parameters

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

Typical	0.001 (unitless)
Worst	0.02 (unitless)

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

(b) Distance from well to landfill (ΔL)

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 (ΔL), 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 m².

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 μ g/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 $\mu\text{g/L}$, at the well.
6. **Preliminary Conclusion** - The maximum groundwater concentrations of malathion produced by landfilled sludge are expected to be less than one part per trillion for all scenarios evaluated, except for disposal sites with worst-case parameters for the unsaturated zone. For these exceptions, malathion concentrations are expected to be in the part per billion and part per million range.

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 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. 3-10.

- 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) = 10.08 $\mu\text{g/day}$**

The Food and Drug Administration (FDA) reported relative daily intakes for various pesticides based on annual market basket surveys. The relative daily intake of malathion averaged 0.1440 $\mu\text{g/kg}$ body weight (bw)/day for fiscal year (FY) 75 to FY78 (FDA, 1979). Assuming an adult weighs 70 kg, the daily intake of malathion is 10.08 μg . (See Section 4, p. 4-3.)

- d. **Acceptable daily intake of pollutant (ADI) = 1600 $\mu\text{g/day}$**

The allowable daily intake for malathion was derived by U.S. EPA (1984). This value is based on a no-observed-effects-level (NOEL) of 16 mg/day for a 70 kg man (0.23 mg/kg bw/day) for plasma and red

blood cell cholinesterase inhibition in humans. This NOEL was based on studies by Rider et al. (1959) and Moeller and Rider (1962), as cited in U.S. EPA (1984). An uncertainty factor of 10 was applied to account for differences in human sensitivity, giving an ADI of 1.6 mg/day. (See Section 4, p. 4-4.)

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** - Disposal of sludge in a landfill is not expected to pose a health threat to humans due to malathion contamination of well water.

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
<u>Unsaturated Zone</u>								
Soil type and characteristics ^d	T	T	W	NA	T	T	NA	N
Site parameters ^e	T	T	T	W	T	T	W	N
<u>Saturated Zone</u>								
Soil type and characteristics ^f	T	T	T	T	W	T	W	N
Site parameters ^g	T	T	T	T	T	W	W	N
Index 1 Value ($\mu\text{g/L}$)	2.8×10^{-7}	3.9×10^{-6}	2.0×10^{-6}	1.2×10^{-3}	1.5×10^{-6}	1.1×10^{-5}	3.6	0.0
Index 2 Value	6.3×10^{-3}	6.3×10^{-3}	6.3×10^{-3}	6.3×10^{-3}	6.3×10^{-3}	6.3×10^{-3}	1.1×10^{-2}	6.3×10^{-3}

^aT = 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.

^bIndex values for combinations other than those shown may be calculated using the formulae in the Appendix.

^cSee Table A-1 in Appendix for parameter values used.

^dDry bulk density (P_{dry}), volumetric water content (θ), and fraction of organic carbon (f_{oc}).

^eLeachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).

^fAquifer porosity (ϕ) and hydraulic conductivity of the aquifer (K).

^gHydraulic gradient (i), distance from well to landfill (Δl), and dispersivity coefficient (α).

SECTION 4

PRELIMINARY DATA PROFILE FOR MALATHION IN MUNICIPAL SEWAGE SLUDGE

I. OCCURRENCE

Malathion is a wide-spectrum, extensively used organophosphorus insecticide. Use in 1972 estimated at 3.6 million pounds and estimated to have increased since then. It is relatively non-persistent.

NAS, 1977
(p. 620)

A. Sludge

1. Frequency of Detection

Detected in sludge from 1 of 14 POTWs.
Data are from a summary of several
surveys of POTWs in the United States.

CDM, 1984b
(p. 8)

2. Concentration

0.63 mg/kg DW in 1 sample, not detected
in 13 samples from POTWs in the United
States. Mean = 0.045 mg/kg DW (assuming
0 mg/kg for POTWs where malathion was not
detected).

CDM, 1984b
(p. 8)

B. Soil - Unpolluted

1. Frequency of Detection

Less than 3% of the soils analyzed
contained malathion

U.S. EPA, 1982
(p. 5-4)

In 33 soil samples from Everglades
National Park and adjacent agricul-
tural areas, no malathion was detected
(1975 data).

Requejo et al.,
1979 (p. 934)

Out of 1,246 soil samples from agricul-
tural sites in 37 states, 2 samples
contained malathion (0.2%) (1972).

Carey et al.,
1979 (p. 212)

2. Concentration

0.01 µg/g average concentration

U.S. EPA, 1982
(p. 5-4)

Out of 1,246 soil samples in 1972 from
agricultural sites in 37 states, 2
samples contained malathion:

Carey et al.,
1979 (p. 214,
219)

South Dakota sample	0.08 µg/g (DW)
California sample	0.13 µg/g (DW)

C. Water - Unpolluted

1. Frequency of Detection

It is quite likely that malathion could appear as a contaminant in drinking water; although there are no reports of its being found yet. NAS, 1977 (p. 625)

In samples from 34 sites in the upper Great Lakes in 1974, no malathion was detected. Glooshenko et al., 1976 (p. 61)

In agricultural areas of California in 1969 and 1970, no malathion was detected in 14 to 18 samples of surface water and 41 to 60 samples of subsurface drain effluents. U.S. EPA, 1982 (p. 6-8)

2. Concentration

Virtually no information exists on levels of malathion in U.S. waters U.S. EPA, 1982 (p. xv)

As part of the Medfly eradication program in California during 1981, malathion accumulation in water bodies was measured. The cumulative average level in reservoirs and natural waters within the spray area was approximately 0.5 ppb for malathion. Oshima et al., 1982

D. Air

1. Frequency of Detection

Out of 880 composite samples from 9 U.S. locations in both urban and agricultural areas, 4 samples from Orlando (agricultural area) contained detectable levels of malathion (0.4%). Stanley et al., 1971 (p. 435)

Only trace amounts have been found in the ambient air. U.S. EPA, 1982 (p. xv)

2. Concentration

Out of 880 composite samples from 9 U.S. locations, 4 from Orlando (agricultural area) contained malathion. Stanley et al., 1971 (p. 435)
Maximum level: 2 ng/m³.

Samples before, during and after fogging for mosquito control (ng/m³): Wheatley, 1973 (p. 391)

Location	Before	During	After
Chesapeake Bay Township	0.2	8 to 22	0.2 to 2.3
Atlantic Coast resort	NR	1 to 30	<0.1 to 1

In 202 air samples from 7 sites in New York, Texas, and Florida, the concentration range for malathion was 0.06 to 3.53 ng/m³. U.S. EPA, 1982 (p. 6-1)

E. Food

1. Frequency of Detection

In 1978, malathion was detected in 39 out of 240 composite samples from 12 food groups in a range of 0.08-0.054 µg/g. FDA, 1979 (Attachment E)

20 of the grain and cereal samples (100%) and 11 of the oils and fats samples (50%) contained malathion.

2. Total Average Intake

Total Relative Daily Intakes (µg/kg bw/day) FDA, 1979 (Attachment G)

FY75	FY76	FY77	FY78
0.1517	0.1278	0.1540	0.1423

Mean = 0.1440 for FY75 to FY78; assuming a 70 kg adult, daily intake = 10.08 µg/day.

II. HUMAN EFFECTS

A. Ingestion

1. Carcinogenicity

a. Qualitative Assessment

Animal studies have indicated that malathion is not carcinogenic. U.S. EPA, 1982 (p. xvi)

b. Potency

Not relevant since malathion is not considered a carcinogen.

c. Effects

Data not immediately available.

2. Chronic Toxicity

a. ADI

WHO/FAO ADI = 20 µg/kg bw/day

Vettorazzi, 1975
in U.S. EPA,
1984 (p. 52)

An ADI of 0.023 mg/kg/day or 1.6 mg/day was derived for a 70 kg man, based on a NOEL of 16 mg/day (0.23 mg/kg/day) for plasma and red blood cell cholinesterase inhibition in humans (Rider et al., 1959, and Moeller and Rider, 1962, both as cited in U.S. EPA, 1984). Uncertainty factor of 10 was applied to account for differences in human sensitivity.

U.S. EPA, 1984
(p. 55)

b. Effects

Five human subjects receiving daily oral doses of 16 mg of malathion for 88 days showed no decrease in red blood cells or plasma cholinesterase activity. Additional treatment consisting of 16 mg/day of malathion and 6 mg/day of ethyl-p-nitrophenyl thionobenzenephosphonate for 42 days resulted in slight depression of red blood cells and plasma cholinesterase activities, but no symptoms of toxicity were noted.

Rider et al.,
1959 in U.S.
EPA, 1984
(p. 32)

In 5 male subjects receiving daily oral doses of 24 mg/day for 56 days, plasma cholinesterase activity was depressed starting at 2 weeks of treatment, with maximum depression of 25 percent occurring 3 weeks after cessation of treatment. Erythrocyte cholinesterase activity was also depressed during last few days of treatment and during post-treatment period. Maximum depression occurred at about 3 weeks post-treatment and was of similar magnitude to plasma cholinesterase depression. No clinical signs of toxicity, no change in blood count or urinalysis observed.

Moeller and
Rider, 1962 in
U.S. EPA, 1984
(p. 32, 33)

3. Absorption Factor

Malathion was rapidly absorbed, with 88.8 percent of administered dose absorbed within 1 hour.

U.S. EPA, 1984
(p. 13)

4. Existing Regulations

U.S. EPA residue tolerances for raw agricultural commodities and for food range from 0.1 to 12 µg/g (40 CFR 180.11, 21 CFR 193.260)

U.S. EPA, 1984
(p. 52)

WHO/FAO ADI - 20 µg/kg bw/day

Vettorazzi, 1975
in U.S. EPA,
1984 (p. 52)

B. Inhalation

1. Carcinogenicity

Data not immediately available.

2. Chronic Toxicity

a. Inhalation Threshold or MPIH

American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV) - 10 mg/m³

ACGIH, 1983
(p. 24)

b. Effects

Prolonged exposure to low, but undetermined, levels of organophosphates (chiefly fenithion, but also malathion) caused symptoms in 38 agricultural college employees. Exposures resulted from spraying vegetable gardens, vineyards, and fruit orchards. Symptoms - diarrhea, decreased plasma cholinesterase.

Perold and
Bezuidenhout,
1980 in U.S.
EPA, 1984

3. Absorption Factor

Data not immediately available.

4. Existing Regulations

TLV - 10 mg/m³

ACGIH, 1983

III. PLANT EFFECTS

A. Phytotoxicity

Data not immediately available on soil or tissue concentrations causing phytotoxicity. Some data available on spray levels causing phytotoxicity.

The normal application concentration of 0.5% malathion has been found to be effective against target organisms and in most cases safe to plants. However, at half this concentration or less, some ornamentals, vegetables, and trees may be damaged. U.S. EPA, 1982

B. Uptake

Malathion is relatively non-persistent. No uptake data is available. There are data on residues from spraying which indicate that malathion is rapidly lost. This suggests a considerable degree of safety to consumers in view of the tolerance limit of 8 µg/g. Narain et al., 1981 (p. 79)

IV. DOMESTIC ANIMAL AND WILDLIFE EFFECTS

A. Toxicity

See Table 4-1.

Malathion has a low acute toxicity compared to other organophosphorus insecticides. NAS, 1977 (p. 625)

Chronic effects to domestic animals are unlikely. U.S. EPA, 1982 (p. xv)

B. Uptake

Data not immediately available.

V. AQUATIC LIFE EFFECTS

A. Toxicity

1. Freshwater

a. Acute

96-hour LC₅₀ values for sensitive species (salmon, trout, sunfish, bass) 0.062 to 0.285 mg/L U.S. EPA, 1984 (p. 38)

96-hour LC₅₀ values for resistant species (carp, fathead minnow, catfish, goldfish, and bullheads) 6.59 to 12.90 mg/L

U.S. EPA, 1984
(p. 38)

b. Chronic

Levels between 0.07 and 0.20 mg/L would allow survival and reproduction based on a 10 month study with fathead minnows exposed to 0.58, 0.20, 0.07, and 0.03 mg/L.

Mount and
Stephan, 1967 in
U.S. EPA, 1984
(p. 44)

Water Quality Criterion - 0.1 µg/L for freshwater and marine aquatic life

U.S. EPA, 1976
(p. 160)

2. Saltwater

a. Acute

Toxicity in marine fish similar to that for freshwater; for various species LC₅₀ values ranged from 0.027 to 3.25 mg/L

U.S. EPA, 1984
(p. 34, 44)

b. Chronic

Water Quality Criterion - 0.1 µg/L for freshwater and marine aquatic life

U.S. EPA, 1976
(p. 160)

B. Uptake

Data not immediately available.

VI. SOIL BIOTA EFFECTS

A. Toxicity

See Table 4-2.

Researchers have reported no disruptive effects on fungi or bacteria.

U.S. EPA, 1982
(p. xv)

B. Uptake

Data not immediately available.

VII. PHYSICOCHEMICAL DATA FOR ESTIMATING FATE AND TRANSPORT

Vapor pressure: 4×10^{-5} mm Hg at 20°C	U.S. EPA, 1982
Estimated median vapor loss from treated areas: 1.8 lb/acre/yr.	(p. 5-7)
Solubility in water: 145 mg/L at 25°C	(p. 5-8)
Persistence: half-life in the environment averages one week; neutral pH values and low temperatures will increase half-life	(p. 5-13)
Molecular wt: 330.4	U.S. EPA, 1982
Boiling pt: 156°C at 7 mm Hg	(p. 2-2, 2-3)
Melting pt: 6.1°C	
Density: 1.2 kg/L	
Completely soluble in most alcohols, esters, solvents	
Half-life in raw river water is less than 1 week	NAS, 1977
Malathion stable in distilled water	(p. 621)
Malathion is degraded in water more rapidly than other organophosphorus insecticides	
Half-life of 1 to 15 days in fresh water	U.S. EPA, 1982
Half-life of 0.5 to 4 days in estuarine and natural sea water	(p. xiv)
Half-life of 0.5 to 20 days in natural soils	
Organic carbon partition coefficient (K_{oc}) = 1796 mL/g	Rao and Davidson, 1980

TABLE 4-1. TOXICITY OF MALATHION TO DOMESTIC ANIMALS AND WILDLIFE

Species	Chemical Form Fed	Feed Concentration (µg/g DW)	Water Concentration (mg/L)	Daily Intake (mg/kg bw/day)	Duration of Study	Effects	References
Mallards	Malathion	NR ^a	NR	1485	NR	LD ₅₀	Tucker and Crabtree, 1970 (p. 76)
Red-winged blackbird	Malathion	NR	NR	400	NR	LD ₅₀	Schafer et al., 1983 (p. 364)
Rats	Malathion	100	NR	NR	8 weeks	No effect	NAS, 1977 (p. 626)
Rats	Malathion	NR	NR	1400-1900		LD ₅₀	Lawless et al., 1975 (p. 38)
Water Buffalo	Malathion	NR	NR	0.5 1.0-1.5	1 year 1 year	No effect level 29-47% reduction in cholinesterase activity	NAS, 1977 (p. 9-2)
Chickens	Malathion	NR	NR	100	1 year	Lowest neurotoxic dose	U.S. EPA, 1982 (p. 9-3)
Hens (laying)	Malathion	15 500	NR NR	NR NR	7 weeks 22 weeks	No effect 6-7% reduction food consumption/egg production	
Chicks	Malathion	100	NR	NR	6.5 days	No effect	U.S. EPA, 1982 (p. 9-4)
Bobwhite quail	Malathion	NR	NR	400	NR	LD ₅₀	U.S. EPA, 1982 (p. 10-13)
Pheasant	Malathion	NR	NR	1600	NR	LD ₅₀	
Quail	Malathion	NR	NR	20	21 days	Inhibited self-righting ability	U.S. EPA, 1982 (p. 10-14)

^a NR = Not reported.

TABLE 4-2. TOXICITY OF MALATHION TO SOIL BIOTA

Species	Chemical Form Applied	Soil Type	Soil Concentration ($\mu\text{g/g DW}$)	Application Rate (kg/ha)	Effects	References
English red worms	Malathion	sandy loam	NR ^a	8.4	10% mortality of adults	Hopkins and Kirk, 1957 (p. 699)
Aerobic bacteria	Malathion	marsh	NR	0.420-4.20	No adverse effects	U.S. EPA, 1982 (p. 7-2)
Centipedes	Malathion	forest soil	NR	3	No effect on population	U.S. EPA, 1982 (p. 10-4)
Millipedes	Malathion	forest soil	NR	3	Slight reduction in population	U.S. EPA, 1982 (p. 10-4)
Mites	Malathion	forest soil	NR	2.24	No effect	U.S. EPA, 1982 (p. 10-4)
Carabid beetles	Malathion	forest soil	NR	1.68	No adverse effect, increased population	U.S. EPA, 1982 (p. 10-9)
Collembola	Malathion	forest soil	NR	1.68	No effect	

^a NR = Not reported.

SECTION 5

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APPENDIX

PRELIMINARY HAZARD INDEX CALCULATIONS FOR MALATHION 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_0 for the unsaturated zone are calculated corresponding to increasing values of t until equilibrium is reached. Assuming a 5-year pulse input from the landfill, Equation 3 is employed to estimate the concentration vs. time data at the water table. The concentration vs. time curve is then transformed into a square pulse having a constant concentration equal to the peak concentration, C_u , from the unsaturated zone, and a duration, t_0 , chosen so that the total areas under the curve and the pulse are equal, as illustrated in Equation 3. This square pulse is then used as the input to the linkage assessment, Equation 2, which estimates initial dilution in the aquifer to give the initial concentration, C_0 , for the saturated zone assessment. (Conditions for B , minimum thickness of unsaturated zone, have been set such that dilution is actually negligible.) The saturated zone assessment procedure is nearly identical to that for the unsaturated zone except for the definition of certain parameters and choice of parameter values. The maximum concentration at the well, C_{max} , is used to calculate the index values given in Equations 4 and 5.

B. Equation 1: Transport Assessment

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

Requires evaluations of four dimensionless input values and subsequent evaluation of the result. $\exp(A_1)$ denotes the exponential of A_1 , e^{A_1} , where $\operatorname{erfc}(A_2)$ denotes the complimentary error function of A_2 . $\operatorname{Erfc}(A_2)$ 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_0 = SC x CF = Initial leachate concentration ($\mu\text{g/L}$)

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)

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

P_{dry} = Dry bulk density (g/mL)

K_d = $f_{\text{oc}} \times K_{\text{oc}}$ (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_0 = Initial concentration of pollutant in aquifer as determined by Equation 2 ($\mu\text{g/L}$)

t = Time (years)

χ = Δl = Distance from well to landfill (m)

D^* = $\alpha \times V^*$ (m^2/year)

α = Dispersivity coefficient (m)

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

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

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

ϕ = Aquifer porosity (unitless)

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

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

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

where:

C_o = Initial concentration of pollutant in the saturated zone as determined by Equation 1 ($\mu\text{g/L}$)

C_u = Maximum pulse concentration from the unsaturated zone ($\mu\text{g/L}$)

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

$$t_o = \left[\int_0^\infty C \, dt \right] \div C_u$$

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

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

1. Formula

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

where:

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

2. Sample Calculation

$$2.794 \times 10^{-7} \mu\text{g/L} = 2.794 \times 10^{-7} \mu\text{g/L}$$

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 ($\mu\text{g/L}$)

AC = Average human consumption of drinking water
(L/day)

DI = Average daily human dietary intake of pollutant
($\mu\text{g/day}$)

ADI = Acceptable daily intake of pollutant ($\mu\text{g/day}$)

2. Sample Calculation

$$6.300 \times 10^{-3} = \frac{(2.794 \times 10^{-7} \mu\text{g/L} \times 2 \text{ L/day}) + 10.08 \mu\text{g/day}}{1600 \mu\text{g/day}}$$

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 ($\mu\text{g/g DW}$)	0.045	0.63	0.045	0.045	0.045	0.045	0.63	N ^a
Unsaturated zone								
Soil type and characteristics								
Dry bulk density, P_{dry} (g/mL)	1.53	1.53	1.925	NA ^b	1.53	1.53	NA	N
Volumetric water content, θ (unitless)	0.195	0.195	0.133	NA	0.195	0.195	NA	N
Fraction of organic carbon, f_{oc} (unitless)	0.005	0.005	0.0001	NA	0.005	0.005	NA	N
Site parameters								
Leachate generation rate, Q (m/year)	0.8	0.8	0.8	1.6	0.8	0.8	1.6	N
Depth to groundwater, h (m)	5	5	5	0	5	5	0	N
Dispersivity coefficient, α (m)	0.5	0.5	0.5	NA	0.5	0.5	NA	N
Saturated zone								
Soil type and characteristics								
Aquifer porosity, ϕ (unitless)	0.389	0.389	0.389	0.389	0.371	0.389	0.371	N
Hydraulic conductivity of the aquifer, K (m/day)	4.04	4.04	4.04	4.04	3.29	4.04	3.29	N
Site parameters								
Hydraulic gradient, i (unitless)	0.02	0.02	0.02	0.02	0.02	0.0005	0.0005	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_0 ($\mu\text{g/L}$)	11.3	158	11.3	11.25	11.3	11.3	157.5	N
Peak concentration, C_u ($\mu\text{g/L}$)	6.166×10^{-4}	8.633×10^{-3}	1.855×10^{-2}	11.25	6.166×10^{-4}	6.166×10^{-4}	157.5	N
Pulse duration, t_0 (years)	20.84	20.84	5.000	5.000	20.84	20.84	5.000	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_0 ($\mu\text{g/L}$)	6.17×10^{-4}	8.63×10^{-3}	1.86×10^{-2}	11.3	6.17×10^{-4}	6.17×10^{-4}	158	N
Saturated zone assessment (Equations 1 and 3)								
Maximum well concentration, C_{max} ($\mu\text{g/L}$)	2.794×10^{-7}	3.912×10^{-6}	2.017×10^{-6}	1.223×10^{-3}	1.485×10^{-6}	1.119×10^{-5}	3.645	N
Index of groundwater concentration resulting from landfilled sludge, Index 1 ($\mu\text{g/L}$) (Equation 4)	2.794×10^{-7}	3.912×10^{-6}	2.017×10^{-6}	1.223×10^{-3}	1.485×10^{-6}	1.119×10^{-5}	3.645	0
Index of human toxicity resulting from groundwater contamination, Index 2 (unitless) (Equation 5)	0.0063	0.0063	0.0063	0.006302	0.0063	0.0063	0.01086	0.0063

^aN = Null condition, where no landfill exists; no value is used.

^bNA = Not applicable for this condition.