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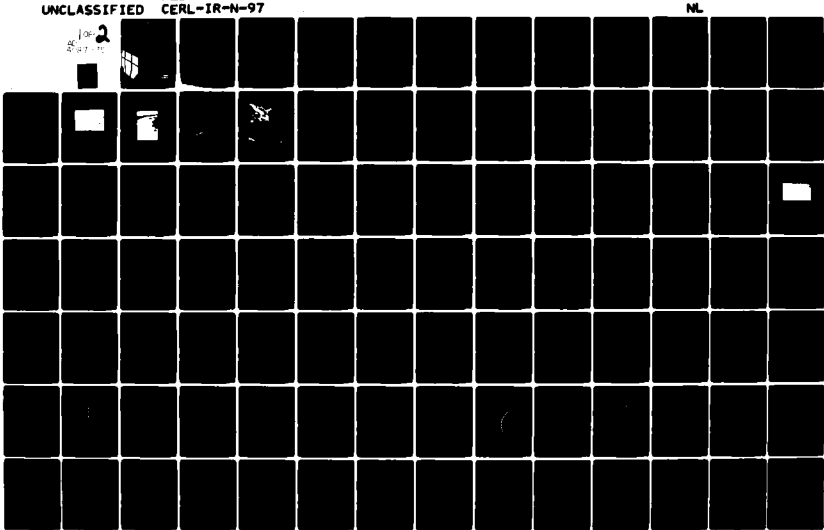

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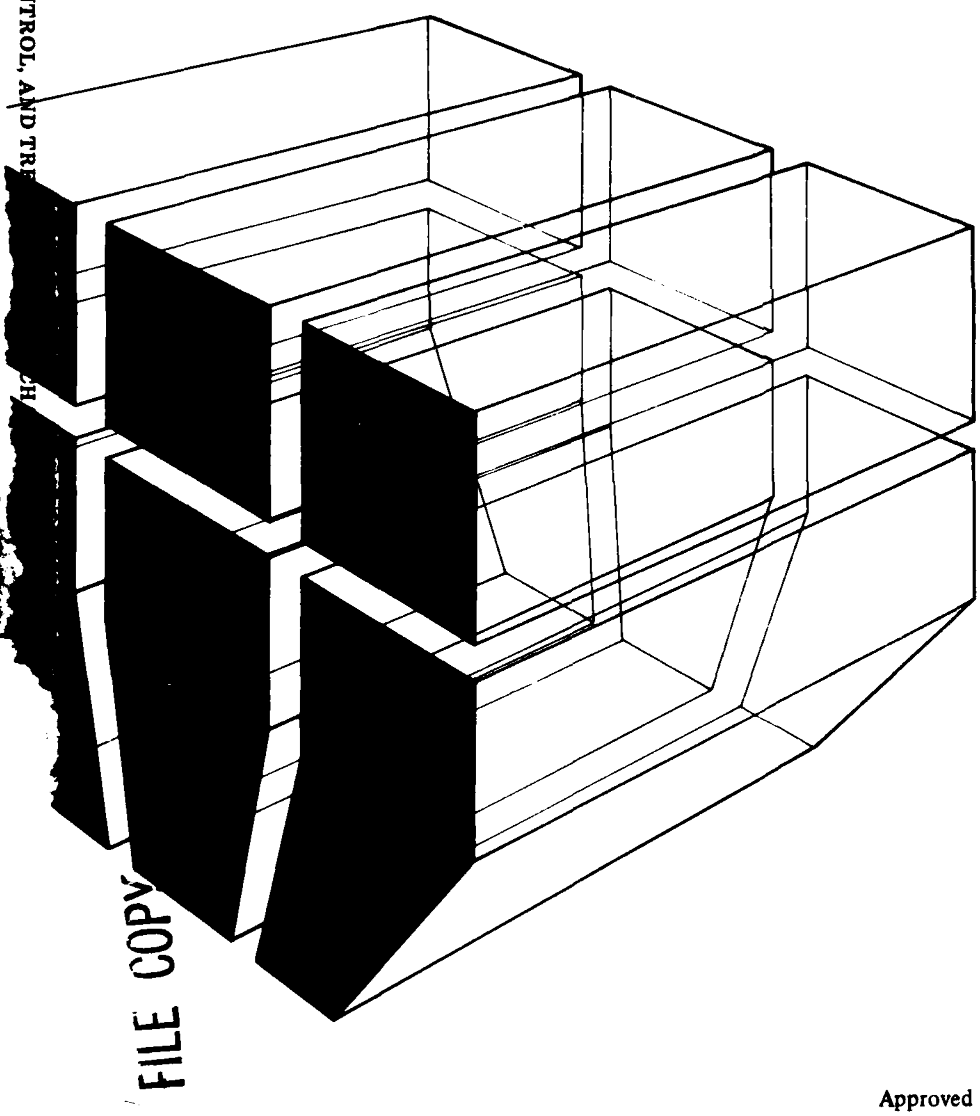
Interim Report N-97
February 1981

CHARACTERISTICS, CONTROL, AND TREATMENT OF LEACHATE AT MILITARY INSTALLATIONS



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This report documents results of an extensive review of literature on leachate, provides introductory information about leachate, and answers such questions as: What is leachate? Why is it important? What are its characteristics? How can a leaching landfill be detected? How can leachate formation be mitigated? What does remedial action cost? This document is intended to educate Army personnel about leachate, provide DA points of contact for assistance, and provide guidelines for problem identification.

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This report may be used by Facilities Engineers to identify leaching landfills, prepare and implement a monitoring program, and institute short-term remedial measures.

FOREWORD

This work was performed under RDT&E project 4A762720A896, "Environmental Protection Techniques in Military Construction"; Task R, "Prevention, Control and Mitigation"; Work Unit 019, "Leachate Treatment and Control Techniques." The technical monitor was W. Medding, DAEN-MPO-U. Mr. F. Bizocco, DAEN-MPO-U, provided advice and assistance.

The investigation was performed by the Environmental Division (EN), U.S. Army Construction Engineering Research Laboratory (CERL). Dr. R. K. Jain is Chief of EN.

COL Louis J. Circeo is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

CONTENTS

CONTENTS (Cont'd)

TABLES

TABLES (Cont'd)

FIGURES

CHARACTERISTICS, CONTROL, AND TREATMENT OF
LEACHATE AT MILITARY INSTALLATIONS

1 INTRODUCTION

Background

Before about 1965, there were no effective regulations controlling the location and operation of municipal garbage dumps, landfills, and industrial hazardous waste disposal grounds throughout the United States. Consequently, the burial of waste material has been a widely accepted method of disposal. In the case of Department of the Army (DA) facilities, waste materials unique to the military (e.g., chemical warfare training residues, propellant, explosive, or pyrotechnic residues, abandoned transformers, etc.) may have entered a land disposal site by inclusion in the general solid waste stream, or when buried separately in engineered sites or casual burial locations such as abandoned sand and gravel pits, rock quarries, or gullies, hollows, or sink holes. Natural processes occurring in the buried waste itself can transform and mobilize the waste's constituents into a liquid effluent called leachate, which may contaminate groundwater and surface water supplies. This leachate becomes especially significant when considering that only 100 grams (3.5 ounces) of leachate (containing toxic metallic, organic, or chlorinated hydrocarbon compounds) dissolved in 1 million kg of clean water may be harmful or even lethal to humans, animals, plants, and many aquatic life forms.[1]

Abandoned and operating land disposal sites (authorized and unauthorized) are found on almost all DA installations. Virtually all of these sites have the potential to generate leachate unless extreme care is taken in both the initial engineering of the disposal site and in subsequent operation and maintenance. The magnitude of leachate problems at all DA facilities is only now being determined as surveys under the Army Pollution Abatement Program are conducted. Therefore, identification of any military-unique aspects of leachate from Army landfills must await execution of a long-term monitoring program and detailed analysis of samples collected during that program. However, in the interim, information gathered from municipal landfills in the civilian sector can be used to explain what leachate is, how it is produced, and why it presents difficulties. Data from civilian sources can also help determine short-term techniques which might help lessen the problem.

Current and anticipated regulations regarding leachate from operating and abandoned waste disposal sites (e.g., dumps and landfills) are going to significantly affect Major Command (MACOM), installation, and Facility Engineer (FE) pollution abatement procedures, and associated budgeting. MACOMs and Facility Engineers have already been exposed to the leachate problem in the form of the Resource Conservation and Recovery Act and the requirement of state-issued permits for DA operating landfills. According to these

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[1] Groundwater Pollution Problems in the Southeastern U.S., EPA-600/3-77-012 (Office of R&D, Ada, Oklahoma (Environmental Protection Agency [EPA], January 1977), p 164.

stipulations, operating DA landfills experiencing leachate problems may have to be closed and monitored for leachate for several years after closure or they may be "upgraded" with leachate control prevention measures and continue to operate after a permit has been issued. The Federal Resource Conservation and Recovery Act (P.L. 94-580, October 21, 1976) on abandoned land disposal sites requires that water supplies be protected from leachate contamination.

In the past, the Army, like many concerns in the private sector (industry, municipalities), buried its wastes according to state-of-the-art, accepted engineering technology. However, the potential leachate problems resulting from this practice now require accommodation of environmental concerns. This report will help DA personnel address current or future leachate problems.

Objective

The overall objectives of this research are (1) to supply information allowing FEs at DA installations both to recognize potential or actual leachate problems and to gauge the magnitude of the problems, (2) to provide guidance on short- and long-term remedial actions which might control leachate formation and migration, and (3) to provide information to installation, FE, MACOM, and District personnel regarding legal ramifications of and responsibilities concerning leachate/gas problems.

The objective of this phase of the study is to provide FEs with introductory information on leachate's characteristics, formation, potential for environmental damage, and short-term remediation or mitigation and legal ramifications. This document is intended to educate, provide DA points of contact for assistance, and provide guidelines for problem identification/evaluation. The report also provides the FE with a procedural plan for systematically evaluating the pollution potential of all currently operating and abandoned landfills.

Approach

Investigators conducted an extensive literature survey, condensed this information, and related the material to leachate problems at military installations. Later phases of the study will involve pilot plant tests of selected leachate treatment techniques, field tests of methods to prevent leachate, and development of guidelines for treating and controlling leachate.

Mode of Technology Transfer

Information in this report and from subsequent research will impact information and guidance contained in AR 420-47, Solid Waste Management, and TM 5-634, Refuse Collection and Disposal.

2 OVERVIEW

What Is Leachate and Where Does It Come From?

According to a recent report, "When water comes in contact with waste, it removes the soluble components, producing a grossly polluted liquid called leachate. Depending on the wastes received at a land disposal site, leachate may contain various decaying organics, bacteria, viruses, and toxic chemicals, including heavy metals and known and suspected carcinogens."[2] The water which produces leachate can be from groundwater infiltration into a landfill, surface water or precipitation seepage through cover material of the landfill, or may be inherent in the buried waste itself, as in the co-disposal of sewage sludge with the solid waste stream. Therefore, the landfill site's geologic and hydrologic characteristics, as well as the precipitation pattern for the locale and the permeability of the material used as final cover for the landfill will influence leachate's presence, quantity, and quality. Figures 1 and 2 show leachate emanating from two separate landfills.

Leachate is often a very high-strength wastewater. "Many pollution control engineers feel it is properly classified as an industrial waste, and some landfill operators who have tried to send leachate to municipal treatment plants have learned through the rude slap of surcharges that it is best to consider it as such."[3]

Although leachate quality varies greatly, the amount of commonly measured water quality pollution parameters, such as BOD, COD, SS, and turbidity, is many times greater in leachate than in raw municipal wastewater. Leachate typically exhibits low pH, low dissolved oxygen, high iron content, heavy metal ions, and toxic chemicals. One study of groundwater leaving a landfill in South Dakota found up to 50 times the chloride content of native waters in groundwater affected by leachate.

How Is Leachate Produced?

A landfill will generally absorb moisture until its retention capacity (field capacity) is reached. The quantity of water required for a landfill to reach field capacity after placement of final cover is a function of the soil type and moisture content of the cover material, character of the refuse, evapotranspiration of surface vegetation, moisture content of the refuse as placed, and the quantity of precipitation entering the fill before placement of the final cover. Figure 3 illustrates the leachate process, which can continue for as long as 50 to 100 years. Figure 4 shows the leachate potential of localities in the United States;[4] the location of major DA installations is superimposed on this map. The potential for leachate formation is greater in

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[2] Waste Disposal Practices -- A Threat to Health and the Nation's Water Supply, Report to the Congress of the United States by the Comptroller General, CED-78-120 (U.S. General Accounting Office, 16 June 1978).

[3] "Leachate Control Doesn't Come Easy," American City and County (May 1980), pp 69-72.

[4] Waste Disposal Practices.

humid areas where the amount of rainfall exceeds the amount of moisture returned to the atmosphere; once the field capacity is exceeded (either from groundwater or surface water infiltration into the refuse), liquid leachate will be discharged.

The soluble materials which moisture extracts from buried refuse consist of alkali, alkali earth, and "heavy" metals which can go into solution either as ions (depending on specific solubility products and specific rates of dis-solution), or as organically complex soluble compounds; soluble organic com-pounds such as intermediate or end products of refuse decomposition; and other soluble constituents which may be present in the refuse.[5] As leaching water percolates through a landfill, the pH of the solution decreases because of an increase in organic acid content and the absorption of carbon dioxide (a product of bacterial metabolism), which produces carbonic acid. These acidic conditions often produce large concentrations of dissolved metals in leachate due to corrosion of metallic refuse (e.g., cans) or the destabilization of metal-containing sludges from alkaline precipitation of some industrial wastewaters (e.g., sludges from treatment of metal-plating wastewater).

How Much Leachate Will Be Produced?

The amount and characteristics of the leachate produced vary seasonally with the amount of moisture infiltrating the refuse. Leachate discharge characteristics typically parallel precipitation and infiltration behavior; during wet periods, both the amount and strength of leachate increase. During freezing periods, no net infiltration occurs, and only slight leachate discharges are observed. When spring thaw occurs, peak flows are recorded.[6]

Most landfills have a relatively flat surface with no vegetation, which is conducive to infiltration. Therefore, it is reasonable to assume that at least half the annual precipitation can become recharged to the groundwater reservoir after it has been in contact with solid waste in the landfill.[7]

The U.S. Environmental Protection Agency (EPA) has devised a water balance method to estimate the quantity of leachate at a specific site. The method and its application to land disposal sites are examined at length in two EPA reports.[8] As a service to the Army, the Solid Waste Division of the U.S. Army Environmental Hygiene Agency (AEHA), Edgewood Arsenal, MD, has programmed the water balance method for computer execution. Further information on this service may be obtained from AEHA (see p 91 for a point of contact).

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[5] Recent Developments in Solid Waste Management, Solid Waste Management Branch Report EPS-3-EC-76-11, Seminar Proceedings (Environmental Conservation Directorate, Canada, August 1976).

[6] Recent Developments in Solid Waste Management.

[7] Groundwater Pollution Problems in the Southeastern U.S., EPA-600/3-77-012 (Office of R&D, Ada, Oklahoma, EPA, January 1977).

[8] R. L. Cummins, Effects of Land Disposal of Solid Waste on Water Quality, SW2TS (U.S. Department of Health, Education, and Welfare, 1968); E. S. K. Chian and F. B. DeWalle, Evaluation of Leachate Treatment; Vol 1: Characterization of Leachate, Environmental Protection Technology Series, EPA-600/2-77-186a (EPA, September 1977).

Figure 1. Leachate emanating from a landfill.

Figure 2. Leachate migrating from landfill site.

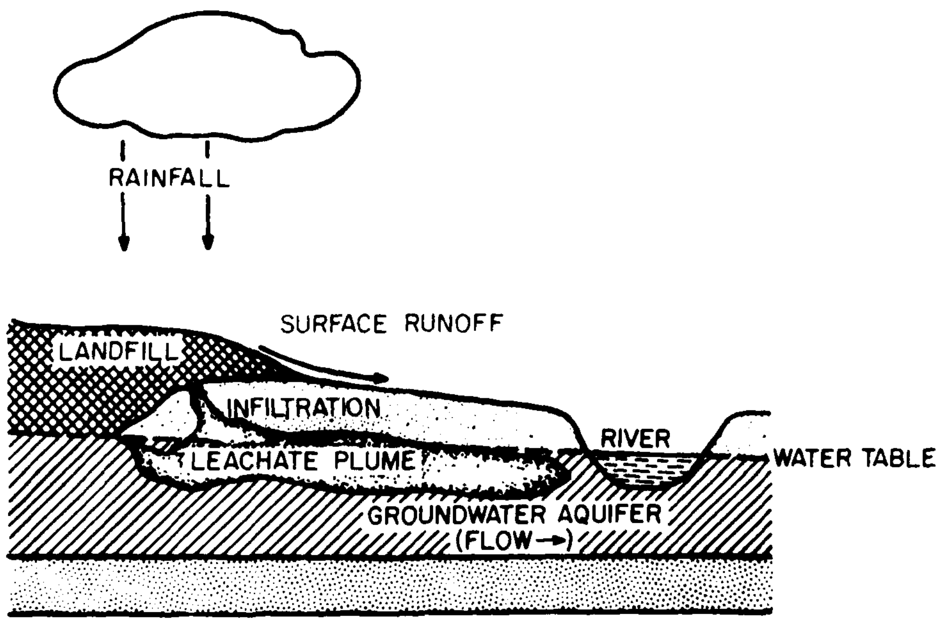

Figure 3. Leachate formation and movement. (From Waste Disposal Practices -- A Threat to Heal.h and the Nation's Water Supply Report to the Congress of the United States by the Comptroller General, CED-78-120 [U.S. General Accounting Office, 16 June 1978].)

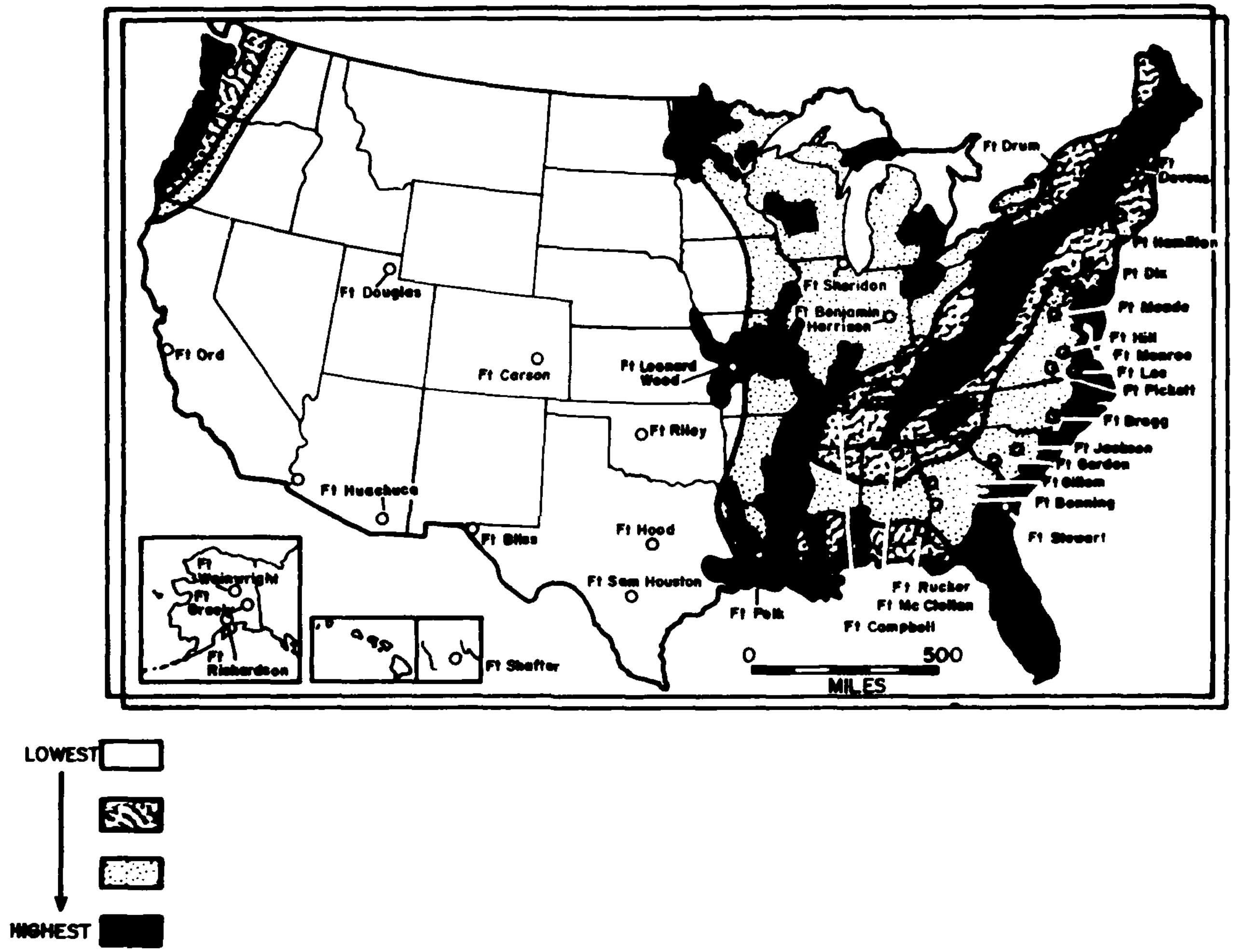

Figure 4. Areas of potential for leachate contamination in the United States, and locations of major DA installations.

However, caution must be exercised in applying the water balance method to land disposal sites; a review of the available information about this method shows that leachate quantity estimates are extremely sensitive to the many variables used in the method. For example, slight changes in runoff, evapotranspiration, and moisture-retention coefficients can significantly change in the leachate quantity estimate.[9]

In arid regions, little water is available to leach or saturate the refuse, while in areas of 30 to 50 in. (762 to 1270 mm) of precipitation, the soil moisture content is high and shallow water tables are common,[10] thus making conditions conducive to leachate generation.

Pacey and Karpinski[11] state that leachate generation is generally of concern in areas having rainfall exceeding 20 in. (508 mm) per year. Two examples highlight the potential extent of leachate production.

1. If 100 percent of the precipitation falling on a land disposal site becomes leachate, and there is 36 in. (914 mm) of precipitation, about 980,000 gal (3 709 300 L) of leachate will be produced per acre of refuse.

2. According to EPA's Office of Solid Waste, an average land disposal site (17 acres [6.9 hectares]) with an annual average infiltration of 10 in. (254 mm) of water can produce 4.6 million gal (17 411 000 L) of leachate per year.[12]

What Is Buried in DA Land Disposal Sites?

The quality and characteristics of leachate from a DA landfill site depend on many factors, but principally on what materials are placed in the landfill. Although leachate contaminants are commonly thought to arise directly from sources such as pesticide residues in containers or on yard wastes, organic solvent residues in containers, and bacterially contaminated organics from disposable baby diapers or animal (pet) wastes, a significant portion of leachate's strength may be attributed to textiles, rubber, leather, wood, paper, and cardboard in the refuse. Most components found in a land disposal site can form leachate; furthermore, the character of leachate

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[9] Cummins; Chian and DeWalle.

[10] R. F. Weston, Inc., Pollution Prediction Techniques for Waste Disposal Siting: A State of the Art Assessment, EPA-1978 PB-283-572 (Office of Solid Waste Management, 1978).

[11] J. Pacey and G. Karpinski, "Retrofitting Existing Landfills to Meet RCRA Standards for Leachate Control," Solid Waste Management (February 1979), p 46.

[12] Waste Disposal Practices -- A Threat to Health and the Nation's Water Supply, Report to the Congress of the United States by the Comptroller General, CED-78-120 (U.S. General Accounting Office, 16 June 1978).

changes as time passes.[13] The biochemical breakdown of refuse constituents into intermediate and final products which may be water-soluble is continuous.

It is beyond the scope of this report to include an exhaustive presentation of refuse characterization studies. However, it is safe to say that refuse characteristics are difficult to generalize because of the nonhomogeneous nature of the waste. The actual composition of DA refuse is ultimately site-specific. Both the physical and chemical composition depends on factors such as geographical location, post activities, etc.

The characteristics of the solid waste generated at most DA military facilities resemble those of many small communities. Primary sources of refuse may include (1) light industrial activity, (2) office buildings, and (3) single- and multiple-family dwelling units. The solid waste composition and generation rate may also be similar to that of a small community. However, there may be a seasonal increase due to training activities.

DA solid waste is often unique; the content of a DA landfill is determined by all installation activities. While material in DA landfills may be essentially the same as that in the civilian sector, the wastes from military-unique activities may also enter the landfill and influence the character of the leachate. Information is scarce about materials placed in DA landfills, but the following discussion on municipal waste may provide an appreciation of the complexity and variety of the wastes.

The following discussion will present data regarding the composition of typical nonmilitary type refuse. Leachate problems from DA land disposal sites (LDSs) originate from the refuse components and from their opportunity to react and release decomposition products into a transport medium; therefore, the refuse's general characteristics must be identified.

Table 1, taken from the EPA report Solid Processing and Disposal Technology in the United States,[14] relates types of refuse and their respective sources. This table provides insight regarding the variety of wastes which may be deposited in an Army LDS. The table's simple categorization of refuse types provides only descriptive information about the potential release of contaminants after their deposition in a landfill. Quantification of the magnitude of the wastes is necessary to assess the quality and extent of leachate production.

Refuse in an LDS may originate from other than municipal sources, i.e., industrial, commercial, and agricultural activities. Refuse from these sources can contain substances classified as hazardous wastes. Hazardous wastes have been characterized as any waste or combination of wastes "which

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[13] R. F. Schoenberger and A. A. Fungaroli, "Chemical and Biochemical Aspects of Leachate," Proceedings of the National Industrial Solid Waste Management Conference (University of Houston and the Bureau of Solid Waste Management, 24-26 March 1970).

[14] An Environmental Assessment of Potential Gas and Leachate Problems at Land Disposal Sites, Environmental Protection Publication SW-110 (Office of Solid Waste Management Programs, Hazardous Waste Management Division, EPA, 1973). Open-file report, restricted distribution.

Table 1

Classification of Refuse Materials
(From Committee on Solid Waste, American Public Works Association Refuse Collection Practices, 3rd ed. [Chicago Public Administration Service, 1966], p 15.)

Kind or Character	Composition or Nature	Origin or Source
Garbage	Wastes from the preparation, cooking, and serving of food Market refuse, waste from the handling, storage, and sale of produce and meats	
Rubbish or Mixed Refuse	Paper, cardboard, cartons Combustible (Primarily Organic): Wood, boxes, excelsior, plastics, rags, cloth, bedding, grass, leaves, yard trimmings Noncombustible (Primarily Inorganic): Metals, tin cans, metal foils, dirt, stones, bricks, ceramics, crockery, glass, bottles, other mineral refuse	From: households, institutions and commercial concerns such as hotels, stores, restaurants, markets, etc.
Ashes	Residue from fires used for cooking, heating buildings, incinerators, etc.	
Bulky Wastes	Large auto parts, tires, stoves, refrigerators, other large appliances, furniture, large crates, trees, branches, palm fronds, stumps, flotage	
Street Refuse	Street sweepings, dirt, leaves, catch basin dirt, contents of litter receptacles	From: streets, sidewalks, alleys, vacant lots, etc.
Dead Animals	Small animals: cats, dogs, poultry, etc. Large animals: horses, cows, etc.	
Abandoned Vehicles	Automobiles, trucks	

Table 1 (Cont'd)

Kind or Character	Composition or Nature	Origin or Source
Construction and Demolition Wastes	Lumber, roofing, sheathing scraps, rubble, broken concrete, plaster, conduit, pipe, wire, insulation, etc.	
Industrial Refuse	Solid wastes resulting from industrial processes and manufacturing operations, such as food-processing wastes, boiler house cinders, wood, plastic, and metal scraps and shavings, etc.	From: factories, power plants etc.
Special Wastes	Hazardous wastes: pathological wastes, explosives, radioactive materials, Security wastes: confidential documents, negotiable papers, etc.	Households, hospitals, institutions stores, industry, etc.
Animal and Agricultural Wastes	Manures, crop residues	Farms, feed lots
Sewage Treatment Residues	Coarse screenings, grit, septic tank sludge, dewatered sludge	Sewage treatment plants, septic tanks

poses a substantial present or potential hazard to human health or living organisms because they are lethal, nondegradable, persistent in nature, can be biologically magnified, or otherwise cause or tend to cause detrimental cumulative effects." Hazardous wastes may also be described as any discarded solid, liquid, semi-solid, contained gas, or combination thereof which because of its quantity, concentration, or characteristics poses a danger to human health because such waste is bio-concentrative, flammable, reactive, toxic, irritating, corrosive, infectious, or explosive. The Resource Conservation Recovery Act itself defines hazardous wastes rather broadly as "significantly contributing to an increase in mortality" or posing "substantial hazard to human health or the environment."[15] There is no "master list" of substances or compounds which are hazardous when placed on or under the land. However, the Office of Solid Waste Management Program has identified a number of likely candidates (Table 2).

The constituents of typical DA solid wastes depend on the function of the installation which produces them. Table 3 describes these types and indicates where they are usually found. The waste generated on a military installation is generally considered to be a mixture of Type 1 rubbish and Type 2 refuse.[16]

What Are the Characteristics of Leachate?

Few data are available regarding the character of leachate from DA landfills, but data about leaching landfills is being collected.

In 1978, the Environmental Effects Laboratory of the U.S. Army Waterways Experiment Station began monitoring leachate from the present and former landfill sites at Fort Belvoir. (See p 91 for a description of WES's Activities and point of contact.) As a part of the Army Pollution Abatement Program (APAP) being administered by the Corps of Engineers' Huntsville Division, additional leachate monitoring wells are being emplaced at several DA installations where leachate problems are suspected. (See p 91 for a point of contact.) These data will enable researchers to compare information about military and civilian landfill leachates and identify similarities and differences between them; this information will influence treatment and/or mitigation techniques. Tables 4 and 5 present the characteristics of leachate from civilian municipal landfills and compare them with those of raw domestic sewage. As shown in the tables, the values of leachate composition reported from different sites vary widely. The breadth of reported data is also typical of individual studies conducted over a long period of time at a site. The many factors contributing to the spread of data include time since deposition, moisture regime (i.e., total volume, distribution, intensity, duration), solid waste characteristics, temperature, sampling and analytical methods, landfill geometry, and leachate interaction with the soil environment prior to collection. It is obvious from Tables 4 and 5 that while data from individual studies vary, leachate typically has a higher concentration of pollutants than does raw domestic sewage. Certainly many of the parameters in Table 4 far

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[15] "EPA Defines 'Hazardous' in Chemical Waste Streams," Chemical Week, Vol 123, No. 23 (6 December 1979), pp 43-44.

[16] W. H. VerEecke, "Using Solid Waste Energy Sources at Military Installations," The Military Engineer, Vol 70, No. 436 (July-August 1978), p 238.

Table 2

A Sample List of Nonradioactive Hazardous Compounds
(From Disposal of Hazardous Wastes, Report to Congress,
Environmental Protection Publication SW-115 [EPA, Office
of Solid Waste Management Programs, 1947].)

Miscellaneous Inorganics

Ammonium chromate
Ammonium dichromate
Antimony trifluoride
Arsenic trichloride
Arsenic trioxide
Cadmium (alloys)
Cadmium chloride
Cadmium cyanide
Cadmium nitrate
Cadmium oxide
Cadmium phosphate
Cadmium potassium cyanide
Cadmium (powdered)
Cadmium sulfate
Calcium arsenate
Calcium arsenite
Calcium cyanides
Chromic acid
Copper arsenate
Copper cyanides
Cyanide (ion)
Decaborane
Diborane
Hexaborane
Hydrazine
Hydrazine azide
Lead arsenate
Lead arsenite
Lead azide
Lead cyanide
Magnesium arsenite
Manganese arsenate
Mercuric chloride
Mercuric cyanide
Mercuric diammonium chloride
Mercuric nitrate
Mercuric sulfate
Mercury
Nickel carbonyl
Nickel cyanide
Pentaborane-9
Pentaborane-11
Perchloric acid (to 72%)
Phoosgene (carbonyl chloride)
Potassium arsenite
Potassium chromate
Potassium cyanide
Potassium dichromate
Selenium
Silver cyanide
Sodium arsenate
Sodium arsenite
Sodium bichromate
Sodium chromate
Sodium cyanide
Sodium monofluoroacetate
Tetraborane
Thallium compounds
Zinc arsenate
Zinc arsenite
Zinc cyanide

Halogens and Interhalogens

Bromine pentafluoride
Chlorine
Chlorine pentafluoride
Chlorine trifluoride
Fluorine
Perchloryl fluoride

Miscellaneous Organics

Acrolein
Alkyl leads
Carcinogens (in general)
Chloropierin
Copper acetylide
Copper chlorotetrazole
Cyanuric triazide
Diazodinitrophenol (DDNP)
Dimethyl sulfate
Dinitrobenzene
Dinitro cresols
Dinitrophenol
Dinitrotoluene
Dipentaerythritol hexanitrate (DPEHN)
GS (propoxy (2)-methylphosphoryl fluoride)
Gelatinized nitrocellulose (PNC)
Glycol dinitrate
Gold fulminate
Lead 2,4-dinitroresorcinate (LDNR)
Lewisite (2-chloroethenyl dichloroarsino
Mannitol hexanitrate
Nitroaniline
Nitrocellulose
Nitrogen mustards (2,2′,2" trichlorotriethylamine)
Nitroglycerin
Organic mercury compounds
Pentachlorophenol
Picric acid
Potassium dinitrobenzfuroxan (KDNBE)
Silver acetylide
Silver tetrazene
Tear gas (CN) (chloroacetophenone)
Tear gas (CS), 2-chlorobenzylidene malononitrile)
Tetrazene
VX (ethoxy-methyl phosphoryl N,N dipropoxy-(2-2), thiocholine)

Organic Halogen Compounds

Aldrin
Chlorinated aromatics
Chlordane
Copper acetoarsenite
2,4-D (2,4-dichlorophenoxyacetic acid)
DDD
DDT
Demeton
Dieldrin
Endrin
Ethylene bromide
Flurorides (organic)
Guthion
Heptachlor
Lindane
Methyl bromide
Methyl chloride
Methyl parathion
Parathion
Polychlorinated-biphenyls (PCB)

Table 3

Types of Solid Waste*
(From W. H. VerEecke, "Using Solid Waste Energy Sources at Military Installations," The Military Engineer, Vol 70, No. 456 [July-August, 1978]. Copyrighted by the Society of American Military Engineers. Reprinted with permission.)

TYPE 0 - Trash, a mixture of highly combustible waste such as paper, cardboard cartons, wood boxes, and combustible floor sweepings from commercial and industrial activities. The mixtures contain up to 10 percent by weight of plastic bags, coated and laminated paper, treated corrugated cardboard, oily rags, and plastic or rubber scraps.

This type of waste contains 10 percent moisture and 5 percent incombustible solids.

TYPE 1 - Rubbish, a mixture of combustible waste such as paper, cardboard cartons, wood scrap, foliage, and combustible floor sweepings, from domestic, commercial, and industrial activities. The mixture contains up to 20 percent by weight of restaurant or cafeteria waste but contains little or no treated papers, plastic, or rubber wastes.

This type of waste contains 25 percent moisture and 10 percent incombustible solids.

TYPE 2 - Refuse, consisting of about an even mixture of rubbish and garbage by weight.

This type of waste, common to apartment and residential occupancy, consists of up to 50 percent moisture, 7 percent incombustible solids.

TYPE 3 - Garbage, consisting of animal and vegetable wastes from restaurants, cafeterias, hotels, hospitals, and markets.

It contains up to 70 percent moisture, up to 5 percent incombustible solids.

TYPE 4 - Human and animal remains, consisting of carcasses, organs, and solid organic wastes from hospitals, laboratories, slaughterhouses, animal pounds, and similar sources, consisting of up to 85 percent moisture, and 5 percent incombustible solids.

TYPE 5 - By-product waste, gaseous, liquid, or semiliquid, such as tar, paints, sludge, and fumes from industrial operations.

TYPE 6 - Solid by-product waste, such as rubber, plastics, and wood waste from industrial operations.

*Portions of this table not pertinent to the discussion of leachate were deleted.

Table 4

Civilian Landfill Leachate Characteristics

Constituent	Boone County, KY* Research Landfill (6 months old)	New York City Landfill (Average)+	Philadelphia Landfill (Range)+	Raw Domestic Sewage
Total Suspended Solids	360**			200
Conductivity	5,200		3-17	700
Chemical Oxygen Demand (COD)	17,500		40-89,520	500
Biochemical Oxygen Demand (5 Day BOD)	10,000	1,987	9-54,610	200
Total Organic Carbon (TOC)	6,100		256-28,000	200
pH	5.5	6.9	4-9	8.0
Alkalinity (as $CaCO_3$)	3,100	2,867	0-20,850	100
Acidity (as $CaCO_3$)	1,400			20
Total Phosphorus	22		0-154	10
Total Nitrogen	250			40
Chloride	660	2,406	34-2,800	50
Calcium	1,500		5-4,080	50
Magnesium	210		16-1,500	30
Iron	70		0-5,500	0.1
Manganese	70		0-1,400	0.1

*Characteristics of Sanitary Landfill and Its Potential Effects on Water Quality, Urban Rainfall Management Conference, University of Kentucky, Lexington, KY (April 1972).
+W. A. Oleckno, "Predicting the Water Pollution Potential of Proposed Sanitary Landfills; Part I: Sanitary Landfill Leachate... What Is It"? Journal of Environmental Health, Vol 38, No. 5, (March-April 1976).
+A. F. Crutcher and F. A. Ravers, The Design of a Natural Leachate Attenuation System, Conference of Applied Research and Practice (September 1978).
**All units in milligrams/liter except pH (pH units) and conductivity (micromhos).

Table 5

Characteristics of Leachate and Domestic Waste Waters
(From An Environmental Assessment of Potential Gas and Leachate Problems at Land Disposal Sites, Environmental Protection Publication SW-110 [Office of Solid Waste, Management Programs, Hazardous Waste Management Division, EPA, 1973]. [Open-file report, restricted distribution.])

Constituent	Range* (mg/L)	Range (mg/L)	Range (mg/L)	Leachate Fresh (mg/L)	Leachate Old (mg/L)	Waste Water+	Ratio# (mg/L)
Chloride (Cl)	34-2,800	100-2,400	600-800	742	197	50	15
Iron (Fe)	0.2-5,500	200-1,700	210-325	500	1.5	0.1	5,000
Manganese (Mn)	.06-1,400	--	75-125	49	--	0.1	490
Zinc (Zn)	0-1,000	1-135	10-30	45	0.16	--	--
Magnesium (Mg)	16.5-15,600	--	160-250	277	81	30	9
Calcium (Ca)	5-4,080	--	900-1,700	2,136	254	50	43
Potassium (K)	2.8-3,770	--	295-310	--	--	--	--
Sodium (Na)	0-7,700	100-3,800	450-400	--	--	--	--
Phosphate (P)	0-154	5-130	--	7.35	4.96	10	0.7
Copper (Cu)	0-9.9	--	0.5	0.5	0.1	--	--
Lead (Pb)	0-5.0	--	1.6	--	--	--	--
Cadmium (Cd)	--	--	0.4	--	--	--	--
Sulfate (SO_4)	1-1,826	25-500	400-650	--	--	--	--
Total N	0-1,416	20-500	--	989	7.51	40	25
Conductivity (mhos)	--	--	6,000-9,000	9,200	1,400	700	13
TDS	0-42,276	--	10,000-14,000	12,620	1,144	--	--
TSS	6-2,685	--	100-700	327	266	200	1.6
pH	3.7-8.5	4.0-8.5	5.2-6.4	5.2	7.3	8.0	--
Alk. as $CaCO_3$	0-20,850	--	800-4,000	--	--	--	--
Hardness tot.	0-22,800	200-5,250	3,500-5,000	--	--	--	-
BOD_5	9-54,610	--	7,500-10,000	14,950	--	200	75
COD	0-89,520	100-51,000	16,000-22,000	22,650	81	500	45

* Procedures Manual for Groundwater Monitoring at Solid Waste Disposal Facilities, EPA/530/84-8v (EPA, August 1977).
R. C. Steiner, A. A. [illegible], [illegible], and [illegible] W. Purdom, "[illegible] for Sanitary Landfill Development," Public Works, Vol 102, No. 2 (March 1971), pp 77-79. Gas and Leachate from Land Disposal of Municipal Solid Waste; Summary Report, (EPA, Municipal Environmental Research Laboratory, [illegible]).

+ D. R. Brunner, and R. A. Carnes, Characteristics of Percolate of Solid and Hazardous Waste Deposits, presented at American Water Works Association (AWWA), Annual Conference (June 17, 1974).

exceed the usual discharge permit levels set by regulatory agencies. In addition to the chemical characteristics of leachate listed in Tables 4 and 5, other researchers report that initial leachate samples are dark green or yellow and quickly turn a darker color when exposed to oxygen.[17] Leachate has also been reported to have a disagreeable and nauseating odor caused by the presence of free volatile acids.[18] An EPA report notes that one study has indicated odors similar to those of garbage (decomposing foodstuffs), oil, and grease.[19]

In summary, leachate is characterized by having a higher hardness, iron, color, taste, odor, conductivity, BOD, and COD content and a lower pH than unpolluted ground or surface waters.

When Does Leachate Start; How Long Will It Last?

Leachate begins to flow when the refuse in the landfill reaches field capacity. The time required to reach field capacity can be estimated through a water balance if site-specific parameters are known. Emrich[20] estimated that in humid areas of the United States, a 7.3-m-thick section of refuse would require 12 to 18 months to reach field capacity; in the semi-arid Southwest and West, it might take decades to reach field capacity. However, once leachate production has begun, it can last for decades. Emrich conducted a comparative study of two sections of a Pennsylvania landfill (both sections were producing leachate) where the deposited waste in the closed section was at least 20 years older than that in the new (operating) section.[21] Table 6 shows that substantial reductions have occurred in the concentrations of virtually all parameters listed; however, comparison of these concentrations to regulatory requirements for discharge to a receiving stream shows that leachate from the older section would still require treatment before discharge. The duration of leachate production is a function of the degradation rate of the organic material in the fill. Landfill disposal sites receive both wastes that readily decompose and those which will never decompose (conservative components, e.g., heavy metals).[22] Therefore, while non-conservative constituents (organics) may eventually decompose and become stabilized, conservative pollutants will remain a potential contaminant long

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[17]G. L. Gerdes and B. A. Donahue, Simplified Sanitary Landfill Design and Operation Analysis, Technical Report N-57/ADA064356 (U.S. Army Construction Engineering Research Laboratory [CERL], December 1978).

[18]P. C. Clark and R. Piskin, "Chemical Quality and Indicator Parameters for Monitoring Landfill Leachate in Illinois," Environmental Geology, Vol 1, No. 6 (1977), pp 329-340.

[19]Sanitary Landfill Stabilization With Leachate Recycle and Residual Treatment, EPA Technical Series, EPA-600/2-75-043 (Municipal Environmental Research Laboratory, Cincinnati, OH, October 1975).

[20]G. H. Emrich, "Guidelines for Sanitary Landfills--Groundwater and Percolation," Compost Science, Vol 13 (May-June 1972), pp 12-15.

[21]G. H. Emrich, "Guidelines for Sanitary Landfills--Groundwater and Percolation," Compost Science, Vol 13 (May-June 1972), pp 12-15.

[22]Solid Waste Management Report, EPS 4-EP-72-2 (Sanitary Landfilling Seminar Proceedings, Canada, December 1972).

Table 6

Comparison of Leachate Quality Characteristics From Two Landfills
(Age Difference > 20 Years)

Parameters	Landfill New Section	Landfill Old Section	Typical Permitted Discharge Levels
Conductivity	3000*	2500	
BOD	1800	18.0	45
COD	3850	246	
Ammonia Nitrogen	160	100	3
Hardness	900	290	
Iron	40.4	2.2	0.3
Sulfate	225	100	50

* All values in mg/L except conductivity (micromhos).

after stabilization has occurred. In fact, it has been noted that landfills 20 to 30 years old are still releasing iron, manganese, chromium, cadmium and zinc.[23] In a stabilized landfill environment, natural conditions which immobilize or at least reduce the concentration of conservative components include a nearly neutral pH, absence of organic acids, moderation of reducing conditions in the landfill, and the ion exchange capacities of some soils possibly found below a landfill. For example, the environment in an unstabilized landfill is extremely conducive to heavy metals becoming water-soluble and results in heavy metal pollution of surface or groundwater supplies. However, the environment inherent to a stabilized landfill is less likely to cause heavy metals to be water-soluble and leach out, thus contaminating water supplies.

A landfill is considered stabilized when the following criteria are met: (1) maximum settlement has occurred, (2) negligible gas production is occurring, and (3) the leachate does not present a pollution hazard.[24]

[23] E. C. MacNamara, "Leachate From Landfilling," Compost Science (November-December 1971).

[24] J. O. Leckie, et al., "Landfill Management With Moisture Control," Journal of the Environmental Engineering Division [JEED], Vol 105, No. EE2 (American Society of Civil Engineers [ASCE], April 1979), pp 337-355.

What Harm Does Leachate Cause?

Although leaching of wastes from land disposal sites has received considerable attention in recent years, definition of its actual environmental impacts, which are quite controversial, has only recently received emphasis. Much of this dilemma is related to the fact that until the Love Canal incident, in which leaching industrial wastes literally drove people from their homes,[25] the public was not greatly concerned about leachate and usually did not demand studies of the liquid's environmental impact. This chapter offers an overview of the damages commonly associated with leachate contamination of surface and ground waters.

Leachate contamination involves not only the safety of humans and the ecosphere, but also affects the development and management of water resources. For instance, contamination of groundwater can mean paying increased costs for treating moderately contaminated water or actually having to abandon potable water supplies in cases of extreme pollution.

Besides polluting ground and surface waters, leachate can be unsightly and can create other undesirable conditions near the landfill. If uncontrolled and allowed to stand on the surface of the ground, leachate can provide breeding places for insects, such as mosquitos, and for many forms of microbial life, which can cause odors at the landfill site. Cameron has summarized the potential impacts of leachate on surface waters; Table 7 lists the expected effects of leachate's characteristic parameters on surface water quality.[26]

The nature of the receiving water and its dilution capability will significantly affect the leachate discharge's potential to cause damage. Therefore, each case must be assessed on its own merits. If dilution exceeds 1000 to 1, most contaminants will not be measurable outside an initial dilution zone. If dilution exceeds 100 to 1, there may be problems in the early life of the site, but as the site ages, contaminant concentrations probably will not be measurable. However, once dilutions reach 20 or 10 to 1, there is potential for damage, no matter how old the site is. (Iron staining may be an exception, since iron stains on rocks in creek and river beds have been seen at very high dilution levels.)[27]

Leachate Toxicity to Fish and Aquatic Organisms

Cameron observes that in a toxicity test, the "typical" landfill leachate will kill half the test fish in 96 hours when 26.5 L of leachate are diluted in 378.5 L of water. Concentrated leachate (from test cells) will kill half the fish in 96 hours when 23.5 L are diluted in 371 850 L of water. However, the regulatory agency requirement is that half the test fish should survive

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[25]Eckardt Beck, "The Love Canal Tragedy," EPA Journal, Vol 5, No. 1 (January 1979), pp 16-18.

[26]R. D. Cameron, "The Effects of Solid Waste Landfill Leachates on Receiving Waters," Journal American Water Works Association, Vol 70, No. 3 (March 1978), p 175.

[27]Cameron, p 175.

Table 7

Potential Leachate Problems in Surface Waters
(From R. D. Cameron, "The Effects of Solid Waste Landfill Leachates on Receiving Waters." Reprinted from Journal American Water Works Association, Vol 70, No. 3 [March 1978], by permission. Copyright 1978, the American Water Works Association.)

Parameter	Effect	Associated Problems
BOD	Oxygen depletion	Septic conditions, discoloration, taste and odor problems
Iron	Rust-colored stains	Discoloration, slime growths on stream bottom, taste and odor problems
pH Reduction	Increased toxicity	Potential problems for domestic use, irrigation and stock watering downstream
Nitrogen*	Increased toxicity	Potential problems for domestic use, irrigation, and stock watering downstream
Metals	Increased toxicity	Potential problems for domestic use, irrigation, and stock
Organics	Increased toxicity	Potential problems for domestic use, irrigation, and stock watering downstream
Increased pH	Metal precipitation	Blanketing of stream bottom, long-term toxicity
Calcium	Increased hardness	Interference with domestic use
Magnesium	Increased hardness	Interference with domestic use
Nitrogen†	Algal blooms	Interference with domestic and recreational use
Phosphorus	Algal blooms	Interference with domestic and recreational use
Color	Discoloration	Reduced photosynthesis and oxygen depletion, aesthetically unpleasant
Bacteria+	Health problems	

*Cameron is probably referring to ammonia.
†Cameron is probably referring to nitrate.
+Bacteria was not listed in the original table; however, its presence in leachate does create problems.

for 96 hours in an *undiluted* waste. Cameron further states, "Thus toxicity to fish (and possibly to other animals, plants or humans) may well be one of the major leachate problems and is felt to be at least a strong warning that difficulcies may arise in the receiving environment."[28]

High BOD loads introduced into a receiving stream can seriously deplete oxygen levels, resulting in an aerobic condition lethal to fish. The severity of this condition is a function of stream flow, the rate of stabilization by stream reaeration, and the rate and strength of the leachate pollution source. Also, precipitation of iron oxides in surface waters can cause gill clogging in fish.

Leachate contamination of streams is often conducive to the growth of "slime" layers of organisms usually associated with pollution. Table 8 presents laboratory results from leachate samples and from a stream before and after it has been contaminated with leachate.

An important consideration in assessing the potential biological effects of leachate on aquatic organisms is the tendency of organisms to accumulate certain toxic components from the contaminated water. This process of accumulation, in which the concentration of substances in the tissues of organisms exceeds the ambient concentration, is called biological magnification. An experience at Clear Lake, CA, demonstrates biological magnification. The lake was treated with the pesticide dichloro-diphenyl-dichloro-ethane (DDD) to control nuisance hatches of flying insects. After treatment, the concentration of DDD in the water was 0.02 ppm. In the lake plankton, however, the concentration of DDD was 5 ppm. The fat of fish that fed on the plankton contained more than 2000 ppm DDD. Grebes then ate the fish and died; the tissues of these birds contained 1600 ppm DDD.

This case illustrates that the concentration of a persistent contaminant generally is greater at successively higher trophic levels. The concentration in the plankton (the minute green plants in the lake) was 250 times greater than the concentration in the water. The concentration in the tissues of fish that fed on those plants was 100,000 times as great as that of the water. The concentration in the grebes, which preyed on the fish was 80,000 greater than that of the water, but was lower than that of the fish. This does not contradict the general rule of "higher concentrations at higher trophic levels." Instead, it demonstrates a second fact: organisms vary in their ability to tolerate the toxic effects of a particular substance. The fish were still alive, even though the concentration of DDD in their fat was 2000 ppm; in contrast, the birds died when the concentration of DDD in their tissues approached 1600 ppm.

Through biological magnification, a substance that is sparse in the environment may be concentrated many thousandfold within organisms that ingest it. This may result in injury or death to sensitive organisms, and also may render fish, shellfish, game, livestock, and crops unfit for human consumption. The only way to protect the biota and man is to minimize or prevent the entry of cumulative pollutants into the environment. This description has

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[28]Cameron, p 175.

Table 8

Effects of Leachate on a Stream
(From W. B. Culhan and R. A. McHugh, Journal of Environmental Health, [May/June 1969].)

	Leachate	Stream Above Leachate Entry	Stream Below Leachate Entry
Temp. °C	10.0	11.0	11.0
DO	3.5	10.5	9.8
BOD	24	0.4	>78
MPN	<450	450	<450
Conductivity	520	34	86
pH	7.1	6.3	5.5
Color	1	5	1
Total Solids	504	54	65
Suspended Solids	40.4	7	11.5
Hardness	209	12.9	29.0
SO_4	12.2	1.7	3.0
NH_3N	0.21	0.01	0.24
NO_3N	0.04	0.14	0.31
PO_4	0.01	0.03	0.02
Cl	23.7	2.3	5.5
Mn	17.2	0.11	1.20
Fe	20.3	0.10	1.30
Alkalinity	257	6	6

been included to emphasize that leachate contamination can potentially cause problems not often associated directly with it.

In summary, leachate increases concentration of pollutants in surface water, which lowers water quality and diminishes its suitability for beneficial use.

Effects of Leachate on Groundwater

According to Geraghty and Miller, "Groundwater contamination is, in the broadest sense, a quite different process from contamination of surface waters. In the case of streams, lakes, and other surface-water bodies, the sources of pollutants are commonly visible, as are the effects of the pollution. An investigator, for example, simply has to collect water samples from such bodies in order to measure directly the degree of the contamination. In the case of groundwaters, however, the situation is markedly different.

All rock formations and earth materials beneath the land surface are entirely saturated with water from the level of the water table on down. The best waterbearing layers in these formations are called aquifers, and the layers that yield little or no water are called confining beds. In some localities, only one or two aquifers may be present, whereas in other places, there may be many alternating aquifers and confining beds that have been deposited one on top of another to depths of as much as several thousands of meters.[29]

Groundwater is chiefly used for irrigation, but is also an important drinking water source because of its generally good quality. National withdrawals of fresh groundwater are projected to rise from about 82 billion gpd (3.1×10^{11} L/day) in 1980 to 127 billion gpd (4.8×10^{11} L/day) in 2010.[30]

Groundwater is the major drinking water source for 32 states and is the only source for extensive parts of several states.[31] Many DA installations mine groundwater directly for the production of potable water or indirectly through the purchase of potable water from municipalities using groundwater sources.

Water quality problems resulting from leachate contamination of aquifers are compounded by the slow movement of the water. The water may be contaminated long before that pollution is detected at a water supply well, and the contamination may persist long after its source has been controlled. Table 9 outlines specific problems caused by leachate contamination of groundwater.

Once an aquifer is contaminated, it is very difficult, and often costly, to purify the water. If treatment is determined to be impractical, impossible, or uneconomical, the only alternative is to declare the water source unfit and seek an alternate supply.

A GAO report[32] states that, "In January 1977 EPA reported to the Congress that effective monitoring of potential sources of groundwater contamination was almost nonexistent and that leachate's elusive nature and long duration were major perils inherent in such contamination. EPA has also found that no action was taken to determine the quality of the water near disposal sites until an official complaint was received by the cognizant agencies. Generally what is known about leachate contamination is a result of investigations made after wells have been found to be contaminated."

Table 10 shows the impact of leachate on the groundwater quality. The table lists three wells and the quality of samples drawn from each. The first well was upstream from the landfill, one was directly beneath the landfill, and the third was downstream. As expected, the deteriorating effect of leachate on groundwater can be seen when the background well data is compared with the monitor well data.

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[29]T. T. Geraghty and D. W. Miller, "Status of Groundwater Contamination in the U.S.," Journal American Water Works Association, Vol 70 (March 1978), p 162.

[30]Waste Disposal Practices -- A Threat to Health and the Nation's Water Supply, Report to the Congress of the United States by the Comptroller General, CED-78-120 (U.S. General Accounting Office, 16 June 1978), p 5.

[31]Geraghty and Miller, p 162.

[32]Waste Disposal Practices - A Threat to Health and the Nation's Water Supply.

Table 9

Potential Leachate Problems in Groundwaters
(From R. D. Cameron, "The Effects of Solid Waste Landfill Leachates on Receiving Waters." Reprinted from Journal American Water Works Association, Vol 70, No. 3 [March 1978], by permission. Copyright 1978, the American Water Works Association.)

Parameters	Effect	Associated Problems
BOD	Oxygen depletion	Discoloration, taste and odor problems
Iron	Rust-colored stains	Staining of clothes and fixtures, taste and odor problems
pH change	Increased toxicity	Possible problems for domestic use, irrigation, and stock watering
Nitrogen	Increased toxicity	Possible problems for domestic use, irrigation, and stock watering
Metals*	Increased toxicity	Possible problems for domestic use, irrigation, and stock watering
Organics	Increased toxicity	Possible problems for domestic use, irrigation, and stock watering
Increased pH	Metal precipitation	Possible aquifer clogging
Total Solids	Attenuation and buildup	Aquifer clogging, possible later desorption
Fluoride	High fluoride levels	Mottled teeth
Selenium	Toxicity	Possible toxicity to humans
Color	Discoloration	Aesthetically unpleasant
Bacteria†	Health problems	

*Author's note: Chromium and cadmium are common heavy metal pollutants.
†Bacteria was not listed in the original table; however, its presence in leachate does create problems.

Potential Health Impacts

The public health significance of leachate must be considered both in terms of disease agents involved (biological or chemical) and in terms of the amount of the contaminating agent affecting susceptible population. This assumes that leachate is contaminating water regimes used for potable water supplies. In many instances, the significance of certain agents, and often whether a substance actually is a contaminating agent, are unknown. Thus, there may be many chemicals in DA landfills that can impair health. Furthermore, there is much uncertainty about the fate of the chemicals during and after the decontamination process, and particularly about their stability and their potential for biotransformation to toxic, or more toxic, forms.

A report of the Committee of Water Quality Criteria of the National Academies of Science and of Engineering, and more recently the Federal Register, named a number of inorganic chemicals and elements that are of concern in public water supplies.[33] Table 11 lists those agents found in water which may have an adverse physiological effect on humans; the table also lists

Table 10

Groundwater Quality in the Vicinity of a Landfill
(Reprinted from Solid Waste Management Technology Assessment, published by General Electric Company.)

Parameter	Uncontaminated Groundwater	Contaminated* Groundwater	Leachate
Total Dissolved Solids (mg/L)	636	1,506	6,712
pH	7.2	7.3	6.7
Chemical Oxygen Demand (mg/L)	20	71	1,863
Total Hardness (mg/L)	570	820	4,960
Sodium (mg/L)	30	316	806
Chloride (mg/L)	18	248	1,710

*The contaminated well was located 150 ft (45 m) down the groundwater gradient from the landfill and was screened 11 ft (3.3 m) below the surface in sandy, clayey silt.

[33]"Water Quality Criteria 1972," EPA Ecological Research Series, EPA-R3-73-033 (EPA, 1973); "National Interim Primary Drinking Water Regulations," Environmental Protection Agency Water Programs, Federal Register, Vol 4, No. 248 (24 December 1975), pp 59566-59588.

Table 11

Selected List of Potentially Toxic Chemical Agents Found in Drinking Water and Recommended Limit Concentrations (From R. C. Cooper, "Health Considerations in Use of Tertiary Effluents," Journal of the Environmental Engineering Division, ASCE, Vol 103, No. EE1 [February 1977], p 39.)

Chemical Agent	Recommended Maximum Standard, mg/L
Arsenic	0.05
Barium	1.
Cadmium	0.01
Chromium	0.05
Cyanide	0.2
Lead	0.05
Mercury	0.002
Nitrate	10*
Selenium	0.01

* Milligrams of nitrite or nitrite-nitrogen.

recommended maximum permissible concentrations for each. Leachate may contain any or all of these agents.

The potential for groundwater contamination resulting from hydrocarbons buried in a DA LDS is certainly significant. Osgood states that, "It is interesting to note that one gallon of gasoline is enough to pollute almost 200,000 gallons of groundwater beyond the threshold of taste."[34]

A GAO report[35] states that "Heavy metal concentrations in undiluted surface leachate have also been found. Samples taken by EPA over a 1-year period at five municipal land disposal sites showed that the average levels of lead, mercury, and selenium in the leachate were 3, 13, and 8 times greater than the respective maximum levels specified in EPA's Interim Primary Drinking Water Standards."

In an EPA-funded study of organic compounds entering groundwater from a landfill near Norman, Oklahoma, researchers found over 40 chemicals in the groundwater of test wells. The compounds able to be identified comprised only a small portion -- less than 10 percent -- of the total organic matter in the sample..."

[34] Proceedings of the Second National Groundwater Quality Symposium, September 25-27, 1974, Denver, CO, NTIS PB-257312, "Hydrocarbon/Dispersion Groundwater: Significant Characteristics," p 99.

[35] Waste Disposal Practices -- A Threat to Health and the Nation's Water Supply, Report to the Congress of the United States by the Comptroller General CED-78-120 (U.S. General Accounting Office, 16 June 1978), p 5.

Table 12 describes the more harmful compounds.

The GAO report further states, "Because of the low levels of pollutants likely to be involved, physical properties of the polluted groundwater would probably not be altered sufficiently to indicate the presence of the offending compounds. This presence could be a matter of considerable concern, however, since the health effects of chronic ingestion through water of even very low levels of compounds such as those identified in this study are largely unknown."

Table 12

Results From EPA Study of Organic Compounds (From Waste Disposal Practices -- A Threat to Health and the Nation's Water Supply, Report to the Congress of the United States by the Comptroller General, CED-78-120 [U.S. General Accounting Office, 16 June 1978]).

Compound Found	Remarks
Ethyl Carbamate	Animal carcinogen as determined by the International Agency for Research on Cancer
p-Cresol	Cresols -- Testing recommended for carcinogenicity, mutagenicity, teratogenicity, other chronic effects, and environmental effects*
o-Xylene p-Xylene	Xylenes -- Testing recommended for mutagenicity, teratogenicity, and epidemiological study*
Diethyl Phthalate Diisobutyl Phthalate Dis-n-Butyl Phthalate Butylcarbobutoxymethyl Phthalate Discyclohexyl Phthalate Dioctyl Phthalate	Alkyl Phthalates -- Testing recommended for environmental effects*

* One of 10 substances or categories selected by the Interagency Testing Committee established by the Toxic Substances Control Act. The substances and categories were recommended for priority testing to determine their hazard to human health or the environment because of unresolved questions associated with their potential hazards.

Environmental Impacts of Gases Associated With Land Disposal Sites

When refuse is first placed in a land disposal site, it usually contains a finite amount of oxygen. Consequently, initial decomposition is aerobic, generating mostly CO_2 and water. However, this oxygen is soon depleted, and since there is only minimal opportunity for new oxygen to enter the refuse, anaerobic conditions prevail, which produce methane, hydrogen sulfide, CO_2, ammonia, and other gases. The gases emitted by the biological degradation of solid wastes are potential sources of serious problems. The quantity of gas released from the landfill will be less than the amount produced, since CO_2, a component of the gas mixture released under both aerobic and anaerobic conditions, is quite soluble in water and forms carbonic acid. This weak acid can cause dissolution of metals in the refuse and, through the formation of carbonates and bicarbonates, contribute to hardness of the water. Hardness causes precipitation of soap, causes scales to be formed on pipes and hot water heaters, and can make water unpalatable.

Hydrogen sulfide, although present in relatively small amounts, gives waters polluted by leachate an offensive taste and odor.[36] High concentrations of gases (especially methane) associated with decomposing wastes are reported to be directly or indirectly toxic to vegetation.[37] Figure 5 is a photograph of the results of such toxicity.

A serious gas problem encountered at landfills is the uncontrolled production and migration of methane. A landfill more than 2 years old will usually produce a gas mixture that is 50 percent carbon dioxide and 50 percent methane. The high combustibility of methane makes it a potential hazard in landfill environments. In concentrations between 5 and 15 percent by volume in air, methane is flammable at atmospheric pressure and ordinary temperatures.

Fire and explosion can be tragic results of uncontrolled methane combustion. The potential for hazard is heightened by the ease with which methane may migrate subterraneously, often to significant distances, through permeable media such as porous soils, trench backfill, and utility or drainage corridors. Public safety may be endangered if migrating methane accumulates in a poorly ventilated area and subsequently achieves combustible concentrations.

In landfills, methane is usually produced in concentrations above the combustion range; therefore, it almost always passes through that range when diluted with air. Fortunately, in most cases an energizer such as an open flame is not present as methane passes through the combustion range, thus averting combustion. Nevertheless, the numerous instances on record of fires and explosions resulting from landfill-produced methane warn that all too

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[36] W. A. Oleckno, "Predicting the Water Pollution Potential of Proposed Sanitary Landfills; Part I: Sanitary Landfill Leachate...What Is It"? Journal of Environmental Health, Vol 38, No. 5 (March-April 1976), p 334.

[37] "EPA's Hazardous-Waste Program: Will It Save Our Groundwater?" Series on Water Pollution Control: No. 10, Civil Engineering, Vol 48, No. 12 (December 1978), pp 39-45.

often gas migration leads to tragic consequences. One of the most publicized explosions occurred in Winston-Salem, NC, when methane became concentrated in an armory a short distance from the edge of a covered dump.[38]

> "The incident occurred on September 27, 1969, in the arms vault of the supply room at the North Carolina National Guard Armory in Winston-Salem, North Carolina... Of the 25 guardsmen that were injured from the explosion, 3 died and 7 were disabled either partially or totally.
>
> The source of the problem was a nearby municipal waste landfill which was opened in 1949. The armory was constructed on grade, with no subsurface ventilation system, within 10 m of the waste disposal site. Soils beneath the area are sandy. Operation of the municipal solid waste disposal site, while perhaps not in strict accordance with current standards for sanitary landfills, was equivalent to or better than operation of its contemporaries.
>
> Prior to the accident, there were several indications that a problem existed. In the summer of 1965, a welder working on part of a storm drainage system near the armory was burned slightly in a flash fire. In November of the same year, a fireman working near one of the street drains dropped a lighted match into a man hole and was burned slightly when gas in the sewer exploded. In December 1965, a flash fire occurred while downspouting was welded on the armory's roof drain system that was connected to an underground drainage system extending into the solid waste landfill. In 1966, an inspector found methane in the storm drains. Soon thereafter, a blower was installed to vent methane from the storm drains.
>
> On September 26, 1969, the day before the explosion, officials investigated the occurrence of gas odors from the arms storage vault of the armory supply room. No source of gas, defective piping, or other causes were noted. Arrangements were made to have the fire department check the vault with portable gas detection equipment the following week. The explosion occurred the morning following the inspection.
>
> Investigations following the explosion indicated that the explosion occurred when someone lit a match in the arms storage vault. Analyses of soil around and beneath the armory after the explosion indicated that gases were present at explosive concentrations. A sampling program verified that combustible gas from

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[38]An Environmental Assessment of Potential Gas and Leachate Problems at Land Disposal Sites, Environmental Protection Publication SW-110 (Office of Solid Waste Management Programs, Hazardous Waste Management Division, EPA, 1973). Open-file report, restricted distribution.

Figure 5. Photo of leachate toxicity to vegetation.

the landfill had migrated beneath the armory, presenting a continuous hazard of gas accumulation and explosion."[39]

The following text by John Pacey[40] provides an excellent discussion of landfill gas problems and control.

"In 1975, buildings at two separate fills in Michigan suffered from damage caused by methane explosions, while in Vancouver, Canada, a newly poured foundation slab was structurally destroyed by an explosion ignited by a match in the underslab air space. One of the most tragic incidents in recent years occurred in Englewood, Colorado, in 1976; three young boys were permanently maimed and scarred after they lit a candle in a storm sewer tunnel near a landfill, thereby triggering an explosion of methane gas. A year later in Denver, Colorado, two men were killed and three others were injured by a methane gas explosion in a water conduit line being constructed near a landfill. The list of similar incidents continues to increase annually, dramatically illustrating the hazards posed by gas migration.

On a less dramatic level, migrating landfill gas may cause significant damage to vegetative growth. Both carbon dioxide and methane may harm vegetation through high gas temperatures (up to 150^{o}) and by displacing oxygen from the root zone. For example, research conducted at Rutgers University has shown that sweet corn, peach trees, rye cover crop, sweet potatoes, and mature black oak trees have been killed by migrating methane at distances up to 800 feet from landfill boundaries. The specific effects of landfill gas on vegetation will depend on the plant's sensitivity to carbon dioxide and methane, oxygen depletion, and elevated temperatures.

The presence of landfill gas need not always spell damage to vegetation, however. In some instances, elevated concentrations of landfill gas reportedly stimulated growth.

Nuisance as a consequence of malodors from landfills is another well documented problem. These gases typically reflect the organic gases of decomposition, as carbon dioxide and methane have no odor. Occasionally, a landfill may have received malodorous wastes, or a mixing of waste products in the landfill may produce a resultant malodor. On occasion, hydrogen

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[39]L. J. Johnson, D. E. Daniel, W. V. Abeele, J. O. Cedbetter, and W. R. Hanson, "Effects From Past Solid Waste Disposal Practices" Environmental Health Perspectives, Vol 27 (December 1978), pp 215-221. Reprinted with permission.

[40]Personal communication between Ed Smith (CERL) and John Pacey, President EMCON Associates, San Jose, CA.

sulfide may be noted, but generally in a marine, brackish environment. Normally, all malodors can be controlled by a few feet of fine-grained cover soil and well sealed surface openings.

The migration of gas to the limits of a refuse fill and into the surrounding soils or overlying structures occurs by two basic processes: convection, or movement in response to pressure gradients; and diffusion, or movement from areas of higher gas concentration to regions of lower concentration. Gas flow is greater in materials with large pore spaces and high permeability (e.g., sands and gravels) and lesser in materials of lower permeability (e.g., clays).

Gas migration from landfills is, therefore, partly dependent on the geological environment of the site. In general, a landfill constructed in a sand-gravel environment experiences greater vertical and lateral movement of gases than one built in a clay environment. Gas migration may also be restricted by methane's relative insolubility in water; the presence of a groundwater table beneath a disposal site may provide a limit to the depth of gas migration. Being lighter than air, methane tends to rise, exiting through a landfill cover that is sufficiently permeable, such as sand or gravel. On the other hand, a cover of clay with small diameter pores is relatively impermeable, restricting gas loss through the cover if lateral escape is possible. While "capping" with clay can be employed as a means of protecting structures and/or human activity <u>on</u> the landfill, it may result in greater danger to off-site activities, as gas previously vented through the landfill surface now travels laterally to the landfill edge and beyond.

Certain climatic effects may reduce the permeability of the soil, thus restricting the passage of gas through the cover. For example, sufficient rain or frost will render any type of soil less permeable, encouraging the lateral migration of gas. In addition to decreasing the permeability of surface soils, rain water or snow melt may infiltrate the refuse; the resulting increase in moisture may stimulate the rate of waste decomposition and gas production. This combination of decreased permeability of the cover and increased gas production may cause a significant increase in lateral migration of the gas during the rainy season. On the other hand, the low temperature snow-melt water may reduce gas generation by slowing microbial metabolism.

The gas produced within a landfill must escape either through vertical permeation or lateral migration; the geologic-hydrologic environment and construction of a particular site together determine the direction in which the gas will exit the site. Typically, most of the gas (80%±) will exit through the cover soil. However, this vertical path may be totally sealed by frost or partially sealed by rain-saturated cover soil. Since gas migration may ultimately results in such hazards as fire or explosion, special control systems have been developed to alleviate this problem.

Methods of controlling landfill gas migration include one or a combination of the following:

1. Placement of impervious liner materials at or just beyond the landfill boundary to block the flow of gas.

2. Selective placement of granular materials at or just beyond the landfill boundary for gas venting and/or collection.

3. Evacuation and venting of gas from the landfill itself.

4. Evacuation and venting of gas from perimeter area beyond landfill.

Impervious liner materials used to control gas flow include plastic, rubber or similar synthetic film, natural clay, and asphalt. Plastic film is the most widely used synthetic material since it not only has the ability to contain gases, but also has a high resistance to deterioration. On the other hand, a disadvantage of some of the synthetic liners is their susceptibility to puncture during placement and their somewhat limited life span. Polyolefin or rubber products have potentially longer life than other synthetics.

Natural soil barriers such as saturated clay may furnish a highly efficient barrier to gas migration, provided the soil is kept nearly saturated; however, dry soils are ineffective, since cracks may develop across the surface, or perimeter boundary of the fill. Barriers typically are best implaced during landfill construction, as subsequent installations are often costly, less extensive than required, and occasionally impossible to accomplish. During construction, barriers can be placed to cover the base and lateral surfaces of the fill space. Installation after fill completion might be limited to trenching in the area requiring protection and to inserting a membrane into the trench, followed by backfilling.

Gravel trenches, perimeter rubble vent stacks, gravel-filled vent wells and combinations thereof are examples of perimeter vent systems. Venting systems may be either passive (relying on naturally occurring pressure or diffusion gradients) or induced exhaust (utilizing pumps to create a pressure gradient), with selection being dependent on site conditions. The passive systems rely on highly permeable material, such as gravel, placed in the path of the gas flow. Since the permeable material offers a path more conducive to gas flow than that of the surrounding medium, flow is redirected to a point of controlled release. Passive systems can be effective in controlling convective gas flow, less so in instances of diffusive flow. Although many passive perimeter control systems have been constructed, there are numerous instances where passive control has been ineffective.

Induced flow systems, particularly those employing suitably designed vertical wells, have proven very effective in migration control. From a practical standpoint, systems combining both migration control and gas recovery are finding increased favor. Typically, these systems incorporate perforated pipe in vertical gravel-filled wells similar to those used in gas recovery for fuel systems where hazard protection is required, depending on system requirements. The wells are spaced at intervals along the perimeter margin of the landfill. Wells are located either interior to the edge of fill or external to it, in the surrounding native soils. Selection of location is site-specific and dependent upon cost, benefit and performance criteria. The wells are connected by manifolding to an exhaust blower which creates a vacuum drawing gas from the well field. The gas flow direction in the volume of refuse or soil influenced by each well is toward the well, effectively controlling migration. Alternatively, to enhance the control ability of a trench system, a collection pipe can be placed in a gravel-filled trench and then connected to a vacuum exhaust system.

Gases collected by exhaust systems are generally disposed of by direct stacking, by incineration, or by passage through various sorption media. Gases from passive vent systems usually are allowed to discharge directly to the atmosphere; in certain cases, the gases are combusted, as in "tiki torches." In all instances uncombusted gas must be exhausted at a location where it is not subject to careless ignition, generally in a protected enclosure or above normal reach. Malodors associated with uncombusted gas may dictate some form of odor control; ignition represents the simplest and most effective malodor control.

A combination of gravel-filled trench and barrier membrane can be a very effective passive system if the control trench depth is within backhoe depth limit and an impermeable barrier is placed within this depth limit. In this instance, the trench is dug and a membrane is placed across the bottom and up the wall away from the landfill. Gravel is then used to backfill the trench; a vent pipe may or may not be included. A shallow depth landfill and high water table typify conditions for this fairly common system.

The potential hazards created by migrating landfill gas may not always warrant the installation of an elaborate, at times costly, control system. For example, only a portion of the landfill surface or its adjacent area may require control measures. In such cases, specific features may be incorporated into the designs of structures, utility lines or other facilities, often at a cost lower than that of a large-scale control system.

For buildings and other structures, protective design features may range from simple to fairly complex. A very basic feature, for example, is the impervious membrane between the slab and subgrade in buildings with slab on grade floors. A more effective system is provided by a permeable blanket with exhaust pipes between membrane and subgrade, permitting passive or exhaust venting of the intercepted gas.

An additional feature which further adds to system credibility is a thin layer of permeable material between the membrane and slab in which automatic methane gas sensors are positioned. The sensors should be selected to trigger an alarm should the methane gas concentration exceed a selected value, for example, one percent.

Building codes generally incorporate requirements for good ventilation and undoubtedly have precluded many methane-related incidents from happening. Nevertheless, many homeowners or building operators are unaware of the potential problem and unknowingly block the vent system, thereby creating a gas hazard. Buildings immediately over the landfill are particularly suspect, as cracks in the soil cover, settlement of the building, and resultant rupture or cracking of slabs may allow gas to flow into the building. Future additions to building codes should consider the requirement that a building or grading permit not be issued for development within 1000 feet of a landfill unless the developer provides adequate safeguards during construction and submits a report and design signed by a qualified engineer addressing and mitigating the gas condition.

The success of any of the migration control systems described must be continuously appraised throughout the gas production life the of the landfill. In areal protection systems, probes may be permanently placed at suitable locations in the interval between the migration control system and the facilities to be protected. These probes may be monitored on a frequent schedule either by gas sampling and analysis, or by in-situ gas detectors connected to an alarm system. Subfloor protection systems also must incorporate similar apparatus for measurement of gas concentrations above the protective layers."

Areas suspected of landfill gas contamination should be monitored by trained safety personnel equipped with properly calibrated gas detection instruments.

Both methane and carbon dioxide are odorless, so landfill gases cannot be detected by smell like commercial natural gas. To insure that gases have not leaked into buildings around the landfill, a gas detection device similar to the type used to detect leaks in natural gas lines must be used.

Economic Impacts

In a statement regarding the fact that hazardous waste disposal sites cost much more than properly disposing of the wastes initially, D. M. Castle, administrator of the EPA, stated, "It's a lot cheaper to do the job the first time than to go back and correct it years later."[41] For example, it would have cost $4 million (1979 dollars) to properly dispose of wastes in the much-publicized Love Canal area. The State of New York and the Federal Government now estimate the cost of cleaning up Love Canal to be more than $23 million. Love Canal residents are seeking more than $2 billion in health and property damage claims.

Castle also stated, "We hear a lot of criticism these days about the costs of environmental protection...We ought to give equal thought to the costs of environmental neglect."[42] Such concepts apply to the situation of abandoned Army LDSs; unless resources are committed now to solving the problem, the costs may escalate.

Potential for Leachate Production at DA Sites

As mentioned previously, leachate production is possible in humid areas where precipitation exceeds moisture return to the atmosphere. Approximately 40 percent of the continental United States (CONUS) falls in the area of moderate leachate production potential. Included in this area is a large number of DA facilities -- both garrison and industrial.

The probability of leachate formation at DA sites is also tied to the methods that the Army has historically used for solid waste disposal. The Army adopted sanitary landfilling in 1942, when it was first recommended that refuse be compacted into trenches and covered daily. TM 5-634, Refuse Collection and Disposal: Repairs and Utilities,[43] which deals with the specifics of refuse collection and disposal, was first issued in October 1946. The primary reasons for landfilling at that time were (1) reduction of garbage odors, (2) reduction of blowing litter, and (3) control of insects and vermin. Historically, the least valuable land available has been chosen as sites for trash dumps and their successors -- the sanitary landfills; thus, filling gullies and ravines, low spots, and marshy areas was standard practice. The natural conditions at such sites may be better understood if one considers that this early TM gave instructions for operating in an area with a high water table. The TM also recommended using sandy soil as cover material; at the time, this represented the best technology available and was a progressive change from the open dump or burning area.

The 1958 version of TM 5-634 was the first to deal with site selection. While site selection criteria dealt mainly with distance to refuse sources and availability of access to the site, the manual also included a statement on water pollution: "Do not select sites which have surface or subsurface

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[41] Environmental Reporter (March 9, 1979), p 2082.

[42] Environmental Reporter, p 2082.

[43] Refuse Collection and Disposal: Repairs and Utilities, TM 5-634 (Headquarters, Department of the Army [DA], October 1946).

drainage which may pollute a water supply."[44] Given the rudimentary technology available then for the disposal of solid waste, it is not surprising that leachate problems occurred in the past and persist today. In fact, the use of lined landfills, which isolate the refuse and any leachate from an aquifer, only came into common use in the mid 1970s, and even these liners may eventually fail and cause release of leachate.

These Army practices were probably common to what was considered state of the art, i.e., occasionally dumping in "informal" or unauthorized areas without regard for immediate or long-term environmental impacts. Authorized disposal sites were often characterized by poor site selection, lack of understanding of the hydrologic cycle, inadequate or nonexistent study of adjacent soils and geology, inadequate knowledge of refuse decomposition mechanisms, improper design and operation, and neglect of maintenance requirements after site completion. Hazardous wastes may have been disposed of without special precautions. In any case, it is unlikely that past (now abandoned) land disposal sites were located, constructed, and maintained in accordance with good engineering and public health protection practices with concern for protection of ground and/or surface water from leachate. In fact, DA personnel often may have been unaware that leachate problems would even arise, with the "out-of-sight, out-of-mind" syndrome being common.

Unfortunately, there is often little known, except by inference, about leachate problems at DA LDSs, often because there has been only a cursory analysis of pollution problems as they emerge. Moreover, such analysis is complicated by the lack of adequate information concerning the age and nature of the site and associated buried wastes, and the myriad of possibilities of interactions between the refuse and its environment. The extent and magnitude of the leachate problem may be unknown, particularly because of the lack of ground and surface water monitoring in close proximity to DA LDSs and because of the lack of understanding of conditions conducive for leachate production. However, it is usually only when fish kills are reported or when wells are polluted that the problem attracts attention.

The problem is compounded by the fact that most monitoring is directed toward the contaminants most often found in drinking water. However, thousands of other contaminants may be associated with leachate. Recognizing these facts, the EPA is stepping up its enforcement program against abandoned and inactive hazardous waste disposal sites.[45] DA LDSs are not generally considered hazardous waste landfills, but because of the unknown nature of the buried wastes it is wise to consider all leachate suspect.

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[44] Refuse Collection and Disposal: Repairs and Utilities, TM 5-634 (Headquarters, DA, July 1958) p 23.

[45] Solid Waste Report, Vol 10, No. 8 (April 9, 1979), p 57.

How Does Leachate Move: Natural Barriers

Once leachate leaves the landfill it will move downward until it reaches the water table (assuming the water table is below refuse levels in the landfill). When the leachate reaches the water table, it moves in the direction of the groundwater flow. Wells withdrawing water can interrupt or even reverse the gradient. The leachate will either exhibit slug flow movement or move as a plume that tends to stay in a narrow zone (see Figure 1). Less dense liquids, such as solvents and petroleum, oil, lubricant (POL) products, tend to float on top of this layer and are a potential fire hazard when the leachate surfaces. Although there is a tremendous variability, typical groundwater and leachate velocities may range significantly, assuming groundwater flow is through a porous medium and not a fissure. Velocities between 20 cm and 2 m per day have been documented in the literature. The velocity of a liquid through an aquifer material depends largely on the particle size and the type of porosity or permeability of the aquifer. In addition to the obvious effects of aquifer contamination by leachate, it should be realized that leachate will enter surface waters either through leachate springs at the sides of a landfill rising above natural grade (under which is an impervious layer), or through groundwater discharging into surface water bodies.

Table 13 contains information about the relative distances of contamination and respective travel times for various types of landfill pollutants. The data in this table emphasize the leachate's potential for migrating relatively great distances and its potential to pollute both on-post or off-post drinking water supplies.

Leachate Attenuation

Soil layers (whether naturally occurring or intentionally placed) under a landfill site may mitigate leachate. The soil's attenuation properties are determined primarily by leachate velocity and by the soil's ion exchange capacity, which is related to its clay content. Tables 14, 15, and 16 show the attenuating properties of some soil materials.[46] Clay materials have the best properties for removing leachate pollutants. In addition, certain physical characteristics of the landfill can contribute to natural attenuation. Compacting the underlying soil layer, the refuse, and the cover material will also reduce the quantity of leachate produced.

Examples of Leachate Problems

Many excellent reports[47] documenting leachate damage assessments are available. These reports describe how the problems were identified and the related litigation, remedial action, leachate damage costs, etc. Tangible impacts listed include loss of a potable well water supply and the subsequent

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[46] Recent Developments in Solid Waste Management, Solid Waste Management Branch Report EPS-3-EC-76-11, Seminar Proceedings (Environmental Conservation Directorate, Canada, August 1976).

[47] Leachate Damage Assessment: Case Study of the Fox Valley Solid Waste Disposal Site in Aurora, Illinois, P261068 (EPA, June 1976).

Table 13

Relative Contamination Distances
(Reprinted from Solid Waste Management Technology Assessment,
published by General Electric Company.)

Nature of Pollution	Pollutant	Observed Distance of Travel	Time of Travel
Industrial wastes	Tar residues, picric acid	197 ft several mi	
Garbage leachings	Misc. leachings	1476 ft	
Industrial wastes	Picric acid	3 mi	4-6 yr
Industrial wastes in cooling ponds	Mn, Fe, hardness	2000 ft	
Garbage reduction plant	Ca, Mg, CO_2	500 ft	
Chemical wastes	Misc. chemicals	3-5 mi	
Industrial wastes	Chromate Phenol Phenol	1000 ft 1800 ft 150 ft	3 yr
Salt	Chlorides	200 ft	24 hr
Gasoline	Gasoline	2 mi	
Weed killer waste	Chemical	20 mi	6 mo
Radioactive rubidium chloride	Radioactivity	--	5 days

Table 14

Leachate Attenuation* in Fine Silty Sand
(Average Age of Refuse: 9 Years)
(From Recent Developments in Solid Waste Management,
Solid Waste Management Branch Report EPS-3-EC-76-11,
Seminar Proceedings [Environmental Conservation Directorate,
Canada, August 1976].)

		Sample Point	
Chemical Characteristics	Leachate	61 m South of Fill	213 m South of Fill
Ammonia nitrogen (N)	175**	60	1.0
Organic nitrogen (N)	125	25	10.0
Chloride (Cl)	350	350	20
Phosphorus (P)	6.0	.6	-
Phenols	30 ppb	12 ppb	0
Hardness (as $CaCO_3$)	900	850	500
BOD_5	200	30	5
Calcium (Ca)	156	215	153
Magnesium (Mg)	122	77	25

*Author's Note: A portion of this apparent attenuation may be the result of dilution.
**All concentrations are in mg/L unless otherwise specified.

Table 15

Leachate Attenuation in Clay-fill
(Age of Site: 10 Years)
(From Recent Developments in Solid Waste Management,
Solid Waste Management Branch Report EPS-3-EC-76-11,
Seminar Proceedings [Environmental Conservation Directorate,
Canada, August 1976].)

Chemical Characteristics	Sample Point			
	Leachate	3 m Beneath Refuse	30 m East of Fill	Base Quality
Ammonia Nitrogen (N)	600*	40	0.[illegible]	0.2
Organic Nitrogen (N)	300	60	1.0	0.4
Chloride (Cl)**	900	250	20.0	4.0
Iron (Fe)	50	25	0.[illegible]	0.[illegible]
Phosphorus (P)	4.5	4.0	.0[illegible]	.06
Phenols	200 ppb	150 ppb	8.0 ppb	8.0 ppb
Hardness (as $CaCO_3$)	1400	700	250	140
BOD_5	250	150	5	4
Calcium (Ca)	156	100	40	25
Magnesium (Mg)	249	120	37	19
pH	7.2 pH units	7.2 pH units	7.6 pH units	[illegible] pH units

*All concentrations are in mg/L unless otherwise specified.
**Author's Note: Chloride ions are not usually absorbed or attenuated, so the steady reduction in the chloride ion may be a result of dilution.

Table 16

Leachate Attenuation in Fine Sand
(Age of Site: 20 Years)
(From Recent Developments in Solid Waste Management,
Solid Waste Management Branch Report EPS-3-EC-76-11,
Seminar Proceedings [Environmental Conservation Directorate,
Canada, August 1976].)

Chemical Characteristics	Sample Point 45.6 m South of Site	243.8 m South of Site	609.6 m South of Site	Base Quality
Chloride (Cl)	252*	132	10	5
Iron (Fe)	2.5	.2	.3	.2
Sodium (Na)	4.3	3.5	7.0	1.7
Potassium (K)	0.4	0.1	2.0	0.1
Hardness (as $CaCo_3$)	414	503	285	301
Alkalinity (as $CaCO_3$)	220	432	252	-
Zinc (Zn)	.08	0.38	.06	.17
Calcium (Ca)	100	147	91	87
Magnesium (Mg)	40	33	14	20
COD	131	83	-	-

* All concentrations are in mg/L unless otherwise specified.

need to use bottled water for drinking and cooking. Intangible damage includes lost time, inconvenience, and psychological impacts.

A few examples of actual leachate pollution are noted below:

1. In 1972, a private domestic well near a closed 56-acre landfill become grossly polluted. After extensive investigation, the landfill was identified as the pollution source. Engineers hired by the county estimated that about 170,000 gal (643 450 L) of leachate a day were entering an aquifer used by thousands of people.[48] The underground aquifer was not only a drinking water supply to more than 40,000 area residents, but was also needed for industrial use.

County officials concluded that they must try to control the spread of contamination because of the aquifer's importance as a drinking water source. The withdrawal rate of water supply wells was reduced by 2 million gal (7 570 000 L) a day, and 11 counterpumping wells were installed. The construction, operation, and maintenance cost for the counterpumping wells was estimated at $710,000 through March 1976. Annual costs of the counter pumping operations were about $200,000.

County officials estimated that the cost of studies and leachate containment efforts from 1972 to 1976 amounted to more than $1.4 million. However, this cost is minor compared to what may be required to overcome the problem. The alternatives suggested included developing an alternative water supply and removing and incinerating the waste. Removal and incineration costs have been estimated at $38.3 million in capital costs and about $1.9 million in annual operation and maintenance costs. In addition, restoring full use of the aquifer will take an estimated 10 years.[49]

2. Four years after a 22-acre landfill was opened in Aurora, IL,[50] leachate polluted seven domestic wells beyond use. The contamination substantially exceeded drinking water standards and was particularly high in chlorides, organic acids, sulfate, sodium, and biological constituents.

Families with contaminated wells were without water for 16 months. Their homes were finally tied into a public water supply system after legal action was initiated against the city and the disposal company. Although the State water agency proved that leachate from the landfill was the source of the problem, it remained in operation another 6 years because no other site was available.

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[48] E. C. Lazar, "Summary of Damage Incidents From Improper Land Disposal," February 3-5, 1979, Management and Disposal of Residue From the Treatment of Industrial Wastewater -- Proceedings of the National Conference on Management and Disposal of Residues From the Treatment of Industrial Wastewaters, pp 253-257.

[49] Attenuation of Pollutants in Municipal Landfill Leachate by Clay Minerals, EPA-600/2-78-157 (EPA, August 1978).

[50] Waste Disposal Practices -- A Threat to Health and the Nation's Water Supply, Report to the Congress of the United States by the Comptroller General, CED-78-120 (U.S. General Accounting Office, 16 June 1978).

An incomplete tabulation of costs directly attributable to the well contamination amounted to about $115,000, but this did not include all costs incurred by the well owners. Damages of $54,000 were awarded to seven plaintiffs.

3. One site in Germany received $5.34 \times 10^5 m^3$ (700,000 cu yd) of refuse over a 16-year period. Nine years after dumping stopped, water wells 1 mile away were found to be contaminated. It took another 18 years for the contaminant levels to drop to background levels.[51] This case illustrates a serious concern -- the amount of time and possibly money required to decontaminate an aquifer.

4. A recent report for the northeastern United States documented 60 cases in which well supplies were made unsuitable for domestic consumption. In one case, an affected subdivision had to develop an off-site water supply at a cost of $500,000.[52]

Information from damage cases and specific site studies on leachate migration and general information on disposal site locations and operations in the United States indicate that at least one-fourth and possibly as many as three-fourths of the municipal land disposal sites in the United States have leachate migration problems.[53]

A GAO report[54] further noted that "federal and state agencies have not assessed the extent of damage to groundwater supplies or determined the number of disposal sites which may be leaching. The limited information that is available is the result of studies made only after specific water wells have been contaminated -- the EPA estimates that about 14,000 of the nearly 20,000 municipal waste land disposal sites do not comply with state standards. In addition, virtually nothing is known about the over 100,000 industrial waste disposal sites."

Craig Vogt, chief of the Science and Technology Branch in the EPA's Office of Drinking Water, told an American Waterworks Association conference that recent research has shown the magnitude of the threat landfills pose to underground water. He estimated that of the 76,000 landfill sites identified, 1200 to 2000 sites could endanger public health. A preliminary investigation of 8200 sites found that 70 percent of them were unlined. Thirty percent of the unlined landfill sites overlie usable aquifers, and 10 percent are within 1 mile (1.61 km) of a drinking water well. He said possible contamination of underground water from landfills is most serious in the Northeast.[55]

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[51] G. Hughes, J. J. Tremblay, H. Anger, and J. D'Crug, Water and Pollution Control, Vol 110, No. 1 (January 1972).

[52] R. D. Cameron, "The Effects of Solid Waste Landfill Leachates on Receiving Waters," Journal American Water Works, Vol 70, No. 3 (March 1978).

[53] Leachate Damage Assessment: Case Study of the Fox Valley Solid Waste Disposal Site in Aurora, Illinois, PB261068 (EPA, June 1975), p 5.

[54] Waste Disposal Practices -- A Threat to Health and the Nation's Water Supply.

[55] "Current Developments," Environment Reporter (June 20, 1980), pp 269-270.

EPA will be issuing maximum contaminant levels for a number of chemicals in drinking water supplies. Standards will be issued for carbon tetrachloride, vinyl chloride, tetrachlorethane, trichloroethylene, 1,2 - dichloroethane, 1,1,1 - tricholoroethane, and might be issued for 1,1 - dichloroethane, dichloroethylenes, methyl chloride, and chlorobenzenes.

D. W Miller,[56] an East Port Washington, NY, consultant, emphasized that minor spills of contaminants into aquifers could cause major cleanup costs. He said a drinking water well in South Brunswick, NJ, had to be taken out of service due to contamination from leakage of solvents at a factory, although the contamination could have been caused by leakage of less than 1 gal (3.8 L) per day. He said the well could not be shut down, because continued pumping was necessary to keep another well from being contaminated by another contaminant plume. The cost of tests, geological studies, and continued pumping of the contaminated well cost more than $1 million.

Attorney E. I. Selig of Waban, MA, urged owners of waterworks to sue actual or potential groundwater polluters. "If you can trace pollution to a waste discharger, you can sue him for common law damages and maybe even for an injunction before damage occurs," Selig said. He said the burden of proof does not require conclusive evidence of who is causing the pollution, but only credible evidence. "I think we can expect this kind of litigation to increase substantially over the next couple of years," Selig said.[57]

Since most communities do not monitor their groundwater, the actual percentage of landfill sites with serious groundwater pollution problems associated with leachate may be as high as 90 percent.[58] Thus, the Army LDS situation could cause leachate problems and resultant economic, technical, and legal ramifications.

Data on leaching DA landfills are only now being developed at installations where the problem was obvious or at least strongly suspected. Because of the time lag between waste deposition and the usual subsurface introduction of leachate contamination into an aquifer, there are no obvious reasons for ever suspecting, much less identifying, a problem in cases other than an operating or recently closed, well-delineated landfill. Potential leachate sources could be widespread, given the age of many of the installations, their vast land area, and the probable casual burial of materials besides substances that are normally landfilled.

Gas and Leachate Legal Overview

The main Federal laws governing the production control and effects of leachate are the Resource Conservation and Recovery Act of 1976 (RCRA) (as amended) (PL 94-580), the Federal Water Pollution Control Act (FWPCA) (as amended) (PL 92-500), and the Safe Drinking Water Act (SDWA) (as amended)

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[56] "Current Developments."

[57] "Current Developments."

[58] Bela Liptak, Environmental Engineering Handbook (Chilton Publ., 1973), p 571.

(PL 93-523). RCRA is the basis of three Federal regulations governing landfill selection, operation, and closure.

Forty CFR (Code of Federal Regulations) 241, (revised as of July 1, 1979) "Guidelines for the Land Disposal of Solid Wastes," lists required and recommended procedures for designing and operating a sanitary landfill. Required activities include compliance to the most stringent air and water quality standards by appropriate site selection, design, and operation. The recommended procedures are far more comprehensive. Site selection and design procedures recommend a complete hydrologic and geologic evaluation of a proposed landfill site and consideration of proposed land use plans of the areas adjacent to the site. Recommended water quality protection procedures include monitoring wells, leachate treatment and control systems, protection against 50-year floods, and infiltration minimization systems. Recommended gas control procedures include gas collection systems, gas ventilation systems, and explosion prevention systems. Recommended recordkeeping practices include leachate and gas sampling records, ground/surface water sampling records, and quantitative measures of types and locations of solid waste disposed of in the landfill. Most state regulations governing landfill sites will usually list the recommended procedures of Part 241 as requirements for obtaining an operating permit, but, to date, no one state has totally adopted all the recommended procedures. States will typically regulate site location, cover material, and recordkeeping. At the discretion of the state agency, leachate, water quality, and gas analyses may be required.

Forty CFR, Part 257, "Criteria for the Classification of Solid Waste Disposal Facilities and Practices," sets out minimum criteria for classifying a land disposal site as a sanitary landfill. Failure to meet the criteria will result in an "open dump" classification which requires either upgrading to the sanitary fill criteria or closure. The regulations stipulate the following: no landfill locations in a 100-year floodplain area; no surface water contamination resulting in an NPDES violation, 404 permit violation, or 208 permit violation; no groundwater contamination beyond landfill boundaries which exceed National Primary Drinking Water Standards; and no explosive gas concentrations which exceed 25 percent of the lower explosive limit of methane. The regulations also stipulate criteria for new landfill sites or expansion of existing landfill sites beyond original planned boundaries. Basically, the regulations require an approved solid waste management plan; evaluation of the site's geologic and hydrologic characteristics; volume, chemical, and physical characteristics of leachate and gas; baseline quality characteristics of surface water and groundwater supplies; location of existing and alternate drinking water supplies; and a complete evaluation of the public [illegible]th effects. Under the regulation, USEPA will, upon approval of a State so[illegible]aste management plan, grant enforcement authority to the states. This sectio[illegible] so outlines a permit procedure.

Forty CFR 250, "Hazardous Waste Guidelines and Regulations," lists the criteria for classifying wastes as hazardous and for designing and operating a hazardous waste landfill. These regulations do not deal directly with a typical minimized landfill except in the possible classification of the landfill's leachate as hazardous. EPA has considered leachate hazardous when it reaches 10 times the National Drinking Water Standards. Classification of a landfill's leachate as hazardous will radically change landfill operation procedures, including leachate monitoring, collection, treatment, and prevention. Since this regulation is relatively new, interpretations are not yet available. Eventually, the states will also enforce this section.

The Federal Water Pollution Control Act is the source of two sets of regulations: the National Pollutant Discharge Elimination System (NPDES) and the National Water Quality Criteria (NWQC). The NPDES applies for leachate which is collected and discharged at one or more points. Basically, this is a permit system which specifies the type, concentration, and amount of pollutants which can be discharged into surface water from a single point. The states will eventually enforce this program. The NWQC specifies the minimum quality allowed for surface water systems (streams, rivers, and lakes). Under these criteria, pollution sources will have to maintain the quality of the receiving water, and the types and amounts of pollutants that they can discharge will be regulated. Again, states will eventually have enforcement authority.

The Safe Drinking Water Act is the source of the National Primary Drinking Water Standards (NPDWS). Table 17 lists the current standards. The standards apply to any water source (ground or surface) used as a drinking water supply. A supply which exceeds these standards will require extensive treatment to remove the offending pollutant. A pollutant source that contaminates this drinking water supply will probably pay greatly increased treatment costs. The NPDWS are also the basis for determining hazardous waste classification (40 CFR, Part 250) and for evaluating water pollution effects from landfill operation (40 CFR, Parts 241 and 257). Eventually, enforcement authority for these regulations will also be turned over to the states.

Most regulations cover existing or proposed landfills, but there are currently very few regulations governing closed or abandoned landfill sites. The states and the EPA are taking a comprehensive inventory of existing and closed landfill sites. Historically, closed sites are only important when a gas or leachate problem occurs. In the near future, regulations will probably be developed that will require gas and leachate monitoring of an offending closed landfill site for up to 15 years after closure. A few state regulations require gas monitoring in buildings near or on old landfill sites and groundwater and surface water monitoring on closed leaching landfill.

Army Regulation 420-47, Solid Waste Management (August 1977), Army TM 5-634, Refuse Collection and Disposal (July 1958), and Army TM 5-814-5, Sanitary Landfill (October 1973) do not give direct guidance on leachate and gas prevention, control, and treatment. Basically, these documents specify that air and water quality standards will not be violated, but do not tell how to avoid these problems through landfill design or operation or how to control an existing gas or leachate problem. In light of the heightened public awareness of leachate problems, these documents must be updated and improved to provide some guidance for field personnel handling and disposing of solid wastes in landfills.

Requirements for resource and energy recovery, conservation of land areas, prevention of ground and surface water contamination, and safe disposal of hazardous materials have all greatly strained existing Army waste disposal methods. As a result, there is a need for new regulations regarding the Army's handling and disposal of solid waste material.

Table 17

National Interim Primary Drinking Water Regulations
Maximum Contaminant Levels (MCL) for Inorganic Chemicals
(From Federal Register, Vol 44, No. 179 (13 September 1979)

Contaminant	Levels (mg/L)
Arsenic	0.05
Barium	1.0
Cadmium	0.010
Chromium	0.05
Lead	0.05
Mercury	0.002
Nitrate (as N)	10.0
Selenium	0.01
Silver	0.05
Fluoride	*

MCL for Organic Chemicals

Contaminant	Levels (mg/L)
Endrin	0.0002
Lindane	0.004
Methoxychlor	0.1
Toxaphene	0.005
Chlorophenoxys	
2-4, D	0.1
2,4,5-TP Silvex	0.01

Proposed Regulations for Additional Maximum Contaminant Levels

Contaminant or Condition	Level (mg/L unless specified otherwise)
Chloride	250
Color	15 (color units)
Copper	1
Foaming Agents	0.5
Iron	0.3
Odor	3 (threshold odor number)
pH	6.5-8.5 (pH units)
Sulfate	250
Total Dissolved Solids	500
Zinc	5

* 40 CFR (Code Federal Register), 257 should be consulted in its entirety for these MCL determinations.

3 ASSESSMENT, CONTROL, AND TREATMENT OF LANDFILL LEACHATE PROBLEMS AT ARMY INSTALLATIONS

Based on the previous discussion, it is clear that sanitary landfill and abandoned LDS leachate/gas is becoming a serious environmental problem at Army military installations. The FE should identify potential post leachate problems early because:

1. The Resource Conservation and Recovery Act requires control and treatment of leachate.

2. Many State regulations require permits for operation of sanitary landfills and for control of leachate.

3. Some investigators[59] believe that even in a well-designed sanitary landfill, leachate production is inevitable and that some leachate will eventually enter surface and/or groundwater regimes. "One of the more disheartening facts about sanitary landfills is that no matter how well they are run, most of them will always produce leachate and produce it for years after the sites are filled up and closed out."[60]

4. Most actively decaying landfills produce methane, an odorless flammable gas which will remain in the groundwater around the landfill even after active decay has diminished. Methane moving from landfill soil may cause serious explosions if it is accidentally ignited inside surrounding structures.

5. Leachate may seriously affect surface water and groundwater supplies which are a source of potable water for Army installations.

6. In addition to normal municipal-type solid waste, sanitary landfills at installations may contain small quantities of explosives and chlorinated hydrocarbons. This makes the leachate quality from military installations rather unique.

7. Generally, Federal facilities must comply with the same stringent environmental requirements as publicly owned treatment plants or landfills. It is the responsibility of FEs to anticipate potential environmental problems and provide solutions. If leachate problems occur, they will have a high public visibility.

The discussion above shows that the Army must define and correct the problem of military-unique wastes in operable and, more particularly, abandoned DA landfills which were constructed when leachate pollution potential was not a design consideration.

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[59]Samuel Weiss, Sanitary Landfill Technology (Pollution Technology Review, No. 10 (Noyes Data Corporation, London, England, 1974).

[60]"Leachate Control Doesn't Come Easy," American City and County (May 1980), pp 69-72.

Chapter 2 provided an overview of the causes, pollution characteristics, and potential dangers inherent in the contamination of leaching landfills. This chapter provides the installation FE with a procedural plan for evaluating the pollution potential of currently operating and abandoned landfills.

Generally, the plan calls for the following:

1. Identification and perimeter location of all existing landfills

2. Interviews with knowledgeable personnel and search of current and historical records pertaining to potentially landfilled materials and landfill operations

3. Collection and analysis of existing or generated topographic, hydrologic, and geologic information for each site

4. Inventory of ground and surface water uses and quality within or adjacent to each site

5. Ranking sites by pollution potential after analysis of the collected information.

Analysis of the information gathered from site investigations will determine if and to what extent corrective action is required and will provide useful information for any necessary subsequent field studies and engineering analysis. Although subsequent studies will usually require the services of expert consultants, a discussion of leachate monitoring systems, control, and treatment methods is included to familiarize the user with these techniques. Points of contact for assistance are listed on p 89.

Landfill Site Identification/Perimeter Location

Identifying and locating the perimeters of currently operating landfill sites is straightforward, unless the landfill has not been in use for many years, and past cell locations have not been documented. However, abandoned dumps, promiscuous dumping sites, and the like, occur on almost all military installations, and their exact locations are unknown. Hazardous wastes may have been discarded at several of these sites. The improper disposal of ordinary waste from mess halls, barracks, motorpools, and households may produce leachate toxic to fauna and flora.

There are several techniques to locate disposal sites, site perimeters, and leachate. An individual may want to monitor an operating site or locate and monitor an abandoned site. Several factors will affect the study, including, but not limited to: the funding level for the study, the length of time allowed for the study, the number of personnel available to work on the project, their knowledge and level of expertise regarding pertinent subject matter, the size of the area to be studied, and the relationship of the site to the installation boundary.

Monitoring personnel must also consider the potentially adverse effects to human health and the environment of unlocated sites and take the necessary steps to alleviate or eliminate the danger.

The perimeter of a disposal site should be located to facilitate monitoring and remedial action. Monitoring wells should be placed outside the perimeter of the disposal site to avoid possible leachate contamination of any aquifers. The cost for covering a disposal site, or for grouting to prevent water from entering the site and producing leachate is expensive. If the individual knows where the perimeter is, he/she can save unnecessary expenses by covering or positioning impervious materials where they will be the most effective, i.e., omit areas where they are not needed.

Steps in the Location Process

The following approach can be used to locate sites, site perimeters, and/or leachate.

Step I

The first step is to obtain background information about the installation.

A. Interview civilian employees, former employees, military personnel, and contractor's employees to see if they can recall any information that might assist in the study. Pilots are a good source of information. They are accustomed to looking at the ground from a different perspective than most people and may notice odd features in the landscape that would indicate a site's position, leachate outbreak, or the like.

B. A records search may locate old master plans for the installation, construction site plans, photographs, reports, or other documents that would reveal the location of disposal sites. Contracts or receipts may indicate the haul distance to sites from a particular location and the amount and types of materials disposed at a site. These documents may be found in the archives of the Major Command, Corps of Engineers District offices, or the post, and in local museums.

C. Several types of thematic maps cover military installations at different scales. The themes may include, but are not limited to, topography, soils, geology, roads, and vegetation. (Small-scale index sheets to large-scale topographic maps and other thematic maps are available for each state and territory of the United States. Information about the index sheets and the maps produced by Federal, State, and private organizations can be obtained by writing or calling the National Cartographic Information Center (NCIC) of the U.S. Geological Survey, 507 National Center, Reston, VA 22092 (Telephone: (703) 860-6045).

Information technicians at NCIC may not be able to provide the investigator with copies of the index sheets, but can direct him/her to the particular agency that is the actual holder.

Additional information about applicable maps may be available through the State department of transportation, State geological survey, county highway departments, and county historical society.

D. Several Federal agencies take, collect, use, archive, and/or sell photos. Many of these agencies have been conducting aerial surveys (photography programs) for a number of years, and some produce small-scale photos. Other agencies provide listings of their photos, which contain pertinent information concerning the photo, i.e., percentage obscured by cloud cover, scale, time of day, etc. Information about aerial photographic coverage in the United States may be obtained from the following agencies:

Center for Cartographic and Architectural Archives
National Archives and Records Service
8 Pennsylvania Avenue, N.W.
Washington, DC 20408
Telephone: (202) 523-3006

Application Assistance Branch
EROS Data Center
Sioux Falls, SD 57198
Telephone: (605) 594-6511, X114

Aerial Photography Field Office
ASCS - U.S. Dept. of Agriculture
2222 West 2300 South
P.O. Box 30010
Salt Lake City, UT 84130
Telephone: (801) 524-5856

Step II

A. Analyze all pertinent background information, including small-scale photo index sheets and map index information, to establish the boundaries of the study area.

B. Order all relevant large-scale aerial photographs and maps providing coverage of the study area. Order all photos that may have been taken of the area at different times.

1. The scales of the photographs may vary according to when they were taken. The predominant scale factor prior to the 1970s was 1:20,000, but beginning in the 1970s, the new coverage has been mostly acquired at 1:40,000 or smaller scales. Although the original aerial photographs may have been taken at a small scale, new techniques allow users to order a good enlargement of a specific photo.

2. Color and color infrared photographs are considered best for analysis. Black and white photographs -- the only type of film available for the early aerial survey programs -- can also be used.

Step III

A. Analyze the large-scale aerial coverage and maps and the background information to identify and locate sites, site perimeters, and leachate outbreaks.

B. Aerial photographs present a permanent unbiased record of the landscape at a specific time. A skilled photo interpreter can locate features that indicate a site, its perimeter, and/or a leachate outbreak(s) by carefully examining a number of photographs taken of a specific area over a period of time. In some cases, the actual disposal operation may have been photographed. The photographs may be analyzed individually or in pairs. If stereoscopic coverage of the area is available, magnification is desirable.

1. The interpreter should look for the following features in the aerial photographs:

a. Surface subsidence and unnatural surface depression(s).

b. Lack of vegetation; vegetation which varies in type or species from the surrounding vegetation; stunted or dead vegetation.

c. Accumulation of metal, glass, paper, rubber, plastic, or other items that may have been disposed of on the surface of the ground.

d. Soil type, color, or texture differing from the surrounding soils.

e. Unnatural topographic elevations.

f. Appearance of leachate (colored liquid) on the surface of the soil or entering surface waters.

g. Dead-end or abandoned roads.

h. Early loss of snow or lack of snow in comparison to the surrounding area.

i. Unnatural drainage patterns.

2. Large-scale aerial photos provide a good base on which to plan field work.

Step IV

Field check the sites located in Step III.

A. Locate and mark disposal sites and as much of their perimeters as possible on the ground and on overlays for the aerial photographs.

B. Locate leachate outbreak(s), and mark the sites on the ground and on the photo overlays.

1. The optimum time for locating leachate outbreaks is during wet periods (when the maximum amount of leachate production should be occurring) or soon thereafter.

2. Odors may help the field crew locate the outbreak(s).

C. Safety should be an important consideration when investigating a disposal site, since there may be toxic and/or hazardous substances in the area.

Step V

Obtain aerial photographic coverage of the study area if the program's funding will permit it.

A. Use film and/or filter combinations that will record the most detail about the study area's feature(s).

1. Color and color-infrared film will probably be adequate under most conditions.

B. The size of the study area and the program's budget will determine the photographic scale and film format.

1. A scale of 1:5000 or larger is preferable for detecting leachate contamination. Smaller scales are acceptable for site and perimeter location.

C. The aerial photography program should be conducted during the season of the year when the feature(s) being recorded for detection purposes is most pronounced in the study area.

D. Several Government agencies can help perform the aerial photographic operations. All such activities should be coordinated through the installation's Major Command.

1. The United States Environmental Protection Agency can plan and perform aerial photographic operations. For information, contact:

Environmental Photographic Interpretation Center
U.S. Environmental Protection Agency
P.O. Box 1587
Vent Hill Station
Warrenton, VA 22186
Telephone: (703) 557-3110

Environmental Monitoring and Support Laboratory
U.S. Environmental Protection Agency
P.O. Box 15027
Las Vegas, NV 89114
Telephone: (702) 798-2100

2. A U.S. Army Mohawk Reconnaissance Group located at Fort Huachuca, AZ, as well as other military reconnaissance units, can perform remote sensing operations, including photographic. For information, call the Mohawk Reconnaissance Group Operations Officer at (602) 538-5652.

E. Several commercial firms in the United States perform remote sensing operations. For a list of commercial firms offering such services, contact the American Society of Photogrammetry, 105 North Virginia Avenue, Falls Church, VA 22046 (Telephone: (703) 534-6617).

F. Military and civilian personnel at the installation can take photographs of the study area. Eastman Kodak Company publishes several books and pamphlets that contain a variety of information regarding this type of photography. For an index of these publications, contact Eastman Kodak Company, Department 454, 343 State Street, Rochester, NY 14650 (Telephone: (716) 722-2599; 722-2924; 722-2305).

G. Several remote sensing techniques can be used to locate abandoned disposal sites, site perimeters, and/or leachate outbreaks. Most of these are being tested to determine how effective they are for these functions under various conditions. The sensors or techniques include, but are not limited to:

1. Ground penetrating radar
2. Thermal scanner
3. Multispectral scanner
4. Metal detection
5. Seismic detection
6. Soil resistivity.

H. The limitations of sensors and remote sensing techniques for locating disposal sites, perimeters, and/or leachate are related to a number of factors, including:

1. Size of the study area
2. Depth and type of cover material
3. Size and type of materials buried
4. Age of the disposal site and the degree of waste decomposition
5. Type, density, and size of the vegetation covering the site
6. Funding level for the study
7. Availability of skilled photo/image interpreters
8. Time of day, season of the year, and climatic conditions.

Step VI

Several Federal organizations will help DA personnel with problems associated with abandoned or operating disposal sites. For information or technical assistance, contact the Team Leader, Water Quality Management Team, Environmental Division, U.S. Army CERL, P.O. Box 4005, Champaign, IL 61820 (Telephone: Commercial: (217) 352-6511, or FTS: 958-7287).

On-Site Inspections

The importance of on-site inspections cannot be overemphasized. The types of wastes accepted and the rate of filling should be documented for operating landfills. Operating procedures, such as lift thicknesses, method and degree of compaction, type of cover material and thickness, and surface run-on control from adjacent areas will have a marked effect on potential leachate production. The on-site survey allows the investigator to document important local topographic and geologic site features, groundwater use, and surface waters near the landfill, and to locate the presence of leachate as indicated by seeps, vegetative anomalies, visual evidence of surface water contamination, etc. A surveying book or similar permanently bound volume should always be used for recording data.

Site Topography, Hydrology, and Hydrogeology

Topographic, hydrologic, and geologic information must be collected for each site.

Area topographic information can be obtained from the U.S. Coast and Geodetic Survey quadrangle sheets and aerial photographs, if available. These sources can be supplemented by field surveys, if necessary.

Area subsurface geologic information can be obtained from U.S.G.S. regional offices, state geological survey offices, from an analysis of logs from existing wells in the area, or from test borings drilled specifically for this purpose adjacent to the landfill site. Soil types in the landfill area can be determined from maps available from U.S. Soil Conservation Service regional offices and from State and county agricultural services.

Historical data for area precipitation should be collected from weather stations immediately adjacent to the landfill area under investigation and analyzed. These data can be obtained from the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, and the Environmental Data Service in Asheville, NC. Station data remote from the landfill sites can be extrapolated to the desired location by use of Thiessen's or other established extrapolation procedures. If available, a recording rain gauge can be placed at the site if long-term monitoring is anticipated.

Evapotranspiration rate for use in the water balance computations can be computed by the method of Thornthwaite and Wather[61] or other methods more appropriate for the regional location of the installation.[62] Estimates of this hydrologic factor can also be obtained from State and county agricultural services and from regional offices of the U.S. Geological Survey.

Area Ground and Surface Water Inventory

Ground and surface water use and quality should be surveyed in the vicinity of each landfill site. Existing water supply wells should be checked against National Primary and Secondary Drinking Water Standards (Table 17). If historical data are available for any of the area wells, this information should be collected and analyzed.

Surface water quality data should be obtained from a minimum of two points in the area adjacent to the landfill. Background data can be obtained

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[61] C. W. Thornthwaite and J. R. Wather, "Instructions and Tables for Computing Potential Evapotranspiration and the Water Balance," Publications in Climatology, Vol 10, No. 3 (1957).

[62] J. L. McGuinness and E. V. Bordne, Comparison of Lysemeter-Derived Potential Evapotranspiration With Computed Values, Agricultural Research Service, Technical Bulletin No. 1452 (U.S. Government Printing Office, March 1972).

by analyzing water samples at a point upstream beyond the influence of any leachate being generated by the landfill site. A second sampling point can be located immediately downstream from the landfill boundary. A suggested list of quality parameters to be measured includes specific conductance, pH, alkalinity, temperature, chloride, iron, color, turbidity, and chemical, oxygen demand (COD).

The inventory should also include details regarding all other potential sources of ground and surface water contamination, such as industrial sources, within the vicinity of the landfill. Samples of all leachate seeps discovered during the investigations should be extensively analyzed for physical, chemical, and biological characteristics. Table 18 provides a list of common leachate indicators.

Assessment of the Pollution Potential of a Landfill Site

Generally, after the necessary background information has been collected and analyzed, it will be possible to assess a given site's pollution potential on the basis of one or more of the following conditions:

1. The detection of leachate seeps as a result of aerial photographic and/or on-site surveys

2. The degradation of ground and surface water quality in the vicinity of the landfill site

3. Suspected leachate production based on water balance computations (see the following section).

Water Balance Computations

Computations based on the water balance method can be used to estimate the quantity of leachate produced under a given set of landfill site and climatological conditions. The literature[63] provides an excellent discussion of the method, as applied to sanitary landfills, and example computations. The following paragraphs summarize the principles of the method, assumptions employed, and practical use in assessment of the pollution potential from operating and abandoned landfills.

The water balance method, as presented by Fenn, et al., allows the investigator to estimate both the quantity of leachate which can be generated over a selected time increment and how soon it will appear after placement of final cover. As presented, the method is based on a site exercising the following modern sanitary landfill design practices:

1. Surface run-on from adjacent areas is routed away from the landfill site

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[63] D. G. Fenn, K. J. Hanley, and T. V. DeGeare, Use of the Water Balance Method for Predicting Leachate Generation From Solid Waste Disposal Sites, EPA/530/SW-168 (EPA, October 1975).

Table 18

Leachate Indicators

Physical	Chemical: Organic	Chemical: Inorganic	Biological
Appearance pH Oxidation-reduction Potential Conductivity Color Turbidity Temperature Odor	Phenols Chemical Oxygen Demand (COD) Total Organic Carbon (TOC) Volatile Acids Tannins, Lignins Organic-N Ether-Soluble (Oil & Grease) MBAS Organic Functional Groups as Required Chlorinated Hydrocarbons	Total Bicarbonate Solids (TSS, TDS) Volatile Solids Chloride Sulfate Phosphate Alkalinity and Acidity Nitrate-N Nitrite-N Ammonia-N Sodium Potassium Calcium Magnesium Hardness Heavy Metals (Pb, Cu, Ni, Cr, Zn, Cd, Fe, Mn, Si, Hg, As, Se, Ba, Ag) Cyanide Fluoride	Biochemical Oxygen Demand (BOD) Coliform Bacteria (Total, Fecal) Fecal Streptococcus Standard Plate Count

2. The landfill is sited to exclude groundwater inflow into any portion of the fill.

The first assumption is probably invalid for almost all of the Army's abandoned and operating landfills. Therefore, the variable described in (1) should be included in the water balance computations if field investigations verify its occurrence.

The second assumption may or may not be valid for a given site. Unless a field measurement or other data is available to determine the magnitude of groundwater inflow, it should be assumed to be negligible.* This will provide a conservative estimate of the amount of leachate which can be produced by the landfill site under investigation.

On this basis, the potential for leachate production can be estimated from a water balance computed on an idealized one-dimensional landfill slice (Figure 6). As shown, the idealized landfill consists of two distinct phases: a final cover and the solid waste mass. The influence of the daily cover on the system is assumed to be negligible. Basically, a water balance for the cover layer stipulates that all precipitation (P) falling on the area will infiltrate the soil cover or run off (R/O) to surrounding site areas. Surface runoff (and run-on) can be quantitatively related to precipitation by standard hydraulic computations[64] based on factors such as surface soil type, vegetative cover, and local topography. All the water that appears on the landfill surface as precipitation or run-on that does not leave the system as run-off, represents infiltration (I) into the soil cover medium. Depending on such factors as type of vegetative cover, ambient soil moisture storage conditions (ST), surface soil type, climatic conditions, and the cover's field capacity, infiltrated water will be distributed as water available for evapotranspiration (AET), changes in soil moisture storage, or percolation (PERC) water available for leachate generation. The basic equation defining these variables is:

$$\text{PERC} = \text{P} - \text{R/O} + (\text{run-on}) - \Delta\text{ST} - \text{AET} \qquad [\text{Eq } 1]$$

The field capacity of a soil or solid waste is defined as the maximum moisture content which the material can retain in a gravitational field without producing downward percolation. In addition, as the soil moisture storage reaches field capacity, the actual AET will approach the potential evaporation (PET) of the vegetative cover/surface soil system. Therefore, when the soil cover's field capacity has been reached, no further increases in soil moisture storage can be expected, and AET = PET. Under these conditions, Eq 1 reduces to

$$\text{PERC} = \text{P} - \text{R/O} + (\text{run-on}) - \text{PET} \qquad [\text{Eq } 2]$$

Similarly, a water balance computed on the solid waste phase is given by the equation:

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* Groundwater inflow is such a common occurrence that an effort should be made to insure that it is not playing a major role in the water balance method.

[64] V. T. Chow, ed., Handbook of Applied Hydrology; A Compendium of Water Resources Technology (McGraw-Hill, 1964).

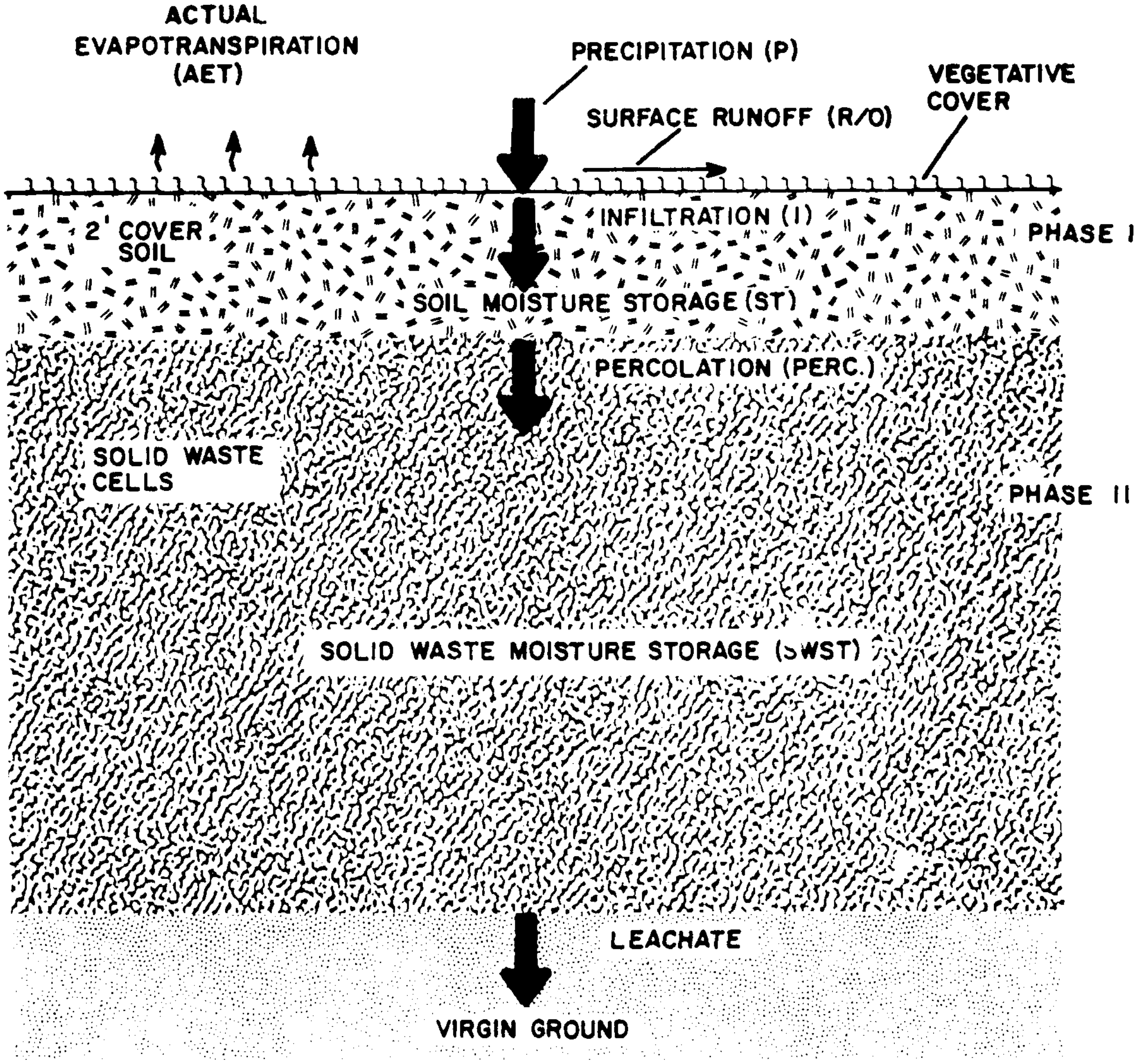

Figure 6. Sanitary landfill water balance.

$$LEACHATE = PERC - \Delta WST \qquad [Eq\ 3]$$

where SWST is equal to the change in solid waste moisture storage.

Tests performed on municipal solid waste have shown that its moisture content upon deposition ranges from 10 to 20 percent by volume. The field capacity of municipal solid waste has been measured and has been found to vary from 20 to 35 percent by volume. If average values for these two factors are assumed, no leachate will be generated until the percolation water exceeds approximately 130 mm of water per meter of solid waste depth. Once the mass of solid waste has reached field capacity, all percolated water will appear as leachate.

It is recommended that available monthly average precipitation data be used in computing the potential leachate production at a given site.

4 LEACHATE MONITORING

If leachate production is observed or is likely to occur, monitoring must be started to determine the effect a leaching landfill will have on surrounding surface and groundwater. For this program to be effective, several hydrological conditions must be evaluated both before and during monitoring: (1) nominal depth of the groundwater table, (2) seasonal groundwater table fluctuations, (3) groundwater velocity, (4) groundwater direction, (5) present and potential use of groundwater and surface water bodies, (6) existing surface and groundwater quality, (7) interrelationships between groundwater and surface water bodies, (8) surface water body ecology, and (9) subsurface soils and rock characteristics as they would affect groundwater movement patterns and quality.[65]

Sampling and analysis techniques, duration and method of sample storage, and other physical and environmental conditions of the site and laboratory will have definite effects on the sample analysis results.[66] These conditions should be documented. Two types of sampling wells can be considered for monitoring leachate. Piezometer wells which sample only at a certain depth -- preferably that of the leachate phase -- can be used. An alternative to the piezometer well is the basic well point, which draws water from many depths and provides a composite from a large vertical interval of water. However, neither of these wells can be depended on to give a clear picture of leachate contamination of an aquifer. However, if the background (upstream) monitoring well shows that water in the aquifer is of acceptable quality, but samples from the "downstream" wells show contaminants at concentration levels exceeding or approaching primary drinking water standards, then a valid inference can be made that the landfill presents a leachate problem.

Groundwater monitoring is used not only to identify a leachate problem, but also to check the effectiveness of any remedial actions and to assure an uncontaminated aquifer. This latter concern will require attention for perhaps several decades after the landfill has been closed. Such long-term monitoring considerations may influence selection of equipment, the choice of a monitoring site that is accessible after the landfill is closed, and other factors which will affect the initial cost of establishing a monitoring system.

Certain precautions should be taken when a sampling well is installed. For example, anaerobic conditions should be maintained at the bottom of the well; this is normally done by packing the sampling pipe with a bentonite clay slurry above the sample collection area. The screened sampling portion of the collection pipe is packed with gravel, and the pore size on the well screen should be large enough that it does not affect the concentration of suspended solids, phosphates, and heavy metals by acting as a filter. One type of EPA

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[65] A. A. Fungaroli, "Hydrogeologic Factors in Landfill Management," Land Application of Residual Materials, Engineering Foundation Conference 1976 (American Society of Civil Engineers, 1976), pp 47-52.

[66] E. S. K. Chian and F. B. DeWalle, Compilation of Methodology Used for Measuring Pollution Parameters of Sanitary Landfill Leachate, EPA-600/3-75-011 (EPA, 1975), p 33.

sampling well uses a 3.2-cm-diameter plastic pipe placed in a 14-cm-diameter hole; the bottom 2.7 m of the pipe is drilled with 0.32-cm-diameter hole. The bottom of the pipe is placed 3 m below the water table and packed with 3 m of gravel. One last precaution in well installation is designed to accommodate the sampling technique that will be used. The influent areas must be constructed so that the entire cavity can be emptied during sampling; i.e., no water that could mix with the next sample is left in the well hole below the sampling pipe. To obtain a more representative sample from the aquifer, discard the liquid first emptied from the cavity, and use the sample taken from the liquid that immediately fills the well hole.

Samples of groundwater containing leachate should be analyzed as soon as possible (within hours of the sampling). If this is not possible, the samples should be stored under anaerobic conditions, kept cold, and stoppered tightly. When surface samples are analyzed, soil should be removed by sedimentation rather than filtration, which might alter analytical results by removing heavy metals and phosphates.

The number of parameters to be tested, if not determined by state laws, will depend on the time and resources of the sampling personnel. First priority should be given to tests for conductivity, color, and pH; next, chemical oxygen demand (COD) and total solids; and finally, total organic color, free volatile fatty acids, BOD, organic nitrogen, and the specific anions, cations, metals, and organics. A GC/MS scan may be desirable to determine if the leachate contains pollutants categorized as "priority" by the EPA. Analyzing many of the parameters identified above demands a sophistication of both instrumentation and technique not usually available at a military installation. If a monitoring program is undertaken, consideration should be given to using external analytical services either from Army, other government, or contract sources. (Refer to the Points of Contact section, p 89.)

5 CONTROL OF LANDFILL LEACHATE PRODUCTION

The key to minimizing leachate production is severely limiting the amount of water entering a landfill disposal site. To be effective, methods of water control must provide for eliminating its contact with the solid waste. If the water control methods are inadequate, the leachate pollution problem may become more severe because a higher strength leachate will be produced. Before attempting to control leachate production, installation personnel must have a thorough understanding of the site's climatic and geological characteristics. A combination of the following water control techniques may be required to sufficiently minimize leachate production. Figure 7 shows various moisture sources. Much of the following information was obtained from the EPA Guidance Manual for Minimizing Pollution from Waste Disposal Sites.[67]

Moisture Control of Solid Waste Stream

The average solid waste stream's moisture content is about 20 percent. For an operational landfill, it is a good practice to restrict disposal of sludges and slurries to maintain that percentage. Although inherent moisture in the refuse is a source of leachate, it is not one of the main sources of water entering a landfill.

Surface Water Control

Surface water is the most highly visible and often the easiest of the two main sources of water to limit. A major method of surface water control is to provide good run-off characteristics by insuring the shortest water flow patterns. To accomplish this, soil material should be graded to produce a mound effect, using a 6 to 12 percent slope, with a maximum of 18 percent, depending on soil type. This native soil material, properly graded, is a primary part of surface water control and should provide a minimum of 24 in. (609.6 mm) of cover over the refuse. Use of a cover material having low permeability characteristics is a stringent requirement, and locally available clayey soils are ideal for this purpose. County Soil Conservation Service agencies can provide information on material availability and source. If native seal materials are not commercially available, bentonite, asphalt, bituminous concrete, or plastics may have to be used. The latter materials are expensive, and special protection may be required to insure their seal. When a seal is applied to a landfill site, gas generated by the refuse decomposition must be collected and vented. After gas generation has been quantified and qualified by means of a sampling program, a collection and venting scheme should be incorporated into the seal operation. Revegetation and the associated support soil required (18 in. [457.2 mm] minimum) stabilize the surface and protect the seal material, as well as provide aesthetic acceptance. Vegetation also seasonally increases the evapotranspiration of precipitation moisture. When revegetating, the choice of plants should be restricted to those with shallow root systems in order to decrease the chance of seal penetration. Surface

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[67]A. L. Tolman, et al., Guidance Manual for Minimizing Pollution From Waste Disposal Sites, EPA-600/2-78-142 (EPA, August 1978).

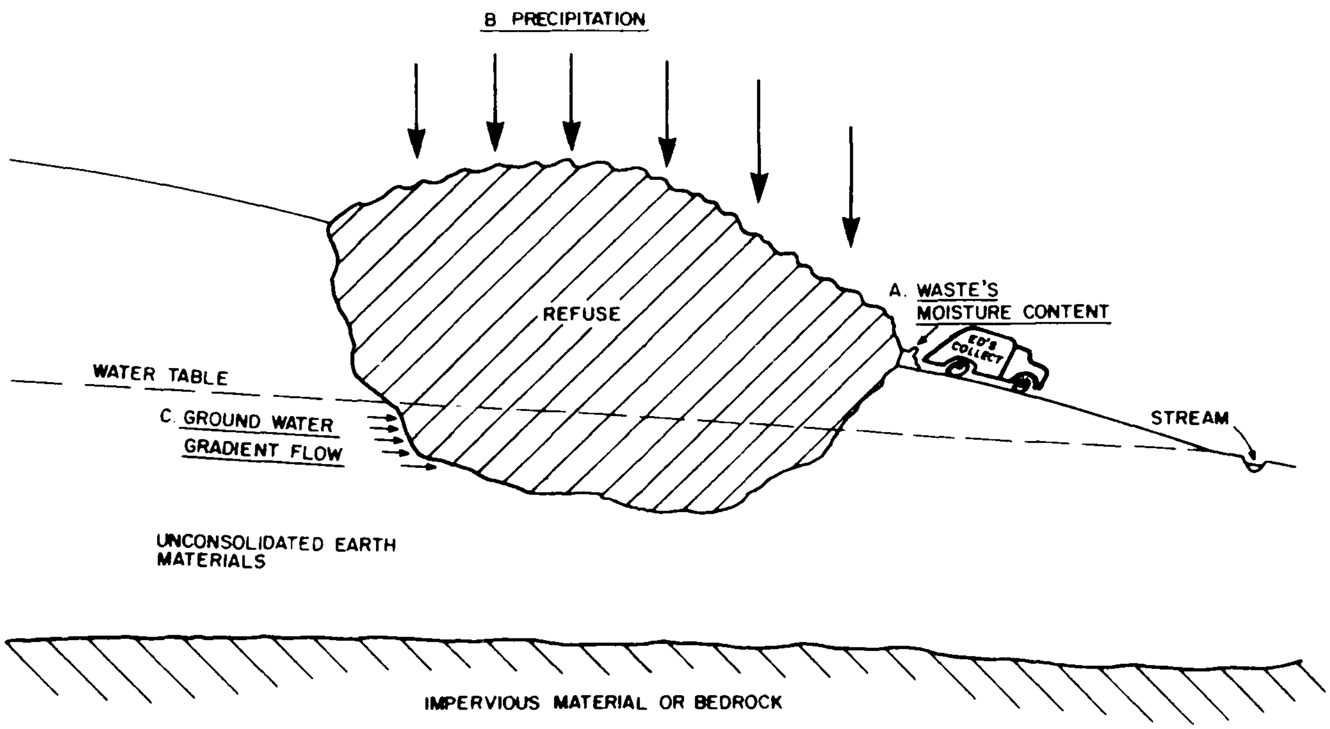

Figure 7. Moisture sources for a landfill.

water control may also be required for the area surrounding the landfill proper; an example is the use of diversion ditches of the standard highway construction type in locations where the disposal site receives surface water from an upslope area. Figure 8 illustrates various surface water controls and types of gas venting.

Groundwater Control

Control of groundwater is usually the most difficult, since it must be diverted from entering the disposed refuse. Diversion is required when the disposal site is below the water table. The two primary methods of groundwater diversion are passive and active barriers. Passive barriers, such as bentonite slurry trenches constructed to bedrock or another low permeability layer, can be used effectively. Other examples of passive barriers are grout curtains and sheet pilings. Figure 9 illustrates the use of a slurry trench. Successful control requires a thorough knowledge of the geology and the groundwater flow characteristics. Examples of active barriers are shallow well points or deep wells with drains; these can be constructed either by injecting water into an aquifer to provide a groundwater barrier or by extracting water to lower the water table. The first method is more popular for controlling groundwater, while the latter is used primarily for leachate diversion and collection. Although active barriers usually have lower capital costs than passive barriers, high operation and maintenance costs tend to restrict their use. Figure 10 illustrates the use of an active extraction system.

Leachate Containment

Containing leachate within a disposal site usually requires, at minimum, bottom sealing of the fill area. If the seal is not installed before refuse deposition, its emplacement will be very costly and will usually require digging through the disposed refuse. The post-deposition process requires drilling or driving tubes through the landfilled material and pumping a grout-type seal to form a barrier or curtain that will curtail moisture movement. Figure 11 shows this process after installation. Caution must be exercised in selecting the grout/liner material because it will be in direct contact with the high-strength leachate, which will deteriorate certain substances. Although this method can be used for groundwater control, it is usually reserved for leachate containment because of the high capital costs involved.

Leachate Control/Collection

Water control is the key to leachate production. The amount of water present dictates the leachate quantity and, together with the refuse characteristics, the contamination potential. Therefore, water control techniques directly control the type and extent of the collection system. Ideally, stringent water control could negate or minimize leachate production to the extent that no further action would be required. In the usual case of reduced leachate production, induction of uncontaminated water into the aquifer is a barrier to leachate movement; however, this technique is costly, because it involves constructing a series of well points or deep wells for the injection

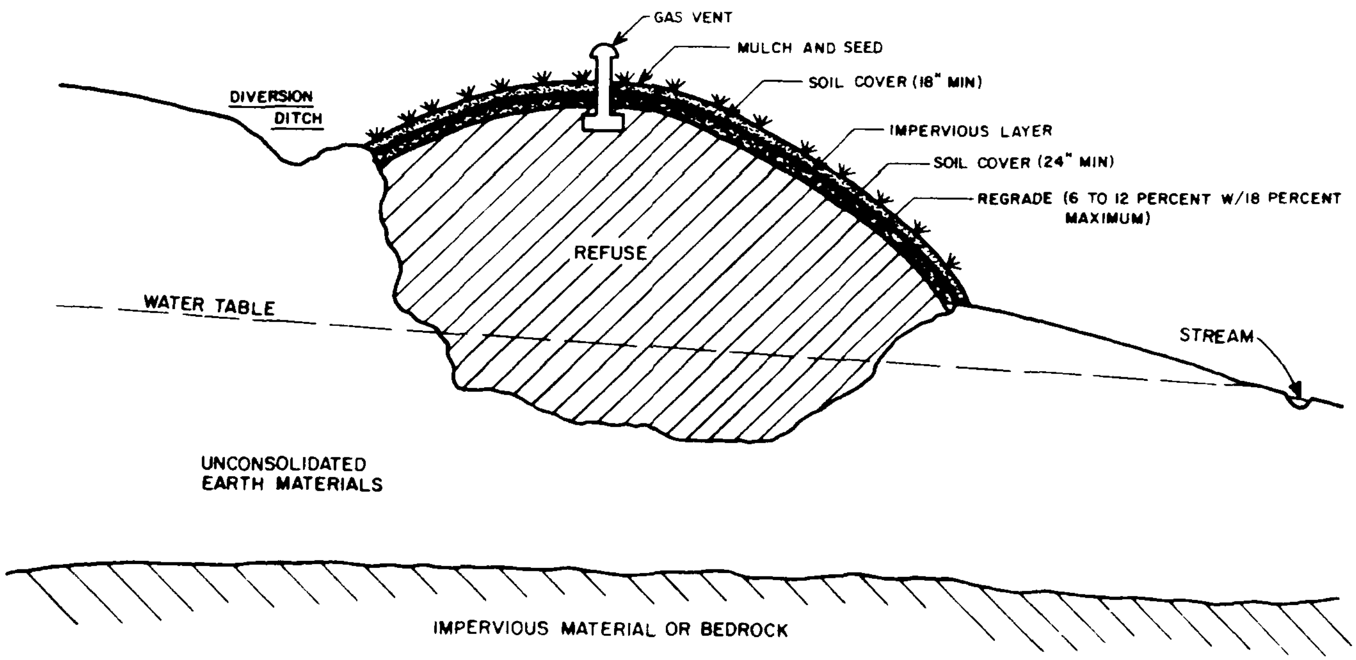

Figure 8. Surface water control.

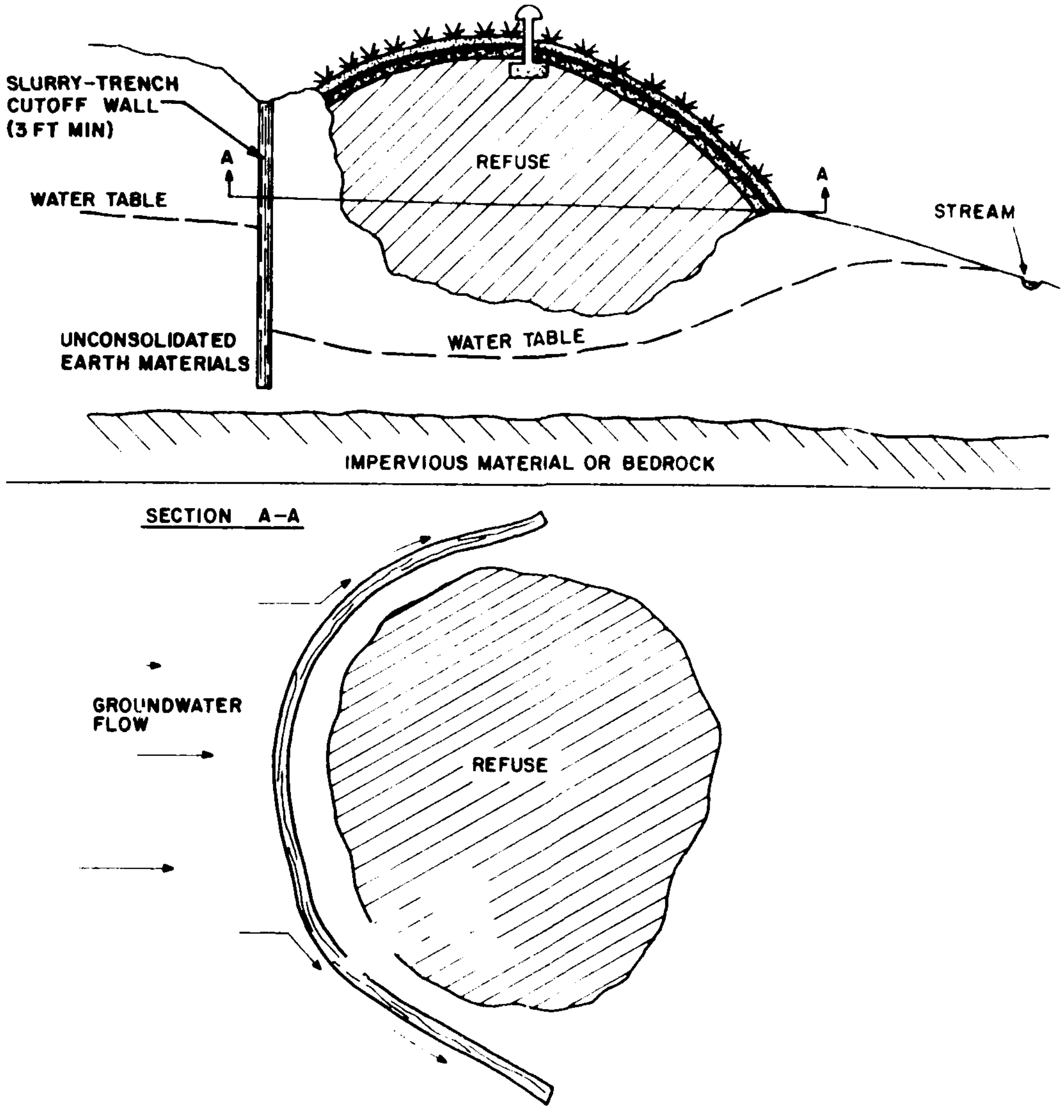

Figure 9. Passive groundwater control.

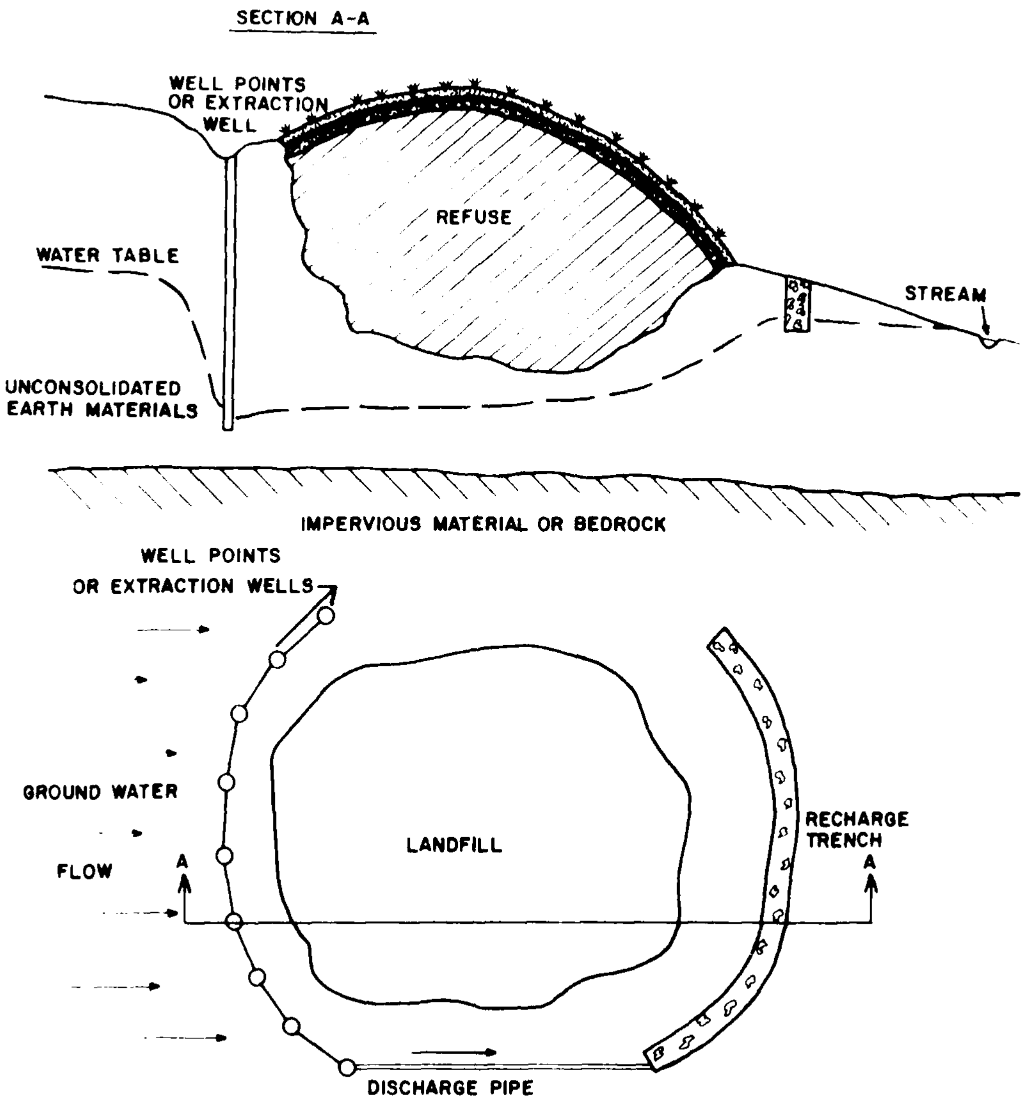

Figure 10. Active groundwater control.

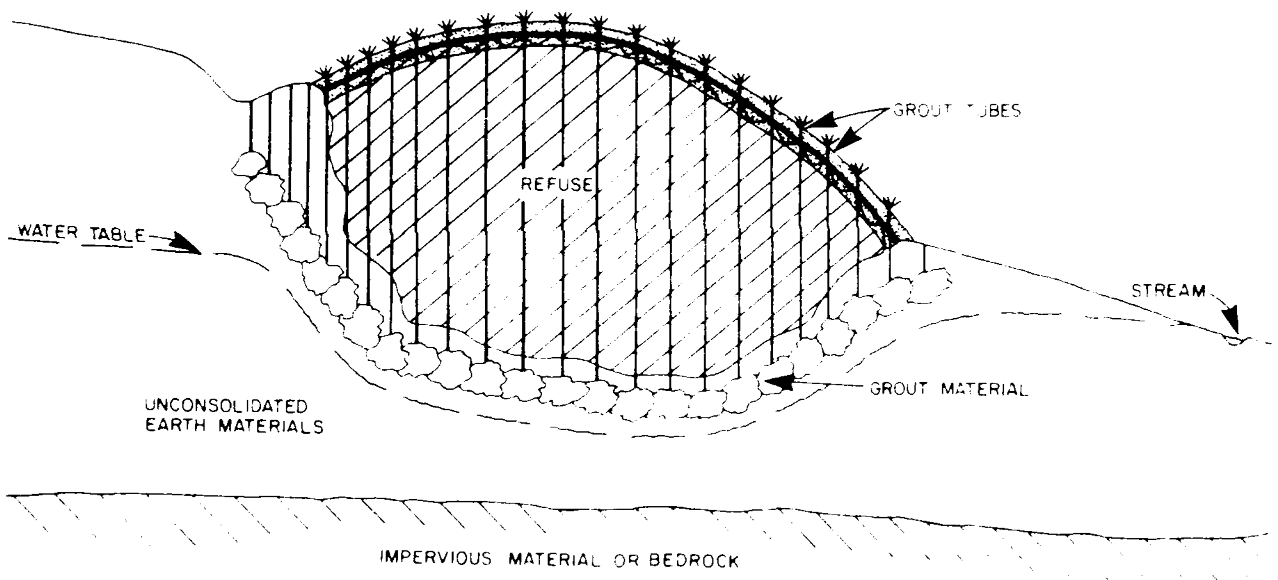

Figure 11. Post deposition landfill seal.

and a series of well points for extracting the leachate. Therefore, it is used only for protecting an important water source. Another control technique is chemical immobilization, accomplished by either chemical destruction or stabilization or by chemical injection. Chemical destruction or stabilization has been used to form landfill covers by chemically fixing a sludge or slurry. This method has not been used in-situ because of the requirements for a relatively homogeneous material and uniform mixing. Chemical injection methods have been used successfully in cases where specific pollutants that respond to chemical control can be neutralized or immobilized; however, success has been restricted to industrial waste landfills, since common landfills contain too wide a variety of potential contaminants for this method to be used.

Costs of Control

Because the economic situation of an area or the country as a whole changes constantly, specific control costs cannot be generated. However, Tables 19, 20, and 21 provide a basis for comparison, giving the relative costs of various control methods. However, a relative cost comparison for well points, deep well extraction, and injection are not possible because both the capital and O&M costs for those methods are site-specific. The cost for chemical use is also site-specific and depends on the type of waste being disposed.

Table 19

Relative Costs for Surface Water Control
(Metric Conversion Factor: 1 in. = 25.4 mm)

A. Soil Cover of Refuse (24-in. min.) - This local excavation cost depends on availability, haul distance, spreading, etc.

B. Surface Seals

1.	Clay Cap (6-in.)	1.00 unit
2.	Clay Cap (18-in.)	1.28 unit
3.	Bituminous Concrete (1.5-in.)	1.35 unit
4.	Bituminous Concrete (5.0-in.)	1.83 unit
5.	Soil-Cement (5.0-in.)	1.34 unit
6.	Lime-Stabilization (12-in.)	1.34 unit
7.	PVC Membrane (30-mil)	2.43 unit

C. Drainage Field Above Cover 0.33 unit

D. Soil Cover of Seal (18-in. min.) -- This is also a local excavation cost.

E. Revegetation -- This is a local cost dependent on native planting and climatic conditions.

Table 20

Relative Costs for Groundwater Control

A.	Slurry Trench (60 ft [18 m] deep and 3 ft [.9 m] wide)	1.00 unit
B.	Grout Curtain (60 ft [18 m] deep)	2.09 unit to 14.63 unit
	1. Portland Cement	2.09 unit
	2. Silicate Base (15%)	2.42 unit
	3. Lignin Base	3.45 unit
	4. Silicate Base (30%)	4.60 unit
	5. Silicate Base (40%)	6.06 unit
	6. Urea Formaldehyde Resin	12.54 unit
	7. Acrylamide (AM-9)	14.63 unit
C.	Sheet Piling (60 ft [18 m] deep)	1.20 unit

Table 21

Relative Costs for Leachate Containment

A.	Grout Bottom (4-ft Portland Cement - 20 percent void soil)	1.00 unit
B.	Grout Bottom (4-ft Portland Cement - 30 percent void soil)	1.50 unit
C.	Grout Bottom (6-ft Portland Cement - 20 percent void soil)	1.50 unit
D.	Grout Bottom (6-ft Portland Cement - 30 percent void soil)	2.24 unit

(Exploratory boring cost is additional.)

6 LEACHATE TREATMENT AND DISPOSAL

Leachate Interception

Even after all feasible steps to exclude moisture from the landfill have been taken, leachate is often still detected in the monitoring wells and must be intercepted and removed. Leachate can be intercepted more easily in new landfills because of the impervious layer now required beneath the refuse, and if collection systems are installed before refuse deposition. However, intercepting the leachate in an old or closed landfill is much harder. Often, collection wells using either gravity or suction must be constructed within the landfill perimeter in order to create a neutral or negative hydraulic gradient that will prevent outflow from the landfill.

Leachate Treatment Processes

Once leachate is intercepted and removed from the landfill environs, it must be treated appropriately to reduce its objectionable characteristics and to permit disposal. The central problem in treating leachate is that because of the extreme variability of the liquid's composition and flow, it is not possible to prescribe one process which will effectively and economically treat all leachates at all times. Successful treatment will almost always require a wastewater characterization study initially. Results of the study generally will indicate the need for a combination of processes whose relative importance will vary with the landfill's age.

Chian and DeWalle[6] studied the aerobic biodegradation of 5-month-old leachate collected from a lysimeter; they identified four distinct stages in the microbial stabilization of the waste. High molecular weight carbohydrates were used first, and then fatty acids. The catabolites of fatty acid metabolism accumulated as the acids were broken down. In the third stage of leachate stabilization, these catabolites, such as amino acids, were consumed. Humic carbohydrate-like materials (molecular weight above 5000) accumulated during the catabolite use. During the last stage of biodegradation, these materials were removed, leaving only fulvic-acid materials (molecular weight between 500 and 10,000). Both the humic and fulvic acid materials were relatively inert to biological breakdown.

These findings are important because the stages identified are also apparent in leachate samples collected from landfills of different ages and having different degrees of waste stabilization. When treatment studies presented in the literature are examined in light of these relationships, it is apparent that biological treatment has been most effective when applied to young leachate (i.e., leachates rich in carbohydrates and fatty acids) while physicochemical treatment has been most successful with more mature leachate (rich in humic or fulvic materials).

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[6] E. S. K. Chian and F. B. DeWalle, Compilation of Methodology Used for Measuring Pollution Parameters of Sanitary Landfill Leachate, EPA-600/3-75-011 (EPA, 1975), p 33.

Although the characteristics of leachate, and hence, their preferred treatment is correlated with landfill age, the more basic criterion is the degree of the waste's stabilization. Using the gross characteristics of a leachate, Chian and DeWalle have explored a number of methods for predicting the efficiency of various treatment processes. Since the concentrations of the various leachate constituents can fluctuate greatly over a short time, they found it best to use ratios of concentrations in predicting waste stabilization. The best indicator of degree of stabilization was found to be the COD/TOC ratio. As the organic carbon of the waste becomes more highly oxidized, it is less readily available as an energy source for microbial growth. Biological treatability decreases correspondingly as the COD/TOC ratio falls from about 3.3 for a young leachate to as low as 1.16 for an older one. Table 22 presents the relative performances of various biological and physical/chemical treatment trains tested by Chian and DeWalle.[69]

Chian and DeWalle have identified the following guidelines for selecting appropriate technology to treat leachate. Leachate which can be treated biologically is generated during the first 5 years of the landfill's use; the intermediate phase corresponds to an age of 5 to 10 years. Leachate generated after approximately 10 years is best treated by physical/chemical methods. These age ranges are very tentative and will depend on such factors as the duration of landfill construction, time for the fill to reach capacity, and refuse density.[70]

Table 23 summarizes the proposed treatment processes for leachate as characterized by four parameters that must be known: COD/TOC and BOD/COD ratios, absolute COD concentration, and age of the fill. These values can form the basis for the preliminary selection of unit processes for pre-design wastewater treatability studies.

Leachate Disposal

The degree of leachate treatment depends on the disposal method chosen. Leachate may require extensive treatment before discharge into a receiving stream; this would be considered a point discharge subject to effluent limitations as outlined in a National Pollutant Discharge Elimination System (NPDES) permit. Leachate can also be partially treated for subsequent combined treatment with sanitary wastewaters in a conventional, secondary treatment plant. Another technique is recycling the leachate onto the landfill. This approach is not feasible where high net production of leachate would outstrip the soil's attenuation capability and the bioactive capacity of landfill organisms. An interesting aspect of this technique is its potential for accelerating waste stabilization in the landfill. Research sponsored by the EPA at the Georgia Institute of Technology is using this approach. The investigation reports, "Recirculation of leachate through a landfill promotes a more rapid development of an active anaerobic population of methane formers, increases the rate and predictability of biological stabilization of the readily

[69]E. S. K Chian and F. B. DeWalle, Evaluation of Leachate Treatment; Volume 1: Characterization of Leachate, Environmental Protection Technology Series, EPA 600/2-77-186a (EPA, September 1977), p 25.

[70]Chian and DeWalle, p 30.

Table 22

Performance of Leachate Treatment Systems

Treatment Process	Leachate (gal/min)	Typical Effluent (COD) (mg/L)	
		25 000 mg/L Influent BOD	5000 mg/L Influent BOD
Activated Sludge (AS):	20	30	30
Combined Treatment	2	30	30
Aerated Lagoon (AL)	20	500	100
Anaerobic Filter (AF)	20	1500	300
	2	1500	300
AL+Sand Filter (SF)+	20	125	25
Activated Carbon (AC)	2	125	25
AL+SF+AC+Reverse	20	25	5
Osmosis (RO)*	2	25	5
AF+SF+AC	20	375	75
	2	375	75
AF+SF+AC+RO*	20	75	15
	2	75	15

* After RO treatment, the total dissolved solids (TDS) decreased to 300 mg/L and 60 mg/L for influent leachate BOD concentrations of 25 000 mg/L and 5000 mg/L, respectively.

Table 23

Proposed Relationship Between COD/TOC, BOD/COD, Absolute COD, and Age of Fill to Expected Efficiencies of Organic Removal From Leachate

Character of Leachate				Effectiveness of Treatment Processes						
COD/ TOC	BOD/ COD	Age of Fill	COD in mg/L	Biological Treatment	Chemical Precipitation (Mass Lime Dose)	Chemical Oxidation, ($CaCO_2$)	Ozonation (O_3)	Reverse Osmosis	Activated Carbon	Ion Exchange Resins
>2.8	>.05	Young (<5 yr)	>10,000	Good	Poor	Poor	Poor	Fair	Poor	Poor
2.0-2.8	0.1-0.5	Medium (5 yr-10 yr)	500-10,000	Fair	Fair	Fair	Fair	Good	Fair	Fair
<2.0	<0.1	Old (>10 yr)	<500	Poor	Poor	Fair	Fair	Good	Good	Fair

available organic pollutants in the refuse and leachate, and reduces the potential of environmental impairment. Leachate recirculation may enhance treatment efficiency so that the time required for biological stabilization of the readily available organic pollutants in the leachate can be reduced to a matter of months rather than years..."[71] These promising results are supported by a Sonoma County, CA, field trial.[72] Thus, using this approach, a landfill could be declared stabilized after some definite period of time, and perpetual monitoring and maintenance could be stopped.

Leachate Control Costs

Leachate control can be very expensive. Monitoring wells reportedly can cost $25 per foot of depth ($75/m), and sampling from one well can cost $1000 annually.[73] Planting vegetation to prevent soil erosion and regrading a landfill site to prevent precipitation ponding and divert surface water can cost from $151,000 to $278,000 for a typical 4-hectare site.[74] Costs for surface sealing, using various natural and synthetic sealants, can range from $140,000 to $575,000 for a 4-hectare site. The costs vary greatly, depending on the type and thickness of the sealing material. Slurry-trench techniques for diverting groundwater range from $294 to $495 per linear foot for a trench 50 ft (18 m) deep and 3 ft (1 m) wide.[75] Grout-curtain diversion costs are highly variable due to the variety of chemical and natural grouts available. A typical cement grout-curtain wall 518 m long and 18 m deep ranges from $801,300 to $2,003,000.[76] Table 24[77] summarizes the costs of leachate treatment using various process trains.

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[71] F. G. Pohland, Sanitary Landfill Stabilization With Leachate Recycle and Residual Treatment, EPA-600/2-75-043 (EPA, 1975).

[72] J. O. Leckie, et al., "Landfill Management With Moisture Control," JEED, Vol 105, No. EE2 (ASCE, April 1979), pp 337-355.

[73] R. A. Paluso, "Well Monitoring at Landfills Can Help Head Off Problems at an Early Stage," Solid Waste Management: 1979 Sanitation Industry Yearbook, Vol 21, No. 13 (1979), p 88.

[74] A. L. Tolman, et al., Guidance Manual for Minimizing Pollution From Waste Disposal Sites, EPA-600/2-78-142 (EPA, August 1978), pp 16-18.

[75] E. S. K. Chian and F. B. DeWalle, Compilation of Methodology Used for Measuring Pollution Parameters of Sanitary Landfill Leachate, EPA-600/3-75-011 (EPA, 1975), p 33.

[76] Tolman, p 24.

[77] Tolman, p 28.

Table 24

Cost Estimates for Leachate Treatment Systems*

Treatment Process	Leachate Flow (gal/min)	(L/sec)	Costs of Treatment: $/1000 gal leachate (3790 L) 25000 mg/L Influent BOD	5000 mg/L Influent BOD
Activated Sludge (AS):	20	1.26	23.6	6.0
Combined Treatment	2	0.126	41.4	11.9
	20	1.26	17.9	4.1
Aerated Lagoon (AL)	2	0.126	31.6	10.0
	20	1.26	22.1(17.9)+	6.8(5.9)
Anaerobic Filter (AF)	2	0.126	43 (38.8)	17.7(16.8)
AL+Sand Filter (SF)+Activated	20	1.26	25.7	7.3
Carbon (AC)	2	0.126	39.9	13.7
AL+SF+AC+Reverse	20	1.26	27.6	9.2
Osmosis (RO)†	2	0.126	44.6	18.4
AF+SF+AC	20	1.26	32.8(28.6)	10.6(9.7)
	2	0.126	54.2(50)	22.0(21.1)
AF+SF+AC+RO	20	1.26	34.7(30.4)	12.5(11.5)
	2	0.126	58.9(54.3)	26.7(25.4)

* Not all treatment processes achieve the same level of effluent quality; therefore, cost comparison between processes is not valid. The data are presented here for magnitude estimation only.

† After RO treatment, the TDS decreased to 300 mg/L and 60 mg/L for influent leachate BOD concentrations of 25 000 and 5 000 mg/L, respectively.

\+ Numbers shown in parentheses indicate the cost of treatment after deducting a credit for methane produced at $1.50/1000 cu ft ($0.053/m^3).

7 POINTS OF CONTACT FOR OBTAINING ASSISTANCE

Several DA laboratories/agencies can assist the FE and MACOM regarding choosing and setting up various types of leachate control systems. Points of contact and brief descriptions of services provided follow.

U.S. Army Construction Engineering Research Laboratory (CERL)

Since 1978, CERL has been involved in a research project, in cooperation with the Waterways Experiment Station (WES), to evaluate the technical and economic aspects of sanitary landfill leachate and gas control at military installations using preventive and remedial measures. CERL is also tasked with developing and pilot testing selected short-range and long-term methods for controlling and treating leachate from abandoned and operating sanitary landfills. Reports will be prepared providing guidance to MACOMS, Districts, and FE personnel. CERL has also begun a "Small Problems Program" through which DA personnel can ask for 16 hours of free assistance to help identify or solve DA-related leachate or gas problems. A related report is also available: Technical Report N-78, Simplified Sanitary Landfill Design, August 1979, by G. L. Gerdes and B. A. Donahue.

A comprehensive, up-to-date reference library of leachate/gas/landfill related documents is stored at CERL that contains a broad subject listing into which publications nave been classified. Category file classifications are as follows:

Analytical Techniques - papers describing the development and/or evaluation of techniques for the chemical, biological, or physical characterization of leachate.

Leachate Characteristics - papers presenting chemical, biological, or physical characterizations of leachate from dumps or sanitary landfills.

Mechanisms of Formation - papers describing the mechanisms by which leachate is formed.

Migration - papers presenting either actual accounts of leachate moving out from landfills or mathematical models of such movement.

Attenuation - papers which describe changes in leachate composition which occur as it moves through the soil.

Collection - papers describing the concentration and removal of landfill leachate, whether from the fill itself or from the surrounding geological formations.

Accelerated Landfill Stabilization - any paper dealing with the accelerated stabilization of landfilled wastes, whether by leachate recycle, mechanical mixing, or admixture of sewage sludge.

Abandoned Landfills - any papers dealing either with the location of abandoned landfills and dumps or with any aspect of their leachate production.

Landfill Perimeter Location - any paper which describes a method for locating the boundaries of active or inactive landfills or dumps.

Monitoring and Detection of Groundwater Pollution - papers presenting the design of groundwater quality monitoring systems and/or the results of their operation; also papers describing methods for delineating groundwater pollution plumes.

Landfill Design and Operation for Leachate Control - papers or manuals of practice which describe methods for preventing or mitigating leachate pollution from landfills (other than treatment, recycling, or proper hydrogeological siting).

Environmental Impact - papers describing the actual or predicted effects of landfill or dump leachate on the environment; also papers describing attempts to mitigate these effects.

Hydrogeological Considerations - papers dealing with the hydrogeological aspects of landfill siting and of leachate pollution prevention.

Secondary Pollutants - papers describing the production of secondary pollutants by landfill leachate (e.g., the mobilization of heavy metals by leachate).

On-Going Research - accounts of leachate-related research which is either still in progress or so recently completed that the results have not yet been published.

Environmental Legislation - proposed and enacted environmental legislation impacting solid and hazardous waste disposal and surface and groundwater quality criteria.

Gas Production Control - papers containing information on the production, migration, and control of gas in landfills.

Other publications may be obtained from the University of Illinois or ordered through the CERL library. For more information, contact CERL, P.O. Box 4005, Champaign, IL 61820; phone 217-352-6511, or Autovon through Chanute AFB. Point of contact is Dr. Ed Smith, team leader of the Water Quality Management Team.

U.S. Army Environmental Hygiene Agency (AEHA)

The Solid Waste Branch AEHA helps Department of Defense installations evaluate existing and proposed solid waste management programs. This assistance includes two major services: (1) on-site evaluation of present sanitary landfill operational techniques, and (2) hydrogeologic and soils analysis for recommending new sanitary landfill sites, as required for obtaining a State sanitary landfill permit. In addition, AEHA will locate and/or install monitoring wells up to a 120-ft (36-m) depth to determine groundwater contamination (i.e., leachate). Soil samples are analyzed at Aberdeen Proving Ground, MD, for permeabilities, densities, soil classification according to the Unified Soil Classification System, specific gravity, and cation exchange capacity, etc.

These services can be requested by the installation MACOM through the Commander, U.S. Army Health Services Command, Attn: HSPA-P, Fort Sam Houston, TX 78234, with an information copy to Commander, U.S. Army Environmental Hygiene Agency, Attn: HSE-ES, Aberdeen Proving Ground, MD 21010. The Commander, U.S. Army Health Services Command will endorse the request with recommended action to the AEHA, which will program requests, by priority, by fiscal year and quarter. All written requests should include an installation point of contact and telephone number.

Telephone consultation can be obtained by contacting Chief, Solid Waste Branch, Autovon 584-4211 (Commercial 301-671-4211) or Chief, Waste Disposal Engineering Division, Autovon 584-2024 (Commercial 301-671-2024).

U.S. Army Waterways Experiment Station (WES)

WES has been involved in several research projects to evaluate problems associated with the generation of leachate and gas in landfills. In cooperation with the EPA, WES has examined the leachate from mixed hazardous industrial and municipal wastes and conducted extensive field investigation on power generation wastes, municipal landfills, and industrial waste landfills. WES has also conducted field gas surveys and established three gas and leachate monitoring systems at Fort Belvoir, VA. In cooperation with CERL, WES is setting up two pilot-scale leachate treatment systems. WES is also doing a design study for a gas control system for a closed landfill.

WES has an extensive information base on landfill design, leachate and gas control, and hazardous waste disposal. More than 30 publications on municipal and hazardous waste disposal technology have been generated from the EPA and Army-sponsored research efforts at WES.

Point of Contact: Dr. Philip G. Malone, P. O. Box 631, Vicksburg, MS 39180, commercial: (601) 634-3960, FTS: 542-3960.

Army Pollution Abatement Program (APAP)

The Corps of Engineers' Huntsville Division has established and maintains a data file of printed material unique to pollution abatement technology. The data base contains publications in the areas of pollution abatement techniques, processes, and equipment; State and Federal pollution laws; lessons learned; and project costs. In addition, the data base provides sources of expertise, including universities, government, industry, and associations, as well as information on existing non-government pollution abatement facilities similar to those needed by the Army. This system provides comprehensive information on air and water pollution control technology and limited information on solid waste. The project is ongoing, and new information is being added continually.

Through its MACOM, an installation may request assistance from APAP in applying for a State-implemented landfill operating permit. APAP maintains a file on all DA landfills (past and present).

Point of Contact: J. M. Ammons, Army Pollution Abatement Program, P.O. Box 1600, Huntsville, AL 35807.

U.S. Army Toxic and Hazardous Materials Agency (USATHAMA)

USATHAMA conducts installation assessments to search for, identify, and assess actual or potential chemical, biological, or radiological contamination and/or migration by reviewing records and interviewing present and former employees. The agency also conducts installation environmental contamination surveys to establish contamination levels and verifies whether there is migration by determining subsurface water movement patterns.

USATHAMA is the lead DOD agency for developing pollution abatement/containment technology for migrating contaminants and for contamination problems on excess properties. The agency also has design and process engineering expertise in these areas.

USATHAMA has developed a data management system for environmental contamination at assigned Army installations. Computer mapping of sampling points, groundwater head, chemical concentration contours, and borelog profiles are provided by interactive programs. In addition to the reduction of raw data, USATHAMA can provide bibliographic searching of open literature data bases. Chemical and physical properties of compounds can be retrieved through telecommunication links with the National Institute of Health and with the Environmental Protection Agency. The agency maintains a registry of contamination from past operations at a summary level for each assigned Army installation.

Point of Contact: John K. Bartel, Aberdeen Proving Ground, MD 21010, DRXTH-TE, commercial: (301) 671-2466; Autovon: 584-2466.

8 CONCLUSION

Leachate is a noxious liquid which is discharged when a landfill's field capacity is exceeded. If it enters ground or surface water, the contamination may render the water unfit for drinking, damage or destroy the natural aquatic ecology of a surface stream, or cause health problems.

Virtually all land waste disposal sites can generate leachate unless extreme care was taken during both the site's initial engineering and its subsequent operation and maintenance.

The literature surveyed for this report noted several points about discovering and controlling leachate problems.

1. Locating closed or abandoned landfills for which there are no records is difficult. A number of methods can be used to locate such a site, but guidelines for choosing the best technique are not available.

2. Identifying the perimeters of old landfills is economically important for monitoring programs as well as for remedial activities aimed at excluding water from the landfill.

3. Leachate generated during the first 5 years of landfill leaching is amenable to biological treatment. Leachate generated after about 10 years is best treated by a physical/chemical method.

4. Leachate control costs are extremely high. Where possible, new landfills should be engineered and sited to minimize leachate formation.

To evaluate the pollution potential of currently operating and abandoned landfills, the FE should follow a procedural plan consisting of:

1. Identification and perimeter location of all existing landfills.

2. Interviews with knowledgeable personnel and searches of current and historical records pertaining to potentially landfilled materials and landfill operations.

3. Collection and analysis of existing or generated topographic, hydrologic, and geologic information for each site.

4. Inventory of ground and surface water uses and its quality within or adjacent to each site.

5. Ranking sites in order of their pollution potential on the basis of an analysis of the collected information.

REFERENCES

Attenuation of Pollutants in Municipal Landfill Leachate by Clay Minerals, EPA-600/2-78-157 (Environmental Protection Agency [EPA], August 1978).

Beck, Eckardt, "The Love Canal Tragedy," EPA Journal, Vol 5, No. 1 (January 1979), pp 16-18.

Brunner, D. R., and R. A. Carnes, Characteristics of Percolate of Solid and Hazardous Waste Deposits, presented at American Water Works Association (AWWA), 94th Annual Conference (June 17, 1964).

Cameron, R. D., "The Effects of Solid Waste Landfill Leachates on Receiving Waters," Journal American Water Works Association, Vol 70, No. 3 (March 1978).

Characteristics of Sanitary Landfill and Its Potential Effects on Water Quality, Urban Rainfall Management Conference, University of Kentucky, Lexington, KY (April 1972).

Chian, E. S. K, and F. B. DeWalle, Compilation of Methodology Used for Measuring Pollution Parameters of Sanitary Landfill Leachate, EPA-600/3-75-011 (EPA, 1975), p 33.

Chian, E. S. K., and F. B. DeWalle, Evaluation of Leachate Treatment; Volume 1: Characterization of Leachate, Environmental Protection Technology Series, EPA-600/2-77-186a (EPA, September 1977).

Chow, V. T., ed., Handbook of Applied Hydrology; A Compendium of Water Resources Technology (McGraw-Hill, 1964).

Clark, P. C., and R. Piskin, "Chemical Quality and Indicator Parameters for Monitoring Landfill Leachate in Illinois," Environmental Geology, Vol [illegible], No. 6 (1977), pp 329-340.

Committee on Solid Waste, American Public works Association Refuse Collection Practices, 3rd ed. (Chicago Public Administration Service, 1966), p 15.

Cooper, R. C., "Health Considerations in Use of Tertiary Effluents," Journal of the Environmental Engineering Division, ASCE, Vol 103, No. EE1 (February 1977), p 39.

Culhan, W. B., and R. A. McHugh, Journal of Environment Health (May/June 1969).

Crutcher, A. F., and F. A. Ravers, The Design of a Natural Leachate Attenuation System, Conference of Applied Research and Practice (September 1978).

Cummins, R. L., Effects of Land Disposal of Solid Waste on Water Quality, SW2TS (U.S. Department of Health, Education, and Welfare, 1968).

"Current Developments," Environmental Reporter (June 13, 1980), p 234.

"Current Developments," Environmental Reporter (June 20, 1980), pp 269-270.

Disposal of Hazardous Wastes, Report to Congress, Environmental Protection Publication SW-115 (EPA, Office of Solid Waste Management Programs, 1974).

Emrich, G. H., "Guidelines for Sanitary Landfills -- Groundwater and Percolation," Compost Science, Vol 13 (May-June 1972), pp 12-15.

An Environmental Assessment of Potential Gas and Leachate Problems at Land Disposal Sites, Environmental Protection Publication SW-110 (Office of Solid Waste Management Programs, Hazardous Waste Management Division, EPA, 1973). Open-file report, restricted distribution.

Environmental Report (March 9, 1979), p 2082.

"EPA Defines 'Hazardous' in Chemical Waste Streams," Chemical Week, Vol 125, No. 23 (6 December 1979), pp 43-44.

"EPA's Hazardous-Waste Program: Will It Save Our Groundwater?" Series on Water Pollution Control: No. 10, Civil Engineering, Vol 48, No. 12 (December 1978), pp 39-45.

Federal Register, Vol 44, No. 179 (13 September 1979).

Fenn, D. G., K. J. Hanley, and T. V. DeGeare, Use of the Water Balance Method for Predicting Leachate Generation From Solid Waste Disposal Sites, EPA/530/SW-168 (EPA, October 1975).

Fungaroli, A. A., "Hydrogeologic Factors in Landfill Management," Land Application of Residual Materials, Engineering Foundations Conference (American Society of Civil Engineers, 1976), pp 47-52.

Gas and Leachate From Land Disposal of Municipal Solid Wastes; Summary Report (EPA, Municipal Environmental Research Laboratory, 1975), in preparation.

Geraghty, T. T., and D. W. Miller, "Status of Groundwater Contamination in the U.S.," Journal American Water Works Association, Vol 70 (March 1978), p 162.

Gerdes, G. L., and B. A. Donahue, Simplified Sanitary Landfill Design and Operation Analysis, Technical Report N-57/ADA064356 (U.S. Army Construction Engineering Research Laboratory [CERL], December 1978).

Groundwater Pollution Problems in the Southeastern U.S., EPA-600/3-77-012 (Office of R&D, Ada, Oklahoma, EPA, January 1977), p 164.

Hughes, G., J. J. Tremblay, H. Anger, and J. D'Crug, Water and Pollution Control, Vol 110, No. 1 (January 1972).

Johnson, L. J., D. F. Daniel, W. V. Abeele, J. O. Cedbetter, and W. F. Hanson, "Effects from Past Solid Waste Disposal Practices," Environmental Health Perspectives, Vol 27 (December 1978), pp 215-221.

...ar, E. C., "Summary of Damage Incidents From Improper Land Disposal," Management and Disposal of Residue From the Treatment of Industrial Wastewater -- Proceedings of the National Conference on Management and Disposal of Residues From the Treatment of Industrial Wastewaters (February 3-5, 1979), pp 253-257.

"Leachate Control Doesn't Come Easy," American City and County (May 1980), pp 69-72.

Leachate Damage Assessment: Case Study of the Fox Valley Solid Waste Disposal Site in Aurora, Illinois, PB261068 (EPA, June 1976).

...s, J. O., et al., "Landfill Management With Moisture Control," Journal of the Environmental Engineering Division [JEED], Vol 105, No. EE2 (American Society of Civil Engineers [ASCE], April 1979), pp 337-355.

Liptak, Bela, Environmental Engineering Handbook (Chilton Publ., 1971), p 571.

McNamara, E. C., "Leachate from Landfilling," Compost Science, (November-December 1971).

Mc Guinness, J. L., and E. V. Bordne, Comparison of Lysemeter-Derived Potential Evapotranspiration With Computed Values, Agricultural Research Service, Technical Bulletin No. 1452 (U.S. Government Printing Office, March 1972).

"National Interim Primary Drinking Water Regulations," Environmental Protection Agency Water Programs, Federal Register, Vol 4, No. 248 (24 December 1975), pp 59566-59588.

Pieckno, W. A., "Predicting the Water Pollution Potential of Proposed Sanitary Landfills; Part I: Sanitary Landfill Leachate...What Is It"? Journal of Environmental Health, Vol 38, No. 5 (March-April 1976), p 334.

Lasey, J., and G. Karpinski, "Retrofitting Existing Landfills to Meet RCRA Standards for Leachate Control," Solid Waste Management (February 1979), p 46.

...s, R. A., "Well Monitoring at Landfills Can Help Head Off Problems at an Early Stage," Solid Waste Management: 1979 Sanitation Industry Yearbook, Vol 21, No. 13 (1979), p 88.

Pohland, F. G., Sanitary Landfill Stabilization With Leachate Recycle and Residual Treatment, EPA-600/2-75-043 (EPA, 1975).

Procedures Manual for Groundwater Monitoring at Solid Waste Disposal Facilities, EPA/530/84-8V (EPA, August 1977).

Proceedings of the Second National Groundwater Quality Symposium, September 25-27, 1974, Denver, CO, NTIS PB-257312, "Hydrocarbon/Dispersion Groundwater: Significant Characteristics," p 99.

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Recent Developm[illegible]t[illegible] Solid Waste Management, Solid Waste Management Branch Report EPS-3-[illegible] 76-11, Seminar Proceedings (Environmental Conservation Directorate, Canada, August 1976).

Refuse Collection and Disposal: Repairs and Utilities, TM 5-634 (Headquarters, Department of the Army, [DA], October 1946).

Refuse Collection and Disposal: Repairs and Utilities, TM 5-634 (Headquarters, DA, July 1958) p 23.

Sanitary Landfill Stabilization With Leachate Recycle and Residual Treatment, EPA-Technical Series, EPA-600/2-75-043 (Municipal Environmental Research Laboratory, Cincinnati, OH, October 1975).

Schoenberger, R. F., and A. A. Fungaroli, "Chemical and Biochemical Aspects of Leachate," Proceedings of the National Industrial Solid Waste Management Conference (University of Houston and the Bureau of Solid Waste Management, 24-26 March 1970).

Solid Waste Management Report, EPS 4-EP-72-2 (Sanitary Landfilling Seminar Proceedings, Canada, December 1972).

Solid Waste Report, Vol 10, No. 8 (April 9, 1979), p 57.

Solid Waste Management Technology Assessment, published by General Electric Company.

Steiner, R. C., A. A. Fungaroli, R. J. Schoenberger, and P. W. Purdom, "Criteria for Sanitary Landfill Development," Public Works, Vol 102, No. 2 (March 1971), pp 77-79.

Thornthwaite, C. W., and J. R. Wather, "Instructions and Tables for Computing Potential Evapotranspiration and the Water Balance," Publications in Climatology, Vol 10, No 3 (1957).

Tolman, A. L., et al., Guidance Manual for Minimizing Pollution From Waste Disposal Sites, EPA-600/2-78-142 (EPA, August 1978), pp 16-18.

Waste Disposal Practices - A Threat to Health and the Nation's Water Supply, Report to the Congress of the United States, by the Comptroller General CED-78-120 (U.S. General Accounting Office, 16 June 1978).

"Water Quality Criteria 1972," EPA Ecological Research Series, EPA-R3-73-033 (EPA, 1973).

Weiss, Samuel, Sanitary Landfill Technology (Pollution Technology Review), No. 10 (Noyes Data Corporation, London, England, 1974).

Weston, R. F., Inc., Pollution Prediction Techniques for Waste Disposal Siting; A State of the Art Assessment, EPA-1978 PB-283-572 (Office of Solid Waste Management, 1978).

VerEecke, W. H., "Using Solid Waste Energy Sources at Military Installations," The Military Engineer, Vol 70, No. 436 (July-August 1978), p 238.

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NTIS, 1980.
97 p. ; 27 cm. (Interim report ; N-97)

1. Sanitary landfills. I. Mikucki, Walter J. II. Smith, Edgar D.
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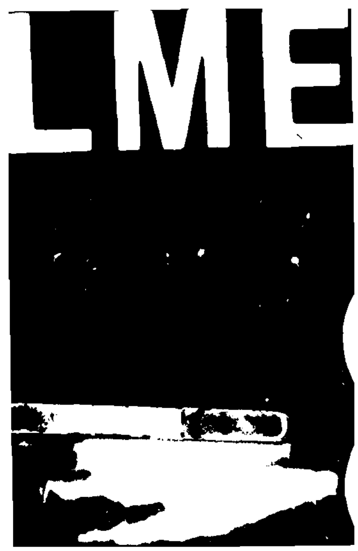
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