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Volume III of VII
Addendum to Characterization of Municipal Landfill Leachates —A Literature Review

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FINAL

ADDENDUM TO CHARACTERIZATION OF MUNICIPAL LANDFILL LEACHATES - A LITERATURE REVIEW

VOLUME III OF VII

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
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EPA Contract Officer
Jon R. Perry

EPA Project Officer
Gerry Dorian

Prepared by

NUS CORPORATION

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ACRONYMS AND DEFINITIONS

BNA	Base-neutral and Acid Extractables
BOD	Biological Oxygen Demand
CAS	Chemical Abstract Service
CB	Chlorobiphenyl
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COD	Chemical Oxygen Demand
Codisposal	Disposal together of municipal solid wastes and municipal solid waste combustion ashes
CP	Chlorinated Phenols
DWE	Deionized Water Extraction Test Method
EP	Extraction Procedure
EPA	U.S. Environmental Protection Agency
ESP	Electrostatic Precipitator
HSWA	Hazardous and Solid Waste Amendments
HWC	Hazardous Waste Combustion
LF	Landfill
MCL	Maximum Contaminant Level
Monofill	A landfill that contains only solid waste combustion ashes and residues
MSW	Municipal Solid Waste
MW	Monitoring Well
MWC	Municipal Waste Combustion
MWEP	Monofilled Waste Extraction Procedure, also known as SW-924
ND	Not Detected
NPDES	National Pollutant Discharge Elimination System
PAHs	Polynuclear Aromatic Hydrocarbons
PCBs	Polychlorinated Biphenyls

ACRONYMS AND DEFINITIONS
PAGE TWO

PCDDs	Polychlorinated dibenzo-p-dioxins
PCDFs	Polychlorinated dibenzofurans
POTW	Publically Owned Treatment Works
RCRA	Resource Conservation and Recovery Act
RDF	Refuse Derived Fuel
RPD	Relative Percent Difference
SS	Suspended Solids
SW-924	Deionized Water Extraction Test Method
TCLP	Toxic Characteristics Leaching Procedure Test Method
TDS	Total Dissolved Solids
TEF	Toxic Equivalency Factors
TNK	Total Nitrogen Kjeldahl
TOC	Total Organic Carbon
TSCA	Toxic Substances Control Act

1.0 INTRODUCTION

The purpose of this report is to summarize the findings of literature focused on the assessment of leachate production at municipal solid waste landfills. This is undertaken in support of the USEPA study of the RCRA Subtitle D Program. The EPA is mandated to assess the potential impacts of solid waste municipal landfills on human health and the environment and to make recommendations concerning possible changes to the Subtitle D Program. This study is one of a series of investigations designed by EPA to aid EPA in this task.

This report summarizes information found on factors influencing both the quantity and quality of leachates generated at Subtitle D municipal landfills and presents data generated on the composition of real leachates and leachates formulated under test conditions (extracts).

The NUS report Determination of Municipal Landfill Leachate Characteristics was the first literature review report issued for this purpose. It reviewed only the following three documents.

- McGinley, P. M., and P. Kmet. Formation, Characteristics, Treatment, and Disposal of Leachate from Municipal Solid Waste Landfills. Wisconsin Department of Natural Resources Special Report, August 1, 1984.

- Sobotka & Co., Inc. Case history data compiled and reported in a July 1986 report to the U.S. EPA's Economic Analysis Branch of the Office of Solid Waste.

- Brown, K. W., and K. C. Donnelly. The Occurrence and Concentration of Organic Chemicals in Hazardous and Municipal Waste Landfill Leachate. Texas A&M University, Soil and Crop Sciences Department, College Station, Texas.

This report summarizes additional reports and published papers on the subject. This literature was searched by EPA and NUS. The list of references reviewed in the course of this study is provided in the Reference section (6.0).

2.0 FACTORS AFFECTING LEACHATE VOLUME

Leachate volume generation is dependent on numerous factors that generally can be grouped into the following four categories:

1. Availability of water
2. Landfill surface conditions
3. Refuse conditions
4. Underlying soil conditions

Some of these factors are directly related to the waste and to the geographic and climatic locations of the landfill whereas others can be controlled by landfill operators and designers.

Factors affecting water availability include precipitation, surface run-on, groundwater intrusion, irrigation, refuse decomposition, and co-disposal of liquid waste or sludge with refuse. Of these, precipitation in the form of both rain and snow should be the largest contributor of liquid to the landfill.

Water reaching the landfill surface may either evaporate or transpire, run off, or infiltrate the soil surface, depending on landfill surface conditions. These conditions include topography, temperature, humidity, wind speed, vegetation, and cover material (type, dimensions, water content, compaction, permeability, etc.).

After the surface cover material has been fully saturated, refuse retention and transmission characteristics determine the rate of percolation of leachate through the refuse. Theoretically, water does not move through a compacted refuse cell until the field capacity of the waste has been exceeded. Realistically though, because of the heterogeneous nature of most wastes, the channeling of some water through the waste does occur prior to the attainment of field capacity. Once field capacity has been reached, any additional moisture will cause leachate movement.

Ultimately, underlying soil conditions can modify the rate and amount of leachate generation. Soils underlying and surrounding the refuse cell, which have lower permeabilities than the cover soil and refuse, can determine the rate of infiltration

and percolation and thus the volume of leachate generated. Where underlying layers are unsaturated, the infiltration rate is determined by the permeability of the upper layers. Where underlying layers are saturated, the layer with least permeability will control infiltration. When fine-grained underlying soils control infiltration and percolation, the upper layers will become saturated or the water will flow laterally.

Landfill design, management or operating procedures can influence factors such as water availability, surface conditions, and refuse conditions and thus influence the volume of leachate generated. These procedures include handling of cover material, watering prior to compaction, variation in compaction and cell construction, and variation in waste composition.

3.0 FACTORS AFFECTING LEACHATE COMPOSITION

Leachate composition, like volume generation, is a function of several variables that are both inherent in the refuse mass and landfill location, and created by landfill operators and designers. These factors include, but are not limited to, refuse composition and processing, landfill age or stage of maturation, rate of water application, and the depth of the leached bed (or thickness of waste layers).

3.1 Refuse Composition

Wastes reaching municipal solid waste landfills can be grouped into five categories:

- Residential
- Agricultural
- Commercial
- Municipal
- Industrial

Residential and commercial wastes are composed primarily of rubbish (paper, plastics and glass), food wastes, and ashes from waste incineration. Agricultural waste includes, in addition to wastes similar to residential wastes, organic materials from crops and animals. Industrial wastes contain materials characteristic of the industry from which they were generated and may include sludges, ashes, and industrial residues. Presently, municipal landfills are not permitted to accept hazardous industrial wastes except those generated from small-quantity generators. Municipal wastes consist of a diverse list of wastes. The relative composition of municipal solid waste, as determined by several investigators, is presented in Table 3-1 (Pohland and Harper, 1984).

The codisposal of industrial sludges, ashes, and residues with residential, commercial, municipal, and other solid wastes can contribute toxic compounds, both organic and inorganic, to leachates and subsequently to groundwater. The small generator exclusion rule under RCRA has allowed the disposal of small quantities of these hazardous materials in sanitary landfills. Additionally, small quantities of hazardous constituents are disposed from households and businesses

TABLE 3-1

RANGE OF COMPOSITION OF MUNICIPAL SOLID WASTE*

Component	Average	Average	Average	Range	Average	Range	Average	Range	Typical
Food Wastes	12	<25.1	25.0	8.8-12.8	10.7	4-9	7	6-26	15
Garden Wastes			0	5.8-17.0	10.4	1-10	5	0-20	12
Paper	39	44.5	50.0	>35.2-25.3	>40.6	45-57	50	25-45	40
Cardboard	7							3-15	4
Plastics		>22	>3.0	>4.2-5.2	>4.5			2-8	3
Rubber	2					4-9	6	0-2	1
Leather								0-2	1
Textiles	3	1.1	5.0	1.1-2.5	1.7	2-5	3	0-4	2
Plastic File	2								
Wood	7		1.0	0.4-1.3	1.0	1-2	1	1-4	2
Glass	10	11.3	7.0	9.1-12.4	10.9	9-17	12	4-16	8
Metallics	8	8.7	4.0	8.0-8.6	9.0	6-15	10		
Tin Cans								2-8	6
Non-Ferous Metals								0-1	1
Ferrous Metals								1-4	2
Dirt, Ashes, Brick. etc.	10	7.1	5.0	1.0-3.6	2.3	3-15	7	0-10	4
Moisture						21-35	27	15-40	20

*Percent by weight, wet weight basis
Source: Pohland and Harper, 1984

and reach the sanitary landfill as residential, commercial, agricultural, or municipal wastes.

Several municipal solid waste landfills throughout the country serve as co-disposal sites where, along with refuse, ash from municipal waste incinerators is disposed. Several studies have been conducted on the characteristics of municipal waste combustion (MWC) leachates and codisposal leachates. Results for these studies are discussed in Section 4.0 of this report.

3.2 Landfill Age or Degree of Stabilization

According to Pohland and Harper, 1984, the coupling of landfill age with leachate production has been one of the most elusive challenges for landfill operators, designers and regulators. Most municipal waste landfills proceed through a series of predictable phases whose significance and longevity are determined by the previously mentioned inherent and controlled climatological and operational factors.

A municipal landfill exists throughout much of its active life as an anaerobic microbial unit that experiences an initial lag period that lasts until sufficient moisture has accumulated to sustain a viable microbial community. Thereafter, further manifestations of waste conversion and stabilization occur in more or less distinct phases. These phases are described by Pohland and Harper (1984) as follows.

Phase I: Initial Adjustment

- Initial waste placement and preliminary moisture accumulation.
- Initial subsidence and closure of each landfill area.
- Changes in environmental parameters first detected to reflect the onset of stabilization processes, which are trending in a logical fashion.

Phase II: Transition

- Field capacity is exceeded and leachate is formed.
- A transition from initial aerobic to anaerobic microbial stabilization occurs.
- The primary electron acceptor shifts from oxygen to nitrates and sulfates with the displacement of oxygen by carbon dioxide in the gas.
- A trend toward reducing conditions is established.
- Measurable intermediates such as the volatile organic fatty acids first appear in the leachate.

Phase III: Acid Formulation

- Intermediary volatile organic fatty acids become predominant with the continuing hydrolysis and fermentation of waste and leachate constituents.
- A precipitous decrease in pH occurs with a concomitant mobilization and possible complexation of metal species.
- Nutrients such as nitrogen and phosphorus are released and utilized in support of the growth of biomass commensurate with the prevailing substrate conversion rates.
- Hydrogen may be detected and affect the nature and type of intermediary products being formed.

Phase IV: Methane Fermentation

- Intermediary products appearing during the acid formation phase are converted to methane and excess carbon dioxide.
- The pH returns from a buffer level controlled by the volatile organic fatty acids to one characteristic of the bicarbonate buffering system.
- Oxidation-reduction potentials are at their lowest values.
- Nutrients continue to be consumed.
- Complexation and precipitation of metal species proceed.
- Leachate organic strength is dramatically decreased in correspondence with increases in gas production.

Phase V: Final Maturation

- Relative dormancy following active biological stabilization of the readily available organic constituents in the waste and leachate.
- Nutrients may become limiting.
- Measurable gas production all but ceases.
- Natural environmental conditions become reinstated.
- Oxygen and oxidized species may slowly reappear with a corresponding increase in oxidation-reduction potential.
- More microbially-resistant organic materials may be slowly converted with the possible production of humic-like substances capable of complexing with and re-mobilizing heavy metals.

Table 3-2 illustrates the variation in leachate composition caused by the progression of the landfill through the stabilization phases.

The rate of progress through these phases is dependent on the physical, chemical, and microbiological conditions developed within each landfill cell. For example, acidic conditions established during acid formation may preclude methane fermentation; high compaction may restrict the movement of moisture and nutrients through the waste; and microbial inhibition may be induced by the presence of toxic substances. This last example means that in-situ stabilization may occur at reduced rates as the leachate becomes more concentrated and the extended stabilization period increases the opportunity for leachate migration from the landfill. In addition, this leachate is likely to be carrying some of the microbe-inhibiting toxic constituents with it.

3.3 Rate of Water Application and Refuse Depth

As mentioned earlier, the rate of water application and refuse depth have an effect on the leachate composition. Once the soil has been saturated with moisture, leaching closely follows the rate of moisture input. Because of this input-output leaching pattern , it is found that higher rates of water application to a landfill will produce a more dilute leachate than lower rates of water applications.

A comparison of refuse test cells with and without continuous flow-through of water showed that continuous flushing brought about a marked trend toward reduced levels of dissolved materials. This proved true for both inorganic and organic solutes, and demonstrates the important effect of dilution on leachate quality.

Refuse depth works in conjunction with water application rates in affecting the composition of the leachate. Water travels from the top of the refuse mass, moving from one void space to the next until it reaches the bottom of the fill. The percolating water will accumulate contaminants until the solubility limit of the leaching solution is attained. Thus, for a deeper landfill, the probability of the leachate reaching its solubility limit is greater than for a shallower landfill, because of greater contact time between refuse and percolate. However, much depends on the rate at which the water percolates through the landfill. Higher infiltration

TABLE 3-2

LANDFILL LEACHATE CONCENTRATION RANGES AND THEIR RELATIVE SIGNIFICANCE TO THE DEGREE OF LANDFILL STABILIZATION

Leachate Constituent	Phase of Biological Stabilization				Overall Range
	Transition Phase	Acid Formation Phase	Methane Fermentation Phase	Final Maturation Phase	
Biochemical Oxygen Demand (BOD_5) mg/l (ppm)	100-10,900 Influence of dilution and aerobic solubilization of waste organics	1,000-57,700 Accumulation of biodegradable organic acids due to methanogenic lag	600-3,400 Conversion of biodegradable organics to gaseous end products (CH_4 and CO_2)	4-120 Influence of high molecular weight organic residuals (humics, fulvics)	4-57,7000
Chemical Oxygen Demand (COD) mg/l (ppm)	480-18,000 Trending in a similar fashion to BOD_5	1,500-71,100 Trending in a similar fashion to BOD_5	580-9,760 Trending in a similar fashion to BOD_5	31-900 Higher influence of residual organics than in BOD_5 assay	31-71,100
Total Volatile Acids (TVA), mg/l (ppm) as Acetic Acid	100-3,000 Beginning to appear as a result of aerobic solubilization	500-27,700 Increasing rapidly; accumulation due to methanogenic lag	300-2,230 Conversion of volatile acids to methane; decrease in aqueous carbon	70-260 Influence of high molecular weight organics	70-27,700
Total Organic Carbon (TOC), mg/l (ppm)	100-3,000 Beginning to appear as a result of solubilization	3,000-18,800 Solubilization of organic polymers to monomers; beta oxidation to volatile acids	250-4,000 Conversion of fatty acids to acetic acid; fermentation of acetic acid to methane	Essentially absent; methanogenic system under-saturated	0-18,800
BOD_5/COD Ratio	0.23-0.87 Increasing bio-degradability of organics due to solubilization	0.4-0.8 High biodegrad-ability	0.17-0.64 Decreasing bio-degradability due to methanation	0.02-0.13 Low degree of biodegradability	0.02-0.87
COD/TOC Ratio	4.3-4.8 Low oxidation state of organics	2.1-3.4 Low to moderate oxidation state of organics	2.0-3.0 Moderate to high oxidation of organics	0.4-2.0	0.4-4.8

TABLE 3-2
LANDFILL LEACHATE CONCENTRATION RANGES AND THEIR RELATIVE SIGNIFICANCE TO THE DEGREE OF LANDFILL STABILIZATION
PAGE TWO

Leachate Constituent	Phase of Biological Stabilization				Overall Range
	Transition Phase	Acid Formation Phase	Methane Fermentation Phase	Final Maturation Phase	
Total Kjeldahl Nitrogen (TKN), mg/l (ppm)	180-360	14-1,970 May be low due to microbial assimilation of nitrogenous compounds	25-82 Low due to microbial assimilation of nitrogenous compounds	7-490	7-1,970
Nitrate Nitrogen (NO_3-N), mg/l (ppm)	0.1-51 Increasing due to oxidation of ammonia	0.05-19 Decreasing due to reduction to ammonia or nitrogen gas	Absent Complete conversion to ammonia or nitrogen gas	0.3-0.6	0-51
Ammonia Nitrogen (NH_3-N), mg/l (ppm)	120-225	2-1,030 Increasing due to nitrate reduction and protein breakdown	6-430 Decreasing due to biological assimilation		
NH3-N/TKN Ratio	0.1-0.9	0-0.98 Protein breakdown; biological assimilation	0.1-0.84	0.3-0.97	0-0.98
Total Phosphate (PO4-P),mg/l (ppm)	0.6-1.7	0.2-120 Biological assimilation and metal complexation	0.7-14 Low due to biological assimilation	0.2-14	0.2-120
Total Alkalinity, mg/l (ppm) as $CaCO_3$	200-2,050	140-9,650 Increasing due to volatile acid formation and bicarbonate dissolution	760-5,050 Decreasing due to volatile acid removal	200-3,520	140-9,650

TABLE 3-2
LANDFILL LEACHATE CONCENTRATION RANGES AND THEIR RELATIVE SIGNIFICANCE TO THE DEGREE OF LANDFILL STABILIZATION
PAGE THREE

Leachate Constituent	Phase of Biological Stabilization				Overall Range
	Transition Phase	Acid Formation Phase	Methane Fermentation Phase	Final Maturation Phase	
Solids (TS), mg/l (ppm)	2,450-2,960	4,120-65,300 Increasing due to solubilization of organics and mobilization of metals	2,050-6,410	1,460-4,640	1,460-65,300
pH (pH units)	6-7	4.7-7.7 Low due to volatile acid accumulation	6.3-6.8 Increasing due to volatile acid removal and bicarbonate dissolution	7.1-8.8	4.7-8.8
Oxidation-Reduction Potential (ORP), mV	+ 40 to -40	+ 40 to -240 Decreasing due to the depletion of oxygen	-70 to -240	-97 to + 163	-240 to + 163
Copper, mg/l (ppm)	0.085-0.39	0.005-2.2	0.03-0.18 Decreasing (complexation)	0.02-0.56	0.005-2.2
Iron, mg/l (ppm)	68-312	90-2,200	115-336 Decreasing (complexation)	4-20	4-2,200
Lead, mg/l (ppm)	0.0001-0.004	0.01-1.44	0.01-0.1 Decreasing (complexation)	0.01-0.1	0.001-1.44
Magnesium, mg/l (ppm)	66-96	3-1,410	81-505 Decreasing (complexation)	81-190	3-1,140
Manganese, mg/l (ppm)	0.6	0.6-41	0.6 Decreasing (complexation)	0.6	0.6-41

TABLE 3-2
LANDFILL LEACHATE CONCENTRATION RANGES AND THEIR RELATIVE SIGNIFICANCE TO THE DEGREE OF LANDFILL STABILIZATION
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Leachate Constituent	Phase of Biological Stabilization				Overall Range
	Transition Phase	Acid Formation Phase	Methane Fermentation Phase	Final Maturation Phase	
Nickel, mg/l (ppm)	0.02-1.55	0.03-79	0.01-1.0 Decreasing (complexation)	0.07	0.02-79
Potassium, mg/l (ppm)	35-2,300	35-2,300	35-2,300	35-2,300	35-2,300
Sodium, mg/l (ppm)	20-7,600				20-7,600
Zinc, mg/l (ppm)	0.06-21	0.65-220	0.4-6.0	0.4	0.06-220
Total Coliform, CFU/100ml	10^0-10^5	10^0-10^5	Essentially absent	Absent	0-10^5
Fecal Coliform, CFU/100 ml	10^0-10^5	10^0-10^5	Essentially absent	Absent	0-10^5
Fecal Streptococci, CFU/100ml	10^0-10^6	10^0-10^6	Essentially absent	Absent	0-10^6
Viruses, PFU/100 ml	-	Essentially absent	Essentially absent	Essentially absent	Absent
Conductivity, umhos/cm	2,450-3,310	1,600-17,100 Increasing due to mobilization of metals	2,900-7,700 Decreasing due to metals complexation with sulfides	1,400-4,500	1,400-17,100
Chloride mg/l (ppm)	30-5,000 Biologically stable; good indicator of washout	30-5,000 Stable; good hydraulic tracer	30-5,000 Stable; good hydraulic tracer	30-5,000 Stable; good hydraulic tracer	30-5,000
Sulfate mg/l (ppm)	10-458 Increasing due to aerobic oxidation	10-3,240 Increasing initially due to aerobic solubilization then decreasing as anaerobic conditions are established	Absent Complete conversion to sulfides	5-40 Reappearing due to aerobic oxidation	0-3,240

TABLE 3-2
LANDFILL LEACHATE CONCENTRATION RANGES AND THEIR RELATIVE SIGNIFICANCE TO THE DEGREE OF LANDFILL STABILIZATION
PAGE FIVE

Leachate Constituent	Phase of Biological Stabilization				Overall Range
	Transition Phase	Acid Formation Phase	Methane Fermentation Phase	Final Maturation Phase	
Sulfide mg/l (ppm)	Essentially absent	0-618 Beginning to appear and increasing due to sulfate reduction under anaerobic conditions	0.9 Low due to heavy metal precipitation	Absent	0-618
Cadmium, mg/l (ppm)	<0.005-0.01	<0.005-0.39	<0.005-0.1 Decreasing due to complexation	0.004	<0.005-0.39
Calcium, mg/l (ppm)	190-490	70-3,900	76-490 Decreasing due to complexation and precipitation	76-254	70-3,900
Chromium, mg/l (ppm)	0.023-0.28	0.06-18	0.05 Decreasing due to complexation, precipitation with sulfides	0.05	0.02-18

Source: Pohland & Harper, 1984

*Information taken from best available copy, some values barely legible.

rates increase the percolation rate and reduce the contact time between percolate and refuse. Thus, a more dilute leachate can be expected.

4.0 LEACHATE COMPOSITION DATA

As discussed in the previous section, a large number of variables determine the composition of a municipal landfill leachate. Table 4-1 presents literature values demonstrating the concentration ranges for the chemical composition of municipal landfill leachates. From this table and the references indicated, the following observations can be made: leachates are highly variable with respect to constituent concentration; leachates are generally high in total organic carbon and total dissolved solids; and leachates tend to be acidic, though the leachate final pH will be influenced by the buffering capacity of the geologic formation the landfill is placed in.

Table 4-2 demonstrates the wide range in types and concentrations of organic constituents detected in municipal leachate. Most of these compounds do not occur naturally and are a result of the wastes placed in the landfill.

4.1 Codisposal of Industrial Wastes and Municipal Solid Wastes

One EPA-sponsored study conducted by Jones et al. (1985) simulated the effects of co-disposal of industrial waste with municipal solid waste (MSW). In this study, MSW leachate was shown to be acidic (pH = 5.3) and to have very high organic and ionic loadings. Early samples in the test exceeded Federal Primary Drinking Water Standards for all constituents with established standards except copper. When untreated industrial wastes, including a glass-electronics etching sludge, a chlorine production brine, and an electroplating waste were added individually to test cells, the leachate pH rose from about 5.3 to 6.3. Also, biological activity was reduced, especially by the glass-electronics etching sludge (COD and BOD values averaged only 28 percent of the values for MSW-only leachates). This illustrates the effect of toxics on biological activity and the stabilization process. Metals in the industrial wastes were generally not readily leached from the test cells. Though the electroplating waste produced significantly increased levels of metals, the increases were small relative to the total metal content in the waste. Soluble salts were readily leached from all of the industrial wastes codisposed with the MSW. Sodium and chlorine concentrations were elevated for all codisposed industrial wastes, especially the chlorine production brine.

TABLE 4-1

RANGE OF CONSTITUENT CONCENTRATIONS IN LEACHATE FROM MUNICIPAL WASTE LANDFILLS
(in mg/l (ppm) unless noted)

Constituent	Concentration Range
COD	50–90,000
BOD	5–75,000
Total organic carbon (TOC)	50–45,000
Total solids (TS)	1–75,000
TDS	725–55,000
Total suspended solids (TSS)	10–45,000
Volatile suspended solids (VSS)	20–750
Total volatile solids (TVS)	90–50,000
Fixed Solids (FS)	800–50,000
Alkalinity (as $CaCO_3$)	0.1–20,350
Total coliform (CFU/100 ml)	$0–10^5$
Iron	200–5,500
Zinc	0.6–220
Sulfate	25–500
Nickel	0.2–79
Total volatile acids (TVA)	70–27,700
Manganese	0.6–41
Fecal coliform (CFU/1,000 ml)	$0–10^5$
Specific conductance (mhg/cm)	960–16,300
Ammonium nitrogen (NH_4-N)	0–1.106
Hardness (as $CaCO_3$)	0.1–36,000
Total phosphorus	0.1–150
Organic phosphorus	0.4–100
Nitrate nitrogen	0.1–45
Phosphate (inorganic)	0.4–150
Ammonia nitrogen (NH_3-N)	0.1–2,000

TABLE 4-1
RANGE OF CONSTITUENT CONCENTRATIONS IN LEACHATE FROM MUNICIPAL WASTE LANDFILLS
(in mg/l (ppm) unless noted)
PAGE TWO

Constituent	Concentration Range
Organic nitrogen	0.1–1,000
Total Kjeldahl nitrogen (TKN)	7–1,970
Acidity	2,700–6,000
Turbidity (Jackson units)	30–450
Chlorine	30–5,000
pH (dimensionless)	3.5–8.5
Sodium	20–7,600
Copper	0.1–9
Lead	0.001–1.44
Magnesium	3–15,600
Potassium	35–2,300
Cadmium	0–0.375
Mercury	0–0.16
Selenium	0–2.7
Chromium	0.02–18

Source: Sobotka, 1986.

TABLE 4-2

PRELIMINARY DATA ON CONCENTRATIONS OF ORGANIC CONSTITUENTS IN LEACHATE FROM MUNICIPAL WASTE LANDFILLS (units in ppb)[a]

Constituent	Minimum	Maximum	Median
Acetone	140	11,000	7,500
Benzene	2	410	17
Bromomethane	10	170	55
1-Butanol	50	360	220
Carbon tetrachloride	2	398	10
Chlorobenzene	2	237	10
Chloroethane	5	170	7.5
Bis(2-chloroethoxy)methane	2	14	10
Chloroform	2	1,300	10
Chloromethane	10	170	55
Delta BHC	0	5	0
Dibromomethane	5	25	10
1,4-Dichlorobenzene	2	20	7.7
Dichlorodifluoromethane	10	369	95
1,1-Dichloroethane	2	6,300	65.5
1,2-Dichloroethane	0	11,000	7.5
Cis 1,2-Dichloroethene	4	190	97
Trans 1,2-Dichloroethene	4	1,300	10
Dichloromethane	2	3,300	230
1,2-Dichloropropane	2	100	10
Diethyl phthalate	2	45	31.5
Dimethyl phthalate	4	55	15
Di-n-butyl phthalate	4	12	10
Endrin	0	1	0.1
Ethyl acetate	5	50	42
Ethyl benzene	5	580	38
Bis(2-ethylhexyl) phthalate	6	110	22

TABLE 4-2
PRELIMINARY DATA ON CONCENTRATIONS OF ORGANIC CONSTITUENTS IN LEACHATE FROM MUNICIPAL WASTE LANDFILLS (units in ppb)[a]
PAGE TWO

Constituent	Minimum	Maximum	Median
Isophorene	10	85	10
Methyl ethyl ketone	110	28,000	8,300
Methyl isobutyl ketone	10	660	270
Naphthalene	4	19	8
Nitrobenzene	2	40	15
4-Nitrophenol	17	40	25
Pentachlorophenol	3	25	3
Phenol	10	28,800	257
2-Propanol	94	10,000	6,900
1,1,2,2-Tetrachloroethene	7	210	20
Tetrachloroethene	2	100	40
Tetrahydrofuran	5	260	18
Toluene	2	1,600	166
Toxaphene	0	5	1
1,1,1-Trichloroethane	0	2,400	10
1,1,2-Trichloroethane	2	500	10
Trichloroethene	1	43	3.5
Trichlorofluoromethane	4	100	12.5
Vinyl chloride	0	100	10
m-Xylene	21	79	26
p-Xylene + o-Xylene	12	50	18

a The table was provided by U.S. EPA, Office of Waste, Economic Analysis Branch. It includes data from 15 municipal landfill case studies performed by OSW[12]; data from landfill leachate sampling studies performed by Wisconsin and Minnesota; and data from NPDES discharge permits for leachates from landfills in New Jersey. These studies provided reliable data, albeit on a relatively small number of facilities.

Source: Sobotka, 1986.

4.2 Codisposal of Municipal Waste Combustion Ash and Municipal Solid Wastes

One codisposal practice currently common in the United States and potentially affecting leachate quality is the codisposal of municipal waste combustion (MWC) ash with other municipal solid wastes. A study by GCA Corporation (1986) reports that by the end of 1986, 61 MWC facilities would be in operation and would produce 9,781 tons per day of residue. Eighty-eight percent of these residues would be land disposed, including codisposal with municipal solid wastes. Thus, the composition of these ashes and the effect they may have on the composition of municipal waste leachates must come under scrutiny.

Varying incineration options and fuel composition vary the characteristics of the MWC residues. Tables 4-3 and 4-4 present data on inorganic and organic compositions, respectively, for both MWC fly ash and bottom ash. Table 4-4 shows that polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) are present in ash and are more abundant in fly ash than bottom ash. The 2,3,7,8-TCDD dioxin isomer exceeds the EPA standard of 1 part per billion (ppb) for most fly ash data. These data are corroborated by a study done in Japan on municipal incinerator ashes (Wakimoto and Tatsukawa, 1985).

Data presented by GCA Corporation (1986) for MWC residue monofill leachates indicate that lead and chromium values exceed Federal Primary Drinking Water Standards. These results are presented in Table 4-5. Also, EP Toxicity leach testing on various MWC residues resulted in lead and cadmium values above the maximum allowable limits. These data are presented in Table 4-6. These results compare well with results obtained in tests conducted by C.W. Francis (1984) from the Oak Ridge National Laboratory. The author found that a simulated codisposal leachate was more acidic than an ash-only leachate and that a municipal waste leachate extracted metals more aggressively than water. Several of the municipal-waste-leachate ash leachates exceeded Federal Drinking Water Standards, particularly for cadmium and lead during initial leaching.

TABLE 4-3

MWC SOLID RESIDUE INORGANIC COMPOSITION (UNITS IN ppm UNLESS NOTED)

Element	SWFC #1, D.C. Fly Ash [1]	Alexandria #4 Fly Ash [2]	Alexandria Scrubber Fly Ash [2]*	Alexandria Scrubber Fly Ash [2]	Alexandria 1973 Fly Ash [2]	Alexandria 1974 Fly Ash [2]	Sample F-1 Fly Ash [3]b	Sample F-2 Fly Ash [3]b	Sample F-3 Fly Ash [3]b	Sample F-4 Fly Ash [3]b
Na	14,700	[illegible]	16,000	14,000	16,700	14,500	26,800	20,000	13,600	13,600
Cs	1.0	[illegible]								
Mg	13,000	13,000	9,700	12,000	9,500	[illegible]	17,100	10,300	10,300	9,800
Ca	50,000	[illegible]	23,000	40,000	22,000	22,000	39,000	49,000	44,000	47,000
Sr	280	[illegible]	210		265	260				
Ba*	3,200	[illegible]	1,500	2,500	1,700	1,400	>4,000	>9,000	>7,000	3,000
Cl	1,300	[illegible]								
Br	35	120								
I	16	35								
Al	13,500	[illegible]	120,000	111,000	126,000	124,000	120,100	128,000	133,300	107,900
Sc	10.1	10.4								
Ti	29,000	32,000	<50				23,100	21,900	34,100	22,400
V	140	135								
Cr*	780	1,290	1,160	1,430	1,140	730	<700	400	300	400
Mn	2,100	4,190	1,500	3,400	1,500	1,120	<900	700	400	>800
Fe	25,000	52,000	25,000	46,000	24,000	22,000	29,300	30,200	20,000	21,300
Co	27	35	100	30	100	90				
Ni		7.0	1,800	740	1,590	160	<100	<100	<100	<300
Cu	950	960	510	1,000	600	445	900	700	600	600
Zn	2[illegible],000	[illegible],500	10,100	9,400	8,600	8,000	4,300	4,000	9,000	3,800
As*	59	[illegible]	77	41						
Se*	12	3.6								
Ag*	220	85	129	106	95	130	<100	<100	>300	<100
Cd*	185	42	64	45	56	57				
In	1.8	0.71								
Sn	2,400	1,430	1,250		850	860	<400	400	300	<500
Sb	580	270	340	260						
La	31	35								
Ce	78	78								
Sm	4.8	[illegible]								
Eu	0.92	1.07								
Lu	≈1	0.22								
Yb	≈0.2	1.5								
Tb	13.7	14								
Hf	4.2	6.8								
Ta	25	3.1					300	<400	<300	<300
W	13	16								
Au	0.61	1.1								
Pb*	[illegible]	0.40%	7,200	4,000	10,000	7,200	1,700	200	2,000	2,600
Be			<4		<4	<4				
Hg*			0.88				<300	<300	<300	<300
K			12,200		13,000	14,000	13,700	15,500	11,000	15,800
Li			34		31	34				
Si							184,500	204,000	199,500	186,400
P							8,900	6,400	6,400	9,300
C							32,000	8,800	2,300	118,200
S							5,700	3,800	4,700	2,800
Cs							<600	600	700	<200
Mo							100	<100	<100	<100
Zr							200	<200	<200	<200
Bi										
B										

(continued)

TABLE 4-3

(continued)

Element	Sample [illegible] Fly Ash [3][b]	Sample [illegible] Bottom Ash [3][b]	Sample [illegible] Bottom Ash [3][b]	Bureau of Mines [4] Bottom Ash	Bureau of Mines [4] Fly Ash[a]	Philadelphia, N.H. Bottom Ash [5]	Chicago, [illegible] Mixed Ash [7]	Prince Edward Island [6] Bottom Ash	Prince Edward Island [6] Boiler Ash	Prince Edward Island [6] Economizer Ash	[illegible] [7] Mixed Ash	[illegible] [7] Mixed Ash	[illegible] [7] Mixed Ash
Na	23,100	19,400	33,300	8,200	16,000		18,000	10,500	49,500	47,000	9,600	[illegible]	[illegible]
Ca													
Mg	10,600	[illegible]	6,100	12,800	9,[illegible]		16,000	8,733	8,950	10,667	7,[illegible]	[illegible]	[illegible]
Ca	52,000	68,500	63,500	48,000	23,000		85,000	54,667	70,167	84,667	39,900	[illegible]	[illegible]
Sr							270				390	[illegible]	[illegible]
Ba*	4,000	2,000	2,000	1,400	1,500		1,600	367	88	70	410	[illegible]	[illegible]
Cl													
Br													
I													
Al	176,000	53,400	24,700	49,000	121,000	19,100	53,000	32,667	48,033	54,000	60,000	[illegible]	45,000
Sc													
Ti	33,700	11,400	3,400				11,000	3,067	4,167	3,467	1,090	[illegible]	[illegible]
V							36	53	61	71	33	51	19
Cr*	900	400	300	520	1,160	50	230	100	180	170	320	[illegible]	[illegible]
Mn	700	>1,000	>1,000	3,100	1,500		1,200	1,111	2,160	2,730	1,600	[illegible]	1,[illegible]
Fe	16,200	35,100	133,500	16,000	24,000	17,000	86,000	52,000	12,100	12,333	50,000	[illegible]	43,000
Co				70	100		<24	13	41	25	<19	<91	11
Ni	<300	<300	<100	210	1,800		<200	67	100	85	<110	<200	<35
Cu	900	3,[illegible]	1,300	450	510	1,400	550	304	415	375	1,000	650	1,[illegible]
Zn	5,000	2,000	3,000	5,500	10,000	2,300		4,233	32,400	27,567			
As*							<1,200	7	154	160	620	<1,[illegible]	<350
Se*							<780	0	10	0	<420	<[illegible]	330
Ag*	200	<100	<100	30	130		<33	0	0	0	<17	<33	<16
Cd*				41	64		<17	24	683	538	8.9	17	4
In													
Sn	600	700	800	400	1,250	110		316	834	590			
Sb				120	340		<250				<140	<250	<120
La													
Ce													
Sm													
Eu													
Lu													
Tb													
Th													
Hf													
Ta	<300	<300	2,000										
W													
Au													
Pb*	4,000	5,000	5,000	1,700	7,200	310	<470	2,635	4,533	8,033	250	[illegible]	230
Br*							<2.4	0	0	0	1.3	[illegible]	1
Hg*	<300	<300	<300	0.4	0.9			0	5	5			
F	12,000	7,000	8,400	4,300	12,200		11,000	13,133	58,167	51,333	5,800	[illegible]	5,500
Li				19	36								
Si	171,100	141,100	188,300				84,000	1,333	1,783	2,133	61,000	[illegible]	[illegible]
P	5,100	8,500	10,300				5,000	5,447	4,600	5,500	2,500	3,600	230
C	14,800	185,700	14,400										
S	9,000	3,600	1,800										
Cl	300	<100	<200										
Mo	<100	<100	<100				290	29	58	64	170	200	263
Zr	200	<100	200										
Bi								0	36	17			
B								85	150	202			

*Appear to be some results.
[b]Converted from percent by weight.
*EP Toxicity Test Element.

Source: GCA Corp., 1986

TABLE 4-4

MWC SOLID RESIDUE ORGANIC COMPOSITION (UNITS IN ppb)

[illegible]	[illegible], [illegible] (8)		Chicago, [illegible] Incinerator (9)	Philadelphia Incinerator (10)[a]		[illegible] (11)[b]		Prince Edward Island Incinerator (6)[c]			Fly Ash Averages (12)		Environment Canada Fly Ash Study (20)	EPA [illegible]
[illegible]	Fly Ash	Bottom Ash	Combined Ash	Fly Ash	Bottom Ash	ESP Ash	Bottom Ash	Bottom Ash	Boiler Ash	Economizer Ash	Canada	N. America		
[illegible]	800	6.32		1,600	110	23	6.5	6	78	31	10.3-19.	26.5-864		
[illegible]	2.1			42	0.7								ND[d]	1
[illegible]	3,000	6.1		1,100	65	46	0.6	0	11	13		56.1-2[illegible]		
[illegible]	<1	1.5				3.4	0.4.	0	4	0				3.,000
[illegible]	9,300	570						360	270	89				
[illegible]	3,500	390						32	0	5				
[illegible]	34	ND(<300)						150	4	1				
[illegible]	7,600	530						340	21	21				
[illegible]	ND(<300)	363	28											
[illegible]	6,500	233	13					110	3	15				
Pyrene	3,400	220	10					150	3	0				
[illegible]	690(<300)	165												
Chrysene	695	ND(<300)						33	6	3				
[illegible]	85	2,100	320											
[illegible]	<70	ND(<303)												
[illegible]	320	ND(<30)						51	0	0				
[illegible]	190	ND(<30)						5	0	3				
Anthracene								53	1	4				
Acenaphthene								28	0	0				
[illegible]						4.2	0.2	17	220	0.				
Chlorophenols						43	3.0	6	520	3				
[illegible]								30	3	9				
[illegible]								3	0	4				
Dibenzoanthracene								4	0	3				

[a]Values are averages for tests at four incinerators
[b]Solid waste reduction unit. Values are averages for 13 runs.
[c]Values are averages for runs 1-6, normal operating conditions.
[d]Estimate from study-wide data
[illegible] Average detected.
ND - Not Detected

[e]Variability in observed levels of dioxin emissions could be attributable to one or more factors including lab quality control, sampling and analysis methods, and waste feeds and operating conditions at different

Source: GCA Corp., 1986

TABLE 4-5

MWC RESIDUE MONOFILL LEACHATE CHEMICAL ANALYSIS (All Units mg/l)

Parameter	Vestskoven, Germany [21]	Grohnehring, Germany [21]	Lacy St., CA [21]	Saugus, MA [21]	Auburn, ME [22]	Philadelphia, PA [23]	Primary drinking water standards	Secondary drinking water standards
COD	36				456.7	1,265		
TSS					5,730.7			
TDS		28,900	11,300			7,933		500
Alkalinity			45			4,260		
Cl		18,500	1,700		7,500	1,803		
Na		4,000	200			3,350		
Pb*	.012	.25		.06	.033	1.16	.05	
Cd*	BDL	BDL		.01	.003		.010	
Cu	24		1	.05	.022	1.15		1
Ni	BDL	BDL		.05				
Zn	.025	BDL		.39	.047	.95		5
pH					8.04	8.3		
Mn								.05
Fe					.168	4.95		.3
Cr*					.006	1.55	.05	
As*							.05	
Ba*			1				1	
Hg*							.002	
N (as nitrate)						3.52	10	
Se*							.01	
Ag*	.040						.05	
Endrin*							.0002	
Lindane*							.004	
Methoxychlor*							.1	
Toxaphene*							.005	
2,4-D*							.1	
2,4,5-TP Silvex*							.01	
Chloride								250
Sulfate								250

*EP Toxicity Test Compound

COD - Chemical Oxygen Demand TSS - Total Suspended Solids TDS - Total Dissolved Solids

BDL - Below Detectable Limits — - Exceed Standard

Source: GCA Corp., 1986

TABLE 4-6

EP TOXICITY RESULTS ON MWC RESIDUES (Units in mg/l)

Contaminant	Site 1[a] [24]	Site 2[b] [24]		Site 2 Burn[b] [24]		Site 3[c] [24]		Site 4[d] [24]			Site 4 Burn[d] [24]		Site 5[e] [24]	Site 6[f] [24]		[illegible]
	Combined Ash	Fly Ash	Bottom Ash	Fly Ash	Bottom Ash	Fly Ash	Bottom Ash	Fine Fly Ash	Coarse Fly Ash	Composite Ash	Fly Ash	Composite Ash	Residue	Fly Ash	Bottom Ash	[illegible]
As	<.0025	<.0025	<.0025	<.008	<.008	<.0025	<.0025	<.0025	<.0025	<.0025	<.008	<.008	<.0025	<.008	<.008	<5.[illegible]
Ba	.386	.126	.131	.565	.460	.092	.298	.091	.067	.184	.490	.510	.488	.690	.310	[illegible]
Cd	.056	2.462	.018	2.720	.041	.097	.018	8.560	17.408	.251	10.880	.165	.020	17.110	.93	[illegible]
Cr	.006	.006	.038	.053	<.02	.016	.027	.012	.019	.039	<.02	<.02	.032	.135	<.020	5.0
Pb	.117	12.20	.203	3.145	.420	.019	.160	12.50	47.10	.337	12.455	2.245	.870	53.350	.590	5.0
Hg	<.0001	.0007	<.0001	<.0002	<.0002	.0001	<.0001	.0009	.0008	<.0001	.0013	<.0002	.0065	.0006	.0003	[illegible]
Se	<.0025	.010	<.0025	.048	<.010	<.0025	<.0025	<.0025	<.0025	<.0025	.052	<.010	.0025	.085	.010	1.0
Ag	<.001	.005	<.001	.035	.015	<.001	<.001	<.007	<.008	<.001	<.030	.015	<.001	<.045	<.010	5.0
Endrin	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	[illegible]
Lindane	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	[illegible]
Methoxy-chlor	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	.005	<.005	.005	<.005	<.005	[illegible]
Toxaphene	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	.005	<.005	<.005	[illegible]
2,4-D	<.04	<.04	<.04	<.001	<.001	<.04	<.096	<.04	<.04	<.04	<.001	.001	.04	.001	<.001	[illegible]
2,4,5-TP Silvex	<.01	<.01	<.01	<.001	<.001	<.01	<.01	<.01	<.01	<.01	<.001	<.001	<.01	.001	<.001	[illegible]

[a]Mass burn MSW in two rotary kilns. Bottom ash is water quenched. Fly ash is captured by low energy, packed bed scrubber and then mixed in quench trough. No heat recovery. Ferrous metal is removed from residue.

[b]Burns MSW, commercial waste, and selected industrial waste. Plant consists of coarse shredders, air classifier, spreader stoker-fired waterwall boilers. Produces steam.

[c]Burns MSW. Plant consists of bag breaker (flail mill), rotary screen, shredder, ferrous separation, and air classifier. Bottom ash is collected in dry ash pit, fly ash is collected by electrostatic precipitators.

[d]Mass burns MSW. No front-end recovery. Fe metal is removed from ash, which is water quenched, and combined with fly ash from Electostatic Precipitator. Produces Steam.

[e]Multiple chamber burning of Raw MSW. Some removal of large metals at front end. No other salvage. No fly ash collection. Produces steam.

[f]Mass burns MSW, in 5 incinerator units with forced air fixed grate. Bottom ash is water quenched and fly ash is captured by Electostatic Precipitator.

___ - Exceed standard.

TABLE 4-6

Continued

[illegible]	Avon, [illegible] [21]		Newport, FL [21]		Saugus, MA [21]			Chicago, IL [21]			Mont. Co., [illegible] [21]			Salem, VA [illegible]	Rockville, TN [21]	Resource Recovery Ash [7]				Max Con: Allowed
[illegible]	Bottom Ash	Fly Ash	Bottom Ash	Fly Ash	Bottom Ash[a]	Fly Ash	Combined Ash[b]	Boiler Ash	Fly Ash	Combined Ash	Combined Ash	Combined Drained	Combined Weathered	Combined Ash	Combined Ash	Chicago, IL	Sumner, TN	Hampton, VA	Auburn, ME	
As	BDL	BDL	.122	.038				BDL	BDL	.0025	BDL	BDL	BDL	BDL	.004	.003	.009	.017	.002	5.0
[illegible]	131	126	1.[illegible]	775		22.8		091	.067	.184	467	325	348	.[illegible]	2.0					[illegible]
[illegible]	.018	7.64	.135	2.35	.58		3.94	8.56	17.6	.251	425	141	.056	.020	BDL	.710	.240	.500	.020	1.0
Cr	.018	.066	ND	.039				.012	.019	.019	.016	.011	.006	.012	BDL	.030	.0-2	.035	.011	5.0
Hg	263	12.7	4.17	8.195	9.19	29.8	20.43	12.5	47.1	.337	1.56	1.30	.117	.070	7	5.8	6.4	10.3	3.15	5.[illegible]
Hg	BDL	.0007	.025	.0014				.0009	.0008	BDL	BDL	BDL	BDL	.0065	BDL					0.2
Se	BDL	.018	.020	.018				BDL	BDL	BDL	BDL	BDL	BDL	BDL	.004	.003	.002	.002	.002	1.0
Ag	.001	.005	.085	.185				.007	.008	BDL	BDL	BDL	BDL	BDL	BDL					5.0
Endrin																				[illegible]
Lindane																				0.4
Methoxychlor																				10
Toxaphene																				0.5
2,4-D																				10.
2,4,5-TP Silvex																				1.0

BDL - Below detectable limits

ND - No determination

[a]Average of 2 sets of data

[b]Average of 3 sets of data

[illegible] No plant descriptions documented except Chicago N.S. (see Table 1 notes).

Source: GCA Corp., 1986

5.0 CONCLUSIONS

Municipal solid waste landfill leachate production volume and leachate chemical composition are dependent on many variables; some of which are related to climatology, geography, geology, and hydrology and others of which are related to landfill engineering design and operating procedures. Thus, some variables are uncontrollable because they are inherent to the location and can only be controlled via a proper site selection process; others are controllable. The controllable and noncontrollable variables include the following:

- Availability of water
- Surface conditions
- Refuse composition, condition, and depth
- Underlying soil conditions
- Landfill age or degree of stabilization

The hazardous small-quantity-generator exclusion rule under RCRA has allowed the disposal of small quantities of hazardous materials in municipal landfills. Codisposal of industrial wastes can cause leachates to contain elevated levels of toxic inorganic and organic materials. Some of these contaminants, particularly the metals, can inhibit the biological activity needed to decompose the solid wastes. Thus they can interfere with the natural stabilization phases of the landfill and create a more concentrated, contaminant-carrying leachate. At the same time, organic solvents may increase the solubility of organics present in the solid waste and thus also increase the contaminant loading of the leachate.

Codisposal of municipal waste combustion ashes with other municipal wastes is practiced in the United States. These ashes have been shown to contain dioxins and chlorinated dibenzofurans and to leach elevated levels of metals under both codisposal and monofill conditions.

Selective and careful sampling of leachates generated from newer solid waste disposal sites and analyses of these leachates for both hazardous organic and inorganic constituents (RCRA, Appendix IX) may provide important information regarding the chemical composition of these leachates. Such information could

serve as a data base to be used for making decisions concerning changes to the Subtitle D Program.

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