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Water

EPA

Summary of Environmental Profiles and Hazard Indices for Constituents of Municipal Sludge: Methods and Results

SUMMARY OF ENVIRONMENTAL PROFILES AND HAZARD INDICES FOR CONSTITUENTS OF MUNICIPAL SLUDGE

U.S. Environmental Protection Agency
Office of Water Regulations and Standards
Wastewater Solids Criteria Branch
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Preface

Section 405 of the Clean Water Act requires the U.S. Environmental Protection Agency to develop and issue regulations which: (1) identify uses for sludge including disposal; (2) specify factors to be taken into account in determining the measures and practices applicable for each use or disposal (including costs); and (3) identify concentrations of pollutants which interfere with each use or disposal. In order to comply with this statutory mandate, EPA has embarked on a major program to develop five major technical regulations: distribution and marketing, land application, landfilling, incineration and ocean dumping. EPA is also developing regulations which govern the establishment of State sludge programs to implement both existing and future technical criteria. Key to the Agency's regulatory effort is the policy that EPA is actively promoting those municipal sludge management practices that provide for the beneficial use of sludge while maintaining or improving environmental quality and protecting public health.

The identification of potential pollutants of concern for each reuse and disposal option is a critical part of the technical sludge regulation development process. The purpose of this document is to describe the data compilation, analyses and conclusions of EPA's effort to identify pollutants of potential concern. The major questions addressed by this document are:

(1) What are the potential pollutants of concern for each reuse or disposal option?

(2) For such pollutants, which environmental pathways are of primary concern?; and

(3) What is the degree of hazard associated with each pollutant for such pathways?

The results of the analyses contained in this document are intended to facilitate selection of pollutants and to determine which pollutants and pathways should be studied further. These further studies may indicate that the pollutant/pathways are not of sufficient concern to require regulation or they may indicate that there are additional pollutants/pathways that need to be studied. Thus, the magnitude of the hazard indices discussed in this document are not, in and of themselves, an indication of the absolute risk for a contaminant/exposure pathway. Rather, this should be viewed only as an initial screening mechanism. For those pollutants/pathways that EPA decides to regulate, the regulations may take the form of numeric limits, best management practices, or other controls and limitations needed to protect the environment and public health.

This summary document will describe in detail the overall process to develop the "technical" sludge regulations and will show how the data profiles/hazard indices fit into the regulatory framework. The individual environmental profile documents for each pollutant will be available for public inspection at EPA's Regional Offices. Any questions related to this document may be directed to:

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TABLE OF CONTENTS

APPENDICES

EXECUTIVE SUMMARY

The following briefly summarizes some of the key points contained in this document:

- The purpose of the environmental profile and hazard indices is to rapidly screen pollutants so that those most likely to pose a hazard to human health or the environment can be identified for further assessment and possible regulatory control. The results from the calculation of the hazard indices also allow for the deletion of pollutants from further consideration for a specific environmental pathway if no environmental or health hazard is evident even under worst case conditions.

- A two tier screening system was developed which allows for (a) the elimination of pollutants which do not present a hazard for a specific pathway and for (b) the prioritization of those pollutants that potentially may present a hazard. The first tier is accomplished by ranking the pollutants based on their hazard index values for each environmental pathway and deleting those pollutants with values less than 1 (indicating no potential problem under assumed worst case scenario). The second tier is the prioritization of pollutants based on incremental values; that is, the portion of the hazard index values solely attributable to sludge. The incremental values were derived by subtracting the "null" or background levels from the total hazard values associated with a pollutant for a specific pathway. The result of this two tier system is a list of pollutants for each environmental pathway (per reuse/disposal option) which identifies priorities for further risk assessment.

- The outcome of the environmental profile evaluations and the two tier screening approach is <u>not</u> a definitive list of pollutants that EPA will ultimately regulate. Rather, the outcome of this process is an identification of those pollutants of "potential concern" which require further analysis and evaluation. The numerical magnitude of the hazard indices discussed in this summary are not in and of themselves an indication of absolute risk for a contaminant/exposure pathway.

- Fifty pollutants were identified at the OWRS expert committee meetings as being of concern to one or more reuse/disposal options. For each of these pollutants, an environmental profile document was generated which included the hazard indices calculated.

- For land application (including distribution and marketing), thirty two pollutants were evaluated. For this option, thirteen hazard indices were developed to evaluate the hazard associated with each of the major environmental pathways related to this option. The pathways and effects examined included: toxicity to soil biota; toxicity to predators of soil biota; phytotoxicity; plant uptake; toxicity to animals resulting from plant consumption; toxicity to animals from sludge ingestion; human toxicity from plant consumption; human toxicity from animal ingestion; and incidental soil ingestion by humans.

- For landfilling, twenty eight pollutants were evaluated. Two hazard indices were developed for this option: an index of groundwater concentration increment resulting from landfilled sludge and an index of human toxicity resulting from groundwater contamination.

- For incineration, thirty compounds were evaluated. Two hazard indices were developed for this option: an index of air concentration increment resulting from incinerator emissions and an index of human toxicity/cancer risk resulting from inhalation of incinerator emissions.

- For ocean dumping, twenty one compounds were evaluated. Four hazard indices were developed for this option: (a) an index of seawater concentration resulting from initial mixing of sludge; (b) an index of seawater concentration resulting from a 24 hour dumping cycle; (c) an index of toxicity to aquatic life; and (d) an index of human toxicity resulting from seafood consumption.

- Based on the environmental profiles and the two tier screening process, 22 pollutants require further analysis for at least one of the 10 pathways related to land application (Table 11); 16 pollutants for the one pathway related to landfilling (Table 12); 17 pollutants for the one pathway related to incineration (Table 13); and 10 pollutants for the two pathways related to ocean dumping (Table 14).

Summary of Environmental Profiles and Hazard Indices for Constituents of Municipal Sludge

I. INTRODUCTION

The need for effective sludge management is continual and growing. The quantity of municipal sludge produced annually has almost doubled since 1972 when the Clean Water Act was enacted. Recognizing the importance of sludge management, Congress enacted Section 405 of the Clean Water Act which requires the U.S. Environmental Protection Agency to develop and issue regulations which: (1) identify uses for sludge including disposal; (2) specify factors to be taken into account in determining the measures and practices applicable for each use or disposal (including costs); and (3) identify concentrations of pollutants which interfere with each use or disposal. In addition to the Clean Water Act, EPA has authority to regulate municipal sludge under other statutes and several regulations have been issued using such authorities (Table 1). Currently municipalities are generating approximately 6.5 million dry tons of wastewater sludge per year with the annual production expected to double by the year 2000.

In 1982, EPA established a Sludge Task Force which was responsible for: (1) assessing the magnitude of and management approaches to municipal sludge reuse and disposal nationwide; (2) evaluating the strengths and weaknesses of past regulatory activities; and (3) identifying data and informational needs in order to direct EPA research in the field. The establishment of the Task Force was a result of the recognition that the authorities and regulations related to municipal sludge were fragmented as each regulation was developed in isolation from other disposal options. Thus, the individual regulations did not provide States and municipalities with adequate guidelines on which to base sludge management decisions. The Task Force was therefore mandated to develop a comprehensive workplan which would: (1) delineate a framework for improving the Agency's regulatory program and (2) identify the entities within EPA responsible for implementing a sludge regulatory program.

In 1983, the Sludge Task Force presented its recommendations and issued an Agency workplan. One of the main conclusions and suggestions was the need for a comprehensive regulatory program with the primary legislative authority being Section 405 of the Clean Water Act and that sludge regulations should be developed by the Agency's Office of Water.

Based on the recommendations of the Task Force, EPA is proceeding with a major regulatory program to develop two sets of

Table 1. Sludge Regulations Issued By The U.S. Environmental Protection Agency

Coverage	Reference	Application
Polychlorinated Biphenyls (PCBs)	40 CFR 761	All sludges containing more than 50 milligrams of PCBs per kilogram
Ocean Dumping	40 CFR 220-228	The discharge of sludge from barges or other vessels
New Source of Air Emissions	40 CFR 60	Incineration of sludge at rates above 1,000 kilograms per day
Mercury	40 CFR 61	Incineration and heat drying of sludge
Cadmium, PCBs, Pathogenic Organisms	40 CFR 257	Land application of sludge, landfills, and storage lagoons
Extraction Procedure Toxicity	40 CFR 261	Defines whether sludges are hazardous

Source: U.S. EPA, 1984 "Environmental Regulations and Technology: Use and Disposal of Municipal Wastewater Sludge." 76 pp.

regulations - State Sludge Management Program Regulations to be developed by the Office of Municipal Pollution Control (OMPC) and Technical Sludge Regulations to be developed by the Office of Water Regulations and Standards (OWRS). The technical regulations are being developed for five major reuse and disposal options: distribution and marketing, land application to food chain and non-food chain crops, landfilling, incineration and ocean dumping. The regulation on ocean dumping will be coordinated with the Office of Marine and Estuarine Protection within the Agency's Office of Water. The regulation for municipal sludge incineration will be coordinated with the Office of Air Quality Planning and Standards. Finally, the regulations for land application, distribution and marketing, and landfilling will be coordinated with the Office of Solid Waste and the Office of Pesticides and Toxic Substances.

In November 1983, OWRS developed an internal workplan which delineated the work elements and steps needed to propose and issue technical sludge regulations for the various reuse/disposal options. A description of the workplan and major steps needed for the development of the technical regulations is contained in the next section of this document and is highlighted in Figure 1. This workplan was developed with the underlying principle that all 5 regulations should be generated concurrently in order to give an intermedia perspective and to provide States and municipalities with the data and information on all the options to facilitate informed decisionmaking. The work plan also was developed to ensure that the regulations would be issued in a timely fashion, with proposed regulations being issued in mid-1986.

II. OWRS WORKPLAN AND STEPS FOR DEVELOPING TECHNICAL REGULATIONS

Initiating a major regulatory program leading to the concurrent development of five regulations requires concise steps and work elements in order to ensure that such an effort will be manageable and timely. The workplan was designed recognizing EPA's available resources and the magnitude of the effort. The following will describe the major steps being pursued by OWRS in the development of these regulations:

° WORK ELEMENT 1: DETERMINING POLLUTANTS OF CONCERN FOR EACH DISPOSAL OPTION

The initial focus of this regulatory development process is the identification of pollutants that may interfere with each reuse and disposal option because of environmental or health considerations. Besides identifying the pollutants of concern, it is also critical to identify the environmental pathways and the magnitude of the hazard to the target organisms be it plant, animal or human. The mechanism used for determining the pollu-

FIGURE 1: STEPS FOR DEVELOPING SLUDGE REGULATIONS

WORK ELEMENT 1:

IDENTIFY POLLUTANTS OF CONCERN

STEPS INCLUDE:

(1) development of strawman list of pollutants
(2) expert meetings on pollutants of concern (April-May 1984)
(3) development of environmental profiles and hazard indices

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WORK ELEMENT 2:

DEVELOP RISK ASSESSMENT METHODOLOGIES

STEPS INCLUDE:

(1) draft risk assessment methodologies for each reuse/disposal option
(2) expert review of draft methods
(3) revisions and sensitivity analyses
(4) finalize methods

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WORK ELEMENT 3:

DERIVE CRITERIA, APPLICATION RATES AND MANAGEMENT PRACTICES

STEPS INCLUDE:

(1) determination of key inputs to models and methodologies
(2) deliniate if pollutant can be controlled by management practices
(3) calculate criteria for constituents
(4) specify application rates

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WORK ELEMENT 4:

GENERATE TECHNICAL SUPPORT DOCUMENT

STEPS INCLUDE

(1) Work elements 1-3 incorporated into document
(2) Fate and transport analyses
(3) Identify site specific factors
(4) Benefits analysis
(5) Economic Evaluations
(6) Compliance Monitoring

→

WORK ELEMENT 5:

DEVELOP AND ISSUE PROPOSED REGULATIONS

STEPS INCLUDE:

(1) Draft regulations
(2) Regulatory Impact Analyses
(3) EPA Agency Reviews
(4) Issue in Federal Register
(5) Public Meetings

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WORK ELEMENT 6:

ISSUE FINAL REGULATIONS

STEPS INCLUDE:

(1) Revisions based on public comment
(2) Agency review
(3) Final issuance in Federal Register

tants of concern has been the environmental profiles containing (a) data compilations for a specific contaminant and (b) hazard indices for each of the major environmental pathways associated with a reuse/disposal option. The next section of this document will describe more fully the process for identifying pollutants and for developing the environmental profiles and hazard indices. the output of this work element is a list of pollutants of potential concern per reuse/disposal option and the relative hazard associated with each of the pathways based on the profiles. This information will allow EPA to begin more intensive analyses and assessments on the highest risk pathways for a pollutant.

° WORK ELEMENT 2: DEVELOPMENT OF RISK ASSESSMENT METHODOLOGIES

Concurrent with the generation of the environmental profiles, EPA has been developing methods for quantifying the risk of a particular pollutant for a specific pathway. These methodologies will ultimately be used to derive maximum permissible contaminant levels and to identify management practices for municipal sludge. The generation of these methodologies is complex due to the number of environmental pathways for which methods are needed. Figure 2 demonstrates this complexity by showing the environmental pathways related to the land application option. The development of these methodologies includes the use of models and will delineate the assumptions and limitations associated with each model and methodology. Sensitivity analyses will also be incorporated. The output of this work element is five final risk assessment methodologies, one per reuse/disposal option. The outputs from work element 1 and 2 are then interlinked in work element 3.

° WORK ELEMENT 3: DERIVATION OF CRITERIA, APPLICATION RATES AND MANAGEMENT PRACTICES

The outputs of work element 1, that is, the pollutants of concern for specific pathways, will be analyzed using the risk assessment methodologies developed in work element 2. The pollutants will be analyzed for degrees of risk for specific application rates or input rates by varying the inputs into the models and methodologies. The outputs of this work element may be either maximum numeric concentrations (e.g. no sludges may be incinerated which contain greater than x ug/kg of pollutant y) or management practices (e.g. incinerators should be operated under certain conditions) or combinations of practices and numbers (e.g. sludge containing pollutant x at concentration y should only be applied twice a year by injection). The reader should clearly understand that the Agency will not be solely regulating on numeric limits but will also utilize management practices. Furthermore, site-specific factors will be considered in the regulatory development process with EPA providing guidance and/or algorithms to the States. The utilization of management practices is consistent with EPA's policy of the beneficial reuse of sludge while main-

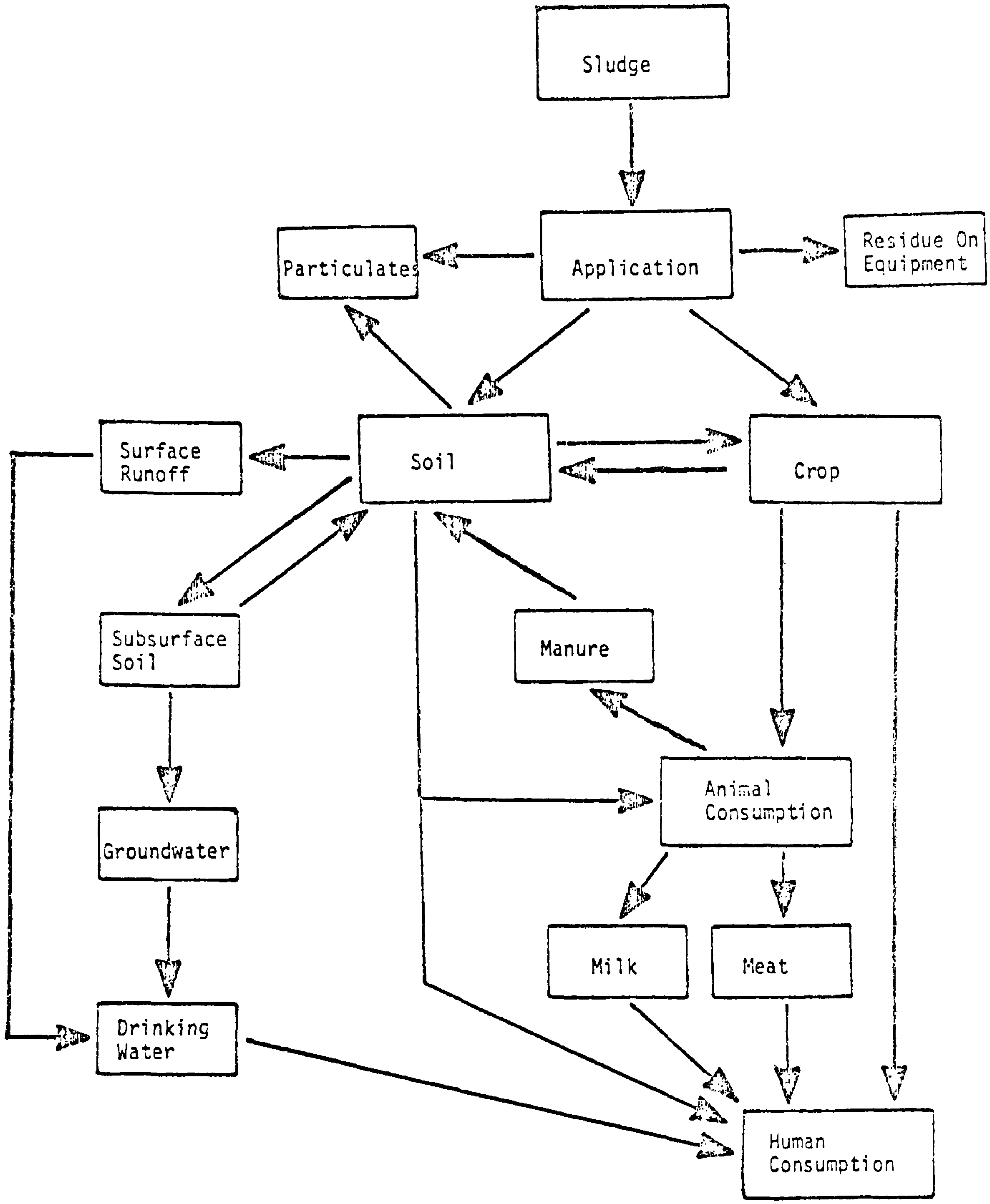

Figure 2 : Land Application Pathways

taining environmental quality and protecting public health. The output of this work element will form the framework for how each of the pollutants of concern will be regulated. Based on the outputs of this element, OWRS will also be able to identify data gaps and informational needs which will be transmitted to EPA's Office of Research and Development to initiate tasks to fill the voids.

° WORK ELEMENT 4: GENERATION OF TECHNICAL SUPPORT DOCUMENTS

Technical background or support documents are being generated for each of the five regulations. The purpose of these documents is to summarize the results of work elements 1-3 as well as incorporate the following analyses and evaluations:

(1) Fate and Transport of Pollutants - Description and data related to the fate and effects of pollutants in each medium (air, water, soil) will be incorporated in the documents. Processes such as biodegradation, absorptability, volatilization and others may affect the availability and toxicity of the compounds to the target organisms.

(2) Site-Specific Factors - Data related to site-specific factors such as soil or climatic variability will be incorporated. For example, certain processes may be viable for certain geographic locations and not others. Soil conditions may enhance or ameliorate the toxicity of certain pollutants. The Agency believes that States should have the flexibility to consider such factors in their sludge management programs.

(3) Economic Evaluations and Benefit Analyses - Costing data on the various technologies associated with each option will be included to provide the States and municipalities with a comprehensive picture of the option both from a standpoint of associated risk and economics. The benefits of reusing sludge in terms of cost savings, e.g. fertilizer value for the land application option, will also be quantified and incorporated.

(4) Compliance Monitoring Requirements - The regulations as well as the technical support documents will describe the requirements for compliance monitoring i.e. frequency of monitoring, methods of analysis, etc.

(5) Intermedia Analysis - Contained within each document will be a section that describes the relative risks among each of the options for specific pollutants. The purpose of this section is to allow the decisionmakers to quickly assess the implications "across the board" without having to refer back to the other four documents. This section will summarize, for example, what the risks of sludges high in pollutant X are for this option as well as for the other reuse/disposal options. This section will not

attempt to equate or assign absolute values associated with each of the options, for example, cases of cancer expected from land applications as opposed to aquatic toxicity effects from ocean disposal.

(6) Description of Data Gaps - An appendix to each of the documents will describe the voids in data and information related to the reuse/disposal option. Much of this will be identified during the course of work elements 1-3 and will also be identified when developing the fate and transport, site-specific and economic/ benefits sections of the document. EPA will continue its research in municipal sludge and will focus its program to fill the identified data gaps.

° WORK ELEMENT 5: DEVELOPMENT AND ISSUANCE OF PROPOSED REGULATIONS

With the completion of the technical support documents, drafting of the proposed regulations can commence. The proposed regulations will clearly delineate the requirements in terms of management practices and generic or site-specific numeric standards. The regulations will also contain compliance monitoring requirements. The technical support document will be available along with the proposed regulations to allow the public to review the analyses used as the basis of the proposal during the public comment period.

° WORK ELEMENT 6: ISSUANCE OF FINAL REGULATIONS

After the public comment period on the proposed regulation closes, EPA will assess the comments and make appropriate changes. The projected date for final promulgation of these regulations is mid-1987.

III. OWRS APPROACH FOR DETERMINING POTENTIAL POLLUTANTS OF CONCERN

After the generation of the OWRS workplan for developing the technical regulations, work began on Element 1 - the determination of potential pollutants of concern. As previously mentioned, the purpose of this element was to identify pollutants which require additional analyses and should undergo a rigorous risk assessment. The lists of pollutants generated from this work element does not constitute a list of pollutants that EPA will definitively regulate. Rather, this work element should be viewed as a screening mechanism which identifies the pollutants needing risk analyses. Subsequent analysis by the Agency may add or delete pollutants from the lists. Several steps were initiated to identify the potential pollutants of concern:

(1) Development of a "Strawman" List of Pollutants - A strawman list of pollutants of concern was developed based on data readily

available to OWRS. The purpose of developing this list was to provide a group of experts (Appendix A) with an initial list from which they could add or delete pollutants. The development of the strawman list was based on data available on frequency of occurrence, aquatic toxicity, phytotoxicity, human health effects, domestic and wildlife effects and plant uptake. Once this strawman list was developed, a series of expert meetings were convened.

(2) Expert Meetings on Each of the Reuse/Disposal Options - Four expert meetings were convened during April and May 1984 to determine the potential pollutants of concern for the various options. The options for land application and distribution and marketing were combined into one meeting as the environmental pathways related to these options overlap. The other meetings were: landfilling, incineration and ocean dumping. The experts for these meetings were selected based on the recommendations of the Sludge Task Force and were from various sectors including academia, State government, consultants and EPA personnel. The experts received the strawman list of pollutants prior to the meetings and were also presented with several questions for their consideration prior to the meeting including:

(a) for which pollutants does sufficient data exist which indicates that such pollutants present a potential hazard if reused or disposed by the option in question?

(b) for which pollutants does sufficient data exist which indicates that such pollutants do not present a potential hazard or problem to human health or the environment?

(c) for which pollutants are there insufficient data to make a conclusive recommendation concerning potential hazard?

The experts were convened and were advised that an environmental profile would be generated for each pollutant suggested by the group as being of potential concern. The experts were given broad latitude in determining the pollutants for evaluation. They were allowed to add or delete from the strawman list. Based on the recommendations of the four expert meetings, 7 pathogens and 50 pollutants (Appendix B) were identified for development of environmental profiles and, therefore, were selected for further analysis.

The experts also were responsible for identifying the major environmental pathways that should be evaluated; that is, which pathways were the worst as related to a specific reuse/disposal option. The experts also identified several pathways that the lack of data precluded an evaluation. For ocean dumping the pathway of sediment contamination and subsequent food chain transfer could not be evaluated using hazard indices. Thus, not all all pathways related to a specific option were analyzed.

During the meetings the experts in some cases suggested a re - presentative of a group of compounds for which a profile would be generated. If that analysis showed a hazard, other members of the group would be analyzed. Upon completion of these meetings the development of environmental profiles commenced.

(3) Development of Environmental Profiles - The development of environmental profiles for 50 pollutants was a major effort for OWRS and the Environmental Criteria and Assessment Office (ORD-Cincinnati) in late 1984 and early 1985. The environmental profiles each consist of two major portions: (a) a compilation of data on toxicity, occurrence and fate and effects for the pollutant and (b) a series of indices for evaluating the hazard relative to the major environmental pathways for the reuse/disposal option of concern. Appendix C is an example of an environmental profile. Drafts of each profile were reviewed by the experts as well as submitted to an internal EPA review. Changes and modifications were incorporated into the final profiles. The results of these profiles and the hazard indices are summarized in this document. Once again the reader must recognize that the primary goal and approach of the data profiles/hazard indices was to screen out those contaminants that do not pose a threat to health and the environment and to establish relative priorities for those that do warrant further investigation. To do this, worst case conditions for exposure and effect were assumed. There was no attempt to assess the relative risk of exposure to contaminants in sludge versus other sources of the contaminant in the environment. The numerical magnitude of the hazard indices discussed in this summary are not in and of themselves an indication of absolute risk for a contaminant/exposure pathway. Rather this is a screening technique to identify contaminants that will be subjected to a more rigorous examination. The remainder of this summary document will discuss the various indices developed for each of the reuse/disposal options, results, interpretation and conclusions based on the indices for each pollutant.

IV. HAZARD INDICES DEVELOPED FOR EACH REUSE/DISPOSAL OPTION

As mentioned, the environmental profiles contain two portions: a compilation of data and a set of hazard indices related to each reuse/disposal option. These indices are intended to identify or screen pollutants which have a reasonable possibility of adverse affects for given exposure scenario from those pollutants that do not. The calculation of these indices facilitate evaluations and decision-making by reducing large bodies of data and information into index values. The hazard indices developed may be separated into two types, one type showing the expected increase of contaminant concentration in an environmental medium ("incremental index") and the other showing whether adverse effects could result ("effect index"). The incremental indices show the expected degree of increase of contaminant concentration in water, soil, air or food resulting from sludge disposal. This type of index does not by itself indicate hazard, since contamination alone does not necessarily mean that adverse effects will occur. However, the incremental index aids in both the calculation and interpreptation of the "effect" indices. The effect indices evaluate whether a given increase of contaminant level could be expected to result in a given adverse impact on health of humans or otheer organisms. Both types of indices were developed for each reuse/disposal option. The purpose of the remainder of this section is to describe the hazard indices developed for each reuse/disposal option.

° (A) LAND APPLICATION/DISTRIBUTION AND MARKETING

Thirteen indices were developed for land application and distribution and marketing to address specific environmental pathways. Each of the indices were calculated for two sludge pollutant concentrations and for several different cumulative application rates (i.e. 5 mt/ha, 50 mt/ha or 500 mt/ha) so that for a single index a determination can be made as to the application rate at which the pollutant becomes a hazard. The following is a general description of each of the thirteen indices and shows how these indices were designed to cover all the pathways associated with these reuse options.

- INDEX 1: INDEX OF SOIL CONCENTRATION INCREMENT - This index shows the degree of elevation of the contaminant in soil after sludge has been applied. This index is calculated for sludges with normal and high contaminant concentrations. The data used for this index is the soil background concentration for the contaminant, the concentration of the contaminant in the sludge and the sludge application rate.

- INDEX 2: INDEX OF SOIL BIOTA TOXICITY - This index compares the contaminant concentration in the sludge-amended soil with concentrations shown to be toxic for a soil organism (e.g. earthworms). This is calculated for sludges with normal and high concentrations to determine if there is a potential hazard to soil biota.

- INDEX 3: INDEX OF SOIL BIOTA PREDATOR TOXICITY - This index compares the concentrations in tissues of organisms inhabiting sludge-amended soil with food concentrations shown to be toxic to predators of soil biota. For example, this index assesses the potential hazard to birds which prey upon earthworms residing in sludge amended soils.

- INDEX 4: INDEX OF PHYTOTOXICITY - This index compares the contaminant concentration in sludge-amended soils with soil concentrations shown to be toxic to plants. This index determines the potential hazard to crops for specific applications of sludge to soils on which the crops are being grown.

- INDEX 5: INDEX OF PLANT CONCENTRATION INCREMENT CAUSED BY UPTAKE This index calculates the incremental amount of the pollutant which is taken into the tissues of plants growing in sludge-amended soils. This index uses data on the uptake in responsive plants. Two plants were chosen to represent all plants in the human and animal diets respectively.

- INDEX 6: INDEX OF PLANT CONCENTRATION INCREMENT PERMITTED BY PHYTOTOXICITY - This index compares the maximum plant tissue concentration associated with phytotoxicity with the background concentration in the same plant tissue. This index determines whether the plant tissue concentration caused by uptake of pollutants from sludge-amended soil may be limited by phytotoxicity.

- INDEX 7: INDEX OF ANIMAL TOXICITY RESULTING FROM PLANT CONSUMPTION This index evaluates the potential hazard to domestic or wild animals which consume crops grown on sludge-amended soils. This index uses data on the dietary concentration toxic to herbivorous animals and the contaminant concentration in the plant tissue. This index builds upon Index 5, described earlier.

- INDEX 8: INDEX OF ANIMAL TOXICITY RESULTING FROM SLUDGE INGESTION This index calculates the amount of contaminant in a grazing animal's diet resulting from consumption of sludge-amended soil or sludge adhering to forage and compares this with the dietary toxic threshold concentration for a grazing animal.

- INDEX 9: INDEX OF HUMAN TOXICITY/CANCER RISK RESULTING FROM PLANT CONSUMPTION This index compares the expected dietary intake of a pollutant from crops grown on sludge-amended soils to the acceptable daily intake for that constituent, if it is a noncarcinogen. For carcinogens, the dietary intake is compared to a daily dietary intake of the pollutant associated with an incremental cancer risk of 10^{-6}. This index builds upon Index 5, described earlier.

- INDEX 10: INDEX OF HUMAN TOXICITY/CANCER RISK RESULTING FROM CONSUMPTION OF ANIMAL PRODUCTS DERIVED FROM ANIMALS FEEDING ON PLANTS - This index calculates the human dietary intake expected to result from contaminant uptake by domestic animals given feed produced from crops grown on sludge-amended soil and compares this to the acceptable daily intake for that contaminant, if a noncarcinogen or to a daily dietary intake of the pollutant associated with an incremental cancer risk of 10^{-6} if a carcinogen. This index builds upon Index 7, described previously.

- INDEX 11: INDEX OF HUMAN TOXICITY/CANCER RISK RESULTING FROM CONSUMPTION OF ANIMAL PRODUCTS DERIVED FROM ANIMALS INGESTING SOIL - This index calculates human dietary intake expected to result from contaminant uptake by grazing animals incidentally ingesting sludge-amended soil or sludge adhering to forage and compares this to the acceptable daily intake for that contaminant if a noncarcinogen or to a daily dietary intake associated with an incremental cancer risk of 10^{-6} if a carcinogen. This index builds upon Index 8 described previously.

- INDEX 12: INDEX OF HUMAN TOXICITY/CANCER RISK RESULTING FROM SOIL INGESTION - This index calculates the amount of contaminant ingestion for a child and adult resulting from inadvertant or intentional ingestion of sludge-amended soil. Consideration of this route of exposure is important for protecting children demonstrating Pica behavior. The amount ingested is compared to the acceptable daily intake or 10^{-6} risk-specific intake level.

- INDEX 13: INDEX OF AGGREGATE HUMAN TOXICITY/CANCER RISK - This index calculates the aggregate amount of the contaminant in the human diet resulting from the pathways described in indices 9-12. This index compares the aggregate amount of contaminant intake with the acceptable daily intake or 10^{-6} cancer risk specific daily intake level.

For land application, the groundwater and surface water pathways were not evaluated based on the recommendation of the OWRS expert committee that such pathways are not of major concern when municipal sludge is applied using good management practices. The experts based their recommendation on EPA's "Process Design Manual: Sludge Treatment and Disposal" document which clearly deliniates practices which would prevent ground water and surface water contamination.

° (B) LANDFILLING

The modelling of contaminants leaching from a landfill is a complex effort. Many assumptions need to be made regarding soil and aquifer properties, mobility of the contaminants, their dilution and other factors. The following describes in general the two indices developed for the disposal option of landfilling:

- INDEX 1: INDEX OF GROUNDWATER CONCENTRATION INCREMENT RESULTING FROM LANDFILLED SLUDGE - The purpose of this index is to evaluate the leaching of pollutants to an aquifer from an unlined sludge landfill. This index is based on the EPA Exposure Assessment Group's model, "Rapid Assessment of Potential Groundwater Contamination Under Emergency Response Conditions (EPA 600/8-83-030)." Calculation of the index involves the following steps: (1) Estimation of pollutant transport through the soil profile to the water table beneath the landfill, and (2) estimation of pollutant transport through the aquifer to a nearby well. The index value gives the degree of increase in groundwater concentration at the well.

- INDEX 2: INDEX OF HUMAN TOXICITY/CANCER RISK RESULTING FROM GROUNDWATER CONTAMINATION - This index calculates the human health impacts due to groundwater contamination in the landfill vicinity. This index is determined by comparing the exposure from the groundwater with the acceptable daily intake values for non-carcinogens. For carcinogens the comparison is made with the intake level calculated to result in an increase in cancer risk of 10^{-6}.

° (C) INCINERATION

As with landfilling, the analysis for incineration requires transport modelling. This effort involves delineating assumptions such as incinerator operation parameters and incinerator plume dispersion to be used in determining the chemical constituents in and the size and shape of the plume. Two indices were developed for incineration to determine the increase in air concentration of the pollutant and the resultant human health impacts from inhalation of incinerator emissions. The residual ash is assumed to be landfilled and is not further considered in this analysis. The indices developed for incineration are:

- INDEX 1: INDEX OF AIR CONCENTRATION INCREMENT RESULTING FROM INCINERATOR EMISSIONS - This index shows the degree of elevation of pollutant concentration in the air due to the incineration of municipal sludge. This index was generated using a model which examines the thermodynamic and mass balance relationships appropriate for multiple hearth incinerators and relates the input sludge characteristics to the stack gas parameters and chemical constituents. Dilution and dispersion of these stack releases can then be described and normalized annual ground level concentration predicted using an algorithm.

- INDEX 2: INDEX OF HUMAN HEALTH OR CANCER RISK FROM INHALATION OF INCINERATOR EMISSIONS - This index evaluates the incremental human health impacts due to incinerator emissions. The annual ground level concentration predicted above is compared to an exposure criterion for that contaminant. The exposure criterion is based on a maximum permissible intake by inhalation (for non-carcinogens) or a 10^{-6} cancer risk-specific intake (for carcinogens).

° (D) OCEAN DUMPING

Four indices were developed for the ocean dumping option:

- INDEX 1: INDEX OF SEAWATER CONCENTRATION RESULTING FROM INITIAL MIXING OF SLUDGE - This index estimates the increase in the sea-water concentration of a contaminant at a dumpsite as a result of sludge disposal assuming initial mixing. The data inputs into this index include: the sludge diposal rate, the contaminant concentration in the sludge, and the disposal site characteristics.

- INDEX 2: INDEX OF SEAWATER CONCENTRATION REPRESENTING A 24-HOUR DUMPING CYCLE - This index calculates the increased concentrations of the pollutant in seawater around an ocean disposal site utilizing a time-weighted average concentration. The time-weighted concentration is that which would be experienced by an organism remaining stationary (with respect the ocean floor) or moving randomly within the disposal vicinity during a 24-hour period.

- INDEX 3: INDEX OF TOXICITY TO AQUATIC LIFE - This index compares the resultant water concentration of the contaminant at the dumpsite with the ambient water quality criterion or with another value judged protective of marine aquatic life and its marketability. This index does not address the possibility of effects arising from contaminant accumulation in sediments since EPA is just beginning to derive methodologies for generating sediment criteria. Once such a methodology is available, EPA can determine effects of sludge constituents on sediment biota.

- INDEX 4: INDEX OF HUMAN TOXICITY RESULTING FROM SEAFOOD CONSUMPTION This index estimates the expected increase in human intake of the contaminant due to seafood consumption, taking into account that fraction which originates from the dumpsite vicinity. This index compares the total expected contaminant intake with the acceptable daily intake or, if a carcinogen, with the intake level calculated to result in an increase of cancer risk of 10^{-6}.

In summary, twenty one indices were generated for the five reuse/disposal options to cover the major associated environmental pathways. Once again, the reader should keep in mind that the selection of pathways was based on the judgment of the experts at the OWRS committee meetings. Not all possible pathways related to a specific reuse/disposal option have been evaluated. The pathways of groundwater and surface water impacts from land application; plant and soil impacts from deposition of incinerator particulates; and marine life impacts from sediment contamination will be evaluated during the risk assessments conducted for each option. Environmental profiles using these indices were generated for each of the fifty pollutants selected as pollutants of potential concern by the experts. The following section describes the types of data used in developing the environmental profiles and in calculating the hazard indices.

V. DATA USED IN ENVIRONMENTAL PROFILES AND HAZARD INDICE CALCULATIONS

In generating the environmental profile documents and calculating the hazard indices, various types of data were gathered and used for the analyses. The information contained in the profiles was based on a compilation of the recent literature and an attempt was made to fill out the profile outline to the greatest extent possible. The following briefly describes some of the types of sources of data used in the profiles and hazard indices calculations.

° Sludge Concentration Data

Data on sludge contaminant concentrations were derived from an EPA report, "Fate of Priority Pollutants in Publicly Owned Treatment Works" (U.S. EPA, 1982), frequently referred to as the "40-City Study." Whenever the 40-City Study provided insufficient information, data from another report prepared for the U.S. EPA, "A Comparison of Studies of Toxic Substances in POTW Sludge" was used (Camp, Dresser and McKee, 1984). The "typical" sludge concentrations used in the hazard indices calculations represent a median or mean value where the "worst" sludge concentration represents a 95th percentile value. Appendix F shows the typical and worst sludge concentrations for each pollutant, which was used in determining the hazard index values.

° Plant and Animal Effects Data

In order to assess the effects of municipal sludge on plants and animal life, several types of data were gathered for the environmental profiles. Data on plant and animal uptake factors and slopes were gathered in order to evaluate tissue concentrations of the polluant. In order to assess the effects on the target organism from a specific pollutant, toxicity data was gathered and evaluated. The uptake data and toxicity data was derived from a literature search and the key data points were extracted in order to evaluate the effects on plants and animals. The reader should refer to Appendices C and ᵀ in order to fully understand and appreciate the types of data gathered for these analyses.

° Human Effects Data

As previously mentioned, the effects indices show whether a given increase in contaminant level could be expected to result in a given impact on health of humans or other organisms. For humans, the type of data used and the benchmarks against which such data is evaluated is dependent on the pollutant; that is, whether it is a carcinogen. For carcinogens, EPA considers the effects to be nonthreshold; that is, any level of exposure to a carcinogenic contaminant is regarded as posing some risk. Since no threshold can be identified, a "benchmark" level of incremental risk was chosen against which to evaluate carcinogen exposure. The Carcinogen Assessment Group of the U.S. EPA has estimated the carcinogenic potency (i.e., the slope of risk versus exposure) for humans exposed to low dose levels of carcinogens. These potency values indicate the upper 95% confidence limit estimate of incremental cancer risk for individuals experiencing a given exposure over a 70 year lifetime. These potency values can also be used to derive the exposure level expected to correspond to a given level of excess risk. An incremental risk level of 10^{-6}, or one in a million, was chosen as a benchmark in the hazard indice evaluations. For non-carcinogens, EPA considers such effects to have thresholds. For humans the threshold value chosen was an established Acceptable Daily Intake (ADI), which is usually chosen to be below the threshold for chronic toxicity.

The data required to evaluate human health effects varied according to the reuse/disposal option being evaluated. For land application of sludge, data was gathered on: (a) the daily human dietary intake of the pollutant; (b) the daily dietary intake of affected plant and animal tissues; (c) the uptake factors of the pollutant in plant and animal tissues; and (d) the amount of soil in the human diet, in order to evaluate the Pica child syndrome. For landfilling of sludge, data on (a) the average human consumption of groundwater and (b) the average daily human intake of the pollutant was gathered and assessed in order to evaluate the human health effects from groundwater which has been contaminated due to landfilling. For incineration, data was gathered on the background concentration of the pollutant in ambient air and an exposure criteria was developed from cancer potency data for carcinogens or from threshold limited values for non-carcinogens. For ocean dumping, data on seafood consumption and bioconcentration factors were used to assess human health effects from ocean dumping.

Once all the data was gathered and evaluated, the calculation of hazard indices commenced. The next section of this document describes the results of the hazard indice calculations for each of the reuse/disposal options.

VI. RESULTS OF HAZARD INDEX CALCULATIONS

Based on the development of the environmental profiles and the calculation of hazard indices for the various environmental pathways, Tables 2-5 were generated to summarize the results of the analyses. These tables report the values calculated for each of the pathways and reuse/disposal options. The following will briefly describe the results presented in each of the tables.

° LAND APPLICATION

Three tables were developed to summarize the results of the analyses conducted for land application (Tables 2a-2c). Table 2a shows the hazard index values for the land application of sludges at a loading rate of 5 metric tons per hectare dry weight (mt/ha DW) which represents a sustainable yearly agronomic application, i.e. loading typical of agricultural nitrogen requirement. Table 2b shows the hazard index values for a loading rate of 50 mt/ha DW as may be used on public lands, reclaimed areas or home gardens. Table 2c summarizes the values at a loading of 500 mt/ha DW which represents a cumulative loading after 100 years of application at 5 mt/ha/year. The analyses for land application were performed for the thirty two pollutants identified at the OWRS expert committee meetings as being of potential concern for this reuse/disposal option. Thirteen indices were calculated for land application as described previously. For Indices 9-13, the indices were calculated both for adult and toddler ingestion and are represented in the tables with an "a" indicating values for adults and a "t" for toddlers. As also can be seen on Tables 2a-c, each index was calculated for a typical sludge concentration of the pollutant (denoted by "T") and for a worst sludge concentration of the pollutant denoted by "W"). The "null" indicated on the tables are the values or concentrations calculated in the absence of sludge application. The hazard indices cover a large array of environmental pathways associated with land application of sludges. For some of the compounds, the paucity of data precluded the calculation of some of the indices. For information on how each of the indices were calculated and the data requirements for such calculations, the reader should consult Appendix D.

As can be seen from Tables 2a-c, Index 2 which evaluates the toxicity for soil biota was calculated for eleven pollutants. The range of hazard index values was from 0.000088 for aldrin/dieldrin to 2.3 for copper. Of these eleven compounds, ten had hazard indice values of less than 1 for the worst case scenario. Thirteen compounds had adequate data for calculating Index 3 which evaluates toxicity to predators of soil biota. Under the worst case conditions, eight compounds had hazard indices less than 1. For Index 4 values were calculated for nineteen compound in order to assess phytotoxicity from sludges being land applied. Index 5 determines the plant uptake in ug/g DW. These concentrations are used in subsequent indices related to land application. The remainder of the indices contained in these tables deal with the effects related to animals and humans. Indices 7 and 8 evaluate toxicity to animals from two routes of exposure - plant consumption and incidental sludge ingestion while grazing. Indices 9-13 all deal with the routes of exposure to humans including plant consumption, animal consumption and incidental ingestion. As can be seen from these tables, many calculations were made to assess the major pathways related to land application.

° LANDFILLING

In the analysis of groundwater contamination, predictions of pollutant movement in soils and groundwater are determined using parameters related to transport and fate, and boundary or source conditions. Transport parameters include the interstitial pore water velocity and dispersion coefficient. Pollutant fate parameters include (1) the degradation/decay coefficient and (2) the retardation factor which is based on a partition coefficient, the soil bulk density and the volumetric water content. A computer program was used for this analysis to facilitate computation of the analytical solution. The program predicted the pollutant concentration as a function of time and location in both the unsaturated and saturated zones. For more detail on the methods used in this analysis, the reader should refer to the summary of methodologies (Appendix D) and to the sample environmental profile (Appendix C).

The results of the analyses for the groundwater concentration increment resulting from landfilled sludge (Index 1) and for human toxicity resulting from groundwater contamination (Index 2)

TABLE 2A: LAND APPLICATION AND DISTRIBUTION AND MARKETING (APPLICATION RATE = 5 MT/HA)

POLLUTANT	INDEX	1‡	2	3	4	5‡	6	7	8	9a	9t	10a	10t	11a	11t	12a	12t	13a	13t
ALDRIN/DIELDRIN	T=	0.0012	0.000039	0.088	0.000094	0.00088	NC	0.000023	0.011	940	140	900	130	3500	1400	900	130	3500	1400
	W=	0.0026	0.000088	0.2	0.00021	0.002	NC	0.000052	0.04	1000	180	910	130	10000	4600	900	130	10000	4700
	(NULL)	0.00063	0.000021	0.047	0.00005	0.00047	NC	0.000012	0	900	130	900	130	910	130	900	130	910	130
ARSENIC	T=	1	NC	NC	0.13	0.99	20	0.00037	0.00023	0.25	0.084	0.26	0.085	0.26	0.085	26	6400	NC	NC
	W=	1	NC	NC	0.13	1.2		0.00041	0.001	0.28	0.092	0.26	0.085	0.27	0.087	26	6400	NC	NC
	(NULL)	1	NC	NC	0.13	1		0.00037	0.0003	0.26	0.085	0.26	0.085	0.26	0.086	26	6400	NC	NC
BENZO(A)ANTHRACENE	T=	0.0071	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	W=	0.017	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	(NULL)	0.0054	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
BENZO(A)PYRENE	T=	0.01	NC	NC	NC	0.019	NC	0.00011	0.00018	170	55	NC	NC	NC	NC	150	56	NC	NC
	W=	0.014	NC	NC	NC	0.026	NC	0.00016	0.0024	440	150	NC	NC	NC	NC	150	56	NC	NC
	(NULL)	0.01	NC	NC	NC	0.018	NC	0.00011	0	140	48	NC	NC	NC	NC	150	60	NC	NC
BIS(2-ETHYL HEXYL)PHTHALATE	T=	0.24	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	W=	1.1	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	(NULL)	0	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
CADMIUM	T=	1.1	NC	1.7	0.088	1	120	0.059	0.082	0.64	0.21	0.54	0.17	0.74	0.2	0.54	0.19	0.85	0.26
	W=	2.1	NC	2.6	0.17	1.4		0.07	0.88	1.7	0.6	0.57	0.18	2.7	0.54	0.54	0.2	3.9	1
	(NULL)	1	NC	1.6	0.08	1		0.058	0.002	0.54	0.17	0.54	0.17	0.54	0.17	0.54	0.19	0.54	0.19
CHLORDANE	T=	0.008	0.0028	NC	0.00064	0.018	NC	0.002	0.064	88	31	6.7	2.7	150	70	1.8	1.2	240	100
	W=	0.03	0.011	NC	0.0024	0.068	NC	0.0075	0.24	320	120	20	9.3	550	260	1.8	3.7	890	390
	(NULL)	0	0	NC	0	0	NC	0	0	1.8	0.25	1.8	0.25	1.8	0.25	1.8	0.25	1.8	0.25
CHROMIUM	T=	1	NC	0.025	0.5	1	13	0.0013	0.0058	0.00068	0.00023	0.00058	0.0002	0.00058	0.0002	0.0006	0.0047	0.0007	0.0047
	W=	1	NC	0.026	0.52	1.5		0.0016	0.038	0.0016	0.00057	0.00058	0.0002	0.00058	0.0002	0.0006	0.0048	0.0016	0.0047
	(NULL)	1	NC	0.025	0.5	1		0.0013	0.0025	0.00058	0.0002	0.00058	0.0002	0.00058	0.0002	0.0006	0.0047	0.0006	0.0047
COBALT	T=	1	0.027	0.35	0.1	1	55	0.16	0.058	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	W=	1	0.027	0.35	0.1	1		0.16	0.2	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	(NULL)	1	0.027	0.35	0.1	1		0.16	0.04	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
COPPER	T=	1	0.2	0.044	0.26	1	4.8	0.3	0.82	0.24	0.084	0.24	0.083	0.43	0.12	0.24	0.092	0.44	0.12
	W=	1.1	0.22	0.049	0.28	1.1		0.3	2.8	0.24	0.084	0.24	0.083	0.91	0.2	0.24	0.093	0.92	0.21
	(NULL)	1	0.19	0.042	0.25	1		0.29	0.05	0.24	0.083	0.24	0.083	0.25	0.085	0.24	0.092	0.25	0.094
DDT/DDE/DDD	T=	0.16	0.011	0.23	0.0032	0.098	NC	0.00032	0.00011	19	13	21	14	110	57	19	17	110	63
	W=	0.16	0.011	0.23	0.0032	0.099	NC	0.00032	0.00015	20	13	22	15	150	75	19	17	150	81
	(NULL)	0.16	0.011	0.23	0.0032	0.098	NC	0.00031	0	19	13	19	13	43	25	19	17	43	29
DIMETHYLNITROSAMINE a	T=		NC	NC	NC	NC	NC	NC		NC	NC	NC	NC	NC	NC			NC	NC
	W=	0.0064	NC	NC	NC	NC	NC	NC	0.0026	NC	NC	NC	NC	NC	NC	740	260	NC	NC
	(NULL)	0	NC	NC	NC	NC	NC	NC	0	NC	NC	NC	NC	NC	NC	740	250	NC	NC
FLUORIDE	T=	1	NC	NC	0.64	1	30	0.15	0.11	0.62	0.21	0.62	0.21	0.63	0.21	0.63	0.57	0.62	0.57
	W=	1	NC	NC	0.65	1		0.15	0.92	0.63	0.21	0.62	0.21	0.63	0.21	0.63	0.57	0.63	0.57
	(NULL)	1	NC	NC	0.64	1		0.15	0.37	0.62	0.21	0.62	0.21	0.63	0.21	0.63	0.57	0.63	0.57

a = dimethylnitrosamine, only worst case calculated
‡ = Indices 1 and 5 are expressed in units of ug/g DW

Note: Results predicated on sludge concentrations derived from "Fate of Priority Pollutants in Publicly Owned Treatment Works" (U.S. EPA,1982) or "A Comparison of Studies of Toxic Substances in POTW Sludges" (CDM,1984). See Text.

TABLE 2A: LAND APPLICATION AND DISTRIBUTION AND MARKETING (APPLICATION RATE = 5 MT/HA)

POLLUTANT	INDEX	1*	2	3	4	5*	6	7	8	9a	9t	10a	10t	11a	11t	12a	12t	13a	13t
HEPTACHLOR	T=	0.0003	0.000091	0.01	0.000003	0.00022	NC	0.000022	0.007	25	5.2	24	5.1	340	150	24	4.8	340	150
	W=	0.00035	0.00011	0.012	0.000003	0.00026	NC	0.000025	0.009	25	5.3	24	5.1	420	200	24	4.8	430	200
	(NULL)	0.00013	0.000038	0.0045	0.000001	0.000094	NC	9.40E-06	0	24	4.8	24	4.8	24	5	24	4.8	24	5
HEXACHLOROBENZENE	T=	0.002	NC	0.045	NC	0.031	NC	0.00049	0.019	81	30	25	12	150	70	5.4	2.9	240	110
	W=	0.0064	NC	0.15	NC	0.1	NC	0.0016	0.11	440	160	120	58	820	390	5.4	3.5	1400	600
	(NULL)	0.001	NC	0.023	NC	0.016	NC	0.00025	0	5.4	2.7	5.4	2.7	5.8	2.9	5.4	2.8	5.7	3
HEXACHLOROBUTADIENE	T=	0.0075	NC	NC	NC	NC	NC	NC	0.0005	NC	NC	NC	NC	4.8	2.3	0.000016	0.0042	NC	NC
	W=	0.02	NC	NC	NC	NC	NC	NC	0.013	NC	NC	NC	NC	130	61	0.00044	0.11	NC	NC
	(NULL)	0	NC	NC	NC	NC	NC	NC	0	NC	NC	NC	NC	0	0	0	0	NC	NC
IRON	T=	1	NC	NC	NC	1	6.6	0.077	1	0.5	0.43	0.5	0.43	0.56	0.44	0.51	3.3	0.57	3.3
	W=	1	NC	NC	NC	1		0.08	2.8	0.51	0.43	0.5	0.43	0.67	0.46	0.51	3.3	0.69	3.3
	(NULL)	1	NC	NC	NC	1		0.076	0.71	0.5	0.43	0.5	0.43	0.54	0.44	0.51	3.3	0.55	3.3
LEAD	T=	1	0.012	0.27	0.12	1	17	0.096	0.16	0.16	0.34	0.14	0.32	0.15	0.32	0.14	0.7	0.18	0.73
	W=	1.2	0.014	0.29	0.14	1		0.096	0.67	0.24	0.42	0.14	0.32	0.2	0.35	0.14	0.77	0.3	0.9
	(NULL)	1	0.011	0.26	0.11	1		0.096	0.0069	0.14	0.32	0.14	0.32	0.14	0.32	0.14	0.68	0.14	0.68
LINDANE	T=	0.13	<.0013	0.0027	0.01	NC	NC	NC	0.00011	NC	NC	NC	NC	160	54	150	63	NC	NC
	W=	0.13	<.0013	0.0027	0.01	NC	NC	NC	0.00022	NC	NC	NC	NC	170	56	150	63	NC	NC
	(NULL)	0.13	<.0013	0.0027	0.01	NC	NC	NC	0	NC	NC	NC	NC	160	54	150	63	NC	NC
MERCURY	T=	1	NC	NC	0.013	1	15	0.0052	0.037	0.25	0.3	0.26	0.32	1.7	3.5	0.25	0.47	1.7	3.7
	W=	1.1	NC	NC	0.014	1		0.0059	0.15	0.25	0.31	0.28	0.38	5.8	13	0.25	0.47	5.8	13
	(NULL)	1	NC	NC	0.012	1		0.005	0.0025	0.25	0.3	0.25	0.3	0.34	0.52	0.25	0.47	0.35	0.68
METHYLENEBIS(2-CHLORO-ANILINE)	T=	2.9	NC	NC	NC	0	NC	0	0.0072	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	W=	3.1	NC	NC	NC	0	NC	0	0.034	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	(NULL)	2.9	NC	NC	NC	0	NC	0	0	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
METHYLENE CHLORIDE	T=	0.004	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	W=	0.047	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	(NULL)	0	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
MOLYBDENUM	T=	1	NC	NC	0.04	1	200	0.23	0.1	0.09	0.03	0.09	0.03	0.091	0.03	0.09	0.034	0.091	0.034
	W=	1	NC	NC	0.041	1		0.25	0.4	0.091	0.03	0.09	0.03	0.093	0.031	0.09	0.034	0.094	0.035
	(NULL)	1	NC	NC	0.04	1		0.22	0.03	0.09	0.03	0.09	0.03	0.09	0.03	0.09	0.034	0.09	0.034
NICKEL	T=	1	NC	0.044	0.37	1.1	17	0.009	0.022	0.12	0.041	0.11	0.039	0.11	0.039	0.11	0.065	0.12	0.067
	W=	1.1	NC	0.05	0.4	2.5		0.0098	0.33	0.26	0.093	0.11	0.039	0.12	0.039	0.11	0.067	0.27	0.12
	(NULL)	1	NC	0.043	0.37	1		0.009	0.093	0.11	0.039	0.11	0.039	0.11	0.039	0.11	0.065	0.11	0.065
PCB'S	T=	0.02	NC	NC	0.002	0.042	NC	0.015	0.04	310	110	1200	590	5900	2800	47	22	7300	3500
	W=	0.067	NC	NC	0.0067	0.14	NC	0.05	0.23	1600	570	6700	3300	34000	16000	47	37	42000	20000
	(NULL)	0.01	NC	NC	0.001	0.021	NC	0.0074	0	47	16	47	16	63	23	47	19	63	27
PENTACHLOROPHENOL	T=	0.00022	5.40E-06	0.000027	NC	0.000076	NC	1.20E-06	8.80E-06	0.00048	0.00016	NC	NC	NC	NC	0.00047	0.00016	NC	NC
	W=	0.076	0.0019	0.094	NC	0.027	NC	0.00043	0.0031	0.0031	0.0011	NC	NC	NC	NC	0.00047	0.00034	NC	NC
	(NULL)	0	0	0	NC	0	NC	0	0	0.00047	0.00016	NC	NC	NC	NC	0.00047	0.00016	NC	NC

a = dimethylnitrosamine, only worst case calculated
* = Indices 1 and 5 are expressed in units of ug/g DW

Note: Results predicated on sludge concentrations derived from "Fate of Priority Pollutants in Publicly Owned Treatment Works" (U.S. EPA,1982) or "A Comparison of Studies of Toxic Substances in POTW Sludges" (CDM,1984). See Text.

TABLE 2A: LAND APPLICATION AND DISTRIBUTION AND MARKETING (APPLICATION RATE = 5 MT/HA)

POLLUTANT	INDEX	1*	2	3	4	5*	6	7	8	9a	9t	10a	10t	11a	11t	12a	12t	13a	13t
SELENIUM	T=	1	NC	NC	0.19	1.2	NC	0.034	0.0079	0.26	0.11	0.28	0.12	0.29	0.12	0.24	0.1	0.35	0.14
	W=	1.1	NC	NC	0.2	1.9	NC	0.054	0.035	0.32	0.13	0.44	0.18	0.45	0.17	0.24	0.1	0.73	0.28
	(NULL)	1	NC	NC	0.19	1	NC	0.029	0.0015	0.24	0.1	0.24	0.1	0.25	0.1	0.24	0.1	0.25	0.11
TOXAPHENE	T=	0.023	0.0013	NC	0.00075	0.02	NC	0.0004	0.0079	110	26	120	36	1400	630	55	7.4	1500	690
	W=	0.03	0.0018	NC	0.001	0.026	NC	0.00053	0.011	130	34	140	47	1900	860	55	8	2000	940
	(NULL)	0.003	0.00018	NC	0.0001	0.0026	NC	0.000053	0	55	5.6	55	5.6	55	5.9	55	5.8	55	6.1
TRICHLOROETHYLENE	T=	0.0018	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	W=	0.045	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	(NULL)	0.00063	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
TRICRESYL PHOSPHATE	T=	0.017	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	W=	4.1	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	(NULL)	0	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
ZINC	T=	1	0.041	1.9	0.2	1.1	15	0.087	0.11	0.39	0.17	0.37	0.16	0.44	0.18	0.36	0.16	0.47	0.2
	W=	1.3	0.05	2.1	0.25	1.6		0.13	0.76	0.57	0.23	0.41	0.17	0.89	0.34	0.36	0.16	1.1	0.44
	(NULL)	1	0.04	1.8	0.2	1		0.08	0.0073	0.36	0.16	0.36	0.16	0.36	0.16	0.36	0.16	0.36	0.16

a = dimethylnitrosamine, only worst case calculated

* = Indices 1 and 5 are expressed in units of ug/g DW

Note: Results predicated on sludge concentrations derived from "Fate of Priority Pollutants in Publicly Owned Treatment Works" (U.S. EPA,1982) or "A Comparison of Studies of Toxic Substances in POTW Sludges" (CDM,1984). See Text.

TABLE 2B: LAND APPLICATION AND DISTRIBUTION AND MARKETING (APPLICATION RATE = 50 MT/HA)

POLLUTANT	INDEX	1‡	2	3	4	5‡	6	7	8	9adult	9toddler	10adult	10toddler	11adult	11toddler	12adult	12toddler	13adult	13toddler
ALDRIN/DIELDRIN	T=	0.006	0.0002	0.44	0.00048	0.0045	NC	0.00012	0.011	1300	260	920	140	3500	1400	900	140	3900	1500
	W=	0.02	0.00068	1.5	0.0062	0.015	NC	0.00041	0.04	2200	610	1000	180	10000	4600	900	170	12000	5200
	(NULL)	0.00063	0.000021	0.047	0.00005	0.00047	NC	0.000012	0	900	130	900	130	910	130	900	130	910	130
ARSENIC	T=	0.99	NC	NC	0.13	0.85	20	0.00033	0.00023	0.24	0.078	0.26	0.085	0.26	0.085	25	6300	NC	NC
	W=	1.1	NC	NC	0.14	2.5		0.00074	0.001	0.45	0.16	0.26	0.086	0.27	0.087	27	6800	NC	NC
	(NULL)	1	NC	NC	0.13	1		0.00037	0.0003	0.26	0.085	0.26	0.085	0.26	0.086	26	6400	NC	NC
BENZO(A)ANTHRACENE	T=	0.022	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	W=	0.12	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	(NULL)	0.0054	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
BENZO(A)PYRENE	T=	0.013	NC	NC	NC	0.023	NC	0.00014	0.00018	340	120	NC	NC	NC	NC	150	59	NC	NC
	W=	0.057	NC	NC	NC	0.1	NC	0.0006	0.0024	3000	1100	NC	NC	NC	NC	150	95	NC	NC
	(NULL)	0.01	NC	NC	NC	0.018	NC	0.00011	0	140	48	NC	NC	NC	NC	150	56	NC	NC
BIS(2-ETHYL HEXYL)PHTHALATE	T=	2.3	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	W=	11	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	(NULL)	0	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
CADMIUM	T=	2	NC	2.5	0.16	1.4	120	0.069	0.082	1.6	0.55	0.56	0.17	0.74	0.2	0.54	0.2	1.8	0.62
	W=	12	NC	11	0.94	5.2		0.18	0.88	12	4.4	0.83	0.22	2.7	0.54	0.54	0.35	15	5
	(NULL)	1	NC	1.6	0.08	1		0.058	0.002	0.54	0.17	0.54	0.17	0.54	0.17	0.54	0.19	0.54	0.19
CHLORDANE	T=	0.078	0.028	NC	0.0062	0.18	NC	0.02	0.064	840	300	50	24	150	70	1.8	9.2	1000	410
	W=	0.29	0.1	NC	0.023	0.67	NC	0.074	0.24	3100	1100	182	89	550	260	2	34	3900	1500
	(NULL)	0	0	NC	0	0	NC	0	0	1.8	0.25	1.8	0.25	1.8	0.25	1.8	0.25	1.8	0.25
CHROMIUM	T=	1	NC	0.026	0.52	1.5	13	0.0016	0.0058	0.0015	0.00054	0.00058	0.0002	0.00058	0.0002	0.0006	0.0048	0.0015	0.0052
	W=	1.3	NC	0.034	0.67	6		0.0041	0.038	0.011	0.0038	0.00058	0.0002	0.00058	0.0002	0.00061	0.0062	0.011	0.0099
	(NULL)	1	NC	0.025	0.5	1		0.0013	0.0025	0.00058	0.0002	0.00058	0.0002	0.00058	0.0002	0.0006	0.0047	0.0006	0.0047
COBALT	T=	1	0.027	0.35	0.1	1	55	0.16	0.058	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	W=	1.1	0.029	0.35	0.11	1.2		0.2	0.2	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	(NULL)	1	0.027	0.35	0.1	1		0.16	0.04	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
COPPER	T=	1.4	0.26	0.061	0.34	1.2	4.8	0.32	0.82	0.25	0.087	0.25	0.085	0.43	0.12	0.24	0.095	0.46	0.13
	W=	2.4	0.45	0.11	0.59	1.7		0.42	2.8	0.28	0.097	0.27	0.088	0.91	0.2	0.24	0.1	0.99	0.24
	(NULL)	1	0.19	0.042	0.25	1		0.29	0.05	0.24	0.083	0.24	0.083	0.25	0.085	0.24	0.092	0.25	0.094
DDT/DDE/DDD	T=	0.17	0.011	0.24	0.0034	0.11	NC	0.00034	0.00011	26	16	41	24	110	57	19	17	140	75
	W=	0.18	0.012	0.25	0.0036	0.11	NC	0.00035	0.00015	30	17	53	30	150	75	19	17	190	100
	(NULL)		0.011	0.23	0.0032	0.098	NC	0.00031	0	19	13	19	13	43	25	19	17	43	29
DIMETHYLNITROSAMINE	T=		NC	NC	NC	NC	NC	NC		NC	NC	NC	NC	NC	NC			NC	NC
	W=	0.062	NC	NC	NC	NC	NC	NC	0.0026	NC	NC	NC	NC	NC	NC	740	363	NC	NC
	(NULL)	0	NC	NC	NC	NC	NC	NC	0	NC	NC	NC	NC	NC	NC	740	250	NC	NC
FLUORIDE	T=	0.98	NC	NC	0.63	0.98	30	0.13	0.11	0.6	0.2	0.62	0.21	0.63	0.21	0.63	0.56	0.6	0.56
	W=	1	NC	NC	0.67	1		0.19	0.92	0.67	0.22	0.62	0.21	0.63	0.21	0.63	0.58	0.68	0.6
	(NULL)	1	NC	NC	0.64	1		0.15	0.37	0.62	0.21	0.62	0.21	0.63	0.21	0.63	0.57	0.63	0.57

a = dimethylnitrosamine, only worst case calculated
‡ = Indices 1 and 5 are expressed in units of ug/g DW

Note: Results predicated on sludge concentrations derived from "Fate of Priority Pollutants in Publicly Owned Treatment Works" (U.S. EPA,1982) or "A Comparison of Studies of Toxic Substances in POTW Sludges" (CDM,1984). See Text.

TABLE 2B: LAND APPLICATION AND DISTRIBUTION AND MARKETING (APPLICATION RATE = 50 MT/HA)

POLLUTANT	INDEX	1*	2	3	4	5*	6	7	8	9adult	9toddler	10adult	10toddler	11adult	11toddler	12adult	12toddler	13adult	13toddler
HEPTACHLOR	T=	0.0018	0.00055	0.063	0.000018	0.0013	NC	0.00013	0.007	36	9.2	30	7.7	340	150	24	5.2	350	160
	W=	0.0023	0.00069	0.08	0.000023	0.0017	NC	0.00017	0.009	39	10	31	8.5	420	200	24	5.3	450	210
	(NULL)	0.00013	0.000038	0.0045	0.000001	0.000094	NC	9.40E-06	0	24	4.8	24	4.8	24	5	24	4.8	24	5
HEXACHLOROBENZENE	T=	0.01	NC	0.24	NC	0.16	NC	0.0026	0.019	740	270	190	96	150	70	5.4	3.9	1100	430
	W=	0.054	NC	1.2	NC	0.87	NC	0.014	0.11	4300	1500	1100	540	820	390	5.4	9.3	6200	2500
	(NULL)	0.001	NC	0.023	NC	0.016	NC	0.00025	0	5.4	2.7	5.4	2.7	5.8	2.9	5.4	2.8	5.8	3
HEXACHLOROBUTADIENE	T=	0.0073	NC	NC	NC	NC	NC	NC	0.0005	NC	NC	NC	NC	4.8	2.3	0.00016	0.041	NC	NC
	W=	0.2	NC	NC	NC	NC	NC	NC	0.013	NC	NC	NC	NC	130	61	0.0043	1.1	NC	NC
	(NULL)	0	NC	NC	NC	NC	NC	NC	0	NC	NC	NC	NC	0	0	0	0	NC	NC
IRON	T=	1	NC	NC	NC	1	6.6	0.081	1	0.51	0.43	0.5	0.43	0.56	0.44	0.51	3.3	0.59	3.3
	W=	1.1	NC	NC	NC	1.2		0.11	2.8	0.63	0.48	0.5	0.43	0.67	0.46	0.51	3.3	0.81	3.6
	(NULL)	1	NC	NC	NC	1		0.076	0.71	0.5	0.43	0.5	0.43	0.54	0.44	0.51	3.3	0.55	3.3
LEAD	T=	1.5	0.017	0.33	0.17	1	17	0.097	0.16	0.36	0.54	0.14	0.32	0.15	0.32	0.14	0.87	0.37	1.1
	W=	3.3	0.037	0.56	0.37	1.2		0.099	0.67	1.1	1.3	0.14	0.32	0.2	0.35	0.14	1.5	1.2	2.6
	(NULL)	1	0.011	0.26	0.11	1		0.096	0.0069	0.14	0.32	0.14	0.32	0.14	0.32	0.14	0.68	0.14	0.68
LINDANE	T=	0.13	<.0013	0.0027	0.01	NC	NC	NC	0.00011	NC	NC	NC	NC	160	54	150	63	NC	NC
	W=	0.13	<.0013	0.0028	0.01	NC	NC	NC	0.00022	NC	NC	NC	NC	170	56	150	64	NC	NC
	(NULL)	0.13	<.0013	0.0027	0.01	NC	NC	NC	0	NC	NC	NC	NC	160	54	150	63	NC	NC
MERCURY	T=	1.3	NC	NC	0.017	1.1	15	0.0052	0.037	0.26	0.33	0.33	0.49	1.7	3.5	0.25	0.52	1.8	4
	W=	2.4	NC	NC	0.03	1.4		0.014	0.15	0.3	0.42	0.59	1.1	5.8	13	0.25	0.7	6.2	14
	(NULL)	1	NC	NC	0.012	1		0.005	0.0025	0.25	0.3	0.25	0.3	0.34	0.52	0.25	0.47	0.35	0.68
METHYLENEBIS(2-CHLORO-ANILINE)	T=	3.3	NC	NC	NC	0	NC	0	0.0072	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	W=	4.9	NC	NC	NC	0	NC	0	0.034	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	(NULL)	2.9	NC	NC	NC	0	NC	0	0	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
METHYLENE CHLORIDE	T=	0.04	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	W=	0.46	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	(NULL)	0	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
MOLYBDENUM	T=	1.1	NC	NC	0.043	1	200	0.27	0.1	0.091	0.031	0.091	0.03	0.091	0.03	0.09	0.034	0.092	0.034
	W=	1.4	NC	NC	0.054	1.2		0.5	0.4	0.095	0.032	0.092	0.031	0.093	0.031	0.09	0.035	0.1	0.038
	(NULL)	1	NC	NC	0.04	1		0.22	0.03	0.09	0.03	0.09	0.03	0.09	0.03	0.09	0.034	0.09	0.034
NICKEL	T=	1	NC	0.046	0.38	1.6	17	0.0093	0.022	0.17	0.06	0.11	0.039	0.11	0.039	0.11	0.066	0.17	0.088
	W=	1.8	NC	0.1	0.69	16		0.017	0.33	1.6	0.57	0.11	0.039	0.12	0.039	0.11	0.088	1.6	0.62
	(NULL)	1	NC	0.043	0.37	1		0.009	0.0093	0.11	0.039	0.11	0.039	0.11	0.039	0.11	0.065	0.11	0.065
PCB'S	T=	0.11	NC	NC	0.011	0.23	NC	0.079	0.04	2600	960	11000	5600	5900	2800	47	49	20000	9000
	W=	0.57	NC	NC	0.057	1.2	NC	0.42	0.23	15000	5500	65000	32000	34000	16000	48	190	110000	54000
	(NULL)	0.01	NC	NC	0.001	0.021	NC	0.0074	0	47	16	47	16	62	23	47	19	63	27
PENTACHLOROPHENOL	T=	0.0021	0.000053	0.0026	NC	0.00074	NC	0.000012	8.20E-06	0.00054	0.00018	NC	NC	NC	NC	0.00047	0.00016	NC	NC
	W=	0.74	0.019	0.092	NC	0.26	NC	0.0042	0.0031	0.026	0.0094	NC	NC	NC	NC	0.00048	0.0019	NC	NC
	(NULL)	0	0	0	NC	0	NC	0	0	0.00047	0.00016	NC	NC	NC	NC	0.00047	0.00016	NC	NC

a = dimethylnitrosamine, only worst case calculated

* = Indices 1 and 5 are expressed in units of ug/g DW

__Note:__ Results predicated on sludge concentrations derived from "Fate of Priority Pollutants in Publicly Owned Treatment Works" (U.S. EPA,1982) or "A Comparison of Studies of Toxic Substances in POTW Sludges" (CDM,1984). See Text.

TABLE 2B: LAND APPLICATION AND DISTRIBUTION AND MARKETING (APPLICATION RATE = 50 MT/HA)

POLLUTANT	INDEX	1†	2	3	4	5†	6	7	8	9adult	9toddler	10adult	10toddler	11adult	11toddler	12adult	12toddler	13adult	13toddler
SELENIUM	T=	1.1	NC	NC	0.21	2.7	NC	0.078	0.0079	0.4	0.16	0.62	0.25	0.29	0.12	0.24	0.1	0.82	0.32
	W=	1.5	NC	NC	0.29	9.8	NC	0.28	0.035	1	0.39	2.2	0.84	0.45	0.17	0.24	0.11	3.2	1.2
	(NULL)	1	NC	NC	0.19	1	NC	0.029	0.0015	0.24	0.1	0.24	0.1	0.25	0.1	0.24	0.1	0.25	0.11
TOXAPHENE	T=	0.2	0.012	NC	0.0065	0.17	NC	0.0034	0.0079	610	210	660	300	1400	630	55	21	2500	1200
	W=	0.27	0.016	NC	0.0089	0.23	NC	0.0047	0.011	820	280	880	410	1900	860	55	27	3400	1600
	(NULL)	0.003	0.0018	NC	0.0001	0.0026	NC	0.000053	0	55	5.6	55	5.6	55	5.9	55	5.8	55	6
TRICHLOROETHYLENE	T=	0.012	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	W=	0.44	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	(NULL)	0.00063	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
TRICRESYL PHOSPHATE	T=	0.17	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	W=	40	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	(NULL)	0	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
ZINC	T=	1.4	0.054	2.2	0.27	1.8	15	0.15	0.11	0.65	0.26	0.42	0.18	0.44	0.18	0.36	0.16	0.79	0.32
	W=	3.5	0.14	4.4	0.69	6.5		0.6	0.76	2.4	0.91	0.82	0.33	0.89	0.34	0.36	0.17	3.4	1.3
	(NULL)	1	0.04	1.8	0.2	1		0.08	0.0073	0.36	0.16	0.36	0.16	0.36	0.16	0.36	0.16	0.36	0.16

a = dimethylnitrosamine, only worst case calculated

† = Indices 1 and 5 are expressed in units of ug/g DW

Note: Results predicated on sludge concentrations derived from "Fate of Priority Pollutants in Publicly Owned Treatment Works" (U.S. EPA,1982) or "A Comparison of Studies of Toxic Substances in POTW Sludges" (CDM,1984). See Text.

TABLE 2C: LAND APPLICATION AND DISTRIBUTION AND MARKETING (APPLICATION RATE = 500 MT/HA)

POLLUTANT	INDEX	1#	2	3	4	5#	6	7	8	9a	9t	10a	10t	11a	11t	12a	12t	13a	13t
ALDRIN/DIELDRIN	T=	0.0031	0.0001	0.23	0.00025	0.0023	NC	0.000062	0.011	1100	190	920	140	3500	1400	900	140	3600	1400
	W=	0.0098	0.00033	0.73	0.00079	0.0074	NC	0.0002	0.04	1500	350	950	150	10000	4600	900	150	11000	4900
	(NULL)	0.00063	0.000021	0.047	0.00005	0.00047	NC	0.000012	0	900	130	900	130	910	130	900	130	910	130
ARSENIC	T=	0.95	NC	NC	0.13	0.19	20	0.000078	0.00023	0.1	0.03	0.25	0.084	0.26	0.085	24	6100	NC	NC
	W=	1.5	NC	NC	0.2	14		0.0034	0.001	1.8	0.66	0.29	0.091	0.27	0.087	28	9500	NC	NC
	(NULL)	1	NC	NC	0.13	1		0.00037	0.0003	0.26	0.085	0.26	0.085	0.26	0.086	26	6400	NC	NC
BENZO(A)ANTHRACENE	T=	0.14	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	W=	0.96	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	(NULL)	0.0054	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
BENZO(A)PYRENE	T=	0.01	NC	NC	NC	0.019	NC	0.00011	0.00018	170	55	NC	NC	NC	NC	150	56	NC	NC
	W=	0.015	NC	NC	NC	0.027	NC	0.00016	0.0024	440	160	NC	NC	NC	NC	150	60	NC	NC
	(NULL)	0.01	NC	NC	NC	0.018	NC	0.00011	0	140	48	NC	NC	NC	NC	150	56	NC	NC
BIS(2-ETHYL HEXYL)PHTHALATE	T=	19	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	W=	92	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	(NULL)	0	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
CADMIUM	T=	9	NC	8.9	0.72	4.1	120	0.15	0.082	9.2	3.3	0.76	0.21	0.74	0.2	0.54	0.31	9.6	3.5
	W=	89	NC	82	7.1	35		1	0.88	96	35	3	0.58	2.7	0.54	0.54	1.6	100	37
	(NULL)	1	NC	1.6	0.08	1		0.058	0.002	0.54	0.17	0.54	0.17	0.54	0.17	0.54	0.19	0.54	0.19
CHLORDANE	T=	0.018	0.0064	NC	0.0014	0.041	NC	0.0046	0.064	200	71	13	5.7	150	70	1.8	2.3	350	150
	W=	0.068	0.024	NC	0.0054	0.15	NC	0.017	0.24	730	260	44	21	550	260	1.8	8	1300	550
	(NULL)	0	0	NC	0	0	NC	0	0	1.8	0.25	1.8	0.25	1.8	0.25	1.8	0.25	1.8	0.25
CHROMIUM	T=	1.3	NC	0.032	0.63	4.8	13	0.0034	0.0058	0.0083	0.003	0.00058	0.0002	0.00058	0.0002	0.00061	0.0059	0.0083	0.0087
	W=	3.8	NC	0.095	1.9	42		0.024	0.0058	0.083	0.03	0.00058	0.0002	0.00058	0.0002	0.00065	0.017	0.083	0.047
	(NULL)	1	NC	0.025	0.5	1		0.0013	0.0025	0.00058	0.0002	0.00058	0.0002	0.00058	0.0002	0.0006	0.0047	0.0006	0.0047
COBALT	T=	1.1	0.029	0.35	0.11	1.2	55	0.19	0.058	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	W=	1.8	0.048	0.35	0.18	2.8		0.45	0.2	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	(NULL)	1	0.027	0.35	0.1	1		0.16	0.04	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
COPPER	T=	4.1	0.78	0.2	.1	2.5	4.8	0.57	0.82	0.32	0.11	0.3	0.094	0.43	0.12	0.24	0.12	0.62	0.21
	W=	12	2.3	0.61	3	6.5		1.3	2.8	0.55	0.19	0.48	0.12	0.91	0.2	0.24	0.18	1.6	0.52
	(NULL)	1	0.19	0.042	0.25	1		0.29	0.05	0.24	0.083	0.24	0.083	0.25	0.085	0.24	0.092	0.25	0.094
DDT/DDE/DDD	T=	0.21	0.014	0.31	0.0034	0.13	NC	0.00042	0.00011	52	25	120	63	110	57	19	18	240	120
	W=	0.24	0.016	0.35	0.0036	0.15	NC	0.00048	0.00015	70	32	170	90	150	75	19	19	360	180
	(NULL)	0.16	0.011	0.23	0.0032	0.098	NC	0.00031	0	19	13	19	13	43	25	19	17	43	29
DIMETHYLNITROSAMINE	T=		NC	NC	NC	NC	NC	NC		NC	NC	NC	NC	NC	NC			NC	NC
	W=	0.0064	NC	NC	NC	NC	NC	NC	0.0026	NC	NC	NC	NC	NC	NC	740	260	NC	NC
	(NULL)	0	NC	NC	NC	NC	NC	NC	0	NC	NC	NC	NC	NC	NC	740	250	NC	NC
FLUORIDE	T=	0.86	NC	NC	0.55	0.87	30	0.012	0.11	0.44	0.14	0.62	0.21	0.63	0.21	0.63	0.52	0.44	0.45
	W=	1.3	NC	NC	0.84	1.3		0.5	0.92	1	0.36	0.62	0.21	0.63	0.21	0.63	0.68	1	0.83
	(NULL)	1	NC	NC	0.64	1		0.15	0.37	0.62	0.21	0.62	0.21	0.63	0.21	0.63	0.57	0.63	0.57

a = dimethylnitrosamine, only worst case calculated
# = Indices 1 and 5 are expressed in units of ug/g DW

Note: Results predicated on sludge concentrations derived from "Fate of Priority Pollutants in Publicly Owned Treatment Works" (U.S. EPA,1982) or "A Comparison of Studies of Toxic Substances in POTW Sludges" (CDM,1984). See Text.

TABLE 2C: LAND APPLICATION AND DISTRIBUTION AND MARKETING (APPLICATION RATE = 500 MT/HA)

POLLUTANT	INDEX	1*	2	3	4	5*	6	7	8	9a	9t	10a	10t	11a	11t	12a	12t	13a	13t
HEPTACHLOR	T=	0.0011	0.00031	0.035	0.00001	0.00075	NC	0.000073	0.007	30	7.1	27	6.3	340	150	24	5	350	160
	W=	0.0013	0.00038	0.044	0.000012	0.00093	NC	0.000092	0.009	32	7.8	28	6.7	420	200	24	5.1	440	200
	(NULL)	0.00013	0.000038	0.0045	0.000001	0.000094	NC	9.40E-06	0	24	4.8	24	4.8	24	5	24	4.8	24	5
HEXACHLOROBENZENE	T=	0.0072	NC	0.17	NC	0.12	NC	0.0018	0.019	500	180	130	66	150	70	5.4	3.6	770	310
	W=	0.037	NC	0.84	NC	0.59	NC	0.0092	0.11	2900	1000	740	360	820	390	5.4	7.2	4400	1800
	(NULL)	0.001	NC	0.023	NC	0.016	NC	0.00025	0	5.4	2.7	5.4	2.7	5.8	2.9	5.4	2.8	5.8	3
HEXACHLOROBUTADIENE	T=	0.06	NC	NC	NC	NC	NC	NC	0.0005	NC	NC	NC	NC	4.8	2.3	0.0013	0.33	NC	NC
	W=	1.6	NC	NC	NC	NC	NC	NC	0.013	NC	NC	NC	NC	130	61	0.036	8.9	NC	NC
	(NULL)	0	NC	NC	NC	NC	NC	NC	0	NC	NC	NC	NC	0	0	0	0	NC	NC
IRON	T=	1.1	NC	NC	NC	1.3	6.6	0.11	1	0.64	0.48	0.5	0.43	0.56	0.44	0.51	3.5	0.71	3.6
	W=	1.6	NC	NC	NC	2.9		0.36	2.8	1.6	0.81	0.5	0.43	0.67	0.46	0.52	5	1.7	5.4
	(NULL)	1	NC	NC	NC	1		0.076	0.71	0.5	0.43	0.5	0.43	0.54	0.44	0.51	3.3	0.55	3.3
LEAD	T=	5.3	0.058	0.82	0.58	1.5	17	0.1	0.16	1.9	2.2	0.14	0.32	0.15	0.32	0.14	2.3	1.9	4.1
	W=	20	0.22	2.7	2.2	3.1		0.12	0.67	8	8.5	0.14	0.32	0.2	0.35	0.15	7.7	8.1	16
	(NULL)	1	0.011	0.26	0.11	1		0.096	0.0069	0.14	0.32	0.14	0.32	0.14	0.32	0.14	0.68	0.14	0.68
LINDANE	T=	0.13	<.0013	0.0027	0.01	NC	NC	NC	0.00011	NC	NC	NC	NC	160	55	150	63	NC	NC
	W=	0.13	<.0013	0.0027	0.01	NC	NC	NC	0.0022	NC	NC	NC	NC	170	56	150	63	NC	NC
	(NULL)	0.13	<.0027	0.0027	0.01	NC	NC	NC	0	NC	NC	NC	NC	160	54	150	63	NC	NC
MERCURY	T=	3.8	NC	NC	0.047	1.7	15	0.023	0.037	0.35	0.53	0.93	1.9	1.7	3.5	0.25	0.93	2.4	6
	W=	12	NC	NC	0.16	4		0.078	0.15	0.65	1.3	3	6.7	5.8	13	0.25	2.4	9	22
	(NULL)	1	NC	NC	0.012	1		0.005	0.0025	0.25	0.3	0.25	0.3	0.34	0.52	0.25	0.47	0.35	0.68
METHYLENEBIS(2-CHLORO-ANILINE)	T=	24	NC	NC	NC	0	NC	0	0.0072	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	W=	25	NC	NC	NC	0	NC	0	0.034	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	(NULL)	0	NC	NC	NC	0	NC	0	0	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
METHYLENE CHLORIDE	T=	0.32	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	W=	3.8	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	(NULL)	2.9	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
MOLYBDENUM	T=	1.6	NC	NC	0.062	1.3	200	0.66	0.1	0.098	0.033	0.094	0.031	0.091	0.03	0.09	0.036	0.1	0.039
	W=	3.9	NC	NC	0.16	2.4		2.5	0.4	0.13	0.45	0.11	0.033	0.093	0.031	0.09	0.044	0.15	0.062
	(NULL)	1	NC	NC	0.04	1		0.22	0.03	0.09	0.03	0.09	0.03	0.09	0.03	0.09	0.034	0.09	0.034
NICKEL	T=	1.3	NC	0.064	0.48	5.9	17	0.012	0.022	0.6	0.22	0.11	0.039	0.11	0.039	0.11	0.073	0.6	0.25
	W=	7.9	NC	0.55	2.9	120		0.076	0.33	12	4.4	0.11	0.039	0.12	0.039	0.12	0.25	12	4.6
	(NULL)	1	NC	0.043	0.37	1		0.009	0.0093	0.11	0.039	0.11	0.039	0.11	0.039	0.11	0.065	0.11	0.065
PCB'S	T=	0.1	NC	NC	0.01	0.21	NC	0.075	0.04	2500	900	11000	5200	5900	2800	47	47	19000	9000
	W=	0.54	NC	NC	0.054	1.1	NC	0.4	0.23	14000	5100	61000	30000	34000	16000	48	180	110000	51000
	(NULL)	0.01	NC	NC	0.001	0.021	NC	0.0074	0	47	16	47	16	63	23	47	19	63	27
PENTACHLOROPHENOL	T=	0.00022	5.40E-06	0.000027	NC	0.000076	NC	1.20E-06	8.20E-06	0.00048	0.00016	NC	NC	NC	NC	0.00016	0.00047	NC	NC
	W=	0.076	0.0019	0.0094	NC	0.027	NC	0.00043	0.0031	0.0031	0.0011	NC	NC	NC	NC	0.00034	0.00047	NC	NC
	(NULL)	0	0	0	NC	0	NC	0	0	0.00047	0.00016	NC	NC	NC	NC	0.00016	0.00047	NC	NC

a = dimethylnitrosamine, only worst case calculated
* = Indices 1 and 5 are expressed in units of ug/g DW

Note: Results predicated on sludge concentrations derived from "Fate of Priority Pollutants in Publicly Owned Treatment Works" (U.S. EPA,1982) or "A Comparison of Studies of Toxic Substances in POTW Sludges" (CDM,1984). See Text.

TABLE 2C: LAND APPLICATION AND DISTRIBUTION AND MARKETING (APPLICATION RATE = 500 MT/HA)

POLLUTANT	INDEX	1‡	2	3	4	5‡	6	7	8	9a	9t	10a	10t	11a	11t	12a	12t	13a	13t
SELENIUM	T=	1.9	NC	NC	0.35	15	NC	0.43	0.0079	1.5	0.56	3.3	1.3	0.29	0.12	0.24	0.11	4.6	1.8
	W=	5.4	NC	NC	1	73	NC	2.1	0.035	6.8	0.25	16	6.2	0.45	0.17	0.24	0.11	23	8.6
	(NULL)	1	NC	NC	0.19	1	NC	0.029	0.0015	0.24	0.1	0.24	0.1	0.25	0.1	0.24	0.1	0.25	0.11
TOXAPHENE	T=	0.32	0.02	NC	0.011	0.29	NC	0.0057	0.0079	990	350	1000	500	1400	630	55	32	3300	1500
	W=	0.44	0.026	NC	0.015	0.39	NC	0.0078	0.011	1300	470	1400	690	1900	860	55	41	4500	2000
	(NULL)	0.003	0.00018	NC	0.0001	0.0026	NC	0.000053	0	55	5.6	55	5.6	55	5.9	55	5.8	55	6
TRICHLOROETHYLENE	T=	0.093	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	W=	3.6	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	(NULL)	0.00063	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
TRICRESYL PHOSPHATE	T=	1.2	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	W=	280	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	(NULL)	0	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
ZINC	T=	3.9	0.16	4.8	0.76	7.3	15	0.63	0.11	2.7	1	0.89	0.36	0.44	0.18	0.36	0.17	3.4	1.3
	W=	22	0.86	23	4.2	46		4.4	0.76	17	6.4	4.1	1.6	0.89	0.34	0.36	0.25	22	8.1
	(NULL)	1	0.04	1.8	0.2	1		0.08	0.0073	0.36	0.16	0.36	0.16	0.36	0.16	0.36	0.16	0.36	0.16

a = *dimethylnitrosamine, only worst case calculated*

‡ = Indices 1 and 5 are expressed in units of ug/g DW

Note: Results predicated on sludge concentrations derived from "Fate of Priority Pollutants in Publicly Owned Treatment Works" (U.S. EPA,1982) or "A Comparison of Studies of Toxic Substances in POTW Sludges" (CDM,1984). See Text.

TABLE 3: LANDFILL HAZARD INDICES

POLLUTANT	INDEX 1 ALL NULL	INDEX 1 ALL TYPICAL	INDEX 1 ALL WORST	INDEX 2 ALL NULL	INDEX 2 ALL TYPICAL	INDEX 2 ALL WORST
ARSENIC	1	1.1	120	0	53	51000
BENZENE	0*	0.00026*	38*	210	210	260
BENZO(A)PYRENE	0*	0.00013*	11*	150	150	3800
BIS(2-ETHYL HEXYL)PHTHLATE	0*	2.6*	2700*	0	1	1100
CADMIUM	1	1.2	510	0.54	0.54	0.54
CHLORDANE	0*	0.044*	69*	1.8	3.8	3200
CHROMIUM	1	2.0	1300	0.00058	0.0007	0.157
COBALT	1	12	8300	NC	NC	NC
COPPER	1	2.1	830	0	0.0086	6.4
CYANIDE	0*	13*	16000*	0	0.0034	4.1
DDT/DDE/DDD	0*	0.0038*	5.4*	19	19	71
2,4-DICHLOROPHENOXYACETIC ACID	0*	0.0186*	41.43*	0.00032	0.00033	0.0098
DIMETHYL NITROSOAMINE	0*	0.0009*	14.8*	740	740	12000
LEAD	1	2.3	1200	0.14	0.17	29
LINDANE	0*	0.0014*	1.3*	160	160	200
MALATHION	0*	2.80E-07*	3.6*	0.0063	0.0063	0.011
MERCURY	1	1.4	340	0.25	0.25	3.6

* = indicates actual concentrations in ug/L

Note: Results predicated on sludge concentrations derived from "Fate of Priority Pollutants in Publicly Owned Treatment Works" (U.S. EPA,1982) or "A Comparison of Studies of Toxic Substances in POTW Sludges" (CDM,1984). See Text.

TABLE 3 (CONTINUED): LANDFILL HAZARD INDICES

POLLUTANT	INDEX 1 ALL NULL	INDEX 1 ALL TYPICAL	INDEX 1 ALL WORST	INDEX 2 ALL NULL	INDEX 2 ALL TYPICAL	INDEX 2 ALL WORST
METHYL ETHYL KETONE	NC	NC	NC	NC	NC	NC
METHYLENE CHLORIDE	0*	0.043*	110*	NC	NC	NC
MOLYBDENUM	1	1	24	0.09	0.09	0.22
NICKEL	1	1.3	800	0.11	0.11	2.3
PCB	0*	0.092*	130*	47	59	17000
PHENANTHRENE	0*	0.101*	120*	NC	NC	NC
PHENOL	0*	1.000E-16*	480*	0	3.000E-20	0.14
SELENIUM	1	1	4.5	0.24	0.24	0.37
TOXAPHENE	0*	0.2*	62*	55	61	2100
TRICHLOROETHYLENE	0*	0.013*	100*	0	0.0068	56
ZINC	1	2.8	2700	0.36	0.36	1.4

NC = Not calculated due to lack of appropriate data

* = indicates actual concentrations in ug/L

Note: Results predicated on sludge concentrations derived from "Fate of Priority Pollutants in Publicly Owned Treatment Works" (U.S. EPA,1982) or "A Comparison of Studies of Toxic Substances in POTW Sludges" (CDM,1984). See Text.

are summarized in Table 3. The analyses related to landfilling were performed for the twenty eight pollutants identified at the OWRS expert committee meetings as being of potential concern. In the table, the columns labelled "all null" reflect the assumed existing conditions in the absence of sludge disposal. In the absence of actual concentration data, a value of zero was used for organics in this analysis. The columns labelled "all typical" reflect the conditions associated with a typical landfill or those most frequently encountered in landfill situations. The "all worst" columns show the results of the analyses when the site parameters and sludge concentrations used were all worst case. Intermediate analyses using several worst case parameters with several typical parameters were also conducted for each pollutant. Appendix E contains the results of the intermediate analyses conducted.

As can be seen in Table 3, the index values associated with human toxicity from ingestion of groundwater contaminated by leaching from an "all worst" case landfill range from 0.0098 for 2,4-dichlorophenoxyacetic acid to 51,000 for arsenic. For four compounds (cobalt, methyl ethyl ketone, methylene chloride and phenanthrene) human toxicity index values could not be calculated due to missing data points. For seven compounds the index values in the worst case situation are less than 1 indicating that no human toxicity problem exists for non-carcinogens or that the risk from cancer is below the 10^{-6} risk level for carcinogens. The seven compounds are: cadmium, chromium, 2,4-dichlorophenoxyacetic acid, molybdenum, malathion, phenol and selenium.

For groundwater contamination from the "all typical" landfill situation, the associated human toxicity index values ranged from 3×10^{-20} for phenol to 740 for dimethyl nitrosamine. Indices for four compounds could not be calculated due to data gaps (cobalt, methyl ethyl ketone, methylene chloride and phenanthrene). For the "all typical" scenario, fourteen compounds have indice values less than 1. These compounds are: cadmium, chromium, copper, cyanide, 2,4-dichlorophenoxyacetic acid, lead, malathion, mercury, molybdenum, nickel, phenol, selenium, trichloroethylene and zinc.

° INCINERATION

For the sludge disposal option of incineration, two indices were calculated. Index 1 shows the degree of elevation of a pollutant's concentration in air due to the incineration of sludge. This index was developed by using two models, the BURN model and the ISCLT dispersion model. The BURN model uses thermodynamic and mass balance relationships appropriate for multiple hearth incinerators to relate the input sludge characteristics to the stack gas parameters. Fluidized bed incinerators were not evaluated due to a paucity of available data. The dilution and dispersion of these stack gas releases were described by the ISCLT dispersion model from which normalized annual ground level concentrations were predicted.

Index 2 shows the human health impacts expected to result from the incineration of sludge. The results of Index 1 were compared to the ground level concentrations used to assess human health impacts. Ground level concentrations for carcinogens were developed based upon assessments published by the U.S. EPA Carcinogen Assessment Group. These ambient concentrations reflect a dose level, which for a lifetime exposure, increases the risk of cancer by 10^{-6}. For non-carcinogens, levels were derived from the American Conference of Governmental and Industrial Hygienists threshold limit values for the workplace. The reader should refer to Appendix D for details on the calculation methods.

The results of the analyses related to incineration of municipal sludge are summarized in Table 4. The analyses related to incineration were performed for thirty compounds identifed at the OWRS expert committee meetings as being of potential concern. The analyses were conducted using two sludge feed rates: 2660 kg/hr DW which represents an average dewatered sludge feed rate into a furnace serving a community of 400,000 people, and 10,000 hg/hr DW which represents a higher feed rate which would serve a major U.S. city. For each feed rate the analysis was conducted using both a "typical" concentration of the pollutant in sludge and a "worst" concentration of the pollutant. Thus the terms "typical" and "worst" in Table 4 refers to the analyses performed using the two concentrations of pollutant in sludge. The null values represent conditions in the absence of sludge incineration.

As can be seen in Table 4 for the disposal of worst case concentration sludges at a feed rate of 2660 kg/hr (DW) the index 2 values range from 0.00035 for selenium to 380 for chromium. For the disposal of worst concentration sludges at the higher feed rate of 10,000 kg/hr six compounds have hazard indices less than 1 indicating that no human toxicity problem exists (for non-carcinogens) or that the risk from cancer is below the 10^{-6} risk level (for carcinogens). The six compounds are: Copper, DDT, heptachlor, lindane, selenium and zinc. For sludges containing the worst concentration of pollutant incinerated at the lower feed rate of 2660 kg/hr (DW), ten compounds have hazard indices less than 1. These compounds are: beryllium, DEHP, copper, DDT, heptachlor, lead, lindane, mercury, selenium and zinc. For sludges containing typical concentrations of the pollutant disposed at the higher feed rate of 10,000 kg/hr (DW), ten compounds have hazard indices less than 1. For sludges containing typical concentrations disposed at the lower feed rate of 2,660 kg/hr (DW), thirteen compounds have hazard indices less than 1.

TABLE 4: INCINERATION HAZARD INDICES

	INDEX 1						INDEX 2					
	2660 Kg/hr			10000 Kg/hr			2660 Kg/hr			10000 Kg/hr		
POLLUTANT	NULL	TYPICAL	WORST	NULL	TYPICAL	WORST	NULL	TYPICAL	WORST	NULL	TYPICAL	WORST
ALDRIN/DIELDRIN	1	1.1	2.9	1	3.2	34	1.9	2.1	5.4	1.9	6.1	64
ARSENIC	1	1.4	3.5	1	8.5	46	36	51	130	36	300	1600
BENZENE	1	1	1	1	1	1	110	110	110	110	110	110
BENZO(A)ANTHRACENE	1	1	2	1	1.6	19	NC	NC	NC	NC	NC	NC
BENZO(A)PYRENE	1	1	2.9	1	1.6	35	0.62	0.64	1.8	0.62	1	22
BERYLLIUM	1	1	1.4	1	1.6	7.2	0.18	0.19	0.25	0.18	0.29	1.3
DEHP	1	1.9	18	1	16	300	0.054	0.1	0.98	0.054	0.9	16
CADMIUM	1	3	31	1	37	520	6.7	20	200	6.7	250	3500
CARBON TETRACHLORIDE	1	1	1	1	1	1	21	21	21	21	21	22
CHLORDANE	1	1.4	7.8	1	9.09	120	0.41	0.59	3.2	0.41	3.7	49.6
CHLOROFORM	1	1	1	1	1	1	98	98	98	98	98	99
CHROMIUM	1	1.2	3.3	1	4.1	41	120	140	380	120	480	4800
COPPER	1	1	1.2	1	1.8	4.6	0.046	0.048	0.055	0.046	0.082	0.21
DDT/DDE/DDD	1	1.1	1.5	1	2.7	11	0.083	0.092	0.13	0.083	0.23	0.89
DIOXINS	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
FURANS	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
HEPTACHLOR	1	1.1	1.3	1	2	6.3	0.14	0.15	0.19	0.14	0.29	0.91

DEHP = Bis-(2-hexyl ethyl)phthalate

Note: Results predicated on sludge concentrations derived from "Fate of Priority Pollutants in Publicly Owned Treatment Works" (U.S. EPA,1982) or "A Comparison of Studies of Toxic Substances in POTW Sludges" (CDM,1984). See Text.

TABLE 4 (CONTINUED): INCINERATION HAZARD INDICES

POLLUTANT	INDEX 1: 2660 Kg/hr NULL	INDEX 1: 2660 Kg/hr TYPICAL	INDEX 1: 2660 Kg/hr WORST	INDEX 1: 10000 Kg/hr NULL	INDEX 1: 10000 Kg/hr TYPICAL	INDEX 1: 10000 Kg/hr WORST	INDEX 2: 2660 Kg/hr NULL	INDEX 2: 2660 Kg/hr TYPICAL	INDEX 2: 2660 Kg/hr WORST	INDEX 2: 10000 Kg/hr NULL	INDEX 2: 10000 Kg/hr TYPICAL	INDEX 2: 10000 Kg/hr WORST
LEAD	1	1.1	1.8	1	2.4	16	0.21	0.23	0.39	0.21	0.51	3.4
LINDANE	1	1.3	3.2	1	5.9	40	0.019	0.024	0.061	0.019	0.11	0.76
MERCURY	1	1.4	2.5	1	7.6	27	0.56	0.076	0.14	0.56	0.42	1.5
METHYLENE CHLORIDE	1	1	1	1	1	1	1.4	1.4	1.4	1.4	1.4	1.4
NICKEL	1	1	2.1	1	1.4	21	3	3	6.2	3	4.3	61
PCB	1	1.1	2.6	1	2.2	29	9.2	9.8	24	9.2	20	260
PHENANTHRENE	1	8.64	172	1	136	3020	NC	NC	NC	NC	NC	NC
SELENIUM	1	1	1.4	1	1.5	7.2	0.00026	0.00027	0.00035	0.00026	0.0004	0.0019
TETRACHLOROETHYLENE	1	1	1	1	1	1	8.3	8.3	8.3	8.3	8.3	8.5
TOXAPHENE	1	1.8	5.5	1	16	81	0.39	0.71	2.1	0.39	6	31
VINYL CHLORIDE	1	1	1	1	1	1.1	220	220	220	220	220	230
ZINC	1	1.1	4.4	1	2.8	62	0.0038	0.0042	0.017	0.0038	0.011	0.24

NC = Not calculated due to lack of appropriate data

Note: Results predicated on sludge concentrations derived from "Fate of Priority Pollutants in Publicly Owned Treatment Works" (U.S. EPA,1982) or "A Comparison of Studies of Toxic Substances in POTW Sludges" (CDM,1984). See Text.

° OCEAN DUMPING

Four indices were calculated for the disposal option of ocean dumping. As mentioned previously, Index 1 calculates the increased concentration of the pollutant in seawater around an ocean disposal site assuming initial mixing; whereas, Index 2 calculates the increased effective concentration of the 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 or moving randomly within the disposal vicinity over a 24-hour period.

Two "effects" indices were calculated for ocean dumping. Index 3 compares the resultant water concentration of the contaminant at the dumpsite with the ambient water quality criterion or with another value judged protective of marine aquatic life and its marketability. Index 4 estimates the expected increase in human intake of the contaminant due to seafood consumption, taking into account that fraction which originates from the dumpsite vicinity. This index compares the total expected contaminant intake with the acceptable daily intake or, if a carcinogen, with the intake level calculated to result in an increase of cancer risk of 10^{-6}.

The results of the analyses conducted for the four indices are summarized in Table 5. The analyses related to ocean dumping were performed for twenty-one compounds identified at the OWRS expert committee meetings as being of potential concern. Each of the indices were calculated for two sludge disposal rates, 825 mt DW/day and 1650 mt DW/day, and for two sludge concentrations - a "typical" and "worst" concentration of the contaminant in sludge. For Index 4 an additional variable was added - "worst" case and "typical" case seafood intake. Thus, in Table 5 the values associated with typical (T) refer to typical sludge concentrations; and in the case of Index 4, T refers to the value for both typical sludge concentrations and typical seafood consumption. The worst case (W) indicates the values for worst sludge contaminant concentrations; and in the case of Index 4, W refers to the value for worst sludge contaminant concentrations as well as worst case seafood consumption. The null values represent the index values in the absence of sludge disposal.

As can be seen in Table 5, Index 3 was calculated for all the compounds except dioxins, furans and trichlorophenol due to a paucity of available data. For the disposal of sludge at the 825 mt DW/day rate using "worst" sludges, the range of Index 3 values was from 0.000011 for benzo(a)pyrene to 14.3 for chlordane. For the disposal of sludge at the 1650 mt DW/day rate using "worst" sludges the range of Index 3 values was from 0.000011 for benzo(a)-pyrene to 29 for chlordane.

Index 4 was calculated for all the compounds except dioxins, furans, benzo(a)anthracene and phenanthrene due to the paucity of data. For the disposal of worst case sludges at the 825 mt DW/day disposal rate, and assuming worst case seafood intake, the values range from 0.00047 for pentachlorophenol to 920 for aldrin/dieldrin. For the worst case sludges disposed at a 1650 mt DW/day rate, and assuming worst case seafood intake, the values ranged from 0.00047 for pentachlorophenol to 930 for aldrin/dieldrin. For this scenario, seven compounds have hazard indices less than 1 indicating that no human toxicity problem exists for the non-carcinogens or that the risk from cancer is below the 10^{-6} risk level for carcinogens.

TABLE 5: OCEAN DISPOSAL HAZARD INDICES

POLLUTANT		INDEX 1 (ug/L) 825[a]	INDEX 1 (ug/L) 1650[a]	INDEX 2 (ug/L) 825[a]	INDEX 2 (ug/L) 1650[a]	INDEX 3 825[a]	INDEX 3 1650[a]	INDEX 4 825[a]	INDEX 4 1650[a]
ALDRIN/DIELDRIN	T=	0.00044	0.00044	0.00012	0.00024	0.063	0.12	900	900
	W=	0.014	0.014	0.0039	0.0077	2	4.1	920	930
	Null=	0	0	0	0	0	0	900	900
BENZIDINE[b]	T=	0.025	0.025	0.0069	0.014	0.00001	0.00001	0.00061	0.0012
	W=	0.22	0.22	0.061	0.12	0.000086	0.000086	30	59
	Null=	0	0	0	0	0	0	0	0
BENZO(A)ANTHRACENE	T=	0.0014	0.0014	0.00037	0.00073	4.50E-06	4.50E-06	NC	NC
	W=	0.082	0.082	0.023	0.046	0.00027	0.00027	NC	NC
	Null=	0	0	0	0	0	0	NC	NC
BENZO(A)PYRENE	T=	0.00029	0.00029	0.000078	0.00016	9.50E-07	9.50E-07	140	140
	W=	0.033	0.033	0.0092	0.018	0.000011	0.000011	170	200
	Null=	0	0	0	0	0	0	140	140
DEHP	T=	0.19	0.19	0.051	0.1	0.055	0.055	4.02E-07	8.00E-07
	W=	7.8	7.8	2.2	4.4	2.3	2.3	0.096	0.19
	Null=	0	0	0	0	0	0	0	0
CADMIUM *	T=	1.8	1.8	1.2	1.4	0.0042	0.0042	0.54	0.54
	W=	76	76	22	43	0.17	0.17	0.61	0.69
	Null=	1	1	1	1	0.0023	0.0023	0.54	0.54
CHLORDANE	T=	0.0064	0.0064	0.0017	0.003	0.43	0.86	1.8	1.8
	W=	0.2	0.2	0.057	0.11	14.3	29	32	64
	Null=	0	0	0	0	0	0	1.8	1.8
DDT/DDD/DDE	T=	0.0013	0.0013	0.00036	0.00072	0.36	0.72	19	19
	W=	0.016	0.016	0.0044	0.0089	4.4	8.9	21	23
	Null=	0	0	0	0	0	0	19	19

DEHP = Bis-(2-ethyl hexyl)phthlate

Note: Results predicated on sludge concentrations derived from "Fate of Priority Pollutants in Publicly Owned Treatment Works" (U.S. EPA,1982) or "A Comparison of Studies of Toxic Substances in POTW Sludges" (CDM,1984). See Text.

TABLE 5 (CONTINUED): OCEAN DISPOSAL HAZARD INDICES

POLLUTANT		INDEX 1 (ug/L)		INDEX 2 (ug/L)		INDEX 3		INDEX 4	
		825[a]	1650[a]	825[a]	1650[a]	825[a]	1650[a]	825[a]	1650[a]
DICHLOROBENZIDINE	T=	0.0033	0.0033	0.00089	0.0018	0.0066	0.0066	0.000002	0.000004
	W=	0.039	0.039	0.011	0.022	0.078	0.078	0.14	0.27
	Null=	0	0	0	0	0	0	0	0
DIOXINS	T=	NC	NC	NC	NC	NC	NC	NC	NC
	W=	NC	NC	NC	NC	NC	NC	NC	NC
	Null=	NC	NC	NC	NC	NC	NC	NC	NC
ENDRIN	T=	0.00028	0.00028	0.000076	0.00015	0.033	0.066	0.014	0.014
	W=	0.0029	0.0029	0.00081	0.0016	0.35	0.71	0.014	0.014
	Null=	0	0	0	0	0	0	0.014	0.014
FURANS	T=	NC	NC	NC	NC	NC	NC	NC	NC
	W=	NC	NC	NC	NC	NC	NC	NC	NC
	Null=	NC	NC	NC	NC	NC	NC	NC	NC
HEPTACHLOR	T=	0.00014	0.00014	0.000038	0.000076	0.011	0.021	24	24
	W=	0.0015	0.0015	0.00043	0.00086	0.12	0.24	24	25
	Null=	0	0	0	0	0	0	24	24
LINDANE	T=	0.00022	0.00022	0.000059	0.00012	0.0014	0.0014	150	150
	W=	0.0037	0.0037	0.001	0.0021	0.023	0.023	150	150
	Null=	0	0	0	0	0	0	150	150
MERCURY*	T=	1.6	1.6	1.2	1.3	0.23	0.26	0.25	0.25
	W=	21	21	6.6	12	1.3	2.4	0.32	0.39
	Null=	1	1	1	1	0.2	0.2	0.25	00.25
PENTACHLOROPHENOL	T=	0.00017	0.00017	0.000047	0.000094	5.10E-06	5.10E-06	0.00047	0.00047
	W=	0.52	0.52	0.14	0.29	0.015	0.015	0.00047	0.00047
	Null=	0	0	0	0	0	0	0.00047	0.00047
PHENANTHRENE	T=	0.0074	0.0074	0.002	0.004	0.000025	0.000025	NC	NC
	W=	0.35	0.35	0.099	0.2	0.0012	0.0012	NC	NC
	Null=	0	0	0	0	0	0	NC	NC

Note: Results predicated on sludge concentrations derived from "Fate of Priority Pollutants in Publicly Owned Treatment Works" (U.S. EPA,1982) or "A Comparison of Studies of Toxic Substances in POTW Sludges" (CDM,1984). See Text.

TABLE 5 (CONTINUED): OCEAN DISPOSAL HAZARD INDICES

POLLUTANT		INDEX 1 (ug/L) 825[a]	INDEX 1 (ug/L) 1650[a]	INDEX 2 (ug/L) 825[a]	INDEX 2 (ug/L) 1650[a]	INDEX 3 825[a]	INDEX 3 1650[a]	INDEX 4 825[a]	INDEX 4 1650[a]
PCBS	T=	0.008	0.008	0.0022	0.0043	0.072	0.14	47	47
	W=	0.39	0.39	0.11	0.22	3.7	7.3	400	760
	Null=	0	0	0	0	0	0	47	47
TOXAPHENE	T=	0.016	0.016	0.0043	0.0086	0.06	0.12	55	55
	W=	0.18	0.18	0.052	0.1	0.73	1.5	81	110
	Null=	0	0	0	0	0	0	55	55
TRICHLOROPHENOL	T=	0.0046	0.0046	0.0012	0.0025	NC	NC	1.6E-08	3.1E-08
	W=	0.078	0.078	0.022	0.044	NC	NC	0.0016	0.0031
	Null=	0	0	0	0	NC	NC	0	0

NC = Not calculated due to lack of appropriate data
[a] = metric tons per day discharge rate
[b] = Reported values all based on worst case sludges
* = Index 1 and 2 for Cadmium and Mercury are unitless; all other compounds in ug/L

Note: Results predicated on sludge concentrations derived from "Fate of Priority Pollutants in Publicly Owned Treatment Works" (U.S. EPA,1982) or "A Comparison of Studies of Toxic Substances in POTW Sludges" (CDM,1984). See Text.

VII. INTERPRETATION OF HAZARD INDICES RESULTS

A. General Description of the Interpretation Approach

In order to facilitate interpretation of the data and results discussed in the previous section (especially Tables 2-5), a two step screening procedure was used:

Step 1 - Ranking of Pollutants for Each Environmental Pathway

This step consisted of arraying the pollutants for each of the indices, in order to determine which pollutants can be eliminated from further consideration for a specific environmental pathway. Pollutants were eliminated from consideration if under the worst case scenario designed for a specific pathway, the resulting hazard index value is less than 1. Values less than 1 indicate that the compound is not toxic to either man, animal or plants, depending on the pathway being evaluated. For the pathways related to man, an index value less than 1 indicates that the pollutant does not pose a toxic hazard in the case of non-carcinogens, or in the case of carcinogens, will not exceed the 10^{-6} cancer risk level. By using the hazard index value associated with the worst case scenario for a particular pathway, the analysis can definitively rule out any pollutants with values less than 1, as these index values represent the total hazard including the background concentration in air or water or soil, depending on the pathway. Pollutants which have been eliminated for a specific pathway by this step will not be considered for future risk assessment for that pathway. Pollutants with values equal to or greater than 1 will undergo Step 2 of the screening procedure.

Step 2 - Incremental Ranking of Pollutants for Each Environmental Pathway

In Step 1, pollutants with values less than 1 were eliminated since they presented no potential hazard even when including the background concentration of the pollutant. All pollutants with values equal to or greater than 1 underwent Step 2, incremental ranking. This step evaluated what portion of the hazard associated with a pollutant for a particular environmental pathway is attributable to sludge. In order to make such an evaluation, the background concentration or background hazard of the pollutant must be discounted. Step 2 discounts the background by subtracting the "null" hazard index value, or background level, determined for a specific pollutant from the total hazard index value determined for that pollutant. The resulting hazard index value is the increment attributable to sludge. For example, if a compound has a total index value of 920 for a specific pathway under worst case conditions and a "null" value of 900, the incremental hazard index value of 20 is attributable to sludge. Once again, the worst case scenario associated with a pathway was used in this analysis. Once all the incremental values had been determined, a ranking of pollutants, from ascending to descending order, was performed. These pollutants were then "bracketed" into several groups: those with incremental values greater than 1,000; those with values from 100 to 1000; those with values from 1 to 100 and those with values less than 1. Pollutants with incremental values in the group from 100-1000 would generally be of more concern than those pollutants found in the grouping from 1-100. Thus the groupings would allow for the prioritization of pollutants for further risk assessment during the regulatory development process.

B. RESULTS OF THE TWO TIER SCREENING APPROACH

° STEP 1: RESULTS

The results of the ranking of pollutants for each index (Step 1) are portrayed in Tables 6-9. The pollutants were ranked using the hazard index values associated with the worst case scenario. As can be seen in the tables, those pollutants with index values less than 1 have been eliminated from further consideration for that pathway. The eliminated pollutants therefore represent those pollutants which will not adversely affect the environment or human health. Table 10 lists all of the pollutants per pathway that were eliminated during Step 1. As can be seen on Tables 6-9, only those indices related to "effects" as defined previously have undergone a Step 1 analysis since such an analysis for other indices, such as groundwater contamination, would be meaningless since these indices relate only to concentrations of the pollutant in the media and do not imply an effect on the environment or human health. These indices have been ranked and placed in these tables simply for reference. The following describes the results of the Step 1 analysis for each reuse/disposal option:

- Step 1: Land Application

Table 6 shows the results of ranking the pollutants for each environmental pathway using the values associated with the assumed worst case scenario. For the "effects" indices (Indices 2,3,4,6,7-13), pollutants with hazard index values less than 1 were "boxed" and will not be considered further in this analysis for that pathway. Table 6 shows that for Index 2, which evaluates toxicity to soil biota, all compounds except copper have hazard index values less than 1 indicating no potential problem to soil biota when "worst" sludges are applied. For Index 3, which evaluates the toxicity to predators of soil biota, eight compounds have hazard indices of less than 1 indicating no potential problem. The eight compounds are: DDT, copper, nickel, cobalt, chromium, pentachlorophenol, heptachlor and lindane. For Index 4 which evaluates phytotoxicity, twelve compounds have indice values less than 1. For Index 7, which evaluates animal toxicity from consuming

TABLE 6: RANKING OF POLLUTANTS FOR LAND APPLICATION BASED ON HAZARD INDICES USING WORST CASE PARAMETERS

SOIL CONCENTRATION INCREMENT (I-1) ORGANICS (ug/g/DW)

Pollutant	Index Value
Tricresyl phosphate	280
Bis(2 ethyl hexyl) phthalate	92
Methylinebis (2 chloro aniline)	25
Methylene chloride	3.8
Trichloroethylene	3.6
Hexachlorobutadiene	1.6
Benzo(a)anthracene	0.96
Pentachlorophenol	0.74
PCB	0.57
Toxaphene	0.49
Chlordane	0.29
DDT	0.24
Lindane	0.13
Dimethyl nitrosamine	0.062
Benzo(a)pyrene	0.057
Hexachlorobenzene	0.054
Aldrin/Dieldrin	0.02
Heptachlor	0.0023

TOXICITY TO SOIL BIOTA (I-2)

Pollutant	Index Value
Copper	2.3
Zinc	0.86
Lead	0.22
Chlordane	0.10
Cobalt	0.048
Toxaphene	0.029
Pentachlorophenol	0.019
DDT/DDD/DDE	0.010
Lindane	0.0027
Heptachlor	0.00069
Aldrin/Dieldrin	0.00068

[dashed box] = those pollutants which would not present a hazard under assumed worst case conditions

SOIL CONCENTRATION INCREMENT (I-1) INORGANICS

Pollutant	Index Value
Cadmium	89
Zinc	22
Lead	20
Copper	12
Mercury	12
Nickel	7.9
Selenium	5.4
Molybdenum	3.9
Chromium	3.8
Cobalt	1.8
Iron	1.6
Arsenic	1.5
Fluoride	1.3

TABLE 6 (CONT): RANKING OF POLLUTANTS FOR LAND APPLICATION BASED ON HAZARD INDICES USING ASSUMED WORST CASE PARAMETERS

TOXICITY TO SOIL BIOTA PREDATORS (I-3)

Pollutant	Index Value
Cadmium	82
Zinc	23
Lead	2.7
Aldrin/Dieldrin	1.5
Hexachlorobenzene	1.2
Copper	0.61
Nickel	0.55
DDT/DDD/DDE	0.35
Cobalt	0.35
Chromium	0.095
Pentachlorophenol	0.092
Heptachlor	0.080
Lindane	0.0028

PHYTOTOXICITY (I-4)

Pollutant	Index Value
Cadmium	7.1
Zinc	4.2
Copper	3.0
Nickel	2.9
Lead	2.2
Chromium	1.9
Selenium	1.0
Fluoride	0.84
Arsenic	0.20
Cobalt	0.18
Mercury	0.16
Molybdenum	0.16
PCB	0.057
Chlordane	0.023
Toxaphene	0.016
Lindane	0.01
Aldrin/Dieldrin	0.0062
DDT/DDD/DDE	0.0036
Heptachlor	0.000023

[dashed box] = those pollutants which would not present a hazard under assumed worst case conditions

TABLE 6 (CONT): RANKING OF POLLUTANTS FOR LAND APPLICATION BASED ON HAZARD INDICES USING ASSUMED WORST CASE PARAMETERS

PLANT UPTAKE (I-5) ORGANICS (ug/g DW)

Pollutant	Index Value
PCB	1.2
Fluoride	1.3
Hexachlorobenzene	0.87
Chlordane	0.67
Toxaphene	0.43
Pentachlorophenol	0.26
DDT/DDD/DDE	0.15
Benzo(a)pyrene	0.10
Aldrin/Dieldrin	0.015
Heptachlor	0.0017
MOCA	0.0

PLANT UPTAKE (I-5) INORGANICS

Pollutant	Index Value
Nickel	120
Selenium	73
Chromium	42
Cadmium	35
Arsenic	14
Zinc	6.5
Copper	6.5
Mercury	4.0
Lead	3.1
Iron	2.9
Cobalt	2.8
Molybdenum	2.4
Fluoride	1.3

ANIMAL TOXICITY RESULTING FROM PLANT CONSUMPTION (I-7)

Pollutant	Index Value
Zinc	4.4
Molybdenum	2.5
Selenium	2.1
Copper	1.3
Cadmium	1.0
Fluoride	0.92
Cobalt	0.45
PCB	0.42
Iron	0.36
Lead	0.12
Mercury	0.078
Nickel	0.076
Chlordane	0.074
Chromium	0.024
Hexachlorobenzene	0.013
Toxaphene	0.0086
Pentachlorophenol	0.0042
Arsenic	0.0010
Benzo(a)pyrene	0.00060
DDT/DDD/DDE	0.00040
Aldrin/Dieldrin	0.00041
Heptachlor	0.00017
MOCA	0.0

[dashed box] = those pollutants which would not present a hazard under assumed worst case conditions

TABLE 6 (CONT): RANKING OF POLLUTANTS FOR LAND APPLICATION BASED ON HAZARD INDICES USING ASSUMED WORST CASE PARAMETERS

ANIMAL TOXICITY RESULTING FROM SLUDGE INGESTION (I-8)

Pollutant	Index Value
Copper	2.8
Iron	2.8
Fluoride	0.92
Cadmium	0.88
Zinc	0.76
Lead	0.67
Molybdenum	0.40
Nickel	0.33
Chlordane	0.24
PCB	0.23
Cobalt	0.20
Mercury	0.15
Hexachlorobenzene	0.11
Aldrin/Dieldrin	0.04
Chromium	0.038
Selenium	0.035
MOCA	0.034
Hexachlorobutadiene	0.013
Toxaphene	0.011
Heptachlor	0.009
Pentachlorophenol	0.0031
Dimethyl nitrosamine	0.0026
Benzo(a)pyrene	0.0024
Lindane	0.0022
Arsenic	0.0010
DDT/DDD/DDE	0.00015

HUMAN TOXICITY RESULTING FROM PLANT CONSUMPTION (I-9)

Pollutant	Index Value
PCB	15000
Hexachlorobenzene	4300
Chlordane	3100
Benzo(a)pyrene	3000
Aldrin/Dieldrin	2200
Toxaphene	1300
Cadmium	96
DDT/DDD/DDE	70
Heptachlor	39
Zinc	17
Nickeel	125
Lead	8.5
Selenium	6.8
Arsenic	1.8
Iron	1.6
Mercury	1.3
Fluoride	1.0
Copper	0.55
Molybdenum	0.45
Chromium	0.083
Pentachlorophenol	0.026

[dashed box] = those pollutants which would not present a hazard under worst case conditions

TABLE 6 (CONT): RANKING OF POLLUTANTS FOR LAND APPLICATION BASED ON HAZARD INDICES USING ASSUMED WORST CASE PARAMETERS

HUMAN TOXICITY RESULTING FROM ANIMAL PRODUCTS [a] (I-10)

Pollutant	Index Value
PCB	65000
Toxaphene	1400
Hexachlorobenzene	1100
Aldrin/Dieldrin	1000
Chlordane	182
DDT/DDD/DDE	170
Heptachlor	31
Selenium	16
Zinc	4.1
Cadmium	3.0
Mercury	3.0
Fluoride	0.62
Iron	0.50
Copper	0.48
Arsenic	0.29
Lead	0.14
Molybdenum	0.11
Nickel	0.11
Chromium	0.00058

HUMAN TOXICITY RESULTING FROM ANIMAL PRODUCTS [b] (I-11)

Pollutant	Value
PCB	34000
Aldrin/Dieldrin	10000
Toxaphene	1900
Hexachlorobenzene	820
Chlordane	550
Heptachlor	420
Lindane	170
DDT/DDD/DDE	150
Hexachlorobutadiene	130
Mercury	13
Cadmium	2.7
Copper	0.91
Zinc	0.89
Fluoride	0.67
Selenium	0.45
Arsenic	0.27
Lead	0.20
Nickel	0.12
Molybdenum	0.093
Chromium	0.0005

a = Index 10 is for animal products derived from animals feeding on plants
b = Index 11 is for animal products derived from animals incidentally ingesting sludge-amended soil

= those pollutants which would not present a hazard under worst case conditions

TABLE 6 (CONT): RANKING OF POLLUTANTS FOR LAND APPLICATION BASED ON HAZARD INDICES USING ASSUMED WORST CASE PARAMETERS

HUMAN TOXICITY RESULTING FROM SOIL INGESTION (I-12)

Pollutant	Index Value
Arsenic	9500
Aldrin/Dieldrin	900
PCB	190
Benzo(a)pyrene	150
Lindane	150
Toxaphene	55
Chlordane	34
Heptachlor	24
Hexachlorobenzene	9.3
Hexachlorobutadiene	8.9
Lead	7.7
Iron	5.0
Mercury	2.4
Cadmium	1.6
Fluoride	0.68
Zinc	0.36
Nickel	0.25
Copper	0.24
Selenium	0.24
Molybdenum	0.090
Chromium	0.017
Pentachlorophenol	0.0019

INDEX OF HUMAN AGGREGATE TOXICITY (I-13)

Pollutant	Index Value
PCB	110000
Aldrin	12000
Hexachlorobenzene	6200
Toxaphene	4500
Chlordane	3900
Heptachlor	450
DDT/DDD/DDE	360
Cadmium	100
Selenium	23
Mercury	22
Zinc	22
Lead	16
Nickel	12
Iron	5.4
Copper	1.6
Fluoride	1.0
Molybdenum	0.15

= those pollutants which would not present a hazard under worst case conditions plants grown on sludge-amended soils, nineteen compounds have hazard indices less than 1 and thus will not be considered further in this analysis. Analysis of Index 8 which evaluates animal toxicity from incidental sludge ingestion shows that all compounds, except copper and iron, have index values less than 1. Human toxicity resulting from consuming plants grown on sludge-amended soils was evaluated by Index 9. The Step 1 ranking shows that four compounds (copper, molybdenum, chromium and pentachlorophenol) have index values less than 1 and thus will not be considered further in this analysis for that pathway.

For Indices 10-13 which are all human health related, the ranking was conducted using the highest index value related to the worst case scenario. Thus if the hazard value associated with pollutant x for Index 10 was higher for adults than toddlers such a value was used. If for pollutant y, the toddler value was higher than the adult value then the toddler value was used. The rationale for this is that the screening must account for the absolute worst values with respect to age differences in order to definitively eliminate pollutants from further consideration; thus by "lumping" the adult and toddler values and choosing the highest, this is accomplished.

For Index 10, which evaluates human toxicity resulting from consuming animal products derived from animals feeding on plants, eight compounds (fluoride, iron, copper, arsenic, lead, molybdenum, nickel and chromium) have index values less than 1 and thus will not be considered further for this pathway. For Index 11, which evaluates human toxicity resulting from consuming animal products from animals incidentally ingesting sludge-amended soils, or sludge adhering to forage, nine compounds have index values less than 1. For Index 12, which evaluates human toxicity from soil ingestion, eight compounds had index values less than 1 and for Index 13 which aggregates the human toxicity indices, only 1 compound has a value less than 1. All compounds with values equal to or greater than 1 underwent a Step 2 incremental analysis for the appropriate environmental pathway. All other chemicals having index values of less than 1 were not considered further in this analysis and will not be considered in subsequent risk assessments for that pathway.

- Step 1: Landfilling

Table 7 shows that for Index 2, which evaluates human toxicity/ cancer risk resulting from groundwater contamination, seven compounds have hazard index values less than 1 indicating no potential toxicity problem for noncarcinogens or for carcinogens a risk less than the 10^{-6} level. The seven compounds (cadmium, selenium, molybdenum, chromium, phenol, malathion, and 2,4-dichlorophenoxyacetic acid) therefore will not be considered further in this analysis and in subsequent risk assessments performed during

TABLE 7: RANKING OF POLLUTANTS FOR LANDFILLING BASED ON HAZARD INDICES USING ASSUMED WORST CASE PARAMETERS

GROUNDWATER CONTAMINATION ORGANICS (I-1)*

Pollutant	Index Value
Cyanide	16,000
Bis(2 ethyl hexyl phthalate	2,700
PCB	130
Phenanthrene	120
Methylene Chloride	110
Trichloroethylene	100
Chlordane	69
Toxaphene	62
2,4 D	41.4
Benzene	38
Dimethyl Nitrosamine	14.8
Benzo(a)pyrene	11
DDT/DDD/DDE	5.4
Malathion	3.6
Lindane	1.3

GROUNDWATER CONTAMINATION INORGANICS (I-1)

Pollutant	Index Value
Cobalt	8,300
Zinc	2,700
Chromium	1,300
Copper	830
Nickel	800
Cadmium	510
Mercury	340
Arsenic	120
Molybdenum	24
Selenium	4.5

HUMAN CONSUMPTION OF GROUNDWATER (I-2)

Pollutant	Index Value
Arsenic	51,000
PCB	17,000
Dimethyl Nitrosamine	12,000
Benzo(a)pyrene	3,800
Chlordane	3,200
Toxaphene	2,100
Bis(2-ethyl hexyl) phthalate	1,100
Benzene	260
Lindane	200
DDT/DDD/DDE	71
Trichloroethylene	56
Lead	29
Copper	6.4
Cyanide	4.1
Mercury	3.6
Nickel	2.3
Zinc	1.4
Cadmium	0.54
Selenium	0.37
Molybdenum	0.22
Chromium	0.157
Phenol	0.14
Malathion	0.011
2,4 D	0.0098

* = for organics, I-1 is actual concentrations in ug/l

= those pollutants which would not present a hazard under assumed worst case conditions the regulatory development process for this pathway. Table 7 also shows that the compounds with the highest total index values (which includes the background hazard) are arsenic, PCBs and dimethyl nitrosamine. All the compounds, with the exception of the seven compounds with index values less than one, were incrementally ranked in Step 2.

- Step 1: Incineration

Table 8 shows that for Index 2, which evaluates human toxicity/cancer risk resulting from the inhalation of incinerator emissions, six compounds have hazard index values less than 1 indicating no potential toxicity problem for noncarcinogens or for carcinogens, a risk less than the 10^{-6} level. The six compounds (heptachlor, DDT, lindane, zinc, copper and selenium) therefore will not be considered further in this analysis and in subsequent risk assessments performed during the regulatory development process for this pathway. Table 8 also shows that the compounds with the highest total index values (which includes the background hazard) are chromium, cadmium and arsenic. All the compounds, with the exception of the six with index values less than one, were incrementally ranked in Step 2.

- Step 1: Ocean Dumping

Table 9 shows the ranking for two effects indices: Index 3 which evaluates aquatic life effects and Index 4 which evaluates human health effects from seafood consumption. For Index 3, ten compounds have hazard index values less than 1 indicating no aquatic toxicity hazards. The ten compounds are: endrin, heptachlor, cadmium, dichlorobenzidine, lindane, pentachlorophenol, phenanthrene, benzo(a)anthracene, benzidine, and benzo(a)pyrene. These compounds will not be considered further in this analysis and in subsequent risk assessments conducted during the regulatory development process for this pathway. All the remaining compounds were incrementally ranked by Step 2. For Index 4, which evaluates human health effects from seafood consumption, seven compounds have hazard index values less than 1 and will not be considered further in this analysis. The seven compounds are: cadmium, mercury, dichlorobenzidine, bis(2-ethyl hexyl) phthalate, endrin, trichlorophenol, and pentachlorophenol. The highest index values for this pathway were for aldrin/dieldrin, PCBs and benzo(a)pyrene. All compounds, with the exception of the seven with values less than 1, underwent Step 2 incremental ranking.

- STEP 1: Summary

Table 10 summarizes the results from the Step 1 analysis by deliniating for each environmental pathway, which compounds are not of concern and thus were not included in the Step 2 analysis. These compounds will not be considered in future risk assessments for that specific environmental pathway. Thus Step 1 screened out many pollutants for each specific environmental pathway.

TABLE 8: RANKING OF POLLUTANTS FOR INCINERATION BASED ON HAZARD INDICES USING ASSUMED WORST CASE PARAMETERS

AIR CONCENTRATION INCREMENT (I-1)

Pollutant	Index Value
Phenanthrene	3020
Cadmium	520
Bis(2-ethyl hexyl) phthalate	300
Chlordane	120
Toxaphene	81
Zinc	62
Arsenic	46
Chromium	41
Lindane	40
Benzo(a)pyrene	35
Aldrin/Dieldrin	34
PCB	29
Mercury	27
Nickel	21
Benzo(a)anthracene	19
Lead	16
Selenium	7.2
Beryllium	7.2
Heptachlor	6.3
Copper	4.6
DDT/DDE/DDD	2.7
Vinyl Chloride	1.1
Benzene	1
Carbon Tetrachloride	1
Chloroform	1
Methylene Chloride	1
Tetrachloroethylene	1

HUMAN INHALATION (I-2)

Pollutant	Index Value
Chromium	4800
Cadmium	3500
Arsenic	1600
PCB	260
Vinyl Chloride	230
Benzene	110
Chloroform	99
Aldrin/Dieldrin	64
Nickel	61
Chlordane	49.6
Toxaphene	31
Benzo(a)pyrene	22
Carbon Tetrachloride	22
Bis(2-ethyl hexyl) phthalate	16
Tetrachloroethylene	8.5
Lead	3.4
Mercury	1.5
Methylene Chloride	1.4
Beryllium	1.3

Pollutant	Index Value
Heptachlor	0.91
DDT/DDE/DDD	0.89
Lindane	0.76
Zinc	0.24
Copper	0.21
Selenium	0.0019

[dashed box] = those pollutants which would not present a hazard under assumed worst case conditions

TABLE 9: RANKING OF POLLUTANTS FOR OCEAN DUMPING BASED ON HAZARD INDICES USING ASSUMED WORST CASE PARAMETERS

INITIAL MIXING SEAWATER CONCENTRATION (I-1) ORGANICS (ug/l)

Pollutant	Index Value
Bis(2 ethyl hexyl) phthalate	7.8
Pentachlorophenol	0.52
Phenanthrene	0.35
Benzidine	0.22
Chlordane	0.20
Toxaphene	0.18
Benzo(a) anthracene	0.082
Trichlorophenol	0.078
Dichlorobenzidine	0.039
Benzo(a)pyrene	0.033
Aldrin/Dieldrin	0.014
Lindane	0.0037
Endrin	0.0029
Heptachlor	0.0015

24 HOUR CYCLE CONCENTRATION (I-2) ORGANICS (ug/l)

Pollutant	Index Value
Bis(2 ethyl hexyl)-phthalate	4.4
Pentachlorophenol	0.29
PCB	0.22
Penanthrene	0.20
Benzidine	0.12
Chlordane	0.11
Toxaphene	0.10
Benzo(a)anthracene	0.046
Trichlorophenol	0.044
Dichlorobenzidine	0.022
Benzo(a)pyrene	0.018
Aldrin/Dieldrin	0.0077
Lindane	0.0021
Endrin	0.0016
Heptachlor	0.00086

AQUATIC LIFE EFFECTS (I-3)

Pollutant	Index Value
Chlordane	29
DDT/DDD/DDE	8.9
PCB	7.3
Aldrin/Dieldrin	4.1
Mercury	2.4
Bis(2 ethyl hexyl) phthalate	2.3
Toxaphene	1.5

Pollutant	Index Value
Endrin	0.71
Heptachlor	0.24
Cadmium	0.17
Dichlorobenzidine	0.078
Lindane	0.023
Pentachlorophenol	0.015
Phenanthrene	0.0012
Benzo(a)anthracene	0.00027
Benzo(a)pyrene	0.000011

HUMAN HEALTH EFFECTS (I-4)

Pollutant	Index Value
Aldrin/Dieldrin	930
PCB	760
Benzo(a)pyrene	200
Lindane	150
Toxaphene	110
Chlordane	64
Benzidine	59
Heptachlor	25
DDT/DDD/DDE	23

Pollutant	Index Value
Cadmium	0.69
Mercury	0.39
Dichlorobenzidine	0.27
Bis(2 ethyl hexyl) phthalate	0.19
Endrin	0.014
Trichlorophenol	0.003
Pentachlorophenol	0.00047

INITIAL MIXING SEAWATER CONCENTRATION (I-1)

Pollutant	Index Value
Cadmium	76
Mercury	21

24-HOUR CYCLE CONCENTRATION (I-2) INORGANICS

Pollutant	Index Value
Cadmium	43
Mercury	12

= those pollutants which would not present a hazard under assumed worst case conditions

TABLE 10: POLLUTANTS WHICH UNDER WORST CASE CONDITIONS DO NOT PRESENT A HAZARD FOR A SPECIFIC PATHWAY (SEE TEXT FOR EXPLANATION)

° LAND APPLICATION

- Toxicity to Soil Biota (Index 2): Zinc, Lead, Chlordane, Cobalt, Toxaphene, Pentachlorophenol, Lindane, Heptachlor, Aldrin/Dieldrin, DDT

- Toxicity to Soil Biota Predators (Index 3): Copper, Nickel, Cobalt, Chromium, Pentachlorophenol, Heptachlor, Lindane, DDT

- Phytotoxicity (Index 4): Fluoride, Arsenic, Cobalt, Molybdenum, Mercury, Chlordane, Lindane, Toxaphene, Heptachlor, Aldrin/Dieldrin, PCB, DDT

- Animal Ingestion of Plants Grown on Sludge-Amended Soil (Index 7): see Table 6 "boxed" compounds.

- Animal Incidental Ingestion (Index 8): see Table 6 "boxed" compounds.

- Human Ingestion of Plants Grown on Sludge-Amended Soil (Index 9): Copper, Molybdenum, Chromium, Pentachlorophenol

- Human Ingestion of Animals Ingesting Plants Grown on Sludge-Amended Soil (Index 10): Fluoride, Iron, Copper, Arsenic, Lead, Molybdenum, Nickel, Chromium

- Human Ingestion of Animals Ingesting Sludge-Amended Soil (Index 11): Copper, Zinc, Fluoride, Selenium, Arsenic, Lead, Nickel, Molybdenum, Chromium

- Incidental Ingestion (Index 12): Fluoride, Zinc, Nickel, Copper, Selenium, Molybdenum, Chromium, Pentachlorophenol.

° LANDFILLING

- Human Consumption of Contaminated Groundwater (Index 2): Cadmium, Selenium, Molybdenum, Chromium, Phenol, Malathion, 2,4 D

° INCINERATION

- Human Inhalation of Incinerator Emissions (Index 2): Heptachlor, DDT, Lindane, Zinc, Copper, Selenium

° OCEAN DUMPING

- Aquatic Life Effects (Index 3): Endrin, Heptachlor, Cadmium, Dichlorobenzidine, Lindane, Pentachlorophenol, Phenanthrene, Benzo(a)anthracene, Benzidine, Benzo(a)pyrene

- Human Health Effects (Index 4): Cadmium, Mercury, Dichlorobenzidine, Endrin, Trichlorophenol, Pentachlorophenol, Bis(2-ethyl hexyl)phthalate

° STEP 2 - RESULTS

The compounds which were not eliminated by Step 1 underwent the Step 2 incremental ranking. As previously mentioned, the purpose of Step 2 was to evaluate what portion of the total hazard associated with a pollutant for a particular pathway is attributable to sludge. In order to make such an evaluation, a discounting of the background hazard was necessary. Tables 11-14 show the results of ranking and bracketing the pollutants based on their incremental value. The incremental value was determined by subtracting the null or background value, for the worst case scenario from the total hazard index value for the worst case scenario. The values recorded in Tables 11-14 are the incremental values after the discounting was accomplished. The bracketing on these tables are for purposes of grouping pollutants. The following describes the results of the Step 2 analysis for each reuse/disposal option.

- Step 2: Land Application

Table 11 shows the incremental ranking and incremental values for the ten "effects" indices related to land application. For Index 2 which evaluates soil biota toxicity only one compound was incrementally ranked (copper). Index 3 which evaluates toxicity to predators of soil biota had 4 compounds incrementally ranked, all found in the 1-100 grouping. All compounds incrementally ranked for Index 4 were found in the grouping from 1-100 with cadmium having the highest incremental values of 7.1. For Index 7 which evaluates animal toxicity from plant consumption, all compounds were found in the 1-100 grouping. Only two compounds were incrementally ranked for Index 8 - copper with a value of 2.8 and iron with a value of 2.1. For Index 9, six compounds were found in the >1000 grouping, with PCBs having the highest value. No compounds were found in the grouping from 100-1000; however, ten compounds did have incremental values between 1 and 100. For Index 10 and Index 11, pollutants were found in all the groupings except the grouping of <1. For both these indices, the highest incremental value was for the same compound - PCB. For Index 12 which evaluates human toxicity from soil ingestion, the highest incremental values were for arsenic and PCB. For Index 13, the highest incremental values were for PCB, aldrin/dieldrin, and hexachlorobenzene.

- Step 2: Landfilling

Table 12 shows the incremental ranking and values for each of the compounds evaluated in Index 2, the index of human toxicity/ cancer risk resulting from groundwater contamination. As can be seen, seven compounds have incremental values greater than 1000 and nine compounds have incremental values between 1 and 100. No compounds were found in the grouping of 100-1000 or the grouping of less than 1. The highest incremental values were for arsenic, PCB and dimethyl nitrosamine. The lowest incremental values were for nickel, mercury, cyanide and copper.

- Step 2: Incineration

Table 13 shows the incremental ranking and values evaluated in Index 2, the index of human toxicity/cancer risk resulting from the inhalation of incineration emissions. As can be seen, three compounds (chromium, cadmium and arsenic) have incremental values greater than 1000. PCB was the only compound in the 100-1000 grouping. Eleven compounds fall into the grouping from 1-100 whereas four compounds fell into the grouping of less than 1. For two compounds, methylene chloride and benzene, no incremental hazard is attributable to sludge.

- Step 2: Ocean Dumping

For ocean dumping, two incremental rankings were performed and are shown in Table 14. For Index 3, the index of toxicity to aquatic life, no compounds were found in the groupings of >1000; 100-1000; and <1. Seven compounds were found to have incremental values between 1 and 100. For Index 4 which evaluates human health effects from seafood consumption, no pollutants were found in the grouping of greater than 1000 and only one compound (PCB) was found in the grouping from 100-1000. Seven compounds were found in the grouping of 1-100. Lindane was found to have no incremental hazard attributable to sludge.

TABLE 11: INCREMENTAL RANKING FOR LAND APPLICATION (See Text)

- For land application, ten effects indices were calculated. This table contains the incremental ranking for each of the effects indices.

INDEX 2: SOIL BIOTA TOXICITY

	COMPOUND	INCREMENTAL VALUE
> 1000	NO POLLUTANTS	
100–1000	NO POLLUTANTS	
1–100	Copper	2.1
<1	NO POLLUTANTS	

INDEX 3: TOXICITY TO SOIL BIOTA PREDATORS

	COMPOUND	INCREMENTAL VALUE
>1000	NO POLLUTANTS	
100–1000	NO POLLUTANTS	
1–100	Cadmium	81.4
	Zinc	21.2
	Lead	2.4
	Aldrin/Dieldrin	1.5
<1	NO POLLUTANTS	

TABLE 11 (CONT): INCREMENTAL RANKING FOR LAND APPLICATION (see Text)

INDEX 4: PHYTOTOXICITY

	COMPOUND	INCREMENTAL VALUE
> 1000	NO POLLUTANTS	
100-1000	NO POLLUTANTS	
1-100	Cadmium	7.1
	Zinc	4.0
	Copper	2.75
	Nickel	2.5
	Lead	2.1
	Chromium	1.4
<1	Selenium	0.8

INDEX 7: ANIMAL TOXICITY FROM PLANT CONSUMPTION

	COMPOUND	INCREMENTAL VALUE
>1000	NO POLLUTANTS	
100-1000	NO POLLUTANTS	
1-100	Zinc	4.4
	Molybdenum	2.3
	Selenium	2.1
	Copper	1.0
	Cadmium	1.0
<1	NO POLLUTANTS	

TABLE 11 (CONT): INCREMENTAL RANKING FOR LAND APPLICATION

INDEX 8: ANIMAL TOXICITY FROM SLUDGE INGESTION

	COMPOUND	INCREMENTAL VALUE
> 1000	NO POLLUTANTS	
100-1000	NO POLLUTANTS	
1-100	Copper	2.8
	Iron	2.1
<1	NO POLLUTANTS	

INDEX 9: HUMAN TOXICITY FROM PLANT CONSUMPTION

	COMPOUND	INCREMENTAL VALUE
>1000	PCB	14953
	Hexachlorobenzene	4295
	Chlordane	3100
	Benzo(a)pyrene	2860
	Aldrin/Dieldrin	1300
	Toxaphene	1245
100-1000	NO POLLUTANTS	
1-100	Cadmium	95
	DDT	51
	Zinc	16.4
	Heptachlor	15
	Nickel	11.9
	Lead	8.2
	Selenium	6.6
	Arsenic	1.5
	Iron	1.1
	Mercury	1.0
<1	Fluoride	0.4

TABLE 11 (CONT): INCREMENTAL RANKING FOR LAND APPLICATION (see Text)

INDEX 10: HUMAN TOXICITY FROM ANIMAL PRODUCTS[a]

	COMPOUND	INCREMENTAL VALUE
> 1000	PCB	64953
	Toxaphene	1345
	Hexachlorobenzene	1095
100-1000	Chlordane	180
	DDT	151
	Aldrin/Dieldrin	100
1-100	Selenium	15.7
	Heptachlor	7.0
	Zinc	3.7
	Mercury	2.75
	Cadmium	2.5
<1	NO POLLUTANTS	

INDEX 11: HUMAN TOXICITY FROM ANIMAL PRODUCTS[b]

	COMPOUND	INCREMENTAL VALUE
>1000	PCB	33947
	Aldrin/Dieldrin	9090
	Toxaphene	1845
100-1000	Hexachlorobenzene	814
	Chlordane	448
	Heptachlor	396
	Hexachlorobutadiene	130
	DDT	117
1-100	Mercury	12.5
	Lindane	10
	Cadmium	2.2
<1	NO POLLUTANTS	

a = Index 10 is for animal products derived from animals fed on plants.
b = Index 11 is for animal products derived from animals incidentally ingesting sludge-amended soil.

TABLE 11 (CONT): INCREMENTAL RANKING FOR LAND APPLICATION (see Text)

INDEX 12: TOXICITY RESULTING FROM SOIL INGESTION

	COMPOUND	INCREMENTAL VALUE
> 1000	Arsenic	3100
100-1000	PCB	171
1-100	Aldrin/Dieldrin	40
	Benzo(a)pyrene	39
	Chlordane	33
	Toxaphene	21
	Hexachlorobutadiene	8.9
	Lead	7.1
	Hexachlorobenzene	6.5
	DDT	2.0
	Mercury	1.9
	Cadmium	1.4
	Iron	1.2
<1	Heptachlor	0.9
	Lindane	0

INDEX 13: INDEX OF HUMAN AGGREGATE TOXICITY

	COMPOUND	INCREMENTAL VALUE
>1000	PCB	109937
	Aldrin/Dieldrin	11090
	Hexachlorobenzene	6200
	Toxaphene	4445
	Chlordane	3900
100-1000	Heptachlor	425
	DDT	317
	Cadmium	100
1-100	Selenium	22.8
	Mercury	21.4
	Zinc	21.4
	Lead	15.3
	Nickel	11.9
	Iron	2.2
	Copper	1.3
<1	Fluoride	0.4

TABLE 12: INCREMENTAL RANKING FOR LANDFILLING (See Text)

For landfilling, the only effects index was Index 2: Index of Human Toxicity/Cancer Risk Resulting from Groundwater Contamination. This table shows the incremental ranking for this index.

	COMPOUND	INCREMENTAL VALUE
> 1000	Arsenic	51,000
	PCBs	16,941
	Dimethyl nitrosamine	11,260
	Benzo(a)pyrene	3,650
	Chlordane	3,198
	Toxaphene	2,045
	Bis(2-ethyl hexyl) phthalate	1,100
100-1000	NO POLLUTANTS	
1-100	Trichloroethylene	56
	DDT	52
	Benzene	50
	Lindane	40
	Lead	29
	Copper	6.4
	Cyanide	4.1
	Mercury	3.3
	Nickel	2.2
< 1	NO POLLUTANTS	

TABLE 13: INCREMENTAL RANKING FOR INCINERATION (See Text)

° For incineration, the only effects index is Index 2: Index of Human Health/Cancer Risk from Inhalation of Incineration Emissions. This table shows the incremental ranking for this index.

	COMPOUND	INCREMENTAL VALUE
> 1000	Chromium	4,860
	Cadmium	3,493
	Arsenic	1,564
100-1000	PCB	251
1-100	Aldrin/Dieldrin	62.1
	Nickel	58.0
	Chlordane	49.2
	Toxaphene	30.6
	Benzo(a)pyrene	21.4
	Bis(2-ethyl hexyl) phthalate)	15.9
	Vinyl Chloride	10.0
	Lead	3.2
	Beryllium	1.1
	Chloroform	1.0
	Carbon Tetrachloride	1.0
< 1	Mercury	0.9
	Tetrachloroethylene	0.2
	Methylene Chloride	0
	Benzene	0

TABLE 14: INCREMENTAL RANKING FOR OCEAN DUMPING (See Text)

° For ocean dumping, two effects indices were calculated:
Index 3: Index of Toxicity to Aquatic Life
Index 4: Index of Human Toxicity/Cancer Risk Resulting from Seafood Consumption. The following is the incremental ranking for these two indices.

INDEX 3

	COMPOUND	INCREMENTAL VALUE
> 1000	NO POLLUTANTS	
100–1000	NO POLLUTANTS	
1–100	Chlordane	29
	DDT	8.9
	PCB	7.3
	Aldrin/Dieldrin	4.1
	Bis(2-ethyl hexyl) phthalate	2.3
	Mercury	2.2
	Toxaphene	1.5
<1	NO POLLUTANTS	

INDEX 4

	COMPOUND	INCREMENTAL VALUE
>1000	NO POLLUTANTS	
100–1000	PCB	713
1–100	Chlordane	62
	Benzo(a)pyrene	60
	Benzidine	59
	Toxaphene	45
	Aldrin/Dieldrin	30
	DDT	4
	Heptachlor	1
<1	Lindane	0

C. Use of Results from Two-Tier Screening Approach

As can be seen from the previous sections, the two tier screening approach accomplishes two objectives: (1) it eliminates those pollutants which under assumed worst case conditions do not pose a hazard for a specific pathway and (2) prioritizes the remaining pollutants based on the incremental hazard attributable to sludge for that pathway. EPA, in conducting such assessments on each environmental pathway, will use the outcome of the Step 2 analysis as the basis for establishing priorities for further analysis and potential regulatory development. Thus pollutants in the grouping of >1000 for a specific pathway will be examined first, with subsequent analyses being done on the grouping of 100-1000, then for the grouping of 1-100 and finally for the grouping of <1. By using this two tier system, EPA can place its resources and emphasis on those pollutants which potentially may present a hazard to human health and the environment. As subsequent more intensive risk assessments are performed, additional pollutants may be found to be of no concern. The key to this whole environmental profile effort has been to recognize that the hazard indices is a screening device which allows EPA to eliminate those pollutants which would not present a health or environmental problem and that the two tier screen would provide a prioritization mechanism for the remaining pollutants.

APPENDIX A:

LIST OF OWRS COMMITTEE MEETING EXPERTS FOR DEVELOPING LIST OF POTENTIAL POLLUTANTS OF CONCERN

OWRS COMMITTEES ON
MUNICIPAL SLUDGE

I. Land Application/Distribution and Marketing - March 27, 28, 1984

- Rufus Chaney, U.S.D.A.
  Biological Waste Management and Organic Resources Lab
  Building 008 Barc-West
  Beltsville, Maryland 20705

- Terry Logan, Ohio State University
  Agronomy Department
  412C Kottman Hall
  2021 Coffey Road
  Columbus, Ohio 43210

- Dale Baker, Pennsylvania State University
  Agronomy Dept.
  221 Tyson Bldg.
  University Park, Pennsylvania 16802

- Dan O'Neill, Michigan Dept. of Natural Resources
  Groundwater Quality Division
  P.O. Box 30028
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- Mike Overcash, North Carolina State University at Raleigh
  Chemical Engineering
  113 Riddich
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- Norm Kowal, U.S. EPA
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- Greg Diachenko, U.S. Food and Drug Administration
  Division Chemical Technology (HFF-424)
  200 C St., S.W.
  Washington, D.C. 20204

II. Landfill - April 10,11, 1984

- Chuck Sorber, University of Texas at Austin
  College of Engineering
  Office of the Dean
  Austin, Texas 78712-1080

- Wallace Fuller, University of Arizona
  Dept. of Soils, Water and Engineering
  Tuscon, Arizona 85721

- Kirk Brown, Texas A & M
  Soil and Crop Sciences
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III. Incineration - May 8,9, 1984

- Walter Niessen, Camp Dresser and McKee
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IV. Ocean Dumping - May 22, 23, 1984

- Tudor Davies, U.S. EPA
  Office of Water - Headquarters

- Jack Gentile, U.S. EPA
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  South Ferry Road
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- Thomas O'Conner, National Oceanic and Atmospheric Admin.
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APPENDIX B:

LIST OF POLLUTANTS FOR ENVIRONMENTAL PROFILE DEVELOPMENT

CHEMICALS FOR SLUDGE ENVIRONMENTAL PROFILE DEVELOPMENT

Compound Name	Applicable Disposal Options: Landspreading/ Distribution and Marketing	Landfilling	Incinceration	Ocean Disposal
Fluoride	●			
Iron	●			
Molybdenum	●	●		
Selenium	●	●	●	
Arsenic	●	●	●	
Copper	●	●	●	
Lead	●	●	●	
Cadmium	●	●	●	●
Beryllium			●	
Nickel	●	●	●	
Zinc	●	●	●	
Cobalt	●	●		
Mercury	●	●	●	●
Cyanide		●		
Chromium	●	●	●	
Aldrin/Dieldrin	●		●	●
Heptachlor	●		●	●
Chloroform			●	
Carbon Tetrachloride			●	
Tetrachloroethylene			●	
Vinyl Chloride			●	
2,4,6-Trichlorophenol				●
Pentachlorophenol	●			●
Benzidine				●
3,3'-dichlorobenzidine				●
Hexachlorobenzene	●			
Hexachlorobutadiene	●			
Benzo(a)anthracene	●		●	●
Tetrachloro-dibenzo-dioxins			●	●
Tetrachloro-dibenzo-furans			●	●
Methylenebis (2-chloro-aniline)	●			
Tricresyl Phosphate	●			
Endrin				●
Chlordane	●	●	●	●
Malathion		●		
2,4-Dichlorophenoxyacetic Acid		●		
Toxaphene	●	●	●	●
Lindane	●	●	●	●
Polychlorinated Biphenyls	●	●	●	●
Methylene Chloride	●	●	●	
DDT/DDE/DDD	●	●	●	●
Trichloroethylene	●	●		
Benzene		●	●	
Methyl Ethyl Ketone		●		
Dimethyl Nitrosamine	●	●		
Phenol		●		
Bis(2-ethylhexyl) phthalate	●	●	●	●
Benzo(a)pyrene	●	●	●	●
Phenanthrene		●	●	●

APPENDIX C:

SAMPLE ENVIRONMENTAL PROFILE

United States
Environmental Protection
Agency

Office of Water
Regulations and Standards
Washington, DC 20460

Water

June, 1985

EPA

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

PREFACE

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

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

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

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

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

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

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

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

SECTION 2

PRELIMINARY CONCLUSIONS FOR LINDANE IN MUNICIPAL SEWAGE SLUDGE

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

I. LANDSPREADING AND DISTRIBUTION-AND-MARKETING

A. Effect on Soil Concentration of Lindane

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

B. Effect on Soil Biota and Predators of Soil Biota

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

C. Effect on Plants and Plant Tissue Concentration

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

D. Effect on Herbivorous Animals

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

E. Effect on Humans

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

II. LANDFILLING

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

III. INCINERATION

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

IV. OCEAN DISPOSAL

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

SECTION 3

PRELIMINARY HAZARD INDICES FOR LINDANE IN MUNICIPAL SEWAGE SLUDGE

I. LANDSPREADING AND DISTRIBUTION-AND-MARKETING

A. Effect on Soil Concentration of Lindane

1. Index of Soil Concentration (Index 1)

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

0 mt/ha	No sludge applied. Shown for all indices for purposes of comparison, to distinguish hazard posed by sludge from 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 2×10^3 mt/ha and is then dissipated through first order processes which can be expressed as a soil half-life.

c. **Data Used and Rationale**

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

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

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

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

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

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

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

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

d. **Index 1 Values (µg/g DW)**

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

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

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

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

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

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

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

c. **Data Used and Rationale**

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

See Section 3, p. 3-2.

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

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

d. **Index 2 Values**

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

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

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

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

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

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

c. **Data Used and Rationale**

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

See Section 3, p. 3-2.

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

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

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

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

d. **Index 3 Values**

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

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

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

C. **Effect on Plants and Plant Tissue Concentration**

1. **Index of Phytotoxic Soil Concentration (Index 4)**

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

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

c. **Data Used and Rationale**

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

See Section 3, p. 3-2.

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

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

d. **Index 4 Values**

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

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

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

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

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

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

c. **Data Used and Rationale**

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

See Section 3, p. 3-2.

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

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

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

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

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

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

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

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

c. **Data Used and Rationale**

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

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

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

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

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

D. **Effect on Herbivorous Animals**

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

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

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

c. **Data Used and Rationale**

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

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

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

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

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

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

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

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

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

c. Data Used and Rationale

i. Sludge concentration of pollutant (SC)

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

See Section 3, p. 3-1.

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

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

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

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

See Section 3, p. 3-8.

d. **Index 8 Values**

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

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

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

E. **Effect on Humans**

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

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

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

c. **Data Used and Rationale**

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

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

Toddler	74.5 g/day
Adult	205 g/day

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

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

Toddler	2.71 µg/day
Adult	8.21 µg/day

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

c. **Data Used and Rationale**

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

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

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

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

Toddler	43.7 g/day
Adult	88.5 g/day

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

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

Toddler	2.71 μg/day
Adult	8.21 μg/day

See Section 3, p. 3-11.

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

See Section 3, p. 3-12.

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

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

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

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

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

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

c. **Data Used and Rationale**

i. **Animal tissue** = Beef fat

See Section 3, p. 3-13.

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

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

See Section 3, p. 3-1.

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

See Section 3, p. 3-2.

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

See Section 3, p. 3-9.

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

See Section 3, p. 3-13.

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

Toddler	39.4 g/day
Adult	82.4 g/day

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

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

Toddler	2.71 μg/day
Adult	8.21 μg/day

See Section 3, p. 3-11.

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

See Section 3, p. 3-12.

d. Index 11 Values

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

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

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

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

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

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

c. **Data Used and Rationale**

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

See Section 3, p. 3-2.

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

Pica child	5 g/day
Adult	0.02 g/day

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

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

Toddler	2.71 μg/day
Adult	8.21 μg/day

See Section 3, p. 3-11.

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

See Section 3, p. 3-12.

d. **Index 12 Values**

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

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

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

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

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

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

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

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

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

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

II. LANDFILLING

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

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

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

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

3. **Data Used and Rationale**

a. **Unsaturated zone**

i. **Soil type and characteristics**

(a) **Soil type**

Typical	Sandy loam
Worst	Sandy

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

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

Typical	1.53 g/mL
Worst	1.925 g/mL

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

(c) **Volumetric water content (θ)**

Typical	0.195 (unitless)
Worst	0.133 (unitless)

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

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

Typical	0.005 (unitless)
Worst	0.0001 (unitless)

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

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

ii. **Site parameters**

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

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

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

Typical	0.8 m/year
Worst	1.6 m/year

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

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

Typical	5 m
Worst	0 m

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

(d) **Dispersivity coefficient (α)**

Typical	0.5 m
Worst	Not applicable

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

iii. **Chemical-specific parameters**

(a) **Sludge concentration of pollutant (SC)**

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

See Section 3, p. 3-1.

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

See Section 3, p. 3-2.

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

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

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

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

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

b. Saturated zone

i. Soil type and characteristics

(a) Soil type

Typical	Silty sand
Worst	Sand

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

(b) Aquifer porosity (ϕ)

Typical	0.44 (unitless)
Worst	0.389 (unitless)

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

(c) Hydraulic conductivity of the aquifer (K)

Typical	0.86 m/day
Worst	4.04 m/day

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

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

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

ii. **Site parameters**

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

Typical	0.001 (unitless)
Worst	0.02 (unitless)

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

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

Typical	100 m
Worst	50 m

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

(c) **Dispersivity coefficient (α)**

Typical	10 m
Worst	5 m

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

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

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

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

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

iii. **Chemical-specific parameters**

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

Degradation is assumed not to occur in the saturated zone.

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

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

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

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

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

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

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

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

3. **Data Used and Rationale**

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

See Section 3, p. 3-26.

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

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

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

See Section 3, p. 3-11.

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

See Section 3, p. 3-12.

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

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

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

III. INCINERATION

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

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

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

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

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

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

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

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

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

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

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

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

3. **Data Used and Rationale**

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

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

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

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

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

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

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

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

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

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

   See Section 3, p. 3-1.

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

Typical 0.05 (unitless)
Worst 0.20 (unitless)

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

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

Typical 3.4 $\mu g/m^3$
Worst 16.0 $\mu g/m^3$

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

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

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

4. **Index 1 Values**

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

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

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

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

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

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

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

3. **Data Used and Rationale**

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

See Section 3, p. 3-28.

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

See Section 3, p. 3-28.

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

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

d. **Exposure criterion (EC)** = 0.00263 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	0.019	0.024	0.11
	Worst	0.019	0.030	0.20
Worst	Typical	0.019	0.040	0.39
	Worst	0.019	0.061	0.76

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

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

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

IV. OCEAN DISPOSAL

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

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

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

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

3. **Data Used and Rationale**

a. **Disposal conditions**

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

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

The assumed disposal practice to be followed at the model site representative of the typical case is a modification of that proposed for sludge disposal at the formally designated 12-mile site in the New York Bight Apex (City of New York, 1983). Sludge barges with capacities of 3400 mt WW would be required to discharge a load in no less than 53 minutes traveling at a minimum speed of 5 nautical miles (9260 m) per hour. Under these conditions, the barge would enter the site, discharge the sludge over 8180 m and exit the site. Sludge barges with capacities of 1600 mt WW would be required to discharge a load in no less than 32 minutes traveling at a minimum speed of 8 nautical miles (14,816 m) per hour. Under these conditions, the barge would enter the site, discharge the sludge over 7902 m and exit the site. The mean path length for the large and small tankers is 8041 m or approximately 8000 m. Path length is assumed to lie perpendicular to the direction of prevailing current flow. For the typical disposal rate (SS) of 825 mt DW/day, it is assumed that this would be accomplished by a mixture of four 3400 mt WW and four 1600 mt WW capacity barges. The overall daily disposal operation would last from 8 to 12 hours. For the worst-case disposal rate (SS) of 1650 mt DW/day, eight 3400 mt WW and eight 1600 mt WW capacity barges would be utilized. The overall daily disposal operation would last from 8 to 12 hours. For both disposal rate scenarios, there would be a 12 to 16 hour period at night in which no sludge would be dumped. It is assumed that under the above 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	0.11 mg/kg DW
Worst	0.22 mg/kg DW

See Section 3, p. 3-1.

c. **Disposal site characteristics**

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

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

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

4. Factors Considered in Initial Mixing

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

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

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

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

5. **Index 1 Values (µg/L)**

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

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

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

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

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

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

3. **Data Used and Rationale**

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

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

See Section 3, p. 3-34.

5. **Index 2 Values ($\mu g/L$)**

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

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

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

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

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

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

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

3. **Data Used and Rationale**

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

See Section 3, p. 3-34.

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

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

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

4. **Index 3 Values**

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

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

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

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

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

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

3. **Data Used and Rationale**

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

   See Section 3, p. 3-35.

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

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

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

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

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

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

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

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

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

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

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

For the typical (deep water) site:

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

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

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)** = 130 L/kg

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

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

See Section 3, p. 3-11.

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

See Section 3, p. 3-12.

4. **Index 4 Values**

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

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

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

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

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

SECTION 4

PRELIMINARY DATA PROFILE FOR LINDANE IN MUNICIPAL SEWAGE SLUDGE

I. OCCURRENCE

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

A. Sludge

1. Frequency of Detection

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

2. Concentration

Lindane not found in Denver-metro sludge Alpha-BHC occurred at 20 ng/g (WW) in waste-activated sludge	Baxter et al., 1983a (p. 315)
<500 μg/L in Chicago sludge	Jones and Lee, 1977 (p. 52)
Summary of lindane in sludge of 74 cities in Missouri (μg/g DW)	Clevenger et al., 1983 (p. 1471)

Min.	Max.	Mean	Median
0.05	0.22	0.11	0.11

B. Soil - Unpolluted

1. Frequency of Detection

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

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

2. Concentration

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

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

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

C. Water - Unpolluted

1. Frequency of Detection

Data not immediately available.

2. Concentration

a. Freshwater

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

b. Seawater

Data not available for seawater concentrations

c. **Drinking Water**

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

D. **Air**

1. **Frequency of Detection**

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

2. **Concentration**

a. **Urban**

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

b. **Rural**

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

E. Food

1. Total Average Intake

10 ug/kg body weight/day acceptable FAO/WHO intake	FDA, 1979
Total relative daily intake ug/kg body weight/day	FDA, 1979

FY75	FY76	FY77	FY78
0.0031	0.0026	0.0038	0.0024

2. Frequency of Detection and Concentration

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

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

* T = Trace

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

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

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

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

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

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

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

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

II. HUMAN EFFECTS

A. Ingestion

1. Carcinogenicity

a. Qualitative Assessment

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

b. Potency

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

2. Chronic Toxicity

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

3. Absorption Factor

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

4. Existing Regulations

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

B. Inhalation

1. Carcinogenicity

a. Qualitative Assessment

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

b. Potency

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

c. Effects

Data not immediately available.

2. Chronic Toxicity

Data not evaluated since assessment based on carcinogenicity.

3. Absorption Factor

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

4. Existing Regulations

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

III. PLANT EFFECTS

A. Phytotoxicity

See Table 4-1.

B. Uptake

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

IV. DOMESTIC ANIMAL AND WILDLIFE EFFECTS

A. Toxicity

See Table 4-2.

B. Uptake

See Table 4-3.

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

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

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

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

V. AQUATIC LIFE EFFECTS

A. Toxicity

1. Freshwater

a. Acute

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

b. **Chronic**

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

2. **Saltwater**

a. **Acute**

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

b. **Chronic**

Data not immediately available.

B. **Uptake**

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

VI. SOIL BIOTA EFFECTS

A. **Toxicity**

See Table 4-4.

B. **Uptake**

See Table 4-5.

VII. PHYSIOCHEMICAL DATA FOR ESTIMATING FATE AND TRANSPORT

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

TABLE 4-1. PHYTOTOXICITY OF LINDANE

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

TABLE 4-1. (continued)

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

[a] NR = Not reported

[b] BHC = Benzene hexachloride, a trade name for the insecticide, hexachlorocyclohexane.

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

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

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

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

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

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

TABLE 4-4. TOXICITY OF LINDANE TO SOIL BIOTA

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

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

TABLE 4-5. UPTAKE OF LINDANE BY SOIL BIOTA

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

[a] NR = Not reported.

SECTION 5

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APPENDIX

PRELIMINARY HAZARD INDEX CALCULATIONS FOR LINDANE IN MUNICIPAL SEWAGE SLUDGE

I. LANDSPREADING AND DISTRIBUTION-AND-MARKETING

A. Effect on Soil Concentration of Lindane

1. Index of Soil Concentration (Index 1)

a. Formula

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

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

where:

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

b. Sample calculation

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

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

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

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

B. Effect on Soil Biota and Predators of Soil Biota

1. Index of Soil Biota Toxicity (Index 2)

a. Formula

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

where:

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

b. Sample calculation

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

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

a. Formula

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

where:

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

b. Sample calculation

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

C. Effect on Plants and Plant Tissue Concentration

1. Index of Phytotoxic Soil Concentration (Index 4)

a. Formula

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

where:

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

b. **Sample calculation**

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

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

a. **Formula**

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

where:

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

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

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

a. **Formula**

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

where:

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

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

D. **Effect on Herbivorous Animals**

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

a. **Formula**

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

where:

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

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

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

a. **Formula**

If AR = 0; Index 8 = 0

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

where:

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

b. **Sample calculation**

If AR = 0; Index 8 = 0

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

E. **Effect on Humans**

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

a. **Formula**

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

where:

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

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

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

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

a. Formula

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

where:

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

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

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

a. Formula

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

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

where:

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

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

b. Sample calculation (toddler)

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

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

a. Formula

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

where:

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

b. Sample calculation (toddler)

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

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

a. Formula

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

where:

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

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

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

II. LANDFILLING

A. Procedure

Using Equation 1, several values of C/C_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. $\mathrm{Erfc}(A_2)$ produces values between 0.0 and 2.0 (Abramowitz and Stegun, 1972).

where:

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

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

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

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

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

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

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

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

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

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

μ = Degradation rate (day^{-1})

and where for the saturated zone:

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

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

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

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

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**

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

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:

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

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:

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

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

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

1. **Formula**

Index 1 = C_{max}

where:

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

2. **Sample Calculation**

$0.00142\ \mu g/L = 0.00142\ \mu g/L$

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

1. **Formula**

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

where:

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

2. **Sample Calculation**

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

III. **INCINERATION**

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

1. **Formula**

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

where:

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

2. **Sample Calculation**

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

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

1. **Formula**

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

where:

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

2. **Sample Calculation**

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

IV. **OCEAN DISPOSAL**

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

1. **Formula**

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

where:

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

2. **Sample Calculation**

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

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

1. Formula

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

where:

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

2. Sample Calculation

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

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

1. Formula

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

where:

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

2. Sample Calculation

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

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

1. Formula

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

where:

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

2. Sample Calculation

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

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

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

TABLE A-1. (continued)

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

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

LINDANE

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

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

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

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

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

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

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

APPENDIX D:

HAZARD INDEX METHODOLOGIES

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

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

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

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

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

IDENTIFICATION OF EXPOSURE PATHWAYS

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

CALCULATION OF CONTAMINANT TRANSPORT

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

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

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

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

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

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

CALCULATION OF HAZARD INDICES

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

Incremental Indices and Their Interpretation

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

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

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

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

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

$$I_1 = A$$

---

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

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

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

Effect Indices and Their Interpretation

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

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

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

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

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

LIMITATIONS OF THE APPROACH

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

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

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

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

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

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

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

HAZARD INDICES

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

I. LANDSPREADING AND DISTRIBUTION-AND-MARKETING

A. Effect on Soil Concentration

1. Index of Soil Concentration Increment (Index 1)

a. For Inorganic Chemicals

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

where:

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

b. For Organic Chemicals

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

or

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

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

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

where:

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

B. Effect on Soil Biota and Predators of Soil Biota

1. Index of Soil Biota Toxicity (Index 2)

a. For Inorganic Chemicals

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

where:

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

b. For Organic Chemicals

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

where:

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

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

a. For Inorganic Chemicals

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

where:

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

b. For Organic Chemicals

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

where:

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

C. Effect on Plants and Plant Tissue Concentration

1. Index of Phytotoxicity (Index 4)

a. For Inorganic Chemicals

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

where:

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

b. For Organic Chemicals

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

where:

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

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

a. For Inorganic Chemicals

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

where:

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

b. For Organic Chemicals

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

where:

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

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

a. For Inorganic Chemicals

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

where:

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

b. For Organic Chemicals

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

where:

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

C. Effect on Herbivorous Animals

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

a. For Inorganic Chemicals

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

where:

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

b. For Organic Chemicals

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

where:

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

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

a. For Inorganic Chemicals

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

$$\text{If } AR \neq 0, \qquad I_8 = \frac{SC \times GS}{TA}$$

where:

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

b. For Organic Chemicals

If AR = 0, Index 8 = 0

If AR $\neq$ 0, $I_8 = \dfrac{SC \times GS}{TA}$

where:

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

E. Effect on Humans

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

a. For Inorganic Chemicals

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

where:

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

b. For Organic Chemicals

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

where:

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

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

a. For Inorganic Chemicals

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

where:

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

b. For Organic Chemicals

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

where:

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

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

a. For Inorganic and Organic Chemicals

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

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

where:

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

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

a. For Inorganic Chemicals

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

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

where:

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

b. For Organic Chemicals

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

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

where:

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

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

a. For Inorganic and Organic Chemicals

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

where:

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

II. LANDFILLING

A. Procedure

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

B. Equation 1: Transport Assessment

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

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

where:

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

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

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

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

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/m³ leachate = $\frac{PS \times 10^3}{1 - PS}$

PS = Percent solids (by weight) of landfilled sludge = 20%

t = Time (years)

x = h = Depth to groundwater (m)

$D^* = \alpha \times V^*$ (m²/year)

α = Dispersivity coefficient (m)

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

Q = Leachate generation rate (m/year)

θ = Volumetric water content (unitless)

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

P_{dry} = Dry bulk density (g/mℓ)

K_d = Soil sorption coefficient (mℓ/g) (for inorganic chemicals)

$K_d = f_{oc} \times K_{oc}$ (mℓ/g) (for organic chemicals)

f_{oc} = Fraction of organic carbon (unitless) (for organic chemicals)

K_{oc} = Organic carbon partition coefficient (mℓ/g) (for organic chemicals)

$\mu^* = \frac{365 \times \mu}{R}$ (year⁻¹)

μ = Degradation rate (day⁻¹)

and where for the saturated zone:

C_o = Initial concentration of pollutant in aquifer as determined by Equation 2 (μg/ℓ)

t = Time (years)

x = $\Delta \ell$ = Distance from well to landfill (m)

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

α = Dispersivity coefficient (m)

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

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

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

$\emptyset$ = Aquifer porosity (unitless)

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

since K_d 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 ($\mu g/\ell$)

C_u = Maximum pulse concentration from the unsaturated zone ($\mu g/\ell$)

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

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

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

where:

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

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

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

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

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

1. For Inorganic Chemicals

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

where:

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

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

2. For Organic Chemicals

Index 1 = C_{max}

where:

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

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

1. For Inorganic Chemicals

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

where:

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

2. For Organic Chemicals

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

where:

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

III. INCINERATION

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

1. For Inorganic and Organic Chemicals

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

where:

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

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

1. For Inorganic and Organic Chemicals

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

where:

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

IV. OCEAN DISPOSAL

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

1. For Inorganic Chemicals

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

where:

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

2. For Organic Chemicals

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

where:

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

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

1. For Inorganic Chemicals

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

where:

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

2. For Organic Chemicals

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

where:

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

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

1. For Inorganic Chemicals

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

where:

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

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

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

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

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

2. For Organic Chemicals

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

where:

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

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

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

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

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

1. For Inorganic Chemicals

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

where:

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

2. For Organic Chemicals

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

where:

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

LITERATURE CITED

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

U.S. EPA. 1982. Fate of Priority Pollutants in Pulicly-Owned Treatment Works. Final Report. Vol. I. EPA 440/1-82-303. Effluent Guidelines Division, Washington, DC. September.

APPENDIX E:

HAZARD INDEX VALUES FOR ALL CONDITIONS OF ANALYSIS RELATED TO LANDFILLING

ARSENIC

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

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

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

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

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

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

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

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

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

BENZENE

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

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

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

BENZO(A)PYRENE

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

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

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

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

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

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

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

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

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

BIS(2-ETHYL HEXL)PHTHALATE

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

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

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

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

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

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

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

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

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

CADMIUM

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

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

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

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

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

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

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

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

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

CHLORDANE

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

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

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

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

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

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

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

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

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

CHROMIUM

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

Site Characteristics	Condition of Analysis[a,b,c] 1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
<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	2.0	7.3	2.0	2.0	6.1	37	1300	0
Index 2 Value	0.00070	0.0013	0.00070	0.00070	0.0012	0.0048	0.157	0.00058

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

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

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

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

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

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

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

COBALT

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

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

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

COPPER

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

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

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

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

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

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

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

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

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

CYANIDE

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

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

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

2,4-D

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

DIMETHYL NITROSAMINE

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

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)	9.0×10^{-4}	9.0×10^{-4}	2.8×10^{-3}	6.9×10^{-2}	4.8×10^{-3}	3.6×10^{-2}	14.8	0
Index 2 Value	740	740	740	790	740	770	12000	740

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

LEAD

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

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

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

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

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

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

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

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

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

LINDANE

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

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

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

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

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

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

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

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

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

MALATHION

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

Site Characteristics	Condition of Analysis[a,b,c] 1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value (μg/L)	2.8×10^{-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}

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

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

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

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

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

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

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

MERCURY

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

Site Characteristics	Condition of Analysis[a,b,c] 1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value	1.4	2.6	1.4	1.4	2.9	4.0	340	0
Index 2 Value	0.25	0.27	0.25	0.25	0.27	0.28	3.6	0.2[illegible]

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

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

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

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

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

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

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

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

Site Characteristics	Condition of Analysis[a,b,c]							
	1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value (μg/L)	0.043	0.52	0.043	0.043	0.23	1.7	110	0
Index 2 Value	NC[h]	NC	NC	NC	NC	NC	NC	NC

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

MOLYBDENUM

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

Site Characteristics	Condition of Analysis[a,b,c] 1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value	1.0	1.1	1.0	1.0	1.1	2.0	24	0
Index 2 Value	0.090	0.091	0.090	0.090	0.091	0.096	0.22	0.090

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

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

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

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

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

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

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

NICKEL

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

	Condition of Analysis[a,b,c]							
Site Characteristics	1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value	1.3	4.8	1.3	1.3	2.3	11	800	0
Index 2 Value	0.11	0.12	0.11	0.11	0.12	0.14	2.3	0.11

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

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

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

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

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

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

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

PHENANTHRENE

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)	0.101	0.563	0.101	0.101	0.532	3.29	120.0	0
Index 2 Value	NC[h]	NC	NC	NC	NC	NC	NC	NC

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

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

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

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

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

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

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

[h]NC = Not calculated due to lack of data.

PCB

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

Site Characteristics	Condition of Analysis[a,b,c]							
	1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
<u>Unsaturated Zone</u>								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
<u>Saturated Zone</u>								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value (μg/L)	0.092	0.53	0.099	0.11	0.30	0.33	130	0
Index 2 Value	59	110	59	61	85	88	17000	47

[a]T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.

[b]Index values for combinations other than those shown may be calculated using the formulae in the Appendix.

[c]See Table A-1 in Appendix for parameter values used.

[d]Dry bulk density (P_{dry}), volumetric water content (θ), and fraction of organic carbon (f_{oc}).

[e]Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).

[f]Aquifer porosity ($\emptyset$) and hydraulic conductivity of the aquifer (K).

[g]Hydraulic gradient (i), distance from well to landfill ($\Delta \ell$), and dispersivity coefficient (α).

INDEX OF GROUNDWATER CONCENTRATION RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND INDEX OF HUMAN TOXICITY RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

Site Characteristics	Condition of Analysis[a,b,c] 1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value (μg/L)	1.0×10^{-16}	1.8×10^{-15}	9.5×10^{-14}	0.13	5.6×10^{-16}	4.2×10^{-15}	480	0
Index 2 Value	3.0×10^{-20}	5.0×10^{-19}	2.7×10^{-17}	3.8×10^{-5}	1.6×10^{-19}	1.2×10^{-18}	0.14	0

[a] T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.

[b] Index values for combinations other than those shown may be calculated using the formulae in the Appendix.

[c] See Table A-1 in Appendix for parameter values used.

[d] Dry bulk density (P_{dry}), volumetric water content (θ), and fraction of organic carbon (f_{oc}).

[e] Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).

[f] Aquifer porosity ($\emptyset$) and hydraulic conductivity of the aquifer (K).

[g] Hydraulic gradient (i), distance from well to landfill ($\Delta \ell$), and dispersivity coefficient (α).

SELENIUM

INDEX OF GROUNDWATER CONCENTRATION INCREMENT RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND INDEX OF HUMAN TOXICITY RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

Site Characteristics	Condition of Analysis[a,b,c] 1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value	1.0	1.0	1.0	1.0	1.0	1.2	4.5	0
Index 2 Value	0.24	0.24	0.24	0.24	0.24	0.25	0.37	0.24

[a]T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.

[b]Index values for combinations other than those shown may be calculated using the formulae in the Appendix.

[c]See Table A-1 in Appendix for parameter values used.

[d]Dry bulk density (P_{dry}) and volumetric water content (θ).

[e]Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).

[f]Aquifer porosity ($\emptyset$) and hydraulic conductivity of the aquifer (K).

[g]Hydraulic gradient (i), distance from well to landfill ($\Delta \ell$), and dispersivity coefficient (α).

TOXAPHENE

INDEX OF GROUNDWATER CONCENTRATION RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND INDEX OF HUMAN CANCER RISK RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

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).

TRICHLOROETHYLENE
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)	0.013	0.49	0.013	0.013	0.066	0.50	100	0
Index 2 Value	0.0068	0.26	0.0068	0.0068	0.036	0.27	56	0

[a]T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.

[b]Index values for combinations other than those shown may be calculated using the formulae in the Appendix.

[c]See Table A-1 in Appendix for parameter values used.

[d]Dry bulk density (P_{dry}), volumetric water content (θ), and fraction of organic carbon (f_{oc}).

[e]Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).

[f]Aquifer porosity ($\emptyset$) and hydraulic conductivity of the aquifer (K).

[g]Hydraulic gradient (i), distance from well to landfill ($\Delta \ell$), and dispersivity coefficient (α).

ZINC

INDEX OF GROUNDWATER CONCENTRATION INCREMENT RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND INDEX OF HUMAN TOXICITY RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

Site Characteristics	Condition of Analysis[a,b,c] 1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value	2.8	13	2.8	2.8	8.7	12	2700	0
Index 2 Value	0.36	0.36	0.36	0.36	0.36	0.36	1.4	0.36

[a]T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.

[b]Index values for combinations other than those shown may be calculated using the formulae in the Appendix.

[c]See Table A-1 in Appendix for parameter values used.

[d]Dry bulk density (P_{dry}) and volumetric water content (θ).

[e]Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).

[f]Aquifer porosity (Ø) and hydraulic conductivity of the aquifer (K).

[g]Hydraulic gradient (i), distance from well to landfill ($\Delta \ell$), and dispersivity coefficient (α).

APPENDIX F: SLUDGE CONCENTRATION DATA USED IN ENVIRONMENTAL PROFILES AND HAZARD INDICES

Typical and Worst Sludge Pollutant Concentrations in Environmental Profiles

Pollutant	Typical	Worst
Aldrin/Dieldrin	0.07	0.81
Arsenic	4.6	20.77
Benzene	0.326	6.58
Benzidine		12.7
Benzo(a)anthracene	0.68	4.8
Benzo(a)pyrene	0.14	1.94
Beryllium	0.313	1.168
Bis(2-ethylhexyl)phthalate	94.28	459.25
Cadmium	8.15	88.13
Carbon Tetrachloride	0.048	8.006
Chlordane	3.2	12
Chloroform	0.049	1.177
Chromium	230.1	1499.7
Cobalt	11.6	40
Copper	409.6	1427
Cyanide	476.2	2686.6
DDT/DDE/DDD	0.28	0.93
3,3-Dichlorobenzidine	1.64	2.29
Dichloromethane	1.6	19
2,4-Dichlorophenoxyacetic Acid	4.64	7.16
Dimethyl Nitrosamine		2.55
Endrin	0.14	0.17
Fluoride	86.4	738.7
Heptachlor	0.07	0.09
Hexachlorobenzine	0.38	2.18
Hexachlorobutadiene	0.3	8
Iron	28000	78700
Lead	248.2	1070.8
Lindane	0.11	0.22
MOCA	18	86
Malathion	0.045	0.63
Mercury	1.49	5.84
Methyl Ethyl Ketone	Data not available	
Molybdenum	9.8	40
Nickel	44.7	662.7
PCB's	0.99	2.9
Pentachlorophenol	0.0865	30.434
Phenanthrene	3.71	20.69
Phenol	4.884	82.06
Selenium	1.11	4.848
TCDD	Data not available	
TCDF	Data not available	
Tetrachloroethylene	0.181	13.707
Toxaphene	7.88	10.79
Trichloroethylene	0.46	17.85
2,4,6-Trichlorophenol	2.3	4.6
Tricresyl Phosphate	6.85	1650
Vinyl Chloride	0.43	311.942
Zinc	677.6	4580

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