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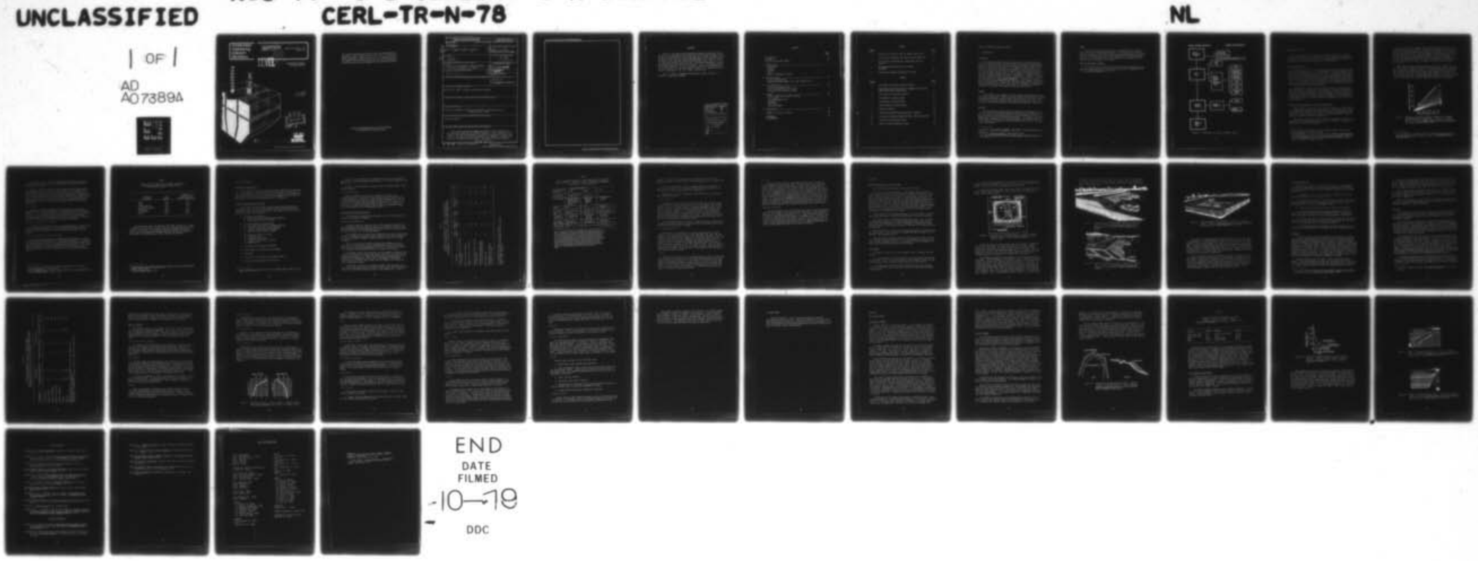

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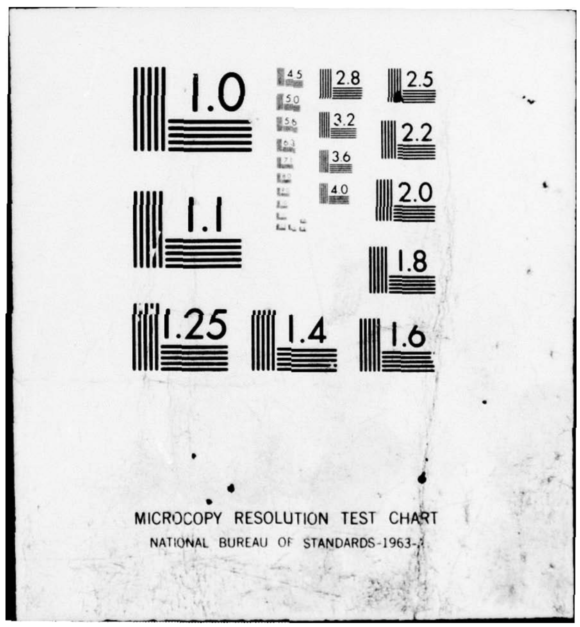
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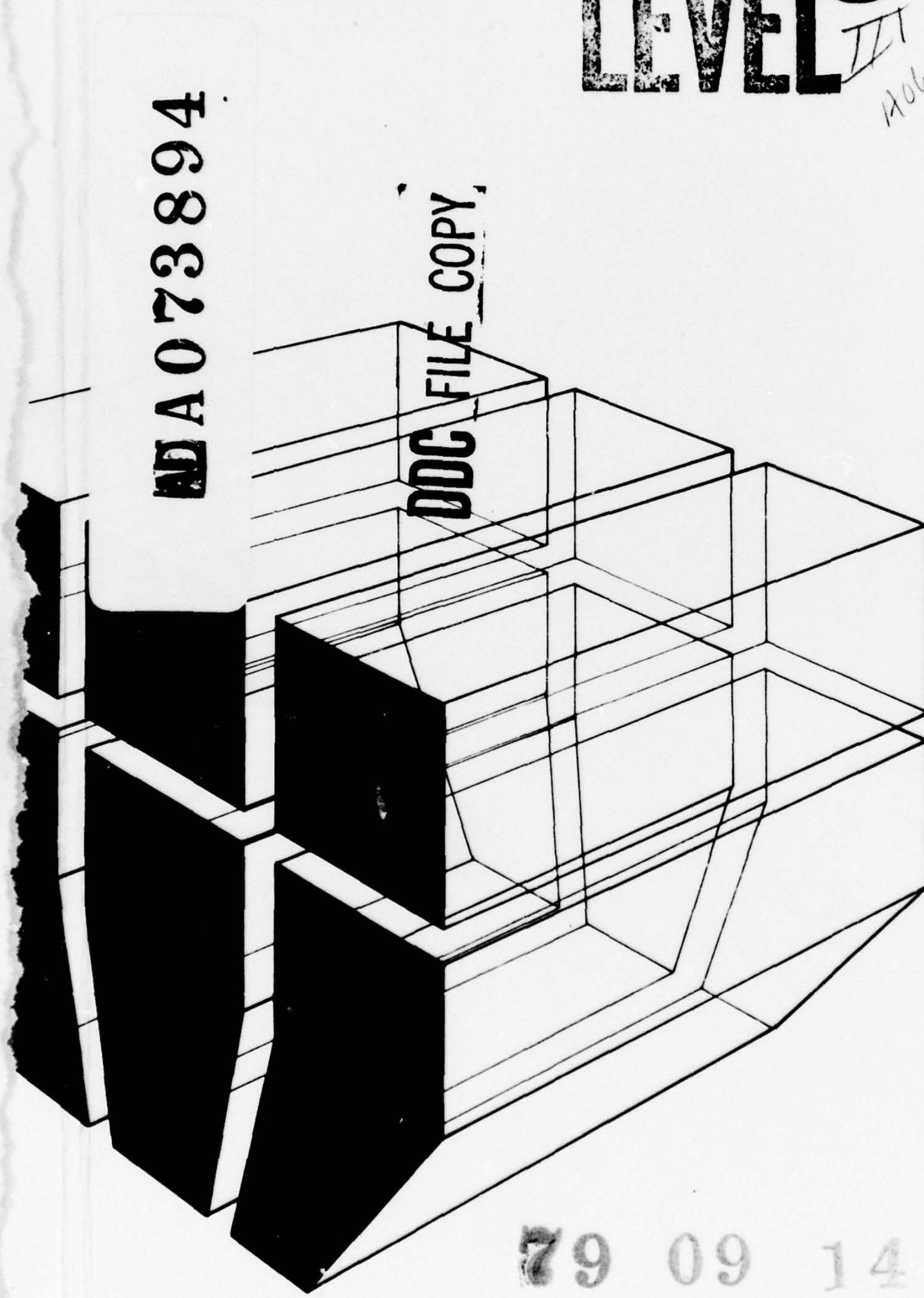
TECHNICAL REPORT N-78
August 1979

SIMPLIFIED SANITARY LANDFILL DESIGN



by
G. L. Gerdes
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This report surveys and summarizes state-of-the-art practices in the design and operation of sanitary landfills. This information is intended to be used as guidelines for Facilities Engineers at Army installations. All aspects of sanitary landfills are covered, including site selection, design, pollution control, operation, and final closure.

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FOREWORD

The U.S. Army Construction Engineering Research Laboratory (CERL) conducted this research for the Directorate of Military Programs, Office of the Chief of Engineers (OCE) under QCR item 3.01.001 (4) Solid Waste Management (CONUS and TO), Project 4A762720A896, "Environmental Quality for Construction and Operation of Military Facilities"; Task T2, "Pollution Abatement System"; Work Unit 007, "Solid Waste Management, Recycle, Resource Recovery for Military Facilities." Mr. F. A. Bizzoco was the OCE Technical Monitor. Mr. B. A. Donahue of the CERL Environmental Division (EN) was Principal Investigator, and Mr. G. L. Gerdes was the Associate Investigator. Dr. R. K. Jain is Chief of EN.

COL J. E. Hays is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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SIMPLIFIED SANITARY LANDFILL DESIGN

1 INTRODUCTION

Background

Solid wastes generated at Army installations must be disposed of properly to minimize their adverse effects on the natural environment. Sanitary landfills provide the least expensive and most commonly used method of solid waste disposal. It is imperative that sanitary landfills be constructed and operated according to a well-organized plan. The Army engineer's major goal in landfill design should be to choose a site and an operating plan that are as inexpensive, aesthetically acceptable, and environmentally sound as possible. A landfill design for an Army installation must be done by a professional engineer in accordance with AR 420-47, Solid Waste Management[1]. Currently, TM 5-814-5[2] and TM 5-634[3] provide guidelines to meet this goal; however, because of recently passed Federal regulations, the Army engineer will require further guidelines in this area. This report is intended to supplement information in AR 420-47 and update TM 5-634 and TM 5-814-5.

Purpose

The purpose of this report is to provide site selection design and operational guidelines to Army facilities engineering personnel in obtaining properly designed sanitary landfills at military facilities, and to provide the Facilities Engineer with information that will facilitate the Army's compliance with state and Federal environmental regulations.

Approach

The most current state-of-the-art information and regulations on sanitary landfill design were gathered from trade and professional journals, engineering society publications, the Environmental Protection Agency, and privately published design manuals. This material was then synthesized, condensed, and altered to conform to the Army's specific needs, while still complying with sound engineering practices and regulatory requirements.

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[1] AR 420-47, Solid Waste Management (Department of the Army [DA], June 1977).

[2] TM 5-814-5, Sanitary Landfill (DA, October 1973).

[3] TM 5-634, Refuse Collection and Disposal Repairs and Utilities (DA, July 1958).

Scope

Because sanitary landfill design is site-specific, this report deals mostly with general design aspects. It discusses the items that must be included in a landfill design plan and indicates topics on which the engineer should seek more detailed guidelines from other sources. Figure 1 is a flow sheet of the major elements and subelements of the design process included in this report.

Mode of Technology Transfer

The results of this study will be used as primary reference information in updating TM 5-634 and TM 5-814-5, and will supplement AR 420-47, Solid Waste Management (June 1977).

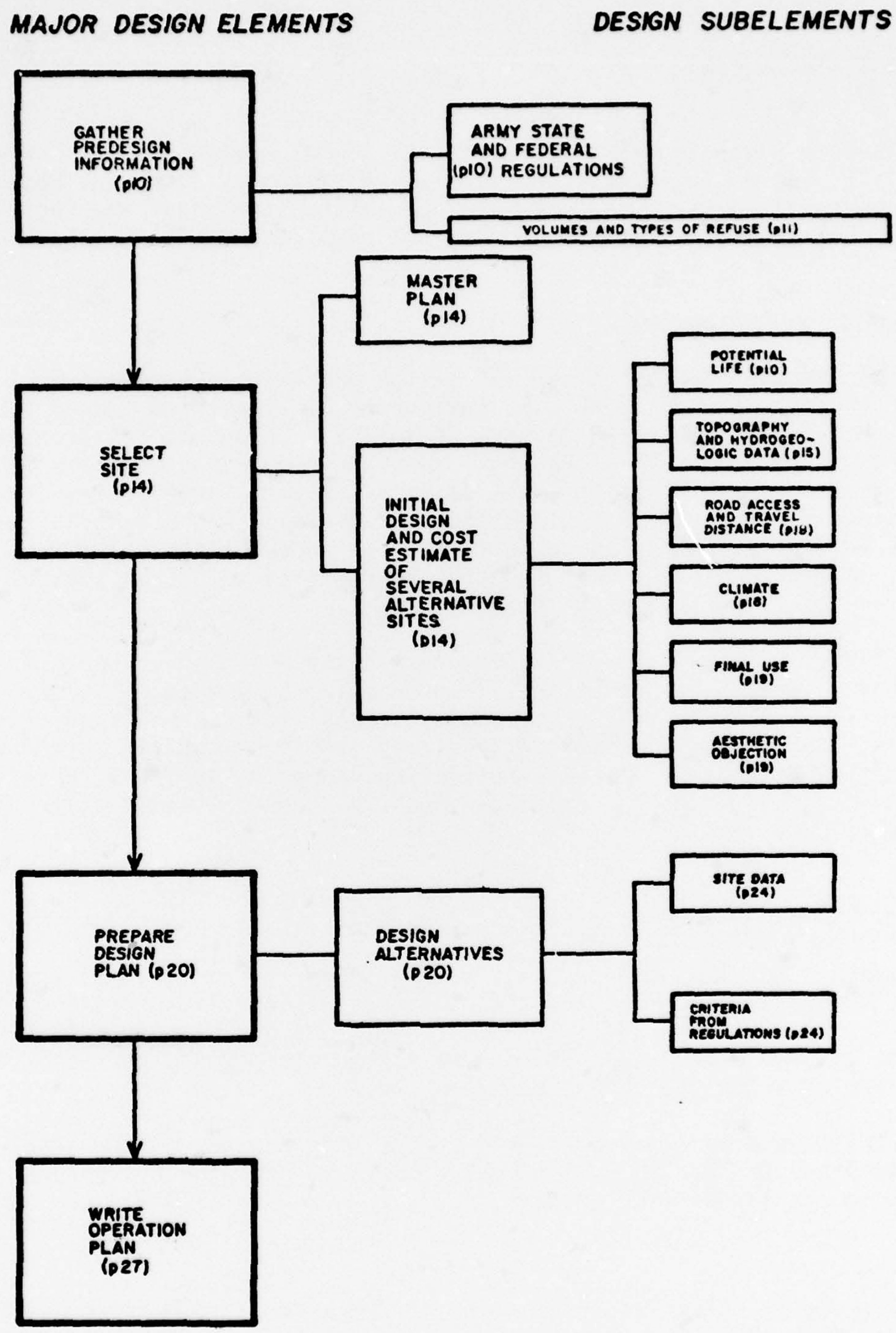

Figure 1. Flow sheet for sanitary landfill design.

2 PREDESIGN EFFORT

Before beginning site selection and formal design of a sanitary landfill, the engineer must gather data on pertinent state and Federal environmental laws and regulations, and information about the facility's unique solid waste emission and disposal requirements.

Laws and Regulations

During the site selection and design processes, the designer should maintain close contact with U.S. Environmental Protection Agency (USEPA) and state environmental regulatory officials. It should be ascertained that the site chosen meets Federal and state requirements before development is begun. The design must satisfy sanitary landfill requirements as stated in "Criteria for Classification of Solid Waste Disposal Facilities."[4] If the landfill must be located in an environmentally sensitive area, other regulations will require the facility to obtain special permits and take special design precautions.

Occasionally, laws not directly associated with solid waste disposal may affect site selection. For example, a Federal Aviation Administration regulation (FAA Order 5200.5) deals with construction of a landfill on or near a commercial airfield runway. Specific information on applicable Federal or state regulations covering sanitary landfills can be obtained from the Computer-Aided Environmental Legislative Data System (CELDS).[5]

Determining Requirements of a Land Disposal Site

When scheduling the design, filling, and closing of a new landfill, it is important to know a new site's potential lifetime and the current site's remaining lifetime. A landfill's lifetime is determined by the volume of available space that can be filled with compacted refuse and the rate at which the refuse is deposited.

The amount of space available at the site depends on the site's topography and the method used to make the fill. Chapter 4 provides information on landfilling methods.

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[4] "Criteria for Classification of Solid Waste Disposal Facilities," Federal Register (6 February 1978).

[5] J. Van Weringh, J. Patzer, R. Welsh, and R. Webster, Computer-Aided Environmental Legislative Data System (CELDS) User Manual, Technical Report N-56/ADA061126 (U.S. Army Construction Engineering Research Laboratory [CERL], September 1978).

Data on the rate of refuse deposit from the records for previous disposal sites should be useful, as long as the number of persons at the installation has not changed significantly. These data are available from the previous year's "Facilities Engineering Technical Data Sheets," DA Form 2788, Part IV, Activity Code M2200. If previous disposal records are considered inaccurate or are unavailable, a haulage survey can be conducted to determine the amount of refuse being collected. Guidance for conducting such a survey can be found in CERL Technical Report E-75.[6]

When these data have been obtained, the volume of landfilled waste can be estimated. Figure 2 contains information that may help determine the volume of the compacted refuse. To use these graphs, the designer must determine the specific per capita waste generation from the information shown on the "Facilities Engineering Technical Data Sheets" or in the haulage survey data. The designer next assumes an in-place density; a typical density range is 800 to 1200 lb/cu yd (475 to 712 kg/m^3).

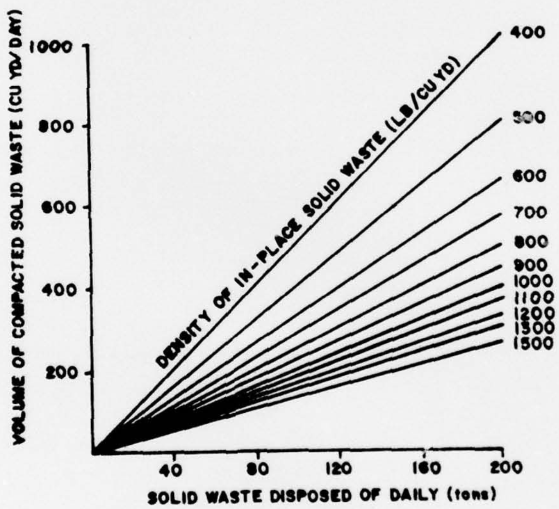

Figure 2. Determining the daily volume of compacted solid waste generated by small communities. (From D. R. Brunner and D. J. Keller, Sanitary Landfill Design and Operation, No. SW-65ts [USEPA, 1972], p 21.)

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[6] G. W. Schanche, L. A. Greep, and B. A. Donahue, Installation Solid Waste Survey Guidelines, Technical Report E-75/ADA018879 (CERL, September 1975).

Cover material must also be considered when determining landfill life, since this material usually comprises 20 to 25 percent of the total landfill volume.

Example: Previous landfill weight records show 100 tons per day (907 kg/day) are being disposed. Using Figure 2, and assuming 1000 lb/cu yd (593 kg/m^3) in-place density, the volume of compacted solid waste would be approximately 200 cu yd/day (150 m^3/day). If cover material accounts for 25 percent of the volume, then 267 cu yd (204 m^3) of landfill space will be filled each day of use. Assuming 250 working days, then the annual landfill volume required would be 66,750 cu yd (51 000 m^3).

Size Required

Studying preliminary designs of the various site alternatives (Chapter 3) will enable the engineer to determine the size of the most economical site. The potential life of a possible site will not be the sole factor in the choice; however, the high costs of opening and closing a landfill would make the choice of a site having a lifetime of less than a few years uneconomical and therefore unlikely.

Disposal Before New Site Is Ready

If space in the current site will be depleted before a new site can be designed and constructed, an interim disposal plan must be formulated. Contracting disposal of the refuse may be the most practical solution.

Effect of Recycling or Processing Refuse

Current or future resource or energy recovery schemes will affect refuse volume and characteristics. The deposit regulation[7] is expected to reduce the glass content by 33 percent, the ferrous and bimetal content by 15 percent, and the aluminum content by 30 percent.[8] This would mean approximately a 5 percent decrease in total refuse by weight. Table 1 shows the effect this regulation will have on waste characteristics.

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[7] "Criteria for Classification of Solid Waste Disposal Facilities," Federal Register (6 February 1978).

[8] Decision Makers Guide, Publication No. SW-500 (U.S. Environmental Protection Agency [USEPA], 1976), p 102.

Table 1

Effect of 40 CFR, Part 244, on Refuse Composition
(From Decision Makers Guide, [USEPA, 1976].)

Component of Refuse	% by Weight	Expected % by Weight After Deposit Regulation
Paper	32.8	34.5
Glass	9.9	6.9
Ferrous Metals	8.2	7.4
Non-Ferrous Metals	1.0	0.7
Food Waste	16.6	17.5
Yard Waste	18.5	19.5
Other	12.8	13.5

Processing the refuse for material and energy recovery will reduce its weight by 75 percent.[9] Volume reduction processes may also be considered; for example, incineration can reduce volume by 90 percent, baling can provide densities between 1000 and 1750 lb/cu yd (593 and 1038 kg/m^3), and shredding can reduce volume by 20 percent.[10]

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[9] Resource Recovery and Waste Reduction, Publication No. SW-600 (USEPA, August 1977), p XV.
[10] Decision Makers Guide, p 112.

3 SITE SELECTION

Installation Master Plan

Site selection is the most important step in developing a new landfill. The physical characteristics of the site almost totally govern the landfill design. Landfill siting may already have been accomplished and included in the Installation Master Plan; however, if this has not been done, a detailed siting procedure must be conducted.

Initial Design and Cost Estimate

First, several likely sites should be chosen and delineated on a topographic map. Then an initial design and cost estimate should be prepared for each site being considered. The important costs that may be unique to each site area are:[11]

1. Planning and engineering
   a. Site investigation, information gathering
   b. Design, plans, specifications

2. Site development and maintenance
   a. Clearing, landscaping, drainage (grading)
   b. Leachate and/or gas control measures
   c. Access roads and their maintenance
   d. Fencing, noise barriers, signs

3. Buildings and other facilities
   a. Administration
   b. Equipment maintenance
   c. Sanitary facilities, utilities
   d. Weight scales

4. Equipment and equipment maintenance

5. Cover material acquisition and placement

6. Personnel

7. Travel cost for collection and other vehicles

8. Closure and preparation for final use

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[11] Decision Makers Guide, Publication No. SW-500 (USEPA, 1976), pp 110, 111.

Design, site development, and operations costs are site-specific. Total cost, including equipment depreciation, is normally between $5 and $10 per ton.

Chapter 4 and the Appendix provide further information about these design elements.

Contracting Disposal

Before implementing the most cost-effective design of an on-installation site, the Facilities Engineer should investigate contracted disposal as a potential viable economic alternative. The cost of contracted disposal can be compared to the landfill's annual life-cycle cost. Inflation and other factors specific to the local area should be considered when determining the cost of contracted disposal over the expected life at the proposed landfill.

Information for Landfill Siting

The following information is pertinent to the initial design and general site selection procedure.

Physical Characteristics

The site's physical characteristics will determine the potential for groundwater pollution and its effect on the landfill design. Data must be gathered on the topography of the site and the surrounding area, the soils at the site, and the groundwater.

A topographic map is useful for determining the site's workability, as well as potential landfill volumes. Because a map cannot reveal all of a site's potentially good or bad features, a site visit is always necessary.

The soil at the site should be analyzed to determine its suitability as a cover material and to determine what effect the subsoil will have on controlling groundwater pollution. Information in Table 2 will be useful for determining the soil's suitability as cover.

Groundwater quality and flow data are also needed to determine the landfill's potential to pollute the water used by the installation and surrounding communities. Information should also be gathered on soil permeability, groundwater flow velocity, groundwater table depth, variations in the water table level, and the location of bedrock and other impermeable layers.

Soils with a great deal of highly permeable sand and gravel are poor underlining materials for landfills, while soils having a high clay content are much better because of their low permeability. Table 3

Table 2

Suitability of General Soil Types as Cover Materials
(From D. R. Brunner and D. J. Keller, Sanitary Landfill and Operations, Publication No. SW-65ts [USEPA, 1972], p 14.)

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.

Table 3

Soil Limitation Ratings for Trench-Type Sanitary Landfills (From J. Reindl, "Landfill Course," Solid Waste Management, Vol 20, No. 8 [1977], p 56.)

Site Characteristic Affecting Use		Degree of Soil Limitation: Slight[2]	Moderate[2]	Severe
Depth to seasonal high water table		Not class determining if more than 72 in.	Less than 72 in.	
Soil drainage class		Excessively drained, somewhat excessively drained, well drained, and some[3] moderately well drained	Somewhat poorly drained and some[3] moderately well drained	Poorly drained and very poorly drained
Flooding		None	Rare	Occasional or frequent
Permeability[4]		Less than 2.0 in./hr	Less than 2.0 in./hr	More than 2.0 in./hr
Slope		0-15 pct	15-25 pct	More than 25 pct
Soil texture[5] (dominant to a depth of 60 in.)		Sandy loam, loam, silt loam, sandy clay loam	Silty clay loam[6] clay loam. sandy clay, loamy sand	Silty clay, clay, muck, peat, gravel, sand
Depth to bedrock	Hard	More than 72 in.	More than 72 in.	Less than 72 in.
	Rippable	More than 60 in.	Less than 60 in.	Less than 60 in.
Stoniness class[7]		0 and 1	2	3, 4, and 5
Rockiness class[7]		0	0	1, 2, 3, 4, and 5

Chart is based on soil depth (5 to 6 ft) commonly investigated in making soil surveys.[2] If probability is high that the soil material to a depth of 10-15 ft will not alter a rating of *slight* or *moderate*, indicate this by an appropriate footnote, such as "Probably *slight* to a depth of 12 ft," or "Probably *moderate* to a depth of 12 ft."[3] Soil drainage classes do not correlate exactly with depth to seasonal water table; the overlap of moderately well drained soils into two limitation classes allows some of the wetter moderately well drained soils (mostly in the Northeast) to be given a limitation rating of *moderate*.[4] Reflects ability of soil to retard movement of leachate from the landfills; may not reflect a limitation in arid and semiarid areas.[5] Reflects ease of digging and moving (workability) and trafficability in the immediate area of the trench where there may not be surfaced roads.[6] Soils high in expansive clays may need to be given a limitation rating of severe.[7] For class definitions, see the Soil Conservation Service Manual.

provides information about when a site characteristic will have a slight, moderate, or severe effect on the acceptability of a landfilling site.

Soil and hydrogeology data are somewhat expensive to gather. To save on design costs, this information should be obtained only for a site which will be considered for final selection.

The Appendix provides information about the control of pollution from sanitary landfills.

Travel Distance

Although the distance that collection trucks must travel to reach the site does not affect the landfill's cost, this aspect must be considered, because it affects total solid waste management costs. Obviously, a shorter traveling distance will make the collection process more economical. However, it is preferable not to route refuse collection trucks traveling to and from the landfill along main roads, through housing areas, or through troop areas. The actual cost of hauling versus the distance traveled may be determined by obtaining information from Buildings and Grounds personnel.

On large installations, the use of transfer stations should be considered to decrease collection, especially if the distance to the landfill will be 8 to 10 miles or longer.

Road Access and Quality

Road access to a candidate site can be determined from a topographic map of the installation or from other maps that show both the landfill site and the area served by the collection vehicles. The roads leading to the site must be capable of carrying the load of the collection trucks in all types of weather with minimal degradation. If collection vehicle traffic will damage the road surface, the cost of repair should be included in the total landfill cost. The site should have an entrance away from hills, railroads, and busy intersections. If possible, the landfill should be away from residential areas and other high land-use areas off-post.

Climate

Because the landfill must be operated whenever refuse is collected, the site should be located in an area where adverse weather will have a minimal effect on the operation. The effects of heavy rains and snow should be considered, as well as the possibility of dust blowing from mounds of cover material and possible litter problems. The site must have an area for storing cover material if freezing temperatures will inhibit excavation during winter months.

Final Use

Knowing the final use for a proposed site may make it easier to obtain approval for use of the land. In the private sector, most completed landfill sites are used for agriculture or for recreational areas, such as ballfields or ski hills. Other uses that may be considered are a parade ground, a training area, or a horseback riding ground. It is not recommended that the completed site be used for a golf course, because the frequent watering may cause a pollution problem; uses involving vehicles are not recommended because they will disturb the final cover. It is generally recommended that structures *not* be placed over a landfill because settling of the filled materials makes it a poor foundation; in addition, the methane gas produced within the landfill by decay processes would be both an explosion hazard and a health hazard.

Aesthetic Objections

Sanitary landfills still suffer from the stigma of being considered "dumps." The thought of having a landfill next door is not appealing to most people, no matter how sanitary it is. People occupying nearby facilities or housing areas may object to a proposed site. To allow time to deal with objections or to select a new site if the one originally chosen is not approved by state authorities or higher headquarters, the site selection process should begin as early as possible and should include as much educational public relations as possible.

4 DESIGN

Overall Approach to Landfill Design

The landfill design process consists of five steps.

The first step is setting goals. The highest priority must be given to meeting current pollution control laws and regulations. Other goals include allowing for the capability to dispose of all types of waste that may be expected at the site; allowing for a specific final use of the land; and accommodating any other requirements placed on the landfill by the facility. Usually the best design would be the most economical one. However, there may be goals that take higher priority than immediate cost. For example, additional pollution control measures may be added to the design because of an expected new regulation. The priority of the various goals and objectives should be used to guide selection of an optimum landfill design.

The second step in the design process is to obtain data. The necessary data are normally collected during the site selection process.

The third step is to identify design alternatives. It is helpful to have several people of different backgrounds submit ideas for the site layout and development. Landfill operators, landscapers, other design engineers, and equipment operators are some of the people who may be consulted.

The fourth step is evaluating the design alternatives and selecting the optimum plan. This requires a thorough engineering analysis of all workable and reasonable plans.

The last step is preparing the final design, which should include all information gathered about the site, the economic evaluation of the final design, an operation plan, an evaluation of the environmental effects, and the projected land use after closing.

Site Layout

As shown in Figure 3, an ideal landfill site is divided into four areas:

1. The perimeter, an outside border of trees or fence around the site, which is used to break the wind, to catch blowing litter, to maintain security, and to prevent unauthorized use of the landfill.

2. The entrance, which should be easily and safely accessible to collection vehicles, and located away from hills, railroads, and busy intersections.

3. The visual zone, which is area seen from outside. While not an integral part of the landfill design, this area is sometimes important, because it gives a positive impression of the operation.

4. The interior area, where the actual landfilling operations take place. Most of the information in this report deals only with operations in the interior zone.

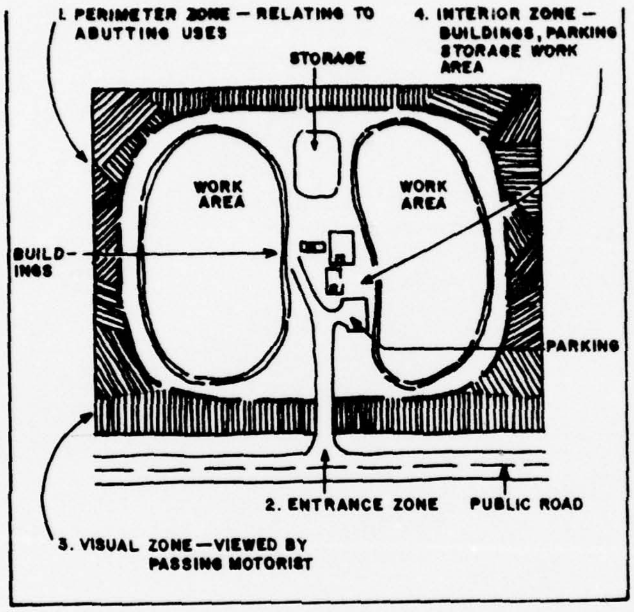

Figure 3. Four zones of a sanitary landfill. (From J. Reindl, "Landfill Course," Solid Waste Management, Vol 20 [1977], p 46.)

Before the layout of the interior zone can be drawn, a method for burying the refuse must be chosen from one of three basic methods: area, ramp, and trench. All three methods involve shaping 1 day's refuse into a cell by spreading and compacting it in layers. The cell should be 8 to 10 ft (2.4 to 3.0 m) deep, and as wide and long as the designer determines necessary for the most efficient burial.

The difference among the three methods is in the way the site is excavated. The area method, illustrated in Figure 4, requires the least excavation, because the refuse is merely placed on a flat surface and covered with soil. The cover material can be hauled to the site, or it can be obtained by excavating the surface of the site. The ramp, or progressive slope method, shown in Figure 5, requires excavating the cover material for a cell from the ground immediately in front of the cell's working face. This excavation also creates a pit for the next day's refuse. In the trench method, shown in Figure 6, a trench up to

20 ft (6.1 m) deep and usually about 20 ft (6.1 m) wide is excavated to a length that will hold at least 2 weeks' refuse. The soil taken from the trench is used as cover material for either that trench or for one which is being filled.

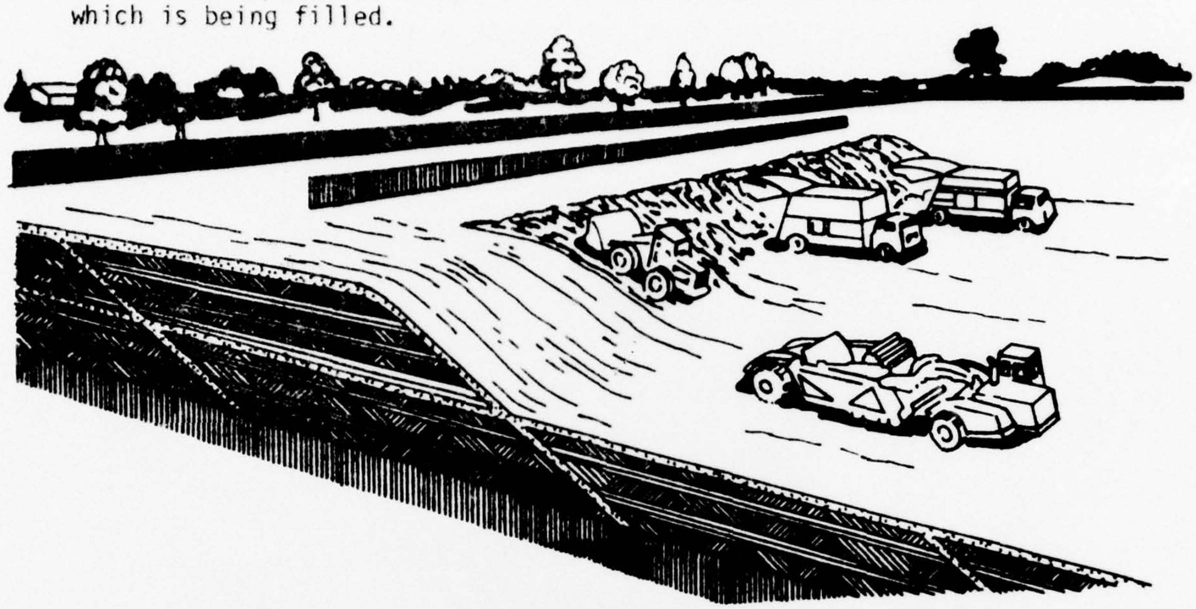

Figure 4. Area method of burying waste. (From D. R. Brunner and D. J. Keller, Sanitary Landfill Design and Operation, Publication No. SW-65ts [USEPA, 1972], p 28.)

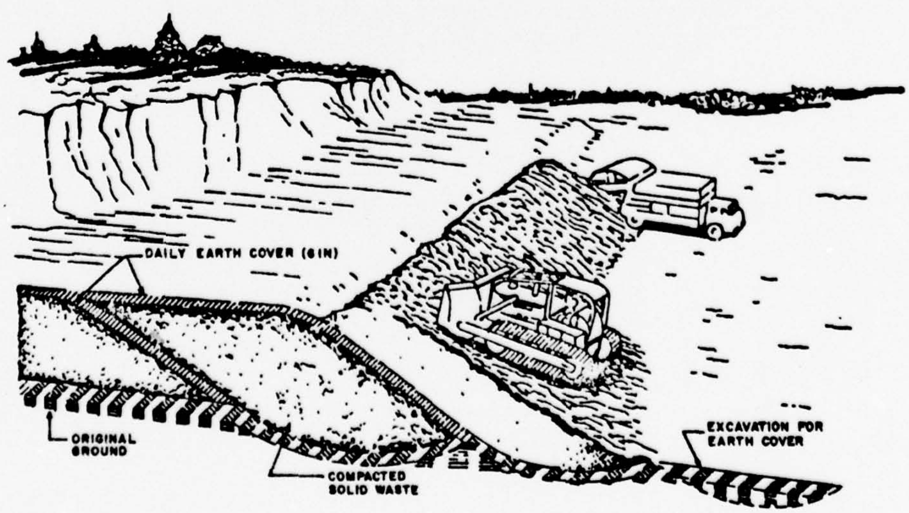

Figure 5. Ramp method of burying waste. (From D. R. Brunner and D. J. Keller, Sanitary Landfill Design and Operation, Publication No. SW-65ts [USEPA, 1972], p 29.)

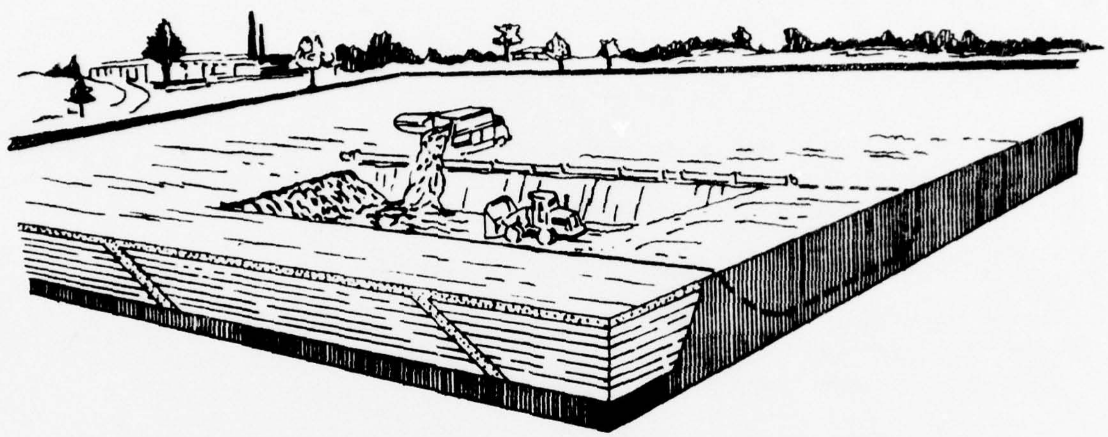

Figure 6. Trench method of burying waste. (From D. R. Brunner and D. J. Keller, Sanitary Landfill Design and Operation, Publication No. SW-65ts [USEPA, 1972], p 29.)

Site data will determine which method should be used for the landfill operation. The trench method is best in flat areas with deep water tables as well as areas where little additional cover material is available. The area or ramp methods are more suitable where the groundwater table is closer to the surface, where there is available cover material, or where there are natural depressions in the land. Refuse should never be placed so it is in contact with the water table. Appendix A provides further pollution control information.

Once the landfilling method has been selected, the layout can be determined. The location of the cells, the sequence in which they will be filled, and the final landscape of the fill can be designed. Provisions for temporary access roads and drainage must also be made. Grading for drainage of the site should be planned from the initial excavation until its closure. The final design should include complete phase development drawings and detailed topographic maps.

Site Development Plan

The sanitary landfill design must incorporate a site development plan which has been prepared or approved by a professional engineer. The USEPA guidelines state that the following items should be included in this plan:

1. Topographic maps of initial and final contours of the site showing intervals of 5 ft (1.5 m) or less.

2. Maps and descriptions of land uses within 1/4 mile (0.4 km) of the site, showing roads, buildings, wells, and any geologic features which would affect surface or groundwater flow.

3. Location of utilities within 500 ft (150 m) of the site.

4. Employee convenience and equipment maintenance facilities. These might include toilet facilities, drinking water, storage, and tools and hardware necessary for maintaining equipment and grounds.

5. The site plan must include drawings of leachate and gas control and monitoring systems where required or otherwise show that the landfill will not degrade surface or groundwater quality.

6. The USEPA guidelines cited above are under revision (as required by Section 1008 [a] of PL 94-480) and will be published in 1979.

Equipment

A landfill operation requires equipment for compacting, loading, dozing, and transporting earth. Recently, the use of specialized compacting equipment has become popular at landfills. Contractors have specially designed steel wheels with cleats that increase the compaction efficiency. Information about landfill compactor selection can be found in CERL Technical Report N-62.[12] Loaders are used to transport the cover material or to load the material into trucks which then transport it to the working face of the fill. The loader can also be used to spread and compact the waste, especially in smaller operations where it is too expensive to have both a loader and a compactor. A dozer is used to excavate the cell area and to spread and compact the refuse.

Loaders and dozers are available in both tracked and wheeled models. The tracked models are slower but are better suited for situations in which the compaction weight must be spread over a larger area, for example, when wet conditions may cause wheeled vehicles to sink.

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[12] D. Kraybill and B. Donahue, Sanitary Landfill Compactor Evaluation, Technical Report N-62/ADA067697 (CERL, March 1979).

Selection of the equipment used to transport cover material to the cell is largely determined by how far the material must be carried. A crawler-loader can economically transfer cover material for up to 300 ft (90 m). Rubber-tired loaders can carry the material up to 600 ft (180 m). For greater distances, dump trucks and scrapers should be used.

Special earth-handling equipment may be used at a landfill. When the trench method is used, a dragline can be efficient in constructing the trench. Backhoes are occasionally used, but are not very efficient for landfill operations.

Table 4 will be helpful in determining the equipment needed for the landfill. Provisions must be made to acquire replacement equipment for use during downtime of regular equipment.

Final Use

The design should include plans for the final closure of the landfill and the future use of the site. The design should also include provisions for premature closure of the site because of pollution or management problems.

The soil used as a cover material should be analyzed before any planting is done on the closed fill. Each soil has a different capacity for plant growth. A state agricultural extension agency can recommend the types of plants that would be best for the final cover landscaping. If the site will be used for agriculture, the final cover should be deep enough that the refuse will not be disturbed by cultivation. Deep cultivation uses should be prohibited.

The completed landfill will continue to require regrading because of uneven settlement of the solid waste. This grading is done chiefly to prevent ponding on the landfill cover. Landfills can settle as much as 50 percent within 5 years of closure, although they normally settle to a much lesser extent. The load-carrying capacity of a finished landfill is estimated to be 500 to 800 lb/sq ft (2440 to 3900 kg/m^2).[13] However, there will be inconsistencies because of factors such as gas pockets and nonhomogeneous waste. Because of settlement and continuing gas production, constructing buildings on the completed fill is not permitted without prior approval of HQDA(DAEN-MPA), Washington, DC.

The USEPA recommends that a detailed description of the closed site, including a plat, should be filed with the area's land recording authority. The description should include the location of the waste, the depth of the fill and cover, groundwater data, and other information

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13 J. Reindl, "Landfill Course," Solid Waste Management, Vol 21, No. 1 (1977).

Table 4

Performance Characteristics of Landfill Equipment
(From D. J. Brunner and D. J. Keller, Sanitary Landfill Design and Operations, Publication No. SW-65ts [USEPA, 1972], p 45.)

Equipment	Solid Waste Spreading	Solid Waste Compacting	Cover Material Excavating	Cover Material Spreading	Cover Material Compacting	Hauling
Crawler Dozer	E	G	E	E	G	NA
Crawler 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 1000 ft.
+Rating Key: E, excellent; G, good; F, fair; P, poor; NA, not applicable.

pertinent to the future use of the site. At most sites, provisions for monitoring and controlling gas and leachate production and discharge must also be included. A plat at the site, as well as monitoring information, should also be included in the Installation Master Plan.

Operation Manual

The operation manual is an integral part of the landfill design and may be required by some state agencies. This manual, which is written for the operator and other landfill personnel, states in simple language how the landfill is to be operated. The following paragraphs provide information and guidelines which will help the designer develop the plan.

Wastes Accepted and Excluded

The landfill will be designed for the disposal of specific types of wastes, in accordance with the guidelines established in 40 CFR 257. The operators, regular users, and collection personnel should have a list of wastes that cannot be disposed of in the landfill because they have chemical, biological, or other characteristics that are potentially hazardous.

Bulky Wastes

The plan should include procedures for landfilling tires and other bulky wastes. Normally, bulky wastes are put at the bottom of the cell so that they are buried by the incoming refuse. They may be put aside on the day they are delivered for placement at the bottom of a new cell the next morning. Bulky wastes can also be crushed against solid ground before they are put into the bottom of the cell's working face. Demolition debris should also be placed at the bottom of the cell.

Tires have a tendency to float to the surface of a landfill if they are not buried deeply. In some operations, tires are fastened to the bottom of the fill or are shredded by a special machine. Demolition debris may be used to anchor tires.

Sludges

Water and wastewater treatment plant sludges should be free of water and may be placed at the working face with the refuse. These sludges should have the consistency of moist earth. Incinerator and air pollution residues should be put into the working face in a manner that will not create dust problems.

Hazardous Wastes

Recommendations and approval for handling special and hazardous wastes should be obtained from the state agencies regulating their disposal. These wastes include pesticides and their containers, explosives and their containers, wet sludges, bulk liquids and semiliquids, manure, industrial wastes, and infectious hospital wastes.

Animal Carcasses

Normally, state regulations provide guidance for the handling of dead animals. In the absence of such regulations, carcasses of small animals may be placed on the working face with the rest of the refuse. Larger carcasses should be buried separately and covered in a manner conducive to precipitation runoff.

Cell Construction

The weight of the compacting vehicle will apply a great deal of pressure to the surface of the working face, but as depth increases, the weight is rapidly distributed over a larger area. Therefore, the refuse should be spread in layers not more than 2 ft (0.6 m) thick before it is compacted. The compacting vehicle should be driven over the refuse two to five times for best compaction results. Figure 7 compares the refuse density to the cell thickness after specified numbers of passes by the compactor.

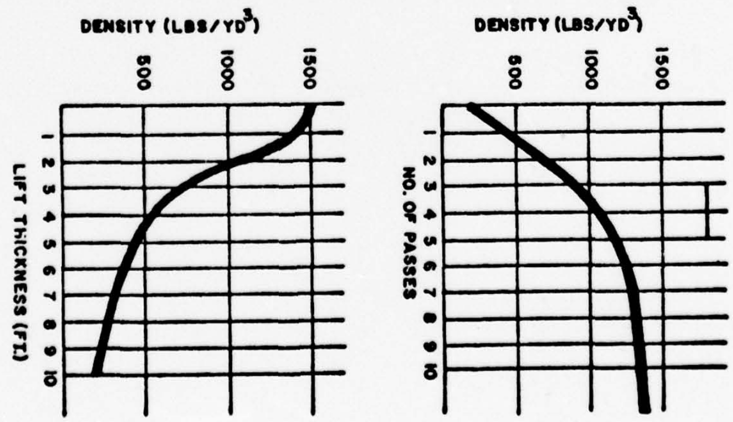

Figure 7. Density of refuse. (From J. Reindl, "Landfill Course," Solid Waste Management, Vol 20, No. 11 [1972], p 60.)

The slope of the cell's working face has traditionally been 30 degrees. Although a flatter slope will provide greater compaction and reduced equipment wear, it is harder to drain and requires greater amounts of cover material. A 20- to 30-degree slope is recommended.

Cover

The daily cover should consist of at least 6 in. (0.15 m) of soil. This depth will stop flies and mosquitoes from breeding, discourage rodents from burrowing, and control bird problems. Intermediate cover on a refuse cell which will remain exposed for 1 week to 1 year should be at least 1 ft (0.3 m) thick. The final cover used to close the landfill should be 2 ft (0.6 m) thick or more, depending on the final use of the area. The final cover should have a 2 percent slope, and should be regraded when settlement occurs.

Surface Water Diversion

Surface water runoff should be diverted away from the working face by trenches, tiles, or grading. Because this water is being diverted to minimize infiltration, the amount of runoff will be larger than normal, and the water may contain a high concentration of soil. If there is a potential problem of stream siltation or flooding of other areas, a catch basin to hold the runoff may be necessary.

Cold Weather Operations

In locations where winter temperatures are often below freezing, excavation of cover material will become difficult. In these areas, cover material should be stockpiled during summer for use during the winter. This cover material should be kept dry and not allowed to freeze.

Dust Control

The operation plan should provide for dust control, although it will not be a daily problem. Use of a water wagon or calcium chloride are two common methods of dust control. The water wagon is probably the best method because it is less expensive and can also be used for fire control. AR 420-47 prohibits the use of oil as a dust control measure.

Litter Control

Litter gives the landfill operation a bad image. Several litter control methods can be used:

1. Wastes should be deposited at the bottom of the cell where they are less likely to be blown by the wind.

2. The landfill should be designed so that the prevailing wind will blow directly into the face of the refuse. If the trench method is used, the trench should be at a right angle to the prevailing wind.

3. Temporary and permanent fences should be used. A permanent fence around the edge of the fill site will stop litter as well as provide security. Temporary fences can be placed downwind of the working face and moved as the operation progresses. Both fences should be cleared of litter routinely.

4. Trees can be planted as a windbreak along the perimeter of the landfill.

Rodent Control

Rodents can be a problem before and after a landfill is completed. Normal sanitary landfill operation should minimize the rodent population. However, if rodents do become a problem, the final closure of the fill may force them to migrate to another part of the installation, such as nearby housing. If this is possible, the division managing pest control should be contacted to arrange for extermination of the rodents before the landfill is closed.

Site Accessibility

It may be necessary to allow individuals to bring wastes to the landfill. The operation plan should state whether such access is allowed, as well as the condition and times of access. The plan should not allow individual dumping to interfere with any of the landfill operations. The site should be accessible only when landfill personnel are on duty. For use after hours, large containers could be placed near the entrance. Scavenging (people removing items from the deposited refuse) is dangerous and should be prohibited.

Safety

The accident rate for solid waste collection and disposal is 11 times higher than the average for all industry. Before completing the operation plan, the landfill designer and the installation's safety office should insure that a strong safety program is included.

The operation must adhere to the provisions of the Occupational Safety and Health Act of 1970 (Public Law 91-596) as they apply to sanitary landfill operations. A safety manual should be written and made available to all employees. Safety devices such as hard hats, safety glasses, gloves, and footwear should be provided to landfill employees. Compaction and earthmoving equipment should be equipped with safety measures such as rollover protection, seat belts, reverse warning sounders, and fire extinguishers.

Procedures should be established to control fires in the refuse being delivered, at the working face, or in the landfill equipment. Provisions should be made for easy communication between the site operator and the employees and between the landfill and other post facilities.

Equipment

Maintenance schedules are provided by the equipment manufacturers. These schedules, as well as provisions for routine daily checks by the equipment operator, should be included in the operation plan.

Special Circumstances

The operation plan should include procedures for breakdowns, shutdowns, and unexpected natural occurrences. Pieces of equipment will sometimes need maintenance. In such cases, suitable temporary replacements should be available, possibly from another facility shop. Since shutdowns may occur as a result of regulatory actions, an alternate plan for operating the fill or for disposing of the refuse should be prepared. Provisions should also be made to minimize the effects of natural occurrences such as floods, heavy snows, earthquakes, or high winds.

Records

Records should be kept of the following items:

1. Major operational problems and complaints.

2. The environmental impact of the site and the effectiveness of gas and leachate control. These records should include the results of groundwater, gas, and leachate sampling and analysis both upstream and downstream of the site.

3. Vector control efforts.

4. Dust and litter control efforts.

5. Measurements of the amount of solid waste handled through routine or periodic use of scales and topographic surveys.

6. Descriptions and sources of materials received.

Traffic Control

Traffic control signs should be placed to maintain an orderly traffic pattern. If necessary, access to hazardous areas may be restricted. The working face area should not be blocked by unattended vehicles.

The number of personnel needed at the landfill site usually depends on the number of pieces of equipment to be operated. A scale operator may be needed if there are scales. Laborers will be needed to control litter and dust, to direct traffic and equipment, and to maintain landfill equipment. Larger landfills may need a foreman, and most landfills need an operator. All personnel should be trained to operate the landfill efficiently under both normal and adverse conditions.

5 CONCLUSIONS

Each Army landfill site is unique and requires a detailed engineering study prior to use. The design guidelines in this report are intended to be of general assistance to Facilities Engineers in supervising preparation of the detailed engineering studies required for sanitary landfill design and operation.

APPENDIX:

POLLUTION CONTROL

The Design Problem

A major goal of the sanitary landfill is to eliminate all harmful environmental effects and the unpleasant aesthetic aspects of refuse disposal. The sanitary landfill can be considered a treatment plant for refuse. It is the designer's responsibility to insure that the treatment is effective. Regulations authorized by the Resource Recovery Act of 1970 (PL 91-512) and proposed guidelines authorized by the Resource Conservation and Recovery Act (PL 94-580) require that a land disposal site be designed and operated so that there is no detrimental effect on surface and groundwater which is or potentially may be used to supply drinking water.

Leachate is water that has come in contact with landfilled refuse and has flowed out of the landfill. Refuse will absorb approximately 2 gal of water per cu ft (267 ℓ/m^3). After the refuse is saturated, leachate is formed. The amount of leachate depends on the amount of water flowing through the refuse. The two main sources of water that form leachate are surface water infiltration and groundwater movement.

Once leachate has moved out of the landfill, it can pollute groundwater supplies and nearby lakes and streams. Leachate is normally acidic because of the large amount of carbon dioxide (CO_2) produced during biological degradation of the refuse. The CO_2 combines with water to produce carbonic acid, which can dissolve salts and minerals from the refuse and soil into the leachate. When combined with the organic compounds in the liquid, this leachate can have a biological oxygen demand (BOD), a chemical oxygen demand (COD), and a total solids concentration up to 100 times greater than those of raw sewage.

The landfill design should show the potential for leachate formation and the measures that will be used to control it. Hydrogeologic data obtained from the site area should show the landfill's potential zone of influence. The design should show both the current and future uses of water in this zone. Elevations of the bottom of the refuse and the highest expected level of the groundwater table should be shown, along with a groundwater quality analysis. If groundwater contamination is possible, sampling stations and a testing program should be included in the operation plan. Leachate monitoring will be mandatory in almost all cases.

Unfortunately, the largest uncertainty in landfill design is not knowing whether the standard design procedure will effectively eliminate pollution. Normally, the pollutants in leachate are thought to be removed by soil attenuation. The soil acts as an ion exchanger and filter medium. However, because not enough is known about the mechanism of soil attenuation and because the subsoil characteristics are seldom homogeneous, it is very difficult to predict the pollution potential of a landfill site. It is therefore difficult to decide whether gas and leachate collection systems should be included in the landfill design. The best recommendation that can be made in this report is that the designer follow the regulations established in the particular area and request additional guidance from state agencies and the USEPA. Seeking such guidance should be the first design step after site data have been collected and the site has been selected.

Control Methods

Gas and leachate pollution can be controlled by managing the production of these effluents, directing their movement, and then treating them. Managing the production seeks to achieve one of two goals: preventing or minimizing the gas and leachate formation, or exhausting the gas and leachate potential as quickly as possible.

Refuse in a landfill produces a finite amount of gas and leachate. If these effluents can be collected over a short period of time, then the potential for further pollution from the landfill can be eliminated. The expense of collection systems increases construction costs, and operating costs are temporarily increased while the gas and leachate are being collected. The collected leachate can be recycled through the landfill, treated on site, or drained into a sanitary sewer. However, introducing untreated leachate into a sewer system is not recommended because it could cause problems at the sewage treatment plant, and recycling leachate through the landfill may not be an adequate solution. A viable method of leachate pollution control is treating the leachate on site through either a complete treatment system to meet effluent discharge standards, or through a pretreatment system for discharge into a sanitary sewer. The most cost-effective method will depend on site-specific factors.

Preventing gas and leachate from forming is the least expensive and most commonly used control method. This method depends on natural diffusion, dilution, and attenuation.

Controlling the amount of water entering the refuse has the greatest effect on gas and leachate production. The designer may reduce the amount of water entering the fill by carefully selecting the landfill location, cover material, cover slope, final cover vegetation, and surface drainage; however, it is nearly impossible to completely eliminate gas and leachate production.

The landfill should never be located where the refuse will be in direct contact with surface water or the groundwater table, and, if at all avoidable, the landfill should not be located in a floodplain.

However, if a landfill must be constructed in a floodplain, the refuse should be protected from at least a 100-year flood by dikes and other suitable means. If the landfill is located in a watershed carrying a large amount of runoff, such as a ravine, the water must be rerouted around the site, as shown in Figure A1.

The soil used as cover material should be of low permeability. The cover material should be sloped so that most water will run off the surface of the fill. Drainage water from outside the fill should be diverted away from the fill, and drainage water from within the fill site should be routed so that there is no standing water; measures should be taken to minimize erosion during these activities. To stop infiltration, vegetation on the final cover should be a species that requires a large amount of water. Table A1 shows the water needs of some general types of plants.

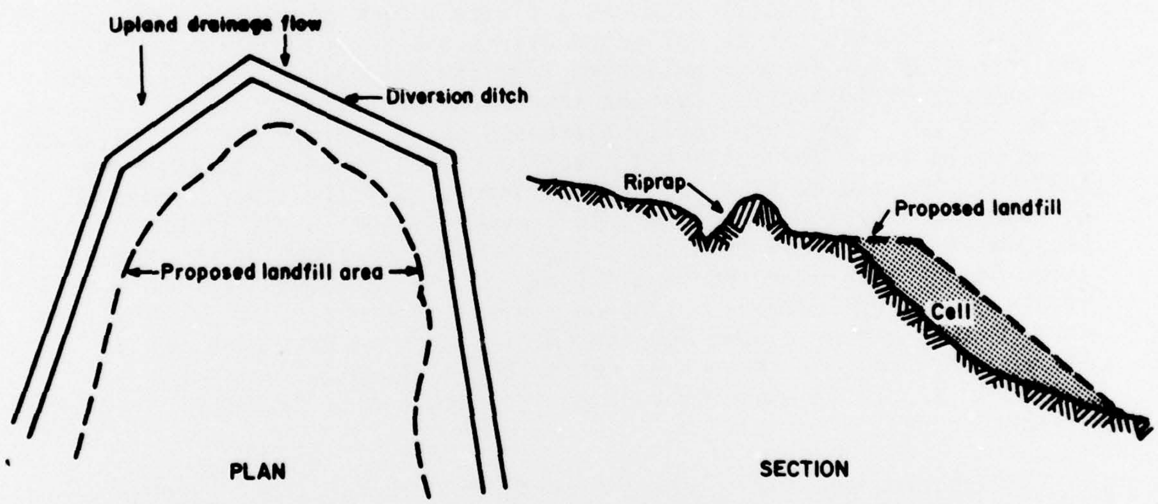

Figure A1. Transmitting upland drainage around a landfill. (From D. R. Brunner and D. J. Keller, Sanitary Landfill Design and Operation, Publication No. SW-65ts [USEPA, 1972], p 23.)

Table A1

Approximate Seasonal Consumption of Water
(From: J. Reindl, "Landfill Course,"
Solid Waste Management, Vol 20, No. 6 [1977], p 48.)

Growth	Inches	Growth	Inches
Coniferous Trees	4-9	Alfalfa and Clover	2.5 up
Deciduous Trees	7-10	Oats	28-40
Rye	18 up	Meadow Grass	22-60
Wheat	20-22	Lucern Grass	26-65

Because of site limitations, it is not always possible to prevent leachate from forming, so procedures for stopping the movement of leachate must be considered. Two major methods are available. The first is drilling in and around the landfill, and then pumping the leachate out. This approach can be expensive but may be discontinued after the pollutant concentration in the leachate reaches a safe level. The second method is creating an impermeable layer between the refuse and the groundwater. The layer, which is emplaced during site preparation, can be made of materials such as clay, bentonite, plastic, or asphalt. Leachate collection pipes can be installed over the liner. The cost of leachate control must be weighed against the cost of using another site where such controls would not be needed.

Gas Production and Control

Through a series of microbial degradations, the organic material in refuse is broken down into a gas consisting of approximately one-half CO_2 and one-half CH_4 (methane). Figure A2 illustrates the variation in methane production with time. Methane is flammable, can cause asphyxiation, and kills vegetation. It is therefore important that gas control be part of a landfill design.

Gas tends to migrate along the path of least resistance. A study of the soils and geology of the area will determine potential flow patterns. If the landfill is next to porous material, then gas control measures should be taken.

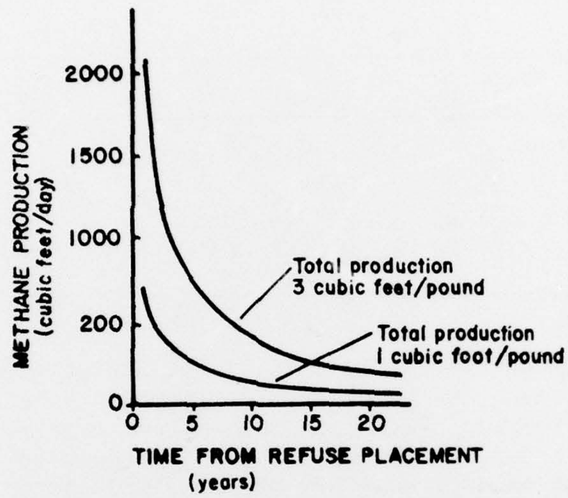

Figure A2. Estimate of methane production from a 1000-ton landfill. (*From* J. Reindl, "Landfill Course," Solid Waste Management, Vol 20, No. 6 [1977], p 23.)

Three methods can be used to control gas migration from landfills: trenches, wells, and barriers. Wells and trenches (see Figures A3 and A4) are used to vent the gas to the surface, where it either diffuses into the air or is collected. Recent studies have shown that wells are not always effective and that trenches are much more effective. Wells can be improved by placing pumps over them to expel the gas. The trench is dug to the lowest level of the landfill, then backfilled with gravel to allow the gas to escape. The third method of control is to place an impermeable wall of material around the landfill which stops migration of gas through the soil.

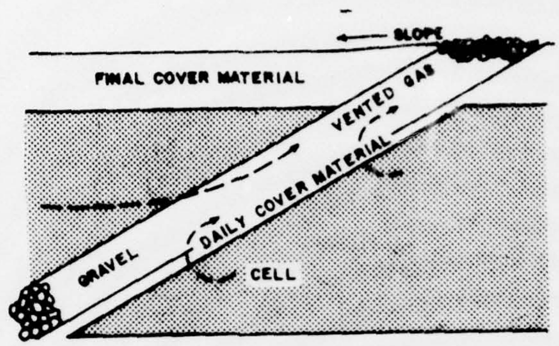

Figure A3. Gravel-filled gas-venting well. (From D. R. Brunner and D. J. Keller, Sanitary Landfill Design and Operation, Publication No. SW-ts [USEPA, 1972], p 23.)

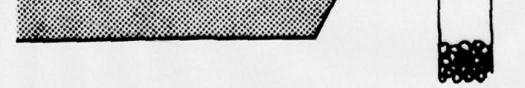

Figure A4. Gravel-filled gas-venting trench. (From D. R. Brunner and D. J. Keller, Sanitary Landfill Design and Operation, Publication No. SW-65ts [USEPA, 1972], p 23.)

CITED REFERENCES

AR 420-47, Solid Waste Management (Department of the Army [DA], June 1977).

Brunner, D. R., and D. J. Keller, Sanitary Landfill Design and Operation, Publication No. SW-65ts (U.S. Environmental Protection Agency [USEPA], 1972), pp 14, 21, 23, 25, 28, 29, 45, and 46.

"Criteria for Classification of Solid Waste Disposal Facilities," Federal Register (6 February 1978).

Decision Makers Guide in Solid Waste Management, Publication No. SW-500 (USEPA, 1976), pp 102, 110-112.

Kraybill, D., and B. Donahue, Sanitary Landfill Compactor Evaluation, Technical Report N-62/ADA067697 (U.S. Army Construction Engineering Research Laboratory [CERL], March 1979).

Reindl, J., "Landfill Course," Solid Waste Management, Vol 20, Nos. 4 through 12 and Vol 21, No. 1 (1977).

Resource Recovery and Waste Reduction, Publication No. SW-600 (USEPA, August 1977), p XV.

Schanche, G. W., L. A. Greep, and B. A. Donahue, Installation Solid Waste Survey Guidelines, Technical Report E-75/ADA018879 (CERL, September 1975).

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

TM 5-814-5, Sanitary Landfill (DA, October 1973).

Van Weringh, J., J. Patzer, R. Welsh, and R. Webster, Computer-Aided Environmental Legislative Data System (CELDS) User Manual, Technical Report N-56/ADA061126 (CERL, September 1978).

UNCITED REFERENCES

Gerdes, G. L., and B. A. Donahue, Simplified Sanitary Landfill Design and Operation Analysis, Technical Report N-57/ADA064356 (CERL, January 1979).

"Guidelines for the Land Disposal of Solid Wastes," Federal Regulations Part 241, Environment Reporter (28 February 1977), pp 101:1104-101:1109.

Nelson, D. L., Sanitary Landfill, Technical Report E-22/AD773714 (CERL, January 1974).

Noble, G., Sanitary Landfill Design Handbook (Technomic Publishing Co., Inc., 1976).

Proposed Guidelines for the Landfill Disposal of Solid Waste (Working Draft) (USEPA, August 1978).

Refuse Collection and Disposal, TM 5-634 (Department of the Army, 1958), pp 22-33.

Sanitary Landfill, Manuals and Reports of Engineering Practice, No. 39 (American Society of Civil Engineers, 1976).

Solid Waste Management, DA PAM 420-47 (Department of the Army, June 1978).

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Simplified sanitary landfill design / by G. L. Gerdes, B. A. Donahue. -- Champaign, IL : Construction Engineering Research Laboratory ; Springfield, VA : available from NTIS, 1979.
41 p. : ill. ; 27 cm. (Technical report ; N-78)

1. Sanitary landfills -- design and construction. I. Donahue, Bernard A. II. Title. III. Series: U.S. Army Construction Engineering Research Laboratory. Technical report ; N-78.