14

Solid Waste/Landfills

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14.1 Introduction

The proper management of solid waste is now, more than ever, a matter of national and international concern. As a nation, we are generating more solid waste than ever before. At the same time, we are finding that there are limitations to traditional solid waste management practices. As the generation of solid waste continues to increase, the capacity to handle it is decreasing. Many landfills and incinerators have closed, and new disposal facilities are often difficult to cite.

Even though municipal solid waste (MSW) constitutes only a portion of the solid waste streams, the rate of its generation is staggering. The U.S. Environmental Protection Agency's (EPA) most recent data show that in 1988, 180 million tons, or 4.0 pounds per person per day of MSW, were generated in the U.S. [EPA, 1990a]. By the year 2000, generation of MSW is projected by the EPA to reach 216 million tons, or 4.4 pounds per person per day. Based on current trends and information, EPA anticipates that 20 to 28% of MSW will be recovered annually by 1995. Exceeding this projected range will require fundamental changes in government programs, technology, and corporate and consumer behavior. According to EPA data [EPA, 1990a], recovery of MSW materials for recycling and composting was 13% in 1988, combustion was 14% of total generation, and the remaining 73% of the MSW stream was taken to landfills.

In response to the growing national concern about the solid waste disposal crisis, EPA developed an "agenda for action" and a national strategy for addressing the MSW management problems [EPA, 1989a]. The cornerstone of the strategy is "integrated waste management," where source reduction (i.e., reduction of the quantity and toxicity of materials and products entering the solid waste stream) followed by recycling are the first steps of an effective solid waste management system, and are complemented by environmentally sound combustion and landfilling.

14.2 Solid Waste

Regulatory Framework

Solid waste is regulated under Subtitle D of the Resource Conservation and Recovery Act (RCRA) and the corresponding federal regulations found in 40 Code of Federal Regulation (CFR) Parts 257 and 258.

Subtitle D solid waste is not subject to the hazardous waste regulations under Subtitle C of RCRA. Solid waste is defined in 40 CFR 257 as "any garbage, refuse, sludge from waste treatment plant, water supply treatment plant, or air pollution control facility and other discarded material, including solid, liquid, semisolid, or contained gaseous material resulting from industrial, commercial, mining, and agricultural operations, and from community activities."

Household hazardous wastes and hazardous small quantity generator (SQG) wastes from businesses and industry generating less than 100 kilograms of hazardous waste per month are exempt from RCRA's Subtitle C regulations for hazardous waste and thus are regulated as solid waste under RCRA's Subtitle D. In accordance with the RCRA definition of solid waste, the following categories of Subtitle D solid waste has been identified by EPA:

- Municipal solid waste
- Household hazardous waste
- Municipal sludge
- Municipal waste combustion ash
- Industrial nonhazardous process waste
- Small quantity generator hazardous waste
- Agricultural waste
- Oil and gas waste
- Mining waste

Subtitle D of RCRA establishes a framework of federal, state, and local government cooperation in controlling the management of nonhazardous solid waste. The federal role in this arrangement is to establish the overall regulatory direction, by providing minimum nationwide standards for protecting human health and the environment from the disposal practices of solid waste. The actual planning, direct implementation, and enforcement of solid waste programs under Subtitle D, however, remain largely state and local functions.

Solid Waste Characteristics

To analyze the characteristics of solid waste, EPA has conducted numerous studies to determine the weight, volume, characteristics, and management methods of wastes, regulated under Subtitle D of RCRA [EPA, 1990a; EPA, 1990b; EPA, 1989a; EPA, 1988a; EPA, 1986]. These studies revealed that based on data collected up to 1988, more than 11 billion tons of solid waste are generated each year, including 7.6 billion tons of industrial nonhazardous waste, which includes about 56 million tons of electric utility waste and 240 million tons of solid wastes generated by three industrial categories: iron and steel, inorganic chemicals, and plastics and resins. The studies also recorded 2 to 3 billion tons of oil and gas waste (including both drilling and produced wastes), more than 1.4 billion tons of mining waste, and nearly 180 million tons of municipal solid waste.

The Subtitle D solid waste regulations in 40 CFR Parts 257 and 258 focus on municipal solid waste, including household hazardous waste and small quantity generator hazardous waste, as well as industrial nonhazardous process wastes and municipal sludge. Several Subtitle D wastes, in particular oil and gas wastes, utility wastes, and mining wastes, are being considered separately for rule making by EPA. In addition, EPA has been closely evaluating, in a separate effort, the characteristics and management practices for municipal waste combustion ash.

Municipal Solid Waste

EPA's definition of municipal solid waste states that MSW comes from residential, commercial, institutional, and industrial sources and includes durable goods, nondurable goods, containers and packaging, food waste, yard wastes, and miscellaneous inorganic wastes [EPA, 1990a; EPA, 1989a]. Examples of wastes from these categories include appliances, newspapers, clothing, food scraps, boxes, disposable diapers, disposable tableware, office and classroom paper, wood pallets, and cafeteria wastes.

TABLE 14.1 Materials Generated in Municipal Solid Waste (MSW) by Weight, 1988

Material	Weight Generated (in Million Tons)	Percent of Total MSW
Paper and paperboard	71.8	40.0
Glass	12.5	7.0
Metals		
Ferrous	11.6	6.5
Aluminum	2.5	1.4
Other nonferrous	1.1	0.6
Plastics	14.4	8.0
Rubber and leather	4.6	2.5
Textiles	3.9	2.2
Wood	6.5	3.6
Food wastes	13.2	7.4
Yard wastes	31.6	17.6
Other	5.8	3.1
Total MSW	179.5	100

TABLE 14.2 Products Generated in Municipal Solid Waste (MSW) by Weight, 1988

Product	Weight Generated (in Million Tons)	Percent of Total MSW
Containers/packaging (boxes, bottles, can, bags, etc., made of glass, steel, aluminum, paper, and plastic)	56.8	31.6
Nondurable goods (newspapers, office paper, disposable tableware, diapers, books/printed material, clothing)	50.4	28.1
Yard wastes (grass, leaves, etc.)	31.6	17.6
Durable goods (appliances, furniture, tires, batteries, electronics)	24.9	13.9
Food wastes	13.2	7.4
Other (stones, concrete, dirt, demolition, etc.)	2.7	1.4
Total MSW	179.5	100

Generation of MSW in 1988, the latest year for which information is available, totaled approximately 180 million tons [EPA, 1990a]. The EPA 1990 MSW characterization report provides detailed information on the generation of MSW and other projections for its future production [EPA, 1990a]. Table 14.1 provides a breakdown by weight of the materials generated in MSW in 1988. Paper and paperboard products were the largest component of MSW by weight (40%) and yard wastes were the second largest component (about 18%).

The various materials in MSW make up the many individual products that enter the MSW stream. The products generated in MSW by weight, grouped into major product categories, are shown in Table 14.2 for 1988. Containers and packaging, including all types of packaging materials, were the largest product category generated in MSW by weight (about 32%). Nondurable goods, such as newspapers, disposable diapers, and disposable tableware, were the second largest category by weight (28%).

Although solid waste is usually characterized by weight, information about volume is important for such issues as determining landfill capacity uptake. Volume estimates of MSW, however, are far more difficult to make than weight estimates. Wide ranges for the volume occupied by solid waste are reported in the literature [Salvato, 1972; Bond et al., 1973]. Loose refuse can weigh from 100 to 240 lb/yd^3, while refuse compacted in a landfill can weigh 700 to 1250 lb/yd^3, depending on the compaction applied. EPA has attempted to estimate the volume of materials as they would typically be found in a landfill, after a significant amount of compaction [EPA, 1990a]. These estimates were largely based on empirical data that were used to estimate density factors (pounds per cubic yard) with corroboration from actual landfill studies. Table 14.3 compares 1988 volume and weight figures for discarded materials in MSW as estimated

TABLE 14.3 Weight and Volume of Materials Discarded in Municipal Solid Wastes (MSW), 1988

Material	Solid Waste Weight Generated (in Million Tons)	Solid Waste Weight Recovered by Recycling/ Composting (in Million Tons)	Solid Waste Weight Discarded (in Million Tons)	Solid Waste Weight (% of Total Discarded MSW)	Solid Waste Volume-Compacted in Landfill (% of Total Discarded MSW)
Paper and paperboard	71.8	18.4	53.4	34.2	34.1
Glass	12.5	1.5	11.0	7.1	2.0
Ferrous metals	11.6	0.7	10.9	7.0	9.8
Aluminum	2.5	0.8	1.7	1.1	2.3
Plastics	14.4	0.2	14.2	9.2	19.9
Rubber and leather	4.6	0.1	4.5	2.9	6.4
Textiles	3.9	0.0	3.9	2.5	5.3
Wood	6.5	0.0	6.5	4.2	4.1
Food wastes	13.2	0.0	13.2	8.5	3.3
Yard wastes	31.6	0.5	31.1	19.9	10.3
Miscellaneous	6.9	1.4	5.5	3.6	2.5
Total	179.5	23.6	155.9	100.0	100.0

by EPA. Discarded materials constitute the MSW remaining after recovery for recycling and composting has taken place. The paper and paperboard category ranked first in both volume and weight, at about 34% of the discarded MSW for the 1988 data. Plastics ranked second in volume at 20%, while yard waste ranked second in weight at 20%. Four materials constitute significantly larger proportions by volume of the discarded MSW than by weight: plastics, rubber and leather, textiles, and aluminum. By contrast, three materials constitute significantly smaller proportions by volume than by weight: yard wastes, food, and glass. The remaining four materials, namely paper and paperboard, ferrous metals, wood, and miscellaneous wastes, make up almost the same portion of the discarded MSW, either by weight or volume.

Trends in Municipal Solid Waste Generation

Generation of municipal solid waste grew steadily between 1960 and 1988, from 88 million to almost 180 million tons per year. The per capita generation of MSW for the same period saw an increase from 2.7 to 4.0 pounds per person per day. By 2000, projected per capita MSW generation is 4.4 pounds per person per day, for a total of 216 million tons per year. The projection for MSW generation in the year 2010 is over 250 million tons, or approximately 4.9 pounds per person per day [EPA, 1990a], marking an increase of more than 21% over the 1988 MSW generation. Figure 14.1 shows the generation, in millions of tons, of materials in MSW between 1960 and 1988, with projections to 2010. Paper and plastics have shown the most remarkable increase over the years and a continued increase in their generation is projected to the year 2010. Food and yard wastes as well as glass and metal, on the other hand, have had only a nominal increase over the period 1960 to 1988, and no marked increased is projected for the generation of these wastes.

Some further insight into projected generation of materials in MSW can be gained from Table 14.4, which presents detailed projected per capita generation of MSW by material category. Paper and plastics are projected to grow substantially in per capita generation. Other materials are projected to decline in per capita generation or to increase only slightly.

14.3 Landfills

A landfill is an area of land or an excavation in which wastes are placed for permanent disposal. While alternative waste disposal methods, such as incineration, along with the advent of recycling, composting, and pollution prevention, are scaling back the numbers of active landfills, the engineering, construction, and operation of landfills are now more complex than ever. Driven by public pressure and subsequent regulatory requirements, landfill design and operation now have to conform to strict federal standards.

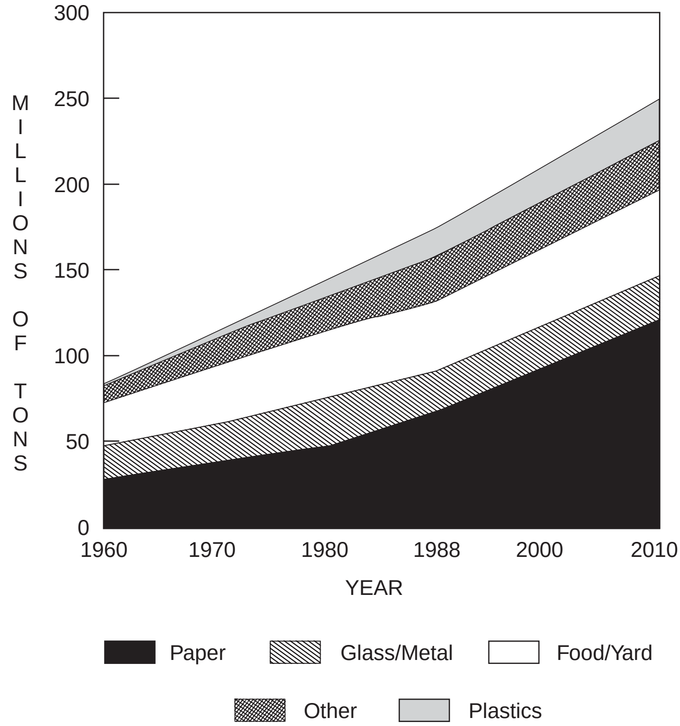

FIGURE 14.1 U.S. municipal solid waste generation, 1960–2010.

TABLE 14.4 Projected Per Capita Generation of Municipal Solid Waste (MSW), by Material, 1988 to 2010 (in Pounds per Person per Day)

Material	1988	1995	2000	2010
Paper and paperboard	1.60	1.80	1.96	2.35
Glass	0.28	0.23	0.21	0.18
Metals	0.34	0.34	0.35	0.34
Plastics	0.32	0.39	0.43	0.50
Rubber and leather	0.10	0.10	0.11	0.11
Textiles	0.09	0.09	0.09	0.09
Wood	0.14	0.16	0.17	0.20
Other	0.07	0.06	0.06	0.06
Food wastes	0.29	0.28	0.27	0.27
Yard wastes	0.70	0.70	0.70	0.70
Miscellaneous	0.06	0.06	0.06	0.06
Inorganic wastes				
Total MSW generated	4.00	4.21	4.41	4.86

Source: U.S. EPA, OSWER, 1990a. *Characterization of Municipal Solid Waste in the United States: 1990 Update.* p. 61, EPA/530-SW-90-042.

The EPA had mandated double liners, environmental controls for groundwater protection, and other design standards for hazardous waste landfills since 1984, under the Subtitle C requirements of RCRA. Since 1993, the nation's 6000 municipal solid waste landfills have been required to comply with similar strict standards under new federal regulations issued in accordance with Subtitle D requirements of RCRA.

Under the authority of Subtitle D of RCRA, EPA first promulgated the Criteria for Classification of Solid Waste Disposal Facilities and Practices (40 CFR Part 257) in 1979 [EPA, 1979]. Those Subtitle D criteria established minimum national performance standards necessary to ensure that "no reasonable probability of adverse effects on health or the environment" will result from solid waste disposal facilities. A facility that meets the criteria is classified in 40 CFR 257 as a "sanitary landfill." A facility that fails to satisfy any of the criteria is considered an "open dump." The criteria under 40 CFR 257 include general environmental performance standards addressing eight major topics: flood plains, endangered species, surface water, groundwater, land application, disease, air, and safety.

In 1984, Congress made significant modifications to Subtitle D of RCRA through the Hazardous and Solid Waste Amendments (HSWA). To fulfill its responsibilities under HSWA, EPA conducted a comprehensive study of solid waste characteristics, waste disposal practices, and environmental and public health impacts resulting from solid waste disposal. The results of this study were submitted to Congress in 1988 [EPA, 1988a]. The 1984 HSWA provisions, furthermore, required EPA to revise the criteria, then in existence, for solid waste disposal facilities that may receive household hazardous waste or hazardous waste from small quantity generators as part of the municipal solid waste stream disposed of at those facilities. As a result of these requirements, EPA promulgated the Criteria for Municipal Solid Waste Landfills, a broad new solid waste regulation [EPA, 1991a] in 1991. The new rule, which took effect in 1993, imposes minimum national criteria for **municipal solid waste landfills (MSWLFs)** in the areas of location, operation, design, groundwater monitoring and corrective action, closure and postclosure, and financial assurance. Under the new rule, states may incorporate the new federal requirements into state solid waste permitting programs and, with EPA approval, assume primary responsibility for implementing and enforcing them. "Approved" states have flexibility in applying EPA criteria, so that state-specific environmental conditions can be accommodated. In states that fail to gain approval, MSWLFs are subject to the federal criteria as specified in 40 CFR 258, with no allowance to alter the criteria for special environmental considerations.

Minimum Federal Regulatory Criteria for Municipal Solid Waste Landfills

The Subtitle D Federal criteria for MSWLFs [EPA, 1991a] apply to all existing and new MSWLFs, as well as to lateral expansions, with few exceptions for some small landfills, under certain conditions. A summary of the Subtitle D minimum criteria imposed on MSWLFs [EPA, 1991a] is presented below.

Location Restrictions

There are six restricted areas. Sites located near airports, floodplains, unstable areas, wetlands, seismic impact zones, and fault areas are unsuitable for operating MSWLFs, unless the MSWLF can meet the specific criteria stated under the rule for each location.

Operating Criteria

Ten new operating criteria for MSWLFs have been mandated, to address procedures for excluding the receipt of regulated quantities of hazardous wastes; daily cover material requirements; disease vector control; explosive gases control; air criteria; public access requirements; run-on/run-off control systems; control of discharges to surface waters; liquid disposal restrictions; and recordkeeping requirements.

Design Criteria

The design criteria of the solid waste disposal rule [EPA, 1991a] have as their goal the protection of groundwater and apply to new MSWLFs and lateral expansions. The design requirements to not apply to MSWLF units in existence as of October 9, 1993. The rule provides owners of MSWLFs with two design options. These two design options are depicted in Fig. 14.2, as presented in the federal regulation (40 CFR Part 258).

The first option is a **composite liner** system, whose minimum requirements are specified in the rule (40 CFR Part 258), and is believed to ensure a protective uniform design standard for MSWLFs in all locations [EPA, 1988b]. It consists of a flexible membrane liner, a two-foot, compacted soil component,

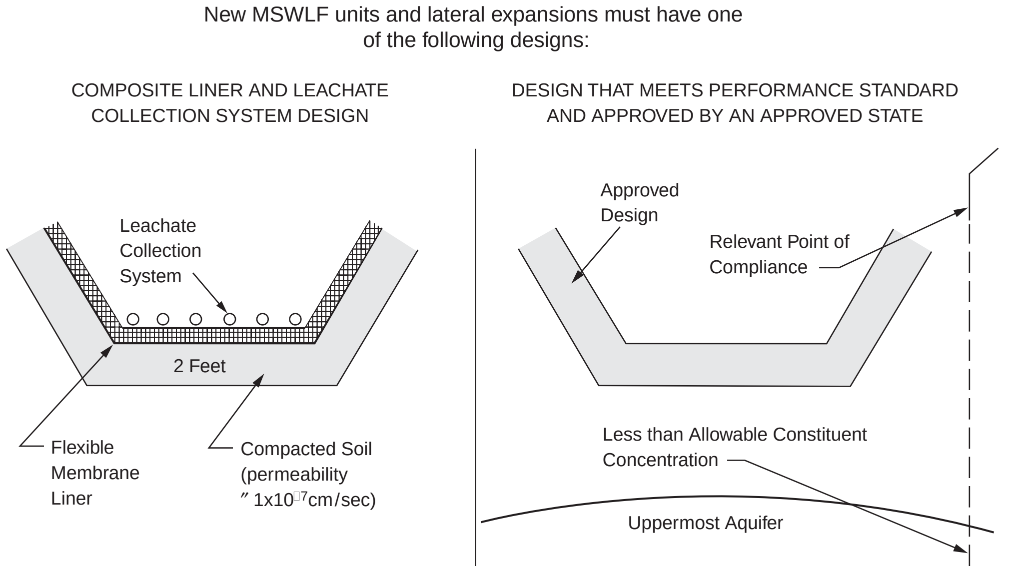

FIGURE 14.2 Municipal solid waste landfill design criteria mandated by federal regulations.

and a **leachate** collection and removal system that is designed to maintain less than a 30-cm depth of leachate over the liner.

The second option, which is available in states with an EPA-approved solid waste program, allows owners of MSWLFs to consider site-specific conditions in developing a design. This design must be approved by the state environmental agency and must meet the performance standard set in the federal regulations (40 CFR Part 258). Under the regulatory performance standard, the design of an MSWLF must ensure that the **maximum contaminant level (MCL)** values will not be exceeded in the groundwater of the **uppermost aquifer** at the **relevant point of compliance** at the landfill. Factors a state will consider when evaluating a site-specific landfill design include, at a minimum, the following: hydrogeologic characteristics of the site and surrounding land; climatic factors of the area; volume and physical and chemical characteristics of the leachate; and public health effects.

Groundwater Monitoring and Corrective Action

Extensive groundwater monitoring systems and a detection groundwater monitoring program are standard requirements for MSWLFs under the federal solid waste regulations (40 CFR Part 258). The groundwater monitoring system must consist of wells able to provide information on the quality of unaffected, background groundwater as well as of groundwater at the MSWLF's relevant point of compliance. If any of the detection monitoring parameters are found at a statistically significant level over background concentrations, the landfill owner is required to proceed to more intensive groundwater monitoring requirements and, subsequently, to investigate studies to define the extent of the groundwater contamination. If contamination has migrated off-site, the owner of the landfill has to develop and implement a corrective action plan. The remedy selected by the MSWLF owner has to be approved by the state prior to its implementation. The regulations provide explicit procedures for sampling wells and methods for the statistical analysis, and provide detailed analytical requirements for the groundwater under the various possible monitoring phases.

Closure and Postclosure Requirements

A final cover system designed to minimize infiltration and erosion is required under federal regulations (40 CFR Part 258). The infiltration layer must be a minimum of 18 inches of soil with permeability less than or equal to the permeability of the bottom liner system or natural subsoils, or no greater than 1×10^{-5} cm/s, whichever is less. The erosion layer must be a minimum of six inches of soil, able to sustain native plant growth. Written closure and postclosure plans, with provisions for maintenance of final cover, groundwater and methane gas monitoring, and leachate management are required by the regulations. Closure must commence within 30 days of last receipt of waste at the MSWLF, and postclosure activities must continue for a period of 30 years.

Financial Assurance

Under the federal solid waste regulations (40 CFR Part 258) the owner of a MSWLF is required to demonstrate financial responsibility for the cost of the landfills closure, postclosure care, and corrective action for known releases in an amount equal to the cost of a third part conducting these activities. The financial assurance requirements must be met by the owner before a construction permit is approved for the landfill by the regulatory agency. The cost estimates must be updated annually for inflation and operational changes.

Environmental Effects of Municipal Landfills

Old municipal landfills typically did not conform to today's location restrictions. In addition, several had poor operational records and minimal environmental controls. As a result of ever tightening regulations, many old landfills were literally abandoned by their owners. Today, abandoned municipal landfills compose approximately 20% of the sites on the Superfund Program's National Priorities List (NPL). Landfill sites on the NPL contain a combination of principally municipal and to a lesser extent co-disposal and hazardous waste landfills and range in size from one acre to over 600 acres. Superfund municipal landfills are primarily composed of municipal solid waste, therefore, they typically pose a low-level environmental threat rather than a principal threat [EPA, 1991b].

Potential concerns stemming from old, unprotected municipal landfills include leachate generation and possible groundwater contamination; soil contamination; landfill contents; landfill gas; and contamination of surface waters, sediments, and adjacent wetlands. Because these sites share similar characteristics, they lend themselves to remediation by similar technologies. The EPA, after considerable study of these landfills due to their high presence in the Superfund NPL, has developed methods and tools to streamline their investigation and selection of remedy process through a simplified Remedial Investigation/Feasibility Study (RI/FS) approach [EPA, 1991b].

Evaluation and selection of appropriate remedial action alternatives for Superfund municipal landfill sites is a function of a number of factors, including:

- Sources and pathways of potential risks to human health and the environment
- Potential Applicable or Relevant and Appropriate Requirements (ARARs) for the landfill as the landfill's cleanup standards under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), commonly known as Superfund; significant ARARs might include RCRA and/or state closure requirements, and federal or state requirements pertaining to landfill gas emissions
- Waste characteristics
- Site characteristics (including surrounding area)
- Regional surface water (including wetlands) and groundwater characteristics and potential uses

Remedial Alternatives for Superfund Municipal Landfills

In general, the remedial actions implemented at most Superfund municipal landfill sites include:

- Containment of landfill contents (i.e., landfill cap)
- Remediation of hot spots
- Control and treatment of leachate
- Control and treatment of landfill gas

Other areas that may require remediation include groundwater, surface waters, sediments, and adjacent wetlands. A summary of the issues associated with the main remedial actions commonly applied to Superfund municipal landfills is presented below.

Landfill Contents

Characterization of a landfill's contents is generally not necessary because containment of the landfill contents by a cap, which is often the most practical remedial alternative, does not require such information. Certain data, however, are necessary to evaluate capping alternatives and should be collected in the field. For instance, certain landfill properties such as the fill thickness, lateral extent, and age will influence landfill settlement and gas generation rates, which will thereby have an influence on the cover type at a site.

The main purpose of a cap is to prevent vertical infiltration of surface water. Lateral migration of water or gases into and out of the landfill can be prevented by a perimeter trench-type barrier. The type of cap would likely be either a native soil cover, single-barrier cap, or composite-barrier cap. The appropriate type of cap to be considered will be based on remedial objectives for the site. For example, a soil cover may be sufficient if the primary objective is to prevent direct contact and minimize erosion. A single barrier or composite cap may be necessary where infiltration is also a significant concern. Similarly, the type of trench will be dependent on the nature of the contaminant to be contained. Impermeable trenches, such as slurry walls, may be constructed to contain liquids while permeable trenches may be used to collect gases.

Hot Spots

More extensive characterization activities and development of remedial alternatives (such as thermal treatment or stabilization) may be appropriate for known or suspected hot spots within a landfill. Hot spots consist of highly toxic and/or highly mobile material and present a potential principal threat to human health or the environment. Hot spots should be characterized if documentation or physical evidence exists to indicate the presence and approximate location of the hot spots. Hot spots may be delineated using geophysical techniques or soil gas surveys and typically are confirmed by excavating test pits or drilling exploratory borings. Excavation or treatment of hot spots is generally practicable where the waste type or mixture of wastes is in a discrete, accessible location of a landfill. A hot spot should be large enough that its remediation would significantly reduce the risk posed by the overall site, but small enough that it is reasonable to consider removal or treatment. Consolidation of hot spot materials under a landfill cap is a potential alternative in cases when treatment is not practical or necessary.

Leachate

Characterization of a site's geology and hydrogeology will affect decisions on capping options as well as on extraction and treatment systems for leachate and possibly groundwater. Although leachate quality is different in each municipal landfill, generally the variables affecting it are the age of the landfill, climate variables such as annual rainfall and ambient temperature, final cover, and factors such as permeability, depth, composition, and compaction of the waste in the landfill. New landfills typically have leachates high in biodegradable organics. As a landfill ages, its contents degrade and produce more complex organics, not so readily amenable to biodegradation, and inorganics.

Characteristics of leachate produced, as well as differences in the quality of leachate generated, by municipal, codisposal, and hazardous waste landfills have been documented [EPA, 1988c]. In general, the collected data show that although the same chemicals are routinely detected at both municipal and hazardous waste landfills, considerably higher concentrations of many chemicals are found at the leachate of hazardous waste facilities. In particulate, chemicals such as 1,1,1-trichloroethane, trichloroethene, vinyl chloride, chloroform, pesticides, and PCBs occur with greater frequency and at higher concentrations in leachates at hazardous waste landfills than at municipal facilities. Typical chemical constituents in leachate from municipal landfills are shown in Tables 14.5 and 14.6 [EPA, 1988c].

Leachate generation is of special concern when investigating municipal landfill sites. The principal factors contributing to the leachate quantity are precipitation and recharge from groundwater and surface

TABLE 14.5 Municipal Landfill Leachate Data — Indicator Parameters and Inorganic Compounds

Indicator Parameters	Municipal Landfills Leachate Concentration Reported (ppm) Minimum	Maximum
Alkalinity	470	57,850
Ammonia	0.39	1,200
Biological oxygen demand	7	29,200
Calcium	95.5	2,100
Chemical oxygen demand	42	50,450
Chloride	31	5,475
Fluoride	0.11	302
Iron	0.22	2,280
Phosphorus	0.29	117.18
Potassium	17.8	1,175
Sulfate	8	1,400
Sodium	12	2,574
Total dissolved solids	390	31,800
Total suspended solids	23	17,800
Total organic carbon	20	14,500
Inorganic Compounds (ppm)		
Aluminum	0.01	5.8
Antimony	0.0015	47
Arsenic	0.0002	0.982
Barium	0.08	5
Beryllium	0.001	0.01
Cadmium	0.0007	0.15
Chromium (total)	0.0005	1.9
Cobalt	0.04	0.13
Copper	0.003	2.8
Cyanide	0.004	0.3
Lead	0.005	1.6
Manganese	0.03	79
Magnesium	74	927
Mercury	0.0001	0.0098
Nickel	0.02	2.227
Vanadium	0.009	0.029
Zinc	0.03	350

Source: U.S. EPA. OSWER. 1988c. *Summary of Data on Municipal Solid Waste Landfill Leachate Characteristics.* EPA/530-SW-88-038.

water. In many landfills, leachate is perched within the landfill contents, above the water table. Placing a limited number of leachate wells in the landfill could be an efficient way to gather information regarding the depth, thickness, and types of wastes present; the moisture content and degree of decomposition of the waste; leachate composition and head levels; and the elevation of the underlying natural soil layer. Leachate wells, in addition, provide good access for landfill gas sampling. It is important to note, however, that without extreme precautions, placing wells into the landfill contents may create health and safety risks. Such installation, furthermore, may create conduits through which leachate can migrate to lower geologic strata, thus contaminating previously nonimpacted groundwater.

Extraction and treatment of leachate may be required to control off-site migration of wastes. Collection and treatment may be necessary indefinitely because of continued contaminant loadings from the landfill. Biological processes are one possible step in the treatment of leachate, given its usually high organic

TABLE 14.6 Municipal Landfill Leachate Data — Organic Compounds

Indicator Parameters	Municipal Landfills Leachate Concentration Reported (ppb) Minimum	Maximum
Acetone	8	11,000
Acrolein	270	270
Aldrin	NA	NA
α-Chlordane	NA	NA
Aroclor-1242	NA	NA
Aroclor-1254	NA	NA
Benzene	4	1,080
Bromomethane	170	170
Butanol	10,000	10,000
1-Butanol	320	360
2-Butanone (methyl ethyl ketone)	110	27,000
Butyl benzyl phenol	21	150
Carbazole	21	150
Carbon tetrachloride	6	397.5
4-Chloro-3-methylphenol	NA	NA
Chlorobenzene	1	685
Chloroethane	11.1	860
Bis(2-chloroethyoxy)methane	18	25
2-Chloroethyl vinyl ether	2	1,100
Chloroform	7.27	1,300
Chloromethane	170	400
Bis(chloromethyl)ether	46	46
p-Cresol	45.2	5,100
2,4,-D	7.4	220
4,4′-DDE	NA	NA
4,4-DDT	0.042	0.22
Dibromomethane	5	5
Di-N-butyl phthalate	12	150
1,2-Dichlorobenzene	3	21.9
1,4-Dichlorobenzene	1	52.1
3,3-Dichlorobenzidine	NA	NA
Dichlorodifluoromethane	10.3	450
1,1-Dichloroethane	4	44,000
1,2-Dichloroethane	1	11,000
1,2-Dichloroethylene (Total)	NA	NA
cis-1,2-Dichloroethylene	190	470
trans-1,2-Dichloroethylene	2	4,800
1,2-Dichloropropane	0.03	500
1,3-Dichloropropene	18	30
Diethyl phthalate	3	330
2,4-Dimethyl phenol	10	28
Dimethyl phthalate	30	55
Endrin	0.04	50
Endrin ketone	NA	NA
Ethanol	23,000	23,000
Ethyl acetate	42	130
Ethyl benzene	6	4,900
Ethylmethacrylate	NA	NA
Bis(2-ethylhexyl)phthalate	16	750
2-Hexanone (methyl butyl ketone)	6	690
Isophorone	4	16,000
Lindane	0.017	0.023
4-Methyl-2-pentanone (methyl isobutyl ketone)	10	710
Methylene chloride (dichloromethane)	2	220,000

TABLE 14.6 (continued) Municipal Landfill Leachate Data — Organic

Indicator Parameters	Municipal Landfills Leachate Concentration Reported (ppb)	
	Minimum	Maximum
2-Methylnaphthalene	NA	NA
2-Methylphenol	NA	NA
4-Methylphenol	NA	NA
Methoxychlor	NA	NA
Naphthalene	2	202
Nitrobenzene	4	120
4-Nitrophenol	17	17
Pentachlorophenol	3	470
Phenanthrene	NA	NA
Phenol	7.3	28,800
1-Propanol	11,000	11,000
2-Propanol	94	26,000
Styrene	NA	NA
1,1,2,2-Tetrachloroethane	210	210
Tetrachloroethylene	2	620
Tetrahydrofuran	18	1,300
Toluene	5.55	18,000
Toxaphene	1	1
2,4,6-Tribromophenol	NA	NA
1,1,1-Trichloroethane	1	13,000
1,1,2-Trichloroethane	30	630
Trichloroethylene	1	1,300
Trichlorofluormethane	4	150
1,2,3-Trichloropropane	230	230
Vinyl chloride	8	61
Xylenes	32	310

Source: U.S. EPA. OSWER. 1988c. *Summary of Data on Municipal Solid Waste Landfill Leachate Characteristics.* EPA/530-SW-88-038.

matter manifested as biochemical oxygen demand (BOD). Chemical and physical processes are also applicable, as well as combinations of the three. A cost-effective alternative to on-site leachate treatment, if available, is the discharge of the leachate into the municipal sewer system and the eventual treatment of the leachate by the city's wastewater treatment plant.

Landfill Gas

Several gases typically are generated by decomposition of organic materials in a landfill. The composition, quantity, and generation rates of the gases depend on such factors as refuse quantity and composition, placement characteristics, landfill depth, refuse moisture content, and amount of oxygen present. The principal gases generated (by volume) are carbon dioxide, methane, trace thiols, and, occasionally, hydrogen sulfide. Volatile organic compounds may also be present in landfill gases, particularly at codisposal facilities. Data generated during the landfill gas characterization should include, in addition to the landfill gas characteristics, the role of on-site and off-site surface emissions, and the geologic and hydrogeologic conditions of the site. Constructing an active landfill gas collection and treatment system should be considered where (1) existing or planned homes or buildings may be adversely affected through either explosion or inhalation hazards, (2) final use of the site includes allowing public access, (3) the landfill produces excessive odors, or (4) it is necessary to comply with ARARs. Most landfills will require at least a passive gas collection system (that is, venting) to prevent buildup of pressure below the cap and to prevent damage to the vegetative cover.

FIGURE 14.3 Geosynthetic fabric liner installation conforms to composite liner federal requirements for MSWLFs at the expansion site of Caldwell Sanitary Landfill. (*Source:* Caldwell Sanitary Landfill. With permission.)

Landfills — Present Status

Several landfills across the country have already incorporated the federal criteria for MSWLF into their expansion process. A typical landfill expansion under the new federal criteria as shown in Fig. 14.3 where the newly installed geosynthetic fabric liner, part of a composite liner system for the expansion of the existing MSWLF, is adjoining the active site of the landfill.

Even though the open dumps of the past have given way to high-tech landfill facilities where advanced engineering principles are applied to ensure environmentally safe and aesthetically pleasing conditions, public opposition to citing new landfills has not diminished. As a result, lateral and vertical expansions of existing MSWLF units are today the predominant means of generating new landfill space.

Defining Terms

Composite liner — A liner system for municipal solid waste landfills which, according to 40 CFR 258, consists of two components with the following specifications: The upper component is a minimum 30 mil flexible membrane liner (FML), and the lower component is at least a two-foot layer of compacted soil with a hydraulic conductivity of no more than 1×10^{-7} cm/sec. FML components consisting of high density polyethylene (HDPE) shall be at least 60 mil thick.

Leachate — A liquid that has passed through or emerged from solid waste in a landfill and contains soluble, suspended, or miscible materials removed from such waste.

Maximum contaminant levels (MCLs) — Enforceable, allowable concentrations of contaminants in public drinking water supplies, protective of human health, under the federal Safe Drinking Water Act.

Municipal solid waste landfill (MSWLF) — A discrete area of land that receives household waste, and that is not a land application unit, surface impoundment, injection well, or waste pile, as those terms are defined in 40 CFR 257. An MSWLF may also receive other types of RCRA Subtitle D wastes, such as commercial solid waste, nonhazardous sludge, and industrial solid waste. Such a landfill may be publicly or privately owned and may be a new MSWLF, an existing MSWLF, or a lateral expansion.

Relevant point of compliance — Under the federal solid waste regulations, this is the point where an MSWLF's impact on groundwater is evaluated. This point, which is specified by a state with an EPA approved solid waste program, cannot be more than 150 meters from the waste management unit boundary and has to be located on land owned by the MSWLF owner.

Uppermost aquifer — The geologic formation nearest the ground surface that is an aquifer, including lower aquifers interconnected with this aquifer within an MSWLF's property boundary.

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