Sanitary Landfill Design and Operation

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foreword

Sanitary Landfill Design and Operation is a state-of-the-art treatise. It not only describes the known in sanitary landfill technology, it also indicates areas in which research is needed.

This publication represents the combined efforts of many individuals within the Federal solid waste management program, other Federal agencies, State and local governments, private industry, and universities.

It is the hope of the U.S. Environmental Protection Agency that planners, designers, operators, and government officials will use this document as a tool to help overcome the poor land disposal practices that are evident today.

—**SAMUEL HALE, JR.**
Deputy Assistant Administrator
for Solid Waste Management

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CHAPTER 1
the solid waste problem

The Nation is emerging from a prolonged period in which it neglected solid waste management, and it is becoming increasingly aware that our present solid waste storage, collection, and disposal practices are inadequate. Much of this awareness has been brought about by active campaigns directed against air and water pollution and has resulted in a third campaign—the abatement of land pollution.

The magnitude of the problem can be appreciated when we consider that the Nation produced 250 million tons of residential, commercial, and institutional solid wastes in 1969. Only 190 million tons were collected. Much of the remainder found its way to scattered heaps across the countryside, was left to accumulate in backyards and vacant lots, or was strewn along our roadways. To compound the problem, an estimated 110 million tons of industrial wastes and nearly 4 billion tons of mineral and agricultural wastes were generated.

Because of our affluence and increasing population, these quantities are expected to increase. In 1920, solid waste collected in our urban areas amounted to only 2.75 lb per capita. In 1970, the figure stood at over 5 lb, and it is estimated that it will reach 8 lb by 1980.

Solid waste processing and disposal practices are grossly inadequate for today's needs. Only 6 percent of land disposal operations and 25 percent of incinerator facilities were considered adequate in the 1968 National Solid Wastes Survey.[1]

This inadequacy is the result of lack of planning and financing and, until recently, public apathy with regard to our environment. There has been far too little effort made to locate and reserve suitable areas for land disposal operations in anticipation of community growth. Consequently, it is becoming more and more difficult to locate disposal sites in urban areas. This directly affects disposal costs, because hauling expenses to a suitable landfill site increase or a more expensive alternative method of processing is required prior to disposal.

More than 90 percent of our Nation's solid waste is directly disposed of on land, the vast majority of it in an unsatisfactory manner. Open and burning dumps, which are all too common, contribute to water and air pollution and provide food, harborage, and breeding grounds for insects, birds, rodents, and other carriers of disease. In addition, these dumps are unsightly and very often lessen the value of nearby land and residences. In response to an aroused public, legislation has been passed on the local, State, and Federal levels to aid the development of satisfactory disposal practices and to plan for all aspects of solid waste management. The development and implementation of such plans will, however, require the combined support of all citizens, industry, and government.

An acceptable alternative to the present poor practices of land disposal is the sanitary landfill. This alternative involves the planning and applying of sound engineering principles and construction techniques. Sanitary landfilling is an engineered method of disposing of solid wastes on land by spreading them in thin layers, compacting them to the smallest practical volume, and covering them with soil each working day in a manner that protects the environment. By definition, no burning of solid waste occurs at a sanitary landfill. A sanitary landfill is not only an acceptable and economic method of solid waste disposal, it is also an excellent way to make otherwise unsuitable or marginal land valuable.

Thorough planning and the application of sound engineering principles to all stages of site selection, design, operation, and completed use will result in

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a successful and efficient sanitary landfill. In order to meet this objective, it is also essential to have an understanding of solid waste decomposition processes—how the many variables may affect the decomposition rate, decomposition products, and how these factors may influence the environment. In essence, these relationships determine the physical stability of the fill and its potential to produce such environmental problems as uncontrolled gas generation and movement and water pollution. Although these relationships are not fully understood, sufficient knowledge is available to enable us to recognize potential problems and to plan and design sanitary landfills that will not harm the environment.

The final selection of a sanitary landfill site, its design, and its operation should be based on a systematic, integrated study and an evaluation of all physical conditions, economics, and social political restraints.

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CHAPTER 2
solid waste decomposition

A knowledge of solid waste decomposition processes and the many influences they exert is essential to proper sanitary landfill site selection and design.

Solid wastes deposited in a landfill degrade chemically and biologically to produce solid, liquid, and gaseous products. Ferrous and other metals are oxidized; organic and inorganic wastes are utilized by microorganisms through aerobic and anaerobic synthesis. Liquid waste products of microbial degradation, such as organic acids, increase chemical activity within the fill. Food wastes degrade quite readily, while other materials, such as plastics, rubber, glass and some demolition wastes, are highly resistant to decomposition. Some factors that affect degradation are the heterogeneous character of the wastes, their physical, chemical, and biological properties, the availability of oxygen and moisture within the fill, temperature, microbial populations, and type of synthesis. Since the solid wastes usually form a very heterogeneous mass of nonuniform size and variable composition and other factors are complex, variable, and difficult to control, it is not possible to accurately predict contaminant quantities and production rates.

Biological activity within a landfill generally follows a set pattern. Solid waste initially decomposes aerobically, but as the oxygen supply is exhausted, facultative and anaerobic microorganisms predominate and produce methane gas, which is odorless and colorless. Temperatures rise to the high mesophilic-low thermophilic range (60 to 150F) because of microbial activity. Characteristic products of aerobic decomposition of waste are carbon dioxide, water, and nitrate. Typical products of anaerobic decomposition of waste are methane, carbon dioxide, water, organic acids, nitrogen, ammonia, and sulfides of iron, manganese, and hydrogen.

Leachate

Groundwater or infiltrating surface water moving through solid waste can produce leachate, a solution containing dissolved and finely suspended solid matter and microbial waste products. Leachate may leave the fill at the ground surface as a spring or percolate through the soil and rock that underlie and surround the waste.

Composition of leachate is important in determining its potential effects on the quality of nearby surface water and groundwater. Contaminants carried in leachate are dependent on solid waste composition and on the simultaneously occurring physical, chemical, and biological activities within the fill. Identification of leachate composition has been the object of several laboratory lysimeter and field studies.[1-6]

The chemical and biological characteristics of leachate were determined in two studies conducted over a period of time with solid waste of the same general type at both sites (Table 1). The data exhibit a significant range of values. As an example, pH of the leachate investigated in study A was found to vary between 6.0 and 6.5[1] while pH in study B varied between 3.7 and 8.5.[2] Chloride varied from 96 to 2,350 mg per liter in study A and from 47 to 2,340 in study B. Although the leachates for the two studies were similar in many respects, there were differences which further indicate the variability of leachate composition with time for individual sites and between sites. For example, mean sulfate concentrations were 614 mg per liter for study A, ranging from 730 near the start of the

TABLE 1

Composition of Initial Leachate* from Municipal Solid Waste

Component	Study A[1]		Study B[2]	
	Low	High	Low	High
pH	6.0	6.5	3.7	8.5
Hardness, $CaCO_3$	890	7,600	200	550
Alkalinity, $CaCO_3$	730	9,500		
Ca	240	2,330		
Mg	64	410		
Na	85	1,700	127	3,800
K	28	1,700		
Fe (total)	6.5	220	0.12	1,640
Ferrous iron	8.7†	8.7†		
Chloride	96	2,350	47	2,340
Sulfate	84	730	20	375
Phosphate	0.3	29	2.0	130
Organic-N	2.4	465	8.0	482
NH_4-N	0.22	480	2.1	177
BOD	21,700	30,300		
COD			809	50,715
Zn			0.03	129
Ni			0.15	0.81
Suspended solids			13	26,500

* Average composition, mg per liter of first 1.3 liters of leachate per cubic foot of a compacted, representative, municipal solid waste.
† One determination.

test to 84 near the conclusion. Sulfate concentrations in study B averaged 152 mg per liter, ranging from 375 at the beginning of sampling to 20 at the conclusion.

The quantity of contaminants in leachate from a completed fill where no more waste is being disposed of can be expected to decrease with time. Only a few studies have attempted to determine the effect of long term leaching of solid waste.[1,3] Much more research is needed in the laboratory and in the field to adequately describe this phenomenon. The limited data available indicate a removal of large quantities of contaminants by leaching during active stages of decomposition, and a slackening off of removal as the fill stabilizes (Figures 1, 2). If the fill is considered as a mass of material containing a finite amount of leachable material, then depending on the removal rate, leaching should eventually cease.

The types and quantities of contaminants that enter the receiving water and the ability of that water to assimilate these contaminants will determine the degree of leachate control needed. In some cases it may be established that introduction of leachate will not upset the ecology or usefulness of the receiving water. Careful examination of dilution and oxygen demand criteria of the stream can be useful tools in showing the ability of a stream to assimilate leachate. In all cases, water quality criteria and the laws and ordinances of Federal, State, and local agencies pertaining to water pollution must be followed.

Some investigators believe that even in a sanitary landfill, leachate production is inevitable and that some leachate will eventually enter surface water or groundwater. This has not been proven but neither has the opposite view. The present philosophy held by the Office of Solid Waste Management Programs, most State solid waste control agencies, and many experts in the field is that through sound engineering and design, leachate production and movement may be prevented or minimized to the extent that it will not create a water pollution problem. The most obvious means of controlling leachate production and movement is to prevent water from entering the fill to the greatest extent practicable.

Contaminant Removal

Leachate percolating through soils underlying and surrounding the solid waste is subject to purification (attenuation) of the contaminants by ion exchange, filtration, adsorption, complexing, precipitation, and biodegradation. It moves either as an unsaturated flow if the voids in soil are only partially filled with water or as a saturated flow if they are completely filled. The type of flow affects the mechanism of attentuation, as do soil particle size and shape and soil composition.

Attentuation of contaminants flowing in the unsaturated zone is generally greater than in the saturated zone because there is more potential for aerobic degradation, adsorption, complexing, and ion exchange of organics, inorganics, and microbes. Aerobic degradation of organic matter is more rapid and complete than anaerobic degradation. Because the supply of oxygen is extremely limited in sat-

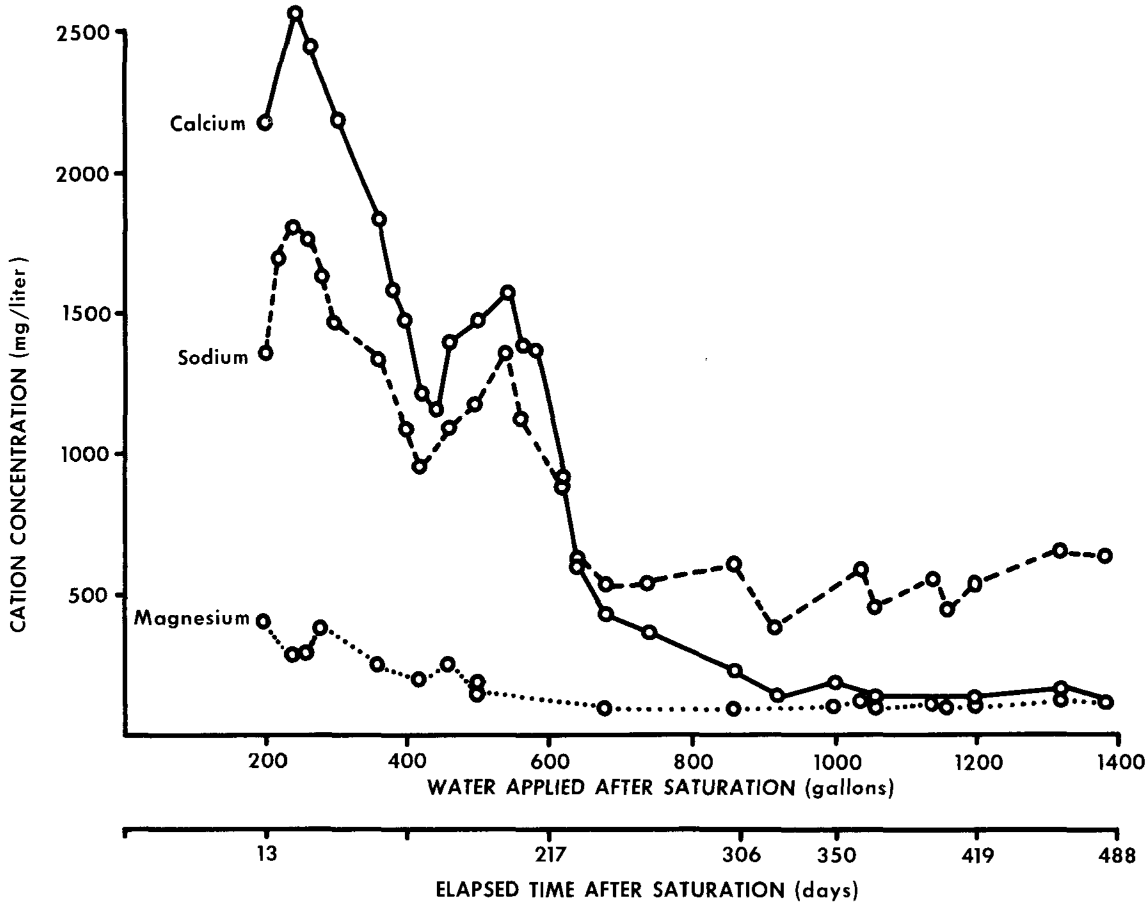

Figure. 1 Concentration of cations in leachate; adapted from Reference 1.

urated flow, anaerobic degradation prevails. Adsorption and ion exchange are highly dependent on the surface area of the liquid and solid interface. The surface area to flow volume ratio is greater in an unsaturated flow than in a saturated flow.

Leachate travel in the saturated zone is primarily controlled by soil permeability and hydraulic gradient, but a limited amount of capillary diffusion and dispersion do occur. The leachate is diluted very little in groundwater unless a natural geologic mixing basin exists. Leachate movement will closely follow the streamlines of groundwater flow.

Information on leachate travel in the unsaturated zone is lacking. Most of the studies made of residential and industrial wastewaters traveling through the unsaturated zone indicate that the organic and microbial removal level achieved is very good. As an example, when a citrus liquid waste was applied to the ground surface, COD was reduced from 5,000 mg per liter to less than 100 in the top 3 ft of soil.[7] However, the rate and frequency at which the waste liquid is applied and the type of soil have great influence on attenuation efficiency. Nitrification can also occur in the unsaturated soil zone and produce nitrate and nitrite from ammonia-nitrogen. A water that was bacteriologically safe, according to USPHS Drinking Water Standards for the coliform group, was obtained by percolating settled domestic waste water through at least 4 ft of a fine, sandy loam soil.[8] This last study is especially important since pathogens have been detected in solid waste and leachate.[9,10]

Travel of leachate in the saturated zone has been monitored by several investigators,[4,5,11] but more research is needed to clearly define its significance. Results obtained so far indicate that the distance the contaminants travel depends on the composition of the soil, its permeability, and the type of contaminant. Organic materials that are biodegradable do not travel far, but inorganic ions and refractive organics can travel appreciable distances. Some inorganic contaminants from a dump located in an abandoned gravel pit have been traced for 1,200 ft.[4] Contaminant movement was through

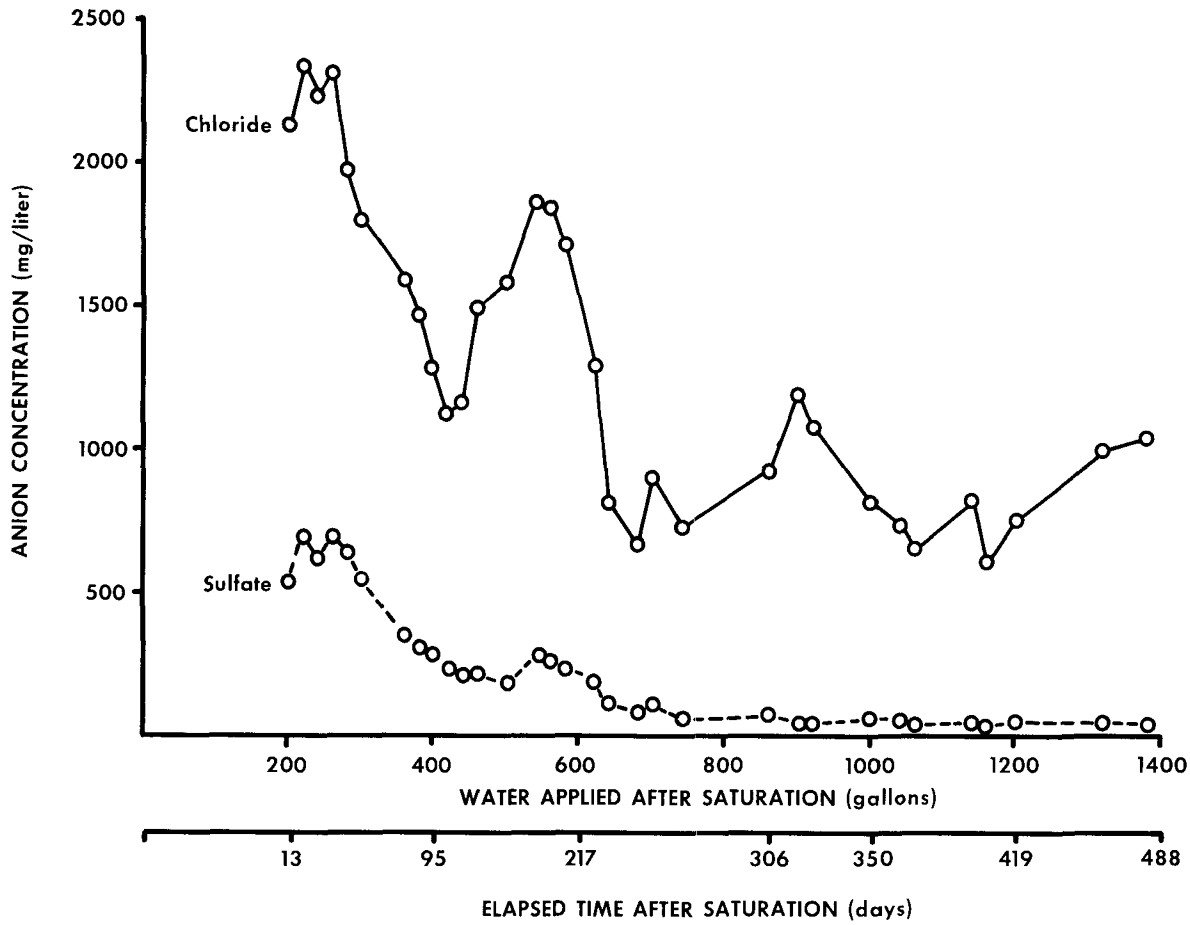

Figure 2. Concentration of anions in leachate; adapted from Reference 1.

a highly porous glacial alluvium. Another study indicates that the rate of movement through some soils is so slow that the full impact of contaminant travel may not be realized for many years.[5] If contaminant travel is slow, the release of contaminants to an aquifer would also be slow.

Inorganic materials appear to be most resistant to attenuation. This is especially true of chloride ion, and it serves, therefore, as a good indicator of leachate movement. Data from monitoring wells surrounding a landfill in Illinois reflected a sharp increase in chlorides and total dissolved solids (Table 2). Chloride concentrations in the unaffected groundwater were 18 mg per liter, those in the fill were 1,710, and those in a monitoring well 150 ft downstream of the fill were 248.

Natural purification processes have only a limited ability to remove contaminants, because the number of adsorption sites and exchangeable ions available is finite. In addition, the processes are time dependent—residence time is shortened by high flow rates. Flow rates through soils near landfills

TABLE 2

Groundwater Quality in the Vicinity of a Landfill[5]

Characteristic	Background mg/l	Fill* mg/l	Monitor well* mg/l
Total dissolved solids	636	6,712	1,506
pH	7.2	6.7	7.3
COD	20	1,863	71
Total hardness	570	4,960	820
Sodium	30	806	316
Chloride	18	1,710	248

* Groundwater quality in a saturated fill and in a monitoring well located approximately 150 ft downstream from the landfill at a depth of 11 ft in sandy, clayey silt.

may be reduced naturally by filtering and settling of suspended contaminants. Porosity and permeability of the soil are then reduced. Thus, additional protection against contaminant travel may be possible as time passes. (Analysis of precipitation, flooding, upland drainage, and evapo-transpiration necessary to determine whether leaching will occur at a site is discussed later.)

Decomposition Gas

Gas is produced naturally when solid wastes decompose. The quantity generated in a landfill and its composition depend on the types of solid waste that are decomposing. A waste with a large fraction of easily degradable organic material will produce more gas than one that consists largely of ash and construction debris. The rate of gas production is governed solely by the level at which microbial decomposition is occurring in the solid waste. When decomposition ceases, gas production also ends. In a field study conducted over a 907-day period, approximately 40 cu ft of gas were produced per cu yd of solid waste.[12] Gas production was monitored throughout the duration of this study (Figure 3). Theoretically, if decomposition is carried to completion, each lb of solid waste containing 25 percent inerts can produce up to 6.6 cu ft of gas.

Methane and carbon dioxide are the major constituents of landfill decomposition gas, but other gases are also present and some may impart a repugnant odor. Hydrogen sulfide, for example, may be generated at a landfill, especially if it contains a large amount of sulfate, such as gypsum board (calcium sulfate) or if brackish water infiltrates the solid waste.

Limited studies have been made on the varying composition of landfill gas over a period of time (Table 3). The data indicate that the percentages of carbon dioxide and methane present three months after solid wastes were placed in the fill were 88 and 5, respectively; four years later the respective figures were 51 and 48. Very little methane is produced during the early stages of decomposition because aerobic synthesis prevails.

Landfill gas is important to consider when evaluating the effect a landfill may have on the environment, because methane can explode and because mineralization of groundwater can occur if carbon dioxide dissolves and forms carbonic acid. Methane is explosive only when present in air at concentrations between 5 and 15 percent. Since there is no oxygen present in a landfill when methane concentrations in it reach this critical level, there is no danger of the fill exploding. If, however, methane vents into the atmosphere (its specific

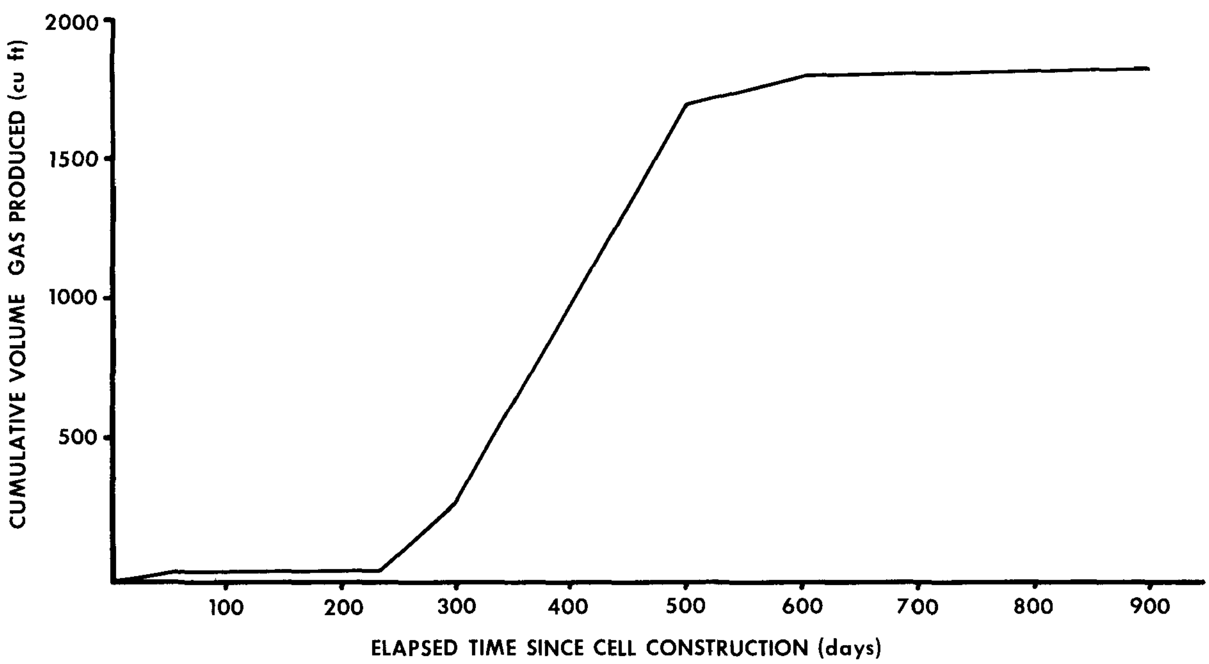

Figure 3. Gas production from an experimental sanitary landfill; adapted from Reference 12. Gas production is from 40 cu yd of residential solid waste at a density of 634 lb per cu yd with a moisture content (wet weight) of 34.6 percent. Composition of the solid waste used, on a percentage basis: paper (42.7); grass and garden clippings (38); plastic (3); glass (5); metal (7); dirt (5).

TABLE 3

Landfill Gas Composition[12]

Time interval since start of cell completion (months)	Average percent by volume		
	N_2	CO_2	CH_4
0-3	5.2	88	5
3-6	3.8	76	21
6-12	0.4	65	29
12-18	1.1	52	40
18-24	0.4	53	47
24-30	0.2	52	48
30-36	1.3	46	51
36-42	0.9	50	47
42-48	0.4	51	48

gravity is less than that of air) it may accumulate in buildings or other enclosed spaces on or close to a sanitary landfill.

The potential movement of gas is, therefore, an essential element to consider when selecting a site. It is particularly important if enclosed structures are built on or adjacent to the sanitary landfill or if it is to be located near existing industrial, commercial, and residential areas.

Gas permeability of the soils surrounding the landfill can influence the movement of decomposition gas. A dry soil will not significantly impair its flow, but a saturated soil, such as clay, can be an excellent barrier. A well-drained soil acts as a vent to gas flow. If cover material acts as a barrier, then the landfill gases will migrate laterally until they can vent to the atmosphere. More research is needed to reliably predict rate and distance of gas movement.

Landfill gas movement can be controlled if sound engineering principles are applied. Of the several methods that have been devised and tested, permeable vents and impermeable barriers are the two basic types. Both are discussed in Chapter 5.

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CHAPTER 3

hydrology and climatology

A major consideration in selecting the site for a sanitary landfill and in designing it is the hydrology of the area. To a large extent, hydrology will determine whether the formation of leachate will produce a water pollution problem.

When solid wastes are placed in a sanitary landfill, they may vary tremendously with regard to moisture content. Wood, concrete, and other construction rubble may have very little, whereas many food wastes may be extremely wet. Paper, a major constituent of solid waste, is usually quite low in moisture. Metals and glass are also generally present in solid waste but are essentially free of moisture.

In general, the moisture content of mixed solid waste generated by a community ranges from 20 to 30 percent by weight. (Wide fluctuations can occur depending on climatic conditions during storage and collection.) In this general range, the moisture alone should not produce leachate provided the solid waste is fairly well mixed and has been well compacted. The water that results from decomposition of the relatively small amounts of intermixed food wastes and other moist, readily degradable organics can be absorbed by the comparatively large amounts of paper and other dry components present.

Leachate is not produced until all of the sanitary landfill or a sizable portion of it becomes saturated by water entering it from outside. For this reason, it is extremely important that a study of the site hydrology be made. Precipitation, surface runoff characteristics, evapo-transpiration, and the location and movement of groundwater with relation to the solid waste are the major factors that should be considered.

Surface Water

Surface water that infiltrates the cover soil and enters the underlying solid waste can increase the rate of waste decomposition and eventually cause leachate to leave the solid waste and create water pollution problems. Unless rapid decomposition is planned and the sanitary landfill is so designed that leachate is collected and treated, as much surface water as is practicable should be kept from entering the fill.

The permeability of a soil is the measure of the ease or difficulty with which water can pass through it. This is greatly affected by the texture, gradation, and structure of the soil and the degree to which it has been compacted. Coarse grained soils (gravels and sands) are usually much more permeable than fine grained soils (silts and clays). However, small amounts of silts and clays (fines) in a coarse grained soil may greatly decrease permeability while cracks in fine grained soils may do the opposite.*

The quantity of water that can infiltrate the soil cover of a sanitary landfill depends not only on these physical characteristics but also on the residence time of the surface water. It can be minimized by: (1) diverting upland drainage; (2) grading and sloping the daily and final cover to allow for runoff; (3) decreasing the permeability of the cover material.

There have been few detailed investigations

* Specific information on the percentage of water infiltrating a particular soil can be obtained from the Soil Conservation Service, U.S. Department of Agriculture

made of the quantity of moisture that can enter a sanitary landfill through a cover and on the amount and quality of water that may leave the fill and enter an aquifer or stream. One investigator claims, however, that it is possible to predict the quantity of surface water that will enter the underlying solid waste if the available water storage capacity, quantity, and frequency of water infiltration, and rates of evaporation and transpiration for a cover material are known.[1] Under ideally controlled laboratory conditions or at a field test site, this would seem plausible, but more studies must be made of leaching potentials at operational sanitary landfills. These are needed because the placement of cover soils cannot be rigidly controlled and some discontinuities always develop in the structure of a sanitary landfill. They derive from variations in soil thickness, texture, and degree of compaction as well as from slight changes that occur in the grade or slope of the cover soil when it settles; this may cause cracks or fissures to develop. Furthermore, slight variations in the amount or intensity of rainfall, minor changes in vegetation, or other presumably less important alterations of the fill's final surface may have major effects on the amount of surface moisture entering the solid waste.

Groundwater

Groundwater is water that is contained within the zone of saturation of soil or rock—that is, all the pores in the containing earth materials are saturated. This zone is just beneath the land surface in many parts of the country and is on the surface at many springs, lakes, and marshes. In some areas, notably most of the arid west, the zone of saturation is deep in the ground.

The water table is the surface where water stands in wells at atmospheric pressure. In highly permeable formations, such as gravel, the water table is essentially the top of the zone of saturation. In many fine grained formations, however, capillary action causes water to rise above this zone, and the inexperienced observer might think this capillary fringe is part of the zone.

The zone of saturation commonly is not continuous with depth nor does it necessarily have lateral continuity. In exploring for underground water, a saturated zone may be found that yields water at a shallow depth, but if the exploration hole is continued, dry material is encountered at a greater depth and then another zone of saturation is found. Isolated high zones or lenses of saturated material are referred to as perched water. Perched water is common to glacial soil (till plain) areas where interstratified lenses or patches of porous sand and gravel are underlaid by relatively impervious glacial clay.

Because the conditions affecting groundwater occurrence are so complex, it is essential that the sanitary landfill site investigation include an evaluation by a qualified groundwater hydrologist. This is needed not only to locate the zone of saturation but also to predict the direction and rate of flow of groundwater and the quality of the aquifer.

Leachate from a landfill can contaminate groundwater. In order to determine if leachate will produce a subsurface pollution problem, it is essential that the quality of the groundwater be established and that the aquifer's flow rate and direction be determined. Water within the zone of saturation is not static. It moves vertically and laterally at varying rates, depending on the permeability of the soil or rock formation in which it is located and the external hydraulic forces acting upon it.

The movement of groundwater is determined by using a tracer such as fluorescein dye or by making piezometer readings. The estimated quantity of groundwater flow is based on the permeability of the aquifer, effective cross-sectional flow area, and the pressure gradient that induces the water to move. The groundwater hydrologist should also determine whether the aquifer is in a discharge or recharge area. In a discharge area, water leaves the aquifer and emerges through the ground surface as a spring. In recharge areas, water infiltrates the ground and enters the aquifer. Lakes, streams, and rivers may serve as recharge or discharge areas, or both, depending on the surrounding groundwater level and geologic conditions.

Climatology

Wind, rain, and temperature directly affect sanitary landfill design and operation. Windy sites need to have litter fences at the operating area and personnel to clean up the area at the end of the day. Such sites can also be very dusty when the soil dries, and this may irritate people living or working nearby. Trees planted on the perimeter of a sanitary landfill help keep dust and litter within the site. Water sprinkling or the use of other dust palliatives are often necessary along haul roads constructed of soil, crushed stone, or gravel.

The effect of rain that infiltrates the sanitary landfill and influences solid waste decomposition has been discussed previously. Rain can also cause operational problems; many wet soils are difficult to spread and compact, and traffic over such soils is impeded.

Freezing temperatures may also cause problems. If the frost line is more than 6 in. below the ground surface, cover material may be difficult to obtain. A crawler dozer equipped with a ripper may be required, or it may be necessary to stockpile cover soil and protect it from freezing. A well-drained soil is more easily worked in freezing weather than one that is poorly drained.

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CHAPTER 4
soils and geology

A study of the soils and geologic conditions of any area in which a sanitary landfill may be located is essential to understanding how its construction might affect the environment. The study should outline the limitations that soils and geologic conditions impose on safe, efficient design and operation.

A comprehensive study identifies and describes the soils present, their variation, and their distribution. It describes the physical and chemical properties of bedrock, particularly as it may relate to the movement of water and gas (Figure 4). Permeability and workability are essential elements of the soil evaluation, as are stratigraphy and structure of the bedrock.

Rock materials are generally classified as sedimentary, igneous, or metamorphic. Sedimentary rocks are formed from the products of erosion of older rocks and from the deposits of organic matter and chemical precipitates. Igneous rocks derive from the molten mass in the depths of the earth. Metamorphic rocks are derived from both igneous and sedimentary rocks that have been altered chemically or physically by intense heat or pressure.

Sands, gravels, and clays are sedimentary in origin. The sedimentary rocks, sometimes called

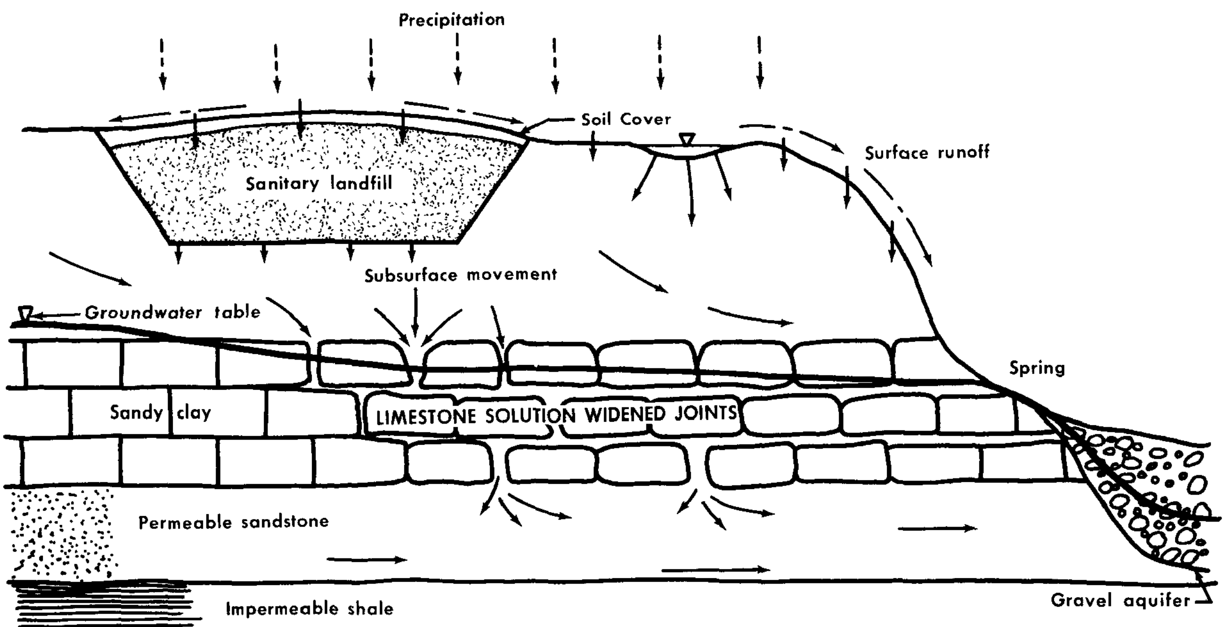


Figure 4. Leachate and infiltration movements are affected by the characteristics of the soil and bedrock.

aqueous rocks, are often very permeable and therefore represent a great potential for the flow of groundwater. If leachate develops and enters the rock strata, contaminant travel will usually be greatest in sedimentary formations. Other rocks commonly classed as sedimentary are limestone, sandstone, and conglomerates. Fracturing and jointing of sedimentary formations are common, and they increase permeability. In fact, the most productive water-bearing strata for wells are formations of porous sandstone, highly fractured limestone, and sand and gravel deposits. Siltstones and shales, which are also of sedimentary origin, usually have a very low permeability unless they have been subjected to jointing and form a series of connected open fractures.

Igneous and metamorphic rocks, such as shist, gneiss, quartzite, obsidian, marble, and granite, generally have a very low permeability. If these rocks are fractured and jointed, however, they can serve as aquifers of limited productivity. Leachate movement through them should not, therefore, be categorically discounted.

Information concerning the geology of a proposed site may be obtained from the U.S. Geological Survey, the U.S. Army Corps of Engineers, State geological and soil agencies, university departments of soil sciences and geology, and consulting soil engineers and geologists.

Soil Cover

The striking visual difference between a dump and a sanitary landfill is the use of soil cover at the latter. Its compacted solid waste is fully enclosed within a compacted earth layer at the end of each operating day, or more often if necessary.

The cover material is intended to perform many functions at a sanitary landfill (Table 4); ideally, the soil available at the site should be capable of performing all of them.

The cover material controls the ingress and egress of flies, discourages the entrance of rodents seeking food, and prevents scavenging birds from feeding on the waste. Tests have demonstrated that 6 in. of compacted sandy loam will prevent fly emergence.[1] Daily or more frequent application of soil cover greatly reduces the attraction of birds to the waste and also discourages rodents from burrowing to get food. The cover material is essential for maintaining a proper appearance of the sanitary landfill.

Many soils, when suitably compacted, have a low permeability, will not shrink, and can be used to control moisture that might otherwise enter the solid waste and produce leachate.

Control of gas movement is also an essential function of the cover material. Depending on anticipated use of the completed landfill and the sur-

TABLE 4

Suitability of General Soil Types as Cover Material*

Function	Clean gravel	Clayey-silty gravel	Clean sand	Clayey-silty sand	Silt	Clay
Prevent rodents from burrowing or tunneling	G	F-G	G	P	P	P
Keep flies from emerging	P	F	P	G	G	E†
Minimize moisture entering fill	P	F-G	P	G-E	G-E	E†
Minimize landfill gas venting through cover	P	F-G	P	G-E	G-E	E†
Provide pleasing appearance and control blowing paper	E	E	E	E	E	E
Grow vegetation	P	G	P-F	E	G-E	F-G
Be permeable for venting decomposition gas‡	E	P	G	P	P	P

* E, excellent; G, good; F, fair; P, poor
† Except when cracks extend through the entire cover.
‡ Only if well drained.

rounding land, landfill gases can be either blocked by or vented through the cover material. A permeable soil that does not retain much water can serve as a good gas vent. Clean sand, well-graded gravel, or crushed stone are excellent when kept dry. If gases are to be prevented from venting through the cover material, a gas-impermeable soil with high moisture-holding capacity compacted at optimum conditions should be used.

Enclosing the solid waste within a compacted earth shell offers some protection against the spread of fire. Almost all soils are noncombustible, thus the earth side walls and floor help to confine a fire within the cell. Top cover over a burning cell offers less protection because it becomes undermined and caves in, thus exposing the overhead cell to the fire. The use of a compactible soil of low permeability is an excellent fire-control measure, because it minimizes the flow of oxygen into the fill.

To maintain a clean and sightly operation, blowing litter must be controlled. Almost any workable soil satisfies this requirement, but fine sands and silts without sufficient binder and moisture content may create a dust problem.

The soil cover often serves as a road bed for collection vehicles moving to and from the operating area of the fill. When it is, it should be trafficable under all weather conditions. In wet weather, most clay soils are soft and slippery.

In general, soil used to cover the final lift should be capable of growing vegetation. It should, therefore, contain adequate nutrients and have a large moisture-storage capacity. A minimum compacted thickness of 2 ft is recommended.

Comparison of the soil characteristics needed to fulfill all of these functions indicates that some anomalies exist. To serve as a road base, the soil should be well-drained so that loaded collection vehicles do not bog down. On the other hand, it should have a low permeability if water is to be kept out of the fill, fire is to be kept from spreading, and gas is not to be vented through the final cover. These differences can be solved by placing a suitable road base on top of the normally low permeability-type cover material. A reverse situation occurs when landfill gases are to be vented uniformly through the cover material. The soil should then be gas permeable, have a small moisture-storage capacity, and not be highly compacted. As before, the criteria for moisture and fire control require the soil to have a low permeability. Leachate collection and treatment facilities may be required if a highly permeable soil is used to vent gas uniformly through the cover materials; if this is not done, an alternative means of venting gas through the cover material must be sought.

There are many soils capable of fulfilling the functions of cover material. Minor differences in soil grain size or clay mineralogy can make significant differences in the behavior of soils that fall within a given soil group or division. In addition, different methods of placing and compacting the same soil can result in a significantly different behavior. Moisture content during placement, for example, is a critical factor—it influences the soil's density, strength, and porosity.

The soils present at proposed sites should be sampled by augering, coring, or excavating, and then be classified. The volume of suitable soil available for use as cover material can then be estimated and the depth of excavation for waste disposal can be determined. Specific information on the top 5 ft of the soil mantle can often be obtained from the Soil Conservation Service, U.S. Department of Agriculture.

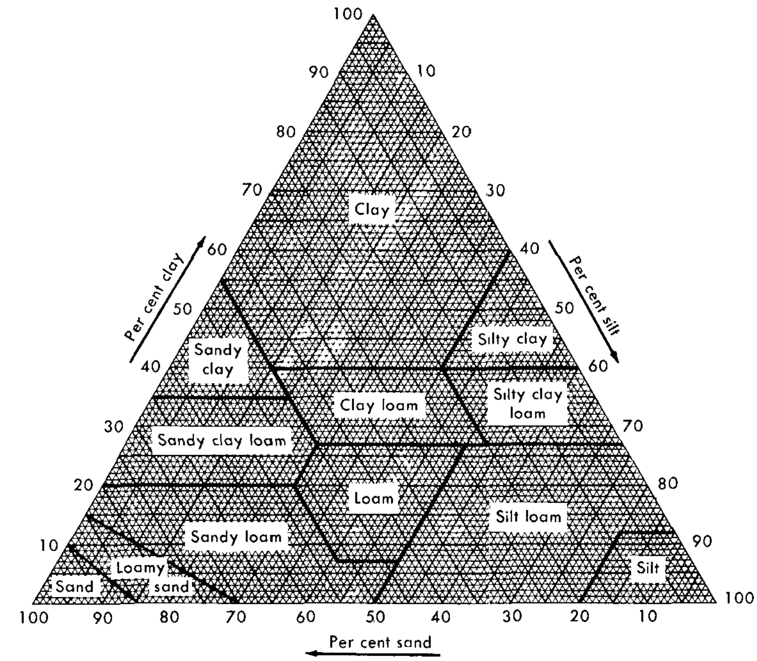
Sanitary landfilling is a carefully engineered process of solid waste disposal that involves appreciable excavating, hauling, spreading, and compacting of earth. When manipulating soils in this manner, the Unified Soil Classification System (USCS) is useful. Although recommendations for soil to be used at a landfill are often expressed in the U.S. Department of Agriculture textural classification system (Figure 5), the USCS is preferred because it relates in more detail the workability of soils from an engineering viewpoint. (Table 5).

Clay soils are very fine in texture even though they commonly contain small to moderate amounts of silt and sand. They vary greatly in their physical properties, which depend not only on the small particle size but on the type of clay minerals and soil water content. When dry, a clay soil can be almost as hard and tough as rock and can support heavy loads. When wet, it often becomes very soft, is sticky or slippery, and is very difficult to handle. A clay soil swells when it becomes wet, and its permeability is very low.

Many clay soils can absorb large amounts of water but, after drying, usually shrink and crack. These characteristics make many clays less desirable than other soils for use as a cover material. The large cracks that usually develop allow water to enter the fill and permit decomposition gases to escape. Rats and insects can also enter or leave the fill through these apertures.

Clay soil can, however, be used for special purposes at a landfill. If it is desirable to construct an impermeable lining or cover to control leachate and gas movement, many clays can be densely compacted at optimum moisture. Once they are in place, it is almost always necessary to keep them moist so they do not crack.

The suitability of coarse grained material (gravel and sand) for cover material depends mostly on grain size distribution (gradation), the shape of grains, and the amount of clay and silt fines present. If gravel, for example, is poorly graded and relatively free of fines, it is not suitable as cover material for moisture, gas, or fly control. It cannot be compacted enough, and the gravel layer will be porous and highly permeable; this would allow water to enter the fill easily. Flies would have little difficulty emerging through the loose particles. On the other hand, a gravel layer no more than 6 in. deep would probably discourage rats and other rodents from burrowing into the fill and would provide good litter control. If gravel is fairly well-graded and contains 10 to 15 percent sand and 5 percent or more



Sand—2 0 to 0 05 mm diameter
Silt—0 05 to 0 002 mm diameter
Clay—smaller than 0.002 mm. diameter

COMPARISON OF PARTICLE SIZE SCALES

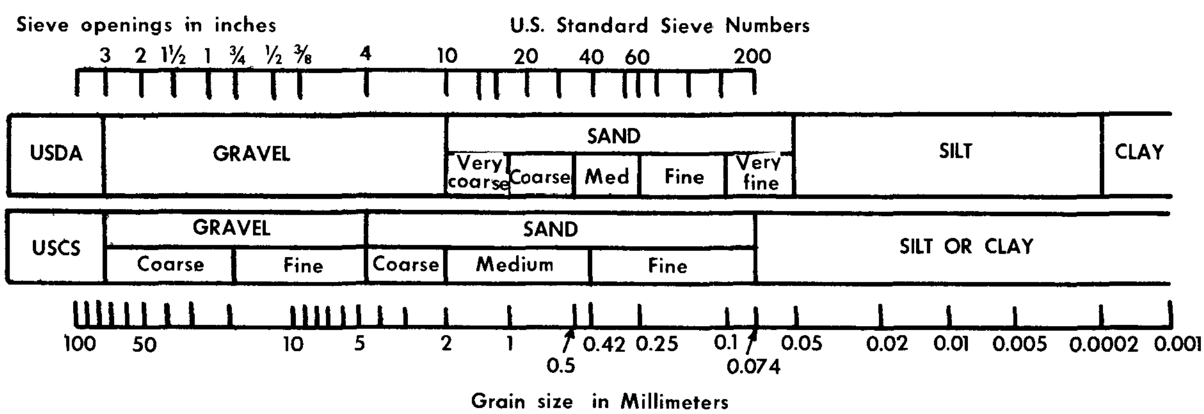


Figure 5. Textural classification chart (U.S. Department of Agriculture) and comparison of particle size scales.

TABLE 5

UNIFIED SOIL CLASSIFICATION SYSTEM AND CHARACTERISTICS PERTINENT TO SANITARY LANDFILLS

Major Divisions		SYMBOL Letter	Hatching	Color	NAME	Potential Frost Action	Drainage Characteristics*	Value for Embankments	Permeability cm per sec	Compaction Characteristics †	Std AASHO Max Unit Dry Weight lb per cu ft ‡	Requirements for Seepage Control
COARSE-GRAINED SOILS	GRAVEL AND GRAVELLY SOILS	GW		RED	Well-graded gravels or gravel-sand mixtures, little or no fines	None to very slight	Excellent	Very stable, pervious shells of dikes and dams	$k > 10^{-2}$	Good, tractor, rubber-tired steel-wheeled roller	125-135	Positive cutoff
		GP			Poorly graded gravels or gravel-sand mixtures, little or no fines	None to very slight	*Excellent*	Reasonably stable, pervious shells of dikes and dams	$k > 10^{-2}$	Good,-tractor, rubber-tired steel-wheeled roller	115-125	Positive cutoff
		GM		YELLOW	*Silty gravels, gravel-sand-silt* mixtures	*Slight to* medium	Fair to poor Poor to practically impervious	Reasonably stable, not particularly *suited* to shells, but may be used for impervious cores or blankets	$k = 10^{-3}$ to 10^{-6}	Good, with close control, rubber-tired, sheepsfoot roller	120 -135	*Toe trench* to none
		GC			*Clayey gravels, gravel-sand-clay* mixtures	*Slight to* medium	Poor to practically impervious	Fairly stable, may be used for impervious core	$k = 10^{-6}$ to 10^{-8}	Fair, rubber-tired, sheepsfoot roller	115-130	None
	SAND AND SANDY SOILS	SW		RED	Well-graded sands or gravelly sands *little or no fines*	None to very *slight*	Excellent	Very stable, pervious sections *slope protection required*	$k > 10^{-3}$	Good, tractor	110-130	Upstream blanket and toe drainage or wells
		SP			Poorly graded sands or gravelly sands, little or no fines	None to very slight	Excellent	Reasonably stable may be used in dike section with flat slopes	$k > 10^{-3}$	Good, tractor	100-120	Upstream blanket and toe drainage or wells
		SM		YELLOW	Silty sands, sand-silt mixtures	Slight to high	Fair to poor Poor to practically impervious	Fairly stable, not particularly suited to shells but may be used for impervious cores or dikes	$k = 10^{-3}$ to 10^{-6}	Good, with close control, rubber-tired, sheepsfoot roller	110-125	Upstream blanket and toe drainage or wells
		SC			Clayey sands, sand-clay mixtures	Slight to high	Poor to practically impervious	Fairly stable, use for impervious core for flood control structures	$k = 10^{-6}$ to 10^{-8}	Fair, sheepsfoot roller, rubber-tired	105-125	None
FINE-GRAINED SOILS	SILTS AND CLAYS LL IS LESS THAN 50	ML		GREEN	Inorganic silts and very fine sands rock flour, silty or clayey fine sands or *clayey silts with slight plasticity*	Medium to very high	Fair to poor	Poor stability, may be used for embankments with proper control	$k = 10^{-3}$ to 10^{-6}	Good to poor, close control essential, rubber-tired roller, sheepsfoot roller	95-120	Toe trench to none
		CL			Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Medium to high	Practically impervious	Stable, impervious cores and blankets	$k = 10^{-6}$ to 10^{-8}	Fair to good, sheepsfoot roller, rubber-tired	95-120	None
		OL			Organic silts and organic silt-clays of low plasticity	Medium to high	Poor	Not suitable for embankments	$k = 10^{-4}$ to 10^{-6}	Fair to poor sheepsfoot roller	80-100	None
	SILTS AND CLAYS LL IS GREATER THAN 50	MH		BLUE	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils elastic silts	*Medium to* very high	Fair to poor	Poor stability, core of hydraulic dam, not desirable in rolled fill construction	$k = 10^{-4}$ to 10^{-6}	Poor to very poor sheepsfoot roller	70 95	None
		CH			Inorganic clays of high plasticity, fat clays	Medium	Practically impervious	Fair stability with flat slopes, thin cores, blankets and dike sections	$k = 10^{-6}$ to 10^{-8}	Fair to poor sheepsfoot roller	75-105	None
		OH			Organic clays of medium to high plasticity, organic silts	Medium	Practically impervious	Not suitable for embankments	$k = 10^{-6}$ to 10^{-8}	Poor to very poor, sheepsfoot roller	65-100	None
HIGHLY ORGANIC SOILS		Pt		Orange	Peat and other highly organic soils	NOT RECOMMENDED FOR SANITARY LANDFILL CONSTRUCTION						

*Values are for guidance only, design should be based on test results

†The equipment listed will usually produce the desired densities after a reasonable number of passes when moisture conditions and thickness of lift are properly controlled

‡Compacted soil at optimum moisture content for Standard AASHO (Standard Proctor) compactive effort

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fines, it can make an excellent cover. When compacted, the coarse particles maintain grain-to-grain contact, because they are held in place by the binding action of the sand and fines and cohesion of the clays. The presence of fines greatly decreases a soil's permeability. A well-graded, sandy, clayey gravel does not develop shrinkage cracks. It can control flies and rodents, provide odor control, can be worked in any weather, and supply excellent traction for collection trucks and other vehicles.

Many soils classified as sand (grain size generally in the range of 4.0 to 0.05 mm) contain small amounts of silt and clay and often some gravel-size material as well. A well-graded sand that contains less than 3 percent fines usually has good compaction characteristics. A small increase in fines, particularly silt, usually improves density and allows even better compaction. A poorly graded sand is difficult to compact unless it contains abundant fines. The permeability of clean sand soils is always high, even when compacted, and they are not, therefore, suitable for controlling the infiltration of water. They are also ineffective in constraining flies and gases.

A well-drained sandy soil can be easily worked even if temperatures fall below freezing, while a soil with a large moisture-storage capacity will freeze.

Practically the only soils that can be ruled out for use as cover material are peat and highly organic soils. Peat is an earthy soil (usually brown to black) and is composed largely of partially decomposed plant matter. It usually contains a high amount of voids, and its water content may range from 100 to 400 percent of the weight of dried solids. Peat is virtually impossible to compact, whether wet or dry. Peat deposits are scattered throughout the country but are most abundant in the States bordering the Great Lakes. Highly organic soils include sands, silts, and clays that contain at least 20 percent organic matter. They are usually very dark, have an earthy odor when freshly turned, and often contain fragments of decomposing vegetable matter. They are very difficult to compact, are normally very sticky, and can vary extremely in their moisture content.

Many soils contain stones and boulders of varying sizes, especially those in glaciated areas. The use of soils with boulders that hinder compaction should be avoided.

Soil surveys prepared by the Soil Conservation Service of the U.S. Department of Agriculture are available for a major portion of the country. Local assistance in using and interpreting them is available through soil conservation districts located in some 3,000 county seats throughout the United States. The surveys cover such specific factors as natural drainage, hazard of flooding, permeability, slope, workability, depth to rock, and stoniness. They are commonly used to locate potential areas for sanitary landfills. They also can serve as the basis for designing effective water management systems and selecting suitable plant cover to control runoff and erosion during and after completion of fill operations. Sanitary landfill owners and their consultants can avoid costly investigations of unsuitable sites by using soil surveys to select areas for which detailed investigations appear warranted. Using soil surveys for the foregoing purposes does not, however, eliminate the need for making detailed site investigations.

Land Forms

A sanitary landfill can be constructed on virtually any terrain, but some land forms require that extensive site improvements be made and expensive operational techniques followed. Flat or gently rolling land not subject to flooding is best, but this type is also highly desirable for farming and industrial parks, and this drives up the purchase price.

Depressions, such as canyons and ravines, are more efficient than flat areas from a land use standpoint since they can hold more solid waste per acre. Cover material may, however, have to be hauled in from surrounding areas. Depressions usually result when surface waters run off and erode the soil and rock. By their nature, they require special measures to keep surface waters from inundating the fill. Permeable formations that intersect the side walls or floor of the fill may also have to be lined with an impervious layer of clay or other material to control the movement of fluids.

There are also numerous man-made topographic features scattered over the country—strip mines, worked-out stone and clay quarries, open pit mines, and sand and gravel pits. In most cases, these abandoned depressions are useless, dangerous eyesores. Many of them could be safely and economically reclaimed by utilizing them as sanitary landfills. Clay pits, for example, are located in most impermeable formations, which are natural barriers to gas and water movement. Abandoned strip mines also are naturally suited for use as sanitary landfills. Most coal formations are underlaid by clays, shales, and siltstones that have a very low permeability. When permeable formations, such as sandstones, are encountered near an excavation, impermeable soil layers can be constructed from the nearby abundant spoil. Abandoned limestone, sandstone, siltstone, granite, and traprock quarries and open pit mines generally require more extensive improvements because they are in permeable or often open-fractured formations. The pollution potential of sand and gravel pits is great, and worked-out pits consequently require extensive investigation and probably expensive improvements to control gas movement and water pollution.

Marsh and tidal lands may also be filled, but they are less desirable from an ecological point of view. They have little value as real estate, but possess considerable ecological value as nesting and feeding grounds for wildlife. Filling of such areas requires, however, the permanent lowering of the groundwater or the raising of the ground surface to keep organic and soluble solid waste from being deposited in standing water. Roads for collection vehicles are also needed, and cover material generally has to be hauled in.

REFERENCE

1. BLACK, R. J., and A. M. BARNES. Effect of earth cover on fly emergence from sanitary landfills. *Public Works*, 89(2):91–94, Feb. 1958. Condensed and reprinted as Fly emergence control in sanitary landfills. *Refuse Removal Journal*, 1(5):13, 25, May 1958.

CHAPTER 5

sanitary landfill design

The designing of a sanitary landfill calls for developing a detailed description and plans that outline the steps to be taken to provide for the safe, efficient disposal of the quantities and types of solid wastes that are expected to be received. The designer outlines volume requirements, site improvements (clearing of the land, construction of roadways and buildings, fencing, utilities), and all the equipment necessary for day-to-day operations of the specific landfilling method involved. He also provides for controlling water pollution and the movement of decomposition gas. The sanitary landfill designer should also recommend a specific use of the site after landfilling is completed. Finally, he should determine capital costs and projected operating expenditures for the estimated life of the project.

Volume Requirements

If the rate at which solid wastes are collected and the capacity of the proposed site are known, its useful life can be estimated. The ratio of solid waste to cover material volume usually ranges between 4:1 and 3:1; it is, however, influenced by the thickness of the cover used and cell configuration. If cover material is not excavated from the fill site, this ratio may be compared with the volume of compacted soil waste and the capacity of a site determined (Figure 6). For example, a town having a 10,000 population and a per capita collection rate of 5 lb per day must dispose of, in a year, 11 acre-ft of solid waste if it is compacted to 1,000 lb per cu yd. If it were compacted to only 600 lb per cu yd, the volume disposed of in a year would occupy 19 acre-ft. The volume of soil required for the 1,000-lb density at a solid waste-to-cover ratio of 4:1 would be 2.75 acre-ft; the 600-lb density waste would need 4.75 acre-ft. A density of 800 lb per cu yd is easily achievable if the compacting of a representative municipal waste is involved. A density of 1,000 lb per cu yd can usually be obtained if the waste is spread and compacted according to procedures described in Chapter 6.

The number of tons to be disposed of at a proposed sanitary landfill can be estimated from data

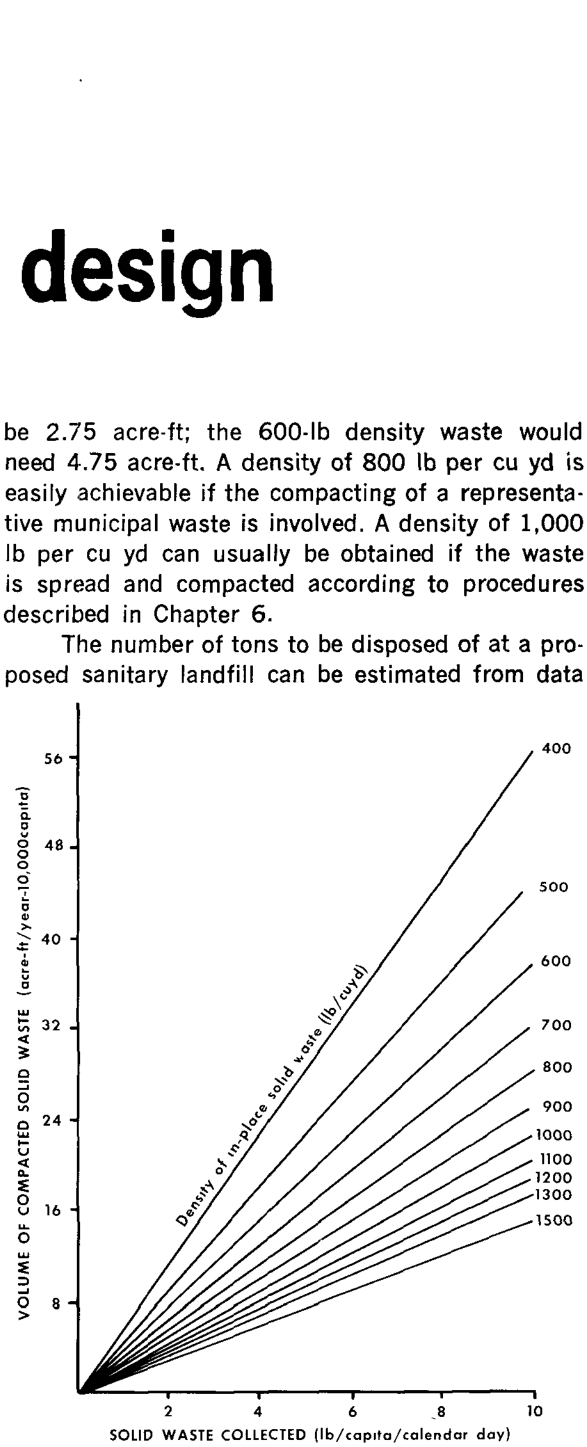

Figure 6. Determining the yearly volume of compacted solid waste generated by a community of 10,000 people.

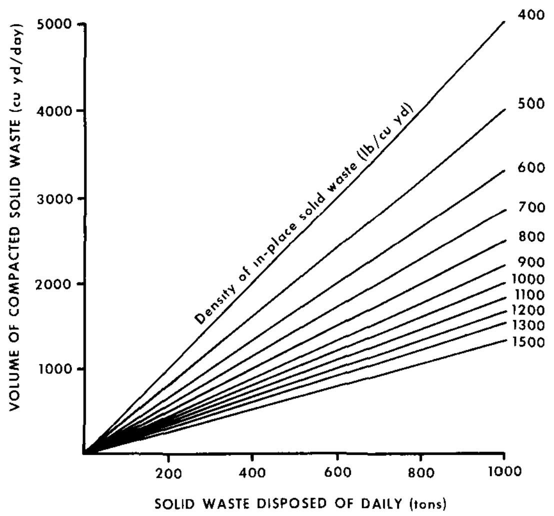

Figure 7. Determining the daily volume of compacted solid waste generated by large communities.

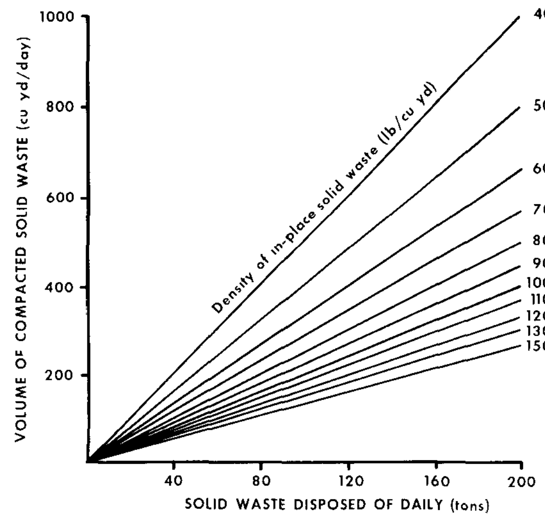

Figure 8. Determining the daily volume of compacted solid waste generated by small communities.

recorded when solid wastes are delivered to disposal sites. The daily volume of compacted solid waste can then be easily determined for a large community (Figure 7) or for a small community (Figure 8). The volume of soil required to cover each day's waste is then estimated by using the appropriate solid waste-to-cover ratio.

The terms used to report densities at landfills can be confusing. Solid waste density (field density) is the weight of a unit volume of solid waste in place. Landfill density is the weight of a unit volume of in-place solid waste divided by the volume of solid waste and its cover material. Both methods of reporting density are usually expressed as pounds per cubic yard, on an in-place weight basis, including moisture, at time of the test, unless otherwise stated.

Site Impovements

The plan for a sanitary landfill should prescribe how the site will be improved to provide an orderly and sanitary operation. This may simply involve the clearing of shrubs, trees, and other obstacles that could hinder vehicle travel and landfilling operations or it could involve the construction of buildings, roads, and utilities.

CLEARING AND GRUBBING. Trees and brush that hinder landfill equipment or collection vehicles must be removed. Trees that cannot be pushed over should be cut as close as possible to the ground so that the stumps do not hinder compaction or obstruct vehicles. Brush and tall grass in working areas can be rolled over or grubbed. A large site should be cleared in increments to avoid erosion and scarring of the land. If possible, natural windbreaks and green belts of trees or brush should be left in strategic areas to improve appearance and operation. Measures for minimizing erosion and sedimentation problems are outlined in the publication **Community Action Guidebook for Soil Erosion and Sediment Control.**[1]

ROADS. Permanent roads should be provided from the public road system to the site. A large site may have to have permanent roads that lead from its entrance to the vicinity of the working area. They should be designed to support the anticipated volume of truck traffic. In general, the roadway should consist of two lanes (total minimum width, 24 ft), for two-way traffic. Grades should not exceed equipment limitations. For loaded vehicles, most uphill grades should be less than 7 percent and downhill grades less than 10. Road alignments and pavement designs have been adequately discussed elsewhere.[2,3] The initial cost of permanent roads is higher than that of temporary roads, but the savings in equipment repair and maintenance could justify the building of permanent, on-site roads.

Temporary roads are normally used to deliver wastes to the working face from the permanent road system, because the location of the working face is constantly changing. Temporary roads may be constructed by compacting the natural soil present and by controlling drainage or by topping them with a layer of a tractive material, such as gravel, crushed stone, cinders, broken concrete, mortar, or bricks. Lime, cement, or asphalt binders may make such roads more serviceable.

If fewer than 25 round trips per day to the landfill are expected, a graded and compacted soil will usually suffice. More than 50 round trips per day generally justifies the use of calcium chloride as a dust inhibitor or such binder materials as soil cement or asphalt. A base course plus a binder is desirable if more than 100 to 150 round trips per day are anticipated.

SCALES. Recording the weights of solid waste delivered to a site can help regulate and control the sanitary landfill operation as well as the solid waste collection system that serves it.

The scale type and size used will depend on the scope of the operation. Portable scales may suffice for a small site, while an elaborate system employing load cells, electronic relays, and printed output may be needed at a large sanitary landfill. Highly automated electronic scales and recorders cost more than a portable, simple, beam scale, but their use may often be justified, because they are faster and more accurate. The platform or scale deck may be constructed of wood, steel, or concrete. The first type is the least expensive, but also the least durable.

The scale should be able to weigh the largest vehicle that will use the landfill on a routine basis; 30 tons is usually adequate. Generally, the platform should be long enough to weigh all axles simultaneously. Separate axle-loading scales (portable versions) are the cheapest, but they are less accurate and slower operating. The scale platform should be 10 by 34 ft to weigh most collection vehicles. A 50-ft platform will accommodate most trucks with trailers.

The accuracy and internal mechanism of the scale and the recording device should meet the commercial requirements imposed by the State and any other jurisdiction involved, particularly if user fees are based on weight. Recommended scale requirements have been outlined by the National Bureau of Standards.[4]

Since weights are seldom recorded closer than to the nearest tenth of a ton and most applied loads are between 8 and 14 tons, a scale accuracy of ± 1.0 percent is acceptable. All scales should be periodically checked and certified as to standard accuracy.

Both mechanical and electronic scales should be tested quarterly under load. The inspection should include: (1) checking for a change in indicated weight as a heavy load is moved from the front to the back of the scale; (2) observing the action of the dial during weighing for an irregularity or "catch" in its motion; (3) using test weights.

BUILDINGS. A building is needed for office space and employee facilities at all but the smallest landfill; it can also serve as a scale house. Since a landfill operates in wet and cold weather, some protection from the elements should be provided. Operational records may also be kept at a large site. Sanitary facilities should be provided for both landfill and collection personnel. A building should also be provided for equipment storage and maintenance.

Buildings on sites that will be used for less than 10 years should be temporary types and, preferably, be movable. The design and location of all structures should consider gas movement and differential settlement caused by the decomposing solid waste.

UTILITIES. All sanitary landfill sites should have electrical, water, and sanitary services. Remote sites may have to extend existing services or use acceptable substitutes. Portable chemical toilets can be used to avoid the high cost of extending sewer lines, potable water may be trucked in, and an electric generator may be used instead of having power lines run into the site.

Water should be available for drinking, fire fighting, dust control, and employee sanitation. A sewer line may be called for, especially at large sites and at those where leachate is collected and treated with domestic wastewater. Telephone or radio communications are also desirable.

FENCING. Peripheral and litter fences are commonly needed at sanitary landfills. The first type is used to control or limit access, keep out children, dogs, and other large animals, screen the landfill, and delineate the property line. If vandalism and trespassing are to be discouraged, a 6-ft high fence topped with three strands of barbed wire projecting at a 45° angle is desirable. A wooden fence or a hedge may be used to screen the operation from view.

Litter fences are used to control blowing paper in the immediate vicinity of the working face. As a general rule, trench operations require less litter fencing because the solid waste tends to be confined within the walls of the trench. At a very windy trench site, a 4-ft snow fence will usually suffice. Blowing paper is more of a problem in an area operation; 6- to 10-ft litter fences are often needed. Some litter fences have been specially designed and fabricated (Figure 9). Since the location of the working face shifts frequently, litter fences should be movable.

Control of Surface Water

Surface water courses should be diverted from the sanitary landfill. Pipes may be used in gullies, ravines, and canyons that are being filled to transmit upland drainage through the site and open channels employed to divert runoff from surround-

Figure 9. Specially designed and fabricated litter-control fences are often used near the working face of a sanitary landfill.

ing areas (Figure 10). Sump pumps may also be used. Because of operating and maintenance requirements, the use of mechanical equiment for water control is, however, strongly discouraged unless the control is needed only temporarily. If trenches or depressions are being filled, collection sumps and pumps may be used to keep them from flooding. Equipment sizes can be determined by analyzing storm and flood records covering about a 50-year period. Counseling and guidance in planning water management measures are available through local soil conservation districts upon request. A landfill located in a flood plain should be protected by impervious dikes and liners. The top of the dike should be wide enough for maintenance work to be carried out and may be designed for use by collection and landfill vehicles.

The top cover material of a landfill should be graded to allow runoff of rainfall. The grade of the cover will depend on the material's ability to resist erosion and the planned use of the completed site. Portable or permanent drainage channels may be

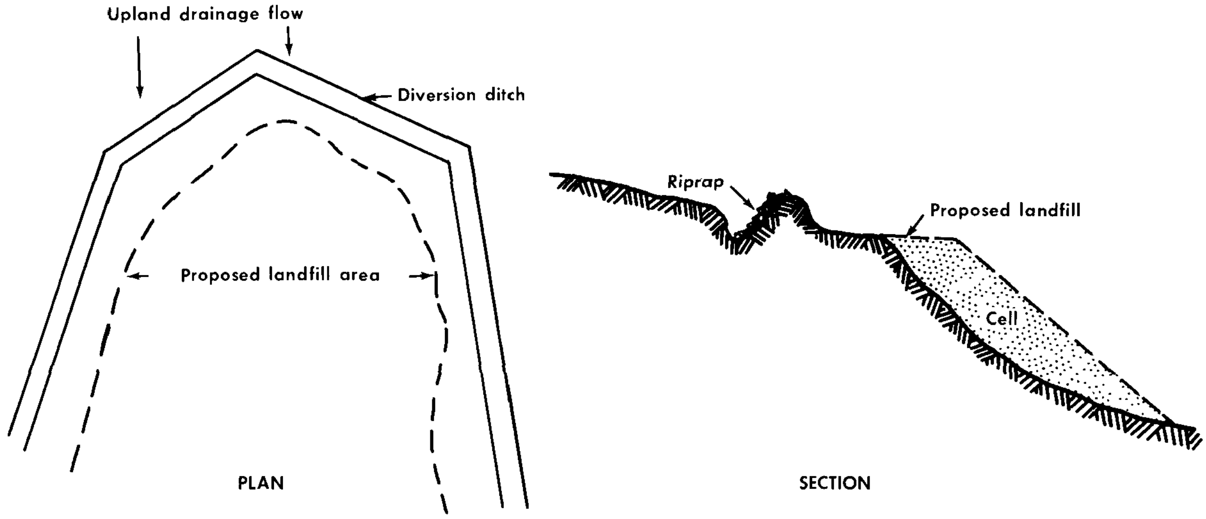

Figure 10. Plan and section views of the use of a diversion ditch to transmit upland drainage around a sanitary landfill.

constructed to intercept and remove runoff water. Low-cost, portable drainage channels can be made by bolting together half-sections of corrugated steel pipes. Surface water that runs off stockpiled cover material may contain suspended solids and should not be allowed to enter watercourses unless it has been ponded to remove settleable solids.

Groundwater Protection

It is a basic premise that groundwater and the deposited solid waste not be allowed to interact. It is unwise to assume that a leachate will be diluted in groundwater because very little mixing occurs in an aquifer since the groundwater flow there is usually laminar.

When issuing permits or certificates, many States require that groundwater and deposited solid wastes be 2 to 30 ft apart. Generally, a 5-ft separation will remove enough readily decomposed organics and coliform bacteria to make the liquid bacteriologically safe.[5, 6] On the other hand, mineral pollutants can travel long distances through soil or rock formations. In addition to other considerations, the sanitary landfill designer must evaluate the: (1) current and projected use of the water resources of the area; (2) effect of leachate on groundwater quality; (3) direction of groundwater movement; (4) interrelationship of this aquifer with other aquifers and surface waters.

Groundwater mounds, rises in the piezometric level of an aquifer in a recharge area, have been found at several landfills.[7] The mounds are reported to be up to 5 ft above the surrounding groundwater level, and they have intersected deposited solid waste. The investigators believe the water table probably rose because: (1) the permeability of the landfill's soil boundary decreased as a result of excavation and reworking; (2) more water infiltrated through the cover material and solid waste than through the undisturbed soils of the surrounding area.[7]

If a groundwater mound intersects the solid waste, leachate will undoubtedly enter the groundwater and may emerge as a spring around the toe of the fill where the groundwater table intersects the ground surface. Both surface and groundwaters may, therefore, be endangered if a mound forms.

An impermeable liner may be employed to control the movement of fluids. One of the most commonly used is a well-compacted natural clay soil, usually constructed as a membrane 1 to 3 ft thick. It must, however, be kept moist. If sufficient clay soil is not available locally, natural clay additives, such as montmorillonite, may be disked into it to form an effective liner. The use of additives requires evaluation to determine optimum types and amounts.

Since synthetic liners have been used to construct wastewater-holding-and-treatment ponds, they may have an application in solid waste disposal operations. They are usually made of butyl rubber, polyethylene, or polyvinyl chloride and are installed in multiple layers. (If the movement of both gas and leachate is to be controlled, polyvinyl chloride should work better than polyethylene because it is less permeable by gas.) The membranes must be put down carefully to avoid punctures, and layers of soil (usually sand) must be placed on both sides of them. Asphalt liners, which have been used to reduce seepage from canals and ditches, may also have an application in a solid waste disposal operation.

The use of an impermeable barrier requires that some method be provided for removal of the contained fluid. If a natural ravine or canyon is involved, the removal point should be the downstream end of the filled area. The fluid in a bowl-shaped liner could be pumped by a well or series of wells or it could exit through gravity outlets in the bottom of the liner. In the latter case, the pipes should be sloped ⅛ to ¼ in. per ft.

It is often possible to permanently or temporarily lower the groundwater in free-draining, gravelly, and sandy soils. Drains, canals, and ditches are frequently used to intercept the groundwater and channel it to surface water or recharge area at a lower elevation. Doing this generally requires that the designer have a thorough knowledge of the soil permeabilities and the groundwater flow system in the area. It is inadvisable to use temporary methods, such as wells, to lower the water table because it will rise after pumping ceases, and the waste will be inundated. It is well to recognize that highly permeable soils that can be readily drained by ditching or pumping will offer equally little resistance to the movement of leachate from the decomposing solid waste. Even though groundwater can be kept from coming into direct contact with the solid waste, in most climates infiltrated surface water will probably enter the solid waste eventually, cause leaching, and then percolate through the underlying porous soil to enter the lowered groundwater. It is advisable, therefore, to view sites in highly permeable material with extreme caution.

Little work has been done to determine the types and costs of leachate treatment. Analysis of leachate samples from a few landfills and laboratory lysimeters indicates that leachate is a complex liquid waste and has variable characteristics. Since most of the contaminants in leachate are water soluble, conventional biological and chemical treatment methods are probably required and, hopefully, will prove effective.

To help establish if a landfill is creating a groundwater and surface water pollution problem, a series of observation wells and sampling stations can be used to periodically monitor the water quality. Data on the upstream or uncontaminated water and downstream water quality are necessary to evaluate the pollution potential.

Gas Movement Control

An important part of sanitary landfill design is controlling the movement of decomposition gases, mainly carbon dioxide and methane. Traces of hydrogen sulfide and other odorous gases may also be involved.

Methane (CH_4) is a colorless, odorless gas that is highly explosive in concentrations of 5 to 15 percent when in the presence of oxygen. In a few instances, methane gas has moved from a landfill and accumulated in explosive concentrations in sewer lines and nearby buildings. Gas from landfills has also killed nearby vegetation, presumably by excluding oxygen from the root zone. Carbon dioxide (CO_2) is also a colorless, odorless gas, but it does not support combustion. It is approximately 1.5 times as heavy as air and is soluble in water. The CO_2 reacts to a limited extent to form carbonic acid (H_2CO_3), which can dissolve mineral matter, particularly carbonates, in refuse, soil, and rock. If this occurs, the mineral content or hardness of the water increases, as has been noted at wells located near landfills and dumps.

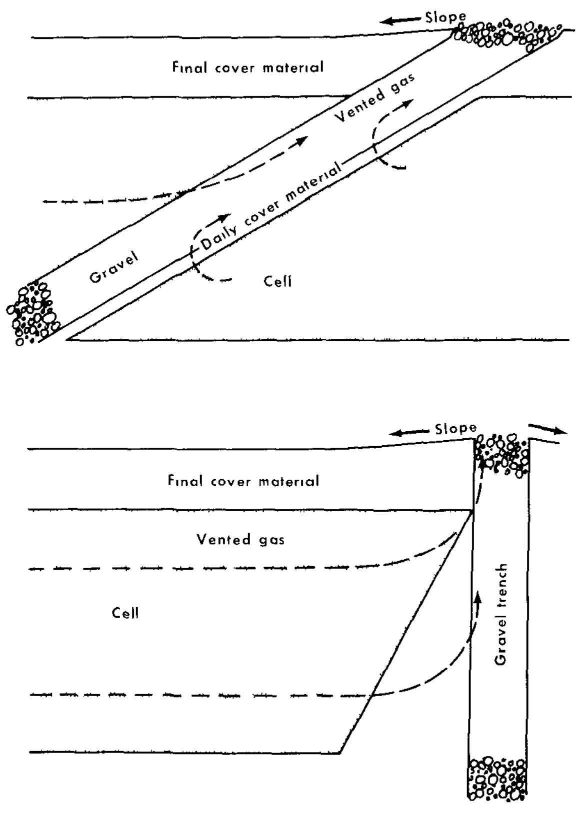

Figure 11. Gravel vents or gravel-filled trenches can be used to control lateral gas movement in a sanitary landfill.

In general, no problems arise when landfill gas can disperse into the atmosphere. If the fill has a relatively impermeable cover, however, the methane will try to vent into the atmosphere by moving laterally through a more permeable material.

The natural soil, hydrologic, and geologic conditions of the site may provide control of gas movement. If not, methods based on controlling gas permeability can be constructed. The following have been used or are considered possible.

PERMEABLE METHODS. Lateral gas movement can be prevented by using a material that is—under all circumstances—more permeable than the surrounding soil; gravel vents or gravel-filled trenches have been employed (Figure 11). Preferably, the trenches should be somewhat deeper than the fill to make sure they intercept all lateral gas flow. The filter material should be graded to avoid infiltration and clogging by adjacent soil carried in by water. If possible, the trench should be built so that it drains naturally; field tile is often placed in the bottom of the trench. The surface of gravel trenches should be kept free of soil and vegetation, because they retain moisture and hinder venting.

In another method, vent pipes are inserted through a relatively impermeable top cover (Figure 12). Collecting laterals placed in shallow gravel trenches within or on top of the waste can be connected to the vertical riser. The sizes and spacings required have not been established, but they depend on the rate of gas production, total weight of solid waste, and the gas permeability of both the cover and the surrounding soil. In some cases, vertical risers have been used to burn off the gas. Pipe vents should not be located near buildings, but if this is unavoidable, they should discharge above the roof line.

Pumped exhaust wells may be used for gas venting. In this method, pipe vents are attached to the line of a suction pump to create differential driving pressure for gas movement. This method is costly and requires frequent maintenance.

IMPERMEABLE METHODS. The movement of gas through soils can be controlled by using materials that are more impermeable to it than the surrounding soil. An impermeable barrier can be used to

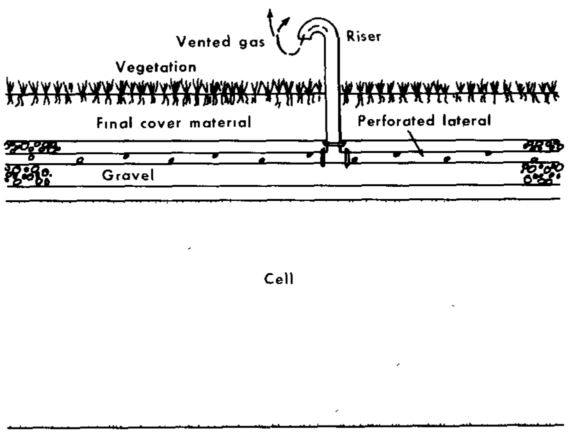

Figure 12. Gases are sometimes vented out of a sanitary landfill via pipes that are inserted through a relatively impermeable top cover and are connected to collecting laterals placed in shallow gravel trenches within or on top of the waste.

contain the gas and vent it through the top cover or simply to block the flow of gas.

The most common method, and possibly the most practical, calls for the use of compacted clay. The material must, however, be kept moist, otherwise it could shrink and crack. (Other fine grained soils may also be used, with the same stipulation.) The clay can be placed as a liner in an excavation or installed as a curtain wall to block underground gas flow (Figure 13). A clay layer 18 to 48 in. thick is probably adequate, but it should be continuous and not be penetrated by solid waste or outcroppings of the surrounding soil or rocks. The liner should be constructed as the fill progresses, because prolonged exposure to air will dry the clay and cause it to shrink and crack.

The use of synthetic membranes was described in the section on Groundwater Protection.

Sanitary Landfilling Methods

The designer of a sanitary landfill should prescribe the method of construction and the procedures to be followed in disposing of the solid waste, because there is no "best method" for all sites. The method selected depends on the physical conditions involved and the amount and types of solid waste to be handled.

The two basic landfilling methods are trench and area; other approaches are only modifications. In general, the trench method is used when the groundwater is low and the soil is more than 6 ft deep. It is best employed on flat or gently rolling land. The area method can be followed on most topographies and is often used if large quantities of solid

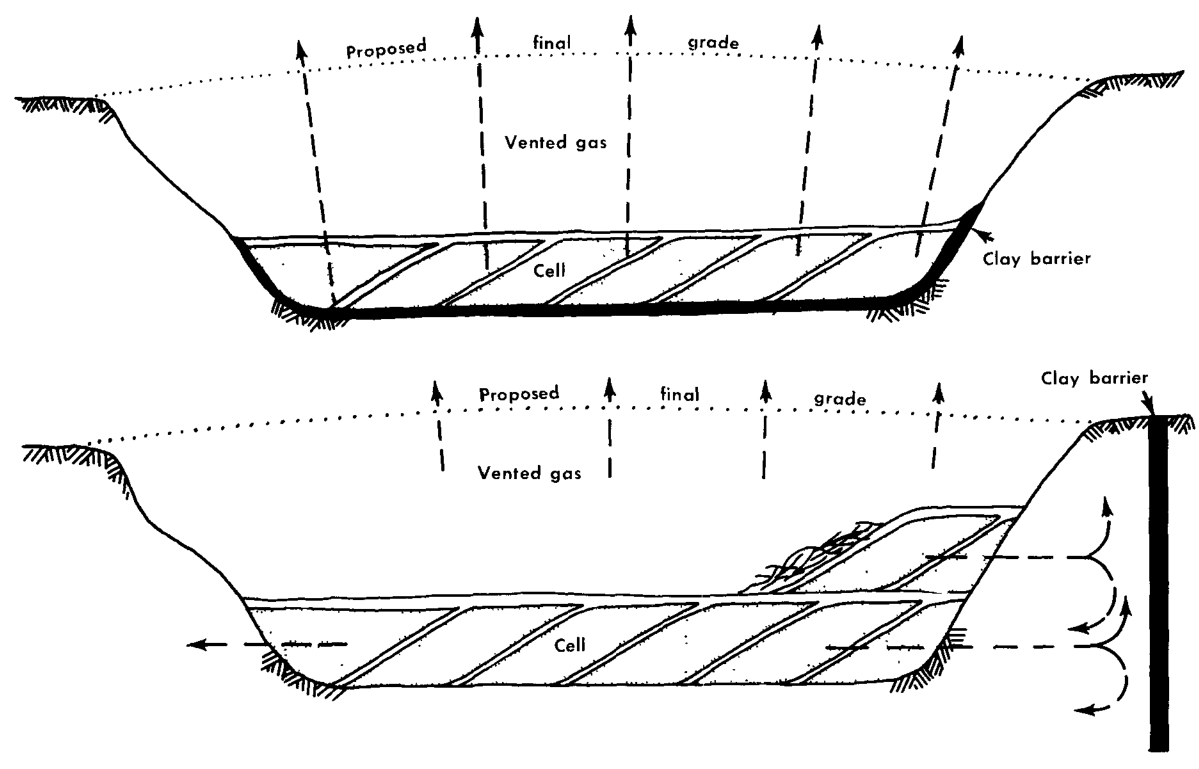

Figure 13. Clay can be placed as a liner in an excavation or installed as a curtain wall to block underground gas flow.

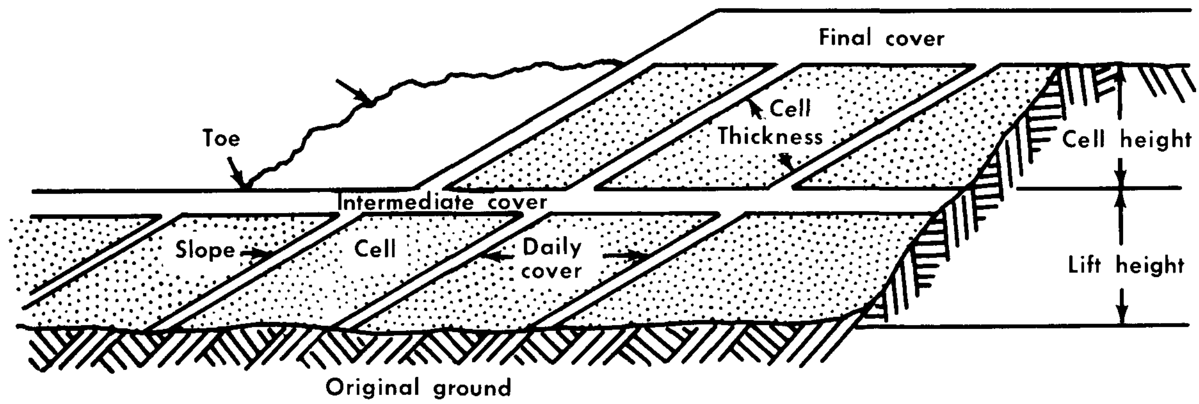

Figure 14. The cell is the common building block in sanitary landfilling. Solid waste is spread and compacted in layers within a confined area. At the end of each working day, or more frequently, it is covered completely with a thin, continuous layer of soil, which is then also compacted. The compacted waste and soil constitute a cell. A series of adjoining cells makes up a lift. The completed fill consists of one or more lifts.

waste must be disposed of. At many sites, a combination of the two methods is used.

CELL CONSTRUCTION AND COVER MATERIAL. The building block common to both methods is the cell. All the solid waste received is spread and compacted in layers within a confined area. At the end of each working day, or more frequently, it is covered completely with a thin, continuous layer of soil, which is then also compacted. The compacted waste and soil cover constitute a cell. A series of adjoining cells, all of the same height, makes up a lift (Figure 14). The completed fill consists of one or more lifts.

The dimensions of the cell are determined by the volume of the compacted waste, and this, in turn, depends on the density of the in-place solid waste. The field density of most compacted solid waste within the cell should be at least 800 lb per cu yd. (It should be considerably higher if large amounts of demolition rubble, glass, and well-compacted inorganic materials are present.) The 800-lb figure may be difficult to achieve if brushes from bushes and trees, plastic turnings, synthetic fibers, or rubber powder and trimmings predominate. Because these materials normally tend to rebound when the compacting load is released, they should be spread in layers up to 2 ft thick, then covered with 6 in. of soil. Over this, mixed solid waste should be spread and compacted. The overlying weight keeps the fluffy or elastic materials reasonably compressed.

An orderly operation should be achieved by maintaining a narrow working face (that portion of the uncompleted cell on which additional waste is spread and compacted). It should be wide enough to prevent a backlog of trucks waiting to dump, but not be so wide that it becomes impractical to manage properly—never over 150 ft.

No hard-and-fast rule can be laid down regarding the proper height of a cell. Some designers think it should be 8 ft or less, presumably because this height will not cause severe settlement problems. On the other hand, if a multiple lift operation is involved and all the cellls are built to the same height, whether 8 or 16 ft, total settlement should not differ significantly. If land and cover material are readily available, an 8-ft height restriction might be appropriate, but heights up to 30 ft are common in large operations. Rather than deciding on an arbitrary figure, the designer should attempt to keep cover material volume at a minumum while adequately disposing of as much waste as possible.

Cover material volume requirements are dependent on the surface area of waste to be covered and the thickness of soil needed to perform particular functions. As might be expected, cell configuration can greatly affect the volume of cover material needed. The surface area to be covered should, therefore, be kept minimal.

In general, the cell should be about square, and its sides should be sloped as steeply as practical operation will permit. Side slopes of 20° to 30° will not only keep the surface area, and hence the cover material volume, at a minimum but will also aid in shredding and obtaining good compaction of solid waste, particularly if it is spread in layers not greater than 2 ft thick and worked from the bottom of the slope to the top.

TRENCH METHOD. Waste is spread and compacted in an excavated trench. Cover material, which is taken from the spoil of the excavation, is spread and compacted over the waste to form the basic cell structure (Figure 15). In this method, cover material is readily available as a result of the excavation. Spoil material not needed for daily

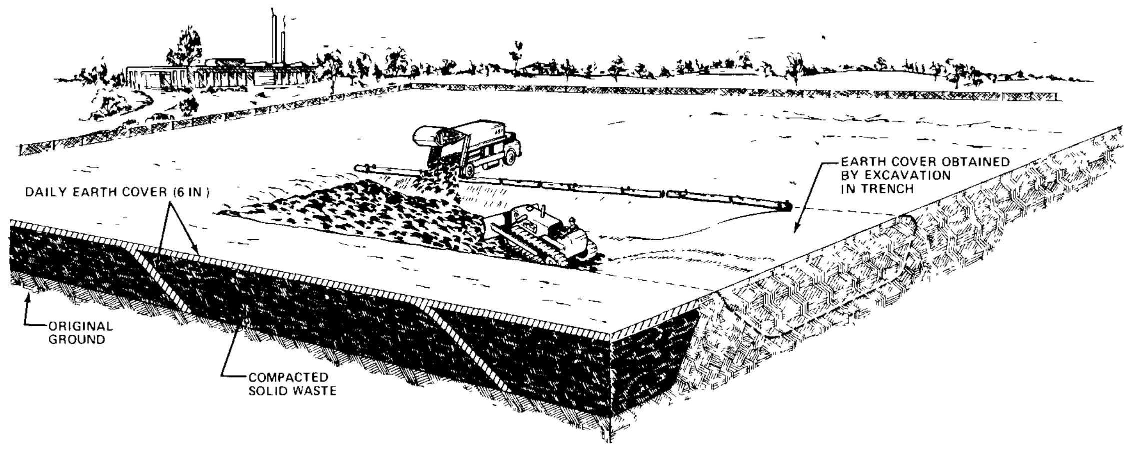

Figure 15. In the trench method of sanitary landfilling, the collection truck deposits its load into a trench where a bulldozer spreads and compacts it. At the end of the day, the trench is extended, and the excavated soil is used as daily cover material.

cover may be stockpiled and later used as a cover for an area fill operation on top of the completed trench fill.

Cohesive soils, such as glacial till or clayey silt, are desirable for use in a trench operation because the walls between the trenches can be thin and nearly vertical. The trenches can, therefore, be spaced very closely. Weather and the length of time the trench is to remain open also affect soil stability and must be considered when the slope of the trench walls is being designed. If the trenches are aligned perpendicularly to the prevailing wind, this can greatly reduce the amount of blowing litter. The bottom of the trench should be slightly sloped for drainage, and provision should be made for surface water to run off at the low end of the trench. Excavated soil can be used to form a temporary berm on the sides of the trench to divert surface water.

The trench can be as deep as soil and groundwater conditions safely allow, and it should be at least twice as wide an any compacting equipment that will work in it. The equipment at the site may excavate the trench continuously at a rate geared

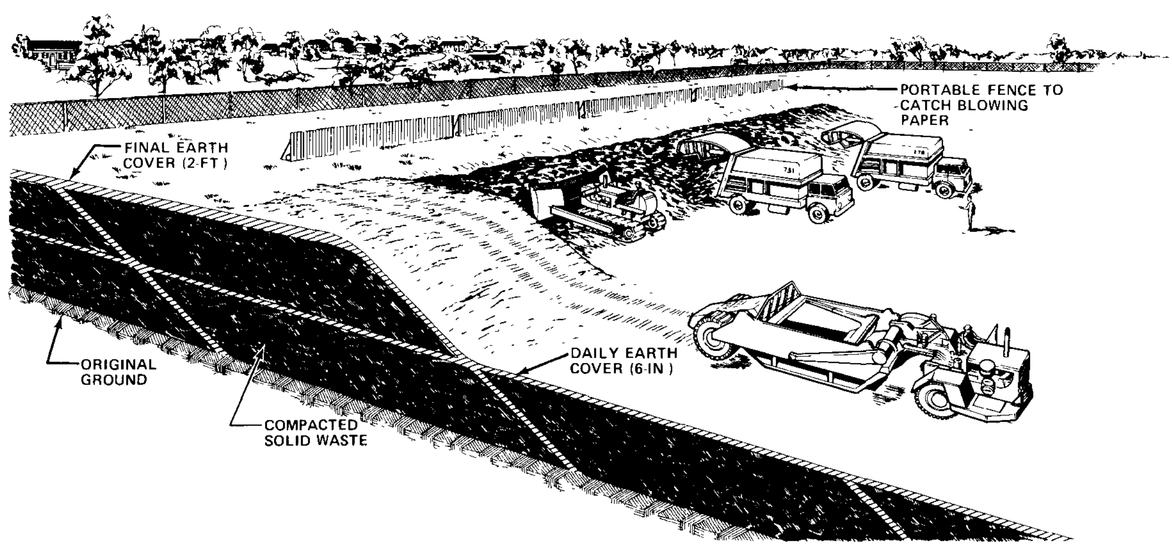

Figure 16. In the area method of sanitary landfilling, a bulldozer spreads and compacts the waste on the natural surface of the ground, and a scraper is used to haul the cover material at the end of the day's operations.

to landfilling requirements. At small sites, excavation may be done on a contract basis.

AREA METHOD. In this method, the waste is spread and compacted on the natural surface of the ground, and cover material is spread and compacted over it (Figure 16). The area method is used on flat or gently sloping land and also in quarries, strip mines, ravines, valleys, or other land depressions.

COMBINATION METHODS. A sanitary landfill does not need to be operated by using only the area or trench method. Combinations of the two are possible, and flexibility is, therefore, one of sanitary landfilling's greatest assets. The methods used can be varied according to the constraints of a particular site.

One common variation is the progressive slope or ramp method, in which the solid waste is spread and compacted on a slope. Cover material is obtained directly in front of the working face and compacted on the waste (Figure 17). In this way, a small excavation is made for a portion of the next day's waste. This technique allows for more efficient use of the disposal site when a single lift is constructed than the area method does, because cover does not have to be imported, and a portion of the waste is deposited below the original surface.

Both methods might have to be used at the same site if an extremely large amount of solid waste must be disposed of. For example, at a site with a thick soil zone over much of it but with only a shallow soil over the remainder, the designer would use the trench method in the thick soil zone and use the extra spoil material obtained to carry out the area method over the rest of the site. When a site has been developed by either method, additional lifts can be constructed using the area method by having cover material hauled in.

The final surface of the completed landfill should be so designed that ponding of precipitation does not occur. Settlement must, therefore, be considered. Grading of the final surface should induce drainage but not be so extreme that the cover material is eroded. Side slopes of the completed surface should be 3 to 1 or flatter to minimize maintenance.

Finally, the designer should consider completing the sanitary landfill in phases so that portions of it can be used as parks and playgrounds, while other parts are still accepting solid wastes.

Summary of Design Considerations

The final design of a sanitary landfill should describe in detail: (1) all employee and operational facilities; (2) operational procedures and their sequence, equipment, and manpower requirements; (3) the pollution potential and methods of control-

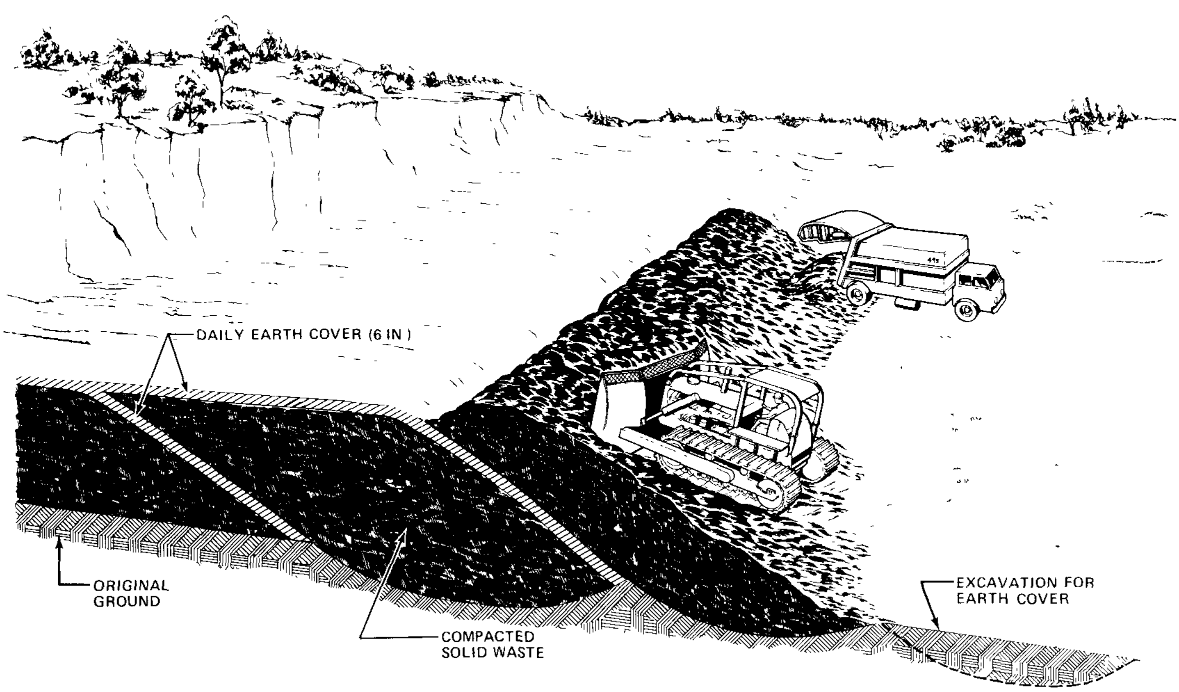

Figure 17. In the progressive slope or ramp method of sanitary landfilling, solid waste is spread and compacted on a slope. Cover material is obtained directly in front of the working face and compacted on the waste.

ling it; (4) the final grade and planned use of the completed fill; (5) cost estimates for acquiring, developing, and operating the proposed site.

The designer should also provide a map that shows the location of the site and the area to be served and a topographic map covering the area out to 1,000 ft from the site. Additional maps and cross-sections should also be included that show the planned stages of filling (startup, intermediate lifts, and completion). They should present the details of:

1. Roads on and off the site;
2. Buildings;
3. Utilities above and below ground;
4. Scales;
5. Fire protection facilities;
6. Surface drainage (natural and constructed) and groundwater;
7. Profiles of soil and bedrock;
8. Leachate collection and treatment facilities;
9. Gas control devices;
10. Buildings within 1,000 ft of property (residential, commercial, agricultural);
11. Streams, lakes, springs, and wells within 1,000 ft;
12. Borrow areas and volume of material available;
13. Direction of prevailing wind;
14. Areas to be landfilled, including special waste areas, and limitations on types of waste that may be disposed of;
15. Sequence of filling;
16. Entrance to facility;
17. Peripheral fencing;
18. Landscaping;
19. Completed use.

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CHAPTER 6
sanitary landfill operation

The best designed disposal facility will be of little value unless it is constructed and operated as prescribed. This is especially true of a sanitary landfill because it is under construction up to the day the last particle of solid waste is disposed of. Constructing the sanitary landfill on a daily basis in accordance with the design should be unequivocally required in an operations plan.

An operations plan is essentially the specification for construction and it should contain all items required to construct the sanitary landfill. It should describe: (1) hours of operation; (2) measuring procedures; (3) traffic flow and unloading procedures; (4) designation of specific disposal areas and methods of handling and compacting various solid wastes; (5) placement of cover material; (6) maintenance procedures; (7) adverse weather operations; (8) fire control; (9) litter control; (10) salvaging operations, if permitted.

Proper operation calls for drawing up a comprehensive plan that spells out routine procedures and anticipates abnormal situations. It must also provide continuity of activities even when personnel changes occur. New supervisors and personnel responsible for solid waste disposal must know what is being done at the landfill and why. The plan must, however, remain open for revision when necessary. Changes should be noted, and the rationale behind them explained. New personnel will benefit from the experience of others, and continuity of operations will be preserved.

The plan should also be used as a tool in training employees, defining their jobs, and giving them an insight into the work of others. In this manner, the employee will more fully understand the overall operation, and he may be able to perform other duties in an emergency.

Hours of Operation

The hours a sanitary landfill operates depend mainly on when the wastes are delivered, and generally this is done during normal working hours. In large cities, however, waste collection systems sometimes operate 24 hr a day. In this case, a site should not be located in a residential area. The usual landfill is open 5 to 6 days a week and 8 to 10 hr a day.

The hours of operation should be posted on a sign at the landfill entrance. It should also indicate: what wastes are not accepted; fees charged; and the name, address, and telephone number of the operating body (sanitation district or private company). All this information must be kept current. Fees are usually levied on a cost-per-ton basis for large loads and on a fee basis for small amounts brought to the site by homeowners. The sanitary landfill should be open only when operators are on duty. If it is anticipated that waste will be brought to a disposal site at other times, a large container should be placed outside the site entrance.

Weighing the Solid Waste

The efficiency of filling and compacting operations can be adequately judged if the amount of solid waste delivered, the quantity of cover material used, and the volume occupied by the landfilled solid waste and cover are known. (Weighing is the most reliable means of measurement.) These values are also used to determine the density of the fill and to estimate the amount of settlement that will probably occur. Weight and volume data can also be used in designing new landfills and predicting the remaining capacity of currently operating landfills.

The number of vehicles that can be weighed in a unit of time will vary. An experienced weighmaster is able to record manually, for short periods of time, the net weight and types of material delivered at a rate of 60 trucks per hr, but it is extremely taxing to maintain this pace for long periods. A highly automated weighing procedure can easily accommodate over 60 trucks per hr, record more data, require less supervision, and be more accurate. Landfills disposing of 1,000 tons or more per day will usually require two or more automatic scales. Truck scales require little maintenance if inspected and maintained as recommended by their manufacturers.

Although a seemingly simple operation, weighing presents many problems. To ensure that all trucks are weighed, vehicle-handling controls and accounting techniques must be developed. Techniques being used include a two-gate system (one at the front and one at the back of the scale) that locks a truck on the scale until weighed, one-way exit barricades, signal lights, curbing, alarms, and numerous automated recording devices.

If a truck is not properly positioned on the platform (one or more axles off) the weight recorded will be wrong. Suitable curbing, markings, elevated transverse bumps, or extra long scales can reduce or prevent unintentional misplacement of vehicles on the scale.

Dirt, water, snow, and ice may accumulate on and under the deck of the scale and cause it to wear and rust, lead to hazardous driving conditions, and generate weighing errors.

Traffic Flow and Unloading

Traffic flow on the site can affect the efficiency of daily operations. Traffic should be allowed to bypass the scale only if it is inoperative. Haphazard routing between the scale and the disposal area can lead to indiscriminate dumping and cause accidents. Pylons, barricades, guardrails, and traffic signs can be used to direct traffic. Large sites may need posted maps to direct drivers. If separate working areas are established for different types of wastes, signs should be used to direct drivers to the appropriate disposal areas.

Wastes are delivered to a landfill in vehicles that range from automobiles to large transfer trailers. Operationally, they comprise groups that are unloaded manually or mechanically. The two categories are established because of the difference in time it takes to unload them at the working face. If large numbers of manually unloaded vehicles must be handled, special procedures may be necessary.

Mechanically discharging vehicles include dump trucks, packer-type collection trucks, tank trucks, and open or closed body trucks equipped with a movable bulkhead that requires the use of a crawler dozer or loader. These vehicles are capable of rapidly discharging their loads and should be routed directly to the working face without delay.

Manually discharging vehicles take more time to unload and should not be permitted to slow the unloading of vehicles that can discharge mechanically. Many of the drivers will not be familiar with the landfill operation and will require close supervision. If a large number of manually discharging vehicles is involved, a separate unloading area may be necessary to avoid delaying other vehicles.

Scavenging should not be permitted, and no vehicle should be left unattended. Waste should be deposited at the toe of the working face, because it can be compacted better there since it is worked up the slope rather than down. If it is necessary to discharge solid wastes at the top of the slope, as in a narrow trench operation, telephone poles or similar objects should be emplaced to warn drivers that they are near its edge. The unloading area should be as level as practical for dump trucks and other vehicles having high centers of gravity in the raised position.

Handling of Wastes

Wastes come from residences, commercial establishments, institutions, municipal operations, industries, and farms. Some may require special methods of handling and burial. The landfill designer should know all the types that will likely be involved and make provision for their disposal. Materials that cannot be safely buried should be excluded.

RESIDENTIAL, COMMERCIAL, AND INDUSTRIAL PLANT WASTES. These wastes (exclusive of process wastes discussed later) are usually highly compactible. They contain a heterogeneous mixture of such materials as paper, cans, bottles, cardboard and wooden boxes, plastics, lumber, metals, yard clippings, food waste, rocks, and soil. When exposed, boxes, plastic and glass containers, tin cans, and brush can be compressed and crushed under relatively low pressure. In a landfill, however, these items are incorporated within the mass of solid waste, which acts as a cushion and often bridges, thus protecting the relatively low-strength materials from being crushed under the load of the compaction equipment.

Cushioning and bridging can be reduced and greater volume reduction achieved if the waste is spread in layers less than 2 ft deep and is then compacted by tracked, rubber-tired, or steel-wheeled vehicles that pass over it 2 to 5 times. Solid waste that contains a high percentage of brush and yard clippings requires the expenditure of more compactive effort. If entire loads of these items are received, they should be spread and compacted near the bottom of the cell so that less resilient wastes can be compacted on top.

The equipment operator should try to develop the working face on a slope between 20° and 30° (Figure 18). Waste is spread against the slope, and the machine moves up and down it, thus tearing and compacting the waste and eliminating voids. The equipment operator should make passes until he no longer can detect that the surface of the waste layer is being depressed more than it is rebounding.

BULKY WASTES. Bulky wastes include car bodies, demolition and construction debris, large appliances, tree stumps, and timbers. Significant volume reduction of construction rubble and stumps by compaction cannot be achieved, but car bodies, furniture, and appliances can be significantly reduced in volume. A small crawler dozer (110 HP and 20,000 lb. or less) has greater difficulty in compacting washing machines and auto bodies than would heavy machines, but some volume reduction can be achieved. Such items should be crushed on solid ground and then pushed onto the working face, near the bottom of the cell or into a separate disposal area. Once in place, most bulky items do not degrade (at least not at a rate comparable to surrounding refuse). Consequently, if bulky items are incorporated into degradable wastes, uneven settlement will result. Special areas for bulky items should be identified on the final plan of the completed site. Even though bulky wastes do not usually contain putrescibles, they should be completely covered at the end of each operating day to eliminate harborage for rats and other pests.

Selected loads of demolition and construction

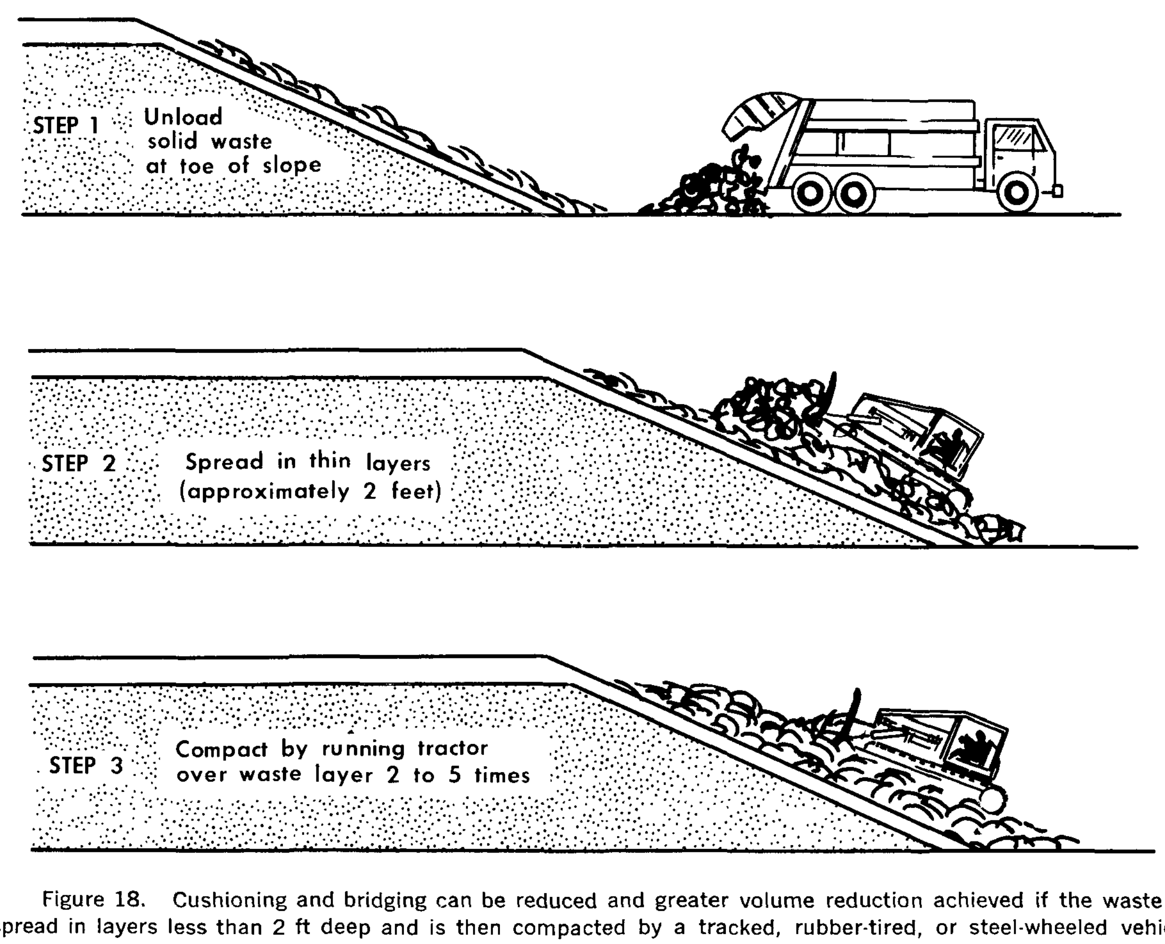

Figure 18. Cushioning and bridging can be reduced and greater volume reduction achieved if the waste is spread in layers less than 2 ft deep and is then compacted by a tracked, rubber-tired, or steel-wheeled vehicle that passes over it 2 to 5 times. The equipment operator should try to develop the working face on a slope between 20 and 30 degrees.

debris—broken concrete, asphalt, bricks, and plaster—can be stockpiled and used to build on-site roads.

INSTITUTIONAL WASTES. Solid wastes from schools, rest homes, and hospitals are usually highly compactible and can often be handled in the same manner as residential and commercial wastes and are often delivered along with them. If hospital wastes are delivered separately, they should be spread immediately, compacted, and enclosed with another layer of waste or a cover material because they could contain pathogenic organisms. Pathological wastes are usually disposed of in a special incinerator, but if accepted, they should be buried immediately under 1 ft of cover material. Some States have restrictions on the way such wastes are buried, and pertinent State laws should be consulted.

DEAD ANIMALS. Dead birds, cats, dogs, horses, and cows are occasionally delivered to sanitary landfills. The burial method is covered by law in most States. Some require that they be immediately incorporated into the landfill and covered, others demand that they be placed in a pit and covered with lime. In general, small animal corpses can be safely disposed of if placed in a landfill along with other wastes and immediately covered. Very large animals are usually dismembered so they can be transported to the disposal site. They are then placed in a pit and covered with 2 ft of compacted soil; this should be graded periodically to avoid ponding and settlement, which could be appreciable.

INDUSTRIAL PROCESS WASTES. Because of the wide variety of industrial process wastes and their different chemical, physical, and biological characteristics, it is difficult to generalize about handling them. The best source of information concerning their characteristics is the industries that produce them. It is extremely important to evaluate the influence of these wastes on the environment. If an industrial waste is determined to be unsuitable for disposal at the landfill, it should be excluded and the respective industries notified. Another important factor is the health and safety of landfill personnel.

Industrial wastes delivered to a landfill may be in the form of a liquid, semi-liquid, films, sheets, granules, shavings, turnings, powders, and defectively manufactured products of all shapes and sizes. Whether or not these are disposed of in the sanitary landfill depends on the environmental conditions of the site and whether or not they are chemically and biologically stable. They should not be allowed to pollute surface water or groundwater.

Liquids and semi-liquids, if deemed safe to place in a landfill, should be admixed with relatively dry, absorbent solid waste or they may be disposed of in a pit well above the groundwater table. The pit should be fenced and the gate locked to prevent unauthorized access; its location should be recorded in the final plan of the completed site.

Films and other light, fluffy, easily airborne materials can be a nuisance at the working face, and they should be covered immediately when deposited there. Spraying them with water may be helpful, but the detrimental effects of adding water should be considered.

Large sheets of metal, plastic, or wood can also be nuisances at the working face. The equipment operator should align the sheets parallel to one another. Random placement leads to large voids, poor compaction, and substantial settlement of the completed landfill.

Granules, shavings, turnings, and powders can be health hazards to operating personnel, nuisances if they become airborne, and very abrasive or corrosive to the landfill equipment; they should be covered immediately.

The workers may have to wear face masks, goggles, or protective clothing to avoid respiratory, eye, or skin ailments.

Defectively manufactured products are delivered to the landfill to keep them off the market. These wastes should be incorporated into the sanitary landfill immediately so that drivers, helpers, and others at the working face are not tempted to engage in scavenging. Their doing so would violate the manufacturer's trust and, even more importantly, would expose them to injury.

VOLATILE AND FLAMMABLE WASTES. Some wastes, such as paints, paint residues, dry cleaning fluids, and magnesium shavings, are volatile or flammable. They may be in powder, solid, or liquid form, and they usually derive from industrial processing or are commercial wastes. If they are not highly flammable or volatile, they may be admixed with other wastes, otherwise they should be excluded from the fill or quickly disposed of in a separate area at the site. If the latter step is taken, the area should be clearly marked with warning signs, and its exact location recorded in the final plan of the completed site. Under no circumstances should smoking or open flames be allowed in the vicinity of volatile or flammable wastes when they are being disposed of.

WATER AND WASTEWATER TREATMENT PLANT SLUDGES. Dewatered sludges received from water treatment plants and dewatered digested sludges received from wastewater treatment plants can be disposed of at a sanitary landfill. In most cases, they can be placed in the regular part of the fill, but they should be covered immediately. If their moisture content is relatively high, the sludges should be mixed with the other wastes before being covered to prevent localized leaching. Raw sewage sludges and septic tank pumpings should not be disposed of at a sanitary landfill.

INCINERATOR FLY ASH AND RESIDUE. Fly ash is a fine particulate material that has been removed from combustion gases. As more stringent air pollution control regulations are enforced, the quantity of fly ash that must be disposed of is expected to increase. Fly ash may be moist or dry, depending on how it is separated from the gas stream. If it is dry, water may have to be added to it so that it does not become airborne and create a nuisance. Covering should take place immediately. Residue is the solid material that remains after a combustion process ends. The amount of decomposable organics present in incinerator residue varies widely, but few incinerators produce a residue low enough in decomposable organics to allow it to be used as a daily cover material. When the residue dries, the fines can create a dust problem. Because of its moisture and food content, residue may have a foul odor and attract flies, birds, and rodents. Residue of this nature should be incorporated into a sanitary landfill.

PESTICIDE CONTAINERS. Pesticide containers may be delivered to landfills in agricultural areas. If they are empty, they can be crushed by the landfill equipment and disposed of along with other solid wastes. If they are full or only partially empty, they should be excluded from the sanitary landfill and stored with proper inspection to avoid environmental insult, pending final detoxification and disposal by incineration or pyrolysis under carefully controlled time and temperature conditions.

ANIMAL MANURE. Another waste originating primarily in agricultural areas is animal manure, which often contains a large amount of hay or bedding. If the waste is not wet enough to flow, it can be placed in the regular part of the fill but should be covered immediately. If the moisture content is high, the manure should be mixed with dry waste and immediately covered.

RADIOACTIVE WASTES AND EXPLOSIVES. Landfills do not accept radioactive wastes.* If any are detected in a delivery, the operator should isolate the wastes, truck, and driver and contact the proper health authorities. Explosives are rarely delivered to a disposal site, and should be handled with extreme caution when they are. If they are accepted, the operations plan should contain a provision that explicitly outlines handling procedures, and a demolitions expert should be consulted if possible. The exact location of the waste should be recorded on the final plan of the completed site, and security fencing and warning signs should be erected.

* Radioactive wastes are disposed of under the auspices of the U.S. Atomic Energy Commission.

TABLE 6

Application of Cover Material

Cover material	Minimum thickness	Exposure time*
Daily	6 in.	0-7 days
Intermediate	1 ft	7-365 days
Final	2 ft	>365 days

* The length of time cover material will be exposed to erosion by wind and rain.

Placement of Cover Material

The operations plan should specify what soils are to be used as cover material, where they are to be obtained, and how they are to be placed over the compacted solid waste. The first two specifications are determined by the landfill designer after he has evaluated the soil investigation and the functional requirements of the cover material. Cover materials used at a sanitary landfill are classed as daily, intermediate, and final; the classification depends on the thickness of soil used. This is determined by its susceptibility to wind and water erosion and its ability to meet certain functional requirements. Guides for using the different classes are determined by the length of time the cover is to be exposed to the elements (Table 6). In general, if the cover is to be exposed for more than 1 week but less than 1 year, intermediate cover should be used. If the cover is to be exposed less than 1 week, daily cover is sufficient, and if the cover is to be exposed longer than 1 year final cover should be used. All cover material should be well compacted. Coarse grained soils can be compacted to 100 to 135 lb per cu ft, fine grained soils to 70 to 120.*

DAILY COVER. The important control functions of daily cover are vector, litter, fire, and moisture. Generally, a minimum compacted thickness of 6 in. of soil will perform these functions. The cover is applied to the compacted waste at least at the end of each operating day. If possible, it should be spread and compacted on the top and sideslopes as construction of the cell progresses, thus leaving only the working face exposed. At the end of the

* *Unit dry weight of compacted soil at optimum moisture content for Standard AASHO compactive effort.*

operating day, the working face is also covered. No waste should be exposed, and the cover should be graded to prevent erosion and to keep water from ponding.

INTERMEDIATE COVER. Functions of intermediate cover are the same as daily cover but include gas control and possibly service as a road base. It is applied in the same manner as daily cover, but the minimum compacted depth recommended is 1 ft. Periodic grading and compacting may be necessary to repair erosion damage and to prevent ponding of water. Cracks and depressions may develop because of moisture loss and settlement of the fill, and periodic maintenance is required.

FINAL COVER. Final cover serves basically the same functions as intermediate cover, but it must also support vegetative growth. At a minimum, 2 ft of soil should be used, compacted into 6-in. thick layers. Such factors as soil type and anticipated use of the completed landfill may require more than 2 ft.

Grading is extremely important, and grades should be specified in the landfill design. The general topographic layout of the completed landfill surface is attained by carefully locating solid waste cells, but the final cover is graded and compacted to achieve the desired configuration. Water should not be allowed to pond on the landfill surface and grades should not exceed 2 to 4 percent to prevent the erosion of cover material. Sideslopes should be less than 1 vertical to 3 horizontal. Preferably, topsoil from the site should be stockpiled and reserved for placement on top of the final cover. Since the topsoil will be seeded, it should not be highly compacted.

Maintenance

A properly operated sanitary landfill is distinguished from an open dump by its appearance. The effectiveness of pollution control measures also depends on how well the landfill is maintained during construction and after completion.

Dust is sometimes a problem, especially in dry climates and if the soil is fine grained. Dust can cause excessive wear of equipment, can be a health hazard to personnel on the site, and can be a nuisance if there are residences or businesses nearby.

Dust raised from vehicular traffic can be temporarily controlled by wetting down roads with water or by using a deliquescent chemical, such as calcium chloride, if the relative humidity is over 30 percent. Calcium chloride may be applied at a rate of 0.4 to 0.8 lb per sq yd and then be admixed with the top 3 in. of the road surface. Frequent applications are usually required, because calcium chloride is soluble in water and is readily leached from the soil surface. Waste oils can also be used as temporary dust palliatives. Periodic treatment or multiple sprayings at a rate of 0.25 to 1.0 gal per sq yd may be necessary. After several treatments, a packed, oily soil crust usually develops that has good resistance to traffic abrasion and is moderately resistant to water. Good penetration by the oil can be expected in more permeable soils. Clayey soils or tightly knit surfaces may resist penetration, in which case it may be desirable to lightly scarify the surface, apply 0.25 to 0.5 gal of oil per sq yd, and compact the surface. Waste oil, water spraying, and calcium chloride treatment are only temporary solutions; heavily traveled roads should be covered with bituminous or cementing materials to provide a more permanent surface.

One of the most important aspects of maintenance is litter control. A landfill operator who permits litter to accumulate and spread from the site is open to warranted public criticism. Public acceptance of proposed sanitary landfills will be easier if those under construction are properly maintained. Blowing litter can be kept at a minimum by maintaining a small-size working face and covering portions of the cell as they are constructed. Snow fences can be positioned around the working face to catch blowing paper and plastic, but unique wind problems may make it necessary to fabricate specially designed fencing. All fences used should be portable so that they can be kept near the working face. Personnel should clean up litter periodically every working day, especialy near the close of business. The litter should be placed on the working face before it is covered.

Equipment used at a landfill requires regular maintenance, and the operations plan should establish a routine preventive maintenance program for all equipment. Information used to develop this program is available from the respective manufacturers.

A daily application of cover material prevents problems associated with rats, flies, and birds. These pests are rarely troublesome at a properly operated sanitary landfill.

Rats are occasionally brought in along with the solid waste delivered. When the waste is unloaded the rats seek cover. They are then buried when the waste is spread, compacted, and covered. Infrequently, rats escape and seek protection elsewhere. If they then become a nuisance, they should be killed by conducting a baiting program that is supervised by an experienced exterminator. Local inhabitants must be informed of the baiting program, signs must be erected, and children and pets must be kept away from the bait stations. If strong poisons are used, guards should keep people away. Generally, an anticoagulant poison should be used over a two-to-three week period. When no more bait is taken, the extermination program can be terminated. Procedures for using and making poisoned bait have been developed for employment at disposal sites.[1-3] In no case, however, should extermination procedures be substituted for daily cover. Poisoning is rarely 100 percent effective, and it is only a short-term solution.

If fly problems become severe in summer and an insecticide is used, daily application is necessary, because the insecticide particle must impinge on the fly. Effective insecticides are malathion, dichlorvos, naled, dimethoate, Diazinon, fenthion, and ronnel (Table 7). Application of cover material as the cell is constructed may control flies without using insecticides.

Birds that are sometimes attracted to landfills can be a nuisance, a health hazard, and a danger to low-flying aircraft. Various methods, such as cannon fire, have been used to frighten the birds, but they become familiar with the particular noise and rapidly return. Falcons have been used with varying success, but they apparently cannot contend with seagulls. Recording the troublesome birds' distress call and playing it back over a public address system has also failed. The only way to reduce the problem is to make each working face as small as possible and to cover all wastes as soon as feasible.

TABLE 7

Insecticides for Fly Control[3]
(Outdoor space sprays)

Insecticide	Approximate lb per acre dosage required for effective kills (up to 200 ft)
Malathion	0.6
Dichlorvos	0.3
Naled	0.1-0.2
Dimethoate	0.1-0.2
Diazinon	0.3
Fenthion	0.4
Ronnel	0.4

Weather Conditions

Weather can slow the construction of a sanitary landfill, and the operations plan should provide detailed instructions on how to operate the landfill during anticipated inclement periods.

In freezing weather, the greatest difficulty is obtaining cover material. If the frost penetrates below 6 in., crawler dozers or loaders equipped with hydraulic rippers are needed to loosen the soil. If several soils are available at the site, well-drained soils, not as susceptible to freezing as those that are poorly drained, should be reserved for use as winter cover material. If the frost line goes more than 1 ft below the surface, cover material should be stockpiled beforehand. Calcium chloride can be admixed into the soil to prevent freezing, or it can be covered with tarpaulins or leaves; tarpaulins should be dark to adsorb the sun's heat. If the trench construction method is used, enough soil should be excavated during warm months to handle the wastes to be disposed of during freezing weather. The trench bottom should be sloped to one end to collect rainfall, which should be pumped out before it freezes.

Rain can cause operational problems. Roads leading from all-weather access roads to the working face can become a quagmire and prevent collection trucks from unloading. Roads leading to the active working area should be passable in any kind of weather. Gravel, crushed stone, and construction and demolition rubble may be applied to the surface. Collection trucks that pick up mud on the site should be cleaned before leaving it to keep them from dirtying the public road system.

Fires

No burning of wastes is permitted at a sanitary landfill, but fires occur occasionally because of carelessness in the handling of open flames or because hot wastes are disposed of. The use of daily cover should keep fire in a cell that is under construction from spreading laterally to other cells. All equipment operators should keep a fire extinguisher on their machines at all times, since it may be able to put out a small fire. If the fire is too large, waste in the buring area must be spread out so that water can be applied. This is an extremely hazardous chore, and water should be sprayed on those parts of the machine that come in contact with the hot wastes. The operations plan should spell out fire-fighting procedures and sources of water. All landfill personnel should be thoroughly familiar with these procedures.

A collection truck occasionally arrives carrying burning waste. It should not be allowed near the working face of the fill but be routed as quickly as possible to a safe area, away from buildings, where its load can be dumped and the fire extinguished.

Salvage and Scavenging

Salvaging usable materials from solid waste is laudable in concept, but it should be allowed only if a sanitary landfill has been designed to permit this operation and appropriate processing and storage facilities have been provided. All salvage proposals must be thoroughly evaluated to determine their economic and practical feasibility. Salvaging is usually more effectively accomplished at the point where waste is generated or at specially built plants. The capital and operating costs of salvage operations at a disposal site are usually high, even if it is properly designed and operated. If salvaging is practiced, it should be accomplished at a specially designed facility away from the operating area. Salvaging should never be practiced at the working face.

Scavenging, sorting through waste to recover seemingly valuable items, must be strictly prohibited. Scavengers are too intent on searching to notice the approach of spreading and compacting equipment, and they risk being injured. Moreover, some of the items collected may be harmful, such as food waste, canned or otherwise; these items may be contaminated. Vehicles left unattended by scavengers interfere with operations at the fill.

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CHAPTER 7

equipment

There is a wide variety of equipment available for sanitary landfill operations. The types selected will depend on the amount and kinds of solid waste to be landfilled each day and on the operational methods to be employed at a particular site. Since money spent on equipment constitutes a large capital investment and accounts for a large portion of operating costs, the selection should be based on a careful evaluation of the functions to be performed and the cost and ability of various machines to meet the needs.

Equipment Functions

Sanitary landfill machines fall into three general functional categories: (1) those directly involved in handling waste; (2) those used to handle cover material; (3) those that perform support functions.

WASTE HANDLING. The practical and safe disposal of solid waste is the primary objective of a sanitary landfill. Although the handling of solid waste at a landfill site resembles an earthmoving operation, differences exist that require special consideration. Solid waste is less dense, more compactible, and more heterogeneous than earth. Spreading a given volume of solid waste requires less energy than an equal amount of soil.

Because of its size, strength, and shape, solid waste is not as conducive as soils to compaction by vibration. In the main, solid waste is compacted by the compressive forces developed by the overall massive loading of a landfill machine. If maximum compaction is desired, a large, heavy machine that is operated in accordance with the recommendations contained in Chapter 6 will give better results than a light machine. Since repeated loading of the solid waste improves its compaction, enough machines should be available that 2 to 5 compaction passes can be made during the operating day. If it is not possible to purchase a large machine, spreading the solid waste into thinner layers and making more passes with a lighter machine may suffice. The optimum number of passes depends on the moisture content and composition of the solid waste. Their exact relationships, as they affect density, have not, however, been determined.

Machines that operate on solid waste, especially during spreading and compaction, are susceptible to overheating because of clogged radiators, to broken fuel and hydraulic lines, to tire punctures, and to damage incurred when waste becomes lodged in the tracks or between the wheels and the machine body. The various accessories that are available to help alleviate these problems are discussed later in this chapter.

COVER MATERIAL HANDLING. The excavating, hauling, spreading, and compacting of cover material are similar to other earthmoving operations, such as highway construction. In landfill operations, however, rigorous control of moisture content to achieve maximum soil density is not usually practiced, although it is desirable to wet a very dry soil somewhat to hold down dust and to improve compaction. The equipment operator who spreads and compacts cover material should be capable of grading it as specified to drain the site. Specific earthmoving requirements vary according to the topographic and soil conditions present. Sand, gravel, and certain loamy clay and loamy silt soils can be excavated with wheeled equipment, but tougher natural soils require tracked machines. If the natural soil cover is thin, underlying formations composed of weathered or partially decomposed bedrock may make suitable cover material, but they may have to be broken with a crawler equipped with a rock ripper. Rippable materials include most uncemented shale, thinly interbedded limestone and shale, poorly cemented siltstone, and partially decomposed granitic rock types. These are, however, only generalizations, and a particular soil may be easier to excavate or more difficult to work because soil properties may change significantly from season to season. Glacial till can usually be excavated by heavy tracked equipment if the compact clay has a moderate to high moisture content, as in the spring and early summer. In the late summer and fall, when less rain falls, glacial tills or clay soils of similar texture and composition dehydrate and become very hard and difficult to excavate. They must often be ripped first. Freezing weather may also require the use of a rock ripper to remove the frost layer.

SUPPORT FUNCTIONS. A sanitary landfill requires support equipment to perform such tasks as road construction and maintenance, dust control, fire protection, and possibly to provide assistance in unloading operations. Road construction and maintenance must be provided so that the working face can be reached in all types of weather. This often requires the adoption of a dust control program which, in turn, may call for the use of special equipment, such as a water wagon and sprinkler or a salt spreader. Mobile firefighting equipment may be stationed on the site or readily available nearby. Assistance in the unloading operation may include emptying collection trucks equipped with a movable bulkhead and pulling out vehicles that become stuck near the operating face during rainy weather. Unless there are many collection trucks requiring assistance, the spreading and compacting machine can handle the situation.

Equipment Types and Characteristics

A knowledge of the types and characteristics of earthmoving machines is essential if the right selection is to be made, especially since most machines can perform multiple functions.

CRAWLER MACHINES. Crawler machines are of two types: dozer and loader. Other common names for them are: bulldozer, crawler, crawler dozer, track loader, front end loader, and bullclam; many trade names are also used. They all have good flotation and traction capabilities, because their self-laying tracks provide large ground contact areas. The crawler is excellent for excavating work and moving over unstable surfaces, but it can operate approximately only 8 mph, forward or reverse.

The crawler dozer is excellent for grading and

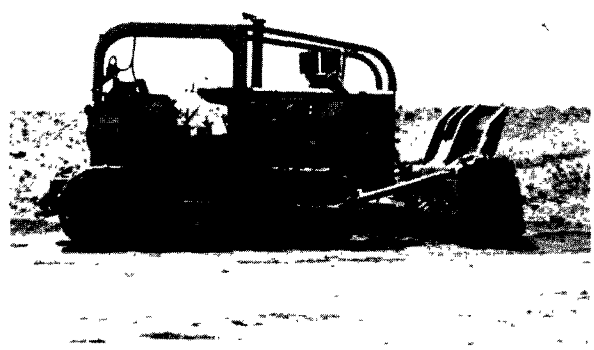

Figure 19. The crawler dozer is excellent for grading and can be economically used for dozing waste for up to 300 ft. It should be equipped with a U-shaped blade that has been fitted with a top extension to increase its pushing area.

can be economically used for dozing waste or earth over distances of up to 300 ft (Figure 19). It is usually fitted with a straight dozer blade for earthwork, but at a sanitary landfill it should be equipped with a U-shaped blade that has been fitted with a top extension (trash or landfill blade) to push more solid waste.

Unlike the crawler dozer, the crawler loader can lift materials off the ground, but its bucket is not as wide, and it is not able, therefore, to spread as much solid waste. The crawler loader is an excellent excavator and can carry soil as much as 300 ft. There are two types of buckets usually used for sanitary landfilling: the general purpose and the multiple purpose (Figures 20-21). The general-purpose bucket is a scoop of one-piece construction. The multiple-purpose bucket, which is also known as a bullclam or 4 in 1, is of two-piece construction, is hinged at the top, and is hydraulically operated. It can thus clamp onto such objects as tree trunks or telephone poles and lift and place them in the fill, or it can crush junked autos or washing machines. It is also useful in spreading cover material. The general-purpose and multiple-purpose buckets come in many sizes. Matching a bucket to a machine should be done with the advice of the machine manufacturer. A landfill blade similar to that used on dozers can also be fitted to loaders.

RUBBER-TIRED MACHINES. Both dozers and loaders are available with rubber-tired wheels. They are generally faster than crawler machines (maximum forward or reverse speed of about 29 mph) but do not excavate as well. The plausible claim has been made that because the weight of rubber-tired machines is transferred to the ground over a much smaller contact area, they provide better compaction, but significant differences of in-place density

Figure 20. Crawler loader with a general-purpose bucket of one-piece construction. The crawler loader is an excellent excavator.

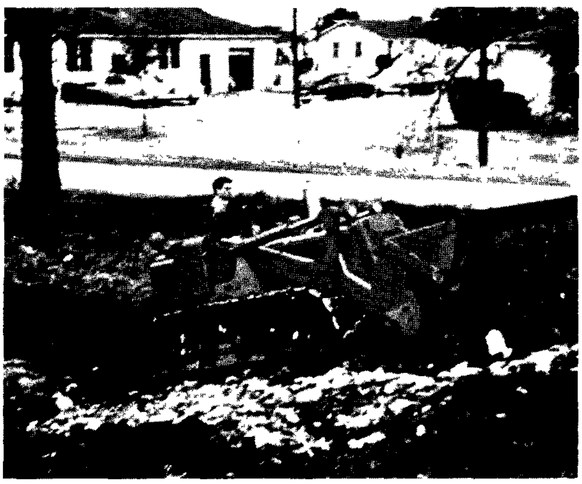

Figure 21. Crawler loader with a multiple-purpose bucket, which is also known as a bullclam or 4 in 1. The bucket can clamp onto such objects as tree trunks and telephone poles and lift and place them in the fill; it can also crush junked cars and washing machines.

Figure 22. The rubber-tired dozer is used only infrequently at sanitary landfills. Because of the rough and spongy surface formed by compacted solid waste, this machine does not grade as well as a crawler dozer.

Figure 23. The rubber-tired loader is usually equipped with a general-purpose or multiple-purpose bucket. Because of its high operating speed, this machine is especially suited for putting cover material into haul trucks or carrying it economically for distances of up to 600 ft.

have not been proven. Because their loads are concentrated more, rubber-tired machines have less flotation and traction than crawler machines. Their higher speed, however, allows them to complete more cycles or passes in the same amount of time than a crawler machine. Rubber-tired machines perform satisfactorily on landfill sites if they are equipped with steel guarded tires, called rock tires or landfill tires. Rubber-tired machines can be economically operated at distances of up to 600 ft.

The rubber-tired dozer is not commonly used at a sanitary landfill. Because of the rough and spongy surface formed by compacted solid waste and the concentrated wheel loads, the rubber-tired dozer does not grade as well as a crawler dozer. The flotation of the crawler dozer makes it much more suitable for grading operations. The rubber-tired dozer should be equipped with a landfill or trash blade (Figure 22) similar to that recommended for a track dozer.

The rubber-tired loader is usually equipped with a general-purpose or multiple-purpose bucket (Figure 23). A particular asset of this machine is the high speed and mobility of its operation. When it is only needed part time at a sanitary landfill, it can be driven over public roads to perform other jobs. Because of its high operating speed, the rubber-tired loader is especially suited for putting cover material into haul trucks or carrying it economically over distances of up to 600 ft.

LANDFILL COMPACTORS. Several equipment manufacturers are marketing landfill compactors equipped with large trash blades. In general, these machines are modifications of road compactors and log skidders. Rubber-tired dozers and loaders have also been modified. The power train and structure of landfill compactors are similar to those of rubber-tired machines, and their major asset is their steel wheels (Figure 24). The wheels are either rubber tires sheathed in steel or hollow steel cores; both types are studded with load concentrators (Figure 25).

Steel-wheeled machines probably impart greater crushing and compactive effort than do rubber-tired or crawler machines. A study comparing a 47,000-lb steel-wheeled compactor, the same unit equipped with rubber tires, and a 62,000-lb crawler dozer indicated that under the same set of conditions, the in-place dry density of solid waste compacted by the steel-wheeled compactor was 13 percent greater than that effected by the crawler dozer and the rubber-tired compactor.[1]

The landfill compactor is an excellent machine for spreading and compacting on flat or level surfaces and operates fairly well on moderate slopes, but it lacks traction when operating on steep slopes or when excavating. Its maximum achievable speed while spreading and compacting on a level surface is about 23 mph, forward and reverse. This makes it faster than a crawler but slower than a rubber-tired machine. Since landfill compactors operate at high speeds and produce good in-place densities, they are best applied when they are used only for spreading and compacting solid waste and cover material. When the cover material is a clay, it and some of the solid waste lodge between the load concentrators and must be continually removed by cleaner bars. The surface of a soil layer compacted with a landfill compactor is usually covered by pits or indentations formed by the load concentrators. Numerous passes are needed to minimize the roughness of the surface.

SCRAPERS. Scrapers are available as self-propelled and towed models having a wide range of capacities (Figure 26). This type of earthmoving machine can haul cover material economically over relatively long distances (more than 1,000 ft for the self-propelled versions and 300 to 1,000 ft for towed models). Their prime function is to excavate, haul, and spread cover material. Since they are heavy when loaded, routing them over the fill area will help compact the solid waste. Hauling capacities range from 2 to 40 cu yd.

Figure 24. In general, landfill compactors are modifications of road compactors and log skidders. The power train and structure are similar to those of rubber-tired machines. The major asset of the landfill compactor is its steel wheels; it can probably achieve better compaction than a rubber-tired or crawler machine.

DRAGLINE. Large excavations can be made economically with a dragline. Its outstanding characteristic is its ability to dig up moderately hard soils and cast or throw them away from the excavation. Because of this feature, it can also be used to spread cover material over compacted solid waste. It is particularly useful in wetland operations. The dragline is most commonly found at large landfills where the trench method is used or where cover material is obtained from a borrow pit. As a rule

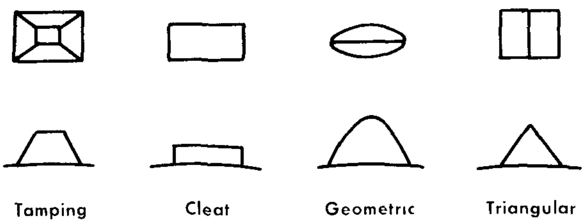

Figure 25. The wheels of a landfill compactor are either rubber tires sheathed in steel or hollow steel cores; both types are studded with load concentrators.

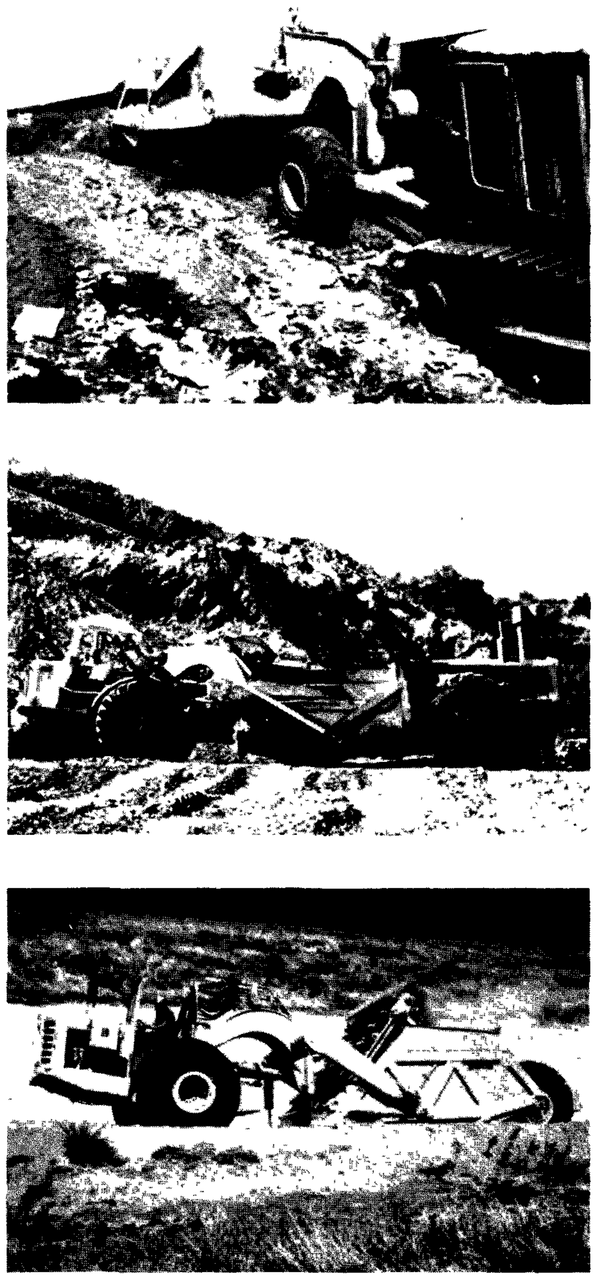

Figure 26. Scrapers are available as self-propelled or towed models; their prime function is to excavate, haul, and spread cover material. Capacities range from 2 to 40 cu yd.

of thumb, the boom length should be two times the trench width. Buckets used at landfills usually range from 1 to 3 cu yd.

SPECIAL-PURPOSE EQUIPMENT. Several pieces of earthmoving and road construction equipment are put to limited use on landfills that dispose of less than 1,000 tons a day. Their purchase may not, therefore, be warranted. When they are needed, they can be borrowed, leased, rented, or the work can be performed under contract.

The road grader can be used to maintain dirt and gravel roads on the site, to grade the intermediate and final cover, and to maintain drainage channels surrounding the fill.

Water is useful in controlling blowing litter at the working face and control of dust from on-site roads. Water wagons range from converted tank trucks to highly specialized, heavy vehicles that are generally used in road construction operations. They can also be used at the landfill to fight fires.

The road sweeper is a real asset at sites where mud is tracked onto the public road system. Its periodic use will encourage local residents to accept the landfill because roadways remain safe.

ACCESSORIES. The equipment used at landfills can be provided with accessories that protect the machine and operator and increase the effectiveness and versatility of the machine (Table 8).

Engine screens and radiator guards keep paper and wire from clogging radiator pores and causing the engine to overheat. A reversible fan can also help alleviate this problem, because the direction of air flow or vane pitch can be changed in less than 5 min. Under-chassis guards can be installed to shield the engine, and hydraulic lines and other essential items of the machine should also be protected if they are susceptible to damage (Figure 27).

The operator's comfort, safety, and efficiency can be increased by providing roll bars, a canopy or cab, cab or helmet air conditioning, and backup warning systems. A canopy is especially desirable for machines that operate in a trench into which waste is dumped from above. Cabs are particularly useful when the working area is very dusty or the operator must work in very cold weather. Because rubber-tired machines and landfill compactors operate at relatively high speeds, an audible backup warning system should be provided to alert other equipment operators and personnel in the immediate area. This system is also desirable on crawler

TABLE 8

Recommended and Optional Accessories for Landfill Equipment

Accessory	Dozers Crawler	Dozers Rubber-Tired	Loaders Crawler	Loaders Rubber-Tired	Landfill compactor
Dozer blade	0*	0	—	—	0
U-blade	0	0	—	—	0
Landfill blade	R†	R	0	0	R
Hydraulic controls	R	R	R	R	R
Rippers	0	—	0	—	—
Engine screens	R	R	R	R	R
Radiator guards-hinged	R	R	R	R	R
Cab or helmet air conditioning	0	0	0	0	0
Ballast weights	0	0	R	R	R
Multiple-purpose bucket	—	—	R	R	—
General-purpose bucket	—	—	0	0	—
Reversible fan	R	R	R	R	R
Steel-guarded tires	—	R	—	R	—
Life-arm extensions	—	—	0	0	—
Cleaner bars	—	—	—	—	R
Roll bars	R	R	R	R	R
Backing warning system	R	R	R	R	R

* O, Optional.
† R, Recommended

machines, especially when two or more are operating in the same area.

Equipment versatility and effectiveness can be increased by use of a number of accessories. A hydraulically operated ripper is needed when extensive excavation must be carried out in hard soils. It should be mounted on a tracked machine to take advantage of its greater traction. (Backrippers, hinged teeth attached to buckets or blades that dig into the soil when the machine is reversing, are not as effective as hydraulically operaed rippers.) To give rubber-tired machines and landfill compactors more traction, their wheels can be ballasted with a calcium chloride solution or water, and steel or concrete counterweights can be used on loaders and landfill compactors.

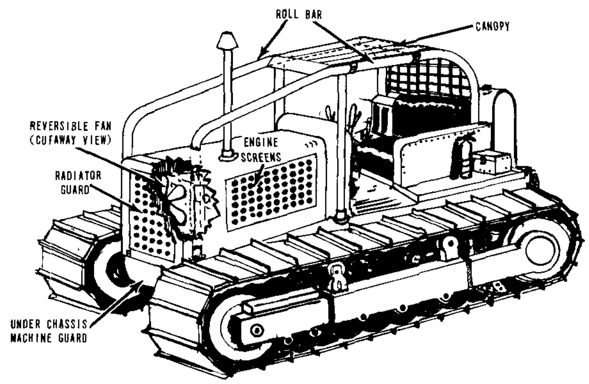

Figure 27. The equipment used at sanitary landfills can be provided with accessories that protect the machine and operator and increase their effectiveness.

Different power trains can be used on many large machines. The power shift and torque converter options are preferable to the dry clutch, direct-drive models because greater speed of operation and less strain on the engine and operator are possible with them.

COMPARISON OF CHARACTERISTICS. The ability of various machines to perform the many functions that must be carried out at a sanitary landfill should be analyzed with respect to the needs and conditions of each site (Table 9). General recommendations regarding the best types and sizes of machines to use at a specific landfill can be misleading. More exhaustive analysis is needed before the final equipment selection is made.

Size of Operation

Definition of functions and evaluation of equipment performance must be matched with the size of the landfill to determine the type, number, and size of the machines needed. No one machine is capable of performing all functions equally well. Neither can it be assumed that equipment effectively used at one site will be the most suitable elsewhere. Unfortunately, production rates expressed in tons of solid waste spread and compacted per hour are not readily available for comparison. Guides that have been proposed by equipment manufacturers and others should be considered only rough estimates of equipment needs for a particular landfill (Table 10).

SINGLE-MACHINE SITES. Particular difficulty is encountered when selecting equipment for a site

TABLE 9

Performance Characteristics of Landfill Equipment*†

Equipment	Solid Waste		Cover Material			
	Spreading	Compacting	Excavating	Spreading	Compacting	Hauling
Crawler dozer	E	G	E	E	G	NA
Carwler loader	G	G	E	G	G	NA
Rubber-tired dozer	E	G	F	G	G	NA
Rubber-tired loader	G	G	F	G	G	NA
Landfill compactor	E	E	P	G	E	NA
Scraper	NA	NA	G	E	NA	E
Dragline	NA	NA	E	F	NA	NA

* Basis of evaluation: Easily workable soil and cover material haul distance greater than 1,000 ft.
† Rating Key: E, excellent; G, good; F, fair; P, poor; NA, not applicable

TABLE 10

Landfill Equipment Needs[3]

Solid waste handled (tons/8 hr)	Crawler loader		Crawler dozer		Rubber-tired loader	
	Flywheel horsepower	Weight* (lb)	Flywheel horsepower	Weight* (lb)	Flywheel horsepower	Weight* (lb)
0–20	<70	<20,000	<80	<15,000	<100	<20,000
20–50	70 to 100	20,000 to 25,000	80 to 110	15,000 to 20,000	100 to 120	20,000 to 22,500
50–130	100 to 130	25,000 to 32,500	110 to 130	20,000 to 25,000	120 to 150	22,500 to 27,500
130–250	150 to 190	32,500 to 45,000	150 to 180	30,000 to 35,000	150 to 190	27,500 to 35,000
250–500	combination of machines		250 to 280	47,500 to 52,000	combination of machines	
500–plus	COMBINATION OF MACHINES					

Note: Compiled from assorted promotional material from equipment manufacturers and based on ability of one machine in stated class to spread, compact, and cover within 300 ft of working face
* Basic weight without bucket, blade, or other accessories

where only one machine will be used. It must be capable of spreading and compacting both solid waste and cover material, but it may also have to be used to excavate trenches or cover material. In general, the most versatile machine for a small landfill is the tracked or rubber-tired loader. If the machine will not be used full time, a wheeled loader is preferable because of its mobility. If the machine is to stay at the site full time and will not be required to load cover material into trucks, a crawler dozer may be better.

Regardless of the size of a single-machine operation, the dependability of the machine should be high. Arrangements should be made in advance to obtain a replacement if a breakdown occurs, because this development is no excuse for unacceptable disposal. A replacement machine may be made available through the equipment dealer, a local

TABLE 11

Machine Capital Cost

Machine type	Flywheel Horsepower	Weight (lb)	Equipped Machine: Approximate weight* (lb)	Equipped Machine: Approximate cost† ($)	Comment
Crawler dozer	<80	<15,000	19,000	21,000	landfill blade
	110–130	20,000–25,000	32,000	38,000	landfill blade
	250–280	47,500–52,000	67,000	70,000	landfill blade
Crawler loader	<70	<20,000	23,000	21,000	GPB‡—1 cu yd
	100–130	25,000–32,500	31,000	30,000	GPB —2 cu yd
	100–130	25,000–32,500	32,000	32,000	MPB**—1¾ cu yd
	150–190	32,500–45,000	45,000	46,000	GPB—3 cu yd
	150–190	32,500–45,000	47,000	49,000	MPB—2½ cu yd
Rubber-tired loader	<100	<20,000	17,000	21,000	GPB—1¾ cu yd
	<100	<20,000	18,000	23,000	MPB—1½ cu yd
	120–150	22,500–27,500	23,000	33,000	GPB—4 cu yd
	120–150	22,500–27,500	26,000	36,000	MPB—2¼ cu yd

* Basic machine plus engine sidescreens, radiator guards, reversible fan, roll bar, and either a landfill blade, general-purpose bucket, or multiple-purpose bucket as noted.
† June 1970.
‡ General-purpose bucket.
** Multiple-purpose bucket

contractor, or a municipal public works department.

SMALL SITES. Municipalities disposing of less than 10 tons a day may find the cost of owning a small dozer or loader too high. If excavation and stockpiling of cover material are done on contract, a farm tractor equipped with a blade or bucket may be sufficient for spreading the solid waste. The tractor will not, however, be able to produce much compaction, even if the waste is spread in thin layers. The poor compaction achieved means that a larger fill area will be needed. This requirement, together with the total cost of the contract work, should be compared to the expense of owning and operating a small dozer or loader.

MULTIPLE-MACHINE OPERATION. It is easier to select equipment for a multiple-machine operation than it is for a one-machine operation. Such specialized machines as scrapers and landfill compactors may then be economical to use. If cover material has been stockpiled and more than one machine is available, operations need not be interrupted when an equipment breakdown occurs. As an added precaution, replacement machines should be available through a lease, contract, or borrowing arrangement.

Costs

The equipment selected for a sanitary landfill must not only be able to perform well under conditions present at the site, it must also do so at the least total cost. Equipment costs, both capital and operating, represent a significant portion of the expenses incurred in operating a sanitary landfill.

CAPITAL COSTS. Except for land, the cost of equipment may be the greatest portion of initial expenditures. The sanitary landfill equipment market is very competitive, but rough approximations of costs have been developed (Table 11). A crawler machine weighing 29,000 lb without accessories costs about $29,000. With engine sidescreens, radiator guards, reversible fan, roll bar, and a multiple-purpose bucket, the same machine costs approximately $32,000. A new dragline can cost between $75,000 and $110,000 depending on the length of its boom and cables, and the size of its bucket. In general, most landfill equipment used for excavating, spreading, and compacting has a useful life of 5 years or 10,000 operating hours.

The price of a used machine depends on its type, size, condition, and number of recorded operating hours. Specific resale values are available from auctioneers and manufacturers of earthmoving equipment. The condition and remaining useful life of used equipment should be determined by an expert.

OPERATING AND MAINTENANCE COSTS. Purchases of fuel, oil, tires, lubricants, and filters and any expenses associated with routine maintenance are considered operating costs. Expenditures on fuel account for approximately 90 percent of operating costs. The expense of operating dozers, loaders, and landfill compactors varies according to type and make; the manufacturer should, therefore, be consulted for specific estimates. Generally speaking, direct operating costs are $3.00 per hour. The skill of the equipment operator, the type of waste handled, topography, and soil conditions also affect operating costs.

Maintenance costs, parts, and labor also vary widely but can be approximated by spreading one-half the initial cost of the machine over its anticipated useful life (10,000 hr). To make these costs more predictable, most equipment dealers offer lease agreements and maintenance contracts. Long downtimes usually associated with major repairs can be reduced by taking advantage of programs offered by most equipment dealers.

High operating costs are frequently associated with low initial costs of the equipment and vice versa. The purchaser should, therefore, require that equipment bids include estimated operating costs.

Actual operating and maintenance expenses should be determined during site operation by use of a cost accounting system.[2] This information can be used to identify areas where costs may be reduced; excessive fuel consumption, for example, may mean the machine needs adjustment or that operating procedures should be modified. Data from the cost accounting system can be used to more accurately predict operating and maintenance costs.

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CHAPTER 8
completed sanitary landfill

Reclaiming land by filling and raising the ground surface is one of the greatest benefits of sanitary landfilling. The completed sanitary landfill can be used for many purposes, but all of them must be planned before operations begin.

Characteristics

The designer should know the purposed use of the completed sanitary landfill before he begins to work. Unlike an earthfill, a sanitary landfill consists of cells containing a great variety of materials having different physical, chemical, and biological properties. The decomposing solid waste imparts characteristics to the fill that are peculiar to sanitary landfills. These characteristics require that the designer plan for gas and water controls, cell configuration, cover material specifications (as determined by the planned use), and the periodic maintenance needed at the completed sanitary landfill.

DECOMPOSITION. Most of the materials in a sanitary landfill will decompose, but at varying rates. Food wastes decompose readily, are moderately compactible, and form organic acids that aid decomposition. Garden wastes are resilient and difficult to compact but generally decompose rapidly. Paper products and wood decay at a slower rate than food wastes. Paper is easily compacted and may be pushed into voids, whereas lumber, tree branches, and stumps are difficult to compact and hinder the compaction of adjacent wastes. Car bodies, metal containers, and household appliances can be compacted and will slowly rust in the fill with the help of organic acids produced by decomposing food wastes. Glass and ceramics are usually easily compacted but do not degrade in a landfill. Plastics and rubber are resilient and difficult to compact; rubber decomposes very slowly, most plastics not at all. Leather and textiles are slightly resilient but can be compacted; they decompose, but at a much slower rate than garden and food wastes. Rocks, dirt, ashes, and construction rubble do not decompose and can be easily worked and compacted.

DENSITY. The density of solid waste in a landfill is quite variable. One that is well constructed can have an in-place density as great as 1,500 lb per cu yd, while that of poorly compacted solid waste may be only 500. Generally, 800 to 1,000 lb per cu yd can be achieved with a moderate compactive effort. Soft and hard spots occur within the fill as a result of different decomposition rates and compaction densities. Density influences such other characteristics as settlement and bearing capacity.

SETTLEMENT. A sanitary landfill will settle as a result of waste decomposition, filtering of fines, superimposed loads, and its own weight. Bridging that occurs during construction produces voids. As the waste decomposes, fine particles from the cover material and overlying solid waste often sift into these voids. The weight of the overhead waste and cover material helps consolidate the fill, and this development is furthered when more cover material is added or a structure or roadway is constructed on the fill.

The most significant cause of settlement is waste decomposition, which is greatly influenced by the amount of water in the fill. A landfill will settle more slowly if only limited water is available to decompose the waste chemically and biologically. In Seattle, where rainfall exceeds 30 in. per year, a 20-ft fill settled 4 ft in the first year after it was completed.[1] In Los Angeles, where less than 15 in. of rain falls per year, 3 years after a landfill had been completed a 75-ft high area had settled only 2.3 ft, and another section that had been 46 ft high had settled a mere 1.3 ft.[2]

Settlement also depends on the types of wastes disposed of, the volume of cover material used with respect to the volume of wastes disposed of, and the compaction achieved during construction. A fill composed only of construction and demolition debris will not settle as much as one that is constructed of residential solid wastes. A landfill constructed of highly compacted waste will settle less than one that is poorly compacted. If two landfills contain the same types of wastes and are constructed to the same height, but one has a waste-to-cover volume ratio of 1:1 and the other a ratio of 4:1, the first will settle less. Because of the many factors involved, a fill may settle as much as 33 percent.[3]

Settling can produce wide cracks in the cover material that expose the wastes to rats and flies, allow water to infiltrate, and permit gas to escape. Differential settling may form depressions that permit water to pond and infiltrate the fill. Settling may also cause structures on the landfill to sag and possibly collapse; the underground utility lines that serve these buildings or traverse the site may then shear. Because every landfill settles, its surface should be periodically inspected and soil should be added and graded when necessary.

BEARING CAPACITY. The bearing capacity of a completed sanitary landfill is the measure of its ability in pounds per square foot to support foundations and keep them intact. Very little information is available on the subject, but a few investigators place the bearing capacity of a completed landfill between 500 and 800 lb per sq ft[4]; higher values have, however, been noted.[5] Since there is no definite procedure for interpreting the results of solid waste bearing tests, any value obtained should be viewed with extreme caution. Almost without exception, the integrity and bearing capacity of soil cover depend on the underlying solid waste. Most bearing strength tests of soil are conducted over a short period—several minutes for granular materials to a maximum of 3 days for clay having a high moisture or air content. During the test, the soil adjusts to its limits under the load imposed and conditions of confinement. Solid waste, on the other hand does not follow this pattern of deformation but continues to alter its structure and composition over a long period of time. Natural soils, which are not as heterogeneous as solid waste, produce test values that fall within a predictable range. Moreover, repeated tests of the soil will produce similar results—similar relationships have not been established for solid waste.

LANDFILL GASES. Landfill gases continue to be produced after the landfill is completed and can accumulate in structures or soil, cause explosions, and stunt or kill vegetation.[6] Placement of a thick, moist, vegetative, final cover may act as a gas-tight lid that forces gases to migrate laterally from the landfill. If the site is converted into a paved parking lot, this may also prevent the gases from venting into the atmosphere. Design of gas controls should, therefore, conform with the planned use of the completed fill.

CORROSION. The decomposing material in a landfill is very corrosive. Organic acids are produced from food, garden, and paper wastes, and some weak acids are derived from ashes. Unprotected steel and galvanized pipe used for utility lines, leachate drains, and building foundations are subject to severe and rapid pitting. All structural materials susceptible to corrosion should be protected. Acids present in a saintary landfill can deteriorate a concrete surface and thus expose the reinforcing steel; this could eventually cause the concrete to fail.

Uses

There are many ways in which a completed sanitary landfill can be used; it can, for example, be converted into a green area or be designed for recreational, agricultural, or light construction purposes. The landfill designer should evaluate each proposal from a technical and economic viewpoint. More suitable land is often available elsewhere that would not require the expensive construction techniques required at a sanitary landfill.

GREEN AREA. The use of a completed sanitary landfill as a green area is very common. No expensive structures are built, and a grassed area is established for the pleasure of the community. Some maintenance work is, however, required to keep the fill surface from being eroded by wind and water. The cover material should be graded to prevent water from ponding and infiltrating the fill. Gas and water monitoring stations, installed during construction, should be periodically sampled until the landfill stabilizes. Gas and water controls and drains also require periodic inspection and maintenance.

If the final cover material is thin, only shallow-rooted grass, flowers, and shrubs should be planted on the landfill surface. The decomposing solid waste may be toxic to plants whose roots penetrate through the bottom of the final cover. An accumulation of landfill gas in the root zone may interfere with the normal metabolism of plants. This can be avoided by selecting a cover material having a low water-holding capacity, but this type of soil provides poor support for vegetation. On the other hand, a moist soil does not allow decomposition gas to disperse and consequently gas venting must be considered.

The most commonly used vegetation is grass. Most pasture and hay grasses are shallow-rooted and can be used on a landfill having only 2 ft of final cover, but alfalfa and clover need more than this. The soil used for final cover influences the choice of vegetation. Some grasses, such as tall meadow oat grass, thrive well on light sand or gravelly soils, while others, such as timothy grass, do better in such heavier soils as clays and loams.

Climate also influences the selection of grasses. Bermuda is a good soil binder and thrives in southern States. Perennial rye does best where the climate is cool and moist and winter is mild; it roots rapidly but dies off in 2 to 3 years if shaded. Redtop and bent grass thrive almost anywhere except in drier areas and the extreme south. The selection of the grass or mixture of grasses depends, therefore, on climate, depth of the root system, and soil used for cover material.* Mowing and irrigating requirements should also be considered. In general, it is not advisable to irrigate the landfill surface, because the water may infiltrate and leach the fill.

AGRICULTURE. A completed sanitary landfill can be made productive by turning it into pasture or crop land. Many of the grasses mentioned above are suitable for hay production. Corn and wheat usually have 4-ft roots, but the latter occasionally has longer ones. The depth of the final cover must, therefore, be increased accordingly.

If cultivated crops are used, the final cover should be thick enough that roots or cultivating do not disturb its bottom foot. If the landfill is to be cultivated, a 1- to 2-ft layer of relatively impermeable soil, such as clay, may be placed on top of the solid waste and an additional layer of agricultural soil placed above to prevent the clay from drying out. Excessive moisture will also be prevented from entering the fill. Such a scheme of final cover placement must also provide for gas venting via gravel trenches or pipes.

CONSTRUCTION. A foundations engineering expert should be consulted if plans call for structures to be built on or near a completed sanitary landfill. This is necessary because of the many unique factors involved—gas movement, corrosion, bearing capacity, and settlement. The cost of designing, constructing, and maintaining buildings is considerably higher than it is for those erected on a well-compacted earth fill or on undisturbed soil. The most problem-free technique is to preplan the use of islands to avoid settlement, corrosion, and bearing-capacity problems. Ideally, the islands should be undisturbed soils that are bypassed during excavating and landfilling operations. Settlement would then be governed by the normal properties of the undisturbed soil. Alternatively, truck loads of rocks, dirt, and rubble could be laid down and compacted during construction of the landfill at places where the proposed structure would be built.

The decomposing landfilled waste can be excavated and replaced with compacted rock or soil fill, but this method is very expensive and could prove hazardous to the construction workers. The decomposing waste emits a very putrid smell, and hydrogen sulfide, a toxic gas, may be present with methane, an explosive gas. These two gases should be monitored throughout the excavating operation. Gas masks may have to be provided for the workmen, and no open flames should be permitted.

Piles can also be used to support buildings when the piles are driven completely through the refuse to firm soil or rock. Some of the piles should be battered (angled) to resist lateral movement that may occur in the fill. Another factor to consider is the load imposed on the piles by solid wastes settling around them. The standard field penetration resistance test is used to determine the strength of the earth material in which the piles are to be founded. During this test, penetration will be resisted by the solid waste, but as the refuse decomposes and settling occurs, it may no longer resist and will more likely create a downward force on the pile. There are no data for established procedures for predicting this change in force.

Several peculiar problems arise when piles are used to support a structure over a landfill. The decomposing waste is very corrosive, so the piles must be protected with corrosion-resistant coatings. It may be very difficult to drive the piles through the waste if large bulky items, such as junked cars and broken concrete, are in the fill where the structure is to be located. The fill underlying a pile-supported structure may settle, and voids or air spaces may develop between the landfill surface and the bottom of the structure. Landfill gases could accumulate in these voids and create an explosion hazard.

Light, one-story buildings are sometimes constructed on the landfill surface. The bearing capacity of the landfill should be determined by field investigations in order to design continuous foundations. Foundations should be reinforced to bridge any gaps that may occur because of differential settling in the fill. Continuous floor slabs reinforced as mats can be used, and the structure should be designed to accommodate settlement. Doors, win-

* Information on the grasses mainly used in a landfill area is available from county agricultural agents and the U.S. Soil Conservation Service.

dows, and partitions should be able to adapt to slight differential movement between them and the structural framing. Roads, parking lots, sidewalks, and other paved areas should be constructed of a flexible and easily repairable material, such as gravel or asphaltic concrete.

Consolidating the landfill to improve its bearing capacity and reduce settlement by surcharging it with a heavy layer of soil does not directly influence the decomposition rate. If the surcharge load is removed and the structure is built before the waste has stabilized, settlement will still be a problem, and the bearing capacity may not be as great as expected.

None of the methods for supporting a structure over a landfill are problem-free. A common difficulty is keeping landfill gases from accumulating in the structure. Even buildings erected on undisturbed islands of soil must be specially designed to prevent this from developing. A layer of sand can be laid over the proposed structural area and then be covered by two or more layers of polyvinyl chloride sheeting. An additional layer of sand can then be emplaced. If the bottom layer of sand is not saturated, it will act as a gas-permeable vent, and the sheeting will prevent the gas from entering or collecting under the structure. The top layer of sand protects the sheeting from being punctured. Another approach is to place an impermeable membrane of jute and asphalt under all below-grade portions of the structure. A gravel or sand layer must underlie the jute-asphalt membrane and be vented to the atmosphere. The most reliable method is to construct a ventilated false basement to keep gas from accumulating.

Utility connections must be made gas proof if they enter a structure below grade. If the building is surrounded by filled land, utility lines that traverse the fill must be flexible, and slack should be provided so the lines can adjust to settlement. Flexible plastic conduits are more expensive than other materials but would probably work best, because they are elastic and resist corrosion. Gravity wastewater pipelines may develop low points if the fill settles. Liquid wastes should be pumped to the nearest sewer unless the grade from the structure to the sewer prevents low points from forming. Shearing of improperly designed water and wastewater services caused by differential settlement can occur where they enter the structure or along the pipeline that traverses the fill.

RECREATION. Completed landfills are often used as ski slopes, toboggan runs, coasting hills, ball fields, golf courses, amphitheaters, playgrounds, and parks. Small, light buildings, such as concession stands, sanitary facilities, and equipment storage sheds, are usually required at recreational areas. These should also be constructed to keep settlement and gas problems at a minimum. Other problems encountered are ponding, cracking, and erosion of cover material. Periodic maintenance includes regrading, reseeding, and replenishing the cover material.

Registration

The completed landfill should be inspected by the governmental agency responsible for ensuring its proper operation. Following final acceptance of the site, a detailed description, including a plat, should be recorded with the proper authority in the county where the site is located. This provides future owners or users with adequate information regarding the previous use of the site. The description should, therefore, include type and general location of wastes, number and type of lifts, and details about the original terrain.

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CHAPTER 9
management

The size and scale of operations carried out at a sanitary landfill and the area served will influence the mechanics of management. The purpose and goal of solid waste managers should be to consolidate and coordinate all the resources necessary to dispose of solid wastes in the most sanitary and efficient manner possible.

Administrative Agency

The responsibility for operating a sanitary landfill is normally determined by the community administrative structure involved, and it must do so in the light of its own circumstances.

MUNICIPAL OPERATIONS. In most municipal operations, administrative responsibility is assigned to the department of public works, one of whose divisions manages the solid waste program. As the scope of this division's activities increases, it is desirable to subdivide the division into functional sections. Regradless of organizational structure, collection and disposal plans and operations must be coordinated to achieve satisfactory and economical solid waste management.

SPECIAL DISTRICTS. Many States have enabling legislation that permits the formation of special-purpose districts, which can include solid waste disposal districts. These districts are advantageous in that they can serve many political jurisdictions and may have provisions for levying special taxes. Before any special district is considered, the State laws applicable to them should be investigated.

COUNTY OPERATIONS. A sanitary landfill administered by a county may have advantages over a municipal operation. A county operation could serve a number of incorporated and unincorporated areas using existing governmental apparatus, and it might allow comprehensive planning for a larger geographic area. Other advantages are economy of scale and greater availability of land.

PRIVATE OPERATIONS. Many sanitary landfills are operated successfully by private industry under a contract, franchise, or permit arrangement. In contract operations, the municipality contracts with the operator to dispose of its solid waste for a fixed charge per ton or load. The municipality usually guarantees that the contractor will receive a certain minimum amount of money. Franchises usually grant the operator permission to dispose of wastes from specified areas and charge regulated fees. Permits allow the operator to accept wastes for disposal without regard to source.

Private operations may be beneficial to municipalities that have limited funds, but the community must not shirk its responsibility for proper solid waste disposal. Of the three methods, contract operations generally give the municipality the best guarantee that solid wastes will be disposed of properly because standards can be written into the contract.[1] Franchises usually provide the next best control of operation.

Administrative Functions

An administrative agency is responsible for proper solid waste disposal, including planning, designing, financing, cost accounting, operating, recruiting and training, informing the public, and establishing minimum disposal standards.

FINANCES. Sanitary landfill capital costs include land, equipment, and site improvements. Operating costs include salaries, utilities, fuel, and equipment maintenance. Equipment and maintenance costs were discussed in Chapter 7.

There are several sources of funds to meet capital and operating costs.* The general fund, derived from taxes, normally cannot provide enough money to meet capital costs but is often used to pay for operating expenses. There are advantages to using the general fund for this purpose. The administrative procedures and extra cost of billing and collecting are eliminated. Since all the taxpayers help pay for the sanitary landfill, they are more likely to use the sanitary landfill rather than an open dump.

Using general funds for landfill operations does, however, have disadvantages. Cost accounting and other administrative procedures may be so relaxed disposal costs are difficult or impossible to determine, and users may have to be monitored. It may also be extremely difficult for solid waste management operations to get money from the general fund because of the low priority often assigned to them.

General obligation borrowing is a common method of financing the capital costs of a sanitary landfill. This type of bond generally carries a low interest rate but is easily marketed because it is secured by the pledge of real estate taxes and because all of the real estate within the taxing district serves as security for the borrowed funds. State statutes usually limit the amount of debt a community can incur. If the debt is already substantial, this method may not be available. In some cases, general obligation bonds are retired with revenues generated by the landfill operation; this minimizes the *ad valorem* taxes necessary for bond retirement.

Revenue bonds differ from general obligation bonds in that they are secured only by the ability of the project to earn enough to pay the interest and retire the bonds. In this case, fees must be charged to landfill users in amounts necessary to cover all capital and operating expenses. It is necessary to set the fees high enough to accumulate a surplus over and above debt service needs in order to make the bonds attractive to prospective purchasers. This method of financing requires that the administering agency follow good cost accounting procedures, and it allows the agency to be the sole beneficiary of cost saving procedures. In addition, the producer of solid waste is forced to pay the true cost of its disposal.

User fees are primarily a source of operating revenue, but a municipality might also employ them to generate funds for future capital expenditures. The fees can be adjusted to cover not only the operating and capital costs of present landfills but also to provide a surplus for acquiring land and equipment. Fees do not provide the capital outlay needed to start a sanitary landfill.

Although fees necessitate more work and expense because of the weighing, billing, and collecting involved, these requirements provide an insight into the management and operation of the landfill. Commercial haulers are usually billed on a per ton basis. Since the individual loads from homes are small, the users are charged on a per load basis to reduce weighing and bookkeeping. Because fee operations require that collection vehicles be recorded at the gate, this provides an additional control over wastes received at the landfill.

OPERATIONAL COST CONTROL. A primary duty of administration is to monitor and control the cost of operation. Cost accounting isolates the detailed expenses of ownership and operation and permits comparison of costs against revenues. The important costs of operation include: wages and salaries, maintenance of and fuel for equipment, utilities, depreciation and interest on buildings and equipment, and overhead. Basic data for cost accounting include the amount of waste disposed of at the fill, either by the ton or cubic yard. A cost accounting system recommended for use at a sanitary landfill has been developed by the Office of Solid Waste Management Programs.[2]

PERFORMANCE EVALUATION. In most cases, there is a control agency at the State or local level that determines if the operation is being conducted in a manner that safeguards against environmental pollution. To ensure a sanitary operation, the administrative agency should conduct its own performance evaluation. This should be done at the administrative, not the operating or supervisory level, and its requirements should be at least as stringent as those of the higher control agency. While operating and supervisory personnel should know that these inspections will occur at specified frequencies, they should not know the exact day. This will help ensure a more representative inspection.

PERSONNEL. To secure and retain competent employees, the administration must have a systematic personnel management plan. First a job description should be prepared for each position at the sanitary landfill. A typical list of positions for a large operation might include: (1) administrative tasks (management, accounting, billing, engineering, typing, filing); (2) operating tasks (weighing, operating equipment—spreading, compacting, excavating, hauling, road maintenance, dust control

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*Additional information is available from *Solid Waste Management Financing*, one of a series of guides developed by the National Association of Counties Research Foundation

—maintaining equipment; traffic control, vector control, litter control, site security).*

Once the job areas are defined, management must determine how many employees are needed; there may be some overlapping responsibilities. For instance, a small sanitary landfill may need only one operator to handle all its equipment. As the size of the operation increases, a division of labor will become necessary for sustained efficiency.

Governmental operations normally will have a civil service system that defines hiring and career-advancement procedures. In this case, management's responsibility is to write good job descriptions and interview applicants. A potential employee should understand the job fully before he is hired. If he is expected to perform other duties during emergencies, he should be fully apprised of this fact. Management must evaluate the ability of potential employees to comprehend and perform their tasks before they are hired.

Private operators may have more latitude in their employment practices. They should also interview and evaluate applicants as to interest in the job, ability to do the work, and potential for increased responsibility.

Once an employee is hired, management must see that he is trained properly. Such training should emphasize the overall operation of the landfill, safety, and emergency procedures. Employees responsible for more critical and complex tasks are given more intensive training. Employees should thoroughly understand work rules as well as procedures for handing out reprimands and submitting grievances.

Wages must be comparable with similar employment elsewhere. Larger operations may increase employee satisfaction by providing lunch room and locker facilities at the site. It is desirable to have on-the-job training, insurance plans, pension plans, uniforms, paid holidays and vacation, and sick leave programs.

PUBLIC RELATIONS. Public relations is one of the manager's most important administrative functions. Solid waste disposal sites represent an extremely emotional issue, particularly to those who live in the vicinity of a proposed site. Many sites are acceptable from an environmental control aspect but are vigorously opposed by citizens who associate them with old-fashion open or burning dumps. Convincing the public of the advantages of a sanitary landfill is a tedious process but can be accomplished by explanation and education. The program should begin early in the long-range planning stages and continue after operations begin. Public information should stress that at a sanitary landfill the waste is covered daily, access is restricted, insects and rodents are controlled, and open burning is prohibited. Examples of properly operated sanitary landfills that have been accepted near residential areas should be pointed out. Benefits to be derived by using the completed site as a park or playground, for example, should be emphasized. The media available to the solid waste manager are not limited to radio, television, billboards, and newspapers, but include collection vehicles, collectors, disposal facilities, and billing receipts. Help provided by community organizations can do much to increase public support. Extensive "stumping" by elected and appointed officials in support of a proposed solid waste disposal system is invaluable if the speakers are knowledgeable and have sufficient aids to help them, such as slides, films, and pamphlets.*

The single most important factor for winning public support of a solid waste disposal system is an elected or appointed official who firmly believes that it is acceptable and needed. A person willing to accept the challenge of developing short- and long-range plans and to see that they are properly implemented is invaluable. Once these plans are developed and implemented, the disposal system must be operated in a manner that upholds the high performance of which it is capable.

A comprehensive solid waste management plan should be developed, preferably on a regional basis. Detailed design and operating plans should cover a 10-year period and long-range, land-use planning should be developed for 20 years. Appropriate locations for sanitary landfill sites can then be identified, based on the needs of the area to be served. These sites can be zoned for waste disposal or other usage that will discourage development of a residential area. The regional approach to planning and implementation is especially desirable because it often is more economically feasible for all concerned. Land suitable for sanitary landfilling is usually scarce or nonexistent within the jurisdiction of a large city. Smaller communities nearby may be able to provide the land and thus be able to dispose of their own solid wastes in an acceptable manner.

A key aspect of public relations is the procedure for handling citizen complaints. Deficiencies in operating methods or employee courtesy should be investigated and acted on promptly. If this prac-

* Depending on the scale of operation, certain of these tasks may be performed either on or off site.

* Information pamphlets on the entire spectrum of solid waste management are available from the Office of Solid Waste Management Programs and in a series of guides issued by the National Association of Counties.

tice is followed, citizens will be less hostile toward the operation, and employees will become more conscientious.

A sanitary landfill represents a positive and relatively inexpensive step communities can take to provide a safe and attractive environment. By proper design, operation, and management, sanitary solid waste disposal can be provided.

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