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Process Design Manual

Surface Disposal of Sewage Sludge and Domestic Septage

U.S. Environmental Protection Agency
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Chapter 1
Introduction

Human domestic activities generate wastewater that is piped into municipal sewer systems, underground septic tanks, or portable sanitation devices. Wastewater in municipal systems is treated before being discharged into the environment, as required under the Clean Water Act. This cleansing process generates a solid, semi-solid, or liquid residue—sewage sludge—which must be used or disposed (see Figure 1-1). Similarly, domestic septage—the solid, semi-solid, or liquid material that collects in septic tanks or portable sanitation devices that receive only domestic septage—must be periodically pumped out and used or disposed (see Figure 1-1).

Sewage sludge and domestic septage may be applied to the land as a soil conditioner and partial fertilizer, incinerated, or placed on land (surface disposal). Placement refers to the act of putting sewage sludge on an active sewage sludge unit[1] at high rates for final disposal rather than using the organic content in the sewage sludge to condition the soil or using the nutrients in the sewage sludge to fertilize crops. This manual provides practical guidance on the surface disposal approach to managing sewage sludge and domestic septage.[2] The manual:

- Describes the various types of active sewage sludge units.
- Provides guidance in selecting the most appropriate type of active sewage sludge unit for a particular situation.
- Details the engineering aspects of designing and operating a surface disposal site.
- Describes the applicable federal regulations.

The manual is intended for owners and operators of surface disposal sites, municipal officials involved in sewage sludge management, planners, design engineers, and regional, state, and local governments concerned with permitting and enforcement of federal sewage sludge management regulations.

[1] A sewage sludge unit is land on which only sewage sludge is placed for final disposal. An active sewage sludge unit is a sewage sludge unit that has not closed.

[2] U.S. EPA (1994), (1984a), (1984b), (1983), and (1979) provide guidance on land application and incineration.

1.1 Regulatory Overview

Most surface disposal of sewage sludge and domestic septage is subject to one of two sets of federal regulations, depending on whether the sewage sludge or domestic septage is disposed with or without household waste:

- Sites on which only sewage sludge, domestic septage, or a material derived from sewage sludge[3] are disposed, are regulated under Subpart C of 40 CFR Part 503.
- Codisposal of sewage sludge/domestic septage and household waste at a municipal solid waste (MSW) landfill[4] is regulated under 40 CFR Part 258.

This manual focuses on surface disposal sites subject to the 40 CFR Part 503 and on landfill units subject to Part 258 regulations. It explains the regulatory requirements for these sites or units and provides guidance on how these requirements influence selection, design, and operation of these sites or units. A complete discussion of the Part 258 regulations is beyond the scope of this manual. Instead, the Part 258 regulations are discussed specifically in regard to their impact on the codisposal of sewage sludge in municipal solid waste landfill units. For a more complete discussion of the Part 258 regulations the reader is referred to U.S. EPA, 1993.

Subpart C of Part 503 includes requirements for sewage sludge, including domestic septage, placed on a surface disposal site. Placing sewage sludge or domestic septage in a monofill, in a surface impoundment, on a waste pile, on a dedicated disposal site (DDS), or on a dedicated beneficial use site is considered surface disposal. A Part 503 standard for surface disposal of sewage sludge or domestic septage includes seven elements—general requirements, pollutant limits, management practices, operational standards, and requirements for the frequency of monitoring, recordkeeping, and reporting, as shown in Figure 1-2.

[3] For example, a ***mixture*** of sewage sludge with nonhazardous solids (except for household waste), such as grit, screenings, commercial septage, and industrial sludge.

[4] Under Part 258, a municipal solid waste landfill is defined as a landfill that receives household waste and that may receive other nonhazardous waste.

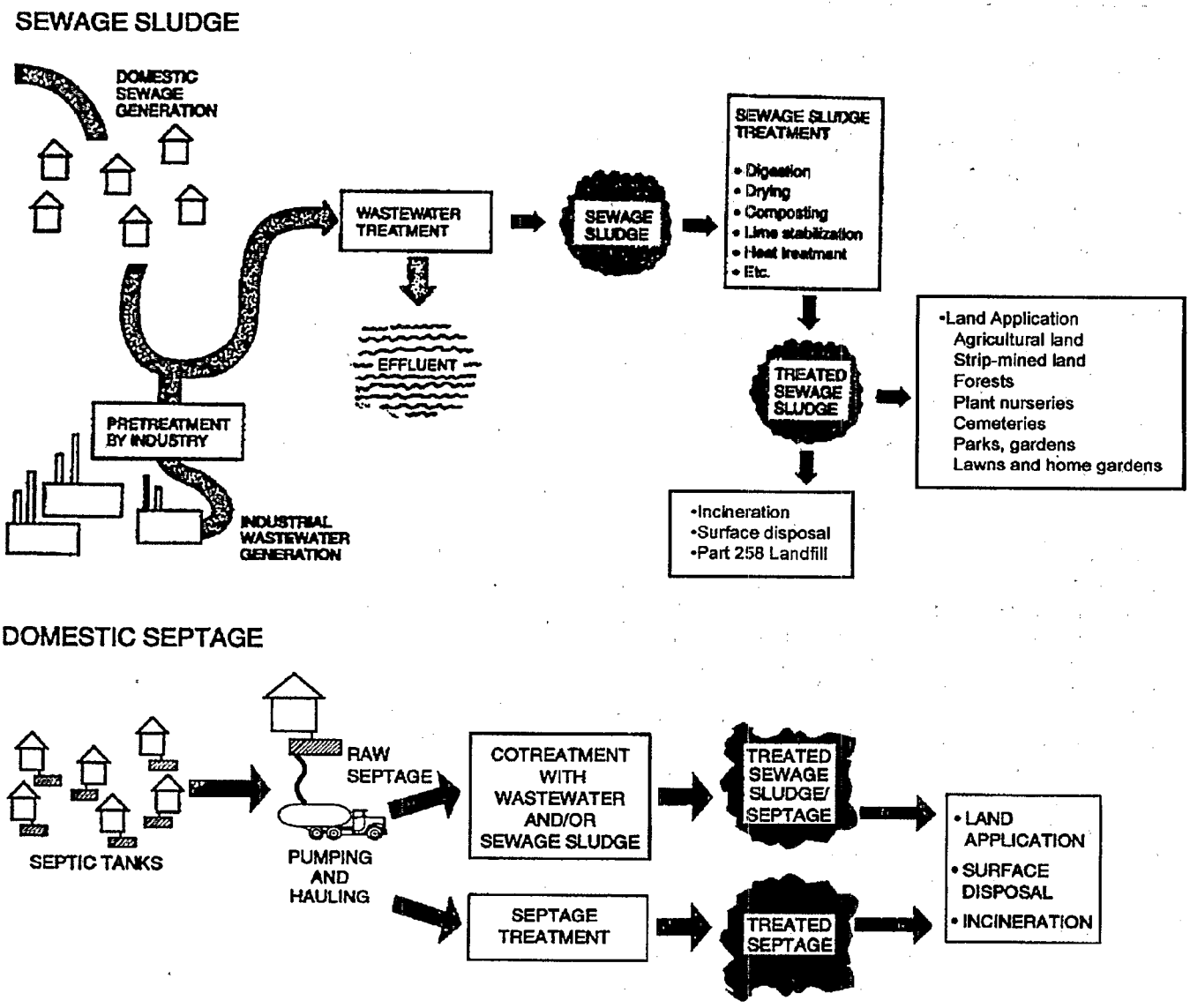

Figure 1-1. Generation, treatment, use, and disposal of sewage sludge and domestic septage.

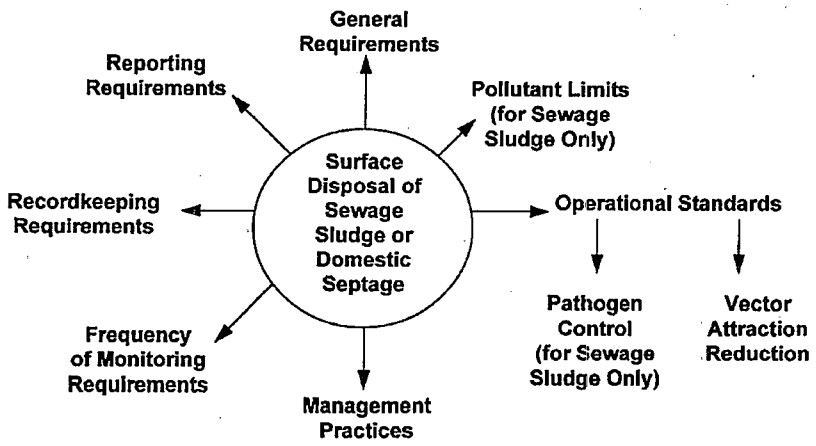

Figure 1-2. Elements of a Part 503 Standard for surface disposal of sewage sludge or domestic septage.

Figure 1-3 provides the Part 503 regulatory definition of sewage sludge and domestic septage. Materials that do not meet these definitions, as well as certain sludges that contain substances of a hazardous nature, are not covered by the Part 503 regulation. Sites accepting these materials must meet other regulatory requirements. Table 1-1 summarizes the Part 503 exclusions and indicates what other regulations sites accepting these materials must meet. Sites that accept mixtures of sewage sludge and nonhazardous solids other than household waste (e.g., grit, screenings, commercial septage, and industrial sludge) must meet the Part 503 regulation if these materials are mixed before they are placed on the site. If these materials are not mixed before they are placed, sites may be subject to both the Part 503 regulation and the additional requirements listed in Table 1-1 for the non-sewage sludge component.

As Table 1-1 indicates, Part 503 does not cover commercial or industrial septage. The specific definition of domestic septage in the Part 503 regulation does not include many of the other materials that are often called septage by industry. Commercial and industrial septage are not considered domestic septage. The factor that differentiates commercial and industrial septage from domestic septage is the type of waste being produced, rather than the type of establishment generating the waste. For example, the sanitation waste residues and residues from food and normal dish cleaning from a restaurant are domestic septage, whereas grease trap wastes from a restaurant are not domestic septage.

While some of the design and operation information contained in this manual may be relevant to operations accepting sludge and septage excluded under Part 503, this manual provides no information on pertinent regulations concerning these operations. Designers, owners, and operators of these sites are encouraged to thoroughly research the applicable regulatory requirements. The manual also does not cover land application of sewage sludge or domestic septage. These practices are regulated under Subpart B of 40 CFR Part 503.

Sewage sludge: A solid, semi-solid, or liquid residue generated during the treatment of domestic sewage in a treatment works. Sewage sludge includes, but is not limited to domestic septage; scum or solids removed in primary, secondary, or advanced wastewater treatment processes; and a material derived from sewage sludge.

Domestic septage: Either liquid or solid material removed from a septic tank, cesspool, portable toilet, Type III marine sanitation device, or similar treatment works that receives only domestic sewage. (Domestic sewage is defined as waste and wastewater from humans or household operations.)

Figure 1-3. Part 503 regulatory definitions of sewage sludge and domestic septage.

Table 1-1. Types of Sludge, Septage, and Other Wastewater Solids Excluded From Coverage Under Part 503

Sludge Type	Applicable Federal Requirements
Sewage sludge that is hazardous in accordance with 40 CFR Part 261	40 CFR Parts 260-268
Sewage sludge with a PCB concentration equal to or greater than 50 mg/kg total solids (dry weight basis)	40 CFR Part 761
Grit (e.g., small pebbles and sand) and screenings (e.g., large materials such as rags) generated during preliminary treatment of sewage sludge (see Chapter 3 for further definition of these materials)	40 CFR Part 257[a]
Commercial septage (e.g., grease from a grease trap at a restaurant) and industrial septage (liquid or solid material removed from a septic tank that receives industrial wastewater)	40 CFR Part 257[a]
Industrial sludge and sewage sludge generated at an industrial facility during the treatment of industrial wastewater combined with domestic septage	40 CFR Part 257 and any other applicable requirements depending on the characteristics of the mixture[a]
Drinking water sludge generated during the treatment of either surface water or ground water used for drinking water.	40 CFR Part 257[a]

[a] Regulated under 40 CFR Part 258 if placed in an MSW landfill for final disposal.

Certain practices also are specifically excluded from coverage under the Part 503 regulation. For example, Part 503 does not cover any operations, such as lagoons or stabilization ponds, that are considered to be a form of sewage sludge treatment rather than use or disposal. Similarly, Part 503 does not cover any sewage sludge storage operation, defined as any operation where sewage sludge that is placed on the land, remains on the land for no longer than 2 years. Owners or operators of a site where sewage sludge remains on the land longer than 2 years are not subject to the Part 503 surface disposal requirements if they demonstrate that the site is not an active sewage sludge unit. The demonstration must include the following information:

- The name and address of the person who prepares the sewage sludge.[5]
- The name and address of the person who either owns the land or leases the land.

[5] Part 503 defines the person who prepares sewage sludge as "either the person who generates sewage sludge during the treatment of domestic sewage in a treatment works or the person who derives a material from sewage sludge." This definition covers two types of operations—those that generate sewage sludge and those that take sewage sludge after it has been generated and blend or mix it with another material to further process or prepare it before its ultimate use or disposal.

- The location, by either street address or latitude and longitude, of the land.
- An explanation of why sewage sludge needs to remain on the land for longer than 2 years prior to final use or disposal, or why the land is used for longer than 2 years to store individual batches of sewage sludge, on a continuous basis, for less than two years (e.g., land is used to store individual batches of sewage sludge for six months out of every year).
- The approximate time when sewage sludge will be used or disposed.

This information must be retained by the person who prepares the sewage sludge for the period that the sewage sludge remains on the land.

1.2 Compliance and Enforcement of the Part 503 Rule

Compliance deadlines under the Part 503 rule vary according to the type of requirement (e.g., compliance dates for frequency of monitoring and for recordkeeping and reporting requirements differ from compliance dates for other requirements) and whether new pollution control facilities will have to be constructed to meet the requirement. Compliance dates for all Part 503 requirements are provided in Table 1-2.

Table 1-2. Compliance Dates for Part 503 Requirements

Part 503 Requirement	Compliance Date
Land Application and Surface Disposal Initial monitoring and recordkeeping	July 20
All other requirements *when construction of new pollution control facilities is not needed to meet requirements*	As expeditiously as possible
All other requirements *when construction of new pollution control facilities is needed to meet requirements*	As expeditiously as possible

To ensure compliance with Part 503, regulatory authorities have the right to inspect operations involved in the use or disposal of sewage sludge or domestic septage; review and evaluate required reports and records; sample sewage sludge or domestic septage; and respond to complaints from persons affected by an alleged improper use or disposal of sewage sludge or domestic septage. If records are not kept or other Part 503 requirements are not met, U.S. EPA can initiate enforcement actions.

Violations of the Part 503 requirements are subject to the same sanctions as wastewater effluent discharge violations—U.S. EPA can sue in civil court and seek remediation and penalties, and it can prosecute willful or negligent violations as criminal acts.

1.3 Relationship of the Federal Requirements to State Requirements

Part 503 does not replace any existing state regulations; rather, it sets minimum national standards for the use or disposal of sewage sludge or domestic septage through certain use or disposal practices. In some cases, the state requirements may be more restrictive or administered in a manner different from the federal regulation. In all cases, persons wishing to use or dispose of sewage sludge or domestic septage must meet all applicable requirements. Readers are encouraged to thoroughly investigate the relevant state requirements as one of the first steps in decision-making about any surface disposal site.

Knowing exactly which state or federal rules to follow can sometimes be complicated. Users or disposers of sewage sludge or domestic septage should keep the following situations in mind when considering the applicability of requirements:

- In all cases, users or disposers of sewage sludge or domestic septage must comply with the requirements of the Part 503 rule, assuming of course that the use or disposal practice is not otherwise excluded from coverage under Part 503.
- If a state has its own rules governing the use or disposal of sewage sludge or domestic septage and has not yet adopted the federal rule, the owner/operator of the surface disposal site will have to follow the most restrictive portions of both the federal and state rules.

It is important to note that sewage sludge or domestic septage may be defined differently by state programs than in the Federal Part 503 rule. Users or disposers of sewage sludge or domestic septage are strongly encouraged to check with the appropriate state sewage sludge coordinator regarding the specific state requirements.

1.4 How To Use This Manual

The manual consists of 15 chapters and 3 appendices:

- Chapter 2 defines and reviews the various types of active sewage sludge units.
- Chapter 3 describes characteristics of sewage sludge and domestic septage that influence the suitability of sewage sludge or domestic septage for particular active sewage sludge units.
- Chapter 4 reviews the regulatory requirements and technical parameters that influence site selection, and presents a process that can be used to select the most appropriate site for surface disposal.
- Chapter 5 describes why, when, and how to involve the public in the site selection process.

- Chapter 6 reviews the various techniques for field investigation that provide valuable information for both site selection and design.
- Chapter 7 provides guidance on the design of active sewage sludge units and surface disposal sites.
- Chapter 8 specifically discusses surface disposal of domestic septage.
- Chapter 9 provides guidance on the operation of active sewage sludge units and surface disposal sites.
- Chapters 10, 11, and 12 discuss: monitoring; management, recordkeeping and reports; and, closure and post-closure care at surface disposal sites.
- Chapter 13 provides typical costs for surface disposal sites.
- Chapters 14 and 15 include design examples and case studies to illustrate the application of the generic principles to specific situations.
- Appendix A provides guidance on what information to include in a permit application.
- Appendix B provides contact information for EPA regional sewage sludge coordinators.
- Appendix C provides information on manufacturers and distributors of equipment for monitoring at sewage sludge surface disposal sites.

Figure 1-4 shows the relationships of the various chapters. Regulatory information on the seven elements of a Part 503 standard (see Figure 1-2) is included throughout this manual as the requirements of each element affect specific aspects of designing a surface disposal site. For example, management practices regulating the siting of surface disposal sites are discussed in Chapter 4, Site Selection; whereas, management practices regulating the design of drainage systems at surface disposal sites are discussed in Chapter 7, Design.

Readers seeking to determine whether surface disposal is a viable option or which type of active sewage sludge unit might be most appropriate for a particular situation are advised to read Chapters 1 through 13. Readers who already have determined the type of active sewage sludge unit to use and seek guidance on selecting an appropriate location for a surface disposal site may wish to focus on Chapters 4, 5, and 6, as well as the sections of Chapters 7 and 9 relevant to the particular active sewage sludge unit selected. Readers seeking guidance on the surface disposal of domestic septage will find this information in Chapter 8. Figure 1-5 gives an overview of the technical evaluations involved in implementing a surface disposal project and outlines relevant chapters of the manual to consult when considering the different phases involved in this implementation process.

1.5 Use of the Terms "Sludge" and "Septage" in This Manual

For simplicity's sake, subsequent chapters of this manual use the term "sludge" to mean sewage sludge as defined under Part 503 (i.e., including domestic septage), unless otherwise stated. Similarly the manual uses the term "septage" to mean only domestic septage and not commercial or industrial septage.

1.6 References

1. U.S. EPA. 1994. Process design manual: Land application of municipal sewage sludge and domestic septage. [Currently being prepared]
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3. U.S. EPA. 1984a. Use and disposal of municipal wastewater sludge. EPA/625/10-84/003. Cincinnati, OH.
4. U.S. EPA. 1984b. Handbook: Septage treatment and disposal. EPA/625/6-84/009. Cincinnati, OH.
5. U.S. EPA. 1983. Process design manual for land application of municipal sludge. EPA/625/1-83/016 (October).
6. U.S. EPA. 1979. Process design manual: Sludge treatment and disposal. EPA/625/1-79/011. Cincinnati, OH.

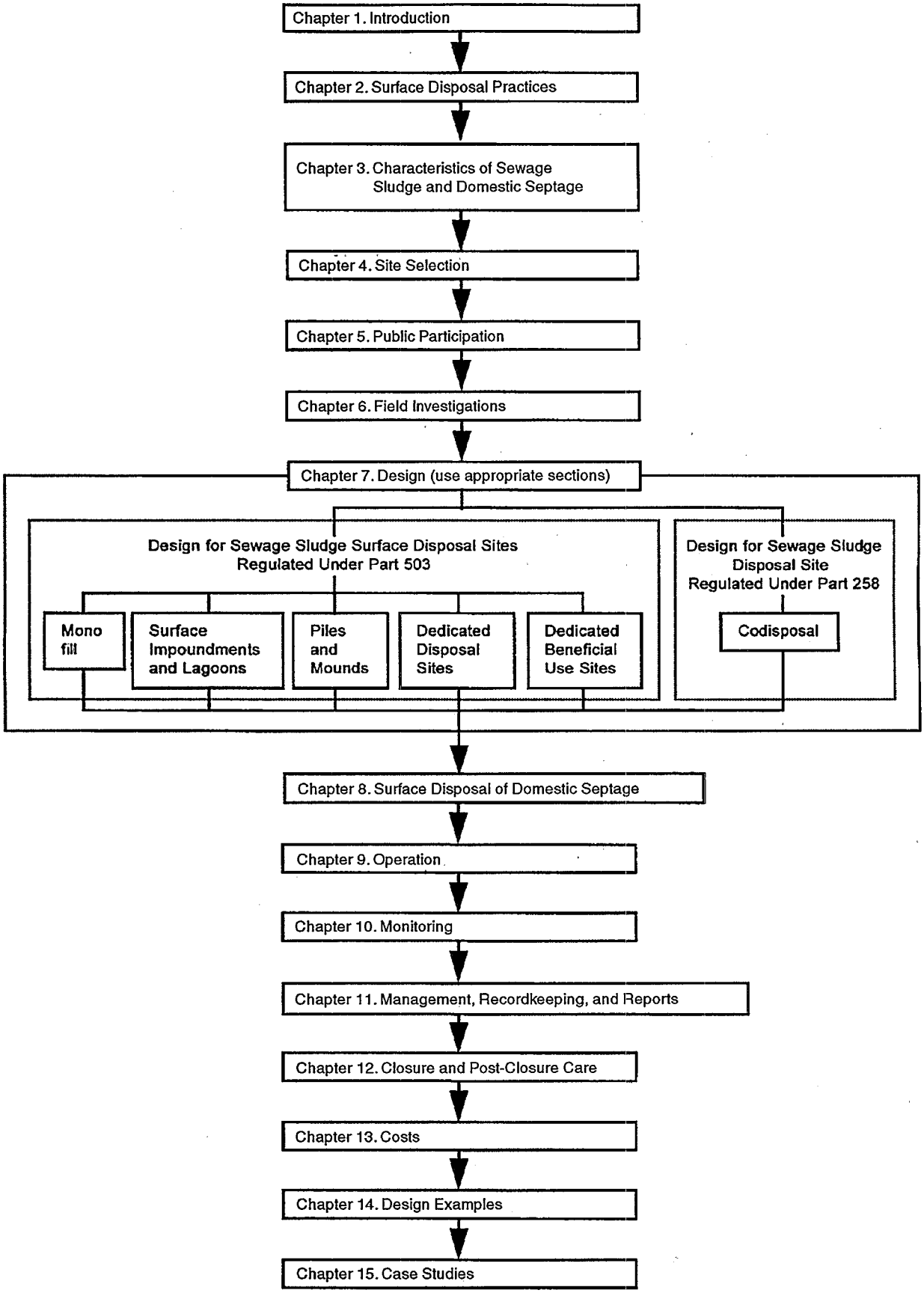

Figure 1-4. Guide to manual contents.

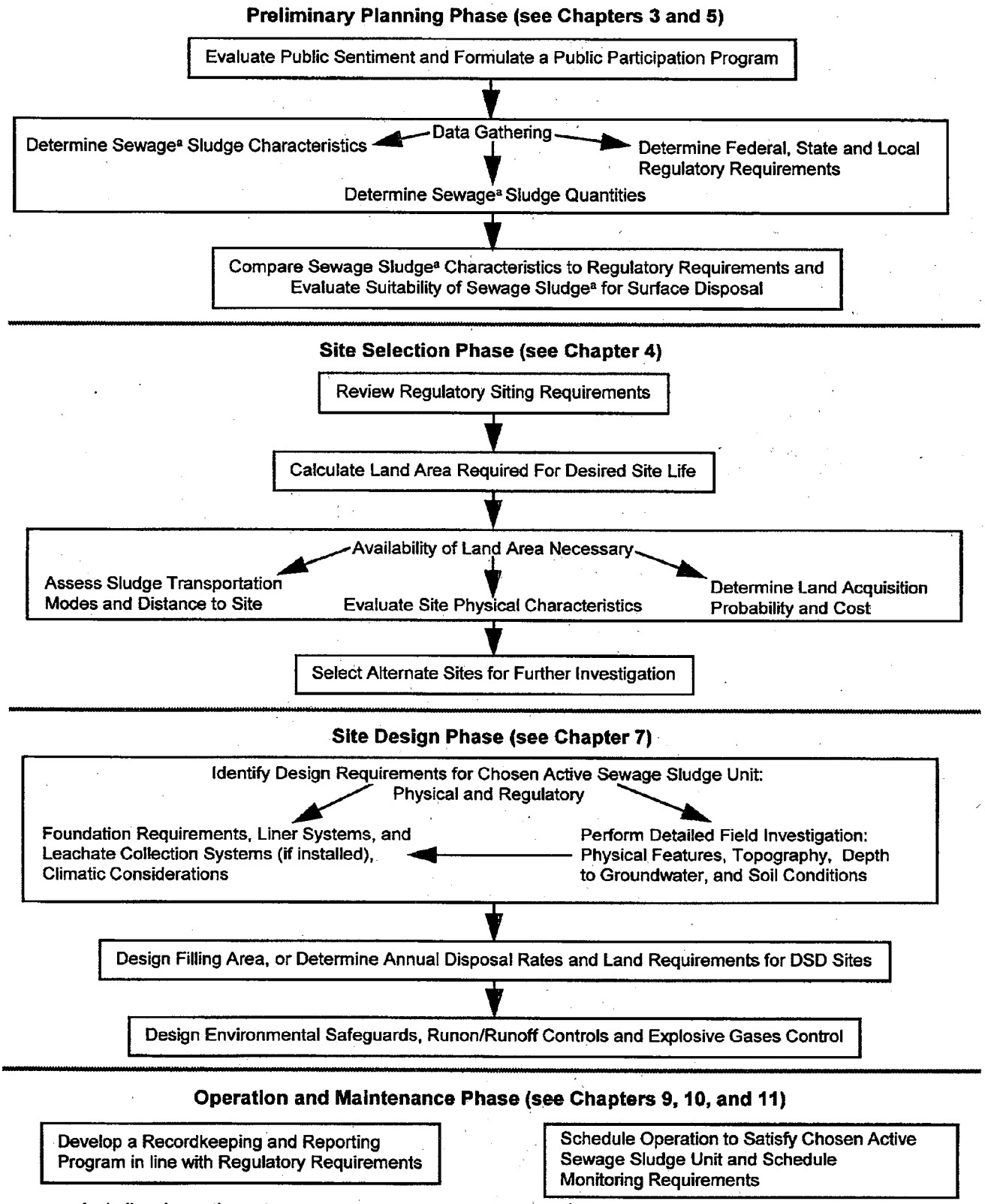

Figure 1-5. Technical evaluations involved in implementing a surface disposal project.

Chapter 2
Active Sewage Sludge Units

2.1 Introduction

A sewage sludge unit is land on which only sewage sludge is placed for final disposal. This does not include land on which sewage sludge is either stored or treated. An active sewage sludge unit is a sewage sludge unit that has not closed. A surface disposal site is an area of land that contains one or more active sludge units. Figure 2-1 illustrates the relationship between active sewage sludge units and a surface disposal site.

This chapter discusses the various types of active sewage sludge units and surface disposal sites, and compares the basic sludge and site requirements and design criteria of each unit so that the reader can assess which unit(s) may be most appropriate for a particular situation. The active sewage sludge units discussed in this chapter include monofills, surface impoundments, waste piles, dedicated surface disposal sites, and dedicated beneficial use sites (see Figure 2-2). There are no differences between any of these active sewage sludge units from a regulatory perspective. Each of these units must meet all of the requirements of the Part 503 regulation. The differences between these units outlined in this chapter are based on design criteria and good engineering practice.This chapter also discusses the options for codisposing sewage sludge in a municipal solid waste (MSW) landfill.

Selection of an active sewage sludge unit is an integral part of the site selection process because the acceptability of a given surface disposal site depends on how the sewage sludge is disposed. Conversely, the acceptability of a given active sewage sludge unit depends on the site where the unit is to be located. The acceptability of both active sewage sludge unit and surface disposal site depend on the characteristics of the sewage sludge to be disposed both from an operational and a regulatory perspective. For example, the solids content of sewage sludge impacts its suitability for placement in different active sewage sludge units whereas regulatory pollutant limits for sludge are based on how far the boundary of each active sewage sludge unit is from the property line of the surface disposal site. For this reason, sludge characteristics should be thoroughly in-

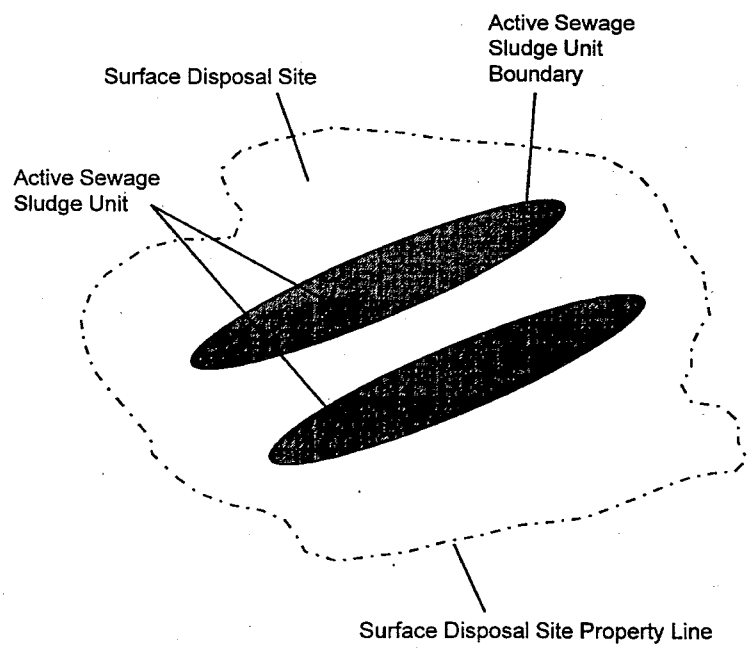

Figure 2-1. Relationship between active sewage sludge unit and surface disposal site.

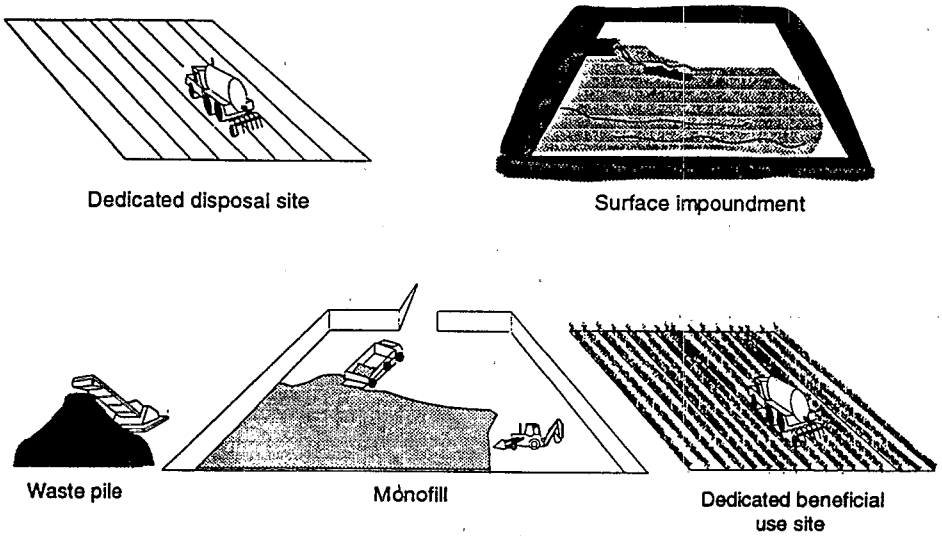

Figure 2-2. Relationship between active sewage sludge unit and surface disposal site.

vestigated first (see Chapter 3), followed by concurrent investigations of sites (see Chapter 4) and types of active sewage sludge units.

It is important to note that there may be no one best active sewage sludge unit for a given sludge or site. The information given in this manual is intended to provide guidance as a starting point in selecting the type of unit or unit(s) that may be most appropriate for a particular situation.

The design criteria given in this chapter are based on experiences at numerous surface disposal sites that span a broad range of sludge and site conditions. These criteria should be valid for most active sewage sludge units; however, variations may be appropriate in some cases. For example, the range of sludge solids contents recommended for each active sewage sludge unit might vary somewhat depending on the sludge source, treatment, and characteristics. Field tests should be performed to ensure that an active sewage sludge unit based on the criteria in this chapter will function properly for a given sludge and site (see Chapter 6). More detailed design and operation information for the various types of active sewage sludge units is provided in Chapters 7 and 8.

2.2 Overview of Sewage Sludge Disposal Sites

From a regulatory standpoint, sewage sludge disposal sites can be divided into two major categories:

- Disposal of sludge in an active sewage sludge unit on a surface disposal site. This is regulated under Part 503.
- Codisposal of sewage sludge with household waste at a MSW landfill. This is regulated under Part 258.

The active sewage sludge units regulated by Part 503 can be further divided into five major categories based on design criteria:

- *Monofills*—areas where only dewatered sewage sludge is disposed and covered with a soil cover that is thicker than the depth of the plow zone. Sludge may be deposited below the ground surface in excavated trenches, or on the ground surface in mounds, layers, or diked containments.
- *Waste piles*—mounds of dewatered sludge placed on the soil surface, without a cover, for final disposal.[1]
- *Surface impoundments and lagoons*—units where sludge is placed in an excavated or constructed area, without daily cover, for final disposal. The solids content of sewage sludge in surface impoundments is generally 2 percent to 5 percent. Below-ground (i.e., excavated) surface impoundments are commonly referred to as lagoons. This document covers lagoons where sludge is placed for final disposal.[2]
- *Dedicated surface disposal sites*—sites where sewage sludge is placed on the land by injecting it below the land surface or incorporating it into the soil after being sprayed or spread on the land surface. Dedicated disposal sites often are located at the treatment

[1] Under Part 503, any site where sludge remains on the ground for more than 2 years is considered to be a surface disposal site regulated under Part 503 unless the person who prepares the sewage sludge (i.e., generator of sewage sludge or a person who derives a material from sewage sludge) demonstrates that the land on which the sewage sludge remains is not an active sewage sludge unit.

[2] The term "lagoon" also refers to below-ground areas where sewage sludge is placed for *treatment* prior to final disposal elsewhere. Lagoons where sewage sludge is treated are not regulated under Part 503 and are not covered in this document. If sewage sludge remains in a lagoon for longer than 2 years it is regarded as surface disposal, unless the person who prepares the sludge specifically demonstrates that treatment is occuring in the lagoon.

works site and receive repeated applications of sewage sludge for the sole purpose of final disposal.

- *Dedicated beneficial use sites*—sites where sewage sludge is placed on the land by injecting it below the land surface or incorporating it into the soil after being sprayed or spread on the land surface. Such sites might or might not receive repeated applications of sewage sludge. In contrast to dedicated disposal sites, crops are grown on dedicated beneficial use sites. For such sites, the permitting authority will issue a permit that specifies appropriate management practices that ensure the protection of public health and the environment if crops are grown or animals are grazed on the site. Dedicated beneficial use sites are considered from a regulatory standpoint to be surface disposal sites because sludge is placed on sites at higher rates than are permissible for land application sites regulated under Subpart B (Land Application) of Part 503.

According to a 1988 National Sewage Sludge Survey conducted by the U.S. Environmental Protection Agency (EPA)(U.S. EPA, 1988), just over 10 percent of sewage sludge used or disposed in 1988 was placed on a surface disposal site. Of that 10 percent, 50 percent was placed in dedicated disposal sites, just over 25 percent was placed in monofills, and just under 25 percent was disposed using some other type of active sewage sludge unit (e.g., impoundment or pile).

Table 2-1 summarizes and compares the sludge and site conditions required by the various types of active sewage sludge units, and Table 2-2 summarizes and compares the design criteria for these units. Active sewage sludge units are distinguishable based on engineering design experience, not on any regulatory requirements. The following discussion outlines the differences between these units based solely on design criteria and established engineering practices.

2.3 Monofills

Monofills are active sewage sludge units where sewage sludge with a solids content of at least 15 percent (or more depending on the type of monofill) is disposed and covered periodically. If cover is applied to the sludge at the end of each operating day, the Part 503 pathogen and vector attraction reduction requirements are met (see Section 3.4.2). The application of cover distinguishes monofills from piles and dedicated disposal sites, where the sludge is not covered (unless it is injected below the surface of the site), and from surface impoundments, which often receive no cover until the site is closed. The disposal of relatively high solids sludge distinguishes monofills from surface impoundments and dedicated disposal sites, where sludge of much lower solids content is typically disposed.

In monofills, insufficient oxygen is available for aerobic decomposition. Monofilled sludge is slowly degraded by anaerobic decomposition. If monofills are properly planned and operated, a completed monofill site can ultimately be used by the owner for recreational or other purposes, such as open space.

Monofills may be divided into two basic categories: trenches (where the sludge is placed in excavated areas below the ground surface) and area fills (in which sludge is placed on the ground surface). These are discussed below. Table 2-1 shows relevant sludge and site conditions for the various types of monofills and Table 2-2 summarizes design criteria for these monofills.

2.3.1 Trenches

Trenches are excavated areas in which the sludge is placed entirely below the original ground surface. Good engineering practice dictates that ground water and bedrock in the area of a trench must be deep enough to allow excavation and still maintain sufficient buffer soils between the bottom of sludge deposits and the top of ground water or bedrock.

With trenches, soil is normally used only for cover and not as a bulking agent. The sludge is usually dumped directly into the trench from haul vehicles. Onsite equipment is generally used only for trench excavation and cover application; it is not normally used to haul, push, layer, mound, or otherwise contact the sludge.

Cover is usually applied over sludge the same day it is received. Cover places a barrier between sludge and vectors and allows the environment to reduce pathogens in sludge. Also, cover reduces odors. Daily cover satisfies both the pathogen and vector attraction reduction requirements of Part 503, Subpart D (see Section 3.4.2), so unstabilized or low-stabilized sludges can be placed in trenches where cover is applied daily. The soil excavated during trench construction usually provides sufficient soil for cover applications, so soil importation is seldom required.

There are two basic types of trenches: narrow trench and wide trench. Narrow trenches are up to 10 ft (3.0 m) wide; wide trenches are more than 10 ft (3.0 m) wide. The depth and length of both narrow and wide trenches vary depending on several factors. Trench depth is a function of (1) depth to ground water and bedrock, (2) sidewall stability, and (3) equipment limitations. Trench length is virtually unlimited, but inevitably depends on property boundaries and other site conditions. Also, trench length may be limited by the need to discontinue the trench for a short distance or place a dike within the trench to contain a low-solids sludge and prevent it from flowing throughout the trench.

Table 2-1. Comparison of Sludge and Site Conditions for Various Active Sewage Sludge Units[a]

Method	Sludge Solids Content	Sludge Characteristics[b]	Hydrogeology[c]	Ground Slope
MONOFILL				
Narrow trench	15-28%	Unstabilized or stabilized	Deep ground water and bedrock	<20%
Wide trench	≥20%	Unstabilized or stabilized	Deep ground water and bedrock	<10%
Area fill mound	≥20%	Unstabilized or stabilized	Shallow ground water or bedrock	Suitable for steep terrain as long as level area is prepared for mounding
Area fill layer	≥20%	Unstabilized or stabilized	Shallow ground water or bedrock	Suitable for medium slopes but level ground preferred
Diked containment	≥20%	Unstabilized or stabilized	Shallow ground water or bedrock	Suitable for steep terrain as long as a level area is prepared inside dikes
PILES				
Piles	≥28%	Stabilized	Shallow ground water or bedrock	<5%
SURFACE IMPOUNDMENTS AND LAGOONS				
Surface impoundments and lagoons	≥2%	Stabilized	Shallow ground water or bedrock	
DEDICATED SURFACE DISPOSAL				
Dedicated surface disposal sites and dedicated beneficial use sites	≥3%	Stabilized	Deep ground water or bedrock	<3%
CODISPOSAL OF SLUDGE IN MUNICIPAL SOLID WASTE LANDFILL				
Sludge/household waste mixture	≥20%[d]	Unstabilized or stabilized	Deep or shallow ground water or bedrock	<30%
Sludge/soil mixture	≥20%[d]	Stabilized	Deep or shallow ground water or bedrock	<5%

[a] Note: This comparison is based on design requirements and not on any regulatory requirements.
[b] To protect human health and the environment, Part 503 regulates three characteristics of sewage sludge: the content of certain heavy metals, the level of pathogens, and the attractiveness of the sludge to vectors. Sewage sludge placed on an active sewage sludge unit must meet the Part 503 requirements. Stabilization of sludge will generally be necessary to meet the Part 503 pathogen and vector attraction reduction requirements of any site where sludge is not covered at the end of each operating day.
[c] Part 503 requires that sewage sludge placed on an active sewage sludge unit shall not contaminate an aquifer.
[d] Sludge disposed of in a municipal solid waste landfill must have a high enough solids content to pass the Paint Filter Liquids Test.

2.3.1.1 Narrow Trenches

In narrow trenches (up to 10 ft [3.0 m] wide), sludge is usually placed on the land once and a layer of cover soil is placed atop the sludge. Narrow trenches are usually excavated by equipment on solid ground adjacent to the trench and the equipment does not enter the excavation. Backhoes, excavators, and trenching machines are particularly useful in narrow trench operations. Excavated material is usually immediately applied as cover over an adjacent sludge-filled trench. However, occasionally, it is stockpiled alongside the trench from which it was excavated for subsequent application as cover over that trench. In this case, the cover material also is applied by equipment based on solid ground outside the trench.

The main advantage of a narrow trench is its ability to handle sludge with a relatively low solids content. As shown in Table 2-2, a 2 to 3 ft (0.6 to 0.9 m) width is required for sludge with a solids content between 15 percent and 20 percent. Normally, soil applied as cover over sludge of such low solids would sink to the bottom of the sludge. However, because of the narrowness of the trench, the soil cover bridges over the sludge, receiving support from solid ground on either side of the trench. Cover is usually applied in a 2 to 3 ft (0.6 to 0.9 m) thickness.

Trenches over 3 ft (0.9 m) wide are too wide to provide a bridging effect for the soil cover. Therefore, sludge with a higher solids contents must be used to support the cover. For 3 to 10 ft (0.9 to 3.0 m) wide trenches, solids content should be 20 percent to 28 percent. For

Table 2-2. Design Criteria for Various Active Sewage Sludge Units

Method	Sludge Solids Content	Trench Width	Bulking Required	Bulking Agent	Bulking Ratio[a]	Cover Thickness		Imported Soil Required	Sludge Disposal Rate[b] (in actual fill areas)	Equipment
						Interim	Final			
MONOFILL										
Narrow trench	15-20% 20-28%	2-3 ft 3-10 ft	No No	— —	—	—	2-3 ft 3-4 ft	No	1,200-5,600 yd^3/acre	Backhoe with loader, excavator, trenching machine[c]
Wide trench	20 to <28% ≥28%	10 ft 10 ft	No No	— —	—	—	3-4 ft 4-5 ft	No	3,200-14,500 yd^3/acre	Track loader, dragline, scraper, track dozer[d]
Area fill mound	≥20%	—	Yes	Soil	0.5-2 soil: 1 sludge	3 ft	3-5 ft	Yes	3,000-14,000 yd^3/acre	Track loader, backhoe with loader, track dozer[e]
Area fill layer	≥20%	—	Yes	Soil	0.25-1 soil: 1 sludge	0.5-1 ft	2-4 ft	Yes	2,000-9,000 yd^3/acre	Track dozer, grader, track loader[e]
Diked containment	20 to <28% ≥28%	— —	No No	Soil Soil	0.25-0.5 soil: 1 sludge	1-2 ft 2-3 ft	3-4 ft 4-5 ft	Yes	4,800-15,000 yd^3/acre	Dragline, track dozer, scraper[d]
PILES										
Piles	≥28%	—	No	—	—	—	—	No	8,000-32,000 yd^3/acre	Spreader, bulldozer[e]
SURFACE IMPOUNDMENTS AND LAGOONS										
Surface impoundments and lagoons	≥2%	—	No	—	—	—	—	No	4,800-15,000 yd^3/acre	Dragline, front-end loader[c]
DEDICATED SURFACE DISPOSAL										
Dedicated surface disposal sites and dedicated beneficial use sites	≥3%	—	No	—	—	—	—	No	50-2,000 tons/acre	Tank truck, subsurface injector, rotary sprayer, bulldozer[e]
CODISPOSAL OF SLUDGE IN MUNICIPAL SOLID WASTE LANDFILL										
Sludge/ house hold waste mixture	≥20%[f]	—	Yes	House-hold waste	4-7 tons/ refuse:1 wet ton sludge	0.5-1 ft	2 ft	No	500-4,200 yd^3/acre	Dragline, track loader
Sludge/soil mixture for cover	≥20%[f]	—	Yes	Soil	1 soil: 1 sludge	0.5-1 ft	2 ft	No	1,600 yd^3/acre	Tractor with disc, grader, track loader

[a] Volume basis unless otherwise noted.
[b] These rates are based on design experience and established engineering practices.
[c] Land-based equipment.
[d] Land-based equipment for <28% solids sludge; sludge-based equipment for ≥28% solids sludge.
[e] Sludge-based equipment.
[f] Sludge disposed of in a municipal solid waste landfill must have a high enough solids content to pass the Paint Filter Liquid Test.

1 ft = 0.35 m
1 yd^3 = 0.765 m^3
1 acre = 0.405 ha

such trenches, cover is usually applied in a 3 to 4 ft (0.9 to 1.2 m) thickness and dropped from a minimum height to minimize the amount of soil that sinks into sludge deposits.

Another advantage of narrow trenches over wide trenches is that narrow trenches can be installed on sloped terrain. This is done by running the narrow trenches parallel to the contours of the slope to ensure that the sludge will spread out evenly within the trenches.

The main disadvantage of narrow trenches is that they are relatively land-intensive, with generally lower sludge disposal rates than for other monofills. As shown in Table 2-2, typical sludge disposal rates for narrow trenches range from 1,200 to 5,600 yd^3/acre (2,300 to 10,600 m^3/ha). Another drawback is that liners are impractical for narrow trenches. Sewage sludge placed on an active sewage sludge unit that has no liner must meet the pollutant limits for arsenic, chromium, and nickel established in Subpart C of Part 503 (see Section 3.4.2.1).

2.3.1.2 Wide Trenches

Wide trenches (i.e., trenches with widths greater than 10 ft [3.0 m]) are usually excavated by equipment operating inside the trench, so track loaders, draglines, scrapers, and track dozers are particularly useful in wide trench operations. Excavated material is usually stockpiled on solid ground adjacent to the trench from which it was excavated for subsequent application as cover over that trench. Occasionally excavated material is immediately applied as cover over an adjacent sludge-filled trench. Relevant sludge and site conditions as well as design criteria are presented in Tables 2-1 and 2-2.

Cover material may be applied to wide trenches in three ways, depending on the sludge solids content:

- *20 percent up to 28 percent solids*—sludge with 20 percent up to 28 percent solids cannot support equipment. Therefore, cover should be applied in a 3 to 4 ft (0.9 to 1.2 m) thickness by equipment based on solid undisturbed ground adjacent to the trench. A wide trench may be only slightly more than 10 ft (3.0 m) wide if a front-end loader is used to apply cover, or up to 50 ft (15 m) wide if a dragline is used to apply cover.
- *28 percent to 32 percent solids*—sludge with 28 percent to 32 percent solids can support equipment. Therefore, cover should be applied by equipment that proceeds out over the sludge pushing a 4 to 5 ft (1.2 to 1.5 m) thick cover before it. Track dozers are the most useful piece of equipment for this task.
- *Greater than 32 percent solids*—sludges with greater than 32 percent or more solids will not spread out evenly in a trench when dumped from atop the trench sidewall. If wide trenches are used for such high solids sludge, haul vehicles should enter the trench and dump the sludge directly onto the trench floor. Cover soil can be applied either by equipment based on solid ground adjacent to the trench (and having long reaches out over the sludge), or by bulldozers and other heavy equipment located within the trench itself.

As with narrow trenches, wide trenches should be oriented parallel to one another to minimize area between trenches. Distances between trenches should only be long enough to provide sidewall stability and adequate space for soil stockpiles, operating equipment, and haul vehicles.

One advantage of wide trenches compared to narrow trenches is that they are less land-intensive. Typical sludge application rates range from 3,200 to 14,500 yd^3/acre (6,000 to 27,400 m^3/ha). Another advantage of wide trenches is that liners can be installed to contain sludge moisture and protect the ground water.

Two disadvantages of wide trenches compared to narrow trenches are the need for a higher (20 percent or more) solids sludge and the need for flatter terrain. For wide trench applications with sludge less than 32 percent solids, sludge is dumped from above and spread out evenly within the trench. Accordingly, the trench floor should be nearly level; this can be more easily effected when the trench is located in low relief areas.

2.3.2 Area Fills

In area fills, sludge is placed on the ground surface. Because excavation is not required and sludge is not placed below the surface, area fill applications are more useful in areas with shallow ground water or bedrock than are excavated trenches. The solids content of sludge received at area fills must be at least 20 percent. Because area fills lack the sidewall containment available from trenches and because the sludge in most area fills must be able to support equipment atop the sludge, sludge stability and bearing capacity must be relatively good. To achieve these qualities, soil is usually mixed with the sludge as a bulking agent. The large quantities of soil required generally must be imported from off site or hauled from other locations on site, because excavation is not usually performed in the area of the fill itself, where shallow ground water or bedrock may prevail.

Liners are often installed at area fills where ground water or bedrock are close to the ground surface. Because sludge is placed on the ground surface at area fills, liners can be more readily installed than at trenches. With or without liners, surface runoff of moisture from the sludge and contaminated rain water can be expected at area fills, and appropriate drainage control facilities should be considered. Part 503 requires that the runoff collection system of an active sewage sludge unit must have the capacity to handle runoff from a

25-year, 24-hour storm event. See Sections 7.5.6 and 7.5.7 for regulatory and design information on liners and leachate collection and removal systems, and Section 7.8.2 for regulatory and design information on run-on/runoff control systems.

In area fills, the sludge/soil mixture is placed on the land in several consecutive lifts. Cover is usually applied after each lift of the sludge/soil mixture is placed on the land. Further cover may be applied as necessary to provide stability for additional lifts. Where daily cover is not applied at the end of each operating day, only sludges capable of meeting the Part 503 pathogen and vector attraction reduction requirements (see Section 3.4.2) may be placed on the area fill.

There are three basic types of area fills: area fill mound, area fill layer, and diked containment. These are described below. Sludge and site requirements and design criteria are summarized in Tables 2-1 and 2-2.

2.3.2.1 Area Fill Mound

In an area fill mound, the solids content of sludge received at the site must be at least 20 percent. Sludge may be mixed with a soil bulking agent to produce a mixture with greater bearing capacity. Appropriate bulking ratios vary between 0.5 and 2 parts soil for each part of sludge. The exact ratio depends on the solids content of the sludge and the need for mound stability and bearing capacity (as dictated by the number of lifts and equipment weight).

The sludge/soil mixing to enhance bearing capacity is usually performed at one location of the site and the mixture hauled to the filling area. At the filling area, the sludge/soil mixture is stacked into mounds approximately 6 ft (1.8 m) high. Cover material is then applied atop these mounds at least 3 ft (0.9 m) thick. Cover thickness may be increased to 5 ft (1.5 m) if additional mounds are applied atop the first lift.

Lightweight equipment with "swamp pad" or "low ground pressure" (LGP) tracks is generally recommended for area fill mound operations, such as mixing, mounding, and covering operations, where the equipment may pass atop the sludge. Heavier wheel equipment may be more appropriate for transporting bulking material to and from soil stockpiles.

An advantage of area fill mounds is their efficient land utilization. Sludge disposal rates are relatively high at 3,000 to 14,000 yd^3/acre (5,700 to 26,400 m^3/ha). A disadvantage of area fill mounds is the constant need to push and stack slumping mounds, which may increase manpower and equipment requirements. Some slumping is inevitable, particularly in high rainfall areas. Slumping can sometimes be minimized by providing earthen containment of mounds. For example, mounds are usually constructed on level ground to prevent them from flowing downhill. If a steeply sloped site is selected, however, a level mounding area can be prepared within the slope and a sidewall created to contain mounds on one side.

2.3.2.2 Area Fill Layer

Area fill layers might receive sludge with as little as 20 percent solids. The sludge is then mixed with a soil bulking agent to produce a mixture with greater bearing capacity. Typical bulking ratios range from 0.25 to 1 part soil for each part sludge. As with area fill mounds, the ratio depends on the sludge solids content and the need for layer stability and bearing capacity (as dictated by the number of layers and the equipment weight).

Mixing, to enhance bearing capacity, may occur either in the filling area or at a separate sludge dumping and mixing area of the site. The mixture is spread evenly on the area fill in 0.5 to 3 ft (0.15 to 0.9 m) thick layers. Layering usually continues for several applications. Intermediate cover between consecutive layers may be applied in 0.5 to 1 ft (0.15 to 0.3 m) thick layers. Final cover, if applied, should be 2 to 4 ft (0.6 to 1.2 m) thick.

Lightweight equipment with swamp pad or LGP tracks is generally recommended for operations, such as mixing, layering, and covering, where the equipment passes on top of the sludge. Heavier wheel equipment may be appropriate for hauling soil. Layered areas should be constructed on flat ground to prevent the sludge from flowing downhill. However, layering can be performed on mildly sloping terrain if the sludge solids content is high and/or sufficient bulking soil is used.

An advantage of area fill layers is that completed fill areas are relatively stable in regard to bearing capacity, so less extensive maintenance, manpower, and equipment are required to push and stack slumping mounds as compared to area fill mounds. A disadvantage is poor land utilization with sludge disposal rates from 2,000 to 9,000 yd^3/acre (3,780 to 17,000 m^3/ha).

2.3.2.3 Diked Containment

In a diked containment, sludge is placed entirely above the ground surface and completely surrounded by dikes, or a combination of dikes and natural slopes if the containment area is at the toe of a steep hill. Haul vehicles dump sludge directly into the containment area from the sides of the dikes. Intermediate cover may be applied at certain points during the filling, and final cover may be applied when filling is discontinued.

Diked containments require sludge with at least 20 percent solids. For sludges with solids contents between 20 percent and 28 percent, cover material should be applied by equipment based on solid ground atop the dikes. Due to its long reach, a dragline is the best equipment for cover application in this situation. Intermediate cover

should be 1 to 2 ft (0.3 to 0.6 m) thick, and final cover should be 3 to 4 ft (0.9 to 1.2 m) thick.

For sludges with 28 percent or greater solids contents, cover material can be applied by equipment that pushes and spreads cover soil into place as it proceeds out over the sludge. A track dozer is the best equipment for cover application in this situation. Intermediate cover should be 2 to 3 ft (0.6 to 0.9 m) thick and final cover should be 4 to 5 ft (1.2 to 1.5 m) thick.

Soil is usually not added to sludge as a bulking agent except for occasional additions as may be necessary to make possible the operations described above.

Diked containments are relatively large—typically 50 to 100 ft (15 to 30 m) wide, 100 to 200 ft (30 to 60 ft) long, and 10 to 30 ft (3 to 9 m) deep, or larger. Thus, one advantage of diked containments is efficient land use, with sludge loading rates of 4,800 and 15,000 yd^3/acre (9,100 to 28,400 m^3/ha). A disadvantage of diked containment is that the depth of the fill and the weight of intermediate and final covers place a significant surcharge on the sludge. As a result, much of the sludge moisture is squeezed into surrounding dikes and into the floor of the containment. For active sewage sludge units that do not have a liner and leachate collection system, the concentrations of arsenic, chromium, and nickel in the sludge must meet the limits for these pollutants in Part 503 (see Section 3.4.2.1).

2.4 Piles

Sludge piles are mounds of sludge typically constructed at or above the ground surface without any auxiliary containment structures (e.g., dikes). Sludge piles differ from sludge area fills (Section 2.3.2) in that cover is not applied to sludge piles and addition of bulking agent is optional. As with area fills, excavation is not required for piles, so piles are appropriate in areas with shallow ground water or bedrock. Operational practices and equipment for sludge piles are often similar to those for wide trenches (see Section 2.3.1.2). Sludge solids content for piles must be at least 28 percent to ensure sufficient sludge stability and bearing capacity. Ground slope must be less than 5 percent to ensure that the pile does not flow downhill. Sludge is typically applied at a rate of 8,000 to 32,000 yd^3/acres (15,200 to 60,000 m^3/ha) using a spreader and a trackhoe. Table 2-1 shows relevant sludge and site conditions and Table 2-2 summarizes design criteria for piles.

Because the sludge is not covered daily, it must be treated prior to disposal to meet the pathogen and vector attraction reduction requirements under Subpart D of Part 503 (see Section 3.4.2). Sometimes, piles are used for storage prior to final use or disposal. Under Part 503, any operation where sludge remains on the ground for more than 2 years is an active sewage sludge unit unless the person who prepares the sludge demonstrates that the land is not an active sewage sludge unit.

2.5 Surface Impoundments and Lagoons

Surface impoundments are above-ground or below-ground installations where liquid sewage sludge is placed for final disposal. The sludge usually has a low solids content (2 percent to 5 percent solids) and does not receive daily cover. Below-ground surface impoundments are often referred to as lagoons. At above-ground installations, dikes are used to contain the sludge, and haul vehicles dump sludge directly into the containment area from the sides of the dikes.

The liquid level in both lagoons and above-ground surface impoundments is maintained at a constant height by an outflow pipe. Liquid usually leaves the impoundment by evaporation and through the outflow pipe. The outflow is either shunted to the inflow of the wastewater treatment plant or treated prior to discharge into the environment. Seepage through the base of the impoundment is controlled either by a liner and leachate system or, in some cases, by natural geological conditions.

The particulate matter settles over time, and a layer of sediment accumulates on the floor of the impoundment. Eventually, the sediment layer reaches the top of the lagoon or impoundment and no further inflow is possible. The lagoon or impoundment may then be covered and closed.[3]

Because of the relatively low sludge solids content, any cover application or dredging should be performed by equipment based on solid ground (i.e., atop the dikes for above-ground installations). Due to its long reach, a drag line is the best equipment in this situation.

Disposal rates for lagoons or surface impoundments are similar to those for diked containments and may range from 4,800 to 15,000 yd^3/acre (9,100 to 28,400 m^3/ha). Thus, one advantage of lagoons or impoundments is relatively efficient land use in comparison to trenches or area fills. Table 2-1 shows relevant sludge and site conditions and Table 2-2 summarizes design criteria for lagoons or impoundments.

[3] Alternatively, the sludge may be dredged and used or disposed through a different practice. If *all* of the sludge is dredged, the lagoon or impoundment is not regarded as a surface disposal site under the Part 503 regulation. If *any* of the sludge remains in the lagoon or impoundment longer than 2 years, the lagoon or impoundment is regarded as a surface disposal site covered under the Part 503 regulations, unless the person who prepares the sewage sludge demonstrates that the surface impoundment or lagoon is not an active sewage sludge unit (see Section 1.1 for more information on differentiation between sludge disposal, storage, and treatment). Disposal of dredged sludge from a lagoon or surface impoundment must meet the Part 503 requirements if the dredged sludge is used or disposed through one of the Part 503 practices.

Because the sludge in a lagoon or surface impoundment is not covered daily, it must be treated prior to disposal to meet the pathogen and vector attraction reduction requirements under Subpart D of Part 503 (see Section 3.4.2).

2.6 Dedicated Surface Disposal Sites

Dedicated surface disposal (DSD) sites are sites where sewage sludge is placed on the land by injecting it below the land surface or incorporating it into the soil after being sprayed or spread on the land surface. Because sludge is placed on surface disposal sites at higher rates than are allowed when sludge is used as a soil amendment, dedicated sites do not qualify as land application sites under Subpart B of the Part 503 regulations. DSD sites typically receive liquid sludges. Disposal of dewatered or dried sludges is possible, but not common, because other types of surface disposal sites are more cost-effective for these sludges. Many existing wastewater treatment plants practice some form of DSD because it is suitable for liquid sludges, has minimal transportation costs (if adequate acreage is available on or adjacent to the treatment plant site), and has relatively low capital and operating costs.

Different methods of sludge placement may be used, depending on sludge solids content, ground slope, and soil condition. These include:

- *Spraying* using fixed or portable irrigation systems.
- *Ridge and furrow methods* similar to those used in agricultural systems.
- *Direct surface spreading* by tank trucks, tractors, and farm tank wagons. Sludge is spread from a manifold on the rear of the truck or wagon as the vehicle is driven across the DSD site.
- *Subsurface injection*, which involves cutting a furrow, delivering sludge into the furrow, and covering the sludge and furrow, all in one operation. Sludge may also be injected beneath the soil surface or incorporated using a disk.

DSD sites are often located on site at treatment works, and sewage sludge is placed on these sites many times each year for several years, for the sole purpose of final disposal. Dedicated sites range in size from less than 10 acres (4 hectares) to greater than 10,000 acres (4,000 hectares). Table 2-1 shows relevant sludge and site conditions and Table 2-2 summarizes design criteria for dedicated surface disposal.

Because no cover is applied to sewage sludge at DSD sites, sludge must be stabilized prior to disposal to meet pathogen and vector attraction reduction requirements and to minimize odor.

Sludge disposal rates are determined by the solids content of the sludge and climate, soil characteristics, and other factors that affect the speed with which the soil dries between sludge applications. Disposal rates range from 50 to 2,000 tons/acre/yr. The disposal rate for a particular site should not exceed the net soil evaporation rate (i.e., evaporation minus precipitation) so that the soil can dry sufficiently between sludge disposal activities to allow the passage of sludge distribution vehicles. If managed properly, water will be eliminated from the soil by evaporation; however, runoff and leachate controls are usually still necessary for those periods when net soil evaporation rates are less than expected or where more sludge than optimal is applied. Disposal also should be managed to maintain aerobic conditions so that the soil does not generate odors. Maintenance of aerobic conditions depends on the rate of sludge application, the sludge: soil ratio, temperature, and frequency of soil turning or disking. Meeting the vector attraction reduction requirements of Part 503 will decrease odors at all surface disposal sites.

Dedicated surface disposal of sewage sludge often requires storage capacity (such as facultative storage lagoons) (1) to provide a buffer between continuous sludge production and intermittent DSD operations, and (2) to store sludge during seasons when climatic factors such as high rainfall or ground-freezing temperatures require a suspension in sludge disposal.

The amount of land required for DSD depends on the quantity of sludge generated and on the acceptable loading rate. Sufficient land must be available to ensure the integrity of the system. A DSD site may have several active sewage sludge units. Individual units should be 10 to 100 acres (4 to 40 ha) in area (50 acres [20 ha] is typical). DSD active sewage sludge units should have fairly uniform elevations, although they may be regraded depending on the requirements of the chosen method for disposal.

Ground-water and surface water contamination can be prevented by choosing a DSD site underlain with impervious soil, hardpan, or rock to prevent vertical movement of ground water and constructing dikes and cutoff trenches to contain horizontal movement. Surface runoff can be controlled by grading the site so that all surface runoff drains to one point near the edge or corner of a field and by disking in the sludge soon after spreading. Each site should be surrounded by a berm to keep uncontaminated surface runoff out and to contain contaminated DSD runoff.

Dewatered sludge can be spread similarly to solid or semi-solid fertilizers, lime, or animal manure on DSD sites. For example, sludge can be spread with bulldozers, loaders, graders, or box spreaders, and then plowed or disked in. Dewatered sludge may be applied at higher rates than liquid sludge.

2.7 Dedicated Beneficial Use Sites

Some DSD sites are used to grow feed and/or fiber crops or vegetative cover. These are known as dedicated beneficial use sites. For such sites, the permitting authority will issue a permit that specifies appropriate management practices that ensure the protection of public health and the environment if crops are grown on the site.

A POTW or other DSD site owner might choose to establish a beneficial DSD site if soil erosion or soil acidity are a problem at the site or if the POTW is committed to a beneficial use policy. The vegetation or crop grown (e.g., a grassy cover crop or animal feed) can help control soil erosion and acidity and the sewage sludge can serve as a fertilizer and soil conditioner for the crop. The primary purpose of a DSD site, however, remains final disposal of sewage sludge; any growth of crops is secondary.

Because vegetation/crops are grown on beneficial DSD sites, disposal rates of sludge are usually lower (e.g., 31 to 83 mt/ha/yr[4]) (U.S. EPA, 1984) at these sites than on DSD sites where no crops are grown. This is because the high sludge disposal rates generally used at non-crop producing DSD sites might result in accumulation of metals and other sludge constituents that might render the soil unsuitable for crop production and may result in phytotoxicity. Conversely, because the sludge disposal rates at beneficial DSD sites are by definition higher than the agronomic rate of the crop, disposal rates at these sites are generally higher (but in accordance with Part 503 Subpart C surface disposal requirements) than application rates at land application sites (e.g., farms, for which sludge must be applied at agronomic rates for nitrogen and must meet the other requirements of Subpart B of Part 503 for land application).

Part 503 requires that an owner/operator of a beneficial DSD site must be able to demonstrate to the permitting authority that, by implementing certain management practices, public health and the environment will be protected if crops are grown or animals are grazed on these sites. Section 9.3.4.3 outlines additional information on growing crops on beneficial DSD sites.

2.8 Codisposal at a Municipal Solid Waste Landfill

Sludge can be codisposed with household waste (solid waste) at an MSW landfill. There are two basic types of codisposal methods: sludge/solid waste mixture and sludge/soil mixture. These two options are described below. Relevant sludge and site conditions as well as design criteria are presented Tables 2-1 and 2-2.

[4] Some DSD sites apply sludge at much higher rates (2,000 tons /acre/yr) and continue to grow crops).

2.8.1 Sludge/Solid Waste Mixture

In a sludge/solid waste mixture operation, sludge is deposited atop solid waste at the working face of the landfill and mixed as thoroughly as possible with the solid waste. The mixture is then spread, compacted, and covered in the usual manner used at MSW landfills.

Sewage sludge placed on a MSW landfill must pass the "paint filter test" under the Part 258 regulations (see Section 3.4.3), therefore the minimum sludge solids content for this option is approximately 20 percent. The sludge is usually spread by conventional landfill operating equipment, such as bulldozers and landfill compactors. To provide adequate workability of the sludge/solid waste mixture, the bulking ratio for a 20 percent solids sludge should be at least 4 tons of solid waste to 1 wet ton of sludge (4 Mg of solid waste to 1 wet Mg of sludge).

Sludge application rates for sludge/solid waste mixtures compare favorably with rates for other types of sludge disposal methods (e.g. monofills regulated under Part 503), despite the fact that sludge is not the only waste being disposed on the land. Disposal rates generally range from 500 to 4,200 yd^3 of sludge per acre (900 to 7,900 m^3 of sludge per ha).

2.8.2 Sludge/Soil Mixture

In a sludge/soil mixture operation, sludge is mixed with soil and applied as intermediate or final cover over completed areas of the MSW landfill. This is not strictly a sludge landfilling method from an engineering standpoint, because the sludge is not buried, but it is a viable and proven option for codisposal of sludge at MSW landfills.

One advantage of this approach over the sludge/solid waste mixture option described above is that it removes sludge from the working face of the landfill where it may cause operational problems including equipment slipping or becoming stuck in sludge, or sludge being tracked around the site by equipment and haul vehicles. Other advantages are that the sludge/soil cover promotes vegetation over completed fill areas, reduces the need for fertilizer, and minimizes siltation and erosion.

One disadvantage of the sludge/soil mixture approach compared to the sludge/solid waste mixture approach is that it generally requires more manpower and equipment. Another disadvantage is that odors may be more severe than for sludge/solid waste mixtures because the sludge is not completely buried. For this reason, only well-stabilized sludges are recommended for use in sludge/soil mixture operations.

2.9 References

1. U.S. EPA. 1994. A plain English guide to the EPA 503 biosolids rule. EPA/832/R-93/003.
2. U.S. EPA. 1988. National sewage sludge survey. Computerized database resident at National Computer Center, U.S. Environmental Protection Agency, Research Triangle Park, NC.
3. U.S. EPA. 1984. Use and disposal of municipal wastewater sludge. EPA/625/10-84/003. Cincinnati, OH.

Chapter 3
Characteristics of Sludge, Septage, and Other Wastewater Solids

3.1 Introduction

All types of wastewater treatment produce solids that must be used or disposed. The characteristics of these solids affect their suitability for surface disposal, either because of regulatory restrictions or potential operational problems. Therefore, when evaluating surface disposal alternatives, a wastewater treatment plant should first determine the amount and characteristics of its wastewater solids, and the degree of variation in these characteristics.

This chapter reviews the characteristics of the various solids generated, and explains how these characteristics impact the choice of an active sewage sludge unit. Sections 3.3 and 3.4 discuss the characteristics of sewage sludge affecting disposal from a regulatory and operational perspective, respectively. This chapter divides wastewater solids into three categories for discussion purposes: sludge, septage, and other (screenings, scum, and grit). EPA (1979) provides more information on wastewater solids.

3.2 Types of Wastewater Solids

3.2.1 Sludge

Sludge is a by-product of treatment of domestic sewage (see Figure 1-1 in Chapter 1). Prior to dewatering, sewage sludge usually contains 93 percent to 99.5 percent water as well as solids and dissolved substances that were present in the domestic sewage and that were added or cultured by wastewater treatment processes (U.S. EPA, 1984). Figure 1-2 in Chapter 1 provides the 40 CFR Part 503 regulatory definition of sewage sludge.

Usually sludge is treated prior to use or disposal. Table 3-1 lists various types of treatment processes and discusses the effects of these processes on the disposal of sewage sludge. EPA (1979) provides more information on sludge treatment technologies. Sludge can be divided into three basic types: primary, secondary, and chemical.

3.2.1.1 Primary Sludge

Primary sludge is sludge generated by primary wastewater treatment, which removes the solids that settle out readily. Primary sludge typically contains 2 percent to 8 percent solids depending on the operating efficiency of the clarifier and the amount of ground garbage in the wastewater (U.S. EPA, 1978a). Usually, the water content can be easily reduced by thickening or dewatering. Primary sludge has a larger particle size than secondary sludge and is frequently mixed with secondary sludge prior to treatment.

3.2.1.2 Secondary Sludge

Secondary sludge (also called biological sludge) is generated by secondary biological treatment processes, including activated sludge systems and attached growth systems such as trickling filters. The quantities and characteristics of secondary sludges vary with the metabolic and growth rates of the various microorganisms present in the sludge (U.S. EPA, 1979). Secondary sludge has a low solids content (0.5 percent to 2 percent) and is more difficult to thicken and dewater than primary sludge and most chemical sludges.

3.2.1.3 Chemical Sludge

Chemical sludge is produced by advanced wastewater treatment processes, such as chemical precipitation and filtration. These processes add aluminum, iron, salts, lime, and/or organic polymers to enhance the removal of colloidal material, suspended solids, and phosphorus from wastewater. Chemical addition increases sludge mass (and usually volume). The characteristics of chemical sludge depend on the wastewater treatment process that produced it. Generally, lime or polymers improve the thickening and dewatering characteristics of a sludge, whereas iron or aluminum salts usually reduce its dewatering and thickening capacity by producing a very hydrous sludge that binds water.

3.2.2 Domestic Septage

Domestic septage is the partially digested mixture of liquid and solid material in domestic sewage that accumulates in a septic tank, cesspool, portable toilet, Type III marine sanitation device, or similar treatment works. Septage accumulates in the treatment system for several months or years until it is pumped out. Domestic septage is either discharged into municipal wastewater systems

Table 3-1. Effects of Sludge Treatment Processes on Sewage Sludge Surface Disposal (U.S. EPA, 1984a, 1978a)

Treatment Process and Definition	Effect on Sludge	Effect on Surface Disposal
Thickening: Low-force separation of water and solids by gravity, flotation, or centrifugation. (Sludge thickeners may also be used as flow equalization tanks to minimize the effect of sludge quantity fluctuations on subsequent treatment processes.)	Increase solids concentration of sludge by removing water, thereby lowering sludge volume. May provide a blending function in combining and mixing primary and secondary sludges.	Lowers sludge transportation costs. Subsequent dewatering will be required if the sludge is to be monofilled or codisposed in an MSW landfill.
Digestion (Anaerobic and Aerobic): Biological stabilization of sludge through conversion of some of the organic matter to water, carbon dioxide, and methane. (Digesters may also be used to store sludge to provide greater flexibility for the treatment operation and to homogenize sludge solids to facilitate subsequent handling procedures.)	Reduces the volatile and biodegradable organic content and the mass of sludge by converting it to soluble material and gas. May reduce volume by concentrating solids into a denser sludge. Reduces pathogen levels and controls putrescibility and odor.	Reduces sludge quantity. Typical stabilization method prior to surface disposal.
Alkali Stabilization: Stabilization of sludge through the addition of alkali.	Raises sludge pH. Temporarily decreases biological activity. Reduces pathogen levels and controls putrescibility. Increases the dry solids mass of the sludge. Because pH effects are temporary, decomposition, leachate generation, and release of gas, odors, and heavy metals may occur over time.	High pH of alkali-stabilized sludge tends to immobilize heavy metals in sludge.
Conditioning: Alteration of sludge properties to facilitate the separation of water from sludge. Conditioning can be performed in many ways, e.g., adding inorganic chemicals such as lime and ferric chloride; adding organic chemicals such as polymers; mixing digested sludge with water and resettling (elutriation); or briefly raising sludge temperature and pressure (heat treatment). Thermal conditioning also causes disinfection.	Improves sludge dewatering characteristics. Conditioning may increase the mass of dry solids to be handled and disposed without increasing the organic content of the sludge. Conditioning may also improve sludge compactability and stabilization. Generally, polymer-treated sludges tend to be sticky, slick, and less workable than other sludges. Some conditioned sludges are corrosive.	Polymer-treated sludges may require special operational considerations at the surface disposal site.
Dewatering: Separation of water and solids for the purpose of thickening. Dewatering methods include vacuum filters, centrifuges, filter presses, belt presses, lagoons, and sand drying beds.	Increases solids concentration of sludge by removing much of the entrained water, thereby lowering sludge volume. Dewatering may increase sludge solids to 15% to 40% for organic sludges and 45% or more for some inorganic sludges. Some nitrogen and other soluble materials are removed with the water. Improves ease of handling by converting liquid sludge to damp cake. Reduces fuel requirements for heat drying.	Reduces land requirements and bulking soil requirements. Lowers sludge transportation costs.
Composting: Aerobic process involving the biological stabilization of sludge in a windrow, aerated static pile, or vessel.	Lowers biological activity. Can reduce most pathogens. Degrades sludge to a humus-like material. Increases sludge mass due to addition of bulking agent.	Most likely not appropriate for surface disposal due to cost. Generally used to create a sludge suitable for land application rather than surface disposal.
Heat Drying: Application of heat to reduce pathogens and eliminate most of the water content.	Disinfects sludge. Lowers potential for odors and biological activity.	Most likely will not be used when sludge is surface disposed.

for cotreatment with domestic sewage, discharged into sludge for cotreatment and use or disposal with the sludge, or treated and used or disposed separately.

Septage may be classified as domestic, commercial, industrial, or a mixture. Figure 1-2 in Chapter 1 provides the 40 CFR Part 503 regulatory definition of domestic septage. Domestic septage generally includes liquid and solid material derived from the treatment of domestic sewage (e.g., wastes derived from the toilet, bath and shower, sink, garbage disposal, dishwasher, and washing machine). Thus, domestic septage might be septage from establishments such as schools, restaurants, and motels, as long as this septage does not contain other types of wastes than those listed above (e.g., grease from grease traps in restaurants). Domestic septage is regulated under Part 503. Commercial and industrial septage and mixtures of these septages with domestic septage are regulated under 40 CFR Part 257 if disposed on the land (or Part 258 if placed in a MSW landfill).

Table 3-2 shows some characteristics of domestic septage. Septage may foam and generally has a strong odor (U.S. EPA, 1978b). Settling properties are highly variable. Some septage solids settle readily to about 20 to 50 percent of their original volume, while others show little settling (U.S. EPA, 1979). Significant amounts of grit may be present, and large concentrations of total coliforms, fecal coliforms, and fecal streptococci have been found in septage (U.S. EPA, 1978b).

3.2.3 Other Wastewater Solids

In addition to sludge, other solids are generated during wastewater treatment that must be handled properly. These include screenings, grit, and scum. Scum is considered sewage sludge and is regulated as such under 40 CFR Part 503. Grit and screenings are regulated under 40 CFR Part 257 (or Part 258 if placed in a MSW landfill).

3.2.3.1 Screenings

Screenings are solids such as rags, sticks, and trash in the raw wastewater that are removed on racks or bar screens placed at the head of the treatment works. Racks and coarse screens (with openings larger than 0.25 inches [6 mm]) prevent debris from interfering with other equipment. Fine screens (with openings from 0.01 to 0.25 inches [0.25 to 6 mm]) remove a significant fraction of the suspended solids and reduce the biological oxygen demand of the influent, thus reducing the load on subsequent treatment processes.

Table 3-2. Chemical and Physical Characteristics of Domestic Septage (U.S. EPA, 1993)

Parameter	Concentration mg/kg (dry weight basis)
Arsenic	4
Cadmium	3
Chromium	14
Copper	140
Lead	35
Mercury	0.15
Molybdenum	—
Nickel	15
Selenium	2
Zinc	290
Nitrogen as N	2%
Phosphorus as P	<1%
pH	6-7
Grease	6-12%
Biochemical oxygen demand (BOD_5)	6,480 mg/L
Total solids (as normally spread)	3.4%

The quantity of screenings captured in a treatment works varies depending on the size of the rack or screen openings. They typically have a moisture content of 85 percent to 95 percent and an organic content of 50 percent to 80 percent (U.S. EPA, 1975b). Screenings are odorous and tend to attract rodents and insects. They may contain pathogens. Screenings may be disposed of separately from sewage sludge in which case they are regulated under Part 257, or mixed with sewage sludge and disposed together in which case they are regulated under Part 503.

3.2.3.2 Grit

Grit is composed of heavy, coarse, inert solids such as sand, silt, gravel, ashes, corn grains, seeds, coffee grounds, and bottle caps associated with raw wastewater. Grit is usually removed at the head of the treatment works, either by velocity control in simple gravity settling chambers or by buoyant induction in air flotation tanks. Grit may also be removed from primary sludge when it has been separated from the wastewater. The amount of grit varies tremendously from one treatment works to another, and can fluctuate widely within a treatment works. Grit is often washed after collection to reduce the concentration of organics, which may be as high as 50 percent of the total grit solids and are largely responsible for the odors associated with grit. When grit is mixed with sewage sludge, the surface disposal of the mixture is regulated under Part 503. If grit is disposed of separately, it is regulated under Part 257.

3.2.3.3 Scum

Scum consists of floatable materials in wastewater and is considered sewage sludge under definition of sewage sludge outlined in the Part 503 regulation (see Figure 1-3 in Chapter 1). Scum may be collected from many different treatment units, including preaeration tanks, skimming tanks, sedimentation basins, chlorine contact tanks, gravity thickeners, and digesters (U.S. EPA, 1979). (The term "skimmings" may also be used to refer to scum that has been removed.) Scum may be subsequently digested, dewatered, and used or disposed. Unstabilized scum may be highly odorous. Treatment of scum in digesters is common, particularly with mixed units.

3.3 Characteristics of Sewage Sludge Affecting Disposal From a Regulatory Perspective

Surface disposal of sewage sludge and domestic septage is regulated under 40 CFR Part 503 and codisposal of sewage sludge in an MSW landfill under 40 CFR Part 258. The Part 503 and 258 requirements that pertain to characteristics of sewage sludge and domestic septage are described below.

3.3.1 Part 503

To protect human health and the environment, Part 503 regulates three characteristics of sewage sludge (excluding domestic septage): the concentration of certain heavy metals, the level of pathogens, and, the attractiveness of the sludge to disease vectors, such as rodents, birds, and insects. For domestic septage, Part 503 only regulates its attractiveness to disease vectors.

Heavy metals are regulated under Subpart C of Part 503. Pathogens and vector attraction reduction requirements are contained in Subpart D of Part 503. Subpart C of Part 503 indicates which pathogen and vector attraction reduction requirements have to be met for surface disposal. These requirements are summarized below. EPA (1992a) provides greater detail on each of the Subpart D requirements and guidance on how to meet the requirements.

3.3.1.1 Heavy Metals

The risk assessment performed to develop the Part 503 regulation found that three heavy metals can pose potential risks to human health and the environment in surface disposed sludges: arsenic, chromium, and nickel (U.S. EPA, 1992a). Therefore, Subpart C of 503 sets pollutant limits for these metals in sewage sludge placed on an active sewage sludge unit. (These are the only pollutants regulated by Part 503 for sewage sludge placed on a surface disposal site.) These limits apply only to active sewage sludge units ***without*** liners and leachate collection systems (see Section 7.2.1 for the definition of a liner and a leachate collection system). Because liners prevent pollutants from migrating to ground water, sludge placed on an active sewage sludge unit with a liner does not have to meet the pollutant limits. There are no pollutant limits for domestic septage placed on a surface disposal site.

When sludge is placed on an active sewage sludge unit that does not have a liner and leachate collection system, representative samples of sludge must be periodically collected (see Table 3-3 for frequency of monitoring) and analyzed for arsenic, chromium, and nickel using the methods listed in the regulation (see Table 3-4).

There are two options for meeting the heavy metal requirements. The first option is to ensure that the levels of arsenic, chromium, and nickel are below the pollutant limits listed in Table 3-5, which are based on how far the boundary of each active sewage sludge unit (e.g., trench) is from the property line of the surface disposal site. There may be more than one active sewage sludge unit at a surface disposal site. Pollutant limits must be determined for each unit separately based on the shortest distance between each particular unit's boundaries and the property line. Thus, there can be different pollutant limits for active sewage sludge units at the same surface disposal site. Most likely, the most stringent of the pollutant limits will be met at all of the active sewage sludge units on the site.

The second option for meeting pollutant limits is to meet "site-specific" limits approved by the permitting authority. To invoke this option, the owner or operator of a surface disposal site must request site-specific limits when applying for a permit. The permitting authority will then evaluate the site conditions, determine whether site-specific limits are appropriate, and, if so, establish those limits.

The need for site-specific limits may be justified if the site conditions vary significantly from those assumed in the risk assessment that EPA used to derive the regulatory pollutant limits. In general, if the depth of ground

Table 3-3. Frequency of Monitoring for Surface Disposal Under Part 503

Amount of Sewage Sludge Placed on an Active Sewage Sludge Unit (metric tons dry solids per 365-day period)	Frequency
Greater than zero but less than 290[a]	Once per year
Equal to or greater than 290 but less than 1,500[a]	Once per quarter (four times per year)
Equal to or greater than 1,500 but less than 15,000[a]	Once per 60 days (six times per year)
Equal to or greater than 15,000[a]	Once per month (12 times per year)

[a]290 metric tons = 319 tons (approximately 0.9 tons/day for a year)
1,500 metric tons = 1,650 tons (approximately 4.5 tons/day for a year)
15,000 metric tons = 16,500 tons (approximately 4.5 tons/day for a year)

Table 3-4. Methods Required by Part 503 for the Analysis of Metals in Sewage Sludge Placed on a Surface Disposal Site

Pollutants	Sample Preparation and Analytical Methodologies SW-846[a]
Arsenic	EPA Methods 3050/3051 + 7061
Chromium	EPA Methods 3050/3051 + 6010/7191/7190
Nickel	EPA Methods 3050/3051 + 6010/5720

[a]*Test Methods for Evaluating Solid Waste, Physical/Chemical Methods,* EPA Publication SW-846, Second Edition (1982) with Updates I (April 1984) and II (April 1985) and the Third Edition (November 1986) with Revision I (December 1987) and Update I (July 1992). The Second Edition and Updates I and II (PB-87-120-291) are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161. The Third Edition and Revision I and Update I (Document number 955-001-00000-1) are available from the Superintendent of Documents, Government Printing Office, 941 North Capitol Street, NE., Washington, DC 20002. Future updates will be noticed in the *Federal Register.*

Table 3-5. Part 503 Pollutant Limits for Sludge Placed on a Surface Disposal Site

Location in the Part 503 Rule	Distance From the Boundary of Active Sludge Unit to Surface Disposal Site Property Line (m)	Pollutant Concentration[a] Arsenic (mg/kg)	Chromium (mg/kg)	Nickel (mg/kg)
Table 2 of Section 503.23	0 to less than 25	30	200	210
	25 to less than 50	34	220	240
	50 to less than 75	39	260	270
	75 to less than 100	46	300	320
	100 to less than 125	53	360	390
	125 to less than 150	62	450	420
Table 1 of Section 503.23	Greater than 150	73	600	420

[a] Dry-weight basis (basically, 100% solids content).

water is considerable or a natural clay layer underlies the site, site-specific limits might be established.

3.3.1.2 Pathogens

Pathogen reduction requirements for sewage sludge are divided into two categories: Class A and Class B. The goal of the Class A requirements is to reduce the pathogens in sewage sludge to below detectable levels through treatment of the sludge. The goal of the Class B requirements is to reduce pathogens (but not to below detectable levels) and to prevent exposure to the sewage sludge to allow the environment to further reduce pathogens to below detectable limits.

No pathogen requirements apply to domestic septage placed on a surface disposal site. Preparers of sewage sludge, however, have two choices in meeting the pathogen requirements:

- Meet one of the Class A alternatives.
- Meet one of the Class B alternatives (excluding the Class B site restrictions, which do not apply to surface disposal sites).

  or

- At the end of each operating day, the owner/operator could cover the sewage sludge with soil or other material, in which case no pathogen requirements apply.

Class A Requirements

The Class A requirements are substantially more stringent than the Class B requirements. Meeting them requires:

- Monitoring sewage sludge to demonstrate that, at the time of disposal, *either* the density of fecal coliform is less than 1,000 MPN (most probable number) per gram total solids (dry weight basis) *or* that *Salmonella* sp. bacteria density is below detectable levels.
- *Either* the use of particular operating conditions (e.g., achievement of particular time-temperature regimes, pH elevation, etc.) and/or treatment technologies, *or* additional monitoring to demonstrate that both enteric viruses and viable helminth ova are below detectable levels.

The Class A requirements are not discussed further in this document, because it is likely that most preparers of sewage sludge will choose the less stringent Class B or daily cover option to meet the Subpart D pathogen requirements. EPA (1992a) provides additional information on the Class A requirements.

Class B Requirements

The Class B pathogen requirements can be met in three different ways:

- *Monitoring of Fecal Coliform.* This alternative requires that the geometric mean fecal coliform in seven samples of sludge collected at the time of disposal (minus the time required to analyze the samples) be less than 2 million CFU (colony-forming unit) or MPN per gram of sewage sludge solids (dry weight basis). Samples must be analyzed using Standard Methods Part 9221 E or Part 9222 D (APHA, 1992). Analysis of multiple samples during each monitoring episode is required because the analytical methods have poor precision and sewage sludge quality varies. Use of at least seven samples is expected to reduce the standard error to a reasonable value (U.S. EPA, 1992a).
- *Use of a Process to Significantly Reduce Pathogens.* Under this alternative, sewage sludge is considered to be Class B if it is treated in one of the "Processes to Significantly Reduce Pathogens" (PSRPs) listed in Appendix B of Part 503 (see Table 3-6). This alternative does not require microbiological monitoring.

Table 3-6. Processes to Significantly Reduce Pathogens (PSRPs) Listed in Appendix B of 40 CFR Part 503

1. Aerobic Digestion

Sewage sludge is agitated with air or oxygen to maintain aerobic conditions for a specific mean cell residence time (i.e., solids retention time) at a specific temperature. Values for the mean cell residence time and temperature shall be between 40 days at 20°C (68°F) and 60 days at 15°C (59°F).

2. Air Drying

Sewage sludge is dried on sand beds or on paved or unpaved basins. The sewage sludge dries for a minimum of 3 months. During 2 of the 3 months, the ambient average daily temperature is above 0°C (32°F).

3. Anaerobic Digestion

Sewage sludge is treated in the absence of air for a specific mean cell residence time (i.e., solids retention time) at a specific temperature. Values for the mean cell residence time and temperature shall be between 15 days at 35°C to 55°C (131°F) and 60 days at 20°C (68°F).

4. Composting

Using either the within-vessel, static aerated pile, or windrow composting methods, the temperature of the sewage sludge is raised to 40°C (104°F) or higher and remains at 40°C (104°F) or higher for 5 days. For 4 hours during the 5-day period, the temperature in the compost pile exceeds 55°C (131°F).

5. Lime Stabilization

Sufficient lime is added to the sewage sludge to raise the pH of the sewage sludge to 12 after 2 hours of contact.

- *Use of Processes Equivalent to PSRPs.* Under this alternative, sewage sludge treated by any process determined to be equivalent to a PSRP is considered to meet the Class B requirements. The permitting authority is responsible for deciding whether a process is equivalent to a PSRP. This alternative does not require microbiological monitoring.

Applying Soil Cover

The Subpart D pathogen requirements are satisfied if, at the end of each operating day, the sewage sludge that has been placed on an active sewage sludge unit is covered with soil or other material. Daily cover isolates the sewage sludge while environmental factors naturally attenuate pathogens. For daily cover requirements based on best engineering judgement, see Table 2-2 in Chapter 2.

3.3.1.3 Vector Attraction

Vectors are any living organisms capable of transmitting pathogens from one organism to another. They are a principal route for transport of pathogens. Vectors for transport of sewage sludge pathogens are generally insects, rodents, and birds. Subpart D of Part 503 requires that the attractiveness of sewage sludge to vectors be reduced to decrease the disease risk from sludge. There are 12 options for demonstrating reduced vector attraction under Part 503. These are summarized in Table 3-7.

Table 3-8 indicates the applicability of these options to various types of sewage sludge and domestic septage. EPA (1992a) provides more information on these options.

Options 1 through 8 apply to sewage sludge that has been treated in some way to reduce vector attraction (e.g., aerobic or anaerobic digestion, composting, alkali addition, drying). These options consist of operating conditions or tests to demonstrate that vector attraction has been reduced in the treated sludge. These options do not apply to domestic septage placed on a surface disposal site.

Options 9 through 11 are barrier methods. These options require the use of soil as a physical barrier to prevent vectors from coming in contact with the sewage sludge. Under option 11 (which applies only to surface disposal sites), owners/operators of surface disposal sites can satisfy the vector attraction reduction requirement by covering the sewage sludge placed on a surface disposal site with soil or other material at the end of each operating day. (This option also automatically satisfies the pathogen reduction requirement under Part 503.) Options 9 through 11 apply to both sewage sludge and domestic septage.

Option 12 is a requirement to demonstrate reduced vector attraction through elevated pH. This option only applies to domestic septage (not sewage sludge) placed on a surface disposal site.

3.3.1.4 Frequency of Monitoring

The frequency of monitoring for the pollutants listed in Table 3-5, the pathogen density levels in the Class A alternatives, the Class B fecal coliform levels, and vector attraction reduction requirements 1 through 8 depends on amount of sludge used or disposed. Table 3-4 lists this frequency. After the sewage sludge has been monitored for 2 years at the frequency given in Table 3-3, the permitting authority may reduce the frequency of monitoring for pollutant concentrations and for the enteric-viruses and viable helminth ova densities in Class A, Alternative 3, down to no less than once a year.

When option 12 (pH reduction) is used to meet the vector attraction reduction requirements, each container of domestic septage must be monitored for compliance.

3.3.1.5 Organic Chemicals

Sludges can contain synthetic organic chemicals from industrial wastes, household chemicals, and pesticides. The risk assessment performed to develop the Part 503 regulation found that these chemicals do not generally pose a risk to public health and the environment in surface-disposed sludges because they are generally present at very low levels and most of these chemicals degrade rapidly. Part 503 does not establish numerical pollutant limits for any organic pollutants because EPA

Table 3-7. Summary of Requirements for Vector Attraction Reduction Under Part 503 (U.S. EPA, 1992a)

Requirement	What Is Required?	Most Appropriate for:
Option 1 503.33(b)(1)	At least 38% reduction in volatile solids during sewage sludge treatment	Sewage sludge processed by: • Anaerobic biological treatment • Aerobic biological treatment • Chemical oxidation
Option 2 503.33(b)(2)	Less than 17% additional volatile solids loss during bench-scale anaerobic batch digestion of the sewage sludge for 40 additional days at 30°C to 37°C (86°F to 99°F)	Only for anaerobically digested sewage sludge that cannot meet the requirements of Option 1
Option 3 503.33(b)(3)	Less than 15% additional volatile solids reduction during bench-scale aerobic batch digestion for 30 additional days at 20°C (68°F)	Only for aerobically digested sewage sludge with 2% or less solids that cannot meet the requirements of Option 1—e.g., sewage sludges treated in extended aeration plants
Option 4 503.33(b)(4)	SOUR at 20°C (68°F) is ≤1.5 mg oxygen/hr/g total sewage sludge solids	Sewage sludges from aerobic processes (should not be used for composted sludges)
Option 5 503.33(b)(5)	Aerobic treatment of the sewage sludge for at least 14 days at over 40°C (104°F) with an average temperature of over 45°C (113°F)	Composted sewage sludge (Options 3 and 4 are likely to be easier to meet for sludges from other aerobic processes)
Option 6 503.33(b)(6)	Addition of sufficient alkali to raise the pH to at least 12 at 25°C (77°F) and maintain a pH ≥12 for 2 hours and a pH ≥11.5 for 22 more hours	Alkali-treated sewage sludge (alkalies include lime, fly ash, kiln dust, and wood ash)
Option 7 503.33(b)(7)	Percent solids ≥75% prior to mixing with other materials	Sewage sludges treated by an aerobic or anaerobic process (i.e., sewage sludges that do not contain unstabilized solids generated in primary wastewater treatment)
Option 8 503.33(b)(8)	Percent solids ≥90% prior to mixing with other materials	Sewage sludges that contain unstabilized solids generated in primary wastewater treatment (e.g., any heat-dried sewage sludges)
Option 9 503.33(b)(9)	Sewage sludge is injected into soil so that no significant amount of sewage sludge is present on the land surface 1 hour after injection, except Class A sewage sludge which must be injected within 8 hours after the pathogen reduction process.	Sewage sludge applied to the land or placed on a surface disposal site. Domestic septage applied to agricultural land, a forest, or a reclamation site, or placed on a surface disposal site
Option 10 503.33(b)(10)	Sewage sludge is incorporated into the soil within 6 hours after application to land or placement on a surface disposal site, except Class A sewage sludge which must be applied to or placed on the land surface within 8 hours after the pathogen reduction process.	Sewage sludge applied to the land or placed on a surface disposal site. Domestic septage applied to agricultural land, forest, or a reclamation site, or placed on a surface disposal site
Option 11 503.33(b)(11)	Sewage sludge placed on a surface disposal site must be covered with soil or other material at the end of each operating day.	Sewage sludge or domestic septage placed on a surface disposal site
Option 12 503.33(b)(12)	pH of domestic septage must be raised to ≥12 at 25°C (77°F) by alkali addition and maintained at ≥12 for 30 minutes without adding more alkali.	Domestic septage applied to agricultural land, a forest, or a reclamation site or placed on a surface disposal site

determined that none of the organics considered for regulation were present in sewage sludge that pose a public health or environmental risk. EPA used the following criteria to make this determination:

- The pollutant is banned or has restricted use in the United States or is no longer manufactured or used in manufacturing a product in the United States; or
- The pollutant is not present in sewage sludge at significant frequencies of detection, based on data gathered from the 1988 National Sewage Sludge Survey;

  or

- The pollutant limit identified in EPA's exposure assessment is not expected to be exceeded in sewage sludge that is used or disposed, based on data from the National Sewage Sludge Survey.

3.3.1.6 Nitrogen

Nitrogen in sludge is a source of potential ground-water pollution. The potential for ground-water pollution is significantly affected by the quantity and type of nitrogen. Nitrogen may be present in sludge as organic nitrogen, ammonia, nitrate, and nitrite. Generally, nitrate is the principal species of concern because it is the most soluble form of nitrogen, and therefore is relatively mobile in most soil types. Aerobic conditions facilitate microbial conversion of other nitrogen species to nitrate, and thus, increase the possibility for nitrogen movement. Conversely, disposal methods providing anaerobic conditions inhibit nitrogen movement and allow microbial destruction of pathogens (U.S. EPA, 1975a).

One of the management practices required under Part 503 states that sewage sludge placed on an active sewage sludge unit must not contaminate an aquifer.

Table 3-8. Applicability of Options for Meeting the Vector Attraction Reduction Options Under Subpart D

	Sewage Sludge (Excluding Domestic Septage) Placed on an Active Sewage Sludge Unit	Domestic Septage Placed on an Active Sewage Sludge Unit
Options 1-8	✓	
Options 9-11	✓	✓
Option 12		✓

Under this management practice nitrate-nitrogen levels in ground water must not exceed the MCL of 10 mg/liter or must not increase the existing concentration of nitrate-nitrogen if the existing concentration already exceeds the MCL.

3.3.2 Part 258

EPA's Solid Waste Disposal Facility Criteria contain provisions that prohibit the receipt of hazardous waste at municipal solid waste landfills (40 CFR 258.20). The regulations also prohibit the receipt of bulk or noncontainerized liquid waste (40 CFR 258.28). Part 503.4 establishes the same requirements for the codisposal of sewage sludge at MSW landfills.

3.3.2.1 Exclusion of Hazardous Waste From Municipal Solid Waste Landfills

Under 40 CFR Part 258.20, owners or operators of municipal solid waste landfills must implement a program for detecting and preventing the disposal of regulated hazardous waste and polychlorinated biphenyls (PCBs). EPA considers a waste to be hazardous if it exhibits the characteristics of ignitability, corrosivity, reactivity, or toxicity (i.e., it is a "characteristic" waste), or if it is on a list of specific wastes determined by EPA to be hazardous.

Sewage sludge is not a listed hazardous waste. Moreover, available evidence suggests that sewage sludges are unlikely to be a characteristic hazardous waste. The non-hazardous nature of sewage sludges cannot necessarily be assumed, however, and as sludge generators, POTWs and other treatment works are required under 40 CFR Part 262.11 to determine whether their sewage sludge is a hazardous waste by virtue of its characteristics (U.S. EPA, 1990).

Although sewage sludge conceivably could exhibit the characteristics of ignitability, corrosivity, or reactivity, most concerns about sewage sludge have focused on toxicity. Few, if any, sewage sludges are expected to exhibit the toxicity characteristic (55 FR 11838). However, if factors are present indicating a likely toxicity problem (e.g., a treatment works receives significant loadings of pollutants covered by the test for toxicity) and the treatment works does not have current data showing that the sludge is not a hazardous waste, it is advisable for the treatment works to test the sludge destined for codisposal for toxicity (U.S. EPA, 1990).

The test for toxicity is the Toxicity Characteristic Leaching Procedure (TCLP). This test simulates leaching in a municipal landfill, measuring the potential of certain toxic constituents to leach out and contaminate ground water at levels of health or environmental concern. Table 3-9 lists the toxicity characteristic constituents and their regulatory levels.

3.3.2.2 Liquids Restriction

One of the key considerations for a sludge/municipal solid waste codisposal operation is ensuring that the sludge meets the liquids restriction of 40 CFR Part 258. This restriction helps reduce the amount of landfill leachate and the concentrations of contaminants in the leachate. Sludge may not be disposed in a municipal solid waste landfill if it is determined to contain free liquids as defined by Method 9095 - Paint Filter Liquids Test, as described in "Test Methods for Evaluating Solid Wastes, Physical/Chemical Methods" (EPA Pub. No. SW-846). The paint filter liquids test is performed by placing a 100-ml sample of waste in a conical, 400-micron paint filter. The waste is considered a liquid waste if any liquid from the waste passes through the filter within 5 minutes. The apparatus used to perform the paint filter test consists of a glass funnel, a ringstand to hold the funnel, a graduated cylinder, and the paint filter (Figure 3-1).

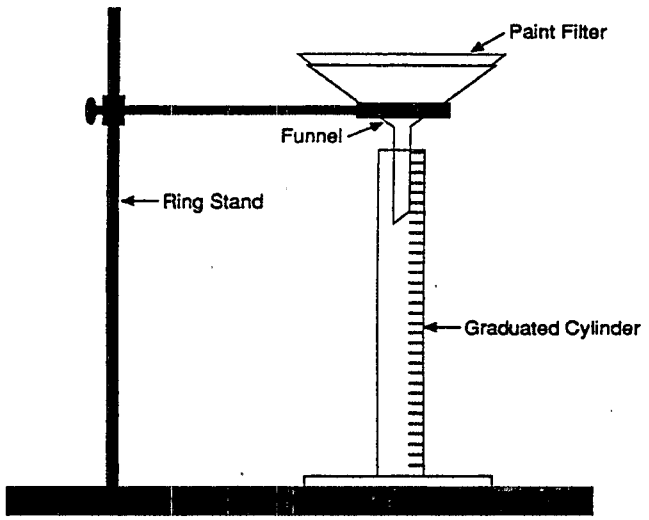

Figure 3-1. Paint filter test apparatus (U.S. EPA, 1993b).

The solids content required for a sludge to pass the paint filter liquids test depends on the origin of the sludge. One study found that primary sludges required an average of 15.6 percent solids to pass the test, mixed sludges 13 percent, and biological sludge 5.5 percent.

Table 3-9. Toxicity Characteristic Constituents and Regulatory Levels

EPA HW No.[1]	Constituent (mg/L)	CAS No.[2]	Chronic toxicity reference level (mg/L)	Regulatory level (mg/L)
D004	Arsenic	7440-38-2	0.05	5.0
D005	Barium	7440-39-3	1.0	100.0
D018	Benzene	71-43-2	0.005	0.5
D006	Cadmium	7440-43-9	0.01	1.0
D019	Carbon tetrachloride	56-23-5	0.005	0.5
D020	Chlordane	57-74-9	0.0003	0.03
D021	Chlorobenzene	108-90-7	1	100.0
D022	Chloroform	67-66-3	0.06	6.0
D007	Chromium	7440-47-3	0.05	5.0
D023	o-Cresol	95-48-7	2	[4] 200.0
D024	m-Cresol	108-39-4	2	[4] 200.0
D025	p-Cresol	106-44-5	2	[4] 200.0
D026	Cresol		2	[4] 200.0
D016	2,4-D	94-75-7	0.1	10.0
D027	1,4-Dichlorobenzene	106-46-7	0.075	7.5
D028	1,2-Dichloroethane	107-06-2	0.005	0.5
D029	1,1-Dichloroethylene	75-35-4	0.007	0.7
D030	2,4-Dinitrotoluene	121-14-2	0.0005	[3] 0.13
D012	Endrin	72-20-8	0.0002	0.02
D031	Heptachlor (and its hydroxide)	76-44-8	0.00008	0.008
D032	Hexachlorobenzene	118-74-1	0.0002	[3] 0.13
D033	Hexachloro-1,3-butadiene	87-68-3	0.005	0.5
D034	Hexachloroethane	67-72-1	0.03	3.0
D008	Lead	7439-92-1	0.05	5.0
D013	Lindane	58-89-9	0.004	0.4
D009	Mercury	7439-97-6	0.002	0.2
D014	Methoxychlor	72-43-5	0.1	10.0
D035	Methyl ethyl ketone	78-93-3	2	200.0
D036	Nitrobenzene	98-95-3	0.02	2.0
D037	Pentachlorophenol	87-86-5	1	100.0
D038	Pyridine	110-86-1	0.04	[3] 5.0
D010	Selenium	7782-49 2	0.01	1.0
D011	Silver	7440-22-4	0.05	5.0
D039	Tetrachloroethylene	127-18-4	0.007	0.7
D015	Toxaphene	8001-35-2	0.005	0.5
D040	Trichloroethylene	79-01-6	0.005	0.5
D041	2,4,5-Trichlorophenol	95-95-4	4	400.0
D042	2,4,6-Trichlorophenol	88-06-2	0.02	2.0
D017	2,4,5-TP (Silvex)	93-72-1	0.01	1.0
D043	Vinyl chloride	75-01-4	0.002	0.2

[1] Hazardous waste number.
[2] Chemical abstracts service number.
[3] Quantitation limit is greater than the calculated regulatory level. The quantitation limit therefore becomes the regulatory level.
[4] If o-, m-, and p-cresol concentrations cannot be differentiated, the total cresol (D026) concentration is used. The regulatory level for total cresol is 200 mg/l.

All wastewater sludges dewatered on conventional dewatering equipment were found to attain a solids content comfortably above the solids content needed to pass the paint filter liquids test (U.S. EPA, 1992b).

The study also found that a sludge that passes the test at the treatment works could fail after standing for several hours. For this reason, it is recommended that the test at the treatment works be conducted under more severe conditions than required by the paint filter liquids test. This can be accomplished by increasing the hydrostatic head of the filter. A simple way to do this is to conduct the test using a larger volume of sludge (e.g., using a larger funnel and 800 ml of sludge instead of 100 ml, thus increasing the hydrostatic head from about 6.5 cm to 13 cm) (U.S. EPA, 1992b).

Mixing a dewatered sludge cake will also help ensure that it will pass the paint filter liquids test. When a sludge has been dewatered, it is usually not uniform in solids content. For example, in filtration, the cake next to the filter cloth has a higher solids content than the sludge at the outer edge of the cake. This lack of uniformity could result in the sludge failing to pass the paint filter liquids test (U.S. EPA, 1992b).

If the sludge is determined through the paint filter liquids test to be liquid waste, absorbent materials (such as soil) may be added to render a "solid" material (i.e., a waste/absorbent mixture that no longer fails the paint filter liquids test).

3.4 Characteristics of Sewage Sludge Affecting Disposal From a Technical Perspective

This section discusses the characteristics of sewage sludge that influence the design of surface disposal sites because of potential operational problems. For example, the solids content of sewage sludge impacts its suitability for disposal at different active sewage sludge units (e.g., monofills versus lagoons). In addition to solids content, this section reviews how sludge quantity, organic content, and pH affect the suitability of sewage sludge for disposal from a technical perspective.

3.4.1 Solids Content

The solids content of sludge—usually expressed as percent total solids (TS)—can affect sludge transportation costs, leachate formation, and the effectiveness of

surface disposal equipment. The solids content of sludge depends on the type of sludge (i.e., primary, secondary, chemical) and on whether and how it has been further treated (see Table 3-1) prior to disposal. Treatment processes such as thickening, conditioning, dewatering, composting, and drying can lower sludge water content and thus raise the percent solids. The efficiency of these treatment processes, however, can vary substantially from time to time, producing sludges with substantially lower solids content than the process was designed to produce. Therefore, it is critical that surface disposal sites be flexibly designed to accommodate the range of variations in sludge solids content that may occur as a result of variations in the efficiency of the wastewater and sludge treatment processes. Without this flexibility, severe operational problems could result at the disposal site.

The sludge solids content that can be tolerated at any particular surface disposal site depends on a variety of operational and site-specific factors. Table 2-2 in Chapter 2 lists the ranges of acceptable sludge solids concentrations for the types of active sewage sludge units. For monofills and codisposal operations, sludge solids concentration should be at least 20 percent. Dedicated surface disposal sites and surface impoundments typically handle sludge of much lower solids concentrations, while piles require sludge of higher solids concentration. Polymers are sometimes added to sludge to create a higher solids content. The addition of polymers to condition sludges creates a more viscous, sticky, slippery material that can cause handling difficulties.

3.4.2 Sludge Quantity

The amount of sludge that must be used or disposed affects the economic and technical feasibility of the surface disposal options. Two ways to look at sludge quantity are the volume of the wet sludge, which takes into account both the water content and the solids content, and the mass of the dry sludge solids. Sludge volume is expressed as gallons (liters) or cubic meters. Sludge mass is usually expressed in terms of weight, in units of dry metric tonnes (tons). Because the water content of sludge can be high and quite variable, the mass of dry sludge solids is often used to compare sludges with different proportions of water (U.S. EPA, 1984).

Key factors affecting sludge volume and mass are sources of the wastewater, wastewater treatment processes, and sludge treatment processes. For example, industrial contributions to the influent wastewater can significantly increase the sludge quantity generated from a given amount of wastewater. Also, higher degrees of wastewater treatment generally increase sludge volume. As documented in Table 3-1, some sludge treatment processes reduce sludge volume, some reduce sludge mass, and some increase sludge mass while improving other sludge characteristics (U.S. EPA, 1984).

The sludge quantity determines the surface disposal area requirements and the probable life of the disposal site. Data on minimum and maximum sludge quantities are important for developing an understanding of the daily operating requirements. Maximum daily sludge quantities will govern equipment and storage facility sizing and daily operating schedules (U.S. EPA, 1979).

3.4.3 Organic Content

Sludge organic content is an important determinant of potential odor problems in surface disposal. Sludge organic content is most often expressed as the percent of total solids (TS) that are volatile solids (VS). VS are organic compounds that are removed when the sludge is heated to 550°C (1,022°F) under oxidizing conditions (U.S. EPA, 1984). Most unstabilized sludge contains 75 percent to 85 percent VS on a dry weight basis. A number of treatment processes can be used to reduce sludge volatile solids content and thus the potential for odor. These include anaerobic digestion, aerobic digestion, and composting. Anaerobic digestion—the most common method of sludge stabilization—generally biodegrades about 50 percent of the volatile solids in a sludge.

3.4.4 pH

The pH of a sludge affects its suitability for surface disposal. Low pH sludges (less than approximately pH 6.5) promote leaching of most heavy metals. High pH sludges (greater than pH 11) destroy many bacteria and, in conjunction with soils of neutral or high pH, can temporarily inhibit movement of most heavy metals through soils. Also, biological activity is reduced in high pH sludges, leading to a reduction in the decomposition of organic material in the sludge which in turn reduces its attraction to vectors.

3.5 References

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3. U.S. EPA. 1993b. Solid waste facility disposal criteria: Technical manual. EPA/530/R-93/017 (NTIS PB94-100-450) (November).
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Chapter 4
Site Selection

4.1 Purpose and Scope

This chapter presents the regulatory, technical, and economic considerations relevant to selecting the location of a surface disposal site, describes a process for site selection, and provides an example showing how this process applies to selecting a surface disposal site. A surface disposal site is an area of land that contains one or more active sewage sludge units. Figure 2-1 in Chapter 2 illustrates the relationship between an active sewage sludge unit and a surface disposal site.

In addition to regulatory, technical, and economic considerations, site selection is also influenced by the degree of public participation and acceptance. Public input should be received throughout the site selection process. Approaches to ensuring effective public participation are addressed in Chapter 5.

When selecting and developing a site, municipalities should be aware of the lead time involved before the site will be operational. Site selection is an iterative process. Often many candidate sites are reviewed leading to many feasible sites, from which a final site is selected. Figure 4-1 illustrates the flow of the screening process for site selection. Site selection methodology is discussed in detail in Section 4.4.

Permitting, evaluation, public review, purchase, and development of a surface disposal site usually take 3 to 5 years or more. Underestimation of this lead time may lead to expensive storage or transportation of sludge.

4.2 Regulatory Requirements

4.2.1 Part 503

Surface disposal sites where sewage sludge is placed for final disposal in monofills, surface impoundments, or piles and mounds, dedicated surface disposal sites, and dedicated beneficial use sites are all covered by the Part 503 Subpart C regulation. Several of the management practices required under Subpart C influence where surface disposal sites can be located. Some of these requirements clearly prohibit sites with certain characteristics from consideration; others, while not prohibitive, may result in increased costs or permitting requirements for sites with certain characteristics, making these sites less desirable than other options. Subpart C requirements influencing siting are summarized in Table 4-1 and explained below.

4.2.1.1 Protection of Threatened or Endangered Species

Under Part 503, sewage sludge cannot be placed on an active sewage sludge unit if it is likely to adversely affect a threatened or endangered species listed under Section 4 of the Endangered Species Act or the designated critical habitat of such a species. The Threatened and Endangered Species List can be obtained from the U.S. Fish and Wildlife Service's (FWS's) Publications Office in Washington, DC. Critical habitat is defined as any place where a threatened or endangered species lives and grows during any stage of its life cycle.

Any direct or indirect action (or the result of any direct or indirect action) in a critical habitat that diminishes the likelihood of survival and recovery of a listed species is considered destruction or adverse modification of a critical habitat. Individuals may contact the Endangered

Table 4-1. Part 503 Subpart C Management Practices Influencing Siting of an Active Sewage Sludge Unit

- Sewage sludge shall not be placed on an active sewage sludge unit if it is likely to adversely affect a threatened or endangered species listed under section 4 of the Endangered Species Act or its designated critical habitat.
- An active sewage sludge unit shall not restrict the flow of a base flood.
- When a surface disposal site is located in a seismic impact zone, an active sewage sludge unit shall be designed to withstand the maximum recorded horizontal ground level acceleration.
- An active sewage sludge unit shall be located 60 meters or more from a fault that has displacement in Holocene time, unless otherwise specified by the permitting authority.
- An active sewage sludge unit shall not be located in an unstable area.
- An active sewage sludge unit shall not be located in a wetland, except as provided in a permit issued pursuant to section 402 or 404 of the CWA.
- Sewage sludge placed on an active sewage sludge unit shall not contaminate an aquifer.

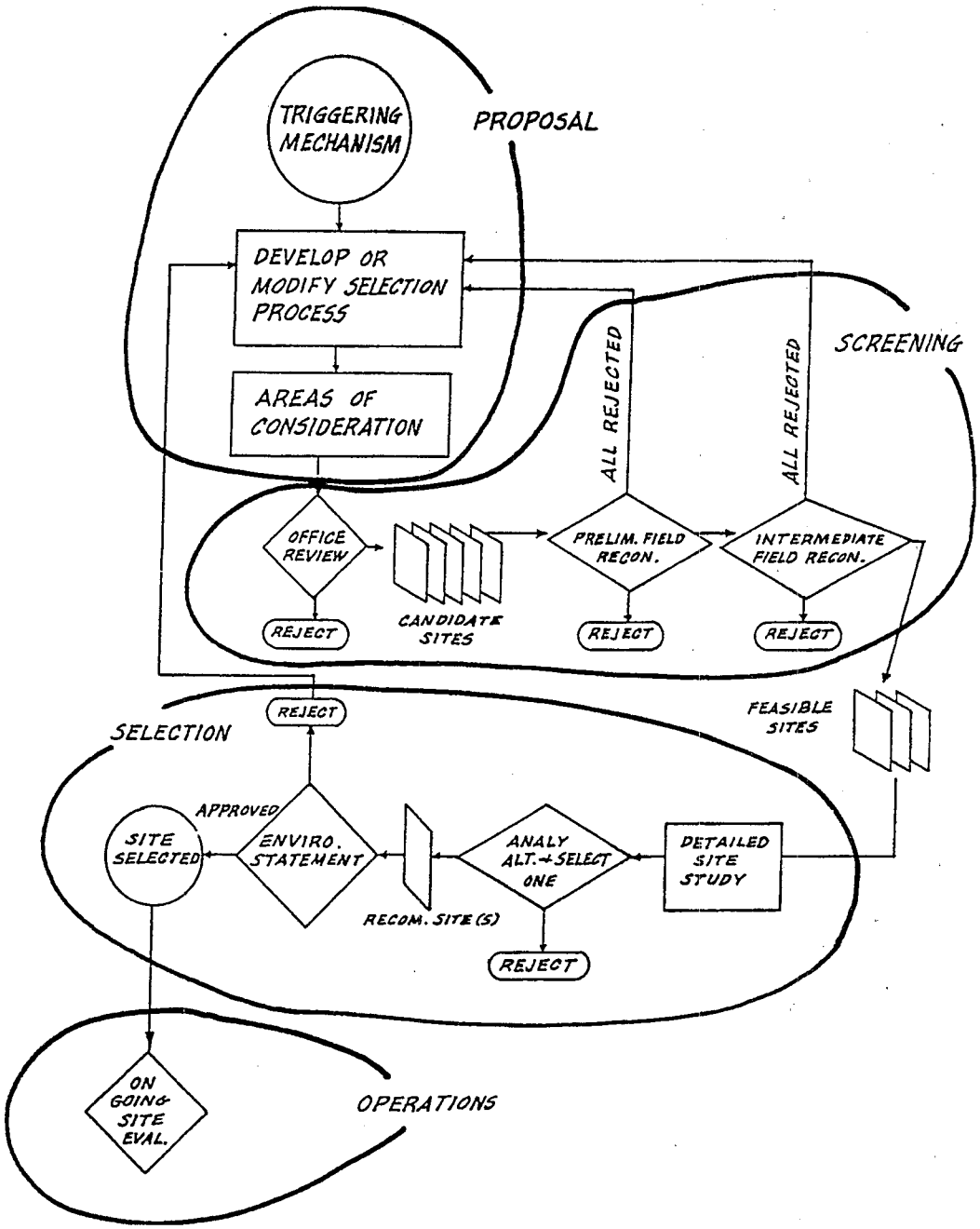


Figure 4-1. Flow of screening process for site selection (U.S. EPA, 1985).

Species Protection Program in Washington, DC, or FWS Field Offices for more information about threatened and endangered species considerations in their area. State departments governing fish and game also should be contacted for specific state requirements.

4.2.1.2 Restriction of Base Flood Flow

Part 503 requires that an active sewage sludge unit "not restrict the flow of a base flood." A base flood is a flood that has a 1 percent chance of occurring in any given year (i.e., a flood that is likely to occur once in 100 years). This management practice:

- Reduces the possibility that a surface disposal site might negatively affect the ability of an area to absorb the flow of a base flood.
- Prevents surface water contamination.
- Protects the public from the possibility of a base flood releasing sewage sludge to the environment.

The flood insurance rate maps (FIRMs) and flood boundary and floodway maps published by the Federal

Emergency Management Agency's (FEMA's) Flood Map Distribution Center in Baltimore, Maryland can be consulted to determine whether a surface disposal site is in a 100-year flood plain. Guidance on using FIRMs is provided in "How to Read a Flood Insurance Rate Map" published by FEMA. FEMA also publishes "The National Flood Insurance Program Community Status Book" that lists communities that are in the Emergency or Regular program including communities that may not be involved in the National Flood Insurance Program but which have FIRMs or Floodway maps published. States, counties, and towns usually also have maps delineating floodplains. Other agencies that maintain flood zone maps are the U.S. Army Corps of Engineers (COE), the U.S. Geological Survey (USGS), the U.S. Soil Conservation Service (SCS), the Bureau of Land Management (BLM), the Tennessee Valley Authority (TVA), and state and local agencies.

Many of the river channels covered by these maps may have been modified for hydropower or flood control purposes, so the floodplain boundaries represented may not be accurate or representative. Comparison of the floodplain map series to recent air photographs may be necessary to identify current river channel modifications and land use in watersheds that could affect floodplain designations.

If floodplain maps are not available, and the potential active sewage sludge unit is located within a floodplain, a field study may be required to delineate the 100-year floodplain. Such a study would likely involve reviewing meteorological records and physiographic information including existing and planned watershed land use, topography, soils and geologic mapping, and air photo interpretation of geomorphologic features.

If the owner/operator of a surface disposal site determines that an active sewage sludge unit is within a 100-year flood zone, the permitting authority will evaluate whether the active sewage sludge unit will restrict the flow of a base flood. This assessment considers the flood plain storage capacity and the floodwater velocities that would exist with and without the presence of the active sewage sludge unit. If the presence of the unit will raise the base flood level 1 additional foot, the unit is considered to restrict the flow of the base flood, potentially causing more flood damage than would otherwise have occurred.

If the permitting authority believes an active sewage sludge unit will restrict the flow of the base flood, it may require the site to close or it may develop permit conditions that would prevent restriction of the base flood flow. Such conditions might include embankments or an alternative unit design.

4.2.1.3 Geological Stability

Three of the management practices in the Part 503 Subpart C regulation are designed to ensure the geological stability of an active sewage sludge unit. These practices regulate the location of an active sewage sludge unit within the vicinity of three types of geologic features: seismic impact zones, fault areas, and unstable areas.

- *Seismic Impact Zone.* For a surface disposal site located in seismic impact zones, Part 503 requires that the active sewage sludge unit be designed to withstand the maximum recorded horizontal ground level acceleration. This management practice helps ensure that the unit's structures, such as liners and leachate collection systems, will not crack or collapse because of ground movement and that leachate will not be released due to seismic activity.

  A seismic impact zone is an area in which certain types of ground movements ("horizontal ground level acceleration") have a 10 percent or greater chance of occurring at a certain magnitude (measured as "0.10 gravity") once in 250 years. The USGS keeps records of the location of these areas (see also Section 4.2.2.5 for additional resources). Seismic impact zones in the continental United States are shown in Figure 4-2, which is based on ongoing work by the U.S. Geological Service (Algermissen et al., 1982; Algermissen et al., 1990). In the western United States, earthquakes of large magnitude tend to occur frequently, to be associated with specific active faults, and therefore affect a relatively small geographic area. Conversely, in the eastern United States, large earthquakes tend to occur infrequently, to be independent of faults, and therefore affect a large geographic area.

  Various seismic design methods are available for active sewage sludge units located in seismic impact zones. Appropriate design modifications may include shallower unit side slopes and more conservative design of dikes and runoff controls. Also, contingencies for the leachate collection system should be considered in case the primary system becomes ineffective.

- *Fault.* A fault is a crack in the earth along which the ground on either side of the crack may move. Such ground movement is called displacement. Part 503 requires that active sewage sludge units be located at least 60 meters (200 ft) from any fault that has displacement measured in "Holocene time" (recent geological time of approximately the last 11,000 years). Requiring this distance from a fault helps ensure that the structures of the unit will not be damaged if ground movement occurs in a fault area and that leachate will not spread into the environment through faults. This management practice must be followed unless the permitting authority specifies otherwise.

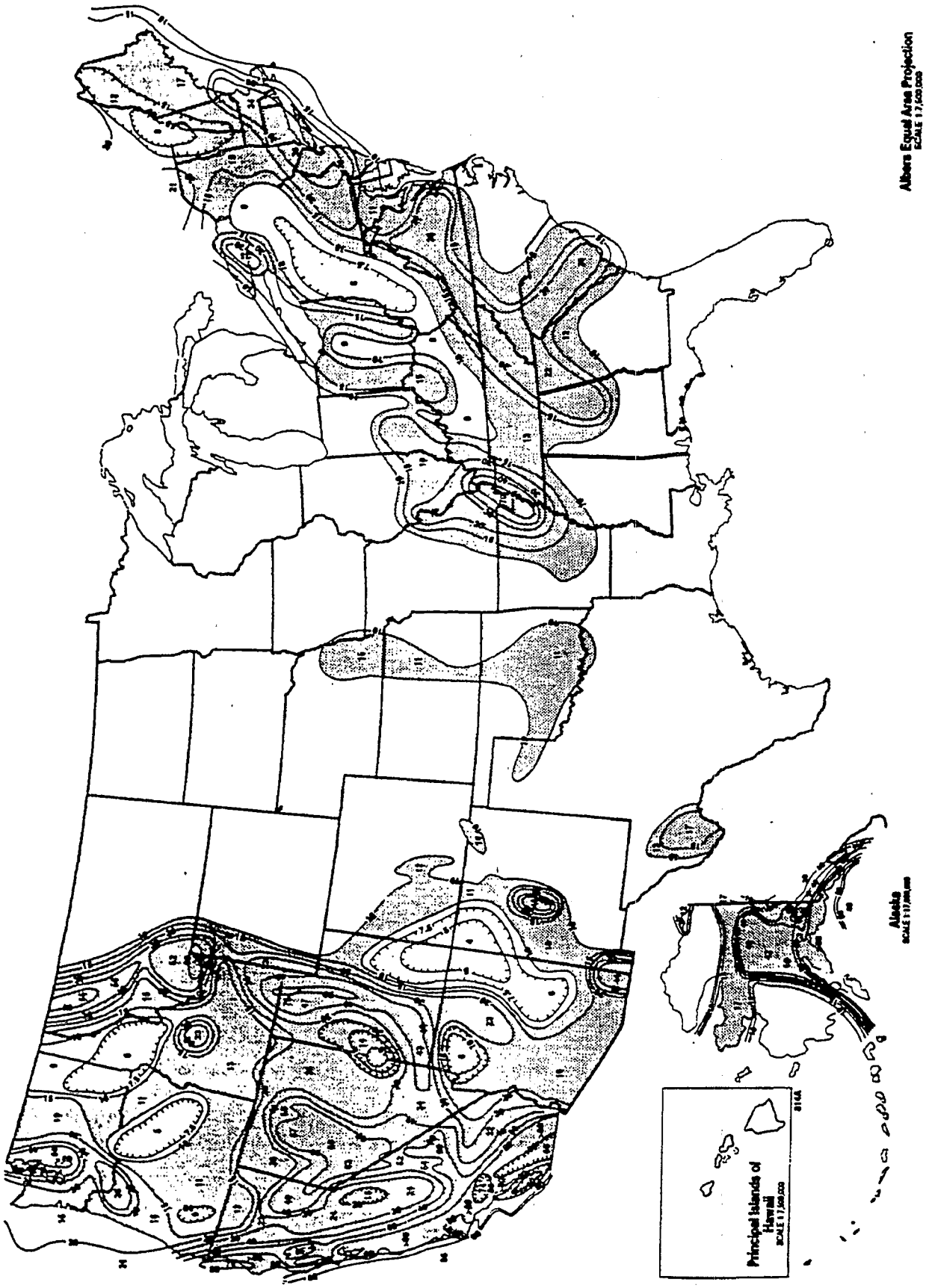


Figure 4-2. Seismic impact zones (U.S. EPA, 1993).

A fault characterization will be necessary to determine whether an active sewage sludge unit is located within 60 meters (200 ft) of a Holocene time fault. This investigation may involve review of available maps, logs, reports, scientific literature and/or insurance claims reports; an aerial reconnaissance of an area within a 5-mile (8-km) radius of the unit; and/or a walking tour of the area within 3,000 feet (914 m) of the unit. Two useful tools for identifying fault zones are (1) the U.S. Geological Survey map series identifying the location of Holocene faults in the United States (Preliminary Young Fault Maps, MF916), and (2) the NAPP/NHAP high altitude, high resolution areal photographs with stereo coverage, available from the U.S. Geological Survey's EROS Data Center. If preliminary investigations indicate the presence of one or more faults within 3,000 feet (914 m) of the proposed active sewage sludge unit, further investigation will be needed to determine whether any faults displaced during Holocene time exist within 200 feet (60 m) of the unit. This investigation should be performed by a qualified professional and may involve subsurface exploration.

- *Unstable Area.* Part 503 requires that an active sewage sludge unit not be located in an unstable area. An unstable area is land where natural or human activities might occur that could damage the unit's structures. Unstable areas include land where large amounts of soil are moved, such as by landslides, or where the surface lowers or collapses when underlying limestone or other materials dissolve. This requirement protects the structures of an active sewage sludge unit from damage by natural or human forces. Local geological studies may be necessary to determine that unstable conditions do not exist at potential units.

If these management practices are followed, it is less likely that pollutants in sewage sludge will be released into the environment because of unstable geological conditions. Whether an active sewage sludge unit is within a geologically unstable area can be determined using maps available through the U.S. Geologic Survey, Earth Science Information Center, 12201 Sunrise Valley Drive in Reston, Virginia. States also have geological surveys that map the locations of geologically unstable areas. (For example, in California, guidelines are available from the California Division of Mines and Geology for identifying fault areas.)

4.2.1.4 Protection of Wetlands

Wetlands are areas where the soils are filled with water (or "saturated") during part of the year and contain vegetation typically found in saturated soils. Examples of wetlands include swamps, marshes, and bogs. Wetlands perform important ecological functions, such as holding flood waters, serving as habitat and providing sources of food for numerous species, and reducing soil erosion. Wetlands also hold pollutants, preventing them from contaminating other areas.

Part 503 requires that an active sewage sludge unit not be located in a wetland, unless a permit is issued under Section 402 (National Pollutant Discharge Elimination System [NPDES] permit) or Section 404 (dredge and fill permit) of the Clean Water Act. Other federal regulations that may apply to surface disposal sites in wetlands are listed below. Figure 4-3 shows a decision tree for considering the wetlands requirement during the siting process.

Any wetlands delineation study to determine whether wetlands are present should be conducted by a qualified and experienced team of experts in soil science and botany/biology. Methods used should be in keeping with the federal guidance in place at the time of delineation. Criteria for identifying wetlands have been developed by a federal task force in a manual published by the U.S. Army Corps of Engineers (COE, 1989). Proposed changes to this manual, however, are still being reviewed. Therefore, as of January 1993, the EPA and COE agreed to use COE (1987) as guidance for delineating wetlands.

Additional published information that may be useful includes USGS topographic maps, National Wetland Inventory maps, USDA Soil Conservation Service soil maps, and wetland inventory maps prepared locally. Some of the local COE District Offices can provide a wetland delineation to indicate whether all or some portion of a potential or actual active sewage sludge unit is in a wetland. The state agency regulating activities in wetlands should also be asked to inspect the area in question. The definition of a wetland and the regulatory requirements for activities in wetlands may be different at the state level.

Other Federal Regulations

In addition, other federal regulations may apply to siting a surface disposal site in a wetland. These include:

- Sections 401, 402, and 404 of the Clean Water Act
- The Rivers and Harbors Act of 1989
- Executive Order 11990, Protection of Wetlands
- The National Environmental Policy Act
- The Migratory Bird Conservation Act
- The Fish and Wildlife Coordination Act
- The Coastal Zone Management Act
- The Wild and Scenic Rivers Act
- The National Historic Preservation Act

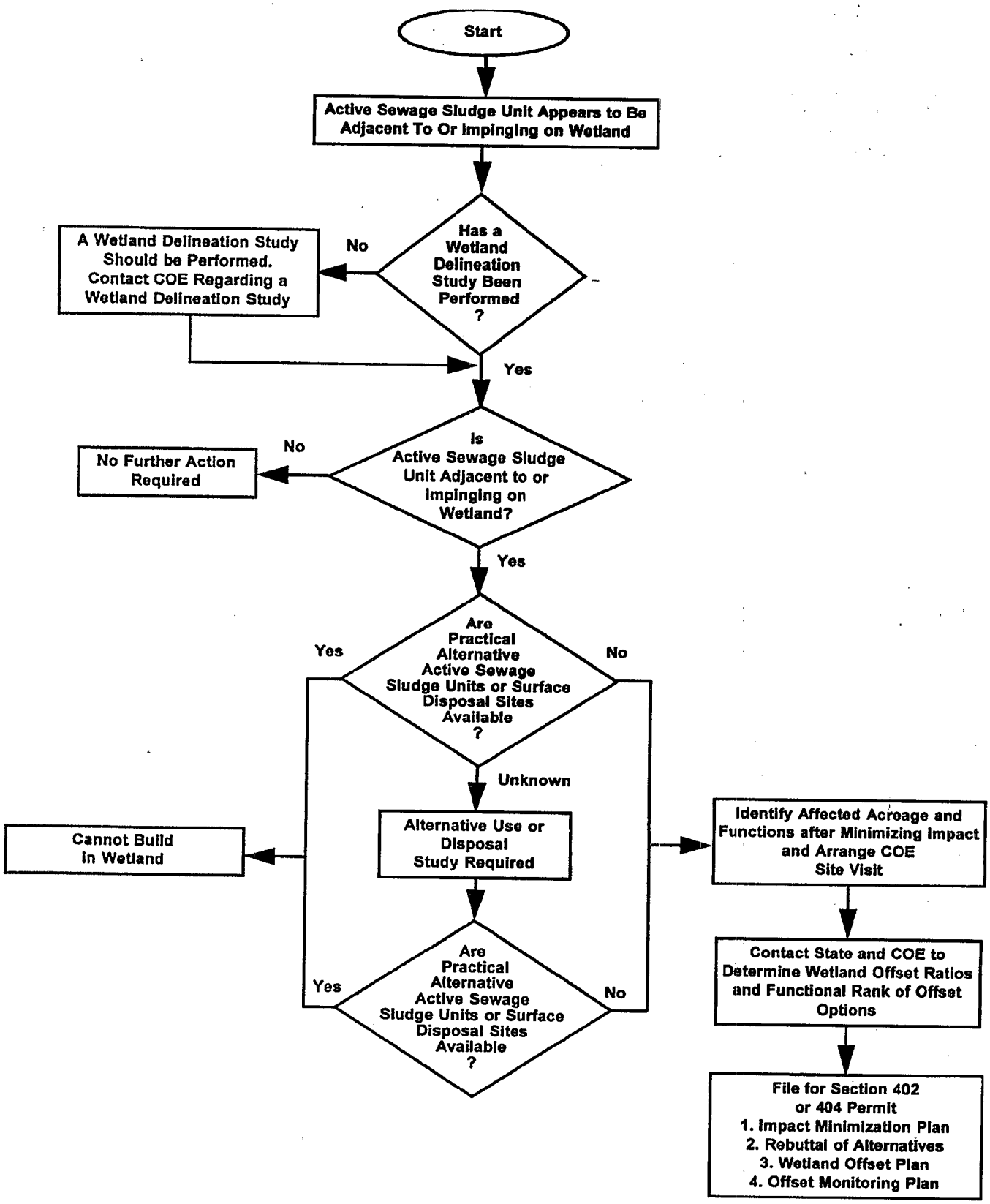


Figure 4-3. Wetlands decision tree for siting active sewage sludge unit (U.S. EPA, 1993).

4.2.1.5 Protection of Surface Water—Collection of Runoff and Leachate

Runoff is rain water or other liquid that drains over the land and runs off the land surface. Part 503 requires that runoff from an active sewage sludge unit be collected and disposed according to permit requirements of the National Pollutant Discharge Elimination System and any other applicable requirements.

Leachate is fluid from excess moisture in sewage sludge or from rain water percolating down from the land surface through an active sewage sludge unit. If an active sewage sludge unit has a liner and leachate collection system, Part 503 requires that leachate be collected and disposed according to applicable requirements. These include NPDES permit requirements for leachate discharged as a point source to surface water. The system must be operated in accordance with applicable requirements while the unit is active and for 3 years after it closes (or longer if required by the permitting authority).

In view of these requirements, selection of a site on or near surface water can compound design and operational difficulties and increase the difficulty in securing permits. This should be considered during the selection process. As part of the site selection process, existing surface water bodies and drainage on or near proposed sites should be mapped and their current and future use considered.

4.2.1.6 Protection of Ground Water

One of the Part 503 management practices requires that sewage sludge placed on an active sewage sludge unit not contaminate an aquifer. An aquifer is an area below the ground that can yield water in large enough quantities to supply wells or springs. "Contaminating an aquifer" in this instance means introducing a substance that can cause the level of nitrate in ground water to increase above a certain amount. Under this management practice nitrate-nitrogen levels in ground water must not exceed the MCL of 10 mg/liter or must not increase the existing concentration of nitrate-nitrogen in ground water if that concentration exceeds the MCL. Pollutants in sewage sludge other than nitrate are addressed by pollutant limits (see Section 3.4.2).

Part 503 also requires proof that the sewage sludge placed on an active sewage sludge unit is not contaminating an aquifer. This proof must be either (1) the results of a ground-water monitoring program developed by a qualified ground-water scientist, or (2) certification by a ground-water scientist that ground water will not be contaminated by the placement of sewage sludge on the active sewage sludge unit. The certification option usually is obtainable only if the unit has a liner and leachate collection system because it can be difficult to certify that ground water will not be contaminated in the absence of a liner, unless ground water is very deep and protected by a natural clay layer.

Assessment of local aquifers is an essential step in helping to ensure that an active sewage sludge unit will not contaminate an aquifer. Data collected should include:

- Depth to ground water (including historical highs and lows).
- Hydraulic gradient.
- Existing ground-water quality.
- Current and projected ground-water use.
- The location of primary recharge zones.

Sludge should not be placed where there is a potential for direct contact with the ground-water table. Also, major recharge zones should be eliminated from consideration, particularly sole source aquifers. As much distance as possible should be maintained between the bottom of the fill and the highest known level of ground water.

The structural and mineralogical characteristics (with respect to nitrate-nitrogen) of any nearby aquifers should be delineated so that the potential for contamination can be accurately assessed. Any faults, major fractures, and joint sets in the vicinity of an active sewage sludge unit should be identified. Karst terrains and other solutional formations should be avoided. In general, limestone, dolomite, and heavily fractured crystalline rock are less desirable than consolidated sedimentary bedrock and unconsolidated alluvial and other unconsolidated formation.

Ground-Water Data Sources

Sources of data on ground-water quality and movement include the U.S Geological Survey "Ground-water Data Network," local well drillers, state geological surveys, state health departments, other state environmental and regulatory agencies, and samplings from nearby wells. The USGS also publishes an annual report entitled "Ground-water Levels in the United States" in the Water-Supply Paper Series. The data for this paper are derived from some 3,500 observation wells located across the nation.

On-site Drilling

If necessary, further background information on ground-water elevations, fluctuations, and quality and on the hydraulic gradient should be collected by performing on-site drilling. The hydraulic gradient is equivalent to the slope of the ground-water table (or, for an artesian aquifer, the slope of the piezometric surface). Data on the hydraulic gradient helps ascertain the rate and amount of ground-water movement and whether hydraulic connections to surrounding aquifers exist.

The direction of ground-water flow (and thus of the hydraulic gradient) can be determined by noting the depth to ground water in nearby wells or borings, calculat-

ing the elevation of the ground water, and drawing contour lines that connect wells of equal ground-water elevations. At least three wells (and normally more) are needed to determine the direction of ground-water flow. Usually large units, units with complex hydrogeology, and/or relatively flat units require more borings than small units. An experienced hydrogeologist should participate in the research and exploratory drilling to interpret field data. He or she can recommend the number, location, and type of exploratory wells needed. Table 4-2 summarizes the methods for collecting data from the subsurface and the type of information available from the methods.

4.2.2 Part 258

The 40 CFR Part 258 regulations promulgated in 1991 under the authority of RCRA Subtitle D establish minimum national siting requirements for municipal solid waste (MSW) landfills, including MSW landfills where sewage sludge is codisposed with household waste. Most states have already implemented stricter landfill

Table 4-2. Summary of Methods for Collecting Data from the Subsurface (U.S. EPA, 1994)

Method	Properties	Comments
Vertical Variations		
Drill logs	Changes in lithology Aquifer thickness Confining bed thickness Layers of high/low hydraulic conductivity Variations in primary porosity (based on material description)	Basic source for geologic cross sections. Descriptions prepared by geologist preferred over those by well drillers. Continuous core samples provided more accurate descriptions.
Electric logs	Changes in lithology Changes in water quality Strike and dip (dipmeter)	Require uncased hole and fluid-filled borehole.
Nuclear logs	Changes in lithology Changes in porosity (gamma-gamma)	Suitable for all borehole condition (cased, uncased, dry, and fluid-filled).
Acoustic and seismic logs	Changes in lithology Changes in porosity Fracture characterization Strike and dip (acoustic televiewer)	Requires uncased or steel cased hole, and fluid-filled hole.
Other logs	Secondary porosity (caliper, television/photography) Variations in permeability (fluid-temperature, flowmeters, single borehole tracing)	Require open, fluid-filled borehole. Relatively inexpensive and easy to use.
Packer Tests	Hydraulic conductivity	Single packer tests used during drilling; double-packer tests after hole completed.
Surface geophysics	Changes in lithology (resistivity, EMI, TDEM, seismic refraction)	Requires use of vertical sounding methods for electrical and electromagnetic methods.
Lateral Variations		
Poteniometric maps	Changes in hydraulic conductivity	Based on interpretation of the shape and spacing of equipotential contours.
Hydrochemical maps	Changes in water chemistry	Requires careful sampling, preservation and analysis to make sure samples are representative.
Tracer tests	Time of travel between points.	Requires injection point and one or more downgradient collection points. Essential for mapping of flow in karst.
Geologic maps and cross-sections	Changes in formation thickness Structural features, faults	Result from correlation features observed at the surface and in boreholes.
Isopach maps	Variations in aquifer and confining layer thickness.	Distinctive strata with large areal extent required.
Geologic structure maps	Stratigraphic and structural boundary conditions affecting aquifers.	See Table 5-6.
Surface geophysics	Changes in lithology (seismic) Structural features (seismic, GPR, gravity) Changes in water quality/ contaminant plume detection (ER, EMI, GPR).	Interpretations require verification using subsurface borehole data.

U.S. Environmental Protection Agency (EPA), 1994. Ground Water and Wellhead Protection. EPA/625/R-94/001. Available from CERI.

siting requirements, such as restrictions on development in critical watershed areas, wellhead protection areas, sole source aquifers, or agricultural lands. A complete discussion of the siting requirements for MSW landfills established under the Part 258 regulations is beyond the scope of this manual. For further information on the Part 258 requirements, consult EPA (1993).

4.3 Additional Considerations

In addition to the regulatory requirements described above, many other considerations govern the suitability of a site for surface disposal of sewage sludge. These include:

- Site life and size
- Topography
- Soils
- Vegetation
- Meteorology
- Site access
- Land use
- Archaeological or historical significance
- Costs

Table 4-3 summarizes these site selection criteria for surface disposal sites.

4.3.1 Site Life and Size

The site life and size are directly related. The larger the site, the longer the site life. Both site life and size are a function of the quantity and characteristics (especially the percent solids) of the sludge, and the surface area requirements of the chosen active sewage sludge unit.

Table 4-3. Surface Disposal Site Selection Criteria

Physical Site:	Should be large enough to accommodate waste for life of production facility.
Proximity:	Locate as close as possible to production facility to minimize handling and reduce transport cost. Locate away from water supply (suggested minimum 1 km) and property line (suggested minimum 250 m).
Access:	Should be all-weather, have adequate width and load capacity, with minimum traffic congestion. Easy access to major highways and railway transport.
Topography:	Should minimize earth-moving, take advantage of natural conditions. Avoid natural depression and valleys where water contamination is likely unless good control of surface water can be assured (suggested site slope of less than 5%).
Geology:	Avoid areas with earthquakes, slides, faults, underlying mines, sinkholes and solution cavities.
Hydrology:	Areas with low rainfall and high evapotranspiration and not affected by tidal water movements and seasonal high water table.
Soils:	Should have a natural clay base, or clay available for liner, and final cover material available; stable soil/rock structure. Avoid sites with thin soil above groundwater, highly permeable soil above shallow groundwater and soils with extreme erosion potential.
Drainage:	Areas with good surface drainage and easy control of runoff.
Surface Water:	Protection of the site against floods. Avoid wetlands or other areas with high watertables.
Groundwater:	No contact with groundwater. Base of fill must be above high groundwater table. Avoid sites above sole-source aquifers and areas of groundwater recharge.
Temperature:	Not within area of recurring temperature inversions.

Table 4-3. Surface Disposal Site Selection Criteria (continued)

Physical Site:	Should be large enough to accommodate waste for life of production facility.
Proximity:	Locate as close as possible to production facility to minimize handling and reduce transport cost. Locate away from water supply (suggested minimum 1 km) and property line (suggested minimum 250 m).
Access:	Should be all-weather, have adequate width and load capacity, with minimum traffic congestion. Easy access to major highways and railway transport.
Topography:	Should minimize earth-moving, take advantage of natural conditions. Avoid natural depression and valleys where water contamination is likely unless good control of surface water can be assured (suggested site slope of less than 5%).
Geology:	Avoid areas with earthquakes, slides, faults, underlying mines, sinkholes and solution cavities.
Hydrology:	Areas with low rainfall and high evapotranspiration and not affected by tidal water movements and seasonal high water table.
Soils:	Should have a natural clay base, or clay available for liner, and final cover material available; stable soil/rock structure. Avoid sites with thin soil above groundwater, highly permeable soil above shallow groundwater and soils with extreme erosion potential.
Drainage:	Areas with good surface drainage and easy control of runoff.
Surface Water:	Protection of the site against floods. Avoid wetlands or other areas with high watertables.
Groundwater:	No contact with groundwater. Base of fill must be above high groundwater table. Avoid sites above sole-source aquifers and areas of groundwater recharge.
Temperature:	Not within area of recurring temperature inversions.

For calculation purposes, the surface area requirements can be divided into three categories (see Figure 4-4):

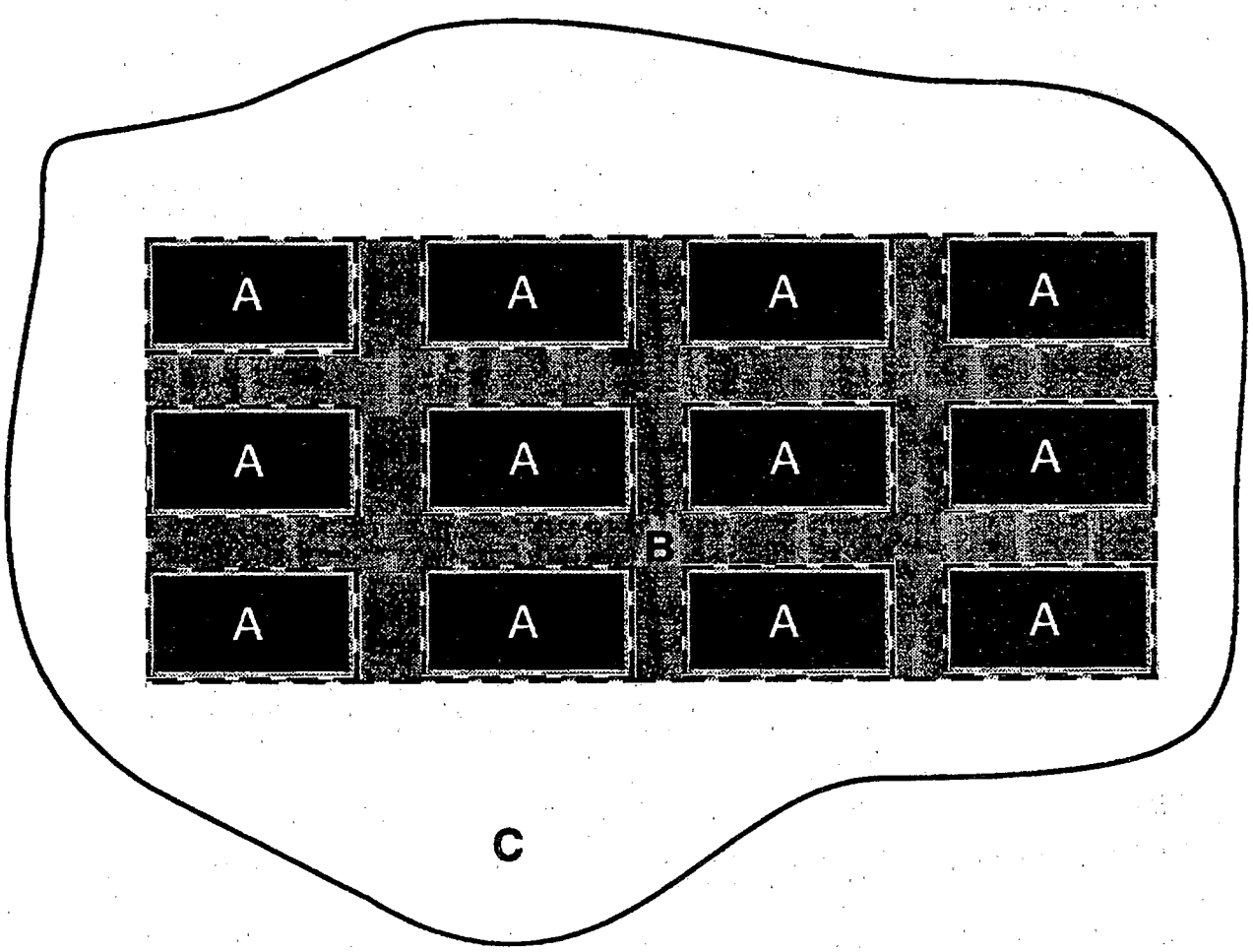
- A. The surface area where the sludge will be placed (e.g., the area of all the active sewage sludge units).
- B. The surface area required for spacing between the active sewage sludge units.
- C. Additional surface area required for buffers, access roads, and soil stockpiles.

The first two are referred to collectively as the usable fill area. They typically consume 50 percent to 70 percent of the site's gross area (i.e., the total site area within the surface disposal site property line).

The site size needed for a desired site life can be calculated by the following process if the total sludge volume, active sewage sludge unit dimensions, spacing between units, and additional area needed for buffer, etc., are known.

- Step 1: Calculate the total fill volume needed over the desired lifetime of the site (F) by calculating the total sludge volume that must be disposed within the site's desired lifetime.
- Step 2: Divide F by the desired individual active sewage sludge unit volume to calculate the number of units needed (N).
- Step 3: Calculate the usable fill area needed (U) by multiplying N by the area of each active sewage sludge unit plus the area required for spacing between each unit.
- Step 4: Calculate the minimum gross area needed by adding to U the acreage needed for buffer, access roads, etc.

Figure 4-5 illustrates this procedure applied to a wide trench operation.



KEY

A = Active sewage sludge units where sludge will be placed.

B = Area required for spacing between active sewage sludge units.

C = Additional surface area required for buffers, access roads, and soil stockpiles.

= Boundary of active sewage sludge units.

= Boundary of surface disposal site.

Figure 4-4. Schematic representation showing different types of surface area requirements at a sludge disposal site.

Similarly, the site life needed for a desired site size can be calculated by the following process if the total sludge volume, disposal unit dimensions, and spacing between units are known:

- Step 1: Divide the surface area of an individual active sewage sludge unit plus the spacing between units by the usable fill area to calculate the number of units that can be constructed in the fill area (N).
- Step 2: Calculate total volume of all sludge units (V) by multiplying N by the volume of an individual unit.
- Step 3: Calculate the site life by dividing V by the sludge volume generated daily or annually.

Given:

1. Sludge volume = 60 yd^3/day, 7 days/week, 29% solids sludge
2. Trench life = 10 yrs
3. Trench dimensions = 45 ft wide x 10 ft deep x 200 ft long
4. Trench spacing = 10 ft of solid ground between trenches
5. Buffer = 100 ft minimum, from usable fill area to property line

Calculations

Step 1. Calculate total fill volume needed:

$$(60\ yd^3/day) \times (365\ days/yr) \times (10\ yrs) = 219{,}000\ yd^3$$

Step 2. Calculate the number of trenches needed:

$$\frac{(219{,}000\ yd^3) \times (27\ ft^3/yd^3)}{(45\ ft \times 10\ ft \times 200\ ft} = 65.7\ trenches$$

Step 3. Calculate the usable fill area needed:

45 ft wide x 200 ft long trenches plus 10 ft between trenches = 55 ft x 210 ft gross space for each trench

$$(65.7\ trenches) \times (55\ ft \times 210\ ft\ trench) = 758{,}835\ ft^2$$

$$\frac{(758{,}835\ ft^2)}{(43{,}560\ ft^2/acre)} = 17.4\ acres$$

Step 4. Calculate minimum gross acreage required:

$$17.4\ acres = 870\ ft \times 870\ ft$$

Minimum site size = $[870 + 2\ (100\ ft\ buffer)]^2$ + 25% for access roads, dumping pad, and miscellaneoous uses = 33 acres

1 ft = 0.305 m
1 yd = 1.609 m
1 acre = 0.405 ha

Figure 4-5. Sample calculation of surface disposal site size required for a wide trench operation. *Note: This method for calculating site size is only approximate.*

Figure 4-6 illustrates this calculation for a sludge-only narrow trench operation. Defining site life is an important factor in long-term planning and in estimating costs.

The chosen active sewage sludge unit impacts site life and size. For example, a wide trench method uses less land than a narrow trench operation, and thus provides a longer site life, all other factors being equal. The sludge application rates given in Table 2-2 (see Chapter 2) provide a means of comparing the land use efficiency (and thus relative life span, all other factors being equal) of the various types of active sewage sludge units.

4.3.2 Topography

Different types of active sewage sludge units have different topographic requirements that may limit the suitability of various sites. For example, monofills are usually limited to areas with slopes greater than 1 percent and less than 20 percent because a relatively flat site could pond, and an excessively steep site could

Given:

1. Sludge volume = 45 yd^3/day, 7 days/week, 22% solids sludge
2. Usable fill area = 6 acres
3. Trench dimensions = 10 ft wide x 5 ft deep x 120 ft long
4. Trench spacing = 5 ft of solid ground between trenches

Calculations

Step 1. Calculate number of available trenches:

Each trench will have area = 15 ft x 125 ft = 1,875 ft^2

Total acreage = 6 acres = 261,360 ft^2

$$\text{Number of trenches} = \frac{261{,}360\ ft^2}{1{,}875\ ft^2} = 139\ trenches$$

Step 2. Calculate total trench volume available:

$$(139\ trenches) \times \frac{(10\ ft \times 5\ ft \times 120\ ft)}{trench} \times \frac{1\ yd^3}{27\ ft^3} = 30{,}889\ yd^3$$

Step 3. Calculate site life:

$$\frac{30{,}889\ yd^3}{45\ yd^3/day} = 686\ days = 1.9\ years$$

1 ft = 0.305 m
1 yd = 1.609 m
1 acre = 0.405 ha

Figure 4-6. Sample calculation of surface disposal site size life for a narrow trench operation. *Note: This method for calculating site size is only approximate.*

erode and create operational difficulties. Dedicated disposal sites, on the other hand, require relatively flat land; natural slopes greater than 0.5 percent must be modified to prevent erosion (U.S. EPA, 1979). Graded or terraced sites can be used for dedicated disposal sites, but this involves increased earthmoving costs. Table 2-1 in Chapter 2 compares the ground slope requirements of the various surface disposal options.

4.3.3 Soils

The role of soil in surface disposal is to provide cover, when appropriate, control runoff and leachate, and serve as a bulking agent (if warranted by the chosen active sewage sludge unit). The chemical and physical/hydraulic properties of a soil determine how effective it will be in performing these roles. Relevant soil properties that should be noted during the selection process are:

- Physical/hydraulic properties:
  - Grain size
  - Plasticity
  - Moisture content
  - Sheer strength
  - Permeability/hydraulic conductivity
  - Atterberg limits

- Chemical properties:
  - pH

4.3.3.1 Physical/Hydraulic Properties

The ideal soil for an active sewage sludge unit would be sufficiently impermeable to prevent movement of pollutants in sewage sludge to the ground water and have appropriate chemical properties to attenuate heavy metals. The actual amount and type of soil needed depends on the type of active sewage sludge unit and the characteristics of the sludge (U.S. EPA, 1977b). In general, however, a desirable geology will have some combination of deep [i.e., 30 feet (9 meters) or more] and fine-grained soils. Figure 4-7 gives the soil textural classes and general terminology used in soil descriptions by the U.S. Department of Agriculture, Soil Conservation Service (SCS).

Permeability depends on soil texture and structure. Fine-grained, poorly structured soils have the lowest permeabilities. Table 4-4 and Figure 4-8 give qualitative ranges for classifying soil permeabilities. Depending on the sludge characteristics, a moderately low to low permeability soil is desirable for an active sewage sludge unit.

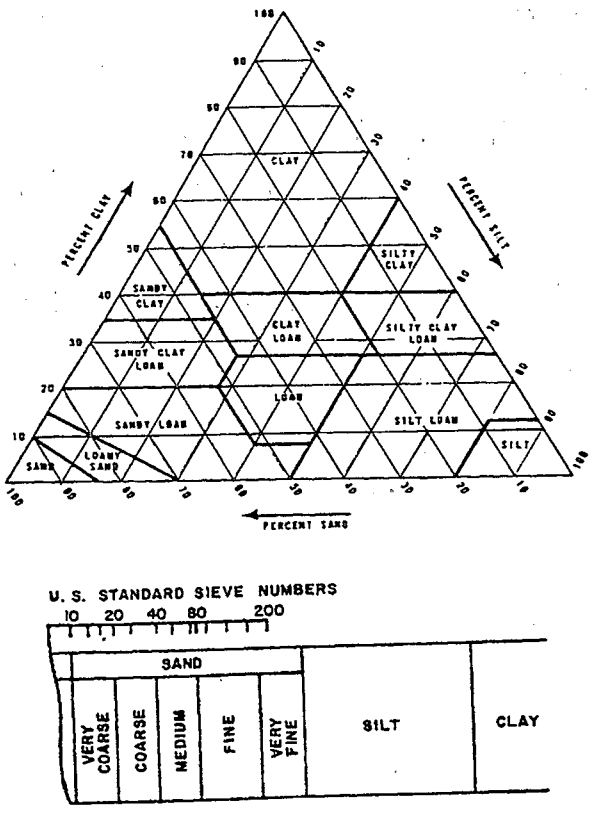


Figure 4-7. Soil textural classes and general terminology used in soil descriptions by the U.S. Department of Agriculture.

Table 4-4. Soil Saturated Hydraulic Conductivity and Permability Classes (U.S. EPA, 1991)

Class	Values	
Saturated Hydraulic Conductivity		
	(μ/s)	(in./hr)
Very Low (VL)	<0.01	<0.001
Low (L)	0.01-0.1	0.001-0.01
Moderately Low (ML)	0.1-1	0.01-0.14
Moderately High (MH)	1-10	0.14-1.4
High (H)	10-100	1.4-14.2
Very High (VH)	>100	>14.2
Permeability (Infiltration)		
	(in./hr)	(cm/hr)
Very Slow	<0.06	<0.15
Very Extremely Slow	<0.01	
Extremely Slow	0.01-0.06	
Slow	0.06-0.2	0.15-0.5
Moderately Slow	0.2-0.6	0.5-1.5
Moderate	0.6-2.0	1.5-5.0
Moderately Rapid	2.0-6.0	5.0-15.2
Rapid	6.0-20	15.2-50.8
Very Rapid	>20	>50.8

U.S. Environmental Protection Agency (EPA). 1991. Description and sampling of contaminated soils: A field pocket guide. EPA/625/2-91/002.

Climate also influences the soil requirements of a specific site. In an area with high rainfalls, for example, soils with permeabilities lower than the sludge permeabilities could result in the so-called "bathtub" effect: a situation in which water accumulates in the fill areas and cannot drain. In such cases, leachate collection systems should be designed to handle excess water.

4.3.3.2 Chemical Properties

Soil pH influences the ability of soils to retain or pass pollutants (U.S. EPA, 1977a). Heavy metals are frequently held by alkali soils. Soil pH was considered when the Part 503 pollutant limits were developed. Results of field studies during which sewage sludge was applied to land with different pHs were used in the Part 503 risk assessment for use and disposal of sewage sludge. Thus, the Part 503 pollutant limits are protective for soils with different pHs. Other significant considerations concerning soils are compaction characteristics, drainage, and slope stability. Coarse-grained soils are more suitable for structural applications such as road bed material, foundations, bulking soil, and daily cover. Fine-grained soils are more suitable for environmental

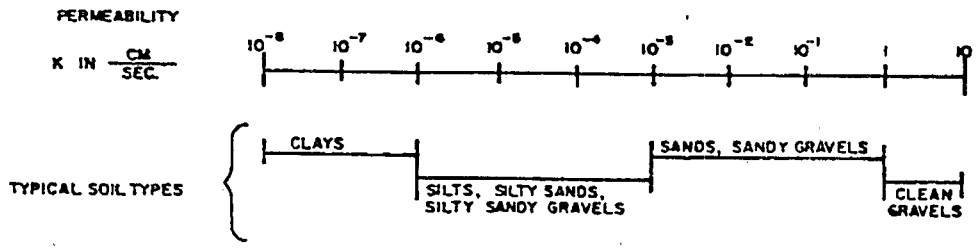


Figure 4-8. Soil permeabilities of selected soils.

applications such as bottom liners and final covers and caps. These are summarized in Figure 4-9.

4.3.4 Vegetation

The amount and type of vegetation on a prospective surface disposal site should be considered in the selection process. Vegetation can serve as a natural buffer, reducing dust, noise, odor, and visibility. However, a vegetated site may require extensive logging and/or clearing of vegetation, which can significantly increase project costs.

4.3.5 Meteorology

Prevailing wind direction, speed, temperature, and atmospheric stability should be evaluated to determine potential odor and dust impacts downwind of the site.

4.3.6 Site Access

The haul routes to the prospective sites should utilize major highways or arterials if possible. Potential routes should be driven and studied to determine the physical adequacy of roadways for truck traffic; the approximate number of residences, parks, and schools fronting the roads; the probable impact on traffic congestion; and the potential effects of accidents. Transport through nonresidential areas is preferable to transport through residential areas, high-density urban areas, and areas with congested traffic. The access roads to the site must be adequate for the anticipated traffic loads. The potential for increased noise, dust, odor, etc., along haul routes can be a major public concern.

4.3.7 Land Use

Both current and possible future zoning of each prospective surface disposal site should be considered. The appropriate county or municipal zoning authority should be contacted to determine zoning status or restrictions for each potential site. The final use for the site (once the site has been closed) should be considered early in the selection process and evaluated relative to future zoning (see Chapter 12).

Regional development should also be considered in site selection, and existing master plans for the area should be consulted. The evaluation of current and future development may present the opportunity for a more strategically centralized location of the site. Also, knowing the projected rate and location of industrial and/or municipal development is important to determine the site size needed to meet projected demands.

4.3.8 Archaeological or Historical Significance

The archaeological and/or historical significance of a potential surface disposal site should be determined by a qualified archaeologist/anthropologist and addressed in an environmental impact report. Any finds of significance in relation to the archaeology or history of the site should be accommodated before the site can be approved and construction can begin.

4.3.9 Costs

Early in the selection process, surface disposal sites should be screened according to their estimated relative costs, including both capital and operating costs. Figure 4-10 shows a method for estimating site costs. However, this method does not account for the time value of money. For most sites—particularly long-lived sites—inflation will tend to favor the selection of sites with high capital costs over sites with relatively higher operating costs. In some cases, it may be necessary to compute amortized capital costs. Nevertheless, the process described in Figure 4-10 is less complex and will be accurate in most cases. Chapter 13 contains additional information on the costs of surface disposal.

4.4 Site Selection: A Methodology for Selecting Surface Disposal Sites

Site selection can be broken down into four basic stages:

- Initial site assessment and screening
- Site scoring and ranking
- Site investigation
- Final selection

Major Divisions		SYMBOL Letter	SYMBOL Hatching	SYMBOL 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.

Figure 4-9. Unified soil classification system with characteristics pertinent to surface disposal site (U.S. EPA, 1972).

1. Determine the capital costs (C) in dollars over the life of the surface disposal site. This should include primarily:
   a. Land acquisition
   b. Site preparation
   c. Equipment purchase.
2. Determine site life (L) in years.
3. Compute unit capital cost (P_1) in dollars/y^3 of sludge based on proposed annual sludge quantity (Q) in yd^3/yr for site life.
   $P_1 = \frac{C}{LQ}$.
4. Determine total operating cost (O) in dollars over 1 year. This should include primarily:
   a. Labor
   b. Equipment fuel, maintenance, and parts
   c. Utilities
   d. Laboratory analysis of water samples
   e. Supplies and materials
   f. Miscellaneous and other.
5. Compute unit operating cost (P_2) in dollars/y^3 of sludge based on proposed annual sludge quantity (Q) in yd^3/yr.
   $P_2 = \frac{O}{Q}$.
6. Determine total hauling cost (H) in dollars over one year.
7. Compute unit haul cost (P_3) in dollars/y^3 of sludge based on proposed annual sludge quantity (Q) in yd^3/yr.
   $P_3 = \frac{H}{Q}$.
8. Compute total annual cost (T) in dollars/yd^3 of sludge.
   $T = P_1 + P_2 + P_3$

Figure 4-10. Method for estimating site costs. *Note: This method does not account for inflation.*

These stages are described in detail in this section and illustrated with an example for Study Area X. Smaller sites may not need as detailed a selection process.

4.4.1 Step 1: Initial Site Assessment and Screening

The purpose of this phase is to develop a list of potential sites that can be evaluated and rapidly screened to produce a manageable number of candidate sites. Information used in this phase is generally available and readily accessible. This phase can be divided into seven steps, described below.

Step 1-1: Determine factors that will constrain site selection. Consider:

- Federal, state, and local regulations.
- Physical limitations (e.g., ground-water depth, maximum slope).
- Demographic limitations (distance to nearest residence, land-use factors, etc.).
- Political limitations (public reaction, special interest groups, budget management).

Step 1-2: Establish suitable study area(s):

- Determine maximum radius of study area based on haul distance(s) from wastewater treatment plant(s) and/or centroid of potential service area.
- Use transparent (mylar) overlays to designate areas that must be excluded due to regulatory constraints or that are problematic due to other considerations. Tables 4-5 and 4-6 list exclusionary and low suitability criteria for sewage sludge surface disposal sites and codisposal sites, respectively.
- Place shaded mylars of these unsuitable or low suitability areas on the study area map. The unshaded area may be considered generally suitable for surface disposal of sewage sludge. Figure 4-11 provides an example of an overlay map for Study Area X using three shaded mylars. (Only three mylars were used in the illustration to keep it simple. In reality, several mylars are often used.)

Step 1-3: Identify potential candidate surface disposal sites:

- Inform local realtors.
- Investigate past site inventories.
- Study maps or aerial photographs.
- Traverse roads in high probability areas and look for "For Sale" or "For Lease" signs.

Table 4-5. Exclusionary and Low Suitability Criteria for Sewage Sludge Surface Disposal Sites

Exclusionary Criteria
• The presence of a surface disposal operation at the site could adversely affect a threatened or endangered species listed under Section 4 of the Endangered Species Act.
• Placement of sewage sludge on an active sewage sludge unit would restrict the flow of a base flood.
• Site is located within 60 meters of a fault that has displacement measured in "Holocene time."
• Site is located in a geologically unstable area.
• Site has wetlands.
Low Suitability Criteria
• Located within a 100-year flood zone.
• Located within a seismic impact zone.
• In the recharge zone of a sole source aquifer.
• Inappropriate slope.
• Other undesirable geological features (karst, fractured bedrock formations).
• Dense population.
• Undesirable soil (shallow, high organics, permafrost areas).
• On or near surface waters.

Table 4-6. Exclusionary and Low Suitability Criteria for Codisposal Sites

Exclusionary Criteria

- Site is located within 10,000 feet (3,048 meters) of the end of any public airport runway used by turbojet aircraft or within 5,000 feet (1,524 meters) of the end of any public airport runway used by only piston-type aircraft and a codisposal operation on the site might pose a bird hazard to aircraft.
- Site is located within a 100-year flood plain and the presence of a codisposal operation might restrict the flow of the 100-year flood, reduce the temporary storage capacity of the floodplain, or result in a washout of the municipal solid waste.
- Site contains wetlands (unless the site is located in an approved state[a] and the owner/operator can demonstrate that no practical alternative not involving wetlands exists and fulfil other demonstration criteria).
- Site is located within 200 ft (60 m) of a fault area that has experienced displacement within the Holocene time (approximately the last 11,000 years) (unless the site is located in an approved state[a] and the owner/operator can demonstrate sufficient structural integrity of the facility to ensure protection of human health and the environment in the event of a displacement).
- Site is located in a seismic impact zone (unless the site is located in an approved state[a] and the owner/operator can demonstrate that all containment structures are designed to resist the maximum horizontal acceleration).
- Site is located in an unstable area (unless the owner/operator can demonstrate that engineering measures have been incorporated into the unit's design to ensure the integrity of the codisposal operation's structural components).

Low Suitability Criteria

- Poses a hazard to a threatened or endangered species.
- Inappropriate slope.
- Dense population.
- Undesirable soil (shallow, high organics, permafrost areas).
- On or near surface waters.
- In the recharge zone of an aquifer.

[a] A state approved by EPA for primary implementation of the Part 258 regulations.

Step 1-4: Assess economic feasibility (ballpark estimate based on experience, rule of thumb, judgment) of candidate sites including:

- Haul distances
- Rough estimate of site development cost
- Quantity of sludge
- Operating hours per week for equipment and personnel

Step 1-5: Perform preliminary site investigations using existing information and tabulate information. Pertinent information includes:

- Location
- Zoning
- Land use (on and near site)
- Access
- Haul distance and routes
- Topography
- Soil characteristics
- Usable area of site
- Drainage basin

Table 4-7 shows an example of tabulated site investigation information for 13 candidate sites for Study Area X.

Step 1-6: Eliminate less desirable sites based on regulatory, economic, and technical considerations.

Step 1-7: Obtain public input via the public participation program (see Chapter 5). For example, a kick-off meeting would help to determine the attitude of the citizenry

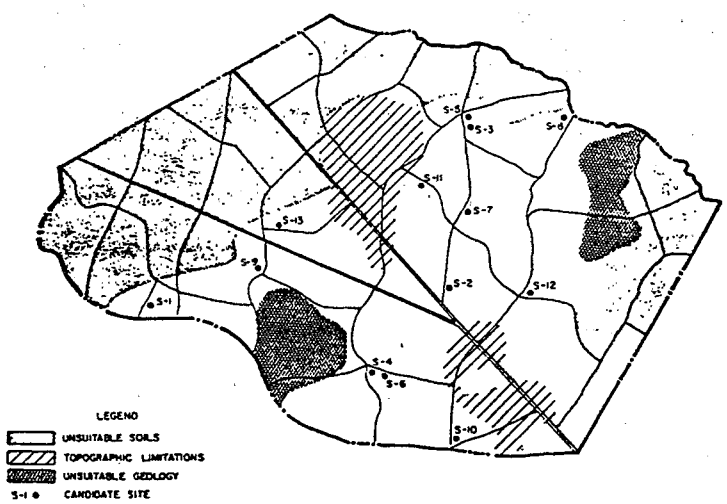


Figure 4-11. Initial assessment with overlays for Study Area X.

Table 4-7. Preliminary Investigations for Initial Assessment of Study Are X

Map ref.	Site name/ location	Zoning	Site	Adjacent areas	Access (mi)	Haul distance (mi)	Available[a]	General terrain	Characteristics	Cover soil adequacy[b]	Estimated Costs ($) Site purchase and preparation	Estimated Costs ($) Haul each year	Site area total/ usable (acres)	Drainage Basin
S-1	North Shore Road Site	Rural Residential	Farmland Vacant land	Farmland Residential	Highway-20 Residential-2 Rural-3	25	P,T	Gently sloping to hilly	Well drained, fine sands and silty materials, some clay	F-G	620,000	250,000	15/10	Middle Run
S-2	Fulton Road Site	Agricultural	Vacant land	Vacant land Residential Commercial	Main access-7 Rural-3	10	—	Flat to steeply sloping	Silty to sands, gravel	F	560,000	200,000	12/8	Middle Run
S-3	Chaffee Avenue Site	Forest & Farming	Farmland Vacant land	Vacant land Residential	Rural-5	5	P,T	Gently to moderately sloping	Silty sands and sands	F	720,000	60,000	20/12	East Branch
S-4	Greenville Road Site	Rural Residential Flood plain	Vacant land	Vacant land Residential	Residential-10 Main access-5 Rural-3	18	P,T	Gently sloping	Silty clayey sands, some gravel and clay	P	500,000	150,000	17/9	North River
S-5	Alton Street Site	Agricultural	Borrow pit Vacant land	Vacant land Industrial Residential	Rural-3	3	P,T,W,S	Hilly with steep slopes	Silty sands & sands with some clay	G-E	170,000	30,000	20/14	East Branch
S-6	Salem Road Site	Forest & Farming Rural Residential	Vacant land	Vacant land Residential	Highway-20 Rural-2	22	—	Gently sloping	Sandy loam overlying clay	F	840,000	220,000	27/15	Middle Run
S-7	Windsor Avenue Site	Forest & Farming	Vacant land	Vacant land Residential	Residential-5 Rural-2	7	P,T,W	Hilly with steep slopes	Fine sand, silts, and some clay	F	500,000	70,000	20/12	East Branch
S-8	La Plata Road Site	Agricultural	Vacant land Farmland	Vacant land Farmland	Rural-9	9	P,T	Gently to moderately sloping	Glacial till with shallow bedrock	G-E	400,000	90,000	15/11	Middle Run
S-9	Newman Street Site	Agricultural	Vacant land Borrow pit	Vacant land Farmland Residential	Residential-5 Rural-12	17	—	Flat to steeply sloping	Sands, silty sands	G	450,000	120,000	17/10	North River
S-10	Hunter Road Site	Forest & Farming	Vacant land	Vacant land Residential Golf Course	Main access-20 Residential-7 Rural-3	30	—	Gently sloping to hilly	Fine silt, sand and gravels	E	1,040,000	300,000	37/25	Beaver River
S-11	Harrington Blvd. Site	Industrial	Borrow pit Vacant land	Borrow pits Vacant land Industrial Residential	Main access-2 Rural-3	5	P,T,W,S	Hilly and irregular	Fine sand and silty sands, clay	F-G	600,000	50,000	25/19	East Branch
S-12	East Avenue Site	Industrial Residential	Borrow pits Vacant land	Vacant land Residential Farmland City landfill	Main access-9 Rural-2	11	—	Hilly and irregular	Fine to course sands with some clay	F	400,000	110,000	10/6	Middle Branch
S-13	Gifford Road Site	Agricultural	Vacant land	Farmland Vacant land Residential	Residential-2 Rural-13	15	—	Gently sloping	Some fine sands and silts overlying clay	E	1,440,000	160,000	30/20	North River

Key:

[a] P = power; T = telephone; W = water; S = sewer

[b] P = poor; F = fair; G = good; E = excellent

1 ft = 0.305 m
1 mi = 1.609 km
1 ac = 0.405 ha

early in the process. Area residents also may assist in identifying candidate sites.

4.4.2 Step 2: Site Scoring and Ranking

This section describes a quantitative approach to scoring and ranking sites. This approach involves defining objectives, defining criteria to meet those objectives, specifying the relative importance of the objectives and criteria, and then assigning scores—weighted according to the relative importance of each criterion and its overall objective—that indicate the ability of each candidate site to fulfil each criterion. The individual scores are then added to produce a total score for each site that can then be used to rank the sites.

This approach may be more extensive than necessary for small sludge surface disposal sites. In such cases, a qualitative system (e.g., using terms such as suitable, marginally suitable, and not suitable in lieu of numerical ratings) may be more appropriate. Table 4-8 illustrates how the site scoring and ranking process described below was applied to the four candidate sites for Study Area X that remained after the less desirable of the 13 original sites were eliminated during Step 1-6 based on regulatory, technical, and economic considerations.

Step 2-1: Determine attainable objectives for the site based on the following considerations:

- Technical considerations:
  - Haul distance
  - Site life and size
  - Topography
  - Soils and geology
  - Ground water
  - Soil quantity and suitability
  - Vegetation
  - Environmentally sensitive areas
  - Archaeological or historical significance
  - Site access
  - Land use
- Economic considerations
- Public acceptance considerations

Column 1 of Table 4-8 shows some examples of objectives.

Step 2-2: List these objectives by order of importance. Assign a value (e.g., on a scale of 1 to 10, 1 to 100, or 1 to 1,000) to each objective to reflect its relative importance. (Column 2 of Table 4-8 rates the Column 1 objectives on a scale of 1 to 1,000.) Discard any objectives that appear insignificant in light of a very low rating relative to other objectives.

Step 2-3: For each objective, develop criteria to measure the ability of a site to attain the objective. Column 3 of Table 4-8 lists criteria for the Column 1 objectives.

Step 2-4: Assign a numerical value on a scale of 1 to 10 to the criteria for each objective to reflect their *relative ability* to contribute to the attainment of the objective, rather than their individual significance. Add the values assigned to all criteria for a particular objective. Column 4 of Table 4-8 shows the relative values assigned to the Column 3 criteria and the addition of values for the criteria within each objective.

Step 2-5: For each criterion, multiply its numerical value by the overall rating for the objective and divide by the total of all criteria values within that objective to get the maximum score that may be assigned to that criterion (see Column 5 of Table 4-8). For example, to obtain the maximum score for the first criterion ("groundwater pollution hazard") of the first objective ("the site must not endanger public health") listed in Table 4-8, the following calculation was performed:

$$\frac{10 \times 1{,}000}{34} = 294$$

The maximum score for each criterion is thus a fraction of the total score for the objective in direct proportion to the criterion's relative ability to contribute to attainment of the objective. The maximum scores for all criteria within an objective should total to the relative overall rating for the objective (Column 2 of Table 4-8).

Step 2-6: For each criterion, assign a rating from 1 to 10 to each site to indicate the site's potential to satisfy that criterion. (If a site cannot meet an objective, the site should be eliminated from further consideration.) Columns 6a, 7a, 8a, and 9a show values assigned for sites 1, 2, 3, and 4, respectively. These values must now be weighted to reflect the relative importance of the objective and the individual criterion. This is done by multiplying the rating by the maximum score for that criterion (Column 5 of Table 4-8) and then dividing the total by the relative ability of the criterion to fulfil the objective (Column 4 of Table 4-8). For example, a rating of 7 was assigned to the ability of site S-5 to satisfy the first criterion for the first objective. The following calculation was then performed to yield a weighted score of 206:

$$\frac{7 \times 294}{10} = 206$$

Columns 6b, 7b, 8b, and 9b of Table 4-8 show the weighted scores calculated for the four candidate sites in Study Area X.

Table 4-8. Use of Quantitative Approach to Score Four Candidate Sites for Study Area X

(1) Principal Objectives of Sludge Landfill	(2) Rating of Objectives By Order of Importance	(3) Criteria	(4) Relative Ability of Criteria to Fulfill Objective	(5) Max Score	(6a) S-5 Rating	(6b) S-5 Score	(7a) S-10 Rating	(7b) S-10 Score	(8a) S-11 Rating	(8b) S-11 Score	(9a) S-13 Rating	(9b) S-13 Score
The site must not endanger public health.	1,000	Groundwater pollution hazard	10	294	7	206	5	147	9	265	9	265
		Gas hazard	8	235	6	176	6	176	8	235	8	235
		Groundwater pollution potential	8	235	5	147	4	118	7	206	7	206
		Surface water pollution potential and hazard	6	176	1	29	1	29	2	59	2	59
		Dust, noise, and odor hazards	1	29	1	29	1	29	1	29	1	29
		Traffic access hazard potential	1	29	1	29	1	29	1	29	1	29
		Total	34	1,000	21	616	18	528	28	823	28	823
The site must be acceptable to the public.	800	Out of sight	10	258	5	129	3	77	9	232	8	206
		Access roads	8	206	6	155	7	181	8	206	7	181
		Isolation from noise, dust, and odor	6	154	3	77	1	26	5	129	4	103
		Surface water pollution potential	4	103	1	26	1	26	3	77	2	52
		Desirability-and benefit of site as completed	2	51	1	26	1	26	1	26	1	26
		Desirability of improved land use	1	25	1	26	1	26	1	26	1	26
		Total	31	800	17	439	14	362	27	696	23	594
Impairment of the site ecology must be avoided.	500	Type and density of vegetation	10	416	7	292	5	208	9	375	8	333
		Influence of existing development in the surrounding area on species, variety and density	2	83	1	42	1	42	1	42	1	42
		Total	12	500	8	334	6	250	10	417	9	377
Use of the site must be compatible with the accepted land-use planning in the area.	500	Compatability of completed fill area with future land use plans	10	333	6	200	6	200	9	300	7	233
		Desirability of improving the existing land use	5	166	1	33	1	33	2	67	1	33
		Total	15	500	7	233	7	233	11	367	8	267
The site must be suitable for ready development and operation as a landfill.	300	Life of site	10	136	8	109	9	123	8	109	9	123
		Availability of cover material on site	5	68	1	14	1	14	4	54	1	14
		Ability to divert surface water	5	68	1	14	1	14	4	54	2	27
		General accessibility of site	2	27	1	14	1	14	1	14	1	14
		Total	22	300	12	165	11	151	18	245	13	178
TOTAL SCORE				3,100	65	1,773	56	1,538	94	2,534	81	2,239

This scoring system works best if all sites are compared one criterion at a time. Different specialists should be used to score the sites under criteria involving their area of expertise. For example, land use planners should be used to score those criteria related to land use.

Step 2-7: For each site, add all the individual scores to get a total score for the site (see bottom row of columns 6b, 7b, 8b, and 9b in Table 4-8). These totals can be compared to rank the overall and relative suitability of the various candidate sites. For example, the sites in Table 4-8 would be ranked S-11, S-13, S-5, and S-10 in order from most suitable to least suitable for a sludge surface disposal site considering all objectives and criteria.

4.4.3 Step 3: Site Investigation

Step 3-1: Investigate four to six candidate sites and identify site-specific problems. Field investigations (see Chapter 6) may be appropriate to supplement information from existing sources. In particular, it may be desirable at this stage to perform initial hydrogeological investigations on the primary candidate sites. This investigation can begin with a preliminary reconnaissance visit to each site to observe aspects such as:

- Site topography
- General geomorphic features
- Bedrock exposure
- Degree of soil development
- Seeps and springs
- Potentially impacting activities (e.g., clear cutting)
- Vegetation types
- Wetlands potential

To perform a hydrogeological investigation that involves drilling, an option for the site must be obtained. Because option negotiations are not always successful, it may be necessary to pursue negotiations for two to three times as many sites as the evaluation team wishes to actually investigate.

Performance of a conceptual design (see Step 4-1), and development of a refined cost estimate based on this design, may also be appropriate for some or all of the candidate sites during the site investigation stage.

Step 3-2: Rescore and rank sites based on results. Once the results of the hydrogeological investigation have been obtained, the ranking of candidate sites should be reexamined and modified as appropriate to incorporate the site-specific results obtained during the hydrogeological investigation. Any sites that are unsuitable hydrogeologically should be eliminated from further consideration.

Step 3-3: If required or appropriate, input site selection findings of top site(s) into an environmental impact report. Environmental impact reports are required in certain states (e.g., New York). Environmental impact reports may also be appropriate under certain circumstances such as for environmentally sensitive sites or for sites where there is a high level of public concern.

Step 3-4: Obtain additional public input.

4.4.4 Step 4: Final Selection

Step 4-1: For each candidate site, develop a conceptual design that is compatible with sludge and site characteristics (see Chapter 3) (or review and revise the conceptual designs if they were already developed under Step 3-1). A conceptual design should first establish site buffers, site facilities, site volume, site life, and the overall landfill footprint. Once these have been established, a preliminary excavation plan and a final grading plan can be developed using conventional civil engineering and computer-aided design and drafting (CADD) tools. The designer can then readily determine the landfill capacity (or airspace) by using CADD tools to compare the excavation and final grading plans. The capacity calculation can in turn be used to determine the soil balance, the overall site life, and other site features. CADD tools can also be used to delineate the shape of the surface disposal site to better enable public perception and interpretation. Finally, the conceptual design can serve as the basis for a cost estimate. A detailed preliminary cost estimate can be developed to address capital costs (liner systems, excavation, roads, facilities, etc.) and operating costs (equipment, personnel, leachate treatment/disposal, etc.).

Step 4-2: Evaluate the options for using the closed site and select the most appropriate use for each candidate site.

Step 4-3: Evaluate life cycle costs in detail for each candidate site.

- Site capital cost
- Site operating cost
- Hauling cost

Tables 4-9 and 4-10 show the capital and operating cost estimates for the four sites under final consideration at Study Area X. (In this example, hauling costs are included as part of operating costs.) The total cost was calculated using the following method to determine prorated cost ($/yd^3) over the life of the site based on the projected sludge volumes.

Table 4-9. Capital Cost Estimates for Four Study Area X Candidate Sites

Description	Site No. S-5	S-10	S-11	S-13
Land Acquisition				
Number of acres	20	37	25	30
Cost per acre	6,600	16,000	4,000	16,600
Purchase price	132,000	592,000	1,000,012	498,000
Site Development Costs				
Initial site preparation	100,000	60,000	60,000	80,000
Clearing and grubbing	240,000	4,000	6,000	10,000
Fence and gate	20,000	24,000	20,000	6,000
Access roadway (onsite)	16,000	32,000	6,000	24,000
Leachate collection system	4,000	—	50,000	—
Storm water management	30,000	40,000	30,000	60,000
Reconstruct primary access roadway	—	—	—	200,000
Equipment storage shed	30,000	30,000	30,000	30,000
Utilities	4,000	6,000	4,000	6,000
Monitoring	8,000	8,000	8,000	8,000
Subtotal	621,600	796,000	314,000	922,000
Engineering Surveying Subsurface Exploration and Permits (20%)	124,000	159,200	62,800	184,400
Contingency (10%) of Land Acquisition and Site Development Costs	62,000	79,600	31,400	92,200
Equipment				
Backhoe Loader	180,000	120,000	180,000	45,000
Total Capital Cost	987,600	1,154,800	588,200	1,243,600
Estimated Site Life (yrs)	10	12	10	12
Unit Cost ($/yd^3) based on 18,000 yd^3/yr	5.49	5.35	3.27	5.76
Annual Unit Capital Cost 8% over Site Life ($/yd^3)	0.89	0.79	0.53	0.85

1 yd^3 = 0.7646 m^3
1 ac = 0.4047 ha

Total Capital Costs = Land Acquisition Cost + Site Development Cost + Engineering and Contingency (20% + 10% of land acquisition and development costs) + Equipment Purchase Cost

Total Operation and Maintenance Costs = Site Operation and maintenance Costs + Sludge Handling Cost

Total Unit Capital Cost = Total Capital Cost/18,000 yd^3/yr

Total Unit Operation and Maintenance Cost = Total Operation and Maintenance Cost/18,000 yd^3/yr

Annual Unit Capital Cost ($/$yd^3$) = Total Unit Capital Cost ($/$yd^3$) amortized at 10% over site life

Total Unit Annual Cost ($/$yd^3$) = Annual unit capital cost ($/$yd^3$) + Annual Operation Cost ($/$yd^3$)

Step 4-4: Evaluate local government policies and obtain public input. A public hearing may be scheduled to receive final comments from local government officials and the public.

Step 4-5: Select site and list alternative sites. In the example Study Area X, the data affecting the final site selection were summarized in a table (Table 4-11). Site

Table 4-10. Operating Cost Estimates for Four Study Area X Candidate Sites

Description	Site No. S-5	S-10	S-11	S-13
One full-time equipment operator: Cost includes an allowance of 30% for fringe benefits	$30,000	$30,000	$30,000	$30,000
Equipment operation and maintenance	$30,000	$30,000	$30,000	$30,000
Site operation and maintenance	$10,000	$10,000	$6,000	$8,000
Leachate haul costs	$2,000	—	$2,000	—
Cover material purchase	$50,000	—	$80,000	—
Temporary road surfacing, access, and highway cleaning	$40,000	$30,000	$30,000	$16,000
Ground-water monitoring samples	$6,000	$4,000	$4,000	$4,000
Subtotal of site costs	$168,000	$104,000	$182,000	$88,000
Sludge hauling cost	$30,000	$300,000	$50,000	$150,000
Total operating cost/yr	$198,000	$404,000	$232,000	$238,000
Unit cost ($/yd^3) based on 18,000 yd^3/yr	$11.00	$22.44	$12.88	$13.22

Table 4-11. Final Site Selection

Map Ref.	Site Name/Location	Scoring System Value	Type of Surface Disposal Site	Proposed Final Site Use	Site Life	Total Annual Cost ($/yd^3)[a]	Public Acceptance Ranking[b]
S-5	Alton Street Site	1,773	Area fill mound	Open space	10 yrs	11.89	3
S-10	Hunter Road Site	1,538	Wide trench	Return to natural state	12 yrs	23.23	2
S-11	Harrington Blvd. Site	2,534	Area fill mound	Pasture	10 yrs	13.41	4
S-13	Gilford Road Site	2,239	Wide trench	Park	12 yrs	14.07	1

[a] Sum of annual capital costs (at 10 percent over site life) and operating costs.
[b] Provided from attitude survey taken at public meetings; lower numbers represent less opposition.
1 yd^3 = 0.7646 m^3

S-13 was selected based on its (1) top public acceptance ranking, (2) longer life, and (3) completed site use as a needed park. Although site S-13 was not the top-ranked site technically, it was technically acceptable. Also, its cost was relatively high, but the operating agency decided to absorb the extra cost due to the obvious site benefits.

Step 4-6: Acquire site. The following options are available:

- Option to purchase and subsequent execution (await site approval).
- Outright purchase (after site approval by regulatory agency and local jurisdiction).
- Lease.
- Condemnation and/or other court action.
- Land dedication.

Purchasing a site is generally more advantageous than holding a long-term lease because the managing agency's responsibility normally extends well beyond the site life. Certain advantages may also be gained by leasing with an option to buy the site at the time of permit approval. This option ensures that the land will be available when the facility planning process is completed. It also allows time for the previous owner to gradually phase out operations, if necessary.

4.5 References

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Chapter 5
Public Participation Programs

5.1 Introduction

Public participation is very important to the success of sludge use or disposal projects. A community's willingness to cooperate with a project depends on:

- Its perceptions of the need for, costs of, and benefits of the project.
- The degree to which the community feels it has been kept honestly informed and has had a chance to express its concerns and have its ideas incorporated into the planning and operation.

The purpose of a public participation program (PPP) in surface disposal is to inform and involve the public. Planning for public participation in a surface disposal project involves careful and early evaluation of what should be communicated, to whom, by whom, and when. This chapter summarizes the major considerations involved in implementing a successful program, including the objectives and value of a public participation program, PPP participants, the design and timing of a program, and areas of public concern in surface disposal.

5.2 Objectives

The objectives of a public participation program are:

- Promoting full and accurate public understanding of the need for surface disposal, the active sewage sludge unit selected, and the advantages and disadvantages of the project.
- Keeping the public well-informed on the status of various planning, design, and operation activities.
- Soliciting from concerned citizens their relevant opinions, perceptions, and suggestions involving surface disposal.

The key to achieving these objectives is continuous two-way communication between surface disposal site planners/designers/operators and the public. A common problem for public officials is the assumption that educational, informational, and other one-way communication techniques provide for an adequate dialogue. When designing a public participation program, sufficient mechanisms must be provided for meaningful public input into the decision process (see Section 5.5). A PPP will increase the lead time required to select, design, and construct a surface disposal site. This must be considered when initially determining the need for a new site.

5.3 Value of a PPP

Public participation has become virtually essential to the success of surface disposal projects. Public resistance to a project, due either to legitimate concerns that are not addressed or to misperceptions or anger resulting from lack of involvement, generally will either make the project impossible or at least more costly and difficult. The process of involving the public does require some investment of cost and time, but this likely will be far less than the potential expense and delays risked by not involving the public. A PPP is well worth the extra cost as more expensive project delays are probable if an irate populace becomes involved late in the process. The PPP process contributes to an effective decision-making process. The advantages of a PPP include (Canter, 1977):

- An increased likelihood of public approval or acceptance for the final plans.
- A method of providing useful information to decision-makers, especially where values or factors that are not easily quantified are concerned.
- Assurance that all issues are fully and carefully considered.
- A safety valve in providing a forum whereby suppressed feelings can be aired.
- Increased accountability by decision-makers.
- An effective mechanism to encourage decision-makers to be responsive to issues beyond those of the immediate project.

5.4 PPP Participants

5.4.1 Public Participants

The success of a public participation program depends, in part, on who is involved. Failure to involve the appropriate people at the appropriate times can result in

unnecessary additional costs or time delays by increasing public concern and inciting public anger. Therefore, PPP design requires an effective publicity campaign that will reach the appropriate people at the proper times *throughout* the planning process. Special efforts should be made to involve groups and individuals who:

- Have demonstrated an interest in environmental affairs.
- Are likely to be directly affected by the proposed surface disposal project.

Table 5-1 lists the types of groups and individuals who should be contacted regarding a public participation program. A list of names and addresses of interested persons and organizations in these categories for formal and informal notifications and contacts should be developed at the beginning of a project. Identifying specific groups and individuals as targets for public involvement efforts helps to focus time and money on the most likely participants, to focus the objectives of the PPP, and to interpret how well the various involvement mechanisms are working.

In addition, a special effort should be made to ensure that the particularly important people, (such as influential individuals, people who are most likely to have strong feelings about the site, and the media) are not only informed, but convinced of the validity of the surface disposal project. It is crucial that as many of these key groups as possible support the surface disposal project and speak out in favor of it during the public participation program. Also, it is important that key participants get involved as early as possible, to avoid situations where previously disinterested individuals develop strong feelings about the project when decisions have already been made.

Local officials should be notified about the project before the issue enters the field of public debate. This allows them to form a more objective opinion about the project and prepares them for inquiries from the public.

Table 5-1. Potential PPP Participants

The following groups and individuals should be contacted as part of any PPP:

- Local elected officials
- State and local government agencies, including planning commissions, councils of government, and individual agencies
- State and local public works personnel
- Conservation/environmental groups
- Business and industrial groups, including Chambers of Commerce and selected trade and industial associations
- Property owners and users of proposed sites and neighboring areas
- Service clubs and civic organizations, including the League of Women Voters, etc.
- Media, including newspapers, radio, television, etc.

The following groups can also be contacted, where appropriate:

- State elected officials
- Federal agencies
- Farm organizations
- Educational institutions, including universities, high schools, and vocational schools
- Professional groups and organizations
- Other groups and organizations, possibly including various urban groups, economic opportunity groups, political clubs and associations, etc.
- Labor Unions
- Key individuals who do not yet express their preferences through, or participate in, any groups or organizations

5.4.2 Program Staff

The success of a public participation program also hinges, in part, on the attitudes, abilities, and experience of the program staff responsible for communicating with the public, either through preparation of informational materials or in live dialogue. One of the most important factors in any PPP is the ability to establish the public's trust. A PPP that fails to establish the public's trust may do more damage than no PPP at all. Trust is the basis on which program staff and participants can have a meaningful and constructive dialogue on the project and associated concerns. Without trust, the public may well maintain an attitude of hostility and resistance. To establish trust, the PPP staff, either individually or collectively will need to have good technical understanding of the project *and* good communication skills. Some abilities and attitudes that help to build trust include (U.S. EPA, 1988):

- Involving *all* parties that may have an interest or stake in the outcome.
- Involving the public *before* decisions have been made.
- Truly listening to the public's concerns and feelings about the project. Being a good listener involves recognizing and respecting people's feelings, demonstrating that you have heard and understood what people have said, recognizing "hidden agendas" and symbolic meanings (for example, property owners near a surface disposal site may sound alarms about ground-water pollution when their major concern is actually property value depreciation), and adopting a truly accepting, compassionate, and nonjudgmental attitude toward the speaker.
- Respecting the public's concerns, even if these concerns have no scientific basis.
- Be the first source of information and maintain the trust of the media. Tell the good news and the bad, and how the project will minimize the bad.

- Being honest, frank, and open. This includes admitting when you are uncertain, do not know, or have made a mistake, and getting back to people with answers. It also involves disclosing information as soon as possible. Any potential problem that is not publicly addressed at the outset of a project will likely be brought to the attention of the media, resulting in the possible reduction of public support and the loss of the project leadership's credibility.
- Communicating in nonscientific language that the public can readily understand.

5.5 Design of a PPP

The PPP should be tailored to each particular situation in terms of cost and scale. A certain minimum effort should be put into every participation program but, within a basic framework, appropriateness and flexibility are the keys. A common sense approach in determining the number and frequency of public involvement mechanisms is recommended. When budget or time restrictions prohibit development of an ideal program, it is more important to apply participation techniques that are highly effective. Table 5-2 indicates the relative effectiveness of the PPP activities suggested in this section.

Public participation is critical at various stages of the surface disposal site development process. Most involvement should come at the beginning of the planning process when public input has the greatest potential to shape the final plan. This early involvement helps determine the limits to public and political acceptability of the project. During this phase, the public plays a constructive, as opposed to a reactive, role in decision-making. This section discusses the critical planning stages where public input is particularly important and the appropriate public participation mechanisms at each stage.

5.5.1 *Initial Planning Stage*

During the initial planning stage, the scope and scale of the entire PPP should be established, and the organization of PPP components and the use of PPP mechanisms should be determined. There are two general types of PPP mechanisms:

- Educational/informational activities that represent one-way communication from officials to the public.
- Interaction techniques that promote two-way communication.

The major activities during the initial planning stage are mostly informational/educational. The officials doing the communicating at this point may be operating authorities, elected officials, engineering consultants, or even public relations firms. These officials should inform the public about the:

Table 5-2. Relative Effectiveness of Public Participation Activities

Public participation technique	Communication characteristics		
	Level of public contact achieved	Ability to handle specific interest	Degree of two-way communication
Public hearings	M	L	L
Public meetings	M	L	M
Advisory Committee meetings	L	H	H
Mailings	M	M	L
Contact persons	L	H	H
Newspaper articles	H	L	L
News releases	H	L	L
Audio-visual presentations	M	L	L
Newspaper advertisements	H	L	L
Posters, brochures, displays	H	L	L
Workshops	L	H	H
Radio talk shows	H	M	H
Tours/field trips	L	H	H
Ombudsman	L	H	H
Task force	L	H	H
Telephone line	H	M	M

L = low value
M = medium value
H = high value

- Purpose of the surface disposal project.
- Rationale for selecting surface disposal over alternative use or disposal practices such as incineration and land application.
- Need for the project in the community.
- General design and operation principles.
- Projected final land use.
- Potential for creation of new jobs, etc.

The public information products will likely also need to include basic information explaining what sludge is, how it is generated, and how it relates to the public demand for clean water.

As initial site investigations get underway, two-way public involvement activities become important. The following mechanisms should be organized during this stage (CH2M Hill, Donahue and Associates, et al., 1977):

- ***Public officials workshop.*** The purpose of this workshop is to acquaint the concerned officials with the technical considerations relevant to the surface disposal project and to obtain input from local officials on appropriate timing of activities and areas of potential public concern.
- ***Advisory Committee.*** The role of this group is to help organize citizen support for the proposed plan, to act as a sounding board in providing citizen reactions to various proposals, and to take an active part in decision-making. The group should include representatives of local government departments, community organizations, private industry, and others. Consultant progress reports can be presented during these meetings and later publicized.
- ***Mailing list.*** Comprehensive mailing lists are the foundation of an information output program. To be effective, they must represent a broad cross-section of groups and individuals and be frequently expanded and updated.
- ***Liaison/contact persons.*** Liaison/contact persons are responsible for receiving input, answering questions, expanding mailing lists, and generally being responsive. They keep logs of all questions and refer issues of general concern to the appropriate people for consideration. These positions should be held by persons who are actively involved in the surface disposal decision-making process; e.g., a consulting engineer, public works official, or other comparably informed individuals. In large municipalities it may be advantageous to hire an individual to handle public relations.
- ***Media program.*** This involves organizing an effective publicity campaign using various media. The media should be contacted as early as possible and every effort should be made to convince them of both the need for and effectiveness of a surface disposal project before the topic becomes an emotional issue. In this way, objective treatment of the issue by the media is more likely. Again, the extent of this program depends upon the particular situation. Various channels include:
  - *Newspapers.* A series of informative articles on surface disposal can be timed to appear throughout the project to sustain public interest and serve as an educational tool. Each article or news release can also transmit hard news such as notices of public meetings, or articles describing events at public meetings.
  - *Television.* This method can be very expensive, but can also be very useful in transmitting information. Through careful planning, some free coverage of the project can probably be arranged through news programs, public service announcements, or station editorials.
  - *Advertisements.* Full-page newspaper advertisements could be used to relate complex information. They can incorporate a mailback feature to highlight citizen concerns, and solicit participation of interested individuals.
  - *Posters, brochures, or displays.* These can be highly effective educational tools, especially when particularly creative and put in high traffic areas or given wide distribution.
  - *Radio advertisements or informational talks.* The radio can be used to advertise events or information in much the same way that newspapers are used.
- ***Classroom educational materials.*** This can be an effective way of educating school children and their parents. Presentations can be made in individual schools or, more economically, special newsletters and brochures can be designed for use in schools and distribution to other audiences.

5.5.2 Site Selection Stage

The major activities of the initial planning stage are preparatory mechanisms for the site selection stage. Site selection generally involves a preliminary screening of numerous potential sites after which several sites are selected for more detailed investigation. These selected sites should be subjected to intense public scrutiny. It is at this point that public participation can play a particularly formative role in determining the final site, design and operation procedures, etc.

Most public interest and involvement—including the most vocal and organized protests—occur during the site selection stage. Therefore, the major thrust of the PPP should come during this stage, with a particular emphasis on two-way communication including:

- ***Public meetings.*** These are an excellent mechanism for providing public information, receiving input, and achieving one-to-one contact between consultants, local officials, and the public. They are normally less structured than public hearings and therefore, more likely to result in dialogue. Generally, a series of such meetings is held in different locations within the planning area to provide maximum opportunity for attendance by the public. These are a good arena for the use of audiovisual presentations. These meetings work especially well when there are concrete issues to be discussed, and should be timed to coincide with particularly critical periods in the decision-making process. For example, the public at these meetings could screen the site selection criteria or even rate the candidate sites against those selected criteria. The more successful meetings are usually a result of heavy advance work. Overcoming public apathy can be difficult, but is critically important in these early planning stages. Consultant contracts should clearly specify the number of public meetings to be held because it is often costly and time-consuming to prepare for them.

- ***Workshops.*** Generally, these have positive results although they are not widely used because of low turnout. Such groups usually involve citizens being given courses of instruction by agency staff, and then addressing specific work efforts on the basis of such instruction. Basically workshops are an educational tool with interaction features.

- ***Radio talk-shows.*** Many communities have local radio talk shows where residents can call in and voice their opinions. The consultant and/or a local official could give a short presentation on the surface disposal plan and then field callers' questions. This is a good opportunity to dispel some misinformation, but views of the callers do not necessarily represent those of the general public.

5.5.3 *Selected Site and Design Stage*

In this stage, the surface disposal site is selected and detailed site design begins. Generally, the number of participants involved may drop off in this stage, but the level of activity may substantially increase. No matter how active the public has been up to this point, nearby residents of the site are not going to be happy with the siting decision. Participation efforts should increase on this particular group. Giving these people a role in site design will alleviate some hostility and, in the long-run, improve the public's opinion of the proposed operation. Appropriate activities in this stage are:

- ***Tours/field trips.*** These are useful activities for special interest groups, such as residents near the selected surface disposal site, and the press. Before the proposed surface disposal site is designed and permitted, a tour of a comparable existing and operational surface disposal site should be made. This can be far more effective than countless abstract discussions. After the proposed surface disposal site is opened, tours can be offered of this site to educational and other groups. Arranging for aerial views of proposed and existing sites for small groups by chartering a plane can be especially effective.

- ***Audiovisual presentations.*** These can be quite useful at public information meetings to reach people missed by the field trips. The effectiveness of this tool depends on the quality of the script and visuals, but audiovisual presentations can dispel much of the misinformation about surface disposal that may result from past experience with improperly run sites.

- ***Task forces.*** The purpose of these groups is to recommend design procedures in areas of particular concern for the public. This group could be a subgroup of the Advisory Committee or a committee made up of residents near the site. To be most effective, the group should represent the various interest groups and have a technical orientation.

- ***Formal public hearings.*** Although at least one is usually required by law, a public hearing is usually only a formality. Public hearings tend to be structured procedures involving prior notification, placement of materials in depositories for citizen review prior to the hearing, and a formal hearing agenda. The hearing itself usually takes the form of a presentation by the consultants, followed by statements from the citizens in attendance. Questions are normally allowed, but argumentative discussion and "debates" are discouraged because of time limitations. Sponsors tend to prefer to adopt a "listening" posture and allow the public to express itself without challenge. This kind of detached attitude tends to generate a great deal of hostility in the public. It conveys the message that the public is powerless to change engineering decisions and this is precisely the type of message that a PPP is supposed to dissipate. Because public hearings are usually held late in the site development process after the design is already completed, they provide an insufficient means of legitimate citizen involvement in the complete planning, design, and operation decision-making process. The responsiveness of a public hearing can be enhanced by having elected officials chairing or at least participating in the process. Nevertheless, public hearings perform their proper legal and review functions only as part of a total PPP.

5.5.4 *Construction and Operation Stage*

The role of the public in this stage is limited, but the actions of engineers and surface disposal site operators are extremely important. It is in this stage that the site

developers must "make good" on their assurances of running a well-operated, well-maintained site. Public confidence in local officials can be reinforced through the proper handling of surface disposal site development. Otherwise, it will be extremely difficult to establish public support for this or any future surface disposal project. Public participation must continue throughout the project—if some minimum level is not maintained even the current project may fail.

Public involvement during the construction and operation stage most likely will consist mainly of complaints related to construction and operation activities. Mechanisms to handle this interaction include:

- ***Telephone line.*** This is a good tool to register complaints and concerns and to answer questions. It is important that each call be followed up with a response addressing the actions taken to alleviate the problem.
- ***Ombudsman or representative.*** This is an individual who has the ear of the site operators and can mediate any difficulties that citizens feel are not being adequately handled.

5.6 Timing of Public Participation Activities

A public participation program should begin very early in the development of a proposed project and continue throughout the project. All persons concerned should have the opportunity to express their views *before* any decisions affecting the general public are made and should be kept informed and involved throughout the course of the project.

To be effective, program activities must be diversified and sustained. Correct timing is critical. Table 5-3 lists suggested timing of PPP activities for a sample surface disposal site project. Public hearings are formalities and, as such, may occur only at the beginning and end of the planning process. Advisory Committee meetings have the function of providing a forum for progress reports and regular input and, therefore, are scheduled to occur from every 2 to 3 months. Public meetings are held jointly with Advisory Committee meetings and are timed to obtain input during the critical points in decision-making. Sufficient time is allowed after each public meeting to give decision-makers time to react to comments and incorporate suggestions before final determinations are made. The various other informational/educational activities are scheduled around the public and Advisory Committee meetings to arouse public interest at times when input will be the most valuable.

5.7 Potential Areas of Public Concern

A PPP should dispel any myths and misinformation the public may have concerning surface disposal—for example, the widely held perception that sludge is always malodorous, highly contaminated, and otherwise repulsive. A PPP also should address the impacts of all surface disposal developments and other issues of concern in an environmental impact report, if one has been prepared. The most effective participation activities for handling these issues are the interaction techniques (i.e., public meetings, tours/field trips, and displays that are manned by personnel to answer questions). Some of the concerns most likely to arise during surface disposal development are:

- Loss of prior land use
- Land planning and zoning problems
- Ground-water pollution and leachate
- Methane gas migration
- Vector attraction
- Noise
- Odor
- Aesthetics, including site visibility
- Safety and health
- Traffic
- Spillage
- Sedimentation and erosion
- Completed site and final land use

Local officials should be prepared to handle questions concerning these issues. Obviously most of these problems simply do not arise with a well-operated, efficiently run site, and this fact should be heavily emphasized. Also, because each situation is unique, mechanisms to ease these concerns have to be tailored to the characteristics of each site. Local residents and officials should be creative in solving any problems that may arise. Above all, the attitude of local officials during interactions with citizens is extremely important and must at all times be open and responsive.

5.8 Conclusion

Even the best program to involve the public in surface disposal site decision-making may not alleviate citizen dissatisfaction or anger. This criticism has often been cited to justify only minimal public participation efforts. However, active public involvement will positively contribute to the long-term political and public acceptability of any plan, increase public confidence in local officials, and give citizens a real opportunity to take part in the land management decisions of their community. A PPP is an essential part of any surface disposal program.

Table 5-3. Suggested Timing of Public Participation Activities for Sample 30-Month Landfill Project

PPP activities and mechanisms	Decision stage: Initial planning	Site selection								Design			Construction		Operation	
	Month: 2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34
Public hearings		⊗										⊗					
Public meetings		⊗				⊗			⊗			⊗			⊗		
Advisory Committee meetings		⊗		X		⊗		X	⊗		X	⊗			⊗		
Mailing list development and mailings													→				
Availability of contact people																	→
Newspaper articles	X	X	X		X			X									
New releases		X			X			X			X			X			
Audio-visual presentations		X				X			X			X			X		
Newspaper advertisements			X				X			X			X				
Posters, brochures, and displays																	→
Workshops			X					X									
Radio talk-shows							X			X							
Tours/field trips								X			X				X		X
Ombudsman																	→
Task force											→			→			
Telephone line																	→

⊗ = joint meeting

5.9 References

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Chapter 6
Field Investigations

6.1 Purpose and Scope

This chapter summarizes the regulatory requirements that might require site-specific field investigations for selecting a site for surface disposal of sludge, and it provides an overview of methods and approaches to planning for field investigations. Because the extent of field investigations for a particular site will depend on the size and complexity of surface and subsurface conditions, this chapter emphasizes relatively simple and inexpensive field techniques that in many instances might be adequate for sludge surface disposal sites for small and medium-sized communities (i.e., tens of acres). Small-scale sites with complex subsurface conditions and sites for surface disposal of sewage sludge produced by large cities (i.e., hundreds of acres) will require use of more sophisticated and expensive field equipment and methods. This chapter also identifies reference sources where more detailed information on such methods can be found.

6.2 Regulatory Requirements

6.2.1 Part 503 Regulation

Section 4.2.1 (Site Selection Regulatory Requirements) describes in more detail the Part 503 requirements concerning field investigations and the siting of sewage sludge surface disposal sites. If the site selection process described in Chapter 4 identifies one or more potentially suitable sites for which Part 503 locational restrictions might apply, one or more of the following types of field investigations might be required:

- A determination about the presence of any threatened or endangered species or a critical habitat.
- Hydrologic engineering studies to determine whether active sewage sludge units can be designed so as not to restrict flow of a 100-year flood, where the proposed active sewage sludge unit is located within the boundaries of a 100-year floodplain.
- Geologic, geophysical, and soil engineering investigations where the active sewage sludge unit is located within a seismic impact zone or in the vicinity of one or more active faults (i.e., movement has occurred within the last 11,000 years or so), or the area comprises geologically unstable materials.
- Geologic and geotechnical investigations (generally required when the active sewage sludge unit will have a liner and leachate collection system).
- Soil and hydrologic investigations, if known or suspected wetlands are located within the proposed surface disposal site.

6.2.2 Part 258 Regulations

A complete discussion of the regulatory requirements under Part 258 concerning field investigations and siting of MSW landfills is beyond the scope of this manual. See U.S. EPA (1993d) for detailed information on the Part 258 regulation.

6.2.3 Other Regulatory Requirements and Programs

Special or more focused field investigations also might be required if use of the site for sewage sludge disposal is restricted by other regulatory requirements of programs at the federal, state, or local level. Examples of siting issues covered by other federal statutes or regulatory programs include:

- Presence of sites of archaeological or historical significance. Significant archaeological sites are often located within floodplains or on terraces along major rivers.
- Areas protected under the EPA-approved state wellhead protection programs or under EPA's sole source aquifer program.
- Areas located over aquifers with a Class I or Class II designation.

Any state environmental protection statutes and regulations not originating at the federal level that might affect siting of sewage sludge surface disposal sites should be identified during the site selection process and appropriate field investigations should be undertaken. Similarly, any local zoning ordinances or restrictions should be identified in the site selection phase, and field investigations should be designed to obtain any information required

to demonstrate compliance or justify the granting of variances.

6.3 Collection of General Site Information

Collection and review of available information about a site and the surrounding area should be the starting point for any field investigation. If multiple potential sites have been evaluated during the site selection process (Chapter 4) then much of the more general types of information for the area (i.e., soil, geologic, and hydrologic maps and reports) will have already been gathered. Such maps are useful for providing a general understanding of the geologic and hydrologic setting for a particular site, but generally will not provide specific information about the site itself. Table 6-1 identifies general sources for identifying and reviewing existing information. Makower (1992) is a useful general reference on types and sources of maps. This section discusses how to obtain more specific types of information: (1) topography and aerial photographs (Section 6.3.1); (2) soils, geologic, and related information (Section 6.3.2); and (3) hydrologic and related information (Section 6.3.3).

Major types of commonly available information that can provide useful information for sites involving tens or hundreds of acres include: (1) topographic maps (scale 1:24,000), (2) aerial photographs (scale 1:15,000 to 1:20,000 are best), (3) published Soil Conservation Service (SCS) soil survey maps (which usually range in scale from around 1:15,000 to 1:20,000), (4) water well drill logs, and (5) Federal Emergency Management Agency (FEMA) floodplain maps. Speaking with knowledgeable individuals in local government utility and planning agencies, state natural resource/environmental agencies, and district offices of the SCS, U.S. Army Corps of Engineers, U.S. Geological Survey (USGS), and U.S. Fish and Wildlife Service is probably the best way to identify existing published and unpublished maps and reports with detailed information about the site or nearby areas. Interviews with local, long-time residents also are an important source of information about the use-history of a site.

In most instances the most important available information relevant to a site can be identified after 2 or 3 days spent contacting agencies on the telephone. It also might be necessary to spend some time in one or more libraries (Table 6-1) reviewing documents that are no longer in print. For large projects, on-line computer searches can save significant time and money by quickly retrieving article citations on a given subject and eliminating manual searches of annual or cumulative indexes. A search is performed using key words, author names, or title words, and can be delimited by ranges of dates or a given number of the most recent or dated references. A search typically requires about 15 minutes online and costs $50 to $100 for computer time and off-line printing of citations and abstracts. Doctoral dissertations and masters theses are another possible source of information about an area. Table 6-1 provides information on how to identify possibly relevant dissertations and theses, and how to obtain them.

6.3.1 Topography and Aerial Photographs

Table 6-2 identifies sources for topographic maps. Topographic maps (at a scale of 1:24,000) published by the USGS are available for most areas of the United States and are available in electronic format from several sources (Table 6-2). The resolution of these maps (which generally have contour intervals of 10 ft or more) are usually not adequate for detailed site engineering and design purposes (see Section 6.4.1), but are useful for identifying significant site surface characteristics during initial field investigations. The simplest method for identifying the availability and titles of topographic maps is to refer to a current state index map, which shows all currently available topographic maps. If a potential site is located near a city, more detailed topographic maps may be available from city planning or utility departments.

The first place to check for available aerial photographs is the nearest district offices of the SCS and the Agricultural Stabilization and Conservation Service. These offices, usually located in the same building and serving one or more counties, should have on file all aerial photographs taken for the U.S. Department of Agriculture throughout the county; these will typically range in scale from 1:15,000 to 1:24,000 (1 in. = 1,250 ft to 1 in. = 2,000 ft). In parts of the United States, the earliest aerial photographs date back to the 1930s. Examination of the full time-series of aerial photographs for a site is an excellent way to learn about changes in vegetation and land use that have taken place. Fracture trace and lineament analysis using aerial photographs is a useful way to identify possible preferential paths of contaminant transport. Again, all available aerial photographs should be viewed stereoscopically to identify fracture traces and other lineaments, because the same lineaments might not be visible on all photographs due to differences in vegetation or atmospheric conditions at the time the photograph was taken.

For site-specific investigations, aerial photographs with a scale larger than 1:40,000 have a relatively limited usefulness; however, larger-scale photographs (up to 1:120,000), including satellite remote sensing imagery might be useful for placing a site in its broader environmental context. Table 6-3 identifies sources for larger-scale aerial photographs and satellite remote sensing imagery. Landsat satellite sensors record images in four spectral bands: Band 4 emphasizes sediment-laden and shallow waters; Band 5 emphasizes cultural features; Band 6 emphasizes vegetation, land/water boundaries,

Table 6-1. General Information Sources (U.S. EPA, 1993e; Sara, 1994)

Source	Type(s) of Information	Comments
Federal agencies	All types of information (see subsequent tables).	See subsequent tables.
State, regional, and local agencies	Soils, land use, flood plains, ground water, aerial photographs, well records, geophysical borehole logs.	Local county, town, and city planning boards commonly provide data on general physical characteristics of areas within their jurisdiction. Most states have environmental protection and natural resource agencies (geology, water, agriculture, etc.) that have information related to geology, remote sensing, and water.
Knowledgeable individuals	Historic information, past site owners and practices. Published and unpublished reports and maps.	Time can be saved in the initial stages of a data search by contacting knowledgeable individuals personally or by telephone for references and an overview of an area, as well as for specific problems and details that may be unpublished. People to contact include: federal agency personnel (USGS, SCS, Army Corps of Engineers, Fish and Wildlife Service); state environmental protection, geological and water survey personnel; local well drillers, consulting engineers, architects, and residents.
State and federal projects	Site specific assessment data for dams, harbors, river basin impoundments, and federal highways.	Project reports contain data on soil, hydrologic, geologic and geotechnical characteristics as well as analysis, construction drawings and references. Most are easily obtained by contacting the responsible agency. Surface water and geological foundation conditions such as fracture orientation, permeability, faulting, rippability, and weathered profiles are particularly well covered in these investigations.
AGI Directory of Geoscience Departments	Faculty members.	Regular updates of faculty, specialties, and telephone numbers.
National Technical Information Service, 5228 Port Royal Rd., Springfield, VA 22161; 800/553-6847	Government and other technical publications that are out of print or for which limited copies were printed.	Documents can be obtained as hard copy of microfiche.
Libraries		
Government Agency	All types.	Excellent library facilities are available at the U.S. Geological Survey offices in Reston, VA; Denver, CO; and Menlo Park, CA. U.S. EPA has excellent libraries in Washington, its 10 Regional Offices, and environmental research laboratories (Cincinnati, OH; Athens, GA; Ada, OK; Las Vegas, NV). State environmental and natural resource agencies often have libraries addressing the Agency's main focus.
Academic Institutions	All types.	The amount of environmental information that can be obtained from academic institutions varies with the size. Larger universities often have separate geology libraries and serve as repositories for federal documents.
Local public libraries	Physical and historical characteristics of the surrounding area.	Especially good sources for local maps and history. Almost any other document can also be obtained through interlibrary loan.
Computerized Online Databases		
DIALOG subscriptions and information: 800/3-DIALOG	Accesses over 425 data bases from a broad scope of disciplines including such databases as GEOREF and GEOARCHIVE.	Provides indexes to book reviews and biographies; directories of companies, people, and associations; and access to the complete text of articles from many newspapers, journals and other sources.
Master Directory (MD), User Support Office, Hughes STX Corp., 7601 OraGlen Dr., Suite 300, Greenbelt, MD 20771; 301/513-1687	The MD is a multidisciplinary database that covers earth science (geology, oceanography, atmospheric science) and space sciences.	MD is a free online data information service for data generated by NASA, NOAA, USGS, DOE, EPA, and other agencies and universities as well as international data bases. Includes personal contact information, access procedures to other databases. Contact MD User Support Office for information on access via span nodes, Internet, or direct dial.
Earth Science Data Directory (ESDD), U.S. Geological Survey, 801 National Center, Reston, VA 22092; 703/648-7112	ESDD is a database that contains information related to geologic, hydrologic, cartographic, and biological sciences.	Also included are databases that reference geographic, sociologic, economic, and demographic information. Information comes from NOAA, NSF, NASA, EPA and worldwide data sources.

Table 6-1. General Information Sources (U.S. EPA, 1993e; Sara, 1994) (continued)

Source	Type(s) of Information	Comments
Dissertations and Theses		
Comprehensive Dissertation Index (CDI)	PhD doctoral dissertations.	Citations began in 1861 and include all doctoral dissertations from U.S. universities and most accepted in North America thereafter. The index is available at larger library reference desks and is organized in 32 subject volumes and 5 author volumes. Specific titles are located through title keywords or author names.
DATRIX II, University Microfilms International, 300 N. Zeeb Rd., Ann Arbor, MI 48106; 800/521-3042, 313/761-4700 (in Alaska, Hawaii, and Michigan)	PhD dissertations and masters theses.	Using title keywords, a bibliography of relevant theses can be compiled and mailed to the user within one week. In addition, the DATRIX Alert system can automatically provide new bibliographic citations as they become available.
United States Geology: A Dissertation Bibliography by State	PhD dissertations and masters theses.	Free index from University Microfilms International (UMI). However, this index does not include dissertations from some universities that do not make submissions to UMI for reproduction or abstracting. DATRIX II or *Comprehensive Dissertation Index* must be used to locate such citations.
Dissertation Abstracts International, Volume B - Science and Engineering and Masters Abstracts	Extended abstracts of PhD dissertations from more than 400 U.S. and Canadian universities; 150-word abstracts of masters theses.	Monthly publication of UMI. Abstracts of potentially useful titles obtained from CDI or DATRIX II can be scanned to determine whether it is relevant to the project at hand. Both *Dissertation Abstracts International* and *Masters Abstracts* are available at many university libraries. A hard (paper) or microfilm/fiche copy on any abstracted dissertation can be purchased from UMI. Non-indexed or abstracted dissertations or theses must be obtained from the author or the university where the research was completed.

Table 6-2. Topographic Data Sources (U.S. EPA, 1993c; Sara, 1994)

Source	Type(s) of Information	Comments
Branch of Distribution, USGS Map Sales, Box 25286, Federal Center, Denver, CO 80225; 303/236-7477.	Index and quadrangle maps for the eastern U.S. and for states west of the Mississippi River including Alaska and Hawaii.	A map should be ordered by name, series, and state. The same quadrangle name may be used at several scales so it is especially important that the series scale be specified: 7.5 minute (1:24,000), 15 minute (1:62,500), or two-degree (1:250,000). Other scales may be available for particular areas.
Geographic Names Information System (GNIS), USGS, 523 National Center, Reston, VA 22092; 703/648-4544	Topographic Names Database: descriptive information and official names for about 55,000 topographic maps, including out-of-print maps. Topographic Maps Users Service: organized and summarized information about cultural or physical geographic entities.	GNIS provides a rapid means of organizing and summarizing current information about cultural or physical geographic name entities. The database contains a separate file for each state, the District of Columbia, and territories containing all 7.5 min. maps published or planned. Printouts and searches are available on a cost recovery basis.
Geographic Information Retrieval and Analysis System (GIRAS), USGS, Earth Science Information Center (ESIC), 507 National Center, Reston, VA 22092; 800/USA-MAPS	Land use maps, land cover maps, and associated overlays for the United States.	Map data are available in both graphic and digital form, and statistics derived from the data are also available. Searches for either locations or attributes can be made.
U.S. Geodata Tapes, Department of the Interior, Room 2650, 18th & C Sts., NW, Washington, DC 20240; 202/208-4047	These computer tapes contain cartographic data available in two forms: (1) graphic to generate computer plotted maps; (2) topologically structured for input into geographic information systems.	Tapes are available for the entire U.S., including Alaska and Hawaii, and are sold in 4 thematic layers: boundaries, transportation, hydrography, and U.S. Public Land Survey System. Each can be purchased individually. Tapes can be ordered through the Earth Science Information Center (ESIC—see above) or through the following ESIC offices: Anchorage, AK (907/786-7011); Denver, CO (303/236-7477); Menlo Park, CA (415/329-4309); Reston, VA (703/860-6045); Rolla, MO (314/341-0851); Salt Lake City, UT (801/524-5652); Spokane, WA (509/456-2524); and Stennis Space Center, MS (601/688-3541).

Table 6-2. Topographic Data Sources (U.S. EPA, 1993c; Sara, 1994) (continued)

Source	Type(s) of Information	Comments
Topographic Database, National Geophysical Data Center, NOAA, Code E/GC1, 325 Broadway, Boulder, CO 80303; 303/497-6764	This system contains a variety of topography and terrain data sets available for use in geoscience applications.	The data were obtained from U.S. Government agencies, academic institutions, and private industries. Data coverage is regional to worldwide; data collection methods encompass map digitization to satellite remote sensing.
State geological surveys	Topographic maps.	Many state geological surveys sell USGS topographic maps for the state in which they are located.
Commercial map supply houses	Topographic and geologic maps.	Commercial map supply houses often have full state topographic inventories that may be out of print through national distribution centers. Digitized topographic maps can also be obtained from some suppliers.

Table 6-3. Aerial Photography and Remote Sensing Sources (U.S. EPA, 1993c; Sara, 1994)

Source	Type(s) of Information	Comments
Aerial Photography Field Office, U.S. Department of Agriculture, P.O. Box 30010, Salt Lake City, UT 84130; 801/975-3503	Conventional aerial photography scales of 1:15,000 to 1:40,000.	Aerial photographs by the various agencies of the U.S. Department of Agriculture: Agricultural Stabilization and Conservation Service (ASCS), Soil Conservation Service (SCS), and Forest Service (USFS) cover much of the U.S.
District ASCS and SCS offices	Aerial photography.	District offices of the USDA Agricultural Stabilization and Conservation Service and the Soil Conservation Service are usually the best starting point for identifying available aerial photography at the county level.
Earth Resources Observation System (EROS) Data Center, USGS, Sioux Falls, SD 57198; 605/594-6151	Aerial photography (scales 1:20,000 to 1:60,000) obtained by USGS and federal agencies other than SCS is available as 230 mm by 230 mm prints. Landsat satellite multispectral imagery can also be obtained from the EROS Data Center.	Because of the large number of individual photographs needed to show a region, photomosaic indexes are used to identify photographic coverage of a specific area. The EROS Data Center has more than 50,000 such mosaics. Mosaics and aerial photographs are also available from the USGS Map Sales office in Denver (Table 6-2). The Data Center can provide a computer listing of all imagery on file for (1) point search (longitude and latitude), (2) area quadrilateral (four lat/long coordinates), and (3) map specification (point or area).
NASA Aerial Photography	Aerial photography available in a wide variety of formats (black and white, color, color infrared). Scales generally range from 1:60,000 to 1:120,000.	Coverage restricted to areas selected for testing of remote-sensing instruments and techniques. Available from EROS Data Center (see above).
Photogrammetry Division, NOAA, 6001 Executive Blvd., Rockville, MD 20852; 301/443-8601	Color and black-and-white aerial photographs at scales ranging from 1:20,000 to 1:60,000.	The Coastal Mapping Division of the National Oceanic and Atmospheric Administration (NOAA) maintains coverage of the tidal zone of the Atlantic, Gulf and Pacific Coasts. An index can be obtained from the Coastal Mapping Division.
Aerial Photo Section, Bureau of Land Management, P.O. Box 25047, Bldg. 46, Federal Center, Denver, CO 80225; 303/236-7991	BLM has aerial photographic coverage of over 50 percent of its land in 11 western states.	
Cartographic and Architectural Branch, National Archives, 8 Pennsylvania Ave. NW, Washington, DC 20408; 703/756-6700	Airphoto coverage from the late 1930s to the 1940s can be obtained for portions of the U.S.	This service may be useful for early documentation of site activities. Early airphotos may also be on file in ASCS and SCS District offices (see above). Foreign airphoto coverage for the World War II period is also available.
Commercial Aerial Photography Firms	Existing air photos flown for other clients, or new photography for site of interest.	Many firms can also develop detailed topographic site maps using photogrammetric techniques. For a listing of nearby firms specializing in these services consult the yellow pages or contact: American Society of Photogrammetry and Remote Sensing, 5410 Grosvenor Lane, Suite 210, Bethesda, MD 20814; 301/493-0290.

and landforms; and Band 7 is similar to Band 6 except that it provides better penetration through haze. Band 5 gives the best general-purpose view of the earth's surface.

6.3.2 Soils, Geologic, Geophysical, and Geotechnical Information

Table 6-4 identifies sources of information on soils, geology, geophysical and geotechnical information. If available, a county soil survey published by the SCS is one of the single best sources of information about a site because it also provides an indication of subsurface geologic conditions and contains a wealth of information on typical soil physical and chemical characteristics (Table 6-5). If a soil survey is not available, check to see if the site is located within a farm property listed with the local Soil and Water Conservation District. If so, there may be an unpublished farm survey on file in the District SCS office. As with published topographic maps generally, the scale of an SCS soil survey is usually not adequate for site engineering and design purposes; thus, part of a field investigation should include more detailed mapping of soils, if possible (see Section 6.4.2). If an unpublished soil survey is available, SCS soil series descriptions and interpretation sheets should be obtained for all soil series that have been mapped in the area. Table 6-5 summarizes the kind of information that can be found on these sheets. Estimated soil properties are typically given as ranges or values for different soil horizons, and direct field observation and sampling is required for more accurate definition of soil properties. Even if a published soil survey is available, these sheets provide a convenient reference for characteristics of soil series occurring within a site. The same information on

Table 6-4. Soils, Geologic, Geophysical, and Geotechnical Data Sources (U.S. EPA, 1993c; Sara, 1994)

Source	Type(s) of Information	Comments
USDA Soil Conservation Service; 202/720-1820	County-level soil surveys are available for about 75% of the country. Soil series descriptions and interpretation sheets contain information on soil physical and chemical properties.	District offices covering one or several counties may contain unpublished soil mapping. Published soil surveys and soil series description and interpretation sheets can be obtained from SCS state offices, located in each state capital.
U.S. Geological Survey (USGS) Books and Open File Reports Sales, Federal Center, Box 25425, Denver, CO 80225; 303/236-7476	USGS produces annually numerous publications including maps, bulletins, circulars, professional papers and open-file reports.	USGS Circular 900, Guide to Obtaining USGS Information (Dodd et al., 1989) is available at no cost.
USGS Main Library, 950 National Center, Reston, VA 22092; 703/648-4302	The Reston library contains more than 800,000 books, monographs, serials, maps and microforms covering all aspects of earth and environmental sciences.	USGS has one of the largest earth science libraries in the world. Library staff and users can access the online catalog from terminals at the Reston library and from the regional libraries located in Denver, CO; Flagstaff, AZ; and Menlo Park, CA. The database can be searched by author, title, key words, subjects, call numbers, and corporate/ conference names.
Geologic Names of the United States (GEONAMES), Geologic Division, USGS, 907 National Center, Reston, VA 22092	GEONAMES is an annotated index of the formal nomenclature of geologic units of the U.S. Data includes distribution, geologic age; USGS usage, lithology, thickness, type locality and references.	Printouts are not available. Diskettes containing data for two or more adjacent from USGS books and reports sales (address above). Magnetic tapes can be obtained from NTIS (Table 6-1).
Geologic Indexes and Databases		
A Guide to Information Sources in Mining, Minerals, and Geosciences (Kaplan, 1965)	Information on more than 1,000 governmental and nongovernmental organizations in 142 countries.	An older, useful guide. Part II lists more than 600 worldwide publications and periodicals including indexing and abstracting services, bibliographies, dictionaries, handbooks, journals, source directories, and yearbooks in most fields of geosciences.
A Subject and Regional Bibliography of Publications and Maps in the Geological Sciences (Ward, 1972)	Bibliographies of geologic information for each state in the U.S. and reference for general maps and ground-water information for many sites.	Provides a useful starting place for many site assessments. A general section outlines various bibliographies and abstracting services, indexes and catalogs, and other sources of geologic references.
Bibliography and Index of Geology		
American Geological Institute (AGI)	Includes worldwide references with listing by authors and subject. Published monthly with annual cumulative index.	Replaces separate indexes published by the USGS (North American references only) and the Geological Society of America/GSA (references exclusive of North America) until 1969. Both publications merged in 1970 and were published by GSA through 1978, when AGI continued its publication.

Table 6-4. Soils, Geologic, Geophysical, and Geotechnical Data Sources (U.S. EPA, 1993c; Sara, 1994) (continued)

Source	Type(s) of Information	Comments
GEOREF		
American Geological Institute	Computer database with bibliographic citations from 1961 to present.	Available through online services or on CD ROM. Includes references contained in the Bibliography and Index of Geology. Available at many university libraries.
GEODEX Retrieval System with Matching Geotechnical Abstracts		
GEODEX International, Inc., P.O. Box 279, Sonoma, CA 95476	Computer database with engineering geological and geotechnical references.	The GEODEX is a hierarchically organized system providing easy access to the geotechnical literature. Can be purchased on a subscription basis, or available at many university libraries.
KWIC (Keyword-in-Contents) Index of Rock Mechanics Literature	Engineering geologic and geotechnical references.	Published as two volumes (Grawlewska, 1969; Jenkins and Brown, 1979), and can be found in many earth science libraries.
Geophysical Data		
U.S. Geological Survey, Box 25046, Federal Center, Denver, CO 80225	Aeromagnetic maps, magnetic declination, landslide information, earthquake data. Many USGS publications contain geophysical survey for specific areas.	Aeromagnetic maps (1:24,000): Branch of Geophysics, MS 964; 303/236-1343. Earthquake data: National Earthquake Information Center (NEIC), MS 967; 303/236-1500 (recent earthquakes only). Landslide data: Landslide Information Center, MS 966; 303/236-1599. Magnetic Declination Information: Branch of Global Seismology and Geomagnetism, MS 967; 303/236-1369. GEOMAG contains current and historical magnetic-declination information. Current or historical values back to 1945 can be obtained by calling 800/358-2663. The entire GEOMAG database can also be accessed via modem.
National Geophysical Data Center (NGDC), NOAA, Mail Code E/GC, 325 Broadway, Boulder, CO 80303; Land data: 303/497-6123; Seismic data: 303/497-6472	NGDC maintains a computer database on earthquake occurrence from prehistoric times to the present. NGDC also maintains databases on other parameter, such as topography, magnetics, gravity, and other topics.	NGDC is a central source for dissemination of earthquake data and information for both technical and general users, except for recent earthquakes (see USGS above). For a fee, a search can be made for one or more of the following parameters: (1) geographic area (circular or rectangular area), (2) time period (starting 1638 for U.S.), (3) magnitude range, (4) date, (5) time, (6) depth, and (7) intensity (modified Mercalli).
Electric Well Log Services, P.O. Box 3150, Midland, TX 79702; 915/682-7773	Electric logs for many petroleum wells can be obtained from one of several well log libraries in the U.S.	The geophysical logs are indexed by survey section. To obtain information on wells in a given area, a list of townships, ranges, and section numbers must be compiled.
Geophysical Survey Firms	Surface and borehole geophysical surveys.	Proprietary geophysical data can sometimes be obtained from private survey firms if the original client authorizes release of the information. Even if the information cannot be released, firms may be willing to provide references to published information they obtained before the survey, or information published as a result of the survey.

individual soil series can be found in the text portion of an SCS soil survey, but is scattered through different sections and tables in the report.

Existing site-specific subsurface geologic information typically will not be available unless water wells or oil and gas exploration holes are located on or near the site. If water well or exploration boreholes are known or thought to exist at the site in nearby locations, available well/borehole logs should be obtained. Water well drill log files are typically maintained by state water resource agencies (Table 6-6), and state geological surveys or oil and gas agencies should be the first place contacted for information about other possible borehole logs. Geophysical survey firms and well log libraries are other possible sources for subsurface borehole data (Table 6-4). If a site is located near a numbered county, state, or federal highway, the appropriate agency should be contacted to identify possible subsurface information collected as part of road or highway construction projects. Table 6-4 identifies geologic indexes and databases for geologic and geotechnical literature, if a more extensive literature search should be appropriate for a site.

Major areas of holocene faulting can be identified by consulting the series of maps that identify young faults (U.S. Geological Survey, 1978), which can be obtained from USGS Map Sales (Table 6-2). Figure 4-1 identifies major potential seismic impact zones in the United States. If the site is located within or near any of the

Table 6-5. Types of Data Available on SCS Soil Series Description and Interpretation Sheets

Soil Series Description Sheet	Gypsum (%)
Taxonomic Class	**Organic matter (%)**
Typical soil profile description	Shrink-swell potential
Range of characteristics	Corrosivity (steel and concrete)
Competing series	Erosion factors (K,T)
Geographic setting	Wind erodability group
Geographically associated soils	**Flooding (frequency, duration, months)**
Drainage and permeability	**High water table (depth, kind, months)**
Use and vegetation	**Cemented pan (depth, hardness)**
Distribution and extent	**Bedrock (depth, hardness)**
Location and year series was established	Subsidence (initial, total)
Remarks	**Hydrologic group**
Availability of additional data	Potential frost action
Soil Survey Interpretations Sheet[a]	Use/Suitability Ratings
Estimated Soil Properties (major horizons)	Sanitary facilities
Texture class (USDA, Unified, and AASHTO)	Source material
Particle size distribution	Community development
Liquid limit	Water management
Plasticity index	Recreation
Moist bulk density (g/cm^3)	Crop/pasture capability and predicted yields
Permeability (in./hr)	Woodland suitability
Available water capacity (in./in.)	Windbreaks (recommended species for planting)
Soil reaction (pH)	Wildlife habitat suitability
Salinity (mmhos/cm)	Potential native plant community (rangeland or forest)
Sodium absorbtion ratio	[a] Units indicated are those used by SCS.
Cation exchange capacity (Me/100g)	**Note:** Boldface entries are particularly useful for evaluating contaminant transport.
Calcium carbonate (%)	

Table 6-6. Hydrologic, Wetland, and Climatic Data Sources (U.S. EPA, 1993c; Sara, 1994)

Source	Type(s) of Information	Comments
Hydrologic Information Unit, USGS, 419 National Center, Reston, VA 22092; 703/648-6817	Locations and phone numbers of USGS Water Resource Division District Offices; state water-resource investigation summary reports.	*Water Resources Investigations in [State, Year]* are booklets describing projects and related publications by USGS and cooperating agencies. Summary folders by the same name show location of hydrologic-data stations and selected publications for the state. Also serves as reference office for Water-Resources Investigation reports released before 1982 that were not issued as Open-File Reports (Table 6-4) or made available through NTIS (Table 6-1).
Office of Water Data Coordination (OWDC), USGS, 417 National Center, Reston, VA 22092; 703/648-5023	Information on current federal water data acquisition activities. Selected publications are also available.	Available publications include: (1) *National Handbook of Recommended Methods for Water-Data Acquisition*, (2) *Index to Water Data Activities in Coal Provinces in the U.S.* (5 Volumes), and (3) *Guidelines for Determining Flood Flow Frequency.*
National Water Data Exchange (NAWDEX), USGS, 421 National Center, Reston, VA 22092; 703/648-5677	NAWDEX *Master Water Data Index* and *Water Data Source Directory* contain information on more than 460,000 water data sites and more than 800 organizations that collect water data respectively.	The NAWDEX Program Office and its 75 Assistance Centers (which includes all USGS Water Resources Division District Offices) help water-data users locate and obtain data, including bibliographic search in the WRSIC database (see below). Fees for services depend on type of request and the organization fulfilling the request.

Table 6-6. Hydrologic, Wetland, and Climatic Data Sources (U.S. EPA, 1993c; Sara, 1994) (continued)

Source	Type(s) of Information	Comments
National Water Data Storage and Retrieval System (WATSTORE)	All types of water data are accessed through the WATSTORE computer database.	NAWDEX (above) or USGS Water Resource Division District Offices (see below) should be contacted for information on availability of specific types of data, acquisition of data or products, and user charges.
Water Resources Scientific Information Center (WRSIC), USGS, 425 National Center, Reston, VA 22092; 703/648-6821	Abstracts of water resources publications throughout the world.	Bibliographic information available through publications and computerized bibliographic information services. For additional information contact Branch of Water Information Transfer.
USGS Water Resources Division District Offices (WRD-DO)	State-level water resources investigation reports and data.	WRD-DOs serve as NAWDEX Assistance Centers, and can provide up-to-date listings of water resource investigation publications and maps by USGS and cooperating agencies.
USGS Hydrologic Publications	Various Series: Water-Supply Papers, Water-Resource Investigation Reports, Hydrologic Investigation Atlases; State Hydrologic Unit Maps.	Publications available from USGS Book and Open File Reports Section (Table 6-4); maps and atlases available from USGS Map Distribution Section (Table 6-2).
Federal Emergency Management Agency, Flood Map Distribution Center, 6930 (A-F) San Thomas Rd., Baltimore, MD 21227-6227; 800/358-9616	100-year floodplain maps are available for most municipal areas at a scale of 1:24,000. In some areas more detailed FEMA Flood Insurance Studies are available that delineate 500-year floodplain.	Flood Insurance Rate maps and other flood maps can be obtained from FEMA. These maps are also available from USGS WRD-DOs and commonly from other agencies such as the relevant city, town, or county planning office.
U.S. Army Corps of Engineers (COE), Washington, DC 20314-1000; 202/272-0660	Location of navigable waters and wetlands.	The COE has primary responsibility for regulation of wetlands. Methods for delineating wetlands are contained in COE (1987), and Federal Interagency Committee for Wetland Delineation (1989). The nearest COE District office should be contacted to identify available information.
Fish and Wildlife Service, U.S. Department of the Interior, 1849 C St. NW, Washington, DC 20240; 202/208-5634	National Wetland Inventory (NWI) maps.	The NWI has been completed largely using remote sensing techniques and other available resource data.
State Water Resource Agencies	Well logs, state-collected hydrologic data.	Hydrologic data can often be accessed through NAWDEX. Ground-water well logs commonly must be obtained from the appropriate state agency. Giefer and Todd (1972, 1976) identify water publications by State Agencies.
National Ground Water Information Center (NGWIC), National Ground Water Association, 6375 Riverside Drive, Dublin, OH 43017; 800/332-2104	Computerized, on-line bibliographic database. Search by author, keyword, and date. Abstracts are relatively short and nontechnical.	Accessible to members and nonmembers through computer, modem, and telecommunications software. Photocopying service of most references and interlibrary loan service available.
Climatic Data		
National Climatic Data Center (NCDC), Federal Building, 37 Battery Park Ave., Asheville, NC 28801-2733; 704/259-0682	The National Oceanic and Atmospheric Administration's (NOAA) NCDC collects and catalogs nearly all U.S. weather records. Hatch (1988) provides a selective guide to climatic data sources.	NCDC services include: (1) publications, reference manuals, and data report atlases, (2) data and map reproduction in various forms (paper copy, microfiche, magnetic tape, diskette), (3) analysis and preparation of statistical summaries, (4) evaluation of data records for specific analytical requirements, (5) library search for bibliographic references, abstracts and documents, and (6) referral to organizations holding requested information.
Gale Research Company (1985)	*Climates of the States - NOAA Narrative Summaries, Tables, and Maps for Each State.*	Provides general summary statistics and maps.
U.S. Department of Agriculture	County-level, local meteorological data.	Published SCS county soil surveys provide summary precipitation and temperature data. Agricultural Research Stations funded by the USDA Cooperative Extension Service often collect climatic data in areas where agricultural research is being done.

shaded areas on this figure, more detailed information about historic seismic activity in the area should be obtained. The National Oceanic and Atmospheric Administration's National Geophysical Data Center (NGDC) in Boulder, Colorado, (Table 6-4) is the primary source of information for earthquake data. If there has been very recent seismic activity in the area, the USGS's National Earthquake Information Center (NEIC), in Denver, Colorado should be contacted (Table 6-4).

General information on geotechnical characteristics of near-surface soils at a site can be obtained from soil survey information (USCS classification of major soil horizons, liquid limit, plasticity index, etc.—see Table 6-5). Site-specific geotechnical information, however, is not likely to be available unless data from highway adjacent or near the site exist (see discussion above). The availability of such information must be addressed during site-specific investigations (see Section 6.4.3).

6.3.3 Hydrologic, Wetland, and Climatic Information

Table 6-6 identifies major information on hydrology, floodplains, wetlands, and climatic data. In general, existing hydrologic data fall into four primary categories: (1) stream discharge, (2) stream water quality, (3) ground-water levels, and (4) ground-water quality. Typically site-specific data will not be available, but relevant data from nearby or hydrogeologically similar monitoring points should be obtained. The state district offices of the USGS's Water Resources Division, which serve as local assistance centers for USGS's National Water Data Exchange (NAWDEX) is the best starting point for identifying available hydrologic data that might be relevant to a specific site. These offices are primarily responsible for floodplain mapping, so they also should be asked about the availability of floodplain maps for the area of interest. Published floodplain maps also can be obtained from the FEMA's Flood Map Distribution Center (Table 6-6) and also might be available from city, town, or county planning offices.

If a National Wetland Inventory (NWI) map is not available for the site being evaluated, a published SCS soil survey will indicate the possible presence of wetlands. Soil series located within a site should be checked against the list of "hydric" soil series that has been developed by SCS (National Technical Committee for Hydric Soils, (1991). If wetlands are known or suspected to be present within or near a site, more detailed site investigations will be required (see Section 6.4.5). An SCS soil survey also will indicate whether all or parts of a site are located within a floodplain, but more detailed investigations may be required to delineate the 100-year floodplain if a FEMA flood map is not available (see Section 6.4.6).

6.4 Site-Specific Data Collection

The characteristics of a site as indicated by existing information about the site and its surrounding area will determine the type and extent of field investigations that will be required. As site geology and hydrogeology increase in complexity, more sophisticated and expensive site investigation techniques are required, as shown in Figure 6-1. The discussion in this section assumes that the ground-water system is relatively simple, consisting of a single unconfined aquifer in unconsolidated materials (Type I in Figure 6-1). Field investigation techniques for this type of site are relatively simple and inexpensive, requiring equipment ranging from handheld soil augers to power-driven equipment that is hand-portable or can be mounted on a pickup truck. Although a detailed discussion of field methods for investigation of more complex sites is beyond the scope of this handbook, Table 6-7 identifies major recent references where information on such techniques can be found. Also, Section 6.4.6 identifies major references that address methods for site-specific geotechnical investigations, and Appendix C identifies manufacturers and distributors of equipment for site-specific data collection.

Table 6-7. Guide to Major Recent References on Environmental Field Investigation Techniques[a]

Reference	Description
ASTM (1994)	*Standard Guide to Site Characterization for Environmental Purposes.* Text and appendices identify hundreds of ASTM standard test methods for field and laboratory methods. See also ASTM D420 (Standard Guide to Site Characterization for Engineering, Design and Construction Purposes).
Nielsen (1991)	*Practical Handbook of Ground-Water Monitoring.* Comprehensive handbook on ground-water monitoring methods, which also includes chapters on soil sampling and vadose zone monitoring.
Sara (1994)	*Standard Handbook of Site Assessment for Solid and Hazardous Waste Facilities.* Comprehensive handbook on solid and hazardous waste facility assessments.
U.S. EPA (1987)	*Technology Briefs: Data Requirements for Selecting Remedial Action Technology.* Sections relevant to design of sewage sludge surface disposal sites include: grading, revegetation, diversion/collection systems, and surface water/sediment containment barriers. Summary tables for each technique identify (1) data needs, (2) purpose of the data, (3) collection methods, and (4) costs.
U.S. EPA (1988a)	*Guide to Technical Resources for the Design of Land Disposal Facilities.* Most relevant sections related to sewage sludge surface disposal sites include sections on foundations (useful if the potentially unstable areas are present, and run-on/runoff controls.

Table 6-7. Guide to Major Recent References on Environmental Field Investigation Techniques[a] (continued)

Reference	Description
U.S. EPA (1991c)	*Site Characterization for Subsurface Remediation.* Covers methods for soil/geologic, ground-water and vadose-zone hydrologic characterization and monitoring techniques with a focus on applications for remediation of contaminated sites. Chapters 2 through 9 cover techniques that are applicable to any type of environmental field investigation.
U.S. EPA (1993a)	*Subsurface Field Characterization and Monitoring Techniques.* 2-volume document providing summary information on more than 280 specific field investigation and monitoring techniques. Volume I covers solid and ground-water and Volume II covers the vadose zone, chemical field screening and analytical techniques. Appendix C contains a comprehensive bibliography of major references on subsurface characterization, monitoring and analytical methods.
U.S. EPA (1993b)	*Solid Waste Disposal Facility Criteria: Technical Manual.* Chapter 2 covers methods for identification and engineering design considerations related to floodplains, wetlands, fault areas, seismic impact zones and unstable areas. Chapter 5 covers ground-water monitoring well design and construction and sampling.

[a] See end of Section 6.4.6 for identification of major references for geotechnical characterization.

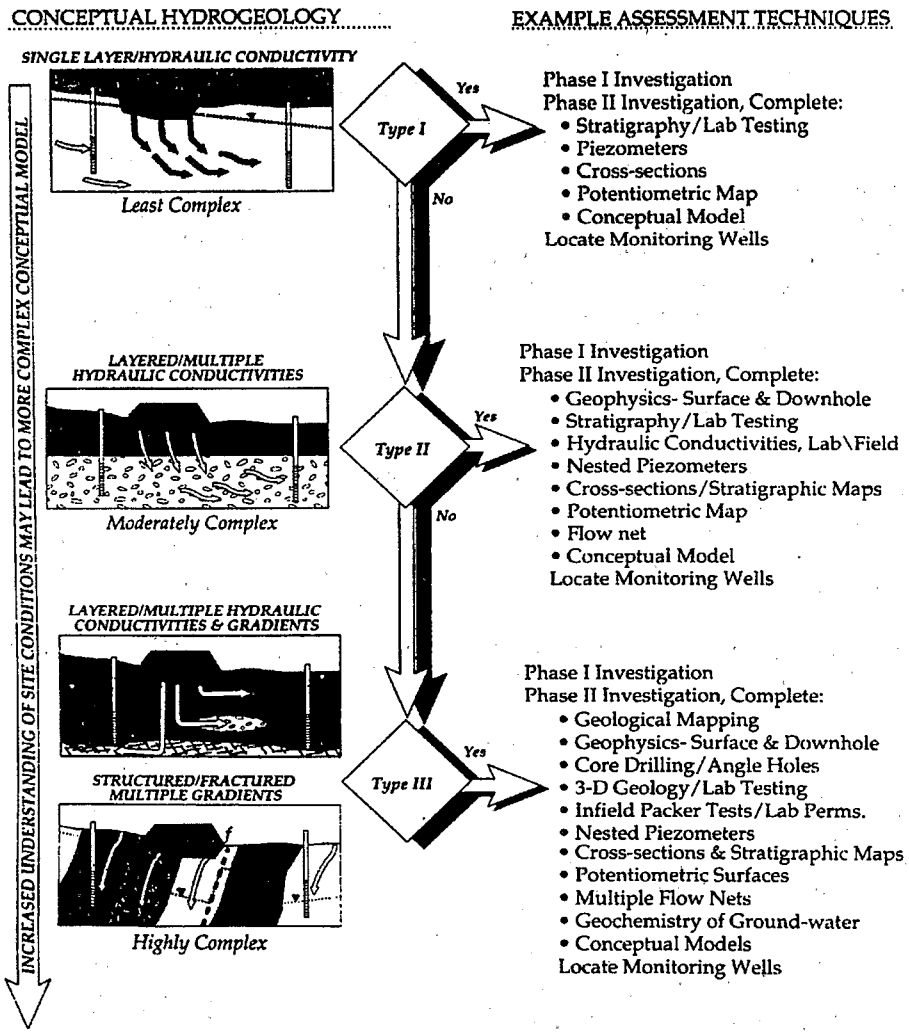


Figure 6-1. Site complexity indicators for selection of assessment techniques (Sara, 1994).

6.4.1 Site Land and Topographic Survey

An accurate boundary survey and topographic base map are essential for developing a base map for plotting observation points during field investigations and for design of pollution control measures such as terraces and sediment ponds. Where a site comprises tens of acres, a scale of 1:1,200 (1 in. = 100 ft) or 1:2,400 (1 in. = 200 ft) with contour intervals ranging from 1 to 5 ft will usually provide the best base map. Sites involving hundreds of acres may require larger scales (up to 1:6,000) to prevent base map size from becoming unmanageable. In very flat areas, contour intervals of 1 or 2 ft are required to accurately delineate subtle topographic variations. In steep areas, larger contour intervals are appropriate. Topographic maps at scales of 1:2,400 or larger can be created using field surveys or photogrammetry from low-altitude aerial photographs. Cost estimates from surveyors and commercial aerial photography/photogrammetry companies should be obtained. If the local yellow pages do not list any photogrammetry firms, the American Society of Photogrammetry and Remote Sensing (ASPRS) might be able to provide the address and phone number of firms that work in the vicinity of the site. Table 6-3 includes ASPRS's address and phone number.

6.4.2 Soil and Geologic Characterization

Although published soil surveys provide much useful information for preliminary site selection, they generally are not adequate for site-specific design of sludge surface disposal sites. For example, areas of similar soils that cover less than 4 or 5 acres are generally not shown on published SCS county soil surveys. For site-specific evaluation and design purposes, it is desirable to identify areas of similar soil characteristics that are as small as an acre. The SCS may be able to prepare a more detailed soil survey of a site that has been selected for surface disposal of sludge. If SCS has a large backlog of requests, however, obtaining a more detailed soil survey can take months. A detailed soil survey prepared by consulting soil scientists will be more expensive, but will usually involve less delay. If a private consultant conducts the soil survey, the person or persons actually carrying out the survey should be trained in soil mapping and classification methods used by SCS for the National Cooperative Soil Survey.

As discussed in Section 6.4.3 (Hydrogeologic Characterization), where the permanent or seasonal high water table is within 5 ft of the ground surface, creation of a water table map by a soil scientist based on observation of soil morphology can be a very cost-effective way to obtain an initial characterization of a site's hydrogeology.

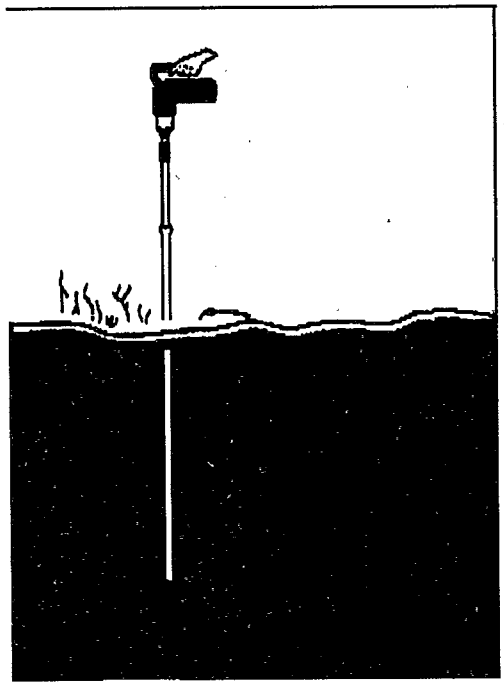
Soil mapping is usually conducted using handheld augers or tube probes with subsurface observations limited to depths of 5 ft or less. Once a detailed soil survey has been prepared, sites for deeper sampling can be selected to evaluate whether surface topography and soil types correlate with geologic characteristics below the soil weathering zone (which generally extends to a depth of 5 ft or less), and for more detailed hydrogeologic and geotechnical characterization.

Test pits are the best way to directly examine subsurface lithology and sedimentary features that affect the potential for transport of pollutants in the near surface because both lateral and vertical variations can be observed, and core samples allow direct observation of vertical changes in subsurface lithology and sedimentary features. Provided that gravel or other rock fragments are absent, the most efficient and cost-effective way to collect deeper cores is usually by using truck-portable power-driven equipment. Such equipment can involve hand-held electric, gasoline-powered, or compressor-operated vibrating hammers for driving rods with probes affixed to the end (Figure 6-2a) and using a special jack to pull the probe to the surface (Figures 6-2b to 6-2d). Also, hydraulic probes can be mounted to a van or pickup truck (Figure 6-3) or on trailers or tractors. Probes driven with handheld power equipment typically yield cores of 1 in. in diameter. Mounted hydraulic probes can provide cores of up to 2 in. Larger diameter cores are generally easier to describe because changes in color, texture, and other features are more discernable. Boulding (1994) and U.S. EPA (1991a) provide guidance on the description and interpretation of subsurface cores. Where the subsurface contains large rock fragments, it may still be possible to collect large-diameter cores (2 inches) using larger drill rigs. Otherwise, drilling methods that do not collect cores may have to be used. Also collection of core deep core samples (generally greater than 10 meters) generally requires use of drill rigs rather than hand-powered or truck-mounted equipment.

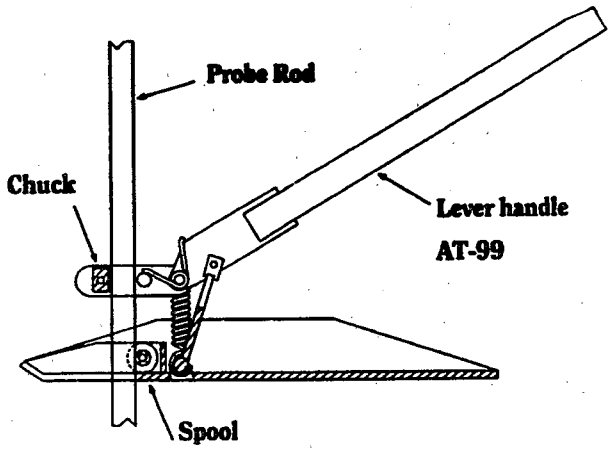
Note: All deep boreholes represent channels for preferential movement of leachate from sewage sludge and therefore should be filled with bentonite or an alternative suitable grout. Shallow boreholes within the sludge surface disposal site or that might receive surface runoff from the site also should be plugged at the surface or grouted. Figure 6-4 illustrates a grouting procedure using a rigid pipe and flexible tremie tube. Where holes do not extend to the water table, plugging of the upper part of the hole with soil material may be adequate as a alternative to grouting.

6.4.3 Hydrogeologic Characterization

Hydrogeologic field investigations should focus on developing a three-dimensional understanding of the ground-water flow system so as to determine: (1) the direction in which pollutants from sewage sludge would travel if it entered an aquifer, (2) the speed with which the pollutants would move, and (3) the best location for



(a)



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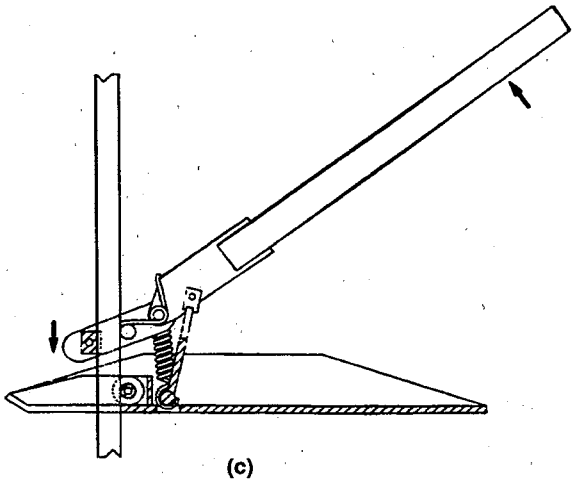

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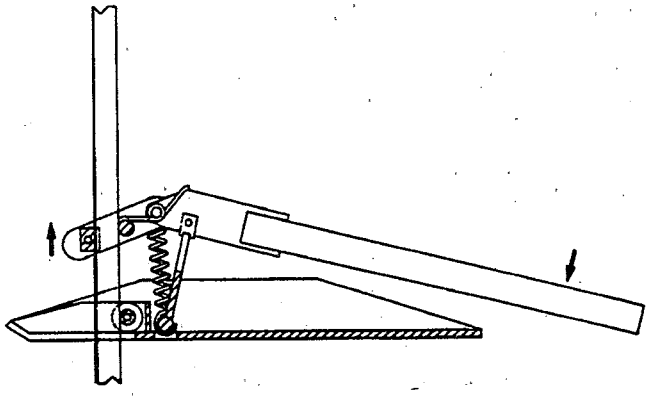

(d)

Figure 6-2. Core sampling with handheld power driver: (a) hammer driver (courtesy Solinst Canada); (b) positioning probe rod jack for manually retrieving deep core samples; (c) chuck in down position; (d) pulling position, level down (courtesy of Geoprobe Systems).

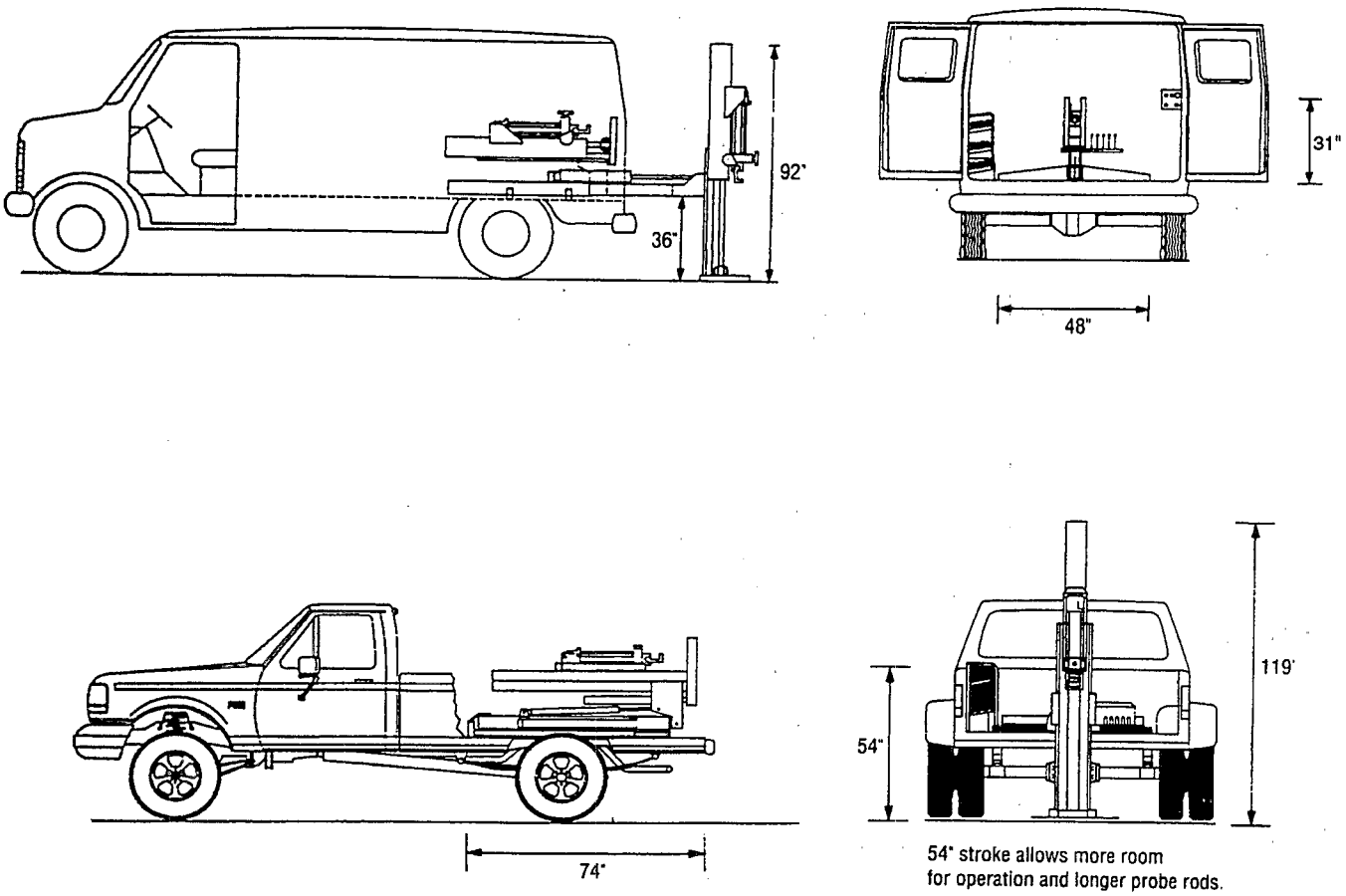

Figure 6-3. Hydraulic probes mounted in van and pickup truck (courtesy of Geoprobe Systems).

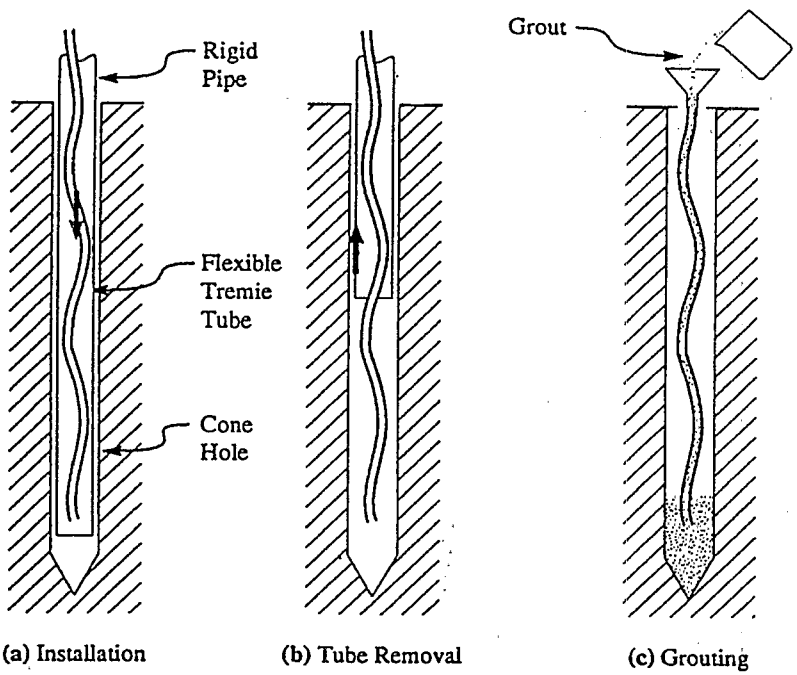

Figure 6-4. Narrow-diameter borehole grouting procedure using rigid pipe and internal flexible tremie tube.

ground-water monitoring wells. Generally, hydrogeologic characterization should be conducted by a qualified ground-water scientist, defined by EPA as

> an individual with a baccalaureate or post-graduate degree in the natural sciences or engineering who has sufficient training and experience in ground-water hydrology and related fields, as may be demonstrated by State registration, professional certification, or completion of accredited university programs, to make sound professional judgements regarding ground-water monitoring, pollutant fate and transport, and corrective action. 40 CFR 503.21(l).[1]

This section focuses on relatively simple and inexpensive techniques for characterizing the ground-water system using: (1) soil morphology where the seasonal high water table is within 5 ft of the ground surface; (2) multiple piezometer installations to develop a three-dimensional picture of hydraulic head distribution; and (3) flow net analysis to determine the direction and speed of ground-water flow. For a Type I hydrogeologic setting (Figure 6-1), this information can be obtained using handheld or portable power-driven equipment similar to that described for soil and geologic characterization in Section 6.4.2. As noted above, references in Table 6-7 provide information on field investigation techniques for more complex sites.

Depth to Water Table Based on Soil Morphology

Soil color serves as a good indicator of soil-water conditions, with grey colors of 2 chroma or less on a Munsell Soil Color Chart typically indicating a dominance of reducing conditions and bright colors indicating oxidizing conditions. In 1992 the SCS adopted an extensively revised and improved approach to describing and interpreting soils that are saturated during all or part of the year (Soil Survey Staff, 1992). The depth and pattern of *redoximorphic* soil features allow estimation of the depth of the permanent and seasonal high water table. Seasonal perched water tables also can be identified based on soil morphology, even if no water is perched at the time of observation. Boulding (1994, Appendix C) and Vepraskas (1992) provide more detailed guidance on description and interpretation of soil redoximorphic features.

Where the water table is within five feet of the ground surface (which is common in large areas of the eastern United States) a detailed water table map can be developed at relatively low cost if a qualified soil scientist is available (see Section 6.4.2). A grid spacing should be chosen that will provide sufficient data points for contouring, but not so many that field work cannot be completed in a day or two. A general rule of thumb would be 20 to 30 soil observations using handheld equipment to record the following information: (1) texture and thickness of A horizon, (2) texture and thickness of E horizon (if present), (3) depth to B or C horizon, and (4) depth to seasonal high and permanent water table. If a ground survey is used to prepare the topographic base map for the site (Section 6.4.1), placement of stakes at the chosen grid spacing and measurement of actual elevation of the grid points would facilitate field work and plotting of data observations. Section 6.5.2 discusses how data collected by this survey can be used to evaluate soil attenuation capacity and the potential for pollutant transport.

Three-Dimensional Mapping of Hydraulic Head

Accurate characterization of the ground-water flow system requires not only a delineation of the water table surface, but also measurement of hydraulic head at different depths in an aquifer. Figure 6-5 shows why this is necessary. In areas of ground-water *recharge*, hydraulic head *decreases* with depth (wells *a* and *b* in Figure 6-5). In ground-water *discharge* zones, hydraulic head *increases* with depth (wells *d* and *e* in Figure 6-5). Areas where lateral flow is dominant are characterized by small changes in hydraulic head with depth. Furthermore, variations in the hydraulic conductivity of different aquifer materials cause changes in the distribution of hydraulic head and, consequently, changes in the direction of ground-water flow. This effect is illustrated in Figure 6-6 where piezometers (discussed below) have been set in three different aquifer materials at each observation point. The water table surface (Unit A) indicates a general flow direction from an elevation of 210 ft on the west edge to 180 ft on the east edge. Unit C in Figure 6-6, however, shows a head distribution favoring ground-water flow south to southeast. Section 6.5.2 discusses further use of flow nets to evaluate the direction of ground-water movement based on three-dimensional pressure head measurements.

Pressure head is measured using a *piezometer*. The two major types of piezometers are (1) *open-tube* or *standpipe* piezometers, in which ground water rises to the level dictated by the pressure head, and (2) *pore pressure* piezometers, which measure pressure directly. Any cased well can function as an open-tube piezometer, provided that the borehole around the casing is well sealed and the well screen or casing slotting at the bottom is short (5 feet or less) so as to prevent mixing of hydraulic heads. Pore pressure piezometers can be further classified as:

[1] The Part 503 rules do not explicitly state that hydrogeologic characterization be done by a qualified ground-water scientist, nevertheless it would make sense to have such a person conduct or supervise this aspect of the field investigations. A qualified groud-water scientist *is* required for developing a ground-water monitoring program or certify that placement of sewage sludge on an active sewage sludge unit will not contaminate ground water if graound-water is not monitored at units that do not have a liner and leachate collection system (40 CFR 5-3.24(n)).

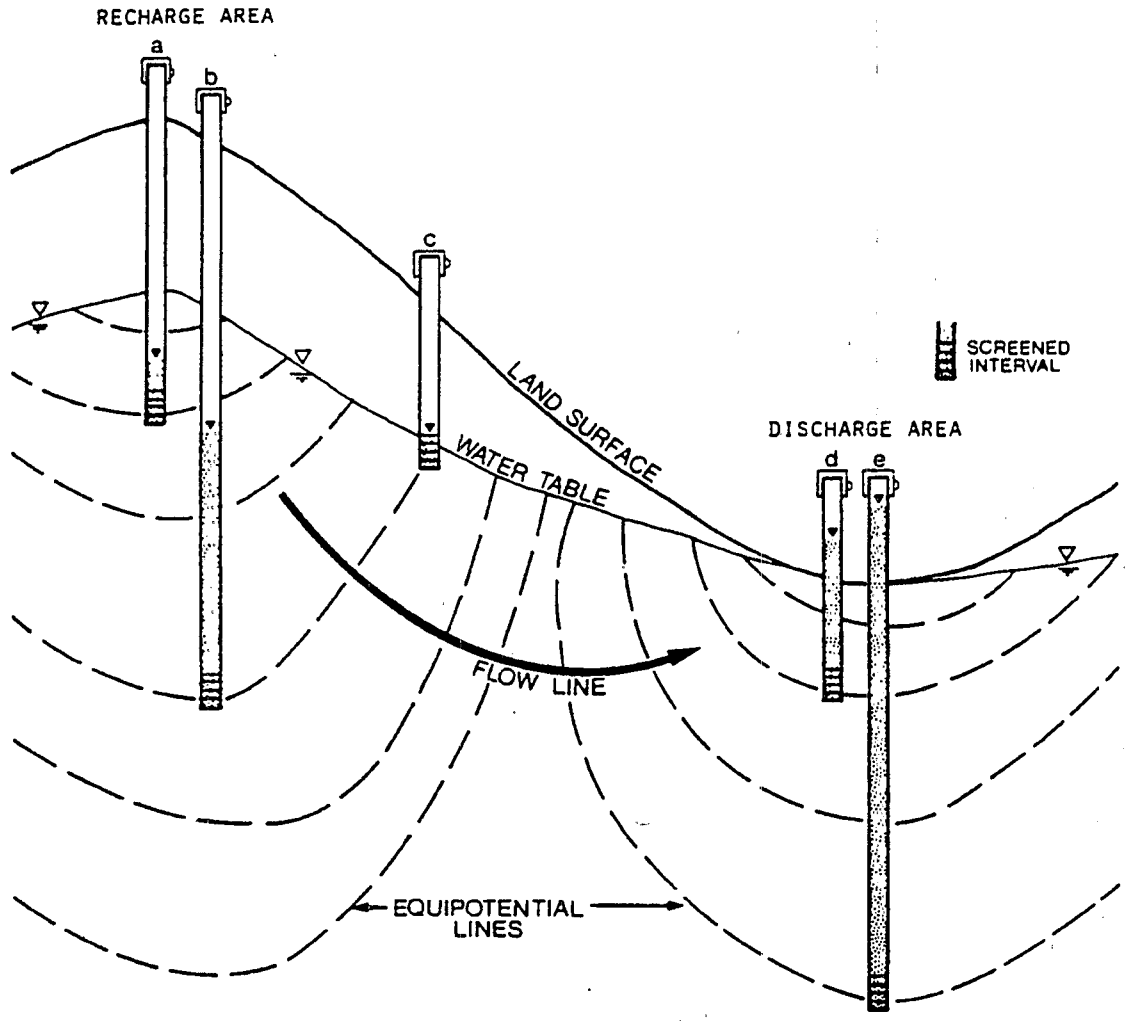

Figure 6-5. Cross-sectional diagram showing depth variations of water level as measured by piezometers located at various depths (Mills et al., 1985).

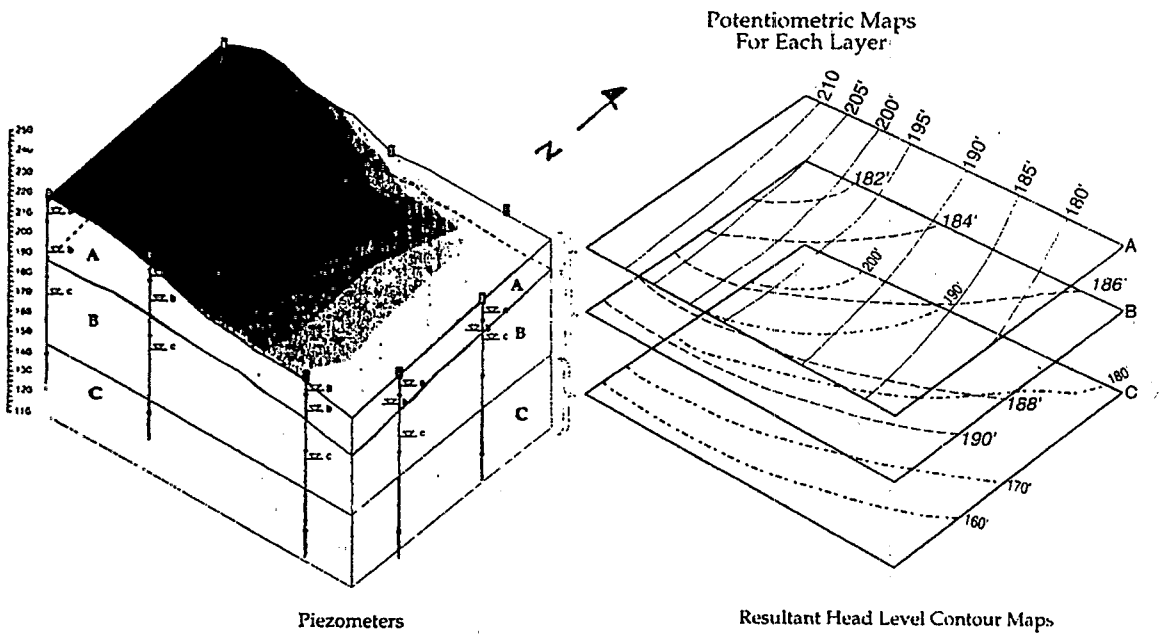

Figure 6-6. Ground-water contour surfaces using multilevel piezometer measurements (Sara, 1994).

- *Electrical resistance* piezometers use strain gauge technology to sense the pressure of a fluid applied to a diaphragm.
- *Vibrating wire* piezometers, which generate electrical signals at the surface as the tension in a wire that is connected to a diaphragm situated behind a filter stone changes in response to higher or lower pore pressure.
- *Pneumatic* piezometers, which use a pressure transducer to measure changes that water pressure has exerted against a diaphragm into which air has been forced.
- *Hydraulic* piezometers, which consist of one or two water-filled tubes that run from the surface to a ceramic or porous stone tip; pressure changes are read from a gage at the surface (mercury manometer, transducer, or Bourdon gage).

Pore pressure probes can be driven into the ground manually or hydraulically (using a cone-penetration rig) to obtain continuous pore pressure profiles that also allow interpretations of subsurface stratigraphy (Figure 6-7). As shown in Figure 6-7, equilibrium pore pressure is often inferred rather than measured directly, because this requires stopping the probe and waiting for equilibration to occur, which may take a long time (especially in clays). However, in clean and dirty sands and gravels with less than 40% fines measurements of equilibrium pore pressure is rapid and useful. A series of potentiometric maps with depth (as shown in Figure 6-6) could be developed with relative ease, however, by stopping to measure equilibrium pore pressure at specified intervals in multiple probe tests. The advantage of this method is that numerous hydraulic head measurements can be obtained over a relatively short period. The cautionary note in Section 6.4.2 *concerning grouting of* boreholes applies here as well. Pore pressure probes can also be driven to the desired depth without profiling as permanent monitoring installations.

The other simple way to develop hydraulic head profiles with depth is to install permanent piezometer nests. This involves placing piezometers at different depths in a cluster. The simplest way to do this is to push a small-diameter, open-hole drive-point or pore pressure probe attached to a metal standpipe to the desired depth. These can be driven manually using a weighted driver (Figure 6-8a) or a crank driven device (Figure 6-8b). Portable power-driven drivers and truck-mounted hydraulic drivers such as those illustrated in Figures 6-2a and 6-3 also can be used to install piezometers.

The advantage of permanent piezometer installations is that changes in hydraulic head distributions with time can be measured. Measurement of seasonal changes in ground-water levels and responses to rainfall events are an important part of characterizing the ground-water flow system. With open-hole piezometers such changes are usually measured using a tape or electric water-level probe. Measurements using permanent pore pressure piezometers can be made manually by reading the appropriate gage or signal, or recorded automatically with a datalogger. An advantage of open-hole piezometers is that they also can be useful for ground-water quality monitoring (see Chapter 9). Pausing at intervals during the driving of the first piezometer in a cluster will provide an indication as to whether it is located in a recharge, discharge, or lateral-flow zone. These measurements then can be used to determine the best depth for placement of shallower piezometers in the cluster.

If subsurface materials are soft enough to be penetrated by drive points (silts, sands, clays) and course frag-

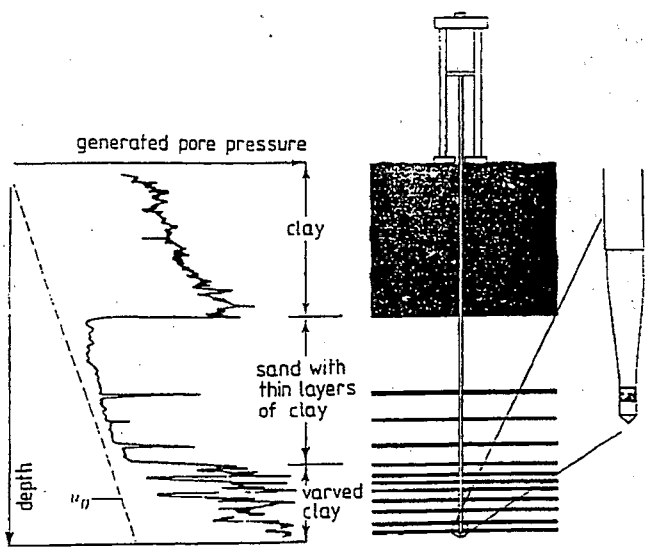

Figure 6-7. Typical pore pressure sounding diagram for a layered soil; u_o = equilibrium pore pressure (courtesy of Hogentogler & Co., Inc.).

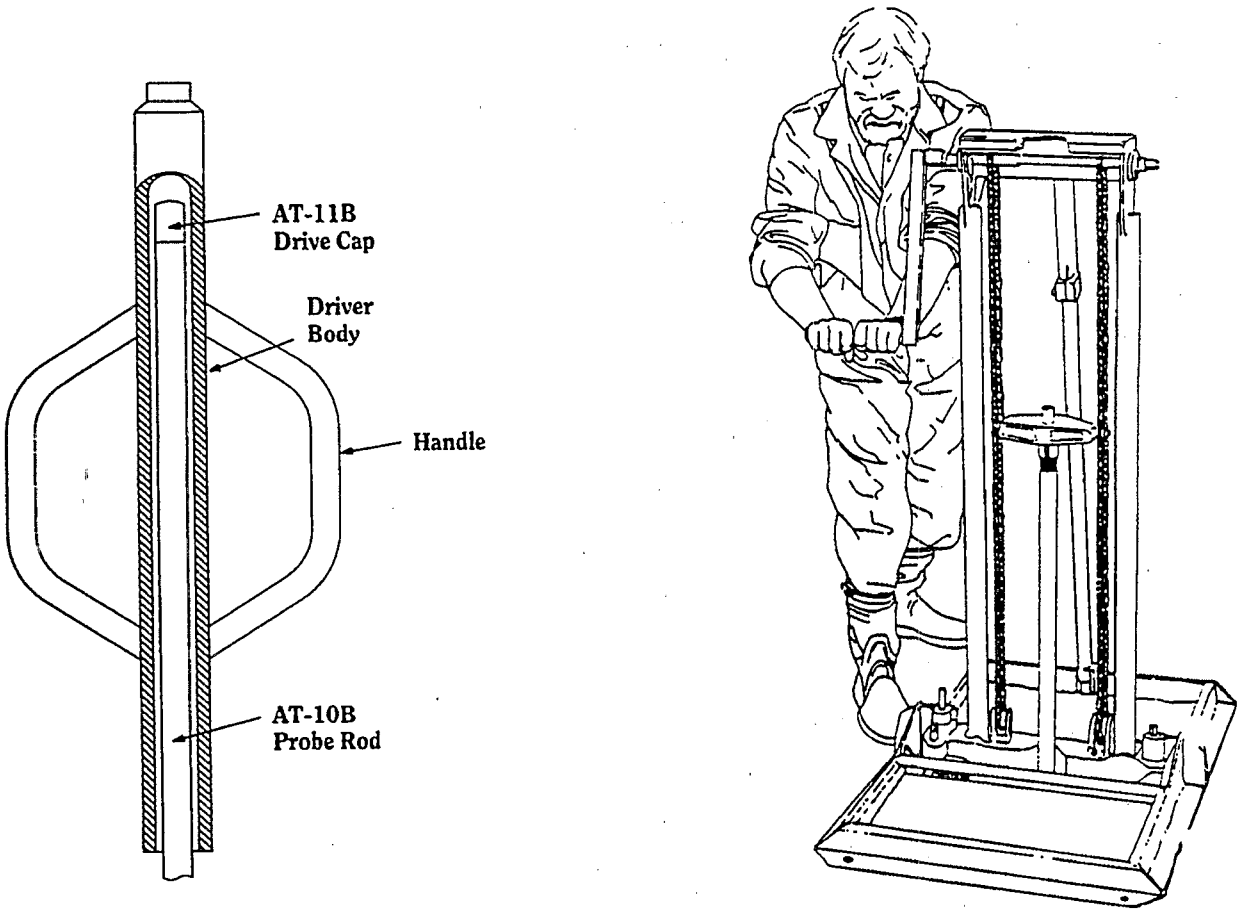

Figure 6-8. Manual piezometer installations methods: (a) weighted driver (courtesy of Geoprobe Systems); (b) crank-driven (courtesy of Hogentogler & Co., Inc.).

ments or very dense layers such as glacial till are absent, installation of piezometers is relatively inexpensive (hundreds vs. thousands of dollars for conventional monitoring well installations). If standard drilling equipment such as hollow-stem augers must be used, costs will be much higher but still less than for installation of conventional monitoring wells if capsule-type piezometers with flexible tubing are used. Section 10.4.2 discusses installation of permanent ground-water quality monitoring wells.

The location and number of multilevel piezometer measurements or installations will depend on the complexity of the site. At a minimum, measurements should be taken at the highest and lowest topographic points on the site and at several intervening points.

6.4.4 Wetland Identification and Delineation

Site-specific investigations of potential sewage sludge surface disposal sites will often require a determination of the presence or extent of wetlands. For example, U.S. EPA (1990b) found that 79 percent of the 110 sanitary landfills in the State of New York for which National Wetland Inventory (NWI) maps were available, either included or were within 1/4 mile of a wetland. Similarly, U.S. EPA (1990a) in a study of 1,153 sanitary landfills in 11 states, found that 72 percent contained wetlands or were within 1/4 of a mile.

The term wetlands includes swamps, marshes, bogs, and any areas that are inundated or saturated by ground water or surface water at a frequency and duration to support a dominant vegetation adapted to saturated soil conditions. As noted in Section 6.3.3, the presence or absence of hydric soils (e.g., soils that are wet long enough to periodically produce anaerobic conditions) in a soil survey of the site will provide a good indication of whether a more detailed investigation will be required. If a wetland is determined to be on the site, its boundaries must be accurately delineated.

Accurate wetland delineation typically requires assessment by a qualified and experienced multidisciplinary team to identify: (1) the limits of the wetland boundary based on hydrology, soil types, and plants types; (2) the type and relative abundance of vegetation, including trees; and (3) rare, endangered, or otherwise protected species and their habitats, if present. Many methods have been developed for assessing wetlands. The main

guidance manuals for wetland delineation for regulatory purposes are the *Corps of Engineers Wetlands Delineation Manual* (COE, 1987) and the *Federal Manual for Identifying and Delineating Jurisdictional Wetlands* (Federal Interagency Committee for Wetland Delineation, 1989). The latter manual places greater emphasis on assessment of the functional value of wetlands, along the lines of earlier work by the U.S. Fish and Wildlife Service (USFWS, 1984).

Appendix C in U.S. EPA (1990c) provides summary information on more than 30 methods for assessment of wetland functions and values. Phillips (1990) describes a quantitative wetness index for use when field indicators of wetness are ambiguous or contradictory. Lyon (1993) may be useful as a supplemental reference for wetland identification and delineation. Finally, Mausbach (1994) provides a recent review of the historical development and current status of criteria developed by the SCS for classification of wetland soils, and notes that definitions are continuing to evolve as SCS develops and tests regional indicators of hydric soils.

6.4.5 Floodplain and Other Hydrologic Characterizations

As noted in Section 6.3.3, whether a site is located wholly or in part within a 100-year floodplain can be initially determined using a FEMA floodplain map or SCS soil survey. If there is any reason to suspect that actual sewage sludge disposal will occur on the floodplain, more detailed investigations will be required to accurately delineate the floodplain boundary. If disposal within the floodplain cannot be avoided, then the surface disposal site must be designed to include protective measures such as embankments or levies so that active sewage sludge units: (1) will not restrict the flow of the 100-year flood, (2) will not reduce the temporary water storage capacity of the floodplain, or (3) will not result in washout of pollutants that pose a hazard to human health and the environment.

Site-specific floodplain investigations may require analysis of meteorological and streamflow records; upstream topography, soils, and geology; aerial photograph interpretation; and assessment of existing and anticipated changes in watershed land use. The Interagency Advisory Committee on Water Data (Hydrology Subcommittee, 1982) provides guidelines for determining flood flow frequency using stream gauge records.

The U.S. Army Corps of Engineers (COE, 1982) has developed several numerical models to: aid in the prediction of flood hydrographs (HEC-1); create water surface profiles due to obstructions for evaluating flood encroachment potential (HEC-2); simulate flood control structures (HEC-5); and gauge river sediment transport (HEC-6). The HEC-2 model is not appropriate for simulation of sediment-laden braided stream systems or other intermittent/dry stream systems that are subject to flash-flood events. Standard runoff and peak flood hydrograph methods would be more appropriate for such conditions to predict the effects of severe flooding.

6.4.6 Geotechnical Characterization

Sewage sludge monofills and dedicated surface disposal sites that involve design of foundations, liners and leachate collections systems, and dikes/embankments will require detailed subsurface exploration, including sampling of subsurface solids and laboratory testing.

Subsurface exploration programs often use both indirect and direct methods, with direct methods required to confirm indirect observations. Indirect investigation methods include remote sensing techniques, such as aerial photograph interpretation (Section 6.3.1), and geophysical techniques, such as DC resistivity, electromagnetic induction, ground-penetrating radar, and seismic refraction. These methods do not require drilling or excavation. Selection of the proper geophysical techniques requires consideration of the purpose of the test, the character of the subsurface materials, depth limits of detection and resolution of possible methods, and susceptibility of methods to electrical or vibrational noise. While geophysical procedures can provide large amounts of data at a relatively low cost, they require careful interpretation that must be carried out by qualified experts only. Furthermore, geophysical data must be verified by direct procedures such as borings or test pits. Chapter 1 of U.S. EPA (1993c) provides additional information on remote sensing and surface geophysical methods.

Direct investigation methods include drilling boreholes and wells and excavating pits and trenches. Direct methods allow the site's geologic conditions to be examined and measured. Typically, boring logs should provide descriptions of the soil strata and rock formations encountered, as well as the depth at which they occur. In addition, the boring logs should provide standard penetration test results for soils and rock quality designation results for rock core runs. The boring logs also should record the intervals for, and the results of, any field hydraulic conductivity testing conducted in the borings.

Foundation soil stability assessments require field investigations to determine soil strength and other soil properties. In clayey materials, in situ field vane shear tests commonly are conducted in addition to collection of samples of subsurface material for laboratory testing of engineering properties. Soil samples can be obtained either by split spoon or thin-walled tube. Split spoon samples are disturbed and are of limited value other than for identification and assessment of water content. The thin-walled tube sample provides an undisturbed sample that can be used for a wide variety of laboratory tests.

Laboratory testing is conducted using representative soil samples. Testing, as appropriate, to evaluate the embankments, the foundation area, and areas under consideration as a source for borrow material covers: (1) ASTM/ Unified Soil Classification System (ASTM D2487-93, Test Method for Classification of Soils for Engineering Purposes), (2) grain-size distribution, (3) shrink/swell potential, (4) shear strength, (5) compressibility, (6) consolidation properties, (7) density and water content, (8) moisture-density relationships, (9) dispersivity, and (10) laboratory hydraulic conductivity. When evaluating foundation materials and liner materials, additional significant parameters for laboratory testing include cation exchange capacity and mineralogy.

The scope of the subsurface exploration program will vary depending on the complexity of the subsurface geology, seasonal variability in site conditions, and the amount of site information available. Typically, the investigator should drill an adequate number of borings across the site to characterize the underlying deposits and bedrock conditions and to establish a reasonably accurate subsurface cross section. Depth of borings is highly dependent on site-specific conditions. Typically, however, the borings should extend below the anticipated site base grade or below the water table, whichever is deeper. A sufficient number of water table observation wells and piezometers should be installed to define both the horizontal and vertical ground-water flow directions (Section 6.4.3). When subsurface heterogeneities are encountered that could lead to seepage or loss in strength in the foundation, additional subsurface exploration is sometimes necessary to identify and determine the extent of these features.

U.S. EPA (1988a) provides more detailed guidance on types of geotechnical information and on field and laboratory methods required for design of surface disposal sites; U.S. EPA (1986a) provides more detailed guidance on design, construction, and evaluation of clay liners. The following major references provide more detailed information on subsurface exploration techniques for geotechnical investigations: Bureau of Reclamation (1989, 1990), Hanna (1985), Hathaway (1988), Hvorslev (1949), USACE (1984), and U.S. Naval Facilities Engineering Command (1982).

Identification of Unstable Areas

U.S. EPA (1993d) classifies unstable areas that might restrict suitability for solid waste disposal as natural and manmade. Naturally unstable areas include:

- *Expansive soils*, which have a large percentage of clays with a high shrink-swell potential (smectite/montmorillonite groups, vermiculites, bentonite) or with sulfate or sulfide minerals present in the soil, make poor foundations. Such soils are readily identified by a soil survey. For example, any soils classified as vertisols (which have a high shrink-swell potential) would probably be unsuitable at a surface disposal site. Expansive soils tend to be found in the arid western states.
- Soils subject to *rapid settlement* (subsidence) also make poor foundations. Such soils include thick loess, unconsolidated clays, and wetland soils. Loess, found in the north central states, tends to compact when it is wetted. Unconsolidated clays and wetlands, on the other hand, subside when water is withdrawn.
- Areas subject to *mass movement* have rock or soil conditions that are conducive to downslope movement of soil, rock, and/or debris (either alone or mixed with water) under the influence of gravity. Examples of mass movement include landslides, debris slides and flows, and rock slides. These tend to occur most commonly on steep slopes, but sometimes conditions on gradual slopes favor mass movement.
- *Karst terrains* develop where soluble bedrock (typically limestone, but dolomite, and gypsum also might be subject to such effects) forms a subterranean drainage system where flow is concentrated in conduits. These areas tend to be characterized by caverns and sinkholes and subject to unpredictable, catastrophic rock collapse. The presence of sinkholes and soluble bedrock at or near the surface are a clear indication of site unsuitability. The absence of obvious karst geomorphic features (i.e., sinkholes) where limestone or other soluble bedrock is near the surface is not sufficient to determine stability. Fracture trace analysis using aerial photographs is an especially useful method for characterizing karst terrain (Section 6.3.1). Additional investigations, perhaps using surface geophysical techniques also might be required if no alternatives to siting in a karst area are available.

Examples of human-induced unstable areas include:

- The creation of cut and/or fill slopes during construction of the sewage sludge surface disposal site can cause slippage of existing soil or rock. At most sites the amount of earth-moving conducted is likely to be small enough that this will not be a major concern.
- Excessive drawdown of ground water can cause excessive settlement or bearing capacity failure of foundation soils. Again, this will not be an issue at most sewage sludge surface disposal sites; however, if a liner and a leachate collection system are to be used, system design should take this effect into consideration.

Another type of naturally unstable area includes *dispersive* soils where sodium-rich clays (which often also have a high shrink-swell) tend to disperse when wetted, allowing a form of subsurface erosion called *piping*. If any of the above conditions exist at a site and alternative sites with fewer problems are not available, more

detailed geotechnical field investigations will likely be required. U.S. EPA (1993d) provides more detailed guidance on the approach that should be taken to assess site stability and design approaches for designing for stable slopes. U.S. EPA (1987 and 1988a) identify specific data needs and field and laboratory methods for geotechnical evaluation and design of different types of engineered structures.

6.5 Data Analysis and Interpretation

Analysis and interpretation of data from site-specific investigations for a dedicated sewage sludge disposal site focus on the following:

- Identification of areas of shallow ground water and assessment of the ground-water flow patterns at the site (Section 6.5.1).
- Provision of data required for establishing routine pollution control measures at the site, mainly surface runoff controls (Section 6.5.2).
- Documentation of the presence or absence of special site conditions that might impose special regulatory restrictions (Section 6.5.3) and, if present, presentation of data that show the limitations can be overcome by one or more engineering design approach (Section 6.5.4).

Computer modeling (Section 6.5.5) can facilitate all of the types of analysis listed above.

6.5.1 Identifying Areas of Shallow Ground Water and Ground-Water Flow Net Analysis

The investigations described in Section 6.4.3 should allow development of a relatively detailed water table contour map, which in combination with the site topographic map will facilitate development of an unsaturated zone thickness isopach map. Such a map can be used in several ways, including: (1) to identify areas of shallow ground water where it may be desirable to place some fill to increase the depth of saturation in the surface disposal site, or (2) to assess the relative attenuation capacity of the vadose zone within the surface disposal site.

Ground-water flow net analysis is a relatively simple graphical technique for gaining an understanding of ground-water flow patterns using water-table surface contour maps and three-dimensional hydraulic head data collected using procedures described in Section 6.4.4. As a first approximation, the general direction of ground-water flow at a site can be determined by drawing flow lines perpendicular to the water table contours. As illustrated in Figure 6-5, apparent directions of flow may change with depth. Flow lines drawn perpendicular to ground water equipotential contours should be considered only a first approximation because anisotropy in the aquifer (e.g., sites where horizontal hydraulic conductivity exceeds vertical hydraulic conductivity) will cause flow lines to diverge from the perpendicular. Figure 6-9 illustrates such a divergence in a fractured rock aquifer where vertical hydraulic conductivity is five times the horizontal hydraulic conductivity.

In ground-water recharge areas (i.e., hydraulic head decreases with increasing depth), it is important to recognize that pollutants entering the ground water will tend to move downward in the aquifer as well as laterally. Figure 6-10 illustrates this effect and shows how flow net analysis can be used to estimate pathlines where layered aquifer materials have different hydraulic conductivities. In this figure, a cross section of the aquifer has been drawn using the borehole logs from three, multilevel piezometer installations, and equipotential lines drawn using hydraulic head measurements at four or five levels in each piezometer. The angle of refraction of flow or equipotential lines is determined from the ratio of the hydraulic conductivities, which equals the ratio of the tangents of the angles formed by the flow lines. Figure 6-10 illustrates that the downward component of pollutant transport increases as hydraulic conductivity decreases. A significant implication of this effect is that downgradient ground-water monitoring wells that are screened in the upper portion of an aquifer may miss a pollutant plume in a recharge area, unless the aquifer has very high hydraulic conductivity.

Flow net construction and analysis requires knowledge of the hydraulic conductivity of aquifer materials. Hydraulic conductivity values also are required to estimate how rapidly pollutants might move if they enter the ground-water system. References in Table 6-7 should be consulted for guidance on the selection of aquifer test methods if field measurement of aquifer properties is required.

This section emphasizes flow net analysis because it provides a maximum amount of information about the hydrogeologic system at relatively low cost if procedures for collecting three-dimensional hydraulic head measurements described in Section 6.4.4 are used. Flow nets can readily be constructed manually, although use of computers for contouring data and graphic analysis can facilitate the process. Cedergren (1989), U.S. EPA (1986b) and Sara (1994) are recommended for more detailed guidance on construction and interpretation of flow nets. Flow net construction in anisotropic aquifers requires special procedures, which are covered in these references. Use of flow nets for placement of ground-water monitoring wells is discussed in Chapter 10.

6.5.2 Other Geotechnical Considerations

As noted in Section 6.4.6, some sewage sludge surface disposal sites will not require extensive geotechnical

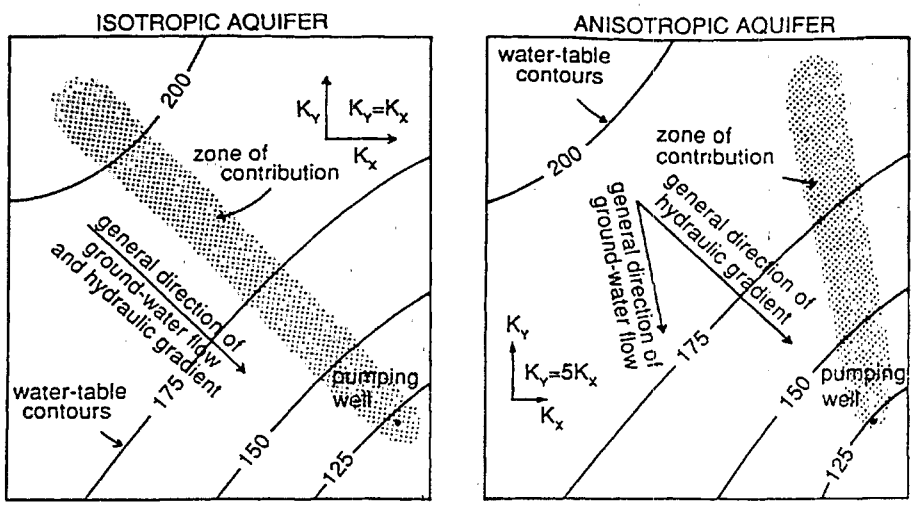

Figure 6-9. Effect of fracture anisotropy on the orientation of the zone of contribution to a pumping well (U.S. EPA, 1991b).

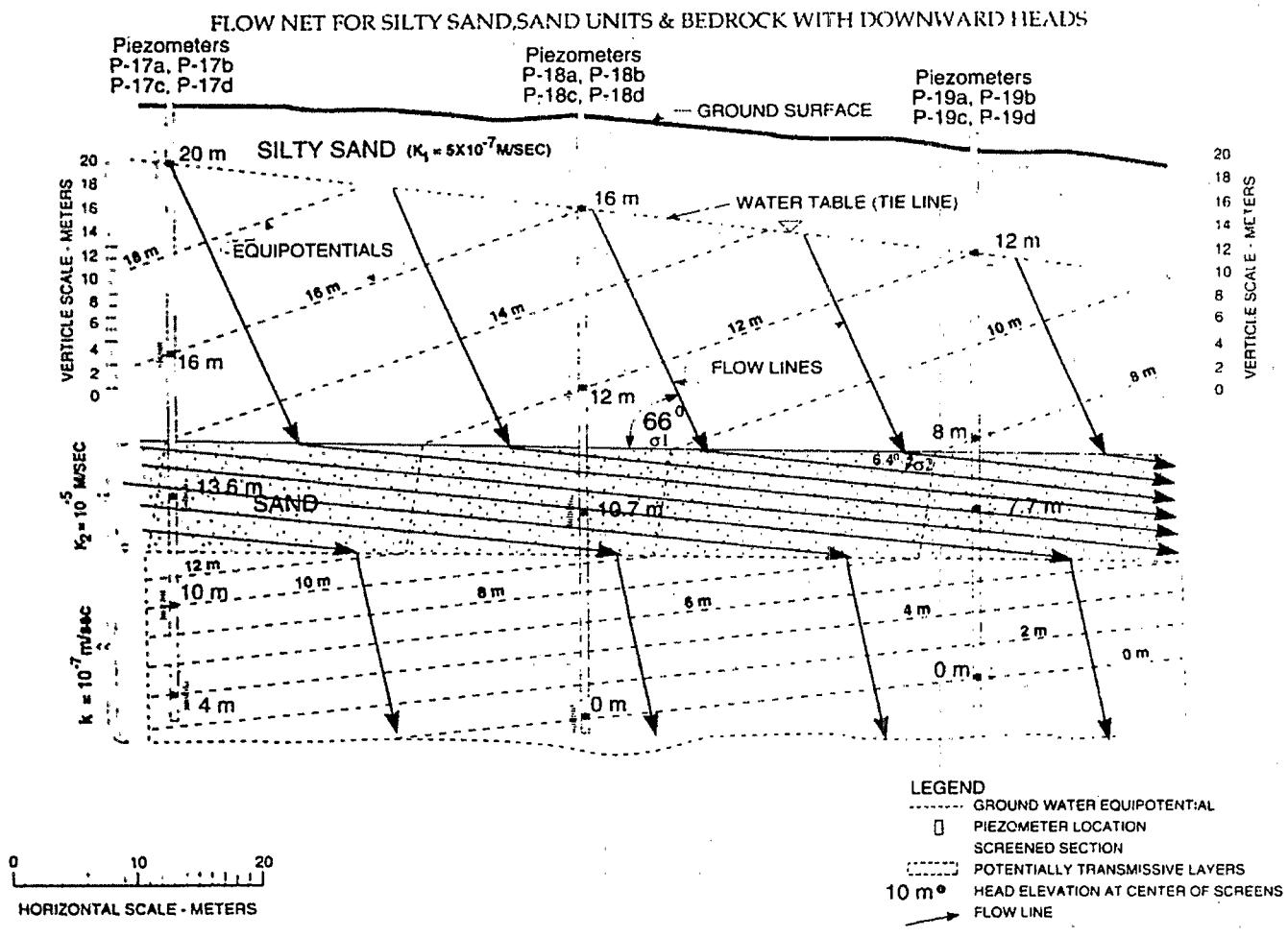

Figure 6-10. Example flow net construction: Three layers with downward flow (Sara, 1994).

characterization because surface runoff controls will be the only routinely required engineered features. The site topographic map will provide most of the information required. If construction of sediment ponds is required to control surface runoff, then the topographic map and geologic cross sections showing depth of unconsolidated material are required to identify areas of suitable soil material for the impoundment. U.S. EPA (1986a),

U.S. EPA (1988a), and U.S. EPA (1993d) should be consulted for guidance when sewage sludge monofills or dedicated surface disposal sites require construction of liners and leachate collections systems and dikes or embankments.

6.5.3 Special Site Conditions

The initial site selection process (Chapter 4) should have eliminated sites from consideration where unfavorable site conditions (e.g., floodplains, wetlands, or unstable geology or soils), would make a site unsuitable. If all possible sites are problematic in one way or another, field investigations should have focused on accurate delineation of problematic areas. Analysis and interpretation of information obtained by these investigations should focus on identification of the site or sites where impacts of disposal or mitigation costs are minimized. In the case of siting within floodplains, the minimal disturbance of the hydrologic regime of the floodplain must be demonstrated, as discussed in Section 6.4.5. If wetlands must be disturbed, the unavailability of a less-damaging alternative must be demonstrated. If site stability is a concern, engineering cross-section and design calculations should demonstrate adequate safety factors based on site geotechnical characteristics and reasonable design assumptions.

6.5.4 Computer Modeling

Numerous computer models have potential value for assessing the possibility of environmental impacts from surface disposal of sewage sludge and for designing systems for minimizing impacts. This section identifies relatively simple computer models that have been identified by U.S. EPA as being appropriate for use in assessment and design of surface disposal sites, where simplifying assumptions are appropriate. These include:

- The Hydrologic Evaluation of Landfill Performance (HELP) model (see discussion on HELP model in Chapter 7) is a water budget model for evaluating the quantity of leachate generation.
- The VADOFT module of the Risk of Unsaturated/Saturated Transport and Transformation of Chemical Concentrations (RUSTIC) model (U.S. EPA, 1989a and 1989b), a vadose zone chemical transport model and AT123D (Yeh, 1981), a saturated zone chemical transport model, were used by U.S. EPA for the risk assessment modeling that developed the Section 503 sludge pollutant limits.
- EPA's Multimedia Exposure Assessment Model (MULTIMED) is intended to be used at surface disposal sites where fate and transport modeling is required to demonstrate that performance criteria can be met, provided that the site allows use of certain simplifying assumptions (U.S. EPA, 1993d). MULTIMED contains modules that estimate pollutant releases to air, soil, ground water, and surface water. U.S. EPA (1993a) and U.S. EPA (1992) provide documentation and guidance on how to use the model.

All of the above models use arithmetic or analytical solutions that assume relatively simple hydrologic systems (e.g., as isotropic, homogeneous unsaturated, and saturated zones), and only should be used if site conditions justify making simplifying assumptions. If they are not justified, then more sophisticated numerical computer models should be used. Appendix D in U.S. EPA (1993a) provides information on 17 commonly used vadose zone flow and transport models. Recommended major EPA documents that provide information on selection and use of subsurface flow and transport modeling include: U.S. EPA (1985), U.S. EPA (1988b), and U.S. EPA (1993f). U.S. EPA (1993b) provides a detailed review of leachate generation and migration models.

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Chapter 7
Design

7.1 Purpose and Scope

The objective of a surface disposal site design is to direct and guide the construction and ongoing operation of the disposal site. A design should ensure:

- Compliance with pertinent regulatory requirements.
- Adequate protection of public health and the environment.
- Cost-efficient utilization of site manpower, equipment, and storage volume.

A design package (consisting of all design documents) should be prepared to provide a record of the site design. These may consist of drawings, specifications, and reports.

The purpose of this chapter is to provide guidance on the design of a surface disposal site. The organization of specific topics addressed in this chapter is outlined in Figure 7-1.

7.2 Regulatory Requirements

7.2.1 Part 503

Many types of active sewage sludge units (monofills, dedicated surface disposal sites, piles and mounds, and impoundments) are covered by the Part 503 Subpart C regulation. The Part 503 regulation includes management practices that must be followed when sewage sludge is placed on an active sewage sludge unit. These management practices help protect human health and the environment from the reasonable anticipated adverse effects of pollutants in sewage sludge. Several of the management practices required under Subpart C influence the design of active sewage sludge units. Management practices influencing the design of these units are summarized as follows (for more detail, see U.S. EPA, 1994):

- Runoff from an active sewage sludge unit must be collected and disposed of properly. Runoff collection systems must be capable of handling a 25-year, 24-hour storm event.
- When an active sewage sludge unit has a liner, leachate must be collected and disposed of properly.
- When an active sewage sludge unit is covered daily, concentrations of methane gas must be monitored in air in any structure within the site and in the air at the property line of the surface disposal site.
- Sewage sludge placed in an active sewage sludge unit must not contaminate an aquifer.

Another management practice required under Subpart C requires the owner/operator of surface disposal sites to restrict public access. Management practices influencing the siting and end uses of active sewage sludge units are discussed in Chapters 4 and 10, respectively.

Two of the management practices listed above refer to active sewage sludge units with liners and leachate collection systems and to units with covers.

- A liner is a layer of relatively impervious soil, such as clay, or a synthetic material that covers the bottom of an active sewage sludge unit with a hydraulic conductivity of 1×10^{-7} cm/s or less. The liner prevents the downward movement of liquid in the active sewage sludge unit from seeping into the ground water below.
- A leachate collection system is a system or device installed immediately above a liner that collects and removes leachate (liquid waste from rainfall that seeps through the contents of the active sewage sludge unit).
- A cover is soil or other material placed over the sewage sludge.

Sewage sludge placed on an active sewage sludge unit with a liner and leachate collection system does not have to meet pollutant limits, based on the assumption that those systems prevent pollutants from migrating to the ground water.

Sewage sludge placed on an active sewage sludge unit without a liner and leachate collection system must meet the pollutant limits for arsenic, chromium, and nickel established under the Part 503 regulation. There are two options for the pollutant limits (U.S. EPA, 1994):

- The first option is to make sure that the levels of arsenic, chromium, and nickel are not above the lev-

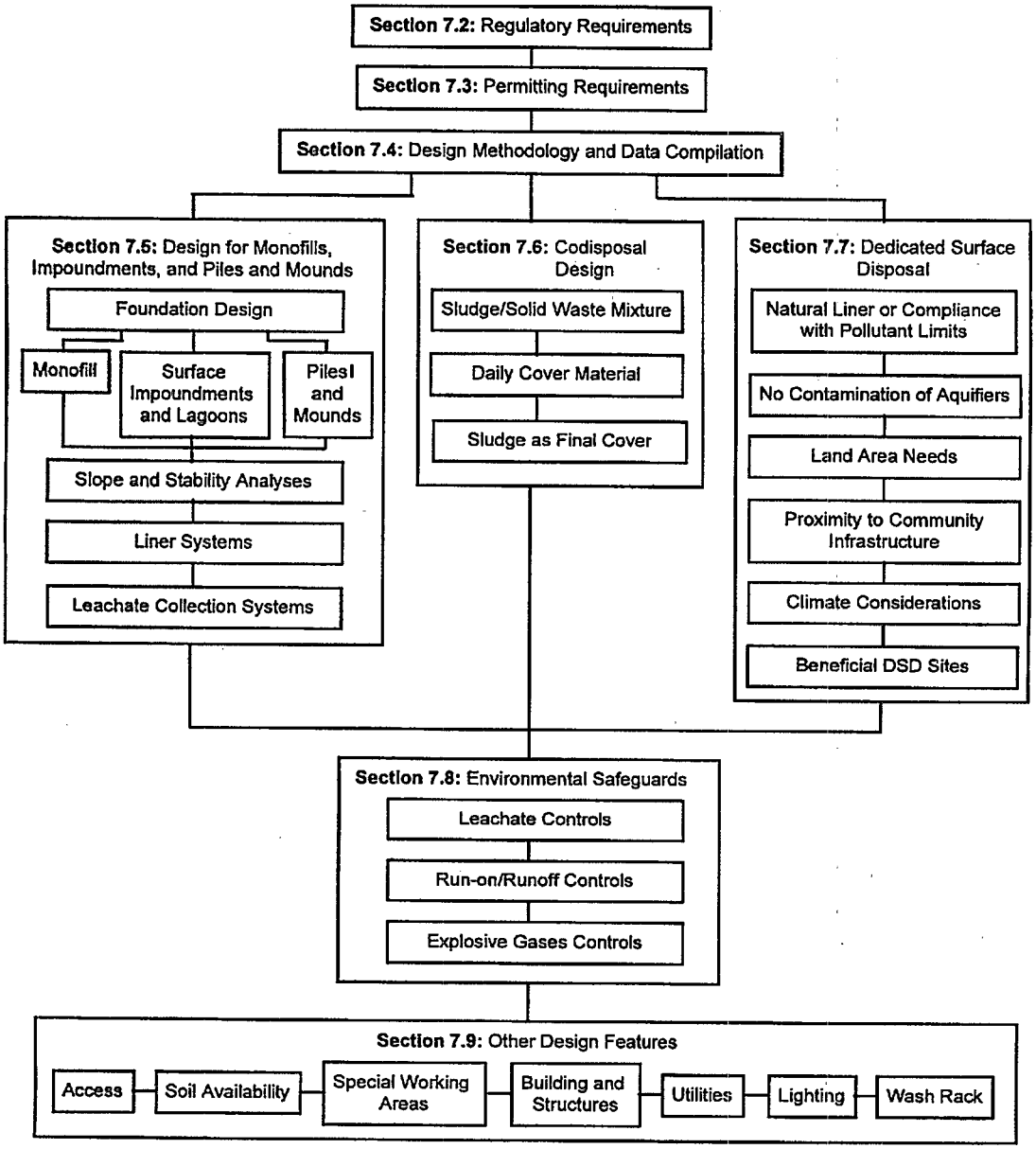


Figure 7-1. Organization of Chapter 7, Design.

els listed in Table 3-6, which are based on the distance between the active sewage sludge unit boundary and the property line of the surface disposal site.

- The second option is to meet the site-specific pollutant limits for arsenic, chromium, and nickel, if site-specific limits have been set by the permitting authority.

(See Chapter 3 for more information on pollutant limits for sewage sludge placed in surface disposal sites.)

7.2.1.1 Collection of Runoff

Runoff is rainwater or other liquid that drains over the land and runs off of the land surface. Runoff from a surface disposal site might be contaminated with sewage sludge or sewage sludge constituents. Runoff from an active sewage sludge unit must be collected and disposed of according to permit requirements of the National Pollutant Discharge Elimination System (NPDES) and any other applicable requirements. Under the requirements of the Part 503 rule the runoff collection system of an active sewage sludge unit must have the capacity to handle runoff from a 24-hour, 25-year storm event (a storm that is likely to occur once in 25 years for a 24-hour period). This requirement helps ensure that runoff (which may contain pollutants) from an active sewage sludge unit site is not released into the environment. The peak flow of water and the total runoff volume of water during the 24-hour, 25-year storm must

be calculated to properly size stormwater controls that will be adequate to collect runoff from this storm (U.S. EPA, 1994). (See Section 7.8.2 for design information on runoff collection systems.)

7.2.1.2 Collection of Leachate

Leachate is fluid from excess moisture in sewage sludge or from rainwater percolating down through the active sewage sludge unit from the land surface. Depending on the pollutant content of the sewage sludge, leachate may contain substances such as metals or organic chemicals. If an active sewage sludge unit has a liner and leachate collection system, two management practices in the Part 503 regulation apply (U.S. EPA, 1994).

The first management practice requires that the leachate collection system be operated and maintained according to design requirements and engineering recommendations. The owner/operator of the surface disposal site is responsible for ensuring that the system is always operating according to design specifications and is properly and routinely maintained (e.g., pumps are periodically cleaned and serviced; the system is periodically inspected to detect clogs and flushed to remove deposited solids).

The second management practice requires that leachate be collected and disposed of according to applicable requirements. Leachate should be collected and pumped out by a system placed immediately above a liner. If leachate is discharged to surface water as a point source, then an NPDES permit is required. Otherwise, leachate may be irrigated on land adjacent to the active sewage sludge unit or discharged to a publicly owned treatment works (POTWs). It is recommended that the leachate be tested to determine whether some kind of treatment is appropriate before being disposed of.

Both management practices must be followed while the unit is active and for 3 years after the unit closes or for a longer period if required by the permitting authority.

These management practices help prevent pollutants in sewage sludge placed on an active sewage sludge unit from being released into the environment. For example, if leachate was not collected regularly, or if the leachate collection system was not operated and maintained properly, then the liner could be damaged by the weight of the leachate pressing against it, and the leachate could leak into the environment. Management practices concerning the collection of leachate only apply to active sewage sludge units *with* a liner. The Part 503 rule regulates active sewage sludge units *without* liners and leachate collection systems through the pollutant limits discussed in Chapter 3 and through other management practices in the regulation. (See Sections 7.5.6 and 7.5.7 respectively for design information on liners and leachate collection systems.)

7.2.1.3 Limitations on Methane Gas Concentrations

The Part 503 regulation contains a management practice that limits concentrations of methane gas in air because of its explosive potential. Methane, an odorless and highly combustible gas, is generated at an active sewage sludge unit when sewage sludge is covered by soil or other material (e.g., geomembranes), either daily or at closure. The gas can migrate and be released into the environment. To protect site personnel and the public from risks of explosions, methane gas must be monitored continuously within any structure on the site and at the property line of the surface disposal site. Air at surface disposal sites where active sewage sludge units *are covered* (either daily or at closure) must be monitored continuously for methane gas; when active sewage sludge units are not covered, air does not have to be monitored continuously for methane gas (U.S. EPA, 1994).

This management practice limits the amount of methane gas in air in both active and closed sewage sludge units. When a cover is placed on an active sewage sludge unit, the methane gas concentration in air in any structure within the property line of a surface disposal site must be less than 25% of the lower explosive limit (LEL). The LEL is the lowest percentage (by volume) of methane gas in air that supports a flame under certain conditions (at 25°C and atmospheric pressure). For methane, the LEL is 5%. Therefore, if 5% of the LEL is 50,000 ppm methane, then air in any structure within the property line must not exceed 12,500 ppm methane (U.S. EPA, 1994).

A methane gas monitoring device must be placed in such a way that air inside any structure on the property is continuously measured for methane gas and the measurement can be read by any individual before entering the structure. (The act of entering the building could create enough of a spark to ignite explosive levels of methane gas.)

For air at the property line of a surface disposal site with a covered sewage sludge unit, the limit for methane gas concentration is the LEL (i.e., 5%). In some cases, the permitting authority may determine that a methane gas monitoring device at one downwind location on the property line is adequate to meet this requirement because the wind patterns are consistent. In other cases, where wind conditions at the site are highly variable, more than one device may be necessary to provide adequate protection.

Methane gas concentrations must be monitored at all times when an active sewage sludge unit is covered daily and for 3 years after the last active sewage sludge unit closes if a final cover is placed on the active sewage sludge unit. If unstabilized sewage sludge is placed on

an active sewage sludge unit, the permitting authority may require air to be monitored for methane gas for longer than 3 years after closure because of the higher potential for methane gas generation with unstabilized sludge (U.S. EPA, 1994).

Methane monitoring devices allow the user to read the level of methane as a percent of the LEL. Some can be equipped with alarms, which may be desirable in structures with a higher potential for collecting methane gas. Various methods (e.g., venting systems, positive or negative air pressure systems) are available to control methane gas concentrations if they exceed the limits. (See Section 7.8.3 for information on explosive gases control.)

7.2.1.4 Restriction of Public Access

Public access to a surface disposal site must be restricted while the site contains an active sewage sludge unit and for 3 years after the last active sewage sludge unit closes (U.S. EPA, 1994). This management practice helps to minimize public contact with any pollutants, including pathogens, that may be present at surface disposal sites. It also keeps the public away from an area with the potential for methane gas explosions, as discussed above. (See Section 7.9.1 for design information on access restrictions.)

7.2.1.5 Protection of Ground Water

This management practice states that sewage sludge placed in an active sewage sludge unit must not contaminate an aquifer. "Contaminate an aquifer" in this instance means to introduce a substance that can cause the level of nitrate in ground water to increase above a certain amount. This management practice also requires that proof be obtained that ground water is not contaminated. This proof must be either (1) the results of a ground-water monitoring program developed by a qualified ground-water scientist, or (2) certification by a ground-water scientist that ground water will not be contaminated by the placement of sewage sludge on an active sewage sludge unit.

The certification option usually is obtainable only if the active sewage sludge unit has a liner and leachate collection system. It is generally infeasible for a ground-water scientist to certify that ground water will not be contaminated in the absence of a liner unless ground water is very deep and there is a natural clay layer or unless the amount of material placed on the site is quite low. (See Chapter 4 for more information on the protection of ground water at surface disposal sites.)

7.2.2 Part 258

EPA's Solid Waste Disposal Facility Criteria, 40 CFR Part 258, regulate the design of municipal solid waste (MSW) landfill units, including codisposal landfills. Sewage sludge placed in an MSW landfill must:

- Pass the paint filter liquids test (i.e., does not contain free liquids).
- Not be a hazardous waste or PCB waste.

These requirements are discussed in Section 3.4.3. In addition, the treatment works must ensure that the sludge goes to a state-permitted landfill. Codisposal is discussed in more detail in Section 7.6, Design for Codisposal With Solid Waste.

7.2.3 State Rules Applicable to the Disposal of Sewage Sludge

Part 503 does not replace any existing state regulations; rather, it sets minimum national standards for the use or disposal of sewage sludge. It is important to note that persons disposing of sewage sludge are subject to state and possibly local regulations in addition to federal regulations. Furthermore, these state and other regulations may be more stringent than the Part 503 rule, may define sewage sludge differently, or may regulate certain types of sewage sludge more stringently than does the Part 503 rule. In addition, some states have established requirements for their MSW landfills, including restrictions on codisposal, that are more stringent than on the federal requirements. (For example, some states have set loading limits for sludge at MSW landfills.) In all cases, persons wishing to use or dispose of sewage sludge must meet all applicable federal and state requirements.

For information on specific state sewage sludge regulations, the reader should consult the appropriate state sewage sludge permitting authority, or state septage coordinator. EPA regional sewage sludge and septage coordinators are listed in Appendix B.

States can change their regulations to meet the minimum federal standards. EPA will be working with states to encourage them to gain approval for administering the Part 503 rule. States can apply to EPA for approval of their sewage sludge program at any time, but they are under no obligation to do so. See Chapter 1 for more information on the relationship of the federal requirements to state requirements.

7.3 Permitting Requirements

Many regulatory and approving agencies require permits before a sewage sludge unit can be constructed or operated. Accordingly, all pertinent agencies should be contacted early in the design phase to: identify regulations impacting on the prospective sewage sludge disposal site; determine the extent, detail, and format of the application; and, obtain any permit application forms. Once this information has been collected, the design

can proceed in a more efficient manner toward the goal of receiving the necessary permits.

Before proceeding to the final design it is advisable to recontact regulatory agencies who were contacted during the site selection process and others to obtain all of their requirements and procedures for permit application submittals. This also will provide an opportunity to discuss design concepts, get questions answered, and determine any special or new requirements. Maintenance of close liaison with federal, state, and local regulatory officials throughout the design effort is normally helpful in securing a permit without excessive redesigns.

Requirements and permits relevant to sewage sludge surface disposal sites exist on the federal, state, and local levels.

7.3.1 Federal Permits

Federal permits required for sewage sludge surface disposal sites include:

- U.S. EPA Interim Sewage Sludge Application covering sewage sludge use or disposal standards required under Part 503. Appendix A outlines the type of information that should be provided in this permit application.
- National Pollutant Discharge Elimination System (NPDES) permit required for location of a sludge surface disposal site in wetlands. It is also required for any point source discharges from surface disposal sites.
- Army Corps of Engineers Permit (a dredge and fill permit) required for the construction of any levee, dike, or other type of containment structure to be placed in the water at a surface disposal site located in wetlands.
- Office of Endangered Species permit may be required from the Fish and Wildlife Service, U.S. Department of the Interior, for location of surface disposal sites in critical habitats of endangered species.

7.3.1.1 Self-Implementing Nature of the Part 503 Rule

The Part 503 rule is *self-implementing*—that is, owner/operators of surface disposal sites must comply with the Part 503 rule (including the compliance dates listed in Table 1-2 in Chapter 1), even if they have not been issued a permit covering sewage sludge surface disposal requirements. Similarly, EPA (or an approved state) can take enforcement actions directly against persons who violate the Part 503 requirements.

7.3.1.2 Who Must Apply for a Permit?

All sewage sludge surface disposal site owner/operators must apply for a permit covering sewage sludge disposal standards (U.S. EPA, 1994). Appendix A lists the type of information that should be provided in a permit application.

In most cases, Part 503 requirements will be incorporated over time into NPDES permits issued to POTWs and other treatment works treating domestic sewage (U.S. EPA, 1994). As dictated by the permitting priorities of EPA Regions and approved states, "sludge-only" permits covering applicable Part 503 requirements are likely to be issued to non-NPDES facilities as well. A permit applicant who has not received a response from EPA should continue to comply with the applicable provisions of the Part 503 rule.

Certain surface disposal sites with unique site conditions may apply for site-specific pollutant limits. These sites would be issued site-specific permits.

7.3.1.3 Who Issues the Permit?

At the time this document was published, the permitting authority for Part 503 was EPA. Thus, owner/operators of a surface disposal site must apply to EPA Regional Offices, not the state, for a federal sewage sludge permit. This will remain the case until the sewage sludge management programs of individual states are approved by EPA (see Section 1.3). When a state has an EPA-approved sewage sludge management program, the permitting authority will be the state; for states without an EPA-approved program, EPA will remain the permitting authority. State laws regarding the use or disposal of sewage sludge, including permit requirements, must be complied with, even if the state program has not received federal approval. For more information on permits, contact the appropriate EPA regional sludge coordinator (Appendix B).

7.3.2 State and Local Permits

State and local regulations and permits are highly variable from jurisdiction to jurisdiction. State and local regulatory agencies that require submittals might include:

- Solid waste management agencies
- Water quality control agencies
- Health departments
- Building departments
- Health departments
- Planning and/or zoning commissions
- Board of county commissioners

In many jurisdictions more than one state or local agency has authority over a surface disposal site. Also, in some jurisdictions, one agency has control over monofills and dedicated surface disposal sites while another agency has control over MSW landfills where sewage sludge is codisposed.

Depending on the jurisdiction, one or more permits might be required for a surface disposal site. Typical permits on the state and local levels include:

- Solid waste management permit.
- Special use permit.
- Zone change certification.
- Sedimentation control permit for surface runoff into water courses.
- Highway department permit for entrances on public roads and increased traffic volumes.
- Construction permit for site preparation.
- Building permit to construct buildings on the site.
- Operation permit for ongoing surface disposal operation.
- Mining permit for excavations.
- Fugitive dust permit.
- Business permit for charging fees.
- Closure permit.

The reviewing agency may require the submittal of information on standard forms or in a prescribed format to facilitate the review process. In any event, applicants are responsible for the completeness and accuracy of the application package. The completed application package is then reviewed by the regulatory agency. The time of the review period will vary depending on the regulatory agency, the number of applications preceding it, etc. After a permit is issued, it can be valid for various durations, depending largely on the submittal of inspection/performance reports and the outcome of onsite inspections.

7.4 Design Methodology and Data Compilation

Adherence to a carefully planned sequence of activities to develop a design for a surface disposal site minimizes project delays and expenditures. A checklist of design activities is presented in Table 7-1. These activities are listed generally in their order of performance; however, in many cases separate tasks can and should be performed concurrently or even out of the order shown.

Initial tasks in any design methodology consist of compiling existing information and generating new information on sludge and site conditions. See Chapter 4, Siting, and Chapter 6, Field Investigation for extensive information on collecting existing and site-specific information for use in the design phase.

A complete design package may include plans, specifications, a design report, cost estimate, and operator's manual. Generally, the cost estimate and operator's manual are prepared strictly for in-house uses, while plans, specifications, and design reports are submitted to regulatory agencies in the permit application. Plans and specifications typically include:

- Topographical map showing existing site conditions. The map should be of sufficient detail, with contour intervals of no more than 5 ft (1.5 m) and a scale not to exceed 1 in. = 200 ft (1 cm = 24 m).
- Soil map, drainage map, and ground-water or piezometric contour map.
- Site plan locating active sewage sludge units and soil stockpile areas as well as site buildings. A small-scale version of a site plan has been included as Figure 7-2.
- Development plan showing initial excavated and final completed contours in sludge filling areas for monofills or surface impoundments and lagoons.
- Elevations showing cross sections to illustrate phased development of filling areas at several interim points.
- Construction details illustrating detailed construction of site facilities.
- Completed site plan including final site landscaping, appurtenances, and other improvements.

A design report typically includes:

- Site description including existing site size, topography and slopes, surface water, utilities, roads, structures, land use, soils, ground water, bedrock, and climatology.
- Design criteria including sludge types and volumes, sludge transport methods, and fill or disposal area design dimensions.
- Operational procedures including site preparation, sludge unloading, sludge handling, sludge storage, sludge disposal rates for dedicated surface disposal (DSD) sites, and sludge covering as well as equipment and personnel requirements.
- Information on environmental safeguards including surface water runoff controls, liners and leachate collection systems, gas controls, odor controls, and vector reduction controls.

Table 7-1. Sewage Sludge Surface Disposal Site Design Checklist

Step	Task
1	Determine sludge volumes and characteristics
	• Existing
	• Projected
2	Compile existing and generate new site information
	• Perform boundary and topographic survey
	• Prepare base map of existing conditions on site and near site
	- Property boundaries
	- Topography and slopes
	- Surface water
	- Utilities
	- Roads
	- Structures
	- Land use
	• Compile hydrogeological information and prepare location map
	- Soils (depth, texture, structure, bulk density, porosity, permeability, moisture, ease of excavation, stability, Ph, and cation exchange
	- Bedrock (depth, type, presence of fractures, location of surface outcrops)
	- Ground water (average depth, seasonal fluctuations, hydraulic gradient, and direction of flow, rate of flow, quality, uses)
	• Compile climatological data
	- Precipitation
	- Evaporation
	- Temperature
	- Number of freezing days
	- Wind direction
	• Identify regulations (federal, state, and local) and design standards
	- Requirements for sludge stabilization
	- Sludge loading rates
	- Frequency of cover
	- Distances to residences, roads, and surface water
	- Monitoring
	- Roads
	- Building codes
	- Contents of application for permit
3	Design filling area
	• Select disposal method based on:
	- Sludge characteristics
	- Site topography and slopes
	- Site soils

Step	Task
3	Design filling area *(continued)*
	- Site bedrock
	- Site ground water
	• Specify design dimensions
	- Trench dimensions
	- Area fill dimensions
	- Surface impoundment and lagoon dimensions
	- Area requirements for DSD
	- Sludge fill depth
	- Intermediate cover soil thickness
	- Final cover soil thickness
	• Specify operational features
	- Use of bulking agent
	- Type of bulking agent
	- Bulking ratio
	- Use of cover soil
	- Method of cover application
	- Need for imported soil
	- Equipment requirements
	- Personnel requirements
	• Compute sludge and soil uses
	- Sludge disposal rate
	- Soil requirements
4	Design facilities
	• Leachate controls
	• Gas controls
	• Surface water controls
	• Access roads
	• Special working areas
	• Structures
	• Utilities
	• Fencing
	• Lighting
	• Washracks
	• Monitoring wells
	• Landscaping
5	Prepare design package
	• Develop preliminary location plan of fill areas
	• Develop contour plans
	- Excavation plans
	- Completed fill plans

Table 7-1. Sewage Sludge Surface Disposal Site Design Checklist (continued)

Step	Task
5	Prepare design package (continued)
	• Compute sludge storage volume, soil requirement volumes, and site life
	• Develop final location plan showing:
	- Normal fill areas and disposal areas
	- Special working areas
	- Leachate controls
	- Gas controls
	- Surface water controls
	- Access roads
	- Structures
	- Utilities
	- Fencing
	- Lighting
	- Washracks
	- Monitoring wells
	- Landscaping
	• Prepare elevation plans for monofills and surface impoundments with cross sections of:
	- Excavated fill
	- Completed fill
	- Phased development of fill at interim points
	• Prepare construction details
	- Leachate controls
	- Gas controls
	- Surface water controls
	- Access roads
	- Structures
	- Monitoring wells
	• Prepare cost estimate
	• Prepare design report
	• Submit application and obtain required permits
	• Prepare operator's manual

7.5 Design for Monofills, Surface Impoundments, and Piles and Mounds

7.5.1 Foundation Design

The following discussion is geared primarily toward active sewage sludge units that are lined and have leachate collection systems; however, good engineering practice requires that proper subsoil foundation design of all surface disposal sites be adequately addressed during the design phase.

Proper subsoil foundation design of an active sewage sludge unit with a liner is critical because liner system components, especially leachate collection pipes and sumps, can be easily damaged by stresses caused by foundation movement.

Good engineering guidance requires that foundations must be capable of providing support to the liner as well as resistance of pressure gradients above and below the liner to prevent failure of the liner due to settlement, compression, or uplift.

Foundations for monofills or surface impoundments and lagoons should provide structurally stable subgrades for the overlying components. The foundations also should provide satisfactory contact with the overlying liner or other system components. In addition, the foundation should resist settlement, compression, and uplift resulting from internal or external pressures, thereby preventing distortion or rupture of overlying components (U.S. EPA, 1988a).

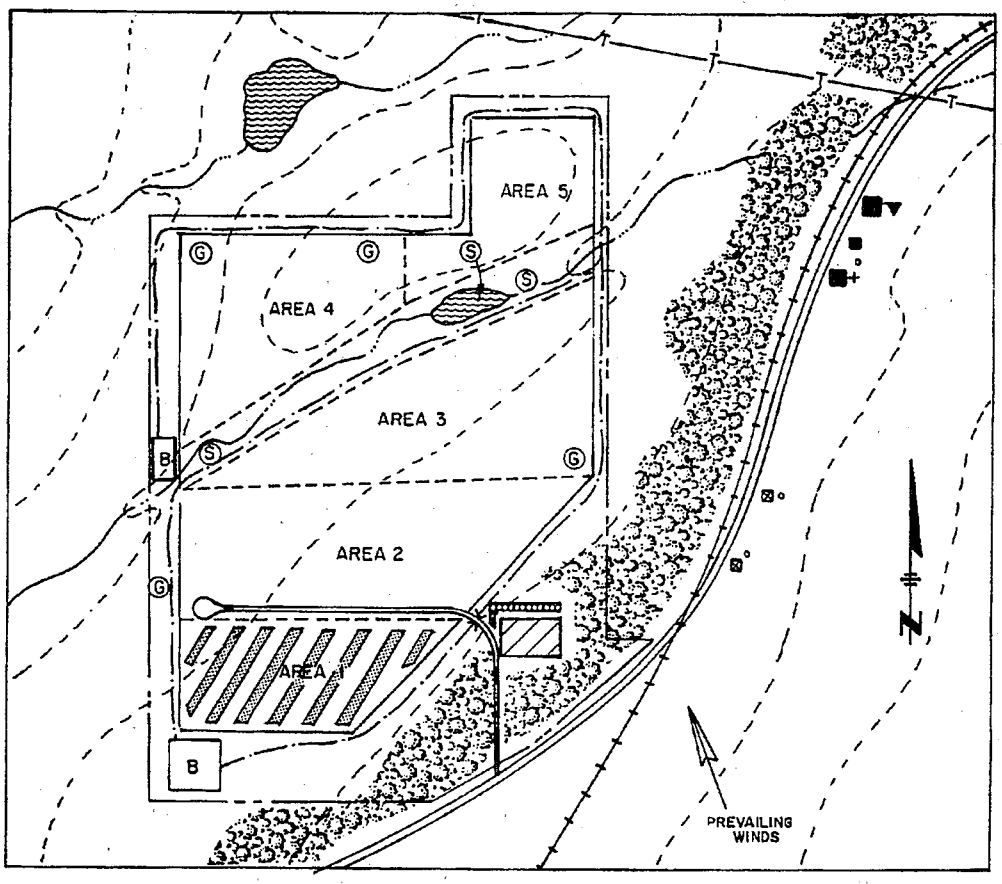
7.5.1.1 Field Investigation

Adequate field investigations are necessary to ensure that the foundation design is developed to accommodate expected site conditions. Field investigations are designed to establish the in situ subsurface properties, site hydrogeologic characteristics, and the area seismic potential, all of which are critical to the design of a surface disposal site. Subsurface exploration programs are conducted to determine a site's in situ subsurface properties, as well as its geology and hydrogeology. The in situ subsurface properties and hydrogeologic characteristics have a significant influence on the bearing capacity, settlement potential, slope stability, and uplift potential for the site. The site's subsurface geology may impact the settlement and seismic potential at the site and exert an influence on the site's hydrogeology characteristics. See Chapter 6 for a more extensive discussion on field investigations and subsurface explorations programs.

7.5.1.2 Foundation Description

Foundation design procedures are site specific and very often are an iterative procedure. A typical preliminary foundation description should include (U.S. EPA, 1988a):

- Geographic setting
- Geologic setting
- Ground-water conditions
- Soil and rock properties
- Surface-water drainage conditions
- Seismic conditions
- Basis of information



LEGEND

- EXISTING CONTOURS
- PROPERTY BOUNDARY
- ROADS
- RAILROAD
- TRANSMISSION LINE
- STREAM
- POND
- DWELLINGS
- PUBLIC BUILDINGS
- WELL
- WOODS
- DISPOSAL AREA BOUNDARY
- GROUNDWATER MONITORING POINT
- SURFACE WATER MONITORING POINT
- SURFACE WATER DRAINAGE SYSTEM
- SILTATION BASIN
- GAS CONTROL/VENTING TRENCHES
- OPERATIONAL FACILITIES
- DISPOSAL TRENCHES

Figure 7-2. Typical site plan.

Site plans should include the active sewage sludge unit locations within the site; the unit depths, configurations, and dimensions; and whether the unit will be completed below or above grade. It is particularly important that the investigation borings, test pits, and other procedures described in Chapter 6 be performed as near as possible to the active sewage sludge units, if not within their boundaries. Some other critical elements of the foundation design that need to be addressed prior to completion of the field investigation are the foundation design alternatives, the foundation grade, the loads exerted by the unit or the foundation, and the preliminary settlement tolerances.

7.5.1.3 Foundation Design

The engineering analysis for foundations is based on subsurface conditions; however, the results of such analyses are based on loading conditions. To perform the appropriate engineering analysis to demonstrate the

loadings should be prepared, in addition to plans showing the structure's shape and size, the expected waste characteristics and volumes, and the foundation elevations.

Foundations are designed to (U.S. EPA, 1988a):

- Provide structural support and to control settlement
- Prevent bearing capacity failure
- Withstand hydrostatic pressures

These are all discussed below.

Settlement and Compression

The foundation should be capable of preventing failure of the liner system due to settlement and compression. Therefore, it is important that an analysis be carried out estimating total and differential settlement/compression expected due to the maximum design loadings. The results of this analysis are then used to evaluate the ability of the liner system as well as the leachate collection and recovery systems to maintain their integrity under the expected stresses (U.S. EPA, 1988a).

A settlement analysis will provide an estimate of maximum settlement. This maximum settlement can be used to aid in estimating the differential settlement and distortion of an active sewage sludge unit. Allowable settlement is typically expressed as a function of total settlement, rather than differential settlement, because the latter is much more difficult to predict; however, the differential settlement is a more serious threat to the integrity of the structure than total settlement (Lambe and Whitman, 1969; Wahls, 1981).

Active sewage sludge unit design calculations should include estimates of the expected settlement, even if it is expected to be small. Small amounts of settlement, even a few inches, can cause serious damage to leachate collection piping or sumps.

Bearing Capacity

For active sewage sludge units, the major issue of concern for foundations is differential settlement; however, for structures such as leachate risers, an additional area of concern is bearing capacity failure (U.S. EPA, 1987a).

The basic criterion for foundation design is that settlement must not exceed some permissible value. This value varies, dependent on the structure and the tolerance for movement without disruption of the unit's integrity. To ensure that the basic criterion is met, the bearing capacity of a soil, often termed its stability, is the ability of the soil to carry a load without failure within the soil mass. The load carrying capacity of soil varies not only with its strength, but often with the magnitude and distribution of the load. The reference Sowers and Sowers (1970) provides information regarding the evaluation of bearing capacities and typical ranges of key parameters. After the bearing capacity is determined, the settlement under the expected load conditions should be estimated and compared to the permissible value. The foundation design should be such that the actual bearing stress is less than the bearing capacity by an appropriate factor of safety (U.S. EPA, 1987a; Winterkorn and Fang, 1975; Lambe and Whitman, 1969).

Seepage and Hydrostatic Pressures

Foundations should be designed to control seepage and hydrostatic pressures. Heterogeneities such as large cracks, sand lenses, or sand seams in the foundation soil offer pathways for leachate migration in the event of a release through the liner and could cause piping failures. In addition, soft spots in the foundation soils due to seepage can cause differential settlement possibly causing cracks in the liner above and damaging any leachate collection or detection system installed. Cracks also can be caused by hydrostatic pressure where the latter exceeds the confining pressure of the foundation and liner (U.S. EPA, 1986b).

Solutions to these problems include various systems that are available to lower the hydraulic head at the active sewage sludge unit. These systems include pumping wells, slurry walls, and trenching. Other methods to control foundation seepage include grouting cracks and fissures in the foundation soil with bentonite and designing compacted clay cut-off seals to be emplaced in areas of the foundation where lenses or seams of permeable soil occur (U.S. EPA, 1986b).

7.5.2 Monofill Design

Several monofills were identified and described in Chapter 2, Surface Disposal Practices. These include:

- Sludge-only trench
  - Narrow trench
  - Wide trench
- Sludge-only area fill
  - Area fill mound
  - Area fill layer
  - Diked containment

Chapter 2 provides a detailed discussion on each of these monofills, and Table 2-1 lists the most significant features affecting monofill selection, which are:

- Sludge percent solids.
- Sludge characteristics (stabilized or unstabilized).
- Hydrogeology (deep or shallow ground water and bedrock).
- Ground slopes.

Having chosen a site (Chapter 4) and a monofill (Chapter 2) appropriate to that site, a suitable design must be established. Sections 7.5.2.1 and 7.5.2.2 discuss considerations that are relevant to trench and area fills. In addition, Chapter 14, Design Examples, provides an illustration of how a monofill is selected for a given site.

7.5.2.1 Trench Designs

In a trench operation, sludge is placed entirely below the original ground surface. Sludge is usually dumped directly into trenches from haul vehicles. Onsite equipment is used only to excavate trenches and apply cover; equipment does not usually come into contact with the sludge.

Trenches have been further classified into narrow trenches and wide trenches. If trenches are selected, design of the filling area consists primarily of determining the following parameters:

- Excavation depth
- Spacing
- Width
- Length
- Orientation
- Sludge fill depth
- Cover thickness

Table 7-2 outlines a methodology for determining each of these parameters.

Trench spacing is perhaps the most important and yet most difficult design parameter to determine. Trench spacing is defined as the width of solid undisturbed ground that is maintained between adjacent trenches. Generally, trench spacing should be as small as possible to optimize land utilization rates; however, the trench spacing must be sufficient to resist sidewall cave-in. Failure of the trench sidewalls is a safety hazard and reduces the volume of the trench available for disposal. Factors to consider in determining trench spacing include:

- The weight of the excavating machinery.
- The bearing capacity of the soil (which is a factor of soil cohesion, density, and compaction).
- Saturation level of the soil (which may be significantly influenced by the moisture content of the sludge).
- The depth of the trench.
- Soil stockpiling and cover placement procedure.

A general rule of thumb to follow in establishing trench spacing is that for every 1 ft (0.3 m) of trench depth, there should be 1 to 1.5 ft (0.3 to 0.5 m) of space between trenches. If large inter-trench spaces are not practical, the problem of sidewall instability may be relieved by utilizing one of the four trench sidewall variations shown in Figure 7-3. In any event, test cell trenches should be used to determine the operational feasibility of any trench design. Such tests should be performed by excavating adjacent trenches to the specified depth, width, and spacing. A haul vehicle fully loaded with sludge should then back up to the trench to determine if the sidewall stability is sufficient.

Using the considerations included in Table 7-2, design parameters can be determined for a variety of sludge and site conditions. These considerations have been employed to develop some alternative design scenarios for trenches shown in Table 7-3. In some cases, sludge

Table 7-2. Design Considerations for Trenches

Design Parameter	Determining Factor	Consideration
Excavation Depth	Depth to groundwater Depth to bedrock Soil Permeability Cation exchange capacity of soil	Sufficient thickness of soil must be maintained between trench bottom and groundwater or bedrock Required minimum separation varies from 2 to 5 ft. Larger separations may be required for higher than normal soil permeabilities or sludge loading rates.
	Equipment limitations	Normal excavating equipment can excavate efficiently to depths of 10 ft. Depths from 10 to 20 ft are less efficient operations for normal equipment; larger equipment may be required. Depths over 20 ft are not usually possible.
	Sidewall stability	Sidewall stability determines maximum depth of trench. If haul vehicles are to dump sludge into trench from above, straight sidewall should be employed. Tests should be performed at site with a loaded haul vehicle to ensure that sidewall height as designed will not collapse under operating conditions.
Spacing	Sidewall stability	Trench spacing is determined by sidewall stability. Greater trench spacing will be required when additional sidewall stability is required. As a general rule, 1.0 to 1.5 ft of spacing should be allowed between trenches for every 1 ft of trench depth.
	Soil stockpiles Vehicle access	Sufficient space should be maintained between trenches for placement of trench soil stockpiled for cover as well as to allow access and free movement by haul vehicles and operating equipment.

Table 7-2. Design Considerations for Trenches (continued)

Design Parameter	Determining Factor	Consideration
Width	Sludge solids content	Widths of 2 to 3 ft for typical sludge with solids content from 15 to 20%. Widths of more than 3 ft for typical sludge with solids content more than 20%. Certain sludge (e.g., polymer treated) may require higher solids contents before these widths can apply.
	Equipment limitations	Widths up to 10 ft for typical equipment (such as front end loader) based on solid ground alongside trench. Widths up to 40 ft for some equipment (such as a dragline) based on solid ground. Unlimited widths for cover applied by equipment (such as bulldozers) which proceed out over sludge.
	Equipment efficiencies	Equipment — Typical Widths Trenching machine — 2 ft Backhoe — 2-6 ft Excavator — 4-22 ft Track dozer — ≥10 ft Track loader — ≥10 ft Dragline — ≥40 ft Scraper — ≥20 ft
Length	Sludge solids content Ground slopes	If sludge solids are low and/or trench bottoms not level, trench should be discontinued or dikes placed inside trench to contain sludge in one area and prevent it from flowing over large area.
Orientation	Land availability	Trenches should be parallel to optimize land utilization.
	Ground slopes	For low solids sludge, axis of each trench should be parallel to topographic contours to maintain constant bottom elevation within each trench and prevent sludge from flowing. With higher solids sludge, this requirement is not necessary.
Sludge fill depth	Trench width Cover application method	Trench width — Cover application method — Minimum distance from top 2-3 ft — Land-based equipment — 1-2 ft ≥ 3 ft — Land-based equipment — 3 ft >10 ft — Sludge-based equipment — 4 ft
Cover thickness	Trench width Cover application method	Trench width — Cover application method — Cover thickness 2-3 ft — Land-based equipment — 2-3 ft > 3 ft — Land-based equipment — 3-4 ft ≥10 ft — Sludge-based equipment — 4-5 ft

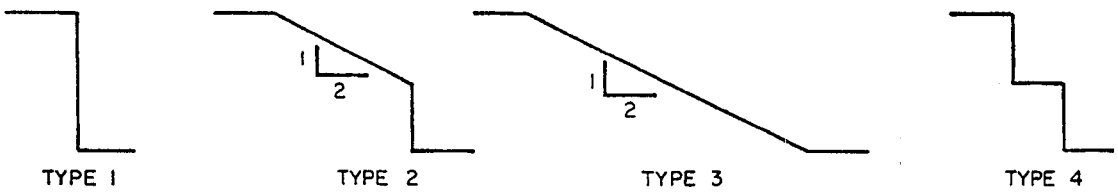


Figure 7-3. Trench sidewall variations.

and site conditions may indicate that it is wholly appropriate to utilize one of these trench scenarios for application to a real-world situation. Given the great variety of sludge and site conditions and their combinations, however, some adaptation of one of these scenarios will be necessary in most cases. In any event, design parameters should not be merely extracted from these tables; parameters should always be well-considered and tested before full-scale application. An example of a trench design (which utilizes these tables initially, fol-

Table 7-3. Alternative Design Scenarios

Identification			Site Preparation				Sludge Bulking			Sludge Filling			Sludge Covering				Miscellaneous	
															Cover Thickness			
Scenario No.	Landfilling Method	Sludge Solids Content (%)	Width (ft)	Depth (ft)	Length (ft)	Spacing (ft)	Bulking Performed	Bulking Agent	Bulking Ratio (agent: sludge)*	Sludge Depth Per Lift (ft)	No. Lifts	Sludge Application Rate (yd^3/acre)	Cover Applied	Location of Equipment	Interim (ft)	Final (ft)	Imported Soil Required	Primary Equipment
1	Narrow trench	15	2	3	1,000	3	No	-	-	2	1	1,290	Yes	Land-based	-	3	No	Trenching machine
2	Narrow trench	17	2	8	1,000	8	No	-	-	6	1	1,940	Yes	Land-based	-	3	No	Backhoe
3	Narrow trench	25	6	10	100	12	No	-	-	7	1	3,750	Yes	Land-based	-	4	No	Backhoe with loader
4	Narrow trench	28	8	8	100	12	No	-	-	5	1	3,230	Yes	Land-based	-	4	No	Excavator
5	Wide trench	26	40	7	400	20	No	-	-	4	1	4,100	Yes	Land-based	-	4	No	Dragline
6	Wide trench	32	60	8	600	30	No	-	-	4	1	4,100	Yes	Sludge-based	-	5	No	Track dozer
7	Area fill mound	20	-	-	-	-	Yes	Soil	2:1	6	1	3,230	Yes	Sludge-based	-	3	Yes	Track loader
8	Area fill mound	35	-	-	-	-	Yes	Soil	0.5:1	6	2	12,910	Yes	Sludge-based	3	5	Yes	Track loader, backhoe
9	Area fill layer	15	-	-	-	-	Yes	Soil	1:1	1	3	2,420	Yes	Sludge-based	0.5	2	Yes	Track dozer
10	Area fill layer	30	-	-	-	-	Yes	Soil	0.25:1	3	2	7,740	Yes	Sludge-based	1	2	Yes	Track dozer, grader
11	Diked containment	25	50	30	100	30	Yes	Soil	0.5:1	6	4	12,410	Yes	Land-based	1	3	No	Dragline
12	Diked containment	32	100	23	200	50	No	-	-	8	2	13,770	Yes	Sludge-based	3	4	No	Track dozer
13	Sludge/refuse mixture	3	-	-	-	-	Yes	Refuse	7 tons:1 wet ton	6	3	2,520	Yes	Sludge-based	0.5	2	Yes	Track dozer
14	Sludge/refuse mixture	28	-	-	-	-	Yes	Refuse	4 tons:1 wet ton	6	3	4,140	Yes	Sludge-based	0.5	2	Yes	Track dozer
15	Sludge/soil mixture	20	-	-	-	-	Yes	Soil	1:1	1.0	1	1,600	No	-	-	-	No	Tractor with disc

*Volume basis unless otherwise noted.

lowed by engineering investigation and field testing) has been included in Chapter 14, Design Examples.

Narrow Trench

The use of narrow trenches has grown considerably despite high area requirements (U.S. EPA, 1986a). This method has found much more acceptance than other forms of monofilling in areas where siting of a conventional MSW landfill or a wide-trench monofill would encounter community resistance (U.S. EPA, 1986a). One of the very important advantages of narrow trench monofilling is that the time during which sludge is uncovered can be reduced to minutes with subsequent minimal likelihood of unpleasant odors.

Narrow trenches have widths less than 10 ft (3.0 m) and usually receive sludge with solids contents as low as 15%. Excavation and cover application in narrow trench operations is carried out via equipment operating on solid ground alongside the trench. Illustrations of typical narrow trench operations are included as Figures 7-4 and 7-5. See also Section 2.3.1.1 for detailed information on narrow trenches. Sludge characteristics, site conditions, and design criteria for narrow trenches are summarized in Tables 2-1 and 2-2.

The method of sludge placement in a narrow trench is dependent on the type of haul vehicle and on trench sidewall stability. Usually trench sidewalls are sufficiently stable and sludge may be dumped from the haul vehicle directly into trenches. If sidewalls are not sufficiently stable, however, the sludge may be delivered to the trench in a chute-extension similar to that found on concrete trucks or pumped in via portable pumps. In some cases, particularly in wet weather, it may be necessary to dump the sludge on solid ground near the trench and have onsite equipment push the sludge into the trench.

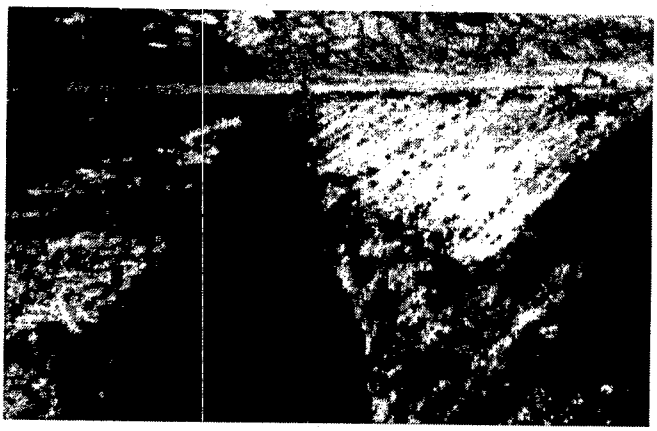


Figure 7-5. Cross section of typical wide trench operation.

Wide Trench

Wide trenches have widths greater than 10 ft (3.0 m) and usually receive sludge with solids contents of 20% and more. Excavation of wide trenches is usually carried out using equipment that enters the trench. Cover application may be carried out using equipment operating on solid ground alongside the trench, but is usually accomplished with equipment that traverses the sludge spreading a layer of cover soil before it. Illustrations of typical wide trench operations are included as Figures 7-6 and 7-7. See also Section 2.3.1.2 for detailed information on wide trenches. Sludge characteristics, site conditions, and design criteria for wide trenches are summarized in Tables 2-1 and 2-2.

Sludge may be placed in wide trenches by haul vehicles, either:

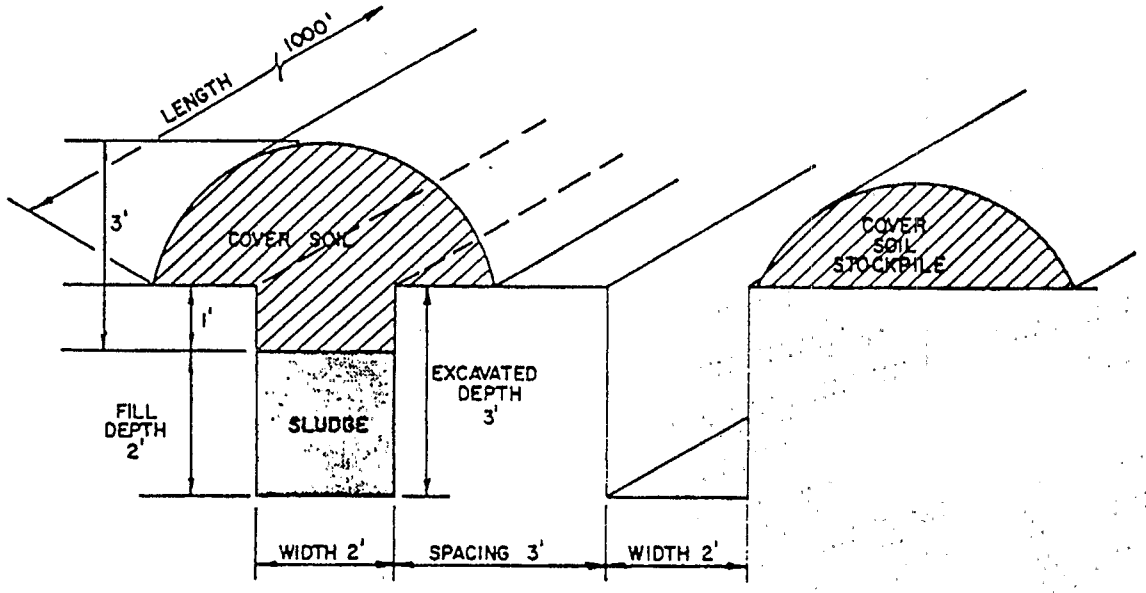


Figure 7-4. Cross section of typical narrow trench operation.

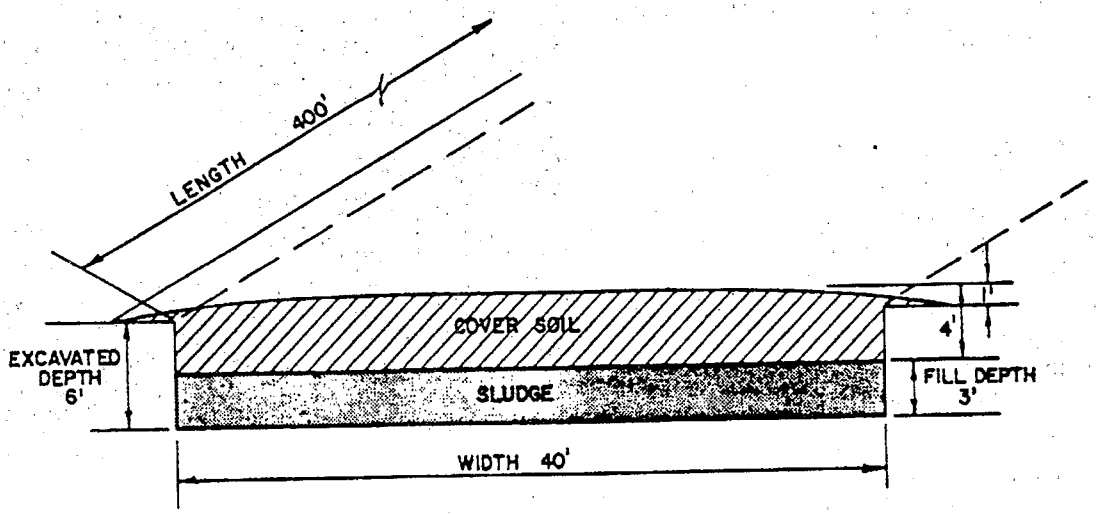


Figure 7-6. Cross section of typical wide trench operation.

Figure 7-7. Wide trench operation.

- Directly entering the trench and dumping sludge in 3 to 4 ft (0.9 to 1.2 m) high piles.
- Parked at the top of trench sidewalls and dumping sludge into the trench.

For the first of these two cases, sludge should have a solids content of 32% or more to ensure that the sludge will not slump and can be maintained in piles. For the second approach, sludge should have a solids content less than 32% to ensure that it will flow evenly throughout the trench and not accumulate at the dumping location. Of course, when sludge is freeflowing, some means will be needed to confine the sludge to specific areas in a continuous trench. Dikes are often used for this purpose as illustrated in Figure 7-8.

7.5.2.2 Area Fill Designs

In an area fill operation, sludge is usually placed entirely above the original ground surface. The sludge as received is usually mixed with soil to increase its effective solids content and stability. Several consecutive lifts of this sludge/soil mixture are usually then applied to the filling area. Soil may be applied for interim cover in addition to its usual application for final cover. Onsite equipment usually does come into contact with the sludge while performing functions of mixing the sludge with soil; transporting this mixture to the fill area; mounding or layering this mixture; and spreading cover over the mixture.

Area fills have been further classified into area fill mounds, area fill layers, and diked containments. If one of these landfilling methods has been selected, design of the filling area may consist primarily of determining the following parameters:

- Bulking ratio
- Cover application procedure
- Width (of diked containment)
- Depth of each lift
- Interim cover thickness
- Number of lifts
- Depth of total fill (or diked containment before final cover)
- Final cover thickness

Table 7-4 outlines a methodology for determining each of these parameters.

Using the considerations included in Table 7-4, the design parameters can be determined for a variety of sludge and site conditions. These considerations have been employed to develop some alternative design scenarios for area fills that are included in Table 7-3. An example of an area fill design (which utilizes these tables initially, followed by investigation and testing) has been included in Chapter 14, Design Examples.

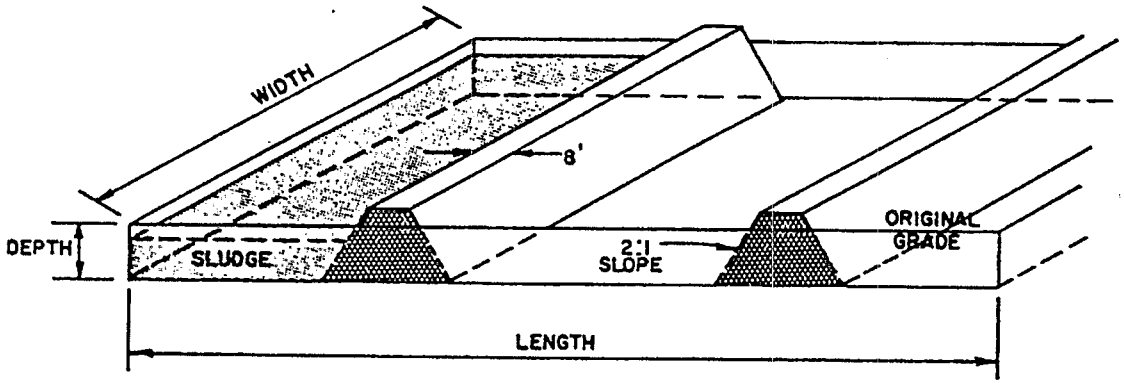


Figure 7-8. Cross section of wide trench with dikes.

Table 7-4. Design Considerations for Area Fills

Design Parameter	Consideration		
	Method	**Solids Content**	**Bulking Ration**
Bulking Ratio	Area fill mound	20-28%	2 soil:1 sludge
		28-32%	1 soil:1 sludge
		≥32%	0.5 soil:1 sludge
	Area fill layer	15-20%	1 soil:1 sludge
		20-28%	0.5 soil:1 sludge
		28-32%	0.25 soil:1 sludge
		≥ 32%	Not required
	Diked containment	20-28%	0.5 soil:1 sludge
		28-32%	0.25 soil:1 sludge
		> 32%	Not required
	Method	**Solids Content**	**Cover Application Procedure**
Cover Application Procedure	Area fill mound	≥ 20%	Sludge-based equipment
	Area fill layer	≥ 15%	Sludge-based equipment
	Diked containment	20-28%	Land-based equipment
		> 28%	Sludge-based equipment
	Cover Application Procedure	**Equipment Used**	**Width**
Width (of diked containment)	Land-based equipment	Dragline	≤ 40 ft
	Sludge-based equipment	Track dozer	Not limited
	Method	**Sludge Solids**	**Lift Depth**
Depth of each lift	Area fill mound	≥ 20%	6 ft
	Area fill layer	15-20%	1 ft
		≥ 20%	2-3 ft
	Diked containment	20-28%	4-6 ft
		> 28%	6-10 ft

Table 7-4. Design Considerations for Area Fills (continued)

Design Parameter	Consideration		
	Method	**Cover Application Procedure**	**Interim Cover Thickness**
Interim cover thickness	Area fill mound	Sludge-based equipment	3 ft
	Area fill layer	Sludge-based equipment	0.5-1 ft
	Diked containment	Land-based equipment	1-2 ft
		Sludge-based equipment	2-3 ft
	Method	**Sludge Solids Contents**	**No. of Lifts**
Number of lifts	Area fill mound	20-28%	1 maximum
		> 28%	3 maximum
	Area fill layer	≥ 15%	1-3 typical
	Diked containment	≥ 20%	1-3 typical
	Cover Application Procedure		**Depth of Total Fill**
Depth of total fill (of diked containment before final cover)	Land-based equipment		No higher than 3 ft below top of dikes
	Sludge-based equipment		No higher than 4 ft below top of dikes
	Method	**Cover Application Procedure**	**Final Cover Thickness**
Final cover thickness	Area fill mound	Sludge-based equipment	1 ft
	Area fill layer	Sludge-based equipment	1 ft
	Diked containment	Land-based equipment	3-4 ft
		Sludge-based equipment	4-5 ft

Area Fill Mound

At area fill mound operations, sludge/soil mixtures are stacked into mounds approximately 6 ft (1.8 m) high. Cover soil is applied atop each lift of mounds in a 3 ft (0.9 m) thickness. The cover thickness may be increased to 5 ft (1.5 m) if additional mounds are applied atop the first lift. Illustrations of typical mound operations are included as Figures 7-9 and 7-10. See also Section 2.3.2.1 for detailed information on area fill mounds. Sludge characteristics, site conditions, and design criteria for area fill mounds are summarized in Tables 2-1 and 2-2.

Sludge as received at the landfill is usually mixed with a bulking agent. The bulking agent absorbs excess moisture from the sludge and increases its workability. The amount of soil needed to serve as an additional bulking agent depends on the solids content of the sludge. Generally the soil requirements shown in Table 7-4 may serve as a guideline. Fine sand appears to be the most suitable bulking agent because it can most easily absorb the excess moisture from the sludge.

Area Fill Layer

At area fill layer operations, sludge/soil mixtures are spread evenly in layers from 0.5 to 3 ft (0.15 to 0.9 m) thick. This layering usually continues for a number of applications. Interim cover between consecutive layers may be applied in 0.5 to 1 ft (0.15 to 0.3 m) thick applications. Final cover should be at least 1 ft (0.3 m) thick. An illustration of a typical area fill layer operation is included as Figure 7-11. See also Section 2.3.2.2 for detailed information on area fill layers. Sludge characteristics, site conditions, and design criteria for area fill layers are summarized in Tables 2-1 and 2-2.

Diked Containment

At diked containment operations, earthen dikes are constructed to form a containment area above the original ground surface. Dikes can be of various heights, but require side slopes of at least 2:1 and possibly 3:1. A 15 ft (4.6 m) wide road, covered with gravel, should be constructed atop the dikes. An illustration of a typical diked containment operation is included as Figure 7-12. See also Section 2.3.2.3 for detailed information on

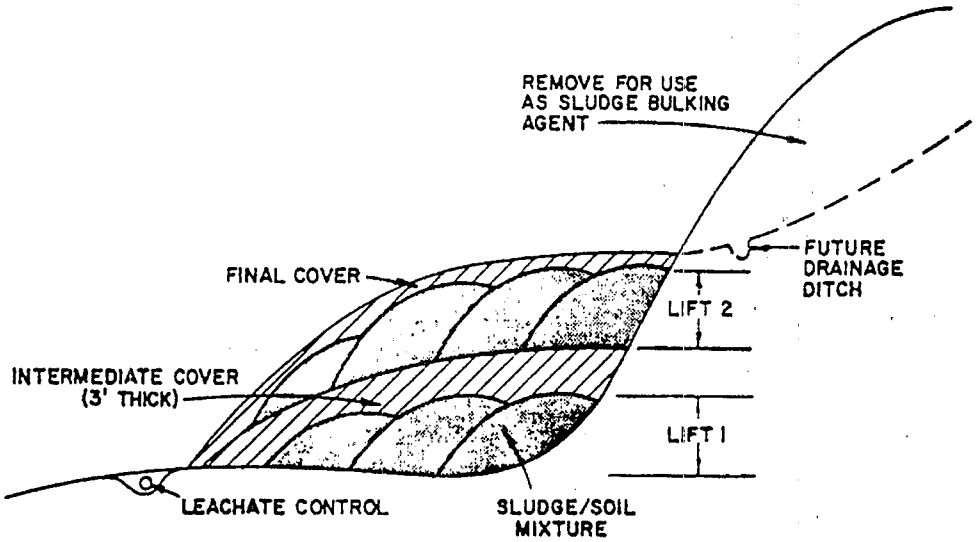


Figure 7-9. Cross section of typical area fill mound operation.

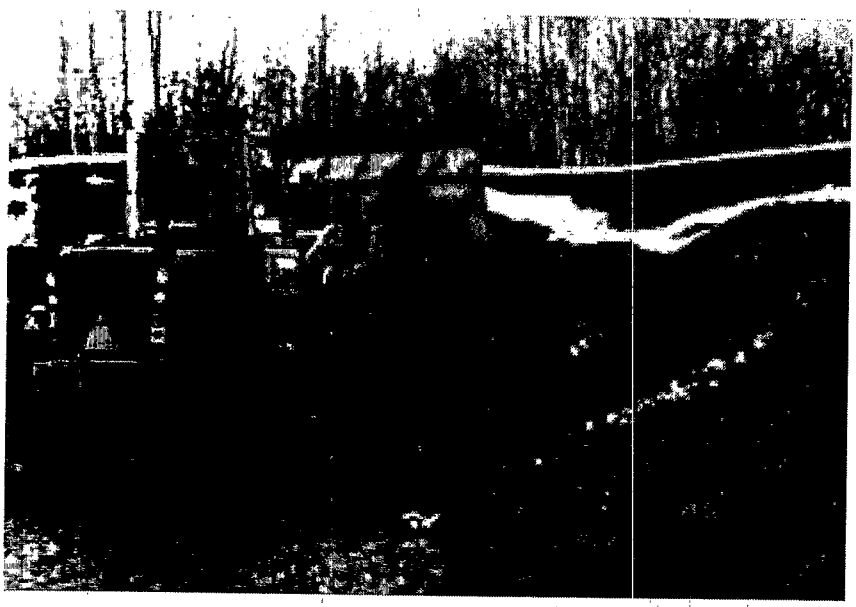


Figure 7-10. Area fill mound operation.

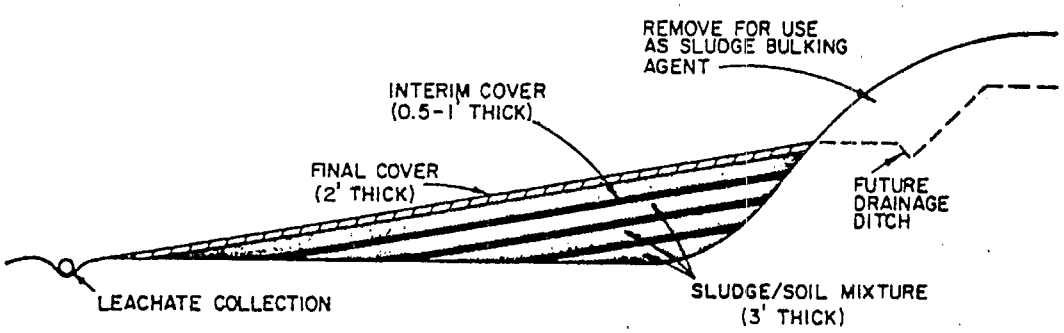


Figure 7-11. Cross section of typical area fill layer operation.

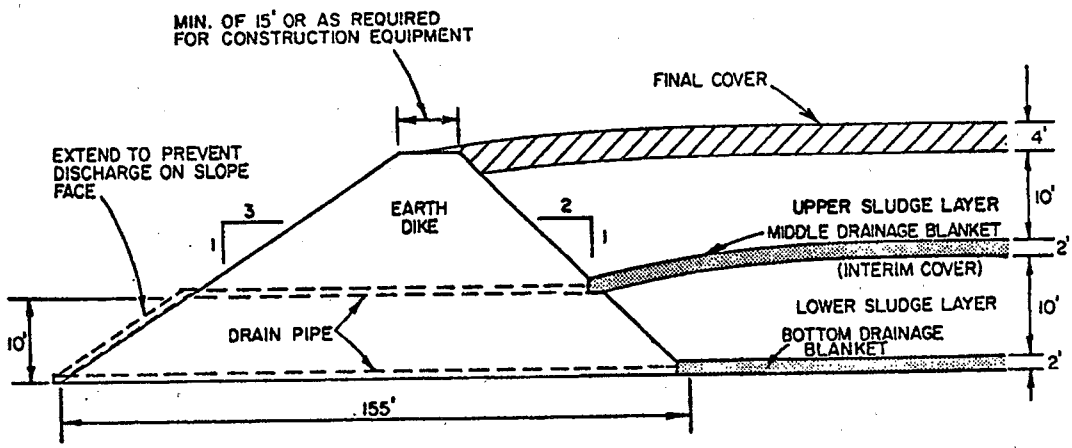


Figure 7-12. Cross section of typical diked containment operation.

diked containment. Sludge characteristics, site conditions, and design criteria for diked containments are summarized in Tables 2-1 and 2-2.

Sludge may be either:

- Mixed with soil bulking for subsequent transport and dumping into the containment area by onsite equipment.
- Dumped directly into the containment area by haul vehicles without bulking soil.

Large quantities of imported soil may be required to meet soil requirements for dike construction and bulking since diked containments are often constructed in high ground-water areas.

Sludge is dumped into diked containments in lifts before the application of interim cover. Often this interim cover is a highly permeable drainage blanket that acts as a leachate collection system for sludge moisture released from the sludge lift above. Final cover should be of a less-permeable nature and should be graded even with the top of the dikes.

7.5.3 Surface Impoundment and Lagoon Design

At aboveground surface impoundments, dikes are used to contain the sewage sludge, and haul vehicles dump sludge directly into the containment area from the sides of the dikes. Design information for diked containment can be found in Section 7.5.2.2.

Belowground surface impoundments or lagoons have been widely used for treatment and storage of sludge. The surface disposal provisions of the Part 503 rule do not apply when sludge is ***treated*** in a lagoon (or otherwise treated on the land) for what could be an indefinite period. Figure 7-13 compares treatment lagoons and storage/disposal lagoons. The surface disposal provisions also do not apply to lagoons used for long-term temporary storage of sludge ***if*** the storage is considered part of the ***treatment process*** and if the facility's owner/operator has a rationale or a plan for final use or disposal of the sludge. If, however, the sludge generator has no intention of ever removing the sludge from the lagoon, the facility is considered a surface disposal site and is subject to the Part 503 surface disposal requirements, including requirements for pollutant limits, closure, management practices, pathogen and vector attraction reduction, monitoring, and recordkeeping and reporting. Many states also have requirements for lagoons. Check with your state for any specific state requirements for designing lagoons.

Ground-water protection is a key concern with respect to sludge lagoons. A minimum soil buffer of 4 ft is recommended between the bottom of a lagoon and the seasonal annual high ground-water table. Liners and leachate collection systems should be considered, depending on sludge quality, distance to drinking water wells, depth to ground water, ground-water flow direction and velocity, aquifer classification, and underlying soil type and permeability (U.S. EPA, 1990).

Three types of lagoons are described below: facultative sludge lagoons, anaerobic liquid sludge lagoons, and sludge drying lagoons. If the dewatered sludge is periodically removed from these lagoons, they are considered treatment lagoons, but if the sludge is never removed, they are considered surface disposal facilities.

7.5.3.1 Facultative Sludge Lagoons

Facultative sludge lagoons (FSLs) are designed to maintain an aerobic surface layer free of scum or membrane-type film buildup. The aerobic layer is maintained by keeping the annual organic loading to the lagoon at or below a critical area loading rate and by using surface mixers to provide agitation and mixing of the aerobic surface layer. The aerobic surface layer of FSLs is usually from 1 to 3 ft (0.30 to 0.91 m) in depth and supports a very dense population of between 50 x 10^3 and 6 x 10^6 organisms/mL of algae (usually *Chorella*). Dissolved

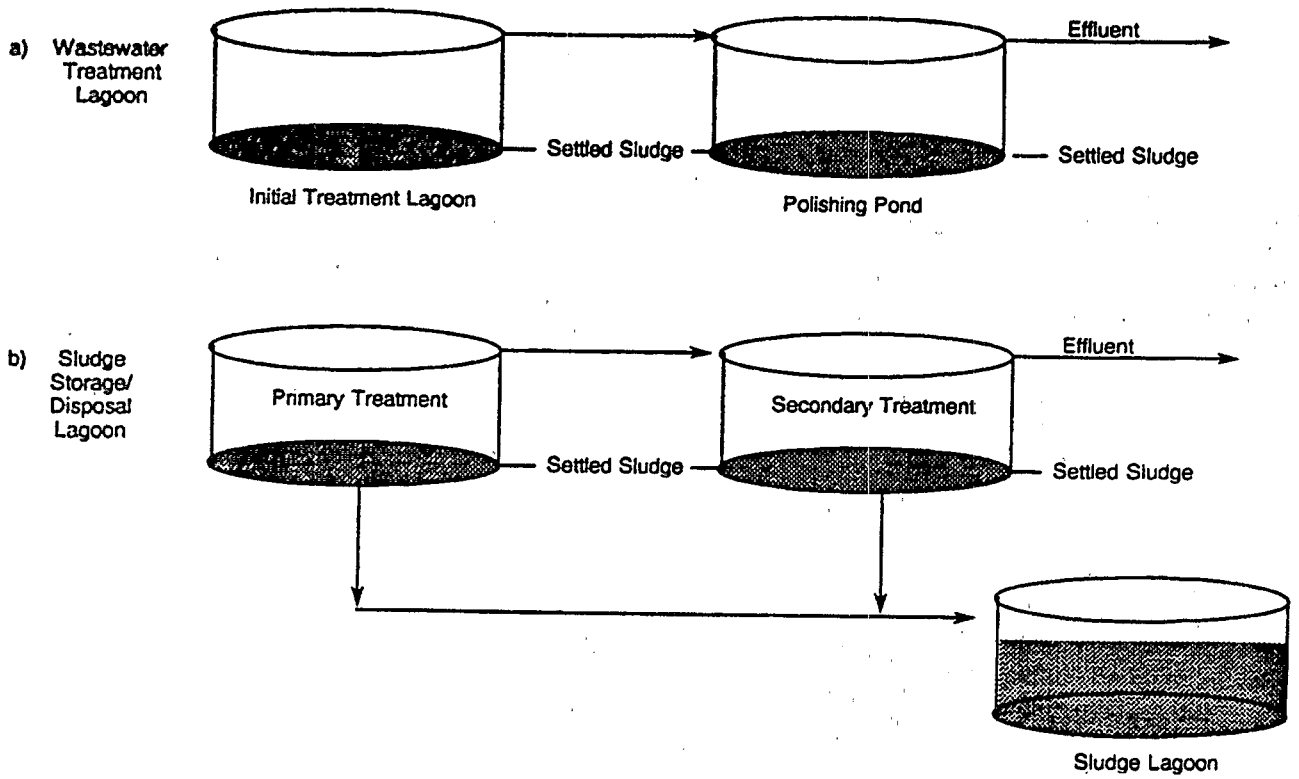


Figure 7-13. Comparison of wastewater lagoon and sludge lagoon (U.S. EPA, 1990).

oxygen is supplied to this layer by algal photosynthesis, by direct surface transfer from the atmosphere, and by the surface mixers. The oxygen is used by the bacteria in the aerobic degradation of colloidal and soluble organic matter in the digested sludge liquor, while the digested sludge solids settle to the bottom of the basins and continue their anaerobic decomposition. Sludge liquor or supernatant is periodically returned to the plant's liquid process stream.

The nutrient and carbon dioxide released in both the aerobic and anaerobic degradation of the remaining organic matter within the digested sludge are, in turn, used by the algae in the cyclic-symbiotic relationship. This vigorous relationship maintains the pH of the FSL surface layer at between 7.5 and 8.5, which effectively minimizes any hydrogen sulfide (H_2S) release and is believed to be a key to the successful operation of this type of sludge storage process.

Facultative sludge lagoons must operate in conjunction with anaerobic digesters (U.S. EPA, 1979). They cannot function properly (without major environmental impacts) when supplied with either unstabilized or aerobically digested sludge (U.S. EPA, 1979). If the acid phase of anaerobic stabilization becomes predominant, the lagoons will give off an offensive odor. Figure 7-14 provides a schematic representation of the reactions in a typical FSL.

Design Criteria

Design considerations for the FSLs include the area loading rate, surface agitation requirements, dimensional and layout limitations, and physical factors:

- *Area Loading Rate.* To maintain an aerobic top layer, the annual organic loading rate to the FSL must be at or below 20 lb of volatile solids (VS) per 1,000 sq ft per day (1.0 t VS/ha-d). Lagoons have been found to be capable of receiving the equivalent of the daily organic loading rate every second, third, or fourth day without experiencing any upset. That is, lagoons have assimilated up to four times normal daily loadings as long as they have had 3 days of rest between loadings. Loadings as high as 40 lb VS per 1,000 sq ft per day (1.0 t VS/ha-d) have been successfully assimilated for several months during the warm summer and fall. Experiments on small basins loaded to failure indicate that peak loadings up to 90 lb VS per 1,000 sq ft per day (4.4 t VS/ha-d) can be tolerated during the summer and fall as long as they do not occur for more than 1 week.
- *Surface Agitation Requirements.* Experiments on FSLs that were continuously loaded at the standard rate (1.0 t VS/ha-d) indicate FSLs cannot function in an environmentally acceptable manner without daily operation of surface agitation equipment. Observations indicate the brush-type mixer is required to breakup the surface film that forms during the feeding

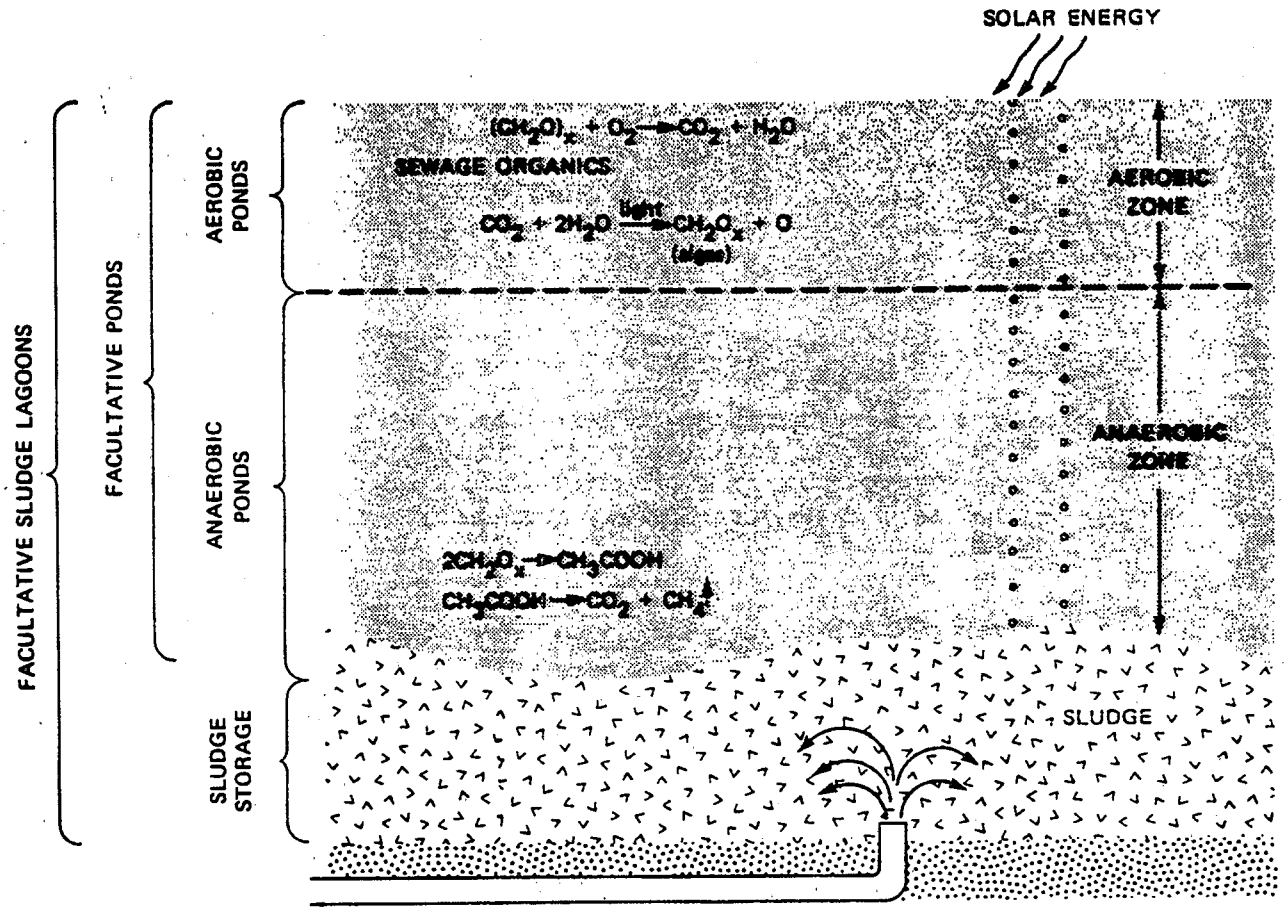


Figure 7-14. Schematic representation of an FSL (U.S. EPA, 1979).

of the lagoon. If this film is not dissipated, a major source of oxygen transfer to the surface layer is eliminated. FSLs with surface areas of from 4 to 7 acres (1.6 to 2.8 ha) require the operation of two surface mixers from 6 to 12 hr per day to successfully maintain scum-free surface conditions. All of the successful installations to date have used brush-type floating surface mixers to achieve the necessary surface agitation. Two brush-type mixers with 8-ft-long (2.4-m) rotors turning at approximately 70 rpm and driven by 15 hp (11.2 kW) motors are required for a 4 to 7 acre (1.6 to 2.8 ha) lagoon. The mixers need to operate 12 hr per day. Lagoons of much less than 4 acres (1.62 ha) should be able to achieve the same results with two mixers with 6-ft (1.8-m) long rotors and 5-hp (3.7 kW) motors. Operation time is expected to be about the same number of hours per day. Brush-type mixers have been used to limit the agitation to the surface layer of the FSLs. So far this has been an acceptable application; however, there is some question as to their applicability for very cold climates. Several submerged pump-type floating aerators have been reviewed, and they could be adapted to provide the necessary surface agitation if the brush-type could not function under severe freezing conditions.

Two mixers are used per FSL to ensure maximum scum breakup in those areas of the lagoon where the prevailing wind deposits the daily loading of scum. The agitation and mixing action of the two mixers located at opposite ends or sides of the lagoon also act to maintain equal distribution of the anaerobic solids.

- *Dimensional and Layout Limitations.* The maximum area for a single lagoon area is somewhat arbitrary but is based on the most practical size for loading, surface agitation, mixing (and, for treatment lagoons, removal) requirements. Large, 4 to 7 acre (1.6-2.8 ha) individual lagoons would be applicable only to plants with over 70 acres (28 ha) of FSLs. FSLs as small as 150 ft (45.7 m) on a side have been operated successfully. Lagoon depths can range from about 11.5 to 15 ft (3.5 to 4.7 m). If surface agitation must be maintained by submerged pump type aerators, it may be necessary to use the deepest lagoon possible to ensure adequate separation between the aerobic zone and the anaerobic settling zone of the FSL.

FSLs are usually best designed to have a long and a short dimension, with the shortest dimension oriented parallel to the direction of the maximum prevailing wind. The longer side is made conducive to

efficient dredge operation, while the short side's parallel orientation to the prevailing wind direction helps to minimize wave erosion on the surrounding levees. Figure 7-15a is a typical FSL layout, while Figure 7-15b is a typical FSL cross section.

When the area of FSLs exceeds 40 acres (16.2 ha), the potential cumulative effect of large odor emission areas to the vicinity must be considered. Figure 7-16 shows the layout for the 124 acres (50.2 ha) of FSLs in Sacramento, California, that were sited on the basis of the least odor risk to surrounding areas. Batteries of FSLs totaling 50 to 60 acres (20 to 24 ha) are about the maximum size for most effectively reducing the transport of odors.

- *Physical Considerations.* Many of the detailed physical considerations applied to the final design of the Sacramento FSLs are shown in Figures 7-15b and 7-16. Supernatant withdrawal is located upstream from the prevailing winds to minimize scum buildup in its vicinity. FSL supernatant will precipitate magnesium ammonia phosphate (struvite) on any rough surface that is not completely submerged; it has also been found to precipitate inside cavitating pumps. This crystalline material can completely clog cast-iron

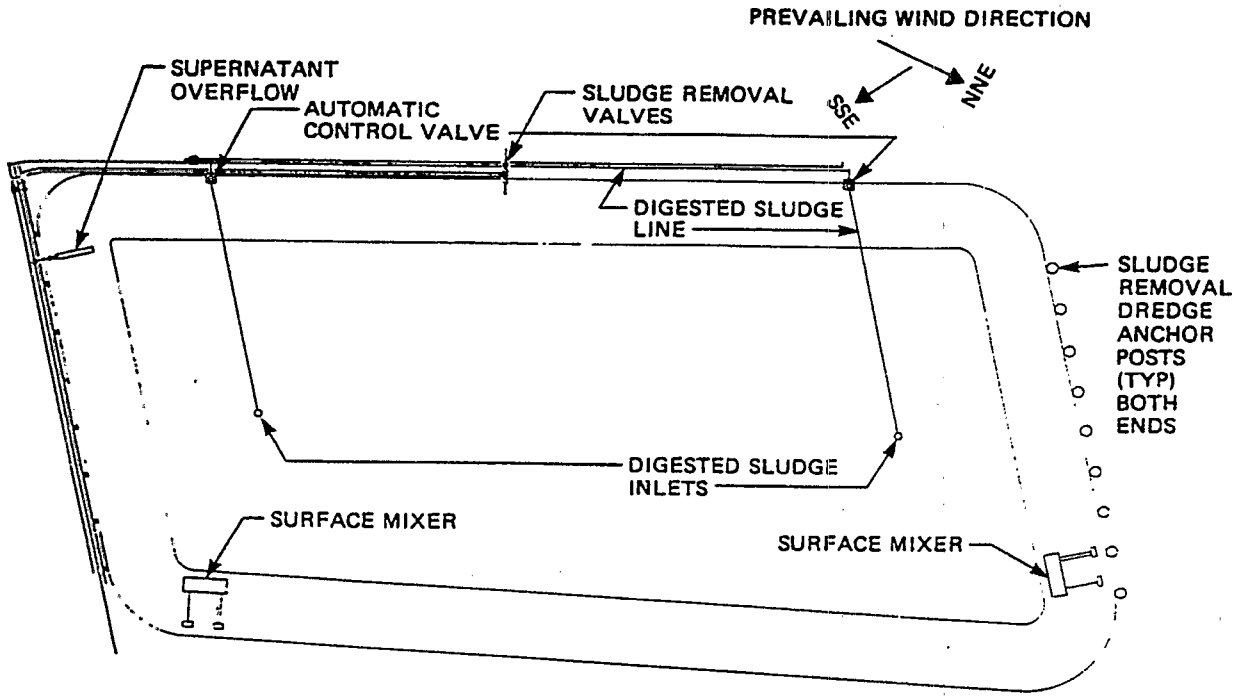


Figure 7-15a. Typical FSL layout (U.S. EPA, 1979).

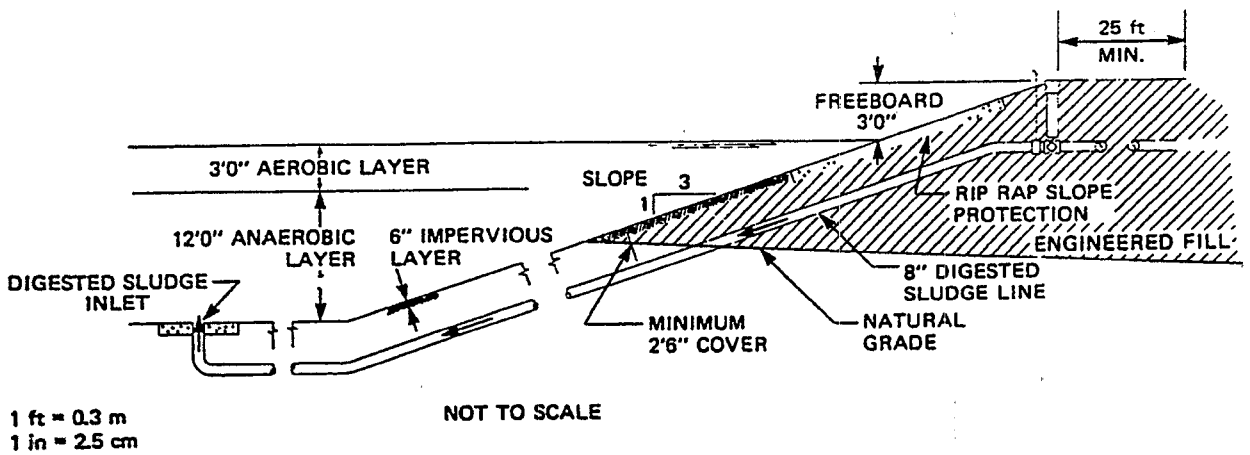


Figure 7-15b. Typical FSL cross section (U.S. EPA, 1979).

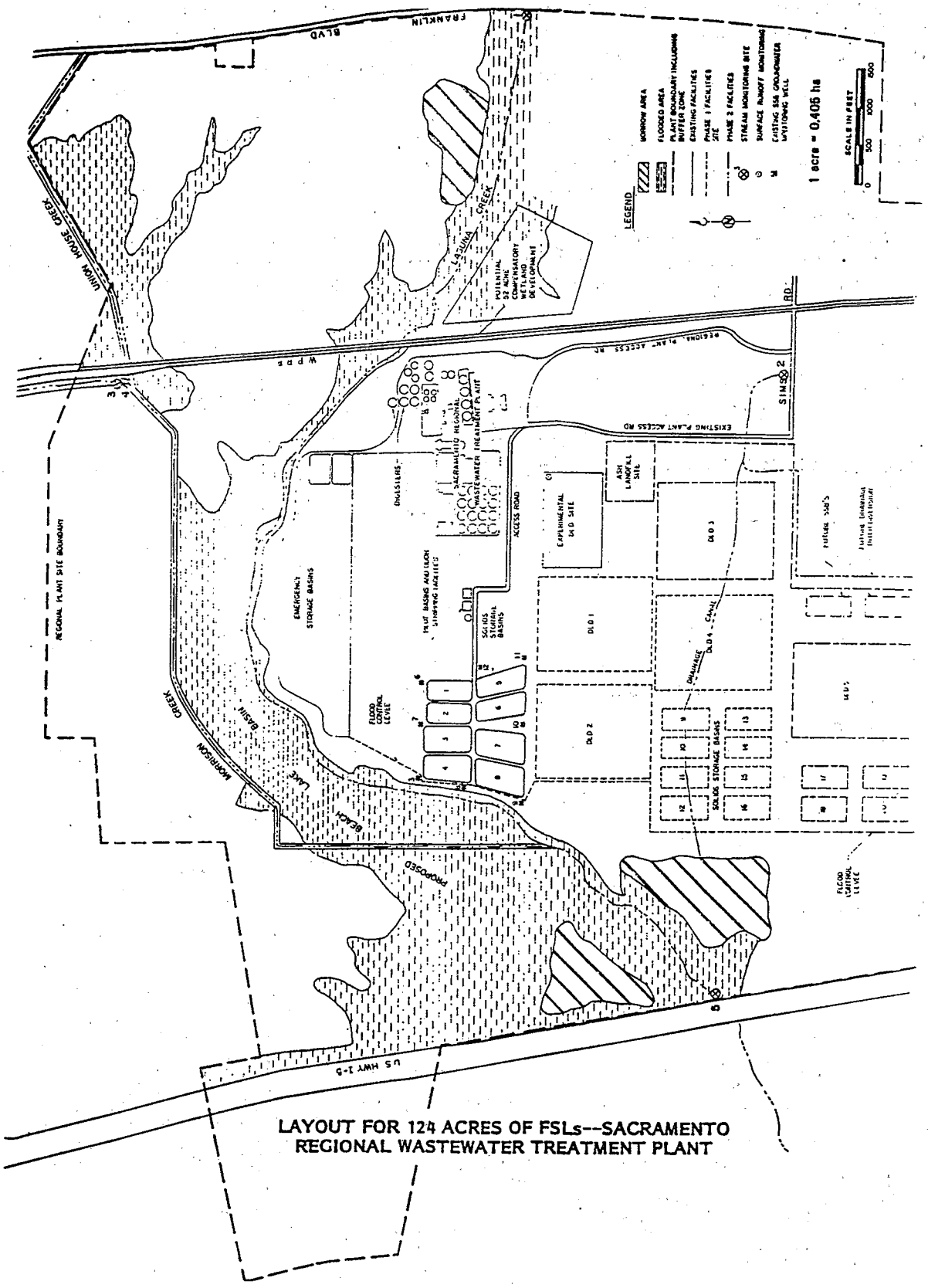


Figure 7-16. Layout for 124 acres of FSLs: Sacramento Regional Wastewater Treatment Plant (U.S. EPA, 1979).

fittings and pump valves when the surface goes through a fill-and-draw cycle or when its operation results in the presence of diffused air. The most practical approach to eliminating this problem has been to use PVC piping throughout the FSL supernatant process and to design the process for gravity return to the plant influent, with a minimum of critical depth conditions. If pumping is required, submerged slow-speed nonclog centrifugal pumps with low suction and discharge velocities (to minimize cavitation) will be the most trouble free. All equipment that is not PVC or another smooth non-metallic material should be coated with a smooth, impervious surface.

Two digested sludge feed lines, each with its own automatic valve, ensure adequate distribution of solids over the whole volume of the FSL. Surface mixers are downstream of the prevailing winds. The harvested sludge dredge hookup is centrally located. Lagoon dike slopes are conservative—3 horizontal to 1 vertical—with adequate rip-rap provided in the working zone of the surface level. Sufficient freeboard is provided to protect against any conceivable overtopping of the dikes. Digested sludge feed pipelines are located directly below the bottom of the lagoons, with the inlet surrounded by a protective concrete surface. All piping within the basin is out of the way of any future dredging operations.

Table 7-5 presents design criteria for the Sacramento, California, facultative sludge lagoons.

7.5.3.2 Anaerobic Liquid Sludge Lagoons

An anaerobic lagoon is usually an open structure similar to the facultative lagoon, but often with a greater depth in relation to surface area (Lue-Hing et al., 1992). These lagoons settle solids with higher specific gravity than water and provide for sludge storage on the bottom. Unlike the facultative lagoon, an aerobic surface layer is not maintained and floatable material is not settled or removed; thus, a thick scum layer can develop on the lagoon surface. Sludge loading rates to anaerobic lagoons are higher than the loading rates of facultative lagoons (Lue-Hing et al., 1992). Figure 7-17 shows the layout of four anaerobic lagoons at the Metropolitan Sanitary District of Greater Chicago Prairie Plan land reclamation project in Fulton County, Illinois.

Table 7-6 presents the advantages and limitations of facultative sludge lagoons and anaerobic lagoons.

Table 7-5. Design Criteria for Sludge Storage Basins: Sacremento (California) Regional Wastewater Treatment Plant (Lue-Hing et al., 1992)

Total number of sludge storage basins	20
Surface area—hectares (acres)	50.6 (125
Depth at normal operation—m (ft)	4.57 (15)
Solids loading rate— kg/m^2/d (lbs/1000 ft^2/d)	0.0975 (20)
Stored solids concentration. %	>6
Surface mixers for aeration	40
Barrier wall height, m (ft)	3.64 (12)
Supernatant return flow metering	3.154-17.0
90° V-notch weir, L/s (gpm)	(50-270)
30.5 cm (12 in.) Parshall flume	8.77-175.3
L/s (MGD)	0.2-4.0)

7.5.3.3 Sludge Drying Lagoons

Sludge drying lagoons consist of retaining walls that are normally earthen dikes 2 to 4 ft (0.7 to 1.4 m) high. The earthen dikes usually enclose a rectangular space with a permeable surface. Appurtenant equipment includes sludge feed lines and metering pumps, supernatant decant lines, and some type of mechanical sludge removal equipment, if sludge is to be removed. In areas where permeable soils are unavailable, underdrains and associated piping may be required.

Figure 7-18 shows a plan view of a sludge drying lagoon.

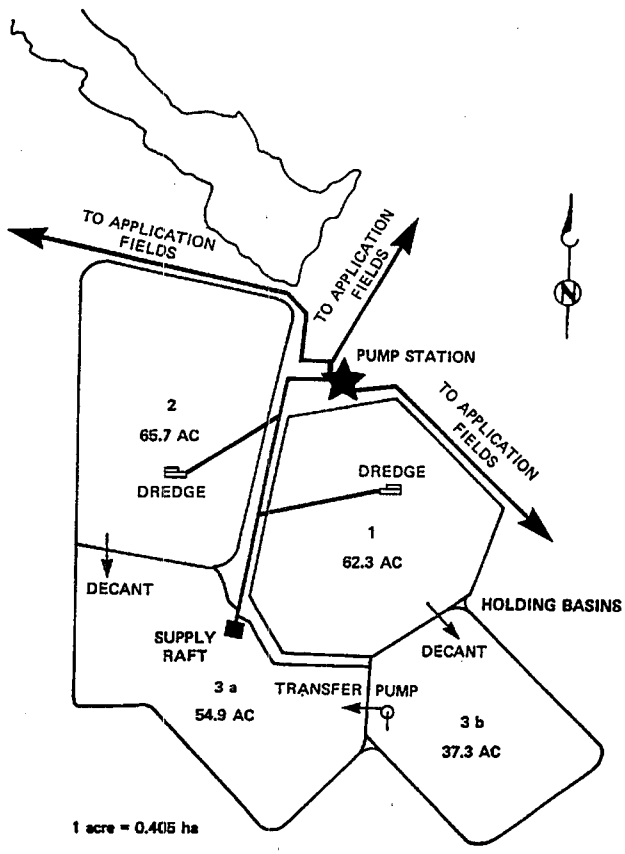


Figure 7-17. Anaerobic liquid sludge lagoons, Prairie Plan land reclamation project, the Metropolitan Sanitary District of Greater Chicago (U.S. EPA, 1979).

Design Criteria

Proper design of sludge drying lagoons requires a consideration of the following factors: climate, subsoil permeability, sludge characteristics, and lagoon depth and area. A discussion of these factors follows.

- *Climate.* After dewatering by drainage and supernating, drying in a sludge lagoon depends primarily on evaporation. Proper size of a lagoon, therefore, requires climatic information concerning:
  - Precipitation rate (annual and seasonal distribution).

Table 7-6. Advantages and Limitations of Faculative Sludge Lagoons and Anaerobic Lagoons (U.S. EPA, 1979)

Advantages	Limitations
Provides long-term storage with acceptable environmental impacts (odor and groundwater contamination risks are minimized).	1. Can only be used following anaerobic stabilization. If acid phase of digestion takes place in lagoons they will stink.
Continues anaerobic stabilization, with up to 45 percent VS reduction in first year.	2. Large acreages require special odor mitigation measures.
Decanting ability assures minimum solids recycle with supernatant (usually less than 500 mg/l) and maximum concentration for storage and efficient harvesting (>6 percent solids) starting with digested sludge of <2 percent solids.	3. Requires large areas of land, for example, 15 to 20 gross acres (6 to 8 ha) for 10 MGD, (438 l/s) 200 gross acres (80 ha) for 136 MGD (6,000 l) carbonaceous activated sludge plants.
Long-term liquid storage is one of few natural (no external energy input) means of reducing pathogen content of sludges.	4. Must be protected from flooding.
Energy and operational effort requirements are very minimum.	5. Supernatant will contain 300-600 mg/l of TKN, mostly ammonia.
Once established, buffering capacity is almost impossible to upset.	6. Magnesium ammonia phosphate (struvite) deposition requires special supernatant design.
Allows for all tributary digesters to operate as primary complete-mix units (one blending unit may be required for large installations).	
Provides environmentally acceptable place for disposal of digester contents during periodic cleaning operations.	
Sludge harvesting is completely independent from sludge production.	

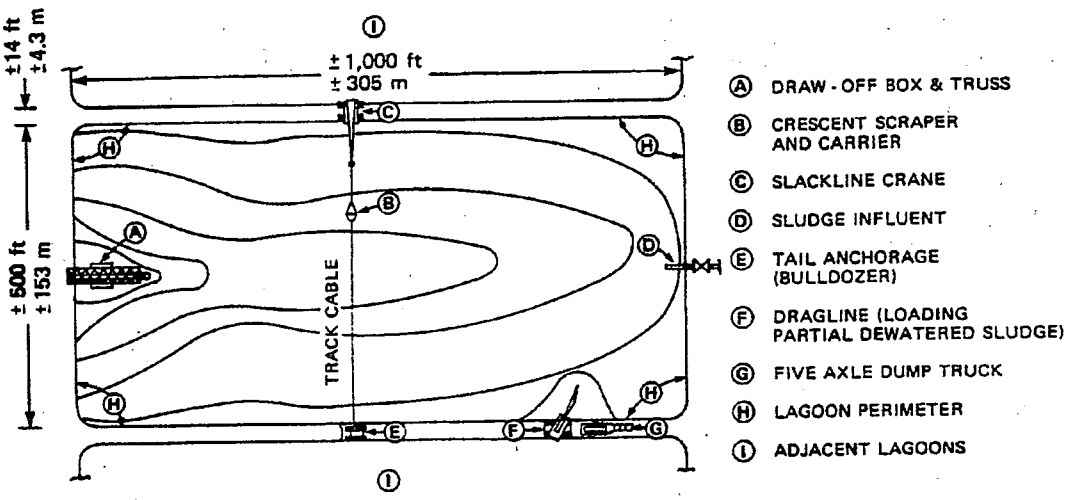


Figure 7-18. Plan view of drying sludge lagoon near west-southwest sewage treatment works, Chicago (U.S. EPA, 1979).

- Evaporation rate (annual average, range, and seasonal fluctuations).
- Temperature extremes.

- *Subsoil Permeability.* The subsoil should have a moderate permeability of 1.6×10^{-4} to 5.5×10^{-4} in. per second (4.2×10^{-4} to 1.4×10^{-3} cm/s).
- *Sludge Characteristics.* The type of sludge to be placed in the lagoon can significantly affect the amount and type of odor and vector problems that can be produced. It is recommended that only anaerobically digested sludges be used in drying lagoons.
- *Lagoon Depth and Area.* The actual depth and area requirements for sludge drying lagoons depend on several factors such as precipitation, evaporation, type of sludge, volume and solids concentration. Solids loading criteria have been given as 2.2 to 2.4 lb of solids per year per cu ft (36 to 39 kg/m^3) of capacity. A minimum of two separate lagoons are provided to ensure availability of storage space during cleaning, maintenance, or emergency conditions.
- *General Guidance.* Lagoons may be of any shape, but a rectangular shape facilitates rapid sludge removal. Lagoon dikes should have a slope of 1:3, vertical to horizontal, and should be of a shape and size to facilitate maintenance, mowing, passage of maintenance vehicles atop the dike, and access for the entry of trucks and front-end loaders into the lagoon. Surrounding areas should be graded to prevent surface water from entering the lagoon. Return must exist for removing the surface liquid and piping to the treatment plant. Provisions must also be made for limiting public access to the sludge lagoons.

Design criteria for drying lagoons are presented in Table 7-7; Table 7-8 lists advantages and disadvantages of sludge drying lagoons.

7.5.4 Design of Piles and Mounds

Piles and mounds are sites where dewatered sludge is placed on part of the POTW property as final disposal. In general, piles and mounds are suitable only for stabilized sludges with a high chemical content (greater than 40 percent lime plus some ferric) or a very low organic content (less than 50 percent solids), or for highly stabilized lagoon sludges. Piles of mechanically dewatered sludge with less than 25 percent solids usually lose all semblance of stability when exposed to extensive rainfall (U.S. EPA, 1979).

As surface disposal facilities, piles and mounds are subject to the requirements of the Part 503 rule (e.g., requirements for pathogen control, vector attraction reduction, pollutant limits, siting, restriction of public access, runoff collection, and ground-water protection). To protect ground water, it is recommended that piles and mounds be located on an impervious surface (U.S. EPA, 1990). Many states also have regulations regarding sludge stockpiles. Check with your state for any specific state requirements for sludge stockpiles.

7.5.5 Slope Stability and Dike Integrity

Certain types of monofills (area fills) and surface impoundments are constructed above natural grade through the use of earthen dikes, excavated below grade slopes constructed around the unit, or some combination of dikes and excavation, depending on site topography. These excavated slopes and earthen dikes are vulnerable to stability failures via several mechanisms. Slope and dike failures can seriously damage a liner system, allowing releases of leachate to surrounding soils and ground water.

For these reasons, earthen dikes must be carefully designed, and excavated slopes must be carefully evaluated to ensure that they are sufficiently stable to

Table 7-7. Design Criteria for Drying Lagoons (Lue-Hing et al., 1992)

	Design Parameter
a. Solids loading rate	
Primary sludge	96.1 kg/m^3/year
—(lagoon as a digester)	(6 lbs/ft^3/year)
Digested sludge	35-38 kg/m^3/year
—(lagoon for dewatering)	(2.2-2.4 lbs/ft^3/d)
b. Area required	
Primary sludge	0.0929 m^2/capita
(dry climate)	(1 ft^2/capita)
Activated sludge	0.31586 m^2/capita
(wet climate)	(3.4 ft^2/capita)
c. Dike height	60 cm (2 ft)
d. Sludge depth after decanting—depths of 60 cm to 1.2 m (2-4 ft) have been used in very warm climates	38 cm (15 in.)
e. Drying time for depth of 38 cm (15 in) or less	3 to 5 months

Table 7-8. Advantages and Disadvantages of Using Sludge Drying Lagoons (U.S. EPA, 1979)

Advantages	Disadvantages
Lagoons are low energy consumers	Lagoons may be a source of periodic odor problems, and these odors may be difficult to control
Lagoons consume no chemicals	There is a potential for pollution of groundwater or nearby surface water
Lagoons are not sensitive to sludge variability	Lagoons can create vector problems (for example, flies and mosquitos)
The lagoons can serve as a buffer in the sludge handling flow stream. Shock loadings due to treatment plant upsets can be discharged to the lagoons with minimal impact	Lagoons are more visible to the general public
Organic matter is further stabilized	Lagoons are more land-intensive than fully mechanical methods
Of all the dewatering systems available, lagoons require the least amount of operation attention and skill	Rational engineering design data are lacking to allow sound engineering economic analysis
If land is available, lagoons have a very low capital cost	

withstand the loading and hydraulic conditions to which they will be subjected during the unit's construction, operation, and post-closure periods. This section describes how to design and evaluate dikes and slopes for stability. For more information on slope stability and dike integrity at land disposal facilities, including information on materials specifications and embankment construction, the reader is referred to references U.S. EPA, 1988a, and U.S. EPA 1993a.

7.5.5.1 Slope Stability Failure

Slope stability failures occur when sliding forces from the weight of the soil mass itself and external forces including sludge pressures exceed the resisting forces from the strength of the soil and from any reinforcing structures. Slope stability analysis consists of a comparison of these resisting forces (or moments) to the sliding forces (or moments) to obtain a factor of safety (FS). Generally, the FS takes the following form (Sowers, 1979):

$$FS = \frac{\text{Sum of resisting moments}}{\text{Sum of sliding moments}}$$

When a stability analysis is performed, a slope is analyzed for one or more of several potential modes of failure. A safety factor is obtained for each mode, the lowest FS being the most critical.

Table 7-9 lists the EPA-recommended minimum factors of safety for slope stability analyses. If a dike or excavated slope design analysis yields lower safety factors, then steps should be taken to reduce the sliding forces or increase the resisting forces, or the slope should be redesigned to produce a safer structure.

Slope stability failures usually occur in one of three major modes, depending on the site soils, slope configuration, and hydraulic conditions (U.S. Dept. of the Navy, 1982). These three major failure modes are the following:

- Rotation on a curved slip surface approximated by a circular arc.
- Translation on a planar surface that is large compared to the depth below ground.
- Displacement of a wedge-shaped mass along one or more planes of weakness in the slope.

Figure 7-19 illustrates basic concepts of rotational and translational failures.

In addition to the three major failure modes, dikes and excavated slopes are also vulnerable to failure due to differential settlement, seismic effects including liquefaction, and seepage-induced piping failure. Safety factors are determined in a manner similar to those for the three major failure modes. These failure modes are discussed in greater detail below.

7.5.5.2 Stability Analyses

A stability analyses should consider (U.S. EPA, 1988a):

- The adequacy of the subsurface exploration program.
- The stability of the dike slopes and foundation soils.
- Liquefaction potential of the soils in the dike and the foundation.
- The expected behavior of the dike when subjected to seismic effects.
- Potential for seepage-induced piping failure.
- Differential settlements in the dike.

Subsurface Exploration Program

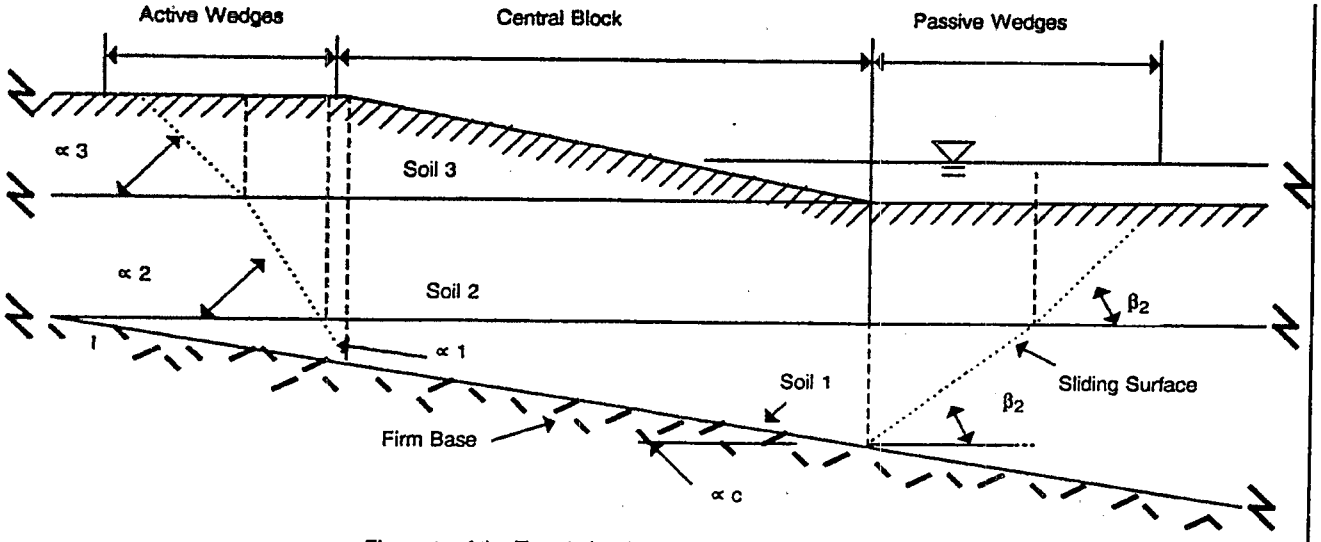
As discussed in Section 7.5.1, field investigations are necessary to evaluate the foundation for a constructed dike, to evaluate dike materials obtained from a borrow area, and to evaluate a slope excavated below ground. Of particular importance in some circumstances are laboratory strength tests performed on soil samples to

Table 7-9. Recommended Minimum Values of Factor of Safety for Slope Stability Analyses (U.S. EPA, 1988a)

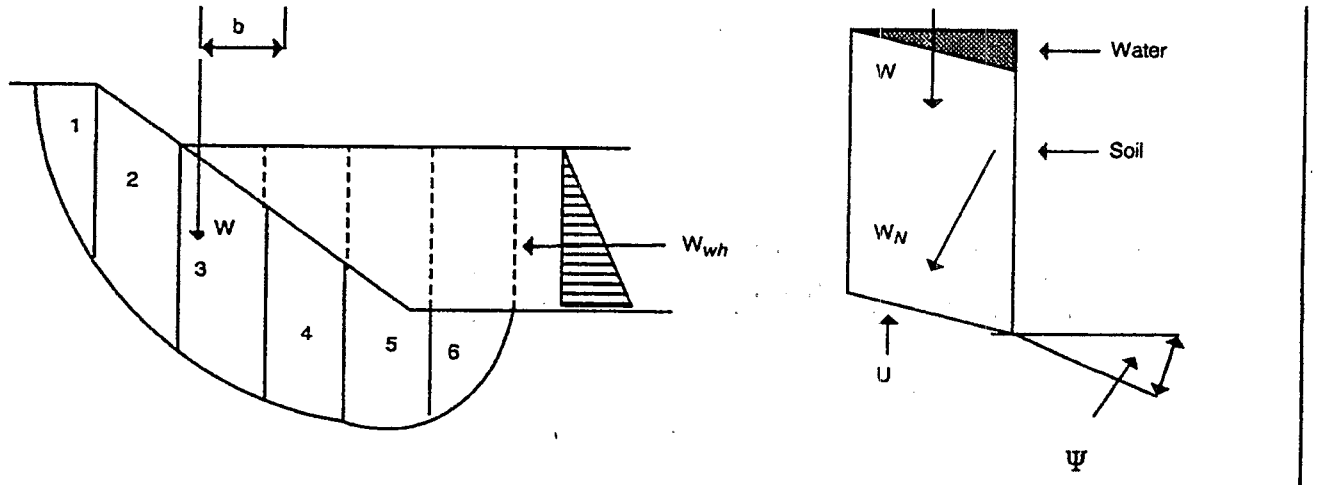
Consequences of Slope Failure	Uncertainty of Strength Measurements	
	Small[1]	Large[2]
No imminent danger to human life or major environmental impact if slope fails	1.25 (1.2)*	1.5 (1.3)
Imminent danger to human life or major environmental impact if slope fails	1.5 (1.3)	2.0 or greater (1.7 or greater)

1. The uncertainty of the strength measurements is smallest when the soil conditions are uniform and high quality strength test data provide a consistent, complete, and logical picture of the strength characteristics.
2. The uncertainty of the strength measurements is greatest when the soil conditions are complex and when available strength data do not provide a consistent, complete, or logical picture of the strength characteristics.

* Numbers without parentheses apply for static conditions and those within parentheses apply to seismic conditions.



Elements of the Translational (Wedge) Slope Stability Analysis
(Reference 4, p. 42)



a. Circular segment divided into slices

b. Forces acting on slice 3

Method of Slices for Circular Arc Analysis of Slopes in Soils Whose Strength Depends on Stress (Reference 3, p. 578)

Figure 7-19. Conceptual slope failure models (U,S. EPA, 1988a).

determine the strength of the foundation and embankment soils under the expected conditions of saturation and consolidation (see Chapter 6).

Field and laboratory data are used to obtain a detailed characterization of the site with respect to the engineering properties of the soils and rock. These engineering properties provide the input data for evaluation of the stability of slopes. Slope stability analysis requires the establishment of various site conditions including (U.S. EPA, 1988a):

- The soil shear strength conditions that represent actual site conditions.
- The steady-state hydraulic boundary conditions occurring through the site's section.
- The seismic conditions established for the site area.

For slope stability analyses, the most critical soil parameter is that of shear strength (U.S. EPA, 1988a). The shear strength of a soil is a measure of the amount of stress that is required to produce failure in plane of a cross section of the soil structure. The shear strength of a soil must be known before an earthen structure can be designed and built with assurance that the slopes will not fail (U.S. EPA, 1986b). To adequately determine a soil's shear strength, the potential effect of pore water pressures from the expected site loading conditions must be considered during testing.

While laboratory soil strength testing data is highly desirable, these tests are limited to small-size samples, and in many locations dikes are constructed using material that contains large particle sizes. Furthermore, in existing dikes, the type of material may make the obtaining of undisturbed soil samples nearly impossible. Therefore, it is not uncommon in standard engineering practice to estimate or assume these parameters based on the best data available. While it is acceptable to do this, it must be done and evaluated by a qualified geotechnical engineer (U.S. EPA, 1988a).

Slope stability also is dependent on hydraulic conditions in the slope. Potential hydrostatic or seepage forces from large hydraulic gradients should be identified and considered during the stability analyses. Ground-water levels and hydraulic analyses are used to determine the configuration of the steady-state piezometric surface through sections of the foundation and/or the dike structure. For sections involving a steep piezometric surface or an upstream static or flood pool, hydraulic analyses also determine seepage quantity, critical (highest) exit gradient, and potential for uplift of a clay liner due to excess pore pressures produced by a confined seepage condition (U.S. EPA, 1986b).

Hydraulic boundary conditions may reflect unconfirmed, steady-state seepage conditions, or confined seepage conditions involving an impermeable barrier (soil liner) and excess pore pressure on the barrier. The hydraulic conditions of a slope are determined using seepage analysis, as discussed by Freeze and Cherry (1979).

Slope Stability

Slope stability analyses are performed for both excavated side slopes and aboveground embankments. Three analyses will typically be performed as appropriate to verify the structural integrity of a cut slope or dike; they are (U.S. EPA, 1988a):

- Slope stability
- Settlement
- Liquefaction

Table 7-10 indicates the minimum required soil parameter data usually needed to perform these analyses.

The slope stability is typically evaluated using either a rotational (slip circle) analysis and/or a translational (sliding block or wedge) analysis using a computer model. These analyses are run for both static and dynamic (seismic) conditions. For large dikes in areas of major earthquakes, a more rigorous method of dynamic analysis may be warranted.

Analyses to establish total and differential settlement are also performed to ensure that the estimated settlement will not adversely affect the integrity of the unit and its components.

The liquefaction analysis determines the potential for liquefaction of the dike and foundation soils to occur during seismic events.

Rotational Slope Stability Analysis. A rotational slope stability analysis is typically performed using a method that divides the slope into discrete slices and sums all driving and resisting forces on each slice (see Figure 7-19). For each trial arc, the section is subdivided into vertical slices, each having its base coincident with a portion of the trial arc. Slices are defined according to the section geometry such that the base of each slice comprises only one soil type. The driving and resisting forces acting on each slice are then used to compute driving and resisting moments about the center of rotation of a circular section of the slope. The overturning and resisting moments for each slice are then summed and the FS is computed (U.S. EPA, 1986b).

Translational Slope Stability Analysis. The major features of the translational analysis are the same as those for the rotational case except that the trial surface consists of straight line segments that form the base of one or more active (thrusting) wedges, a neutral or thrusting central block, and one or more passive (restraining) wedges (see Figure 7-19). This analysis is based upon selection of a trial central block defined by the surface and subsurface soil layer geometry, followed by compu-

Table 7-10. Minimum Data Requirements for Stability Analysis Options (U.S. EPA, 1988a)

Soil Parameter	Units	Stability Analysis Options			
		Rotational	Translational	Settlement	Liquefaction
1. Cohesion* (UU, CU, CD cases)	pounds/sq.ft. (psf)	X	X		X CD
2. Angle of internal friction* (UU, CU, C cases)	degrees	X	X		
3. Total (wet) unit weight	pounds/cu. ft. (pcf)	X	X	X	X
4. Clay content	percent (0 to 100)				X
5. Overconsolidation ratio	unitless (decimal)			X	
6. Initial void ratio	unitless (decimal)			X	
7. Compression index	unitless (decimal)			X	
8. Recompression index	unitless (decimal)			X	
9. Hydraulic conductivity** (permeability, k)	ft/yr				
10. Median grain size	mm				X
11. Plasticity index (PI)	percent (0 to 100)				X
12. Liquid limit (LL)	percent (0 to 100)				X
13. Standard penetration number (N)	unitless (integer)				X

* Required strength case dependent upon hydraulic boundary condition selected
** Used only in hydraulic analysis

tation of the coordinates for the associated active and passive wedges (U.S. EPA, 1986c).

Settlement Analysis. Settlement analysis is used to determine the compression of foundation soils due to stresses caused by the weight of an overlying dike. Required parameters for each soil include unit weight, initial void ratio, compression and recompression indices, and the over-consolidation ratio (U.S. EPA, 1986c). Settlements are calculated at the toes, crest points, and centerline of the dike. The consolidation of each soil is calculated for each layer and summed up for all soils to determine the total settlement at each point. Differential settlements are calculated between each toe and crest, toe and centerline, and crest and centerline on both sides of the dike. Recommended maximum differential settlements can be found in EPA, 1986c.

Liquefaction Analysis. Factors that most influence liquefaction potential are soil type, relative density, initial confining pressure, and the intensity and duration of earthquake motion (U.S. EPA, 1986c). Methods for estimating the potential for liquefaction are provided in a computer software package called Geotechnical Analysis for Review of Dike Stability (GARDS) that has been developed by EPA's Risk Reduction Engineering Laboratory (RREL) to assist permit writers and designers in evaluating earth dike stability. GARDS details the basic technical concepts and operational procedures for the analysis of site hydraulic conditions, dike slope and foundation stability, dike settlement, and liquefaction potential of dike and foundation soils. It is designed to meet the expressed need for a geotechnical support tool to facilitate evaluation of existing and proposed dike structures at hazardous waste sites.

For additional information on seismic risk zones of the United States, the range of seismic parameters for source zones, and GARDS, the reader is referred to EPA, 1986c.

7.5.5.3 Slope Stability Design Plans

The design plans for dikes and cut slopes should show the design layout, cross sections portraying the proposed grade and bearing elevations relative to the existing grade, and details of the dikes or cut slopes, including all slope angles and dimensions. Materials present at the cut slope or to be used to construct the dike must be adequately characterized (see EPA, 1986b). This design configuration then must be evaluated for its stability under all potential hydraulic and loading conditions. If the stability analyses result in unacceptably low factors of safety, then the design must be modified to stabilize the slope. The revised design must then be evaluated to verify that it is sufficiently stable.

In addition, in a monofill or surface impoundment, often the cut slopes or dikes will not be identical around the entire perimeter of the unit. For this reason, it is important that the most critical slope or dike section be identified for analysis. Generally, the most critical section will be the steepest and/or the highest portion of the slope or dike. Particularly in a cut slope, however, the in situ materials may vary enough that the more critical slope may be shallower or flatter, but may be composed of weaker soils or may be subject to significant pore pressures or seepage from high ground-water levels.

7.5.6 Liner Systems

Current regulations for sewage sludge surface disposal sites (Part 503, Subpart C) do not require that land

disposal facilities be constructed with liner systems. Twenty-eight states and Puerto Rico, however, do specify some requirement for liners at sludge landfills (U.S. EPA, 1990). Under the Part 503 regulation, where there is a liner, the owner/operator of a surface disposal site must maintain and operate a leachate collection system (see Section 7.2.1). This section provides criteria for the design and construction of liner systems and reviews liner system designs on a component-by-component basis. An extensive body of literature has been developed on the design of liners and leachate collection systems. For additional information on these systems, including information on materials specifications, construction procedures, and quality control issues, see the references U.S. EPA, 1988a, and U.S. EPA, 1993b.

There are two types of liner systems currently used in land disposal facilities. A single liner system consists of one liner and one leachate collection system as shown in Figure 7-20. A double liner system includes two liners (primary and secondary), with a primary leachate collection system above the primary (top) liner and a secondary leak detection/leachate collection system between the two liners, as shown in Figure 7-21.

The term "liner system" includes the liner(s), leak detection/leachate collection system(s), and any special additional structural components such as filter layers or reinforcement. The major components of both single and double liner systems are the following:

- Low-permeability soil liners
- Flexible membrane liners (FML)
- Leachate collection and removal systems (LCRS)

7.5.6.1 Low-Permeability Soil Liners

Low-permeability soil liner design is site- and material-specific. Prior to design, many fundamental yet important criteria should be considered such as: in-place permeability of the liner; liner stability against slope failure, settlement, and bottom heave; and the long-term integrity of the liner.

Important criteria to consider when reviewing a design for a soil liner include (U.S. EPA, 1988a):

- Liner site and material selection
- Hydraulic conductivity
- Liner thickness
- Strength and bearing capacity
- Slope stability and controls for liner failure

These design considerations are important throughout the installation and construction phases of a clay liner.

Site and Material Selection

A site investigation should be conducted prior to the design phase, and the following factors should be considered (see Chapter 6):

- Site geology
- Topography (especially drainage patterns)
- Analyses of soil properties
- Field and laboratory hydraulic conductivity
- Bedrock characteristics
- Hydrology
- Climate

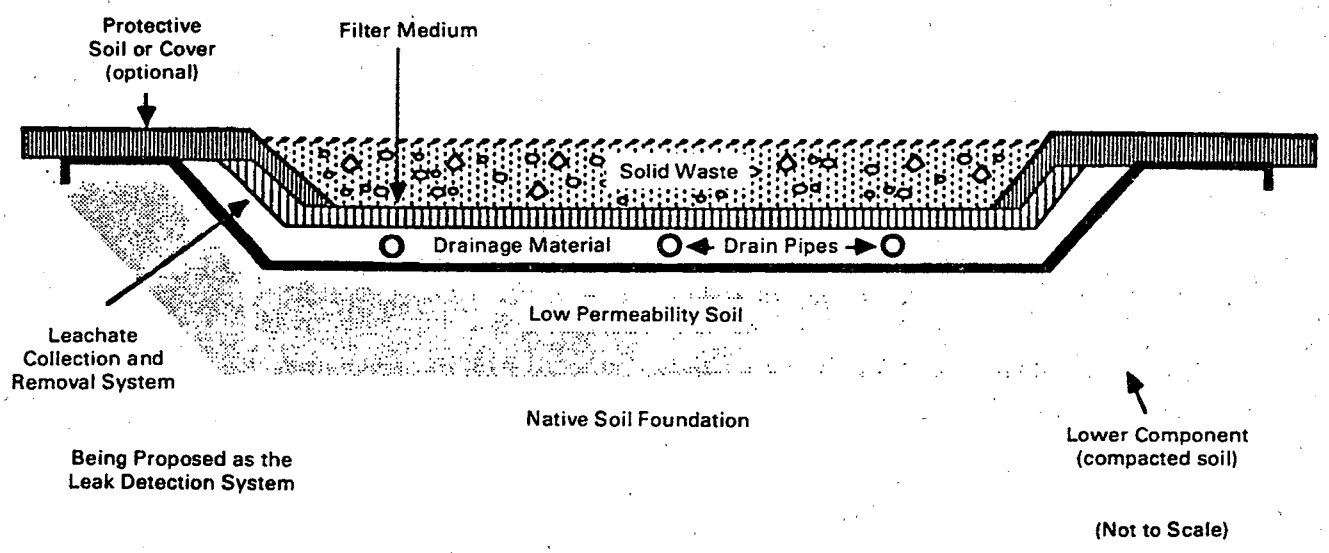


Figure 7-20. Schematic of a single clay liner system for a landfill (U.S. EPA, 1988a).

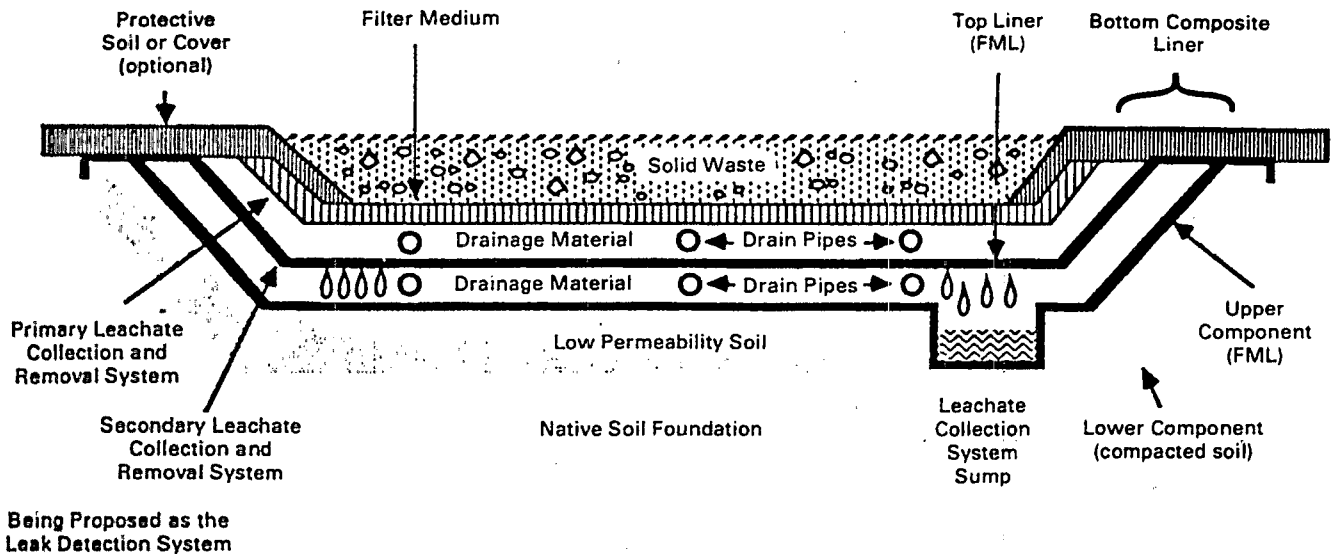


Figure 7-21. Schematic of a double liner and leak detection system for a landfill (U.S. EPA, 1988a).

All these factors are important to the design of the soil liner. The site will require a foundation designed to control settlement and seepage and to provide structural support for the liner (see Section 7.5.1). If satisfactory contact between the liner and the natural foundation is achieved, settlement and cracking will be minimized (U.S. EPA, 1988a).

Soil liners for sewage sludge disposal units must meet the following requirements:

- A field hydraulic conductivity of 1×10^{-7} cm/sec when compacted.
- Sufficient strength after compaction to support itself and the overlying materials without failure.

Soil liner material may originate at the site or may be hauled in from a nearby borrow site if the native soil is not suitable. If the available soils do not achieve the specified hydraulic conductivity, it may be necessary to introduce a soil additive to increase the performance potential of the selected material. The most common additive used to amend soils is sodium bentonite (U.S. EPA, 1993b). Although soil additives are known to decrease hydraulic conductivity, it is important to test additives under actual field conditions as with any potential soil liner material (U.S. EPA, 1987b). For additional information on soil additives, see U.S. EPA, 1993b.

Because physical properties differ from one soil to the next, testing procedures are necessary to assist in the selection of liner material. Once potential soil sources have been identified, it is necessary to begin testing to eliminate undesirable soils or to determine whether the source requires an amendment. Many procedures have been standardized for soil testing by organizations such as the American Society of Testing and Materials (ASTM) and by individuals currently researching clay soils for use in soil liner construction (ASTM, 1987; U.S. EPA, 1986d).

Representative samples of the proposed material must be subjected to laboratory testing. This will establish the properties of the material with respect to water content, density, compactive effort, and hydraulic conductivity. Clay soils exhibit characteristic changes when compacted; therefore, all analyses of a potential material must be performed on a compacted sample. Table 7-11 provides a listing of pertinent soil tests and methods (U.S. EPA, 1986d).

Thickness

Two feet of soil is generally considered the minimum thickness needed to obtain adequate compaction to met the hydraulic conductivity requirement (U.S. EPA, 1993b). Liners are designed to be of uniform thickness over the entire facility. The 2-ft minimum thickness is believed to be sufficient to inhibit hydraulic short-circuiting of the entire layer (U.S. EPA, 1993b). Thicker areas may be encountered wherever there may be recessed areas for leachate collection pipes or collection sumps. Some engineers suggest extra thickness and compactive effort for the edges of the sidewalls to adequately tie them together with the liner itself. In smaller facilities, a soil liner may be designed for installation over the entire area, but in larger or multicell facilities, liners are designed in segments. If this is the case, it will be necessary to specify in the design a beveled or step-cut joint between segments to ensure that the segments properly adhere together (U.S. EPA, 1988b).

Hydraulic Conductivity

The coefficient of permeability or hydraulic conductivity expresses the ease with which water passes through a soil. Achieving the hydraulic conductivity standard

Table 7-11. Methods for Testing Low-Permeability Soil Liners (U.S. EPA, 1988a)

Parameter to be Analyzed	Methods	Test Method Reference
Soil type	Visual-manual procedure	ASTM D2488
	Particle size analysis	ASTM D422
	Atterberg limits	ASTM D4318
	Soil classification	ASTM D2487
Moisture content	Oven-dry method	ASTM D2216
	Nuclear method	ASTM D3017
	Calcium carbide (speedy)	AASHTO T217
In-place density	Nuclear methods	ASTM D2922
	Sand cone	ASTM D1556
	Rubber balloon	ASTM D2167
	Drive cylinder	ASTM D2937
Moisture-density relations	Standard effort	ASTM D698
	Modified effort	ASTM D1557
Strength	Unconfined compressive strength	ASTM D2166
	Triaxial compression	ASTM D2850
Cohesive soil consistency (field)	Penetration tests	ASTM D3441
	Field vane shear test	ASTM D2573
	Hand penetrometer	Horslev, 1943
Hydraulic conductivity (laboratory)	Fixed-wall double ring permeameter	EPA, 1983 SW-870 Anderson et. al., 1984
	Flexible wall permeameter	Daniel et al., 1985 SW-846 Method 9100 (EPA, 1984)
Hydraulic Conductivity (field)	Sealed Double-Ring Infiltrometer	Day and Daniel, 1985
	Sai-Anderson-Gill double-ring Infiltrometer	Anderson et al., 1984

(1×10^{-7} cm/sec) depends on the degree of compaction, compaction method, type of clay, soil moisture content, and density of the soil during liner construction (U.S. EPA, 1993b). Hydraulic conductivity is the most critical design criterion for a potential soil liner (U.S. EPA, 1988a). The hydraulic conductivity of a soil depends in part on the viscosity and density of fluid flowing through it. The hydraulic conductivity of a partially saturated soil will be less than the hydraulic conductivity of the same soil when saturated. Because invading water only flows through water-filled voids (and not air-filled voids), the dryness of a soil tends to lower its permeability (U.S. EPA, 1993b).

When designing a soil liner, field hydraulic conductivity is the most important factor to consider. Hydraulic conductivity testing should be conducted on samples that are fully saturated to attempt to measure the highest possible hydraulic conductivity (U.S. EPA, 1993b).

Strength and Bearing Capacity

Another important criterion to consider when designing a soil liner is the strength and bearing capacity of the liner material. Analysis of these parameters will determine the stability of the liner material. More detailed discussions of bearing capacity and strength can be found in Section 7.5.1.3.

Slope Stability

The strength of a soil also controls its resistance to sliding. Failure of a liner slope can result in slippage of the compacted soil liner along the excavated slope. Therefore, analysis of slope stability must be considered in the design of a soil liner (see Section 7.5.5).

7.5.6.2 Flexible Membrane Liners (FMLs)

The design of a lined sewage sludge surface disposal site requires consideration of more than the performance requirements of the FML; it also requires careful design of the foundation supporting the FML (see Section 7.5.1). The foundation provides support for the liner system, including the FMLs and the leachate collection and removal systems. If the foundation is not structurally stable, the liner system may deform, thus restricting or preventing its proper performance.

Performance Requirements of the FML

The performance requirements of an FML include (U.S. EPA, 1988a):

- Low permeability to waste constituents
- Strength or mechanical compatibility of the sheeting
- Durability for the lifetime of the facility

The designer must specify the necessary criteria for each of these properties based on engineering requirements, performance requirements, and the specific site conditions. In addition, the FML design must be compatible with the present technology used in the installation of FMLs (U.S. EPA, 1988c).

These performance requirements are assessed through laboratory and pilot-scale testing of the various properties of FML sheeting (U.S. EPA, 1988c). The analyses and tests that are performed on FML sheeting measure its inherent analytical properties, physical properties, permeability characteristics, environmental and aging properties, and performance properties (U.S. EPA, 1988c). Testing is essential to the designer/engineer who uses the data to determine whether a specific FML sheeting will meet the design requirements of the waste facility. These tests are discussed in detail in the references U.S. EPA, 1983a, and U.S. EPA, 1988c.

Permeability

The primary function of a liner system in a sewage sludge surface disposal site is to minimize and control the flow of leachate from the site to the environment, particularly the ground water. A properly designed FML has a low permeability to the sewage sludge contained within the liner, allowing it to perform its primary function.

Mechanical Compatibility

An FML must be mechanically compatible with the designed use of the lined facility in order to maintain its integrity during and after exposure to short-term and long-term mechanical stresses. Short-term mechanical stresses can include equipment traffic during the installation of a liner system, as well as thermal expansion and shrinkage of the FML during operation of the unit. Long-term mechanical stresses usually result from the placement of sewage sludge on top of the liner system or from differential settlement of the subgrade (U.S. EPA, 1988c).

Mechanical compatibility requires adequate friction between the components of a liner system, particularly the soil subgrade and the FML, to ensure that slippage or sloughing does not occur on the slopes of the unit. Specifically, the foundation slopes and the subgrade materials must be considered in design equations in order to evaluate (U.S. EPA, 1988c):

- The ability of an FML to support its own weight on the side slopes.
- The ability of an FML to withstand downdragging during and after filling.
- The best anchorage configuration for the FML.
- The stability of a soil cover on top of an FML.

Durability

An FML must exhibit durability; that is, it must be able to maintain its integrity and performance characteristics over the operational life and the post-closure care period of the unit. The service life of an FML is dependent on the intrinsic durability of the FML material and on the conditions to which it is exposed (U.S. EPA, 1988c; EPA, 1987a; EPA, 1987b).

Selection of the FML

The performance requirements determined by a designer/engineer serve as the basis for the selection of an FML for a given facility. Based upon the designed use of the unit, the designer must make decisions on the composition, thickness, and construction (fabric-reinforced or unreinforced) of an FML. Mechanical compatibility and sometimes permeability determine the thickness of the FML sheeting. It should be noted that liner performance does not correlate directly with any one property (e.g., tensile strength) and that specifications that appear in specific technical resource documents such as the reference EPA, 1988c, should not be used alone as the basis for selection of an FML.

FMLs are made of polymeric materials, particularly plastics and synthetic rubbers. There are four general types of polymeric materials used in the manufacture of FML sheeting (U.S. EPA, 1988c):

- Thermoplastics and resins, such as PVC and EVA
- Semicrystalline plastics, such as polyethylenes

The various polymers are used to make a variety of liners that can be classified by production process and reinforcement. Table 7-12 lists the polymers currently used in lining materials (U.S. EPA 1988c).

The polymers used in FMLs have different physical and chemical properties, and they also differ in method of installation and seaming as well as costs. The reference U.S. EPA, 1988c, provides detailed information about the composition and properties of each of these polymers.

Seaming of FML Sheeting

The construction of a continuous watertight FML is critical to the containment of leachate and is heavily dependent on the construction of the seams bonding the sheeting together. The seams are the most likely source of failure in an FML. Sheeting is seamed together both in the factory and in the field. Sheeting manufactured in relatively narrow widths (less than 90 in.) is seamed together to fabricate panels. These factory seams are made in a controlled environment and are generally of high quality. Both fabricated panels and sheeting of wider widths (21 to 64 ft) are seamed on site during the installation of the FML. The quality of field seams is difficult to maintain since the installer must deal with changing weather conditions, including temperature, wind, and precipitation, as well as construction site conditions, which include unclean work areas and working on slopes. Constant inspection under a construction quality assurance plan is necessary to ensure the integrity of field seams (U.S. EPA, 1988c).

Several bonding systems are available for the construction of factory and field seams in FMLs. Bonding systems include solvent methods, heat seals, heat guns, dielectric seaming, extrusion welding, and hot wedge techniques. The selection of a bonding system for a particular FML is dependent primarily on the polymer making up the sheeting (U.S. EPA, 1988a).

7.5.7 Leachate Collection and Removal Systems (LCRSs)

Leachate refers to liquid that has passed through or emerged from sewage sludge and contains dissolved, suspended, or immiscible materials removed from the

Table 7-12. Polymers Currently Used in FMLs for Waste Management Facilities (U.S. EPA, 1988c)

Polymer	Type of compound used in liners		Fabric reinforcement	
	Thermoplastic	Cross-linked	With	Without
Chlorinated polyethylene (CPE)	Yes	Yes	Yes	Yes
Chlorosulfonated polyethylene (CSPE)	Yes	Yes	Yes	No
Elasticized polyvinyl chloride (PVC-E)	Yes	No	Yes	No
Polyester elastomer (PEL)	Yes	No	Yes	Yes
Polyethylene (LDPE, LLDPE, HDPE)	Yes	No	No	Yes
Polyvinyl chloride (PVC)	Yes	No	Yes	Yes

sewage sludge. The primary function of the leachate collection system is to collect and convey leachate out of the surface disposal unit and to control the depth of the leachate above the liner (U.S. EPA, 1993b). Leachate is generally collected from the surface disposal unit through sand drainage layers, synthetic drainage nets, or granular drainage layers with perforated plastic collection pipes, and is then removed through sumps or gravity drain carrier pipes. An LCRS should consist of the following components (U.S. EPA, 1988a):

- A low-permeability base that is either a soil liner, composite liner, or flexible membrane liner (FML).
- A high-permeability drainage layer constructed of either natural granular materials (sand and gravel) or synthetic drainage material (geonet) that is placed directly on the primary and/or secondary liner or its protective bedding layer.
- Perforated leachate collection pipes within the high-permeability drainage layer to collect leachate and carry it rapidly to the sump.
- A protective filter material surrounding the pipes, if necessary, to prevent physical clogging of the pipes or perforations.
- A leachate collection sump or sumps, where leachate can be removed.
- A protective filter layer over the high-permeability drainage material that prevents physical clogging of the material.
- A final protective layer of material that provides a wearing surface for traffic and landfill operations.

The design features of each of these components and operation of the entire LCRS is summarized below. For more detailed information, see the references U.S. EPA, 1993b, and U.S. EPA, 1988a.

7.5.7.1 Grading and Drainage

For leachate to be effectively collected and removed, liner systems must be sloped to drain toward their respective collection sumps. The recommended bottom liner slope is 2 percent at all points in each system (U.S. EPA, 1987b). This slope is necessary for effective leachate drainage through the entire operating and post-closure period; therefore, these slopes must be maintained under operational and post-closure loadings. The settlement estimates performed as discussed in Section 7.5.1 must be evaluated to ensure that the slopes will be 2 percent throughout the period of operation of the LCRS. It may be necessary to initially design the slopes steeper than 2 percent to allow for settlement (U.S. EPA, 1988a).

Good engineering practice requires that the design, construction, and operation of the LCRS should maintain a maximum height of leachate above the composite liner of 30 cm (12 in.). Design guidance for calculating the maximum leachate depth over a liner for granular drainage system materials is provided in U.S. EPA, 1989.

Granular Drainage Layers and Geosynthetic Drainage Layer-Geonets

The high-permeability drainage layer is placed directly over the liner or the protective bedding layers. Often the selection of a drainage material is based on the onsite availability of natural granular materials. Since hauling costs are high for sand and gravel, a facility may elect to use geonets or synthetic drainage materials as an alternative. Frequently, geonets are substituted for granular materials on steep sidewalls in order to provide a layer that is more stable with respect to sliding than a granular layer.

Geonets may be substituted for the granular layers in either of the LCRSs on the bottoms and sidewalls of the landfill cells. Geonets may be used if their characteristics are in keeping with design, including chemical compatibility, flow under load, clogging resistance, and protection of the FML (U.S. EPA, 1987c).

Piping

The design of piping systems requires the consideration of pipe flow capacity and structural strength. The spacing of leachate collection pipes can be determined based on the maximum allowable leachate head on the liner. This maximum head calculation assumes that liquids can drain away freely through the piping systems; therefore, the pipes must be sized to carry the expected flow (U.S. EPA, 1988a).

The leachate piping configuration shown on facility design drawings should be evaluated for its ability to maintain the maximum leachate head and for its ability to carry the expected flows.

Sumps, located in a recess at the low point(s) within the leachate collection drainage layer, provide one method for leachate removal from a surface disposal unit. These sumps typically house a submersible pump, which is positioned close to the sump floor to pump the leachate and to maintain a 30 cm (12 in.) maximum leachate depth. Pumps used to remove leachate from sumps should be sized to ensure removal of leachate at the maximum rate of generation. These pumps also should have a sufficient operating capacity to lift the leachate to the required height from the sump to the access port. Portable vacuum pumps can be used if the required lift height is within the limit of the pump. They can be moved in sequence from one leachate sump to another. The type of pump specified and the leachate sump access pipes should be compatible and should consider performance needs under operating and closure conditions (U.S. EPA, 1988a).

Alternative methods of leachate removal include internal standpipes and pipe penetrations through the geomembrane, both of which allow leachate removal by gravity flow to either a leachate pond or exterior pump station. If a leachate removal standpipe is used, it should be extended through the entire surface disposal unit from liner to cover and then through the cover itself. If a gravity drainage pipe that requires geomembrane penetration is used, a high degree of care should be exercised in both the design and construction of the penetration so that it allows nondestructive quality control testing of 100% of the seal between the pipe and the geomembrane. If not properly constructed and fabricated, geomembrane penetrations can cause leakage through the geomembrane (U.S. EPA, 1993b).

The HELP Model

EPA has developed a computer program called the Hydrologic Evaluation of Landfill Performance (HELP), which is a quasi-two-dimensional hydrologic model of water movement across, into, through, and out of landfills. The model uses climatologic, soil, and landfill design data and incorporates a solution technique that accounts for the effects of surface storage runoff, infiltration, percolation, evapotranspiration, soil moisture storage, and lateral drainage. The program estimates runoff drainage and leachate expected to result from a wide variety of landfill conditions, including open, partially open, and closed landfill cells. Most importantly, in consideration of this topic, the model can be used to estimate the buildup of leachate above the bottom liner of the landfill. The HELP program can be used to estimate the depth of leachate above the bottom liner for a variety of landfill designs, time averages, and storm events. The results may be used to compare designs or to design leachate drainage and collection systems. References U.S. EPA, 1984a, and U.S. EPA, 1984b, a user's guide and model documentation, respectively, should be obtained before attempting to run the HELP model. Version 3.0 of the HELP model became available during the fall of 1993. To obtain a copy, call EPA's Office of Research and Development (ORD) in Cincinnati at 513-569-7871.

7.5.7.2 System Strength

All components of the LCRS must have sufficient strength to support the weight of the overlying sewage sludge, cover system, and post-closure loadings, as well as stresses from operating equipment and from the weight of the components themselves. LCRs are also vulnerable to sliding under their own weight and the weight of equipment operating on the slopes. The components that are most vulnerable to strength failures are the drainage layers and piping. LCRS piping can fail by excessive deflection leading to buckling or collapsing.

Sidewall Stability

For liner systems placed on excavated sidewalls, the issue of the stability of the individual liner components on the slope, including the LCRS, must also be considered. Koerner (1986) provides a method for calculating the factor of safety against sliding for soils placed on a sloped FML surface. It considers the slope angle and the friction angle between the FML and its cover soil.

From the slope angle and the FS, a minimum allowable friction angle is determined, and the various components of the liner system are selected based on this minimum friction angle. If the design evaluation results in an unacceptably low FS, then either the sidewall slope or the materials must be changed to produce an adequate design.

Stability of Drainage Layers

If the drainage layer of the LCRS is constructed of granular soil materials (i.e., sand and gravel), then this granular drainage layer must be shown to have sufficient bearing strength to support expected loads. The leachate system design should provide calculations demonstrating that the selected granular drainage materials will be stable on the steepest slope (i.e., the most critical) in the design. The calculations and the assumptions should be shown, especially the friction angle between the geomembrane and soil, and if possible, supported by laboratory and/or field testing data.

Pipe Structural Strength

Pipes installed at the base of a landfill can be subjected to high loading of waste. The evaluation of a design

should consider both the maximum depth of fill over the piping and the loading exerted by landfill equipment on a pipe with very little cover. The pipe must be selected based upon the most critical of these loadings.

Leachate collection pipes beneath land disposal facilities are generally installed in one of two configurations:

- A trench condition, where the pipe is placed in a shallow trench excavated into the underlying soil liner or foundation soil and does not project above the top of the trench.
- A positive projecting condition, where the pipe is placed directly upon a lower liner system component and projects above it.

Loads on the pipe in the trench condition are caused by both the fill material and the trench backfill. These two loads are computed separately and then added to obtain the total vertical pressure acting on the top of the pipe. For the projecting condition the vertical pressure on the pipe is assumed to be equal to the unit weight of the fill multiplied by the height of the fill above the pipe (U.S. EPA, 1988a).

In the early phases of landfilling the piping system is subject to concentrated and impact loadings from trucks and landfill equipment. Since the pipe at this point may be covered with only a foot or so of granular drainage material, wheel and impact loads are transmitted directly to the pipes. These loads may be calculated using a method found in the reference ASCE/WPCF, 1969. This traffic load should be compared to the static load from the waste, and the pipe selected based upon the larger of the two loads.

Pipes are slotted or perforated to allow flow of leachate into the collection system. These perforations reduce the effective length of the pipe available to carry loads and to resist deflection. See U.S. EPA, 1983a for a discussion of how to allow for perforations in pipe strength calculations.

7.5.7.3 Prevention of Clogging

The piping system must be protected from physical clogging by the granular drainage materials. This is most effectively accomplished by careful sizing of pipe perforations and by surrounding the pipe with a filter medium, either a graded granular filter or a geotextile material (a filter fabric). In addition, clogging of the pipes and drainage layers of the LCRS can occur through several other mechanisms, including chemical and biological clogging. For more information on these mechanisms, see U.S. EPA, 1988a.

To prevent physical clogging of leachate drainage layers and piping by soil sediment deposits, filter and drainage layer size gradations should be designed using criteria established by the Army Corps of Engineers. Drainage layers should be designed to have adequate hydraulic conductivity; and granular drainage media should be washed before installation to minimize fines. Drain pipes should be slotted or perforated with a minimum inside diameter of 6 in. to allow for cleaning.

Two criteria are suggested for use in design of drainage and filter layers for drain systems. The first criterion is for the control of clogging by piping of small soil particles into the filter layer and the drain pipe system, while the second criterion is meant to guarantee sufficient permeability to prevent the buildup of large seepage forces and hydrostatic pressure in filters and drainage layers. When geotextiles are used in place of graded filters, the protective filter may be only about 1 mm in thickness. Caution should be exercised to ensure that no holes, tears, or gaps are permitted to form in the fabric. The advantages to using geotextiles in place of granular filters are cost, uniformity, and ease of installation. With increases in costs of graded aggregate and its installation, geotextiles are competitive with graded filters. One of the most important advantages to geotextiles is quality control during construction. The properties of geotextiles will remain practically constant independent of construction practices, whereas graded filters can become segregated during placement. These geotextiles must be designed, and the references Koerner, 1986, and U.S. EPA, 1987c, provide guidance on how to design such systems.

When drainage pipe systems are embedded in filter and drainage layers, no unplugged ends should be allowed, and the filter materials in contact with the pipes must be coarse enough to be excluded from joints, holes, or slots. Specifications for the drainage layer materials should be checked against pipe specifications to be sure that the piping system will not become clogged by the granular drainage layer particles.

7.5.7.4 Layout of System Components

The design of an LCRS for a sewage sludge surface disposal unit begins with a layout of the system components within the unit. This layout should be presented in plan view, cross-section, and detail drawings of the unit. The drawings should show dimensions and slopes of the unit design features and all the components of the LCRS.

The system components should be shown on the plan and cross-section drawings and should clearly show the lateral and vertical extent of the liners. The drawings should show the elevations of the tops of the liner system components at critical points, including the toes of the sidewalls, the boundaries of any sub-areas of the unit that drain to different sumps, and the inlet and low-point elevations of the sumps. This information is essential to evaluate the ability of the system to drain leachate toward the collection sumps.

7.5.7.5 Leachate Treatment

Collected leachate may be treated by one or more of the following methods:

- Discharge to a wastewater collection system or haul directly to a treatment plant.
- On-site treatment.
  - Recycle through the landfill
  - Evaporation of leachate in collection ponds
  - Onsite treatment plant

Depending on the leachate characteristics, volume, and local regulations, it may be possible to discharge collected leachate to an existing wastewater system for subsequent treatment with municipal wastewater. Local wastewater treatment plant personnel should be consulted about leachate acceptability to determine special requirements for discharge to the treatment plant (e.g., large slugs of highly contaminated leachate may have to be mixed with municipal wastewater to prevent plant upsets).

If discharge to the wastewater system is not practical or if the leachate is potentially disruptive to treatment plant operations, onsite treatment or transportation to a chemical waste disposal site will have to be utilized.

Onsite treatment may consist of recycling the leachate through the landfill, placing the leachate in a shallow basin to allow it to evaporate, or installing a small (specially designed) treatment plant on site. Leachate recycling systems are not feasible at most sites; specifically at areas with high rainfalls and high application rates. The primary application of such systems should be restricted to codisposal sites in climates where the evaporation rate exceeds rainfall to a significant extent. The latter alternative should be avoided if at all possible due to its high cost and the unproven reliability of such small plants.

7.6 Design for Codisposal with Solid Waste

Codisposal is the disposal of sewage sludge with household waste (solid waste) at an MSW landfill. Figure 7-22 presents a generalized flow chart for codisposal of refuse and sewage sludge in a landfill. Methods of codisposal include:

- Landfilling a sewage sludge/solid waste mixture.
- Use of sewage sludge/soil mixture or sewage sludge as daily cover material.
- Use of sewage sludge/soil mixture or sewage sludge as final cover material.

The design of MSW landfills is regulated by EPA's Solid Waste Disposal Facility Criteria, 40 CFR Part 258. This manual does not provide detailed information about the design of a solid waste landfill receiving sludge. Rather, it addresses only the design features that distinguish solid waste landfills receiving sludge from those not receiving sludge. For information relating to the design and operation of an MSW landfill, consult U.S. EPA, 1993b.

7.6.1 Sludge/Solid Waste Mixture

In a sewage sludge/refuse mixture operation, sludge is delivered to the working face of the landfill where it is mixed and buried with the solid waste. At codisposal sites, some sludge handling difficulties arise because the sludge is more liquid in nature than the solid waste. These difficulties include the following:

- The sludge is difficult to confine at the working face.
- Equipment slips and sometimes becomes stuck in the sludge while operating at the working face.

These difficulties can be minimized if proper planning is employed to control the quantity of sludge received at the solid waste landfill. Every effort should be made not to exceed the absorptive capacity of the refuse. The maximum allowable sludge quantity will vary, primarily depending on the quantity of solid waste received and the solids content of the sludge. Table 7-13 presents some design considerations for codisposal landfills. This table includes suggested bulking ratios for sludge/refuse mixtures at various sludge solids contents, but determinations should be made on a site-by-site basis using test operations. It should be noted that any sludge disposed of in an MSW landfill must pass the paint filter liquids test (Figure 7-23), as discussed in Section 3.4.3.

A second planning and design consideration for sludge/solid waste mixture operations concerns leachate control. The impact of sewage sludge receipt on leachate at MSW landfills is highly site specific. Generally, increased leachate quantities should be expected. Leachate control systems may have to be designed or modified accordingly.

While sludge might be expected to degrade leachate quality in an MSW landfill, a 4-year landfill simulator study (Stamm and Walsh, 1988) evaluating codisposal, municipal refuse-only disposal, and sludge-only disposal found that codisposal had the least detrimental effect on leachate quality (Table 7-14), with the bulk of contamination being released approximately 1 year sooner than sludge-only or solid waste-only configurations. Codisposal also enhanced the decomposition process as measured by methane generation. Codisposal test cells generated methane much sooner than the refuse-only cell in this study. This is significant because methane collection and treatment is much more effective in the early life of a landfill as compared to after its closure.

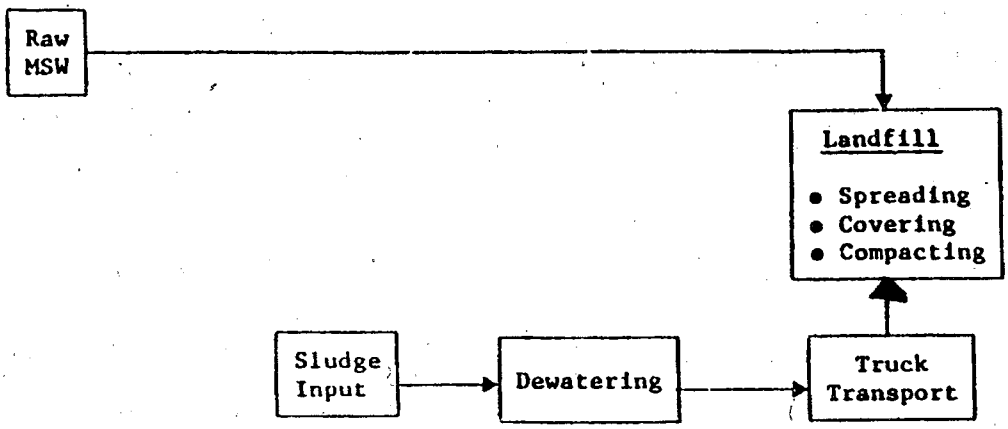


Figure 7-22. Landfill codisposal.

Table 7-13. Design Considerations for Codisposal Operations

Design Parameter	Consideration			
	Method	Bulking agent	Sludge solids content	Bulking ratio
Bulking ratio	Sludge/refuse mixture	Refuse	10-17%	6 tons refuse :1 wet ton sludge
			17-20%	5 tons refuse : 1 wet ton sludge
			20%	4 tons refuse : 1 wet ton sludge
	Sludge/soil mixture	Soil	20%	1 soil : 1 sludge

1 ton = 0.907 Mg

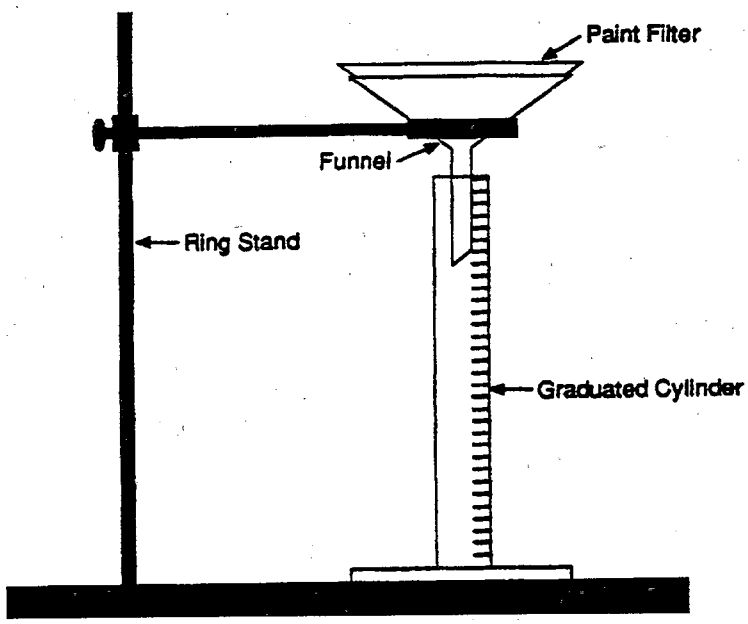


Figure 7-23. Paint filter test apparatus (U.S. EPA, 1993).

Table 7-14. Various Average Leachate Values for Codisposal, Refuse-Only, and Sludge-Only Test Cells Averaged Over 4 Years (Stamm and Walsh, 1988)

Parameter	Codisposal*	Refuse-Only+	Sludge-Only#
COD (mg/L)	2,889	22,453	2,258
TOC (mg/L)	903	4,640	737
pH	7.1	6.4	6.2
Volatile Acids (mg/L)	868	7,434	1,213
Volatile Solids (mg/L)	2,171	7,659	5,555
Specific Volume (L/kg/mo.)	0.03	0.03	0.07

* Average of Cell 1, 5, and 9.
\+ Average of Cell 17 and 19.
\# Average of Cell 21 and 23.

A third planning and design consideration is storage for sludge received in off-hours. In many cases sludge is delivered around the clock, while solid waste delivery is confined to certain hours. Sludge storage facilities might have to be installed to contain sludge overnight or over weekends until sufficient refuse bulking is delivered.

7.6.2 Sludge/Soil Mixture and Sludge as Daily Cover Material

The Solid Waste Disposal Facility Criteria require that all owners and operators of MSW landfill units cover disposed solid waste with 6 in. of earthen material at the end of each operating day, or at more frequent intervals if necessary, to control disease vectors, fires, odors, blowing litter, and scavenging. A state may approve an alternative material if the owner or operator demonstrates that it controls disease vectors, fires, odors, blowing litter, and scavenging without presenting a threat to human health and the environment.

A sludge/soil mixture (in an approximately 1:1 ratio) may be a suitable material for daily cover. Some landfills have used sludge mixed with compost as daily cover material (U.S. EPA, 1993a). In a sludge/soil mixture operation, sludge is mixed with soil and applied as daily cover or as cover over completed solid waste fill areas. If a sludge/soil mixture operation is planned, an area must be reserved at the planning/design stage for sludge/soil mixing. This area must be of sufficient size and have sufficient soil available for sludge bulking. Information on suggested bulking ratios is included in Table 7-13. The soils in the mixing area must also be adequate to protect the ground water.

Sewage sludge also may be a suitable daily cover material if it has a solids content of 50 percent or higher and if it has undergone a process such as biological stabilization to reduce the volatile solids content. Sludge with these characteristics has the following advantages as daily cover material (Lue-Hing et al., 1992):

- It has a high moisture absorption capacity, thereby helping to control insects, rodents, and other vectors that thrive under wet conditions.
- Like soil, it has a high odor-absorbing capacity. It also reduces the emission of odorous gases from the landfill by reducing the surface area of municipal solid waste exposed to the atmosphere.
- Like soil, it acts as a physical barrier to control blowing litter and improves the aesthetic appearance of the landfill.
- If the volatile solids content of the sludge has been reduced, it can reduce the fire hazard associated with municipal solid waste landfills. Municipal sewage sludge with a volatiles content of 50 to 55 percent has a flash point of approximately 250°C, making it suitable for use as a fire control agent at solid waste landfills.
- It helps reduce the potential for leachate contamination of ground water and surface water.

Certain sludge-derived products have also been used as alternative materials for daily cover at landfills. Sludges can be treated by chemical fixation processes using additives such as lime, cement kiln dust, fly ash, and silicates to produce a suitable soil-like material. Examples include the N-VIRO process, a patented pasteurization and chemical fixation process in which dewatered sludge is blended with alkaline additives, cured, and then aerated and windrowed. Another process, CHEMFIX, is a proprietary chemical fixation process using soluble silicates and silicate settling agents blended with the sludge to produce a chemically and physically stable solid material. These and similar fixation processes require the construction of sludge processing and curing facilities, possibly at significant capital investment (U.S. EPA, 1993a).

To avoid workability problems when these sludge-derived products are placed on the working face of a

landfill, they must be cured and dried to a moisture content of approximately 60 percent. At the proper moisture content, they are reported to be lighter and easier to spread than soil. An ammonia-like odor (usually restricted to the working face) has been reported when these products are initially placed on the working face. To improve workability and control odors, the products are sometimes blended with natural soil at a 1:1 ratio. Problems with dust generation have also been reported at some sites using sludge-derived products as daily cover (U.S. EPA, 1993a).

7.6.3 Sludge/Soil Mixture and Sludge as Final Cover Material

The Part 258 regulation requires that when an MSW landfill has reached the end of its useful life, it must receive a final cover designed and constructed to have a permeability less than or equal to the permeability of the bottom liner system or the natural subsoils present, or a permeability no greater than 1×10^{-5} cm/sec, whichever is less (Figure 7-24). The final cover must include an infiltration layer composed of at least 18 in. of an earthen material (such as clay) to minimize the flow of water into the closed landfill. The cover must also contain an erosion layer to prevent the disintegration of the cover. The erosion layer must be composed of a minimum of 6 in. of earthen material capable of sustaining native plant growth.

EPA allows a state or tribe to approve an alternative erosion layer design that provides equivalent protection from wind and water erosion. This may include the use of sludge/soil mixtures or sludge.

Sewage sludge may be suitable as material for the erosion layer if it has a solids content greater than 20 percent and has undergone a process such as anaerobic digestion to reduce its volatile solids content. About 1 to 3 ft (0.3 to 0.9 m) of sludge is usually sufficient to establish a vegetative cover. To prevent the sludge from sliding down the side slopes, it should be mixed with the surface soil at a 1:1 ratio (Lue-Hing et al., 1992).

7.7 Design Considerations for Dedicated Surface Disposal Sites

DSD sites, including beneficial DSD sites on which vegetation is grown, must be designed to meet the Part 503 Subpart C surface disposal requirements for leachate collection (unless pollutant limits are met), aquifer protection, and collection of surface water runoff. Other important design considerations at DSD sites include determining the most appropriate sludge disposal method to use, calculating the acceptable sludge disposal rate, ascertaining land area needs, the site's proximity to needed community infrastructure, and climatic considerations. Design considerations for DSD sites are discussed below, with the exception of the collection of surface water runoff, which is discussed in Section 7.9.1.

7.7.1 Presence of a Natural Liner and Design of a Leachate Collection System

A well chosen DSD site will be completely underlain with a relatively impervious soil such as clay with a hydraulic conductivity of 1×10^{-7} cm/sec or less, thus meeting the Part 503 requirement for a liner as applicable to DSD sites. If the DSD site owner is choosing to use this liner to comply with Part 503 rather than by meeting pollutant limits, then Part 503 requires that leachate be collected at the site. If the DSD site contains both a liner and leachate collection system, the sewage sludge at the site is not required to meet the Part 503 pollutant limits for surface disposal.

If the DSD site is not underlain with impervious soil, then the sewage sludge at the DSD site must meet the pollutant limits for arsenic, chromium, and nickel speci-

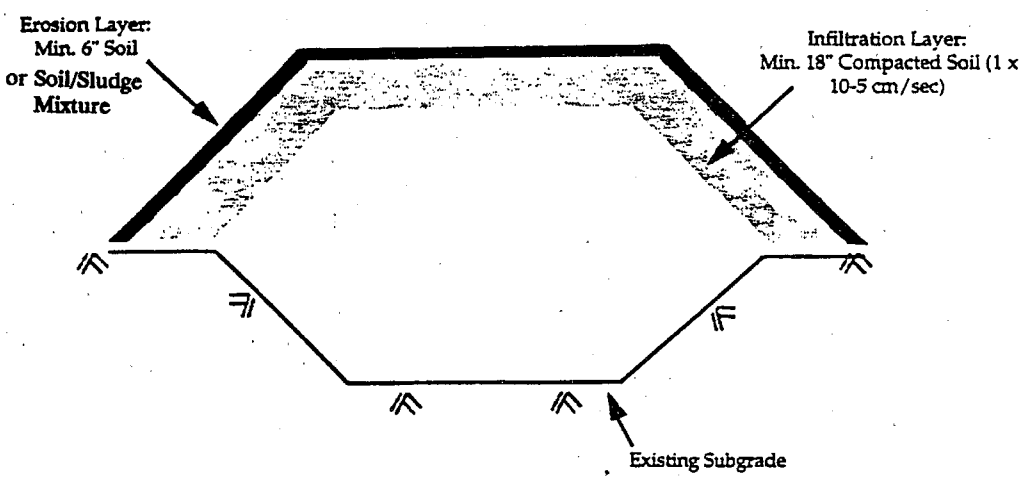


Figure 7-24. Example of minimum final cover requirements (U.S. EPA, 1993).

In addition to installing a leachate collection system to comply with Part 503, a subsurface drainage system to collect leachate may also need to be designed in areas with a high ground-water table. In addition to increasing the potential for ground-water contamination, a high ground-water table may create serious problems for sludge disposal at DSD sites, such as ponding, anaerobic soil conditions, or muddy surfaces.

Buried plastic pipe or clay tile, 10 to 20 cm (4 to 8 in.) in diameter, is generally used for underdrains. Concrete pipe is less suitable because of the sulphates that may be present in leachate from soils on which sludge has been disposed. Underdrains usually are buried 1.8 to 2.4 m (6 to 8 ft) deep, but can be as deep as 3 m (10 ft) or as shallow as 1 m (3 ft). Spacing of drains typically ranges from 15 m (50 ft) in clayey soils up to 120 m (400 ft) in sandy soils. Procedures for determining the proper depth and spacing of drains can be found in other publications, such as EPA's *Process Design Manual for Land Treatment of Municipal Wastewater* (U.S. EPA, 1981), (U.S. Soil Conservation Service, 1972), and (Van Schilfgaarde, 1974).

If a subsurface drainage collection system is installed beneath the DSD site, the leachate collected from the system may need to be treated and will need to be properly stored and disposed or reused.

7.7.2 No Contamination of Aquifers: Nitrogen Control at DSD Sites

The DSD owner must prove that ground-water is not being contaminated, as specified in Part 503 based on nitrate levels, through either a ground-water monitoring program developed by a qualified ground-water scientist or certification by a ground-water scientist, as discussed in Chapter 4.

Several topographical and design conditions at a DSD site will help in meeting the Part 503 regulatory requirement for controlling nitrates so the site does not contaminate an aquifer. These conditions include:

- No aquifer exists at potentially useful elevations.
- It can be shown that the volume of leachate containing nitrates reaching the aquifer is such a small percentage of the ground-water aquifer flow volume that potential degradation is negligible.
- The local climate is arid with a high net evaporation rate, and useful aquifers are deep.
- An impervious geological barrier, such as unfractured bedrock or thick clay, lies between the DSD site and a useful aquifer and serves as a liner, effectively preventing significant volumes of leachate from percolating into the aquifer.
- A below-ground leachate collection system is constructed (e.g., drain tiles, well points, etc.) which collects the leachate before it can percolate into the aquifer.

If none of the above possibilities is feasible, singly or in combination, then the site is probably an inappropriate location for a DSD site.

7.7.3 Methods for Disposal of Sewage Sludge on DSD Sites

The choice of sludge disposal methods at DSD sites are dictated by sewage sludge characteristics and often by cost and/or aesthetics (e.g., odors or other community concerns). The owner/operator of a DSD site has a number of methods to choose from for sludge disposal, including:

- Subsurface methods for liquid sludge, including (1) subsurface injection or (2) plow or disc covering.
- Surface spreading of liquid sludge by tank trucks or tank wagons.
- Spraying of liquid sludge.
- Surface spreading of dewatered sludge.

Each disposal method has advantages and disadvantages which are discussed below. Tables 7-15a and 7-15b describe the methods, characteristics, and limitations of disposing liquid sludge by surface methods and subsurface methods. In all of the disposal techniques, the sludge eventually becomes incorporated into the soil, either immediately by mechanical means or over time by natural means.

The technique used to apply sludge to the land can be influenced by the means used to transport the sludge from the POTW(s) to the DSD site. Commonly used methods include:

- Same transport vehicle both hauls sludge from the POTW to the DSD site and spreads sludge on the land.
- One type of transport vehicle, usually with a large volume capacity, hauls sludge from the POTW to the DSD site. At the DSD site, the sludge haul vehicle transfers the sludge to an application vehicle, into a storage facility, or both.
- Sludge is pumped and transported by pipeline from the POTW to a storage facility at the DSD site. Sludge is subsequently transferred from the storage facility to the sludge application vehicle.

Table 7-15a. Surface Spreading Methods and Equipment for Liquid Sludges (Cunningham and Northouse, 1981)

Method	Characteristics	Topographical and Seasonal Limitations
Tank truck	Capacity 500 to more than 2,000 gallons; it is desirable to have flotation tires; can be used with temporary irrigation set-up; with pump discharge can achieve a uniform spreading rate.	Tillable land; not usable at all times with row crops or on very wet ground.
Farm tank wagon	Capacity 500 to 3,000 gallons; it is desirable for wagons to have flotation tires; can be used with temporary irrigation set-up; with pump discharge, can achieve a uniform spreading rate.	Tillable land; not usable at all times with row crops or on very wet ground.

Metric conversion factor: 1 gal = 3.78 L

Table 7-15b. Subsurface Spreading Methods, Characteristics, and Limitations for Liquid Sludges (Keeney et al., 1975) for Liquid Sludges (Cunningham and Northouse, 1981)

Method	Characteristics	Topographic and Seasonal Limitations
Flexible irrigation hose with plow or disc cover	Use with pipeline or tank truck with pressure discharge; hose connected to manifold discharge on plow or disc.	Tillable land; not usable on very wet or frozen ground.
Tank truck with plow or disc cover	500-gallon commercial equipment available; sludge discharge in furrow ahead of plow or disk mounted on rear on four-wheel-drive truck.	Tillable land; not usable on very wet or frozen ground.
Farm tank wagon with plow or disc cover	Sludge discharged into furrow ahead of plow mounted on tank trailer; disposal of 170 to 225 wet tons/acre; or sludge spread in narrow band on ground surface and immediately plowed under; disposal of 50 to 120 wet tons/acre.	Tillable land; not usable on very wet or frozen ground.
Subsurface injection	Sludge discharge into channel opened by a chisel tool mounted on tank truck or tool bar; disposal rate 25 to 50 wet tons/acre; vehicles should not traverse injected area for several days.	Tillable land; not usable on very wet or frozen ground.

Metric conversion factors: 1 gal = 3.78 L, 1 ton/acre = 2.24 metric tons/hectare

7.7.3.1 Disposal Methods for Liquid Sludge at DSD Sites

Subsurface Methods

Subsurface methods for disposal of liquid sludge at DSD sites have a number of advantages over surface methods, including:

- Minimization of potential odor and other nuisance problems, and thus possibly better public acceptance.
- Reduction of potential surface water runoff.
- Conservation of nitrogen (because ammonia volatilization is minimized), which may be important if vegetation is grown onsite.

Advantages of subsurface methods compared to spraying include:

- Greater amounts of sludge can be disposed per spreading activity
- Less visibility to the surrounding community
- Better disposal at DSD site perimeters

Nevertheless, subsurface methods have a number of potential disadvantages compared to surface methods for liquid sludge, including:

- Possibly more difficulty in achieving even distribution of the sludge
- Higher fuel consumption costs than surface methods

Subsurface incorporation of liquid sludge can be done in two basic ways—subsurface injection or plow or disc covering. Figures 7-25 through 7-27 illustrate one type of vehicle designed specifically for subsurface injection of liquid sludge which consists of a tank truck with special injection equipment attached. Tanks for the trucks are generally available with 6,000, 7,500, and 11,000 l (1,600, 2,000, and 3,000 gal) capacities. Figure 7-28 shows another type of subsurface injection vehicle—a tractor with a rear-mounted injector unit. Sludge

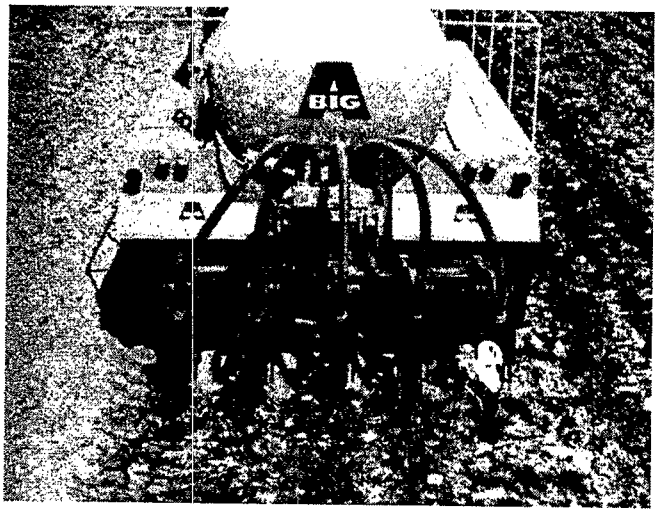
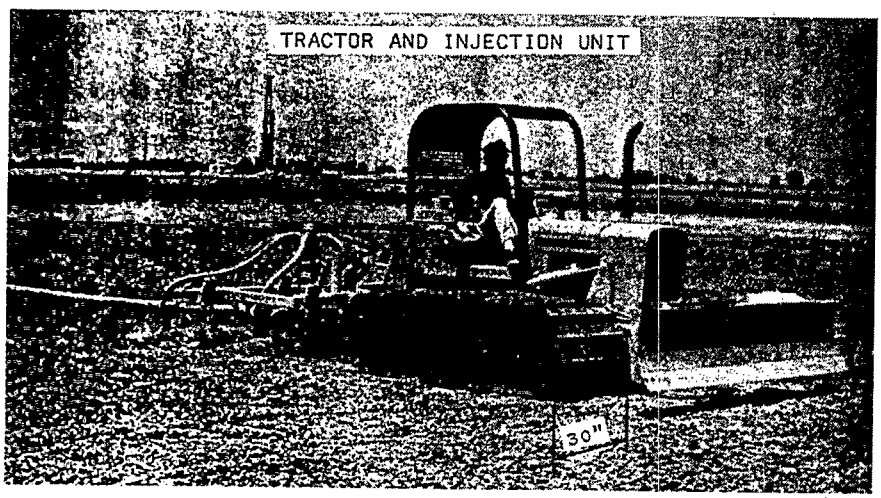


Figure 7-26. Tank truck with liquid sludge tillage injections (courtesy of Rickel Mfg. Co.).



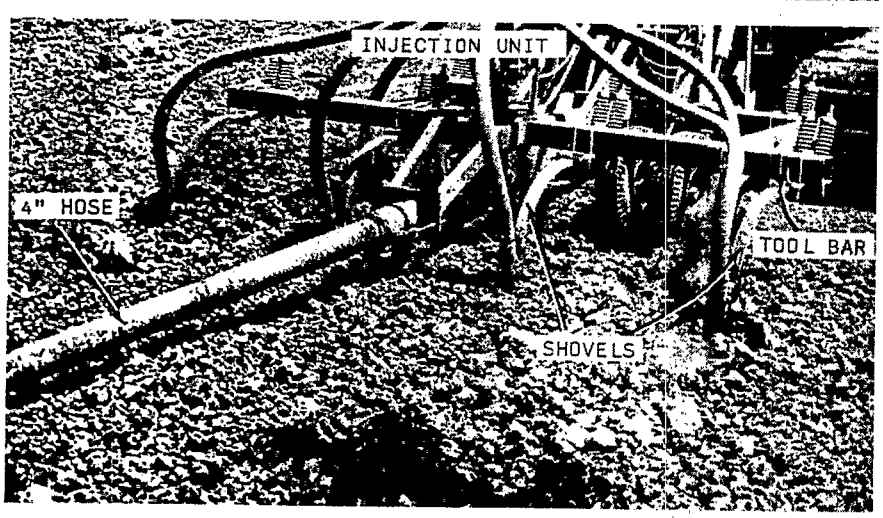


Figure 7-25. Tractor and injection unit.

is pumped from a storage facility to the injector unit through a flexible hose attached to the tractor. Discharge flow capacities of 570 to 3,800 l/min (150 to 1,000 gpm) are used. The tractor requires a power rating of 40 to 60 hp.

The plow or disc cover method involves discharging the sludge into a narrow furrow from a tank wagon or flexible hose linked to a storage facility through a manifold mounted on a plow or disc; the plow or disc then immediately covers the sludge with soil. Figures 7-29a and 7-29b depict a typical tank wagon with an attached plow. These systems seem to be best suited for high loading rates, (i.e., a minimum of 3.5 to 4.5 mt/ha [8 to 10 dry T/ac]) of 5 percent slurry (Keeney et al., 1975).

Surface Methods

Surface spreading of liquid sludge involves spreading without subsequent incorporation into the soil. Surface spreading is less expensive than subsurface injection in

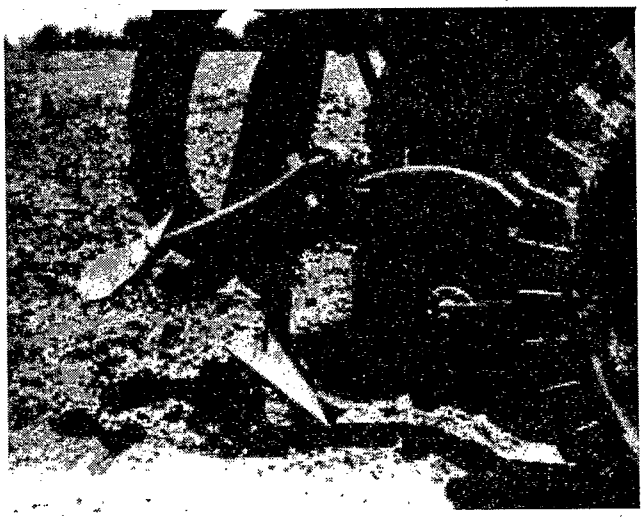


Figure 7-29a. Tank wagon with sweep shovel injectors (Cunningham and Northouse, 1981).

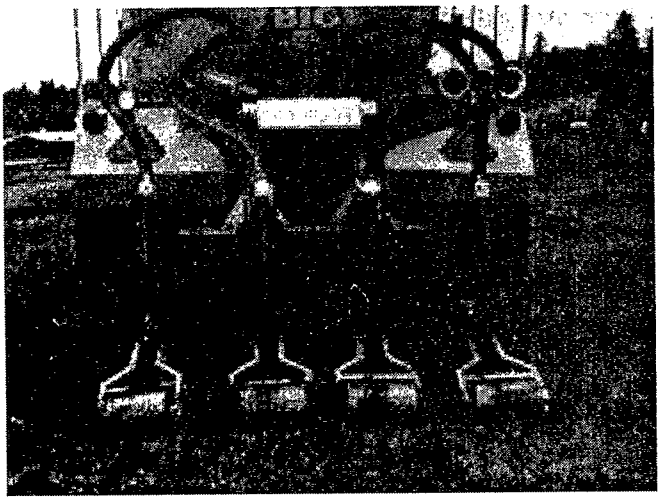


Figure 7-27. Tank truck with liquid sludge grassland injectors (courtesy Rickel Mfg. Co.).

Figure 7-29b. Sweep shovel injectors with covering spoons mounted on tank wagon (Cunningham and Northouse, 1981).

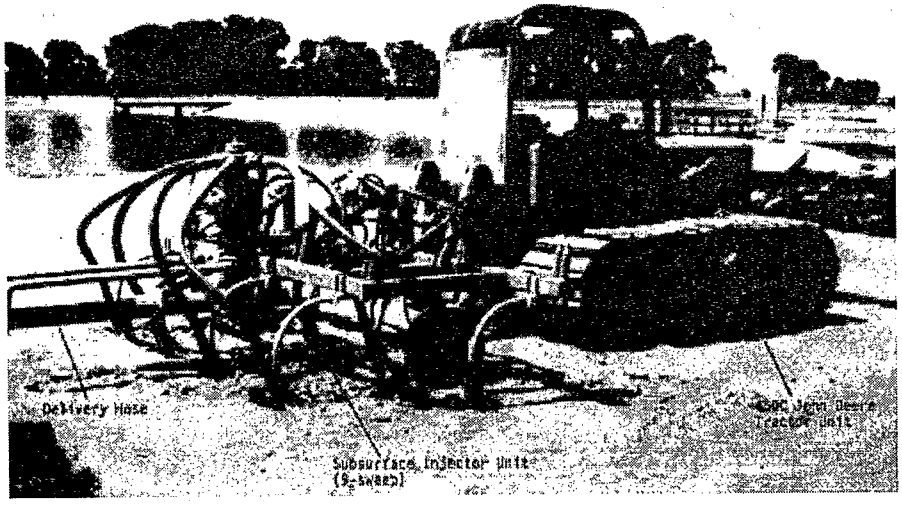


Figure 7-28. Tractor pulled liquid sludge subsurface injection unit connected to delivery hose (courtesy Briscoe Maphis Co.).

terms of equipment and labor. But the DSD sites reviewed during preparation of this manual had experienced problems when using surface spreading methods, including odors, uneven distribution of sludge, clogging of soil surface, and difficult vehicle access into the area.

Liquid sludge can be surface spread by vehicles equipped with splash plates or a slotted T-bar. Selection of either of these attachments should primarily be based on whichever method results in the most uniform spreading at an individual site. Figure 7-30 depicts a tank truck equipped with splash plates, and Figure 7-31 depicts a tank truck with a rear mounted "T" pipe. For these two methods, disposal rates can be controlled either by valving the manifold or by varying the speed of the truck. A much heavier spreading will be made from a full truck than from a nearly empty truck unless the speed of the truck or wagon advancing across the field is steadily decreased to compensate for the steadily decreasing hydraulic head (U.S. EPA, 1977).

Spray Method

Liquid sludge can also be sprayed on a site through spray bars or nozzles. Spraying can be useful in dispersing liquid sludge on DSD sites, particularly in remote areas where public acceptance is less of a concern; when sludge characteristics preclude using a sludge storage lagoon onsite (e.g., because the sludge solids at the bottom of the lagoon are difficult to remove even

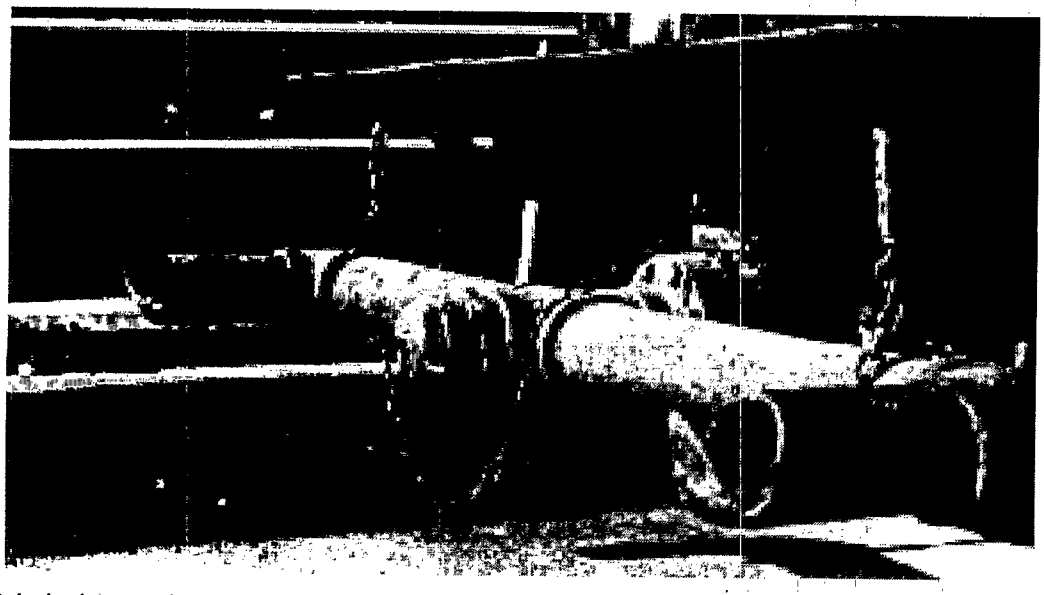


Figure 7-30. Splash plates on back of tanker truck (U.S. EPA, 1978a).

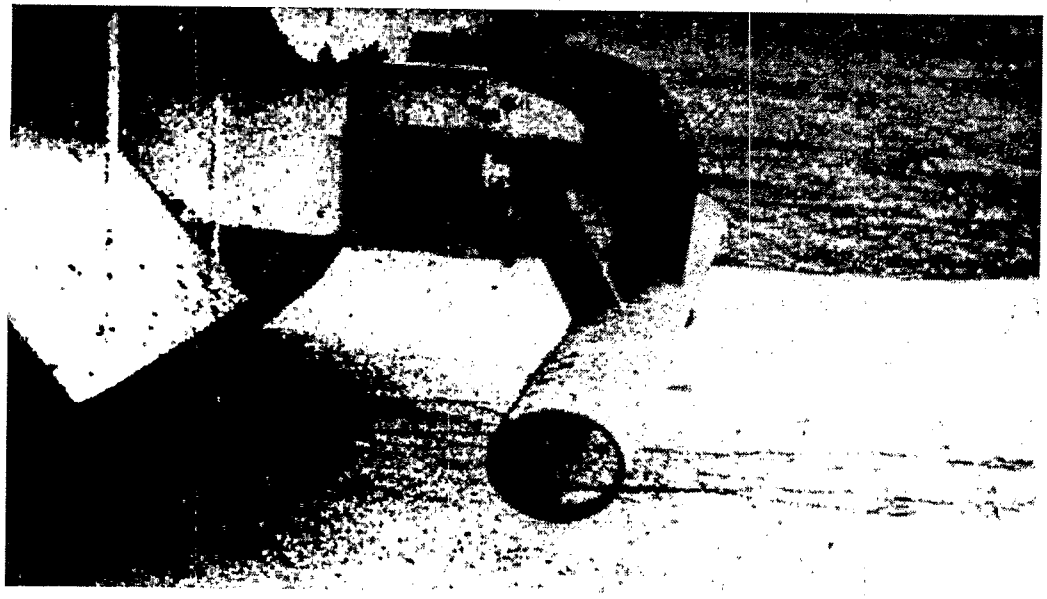


Figure 7-31. Slotted T-bar on back of tanker truck (U.S. EPA, 1978a).

with air mixing or other processes); or in colder climates where freezing is a concern (U.S. EPA, 1984c).

Liquid sludge is readily dispersed by use of properly designed spray equipment. By spraying the liquid sludge under pressure, a more uniform coverage is obtained. Sludge solids must be relatively small and uniformly distributed throughout the sludge to achieve uniform spray and to avoid system clogging.

The main component of a typical spray system is a rotary sprayer (rain gun) to disperse the liquid sludge over the site. The sludge, pressurized by a pump, is transferred from storage to the sprayer via a pipe system. Both portable or permanent systems are available, including (Loehr et al., 1979):

- Solid set, buried or above-ground
- Center pivot
- Side roll
- Continuous travel
- Towline laterals
- Stationary gun
- Traveling gun

All the systems listed, except for the buried solid set system, are designed to be portable. Main lines for systems are usually permanently buried, providing protection from freezing weather and heavy vehicles.

The proper design and operation of spray systems for liquid sludge requires thorough knowledge of the commercial equipment available and its adaptation to use with liquid sludge. The sludge spray systems in use are generally associated with DSD sites. It is beyond the scope of this manual to present engineering design data; qualified spray system engineers and experienced spray system manufacturers should be consulted. Figures 7-32 and 7-33 illustrate two of the spray systems available.

7.7.3.2 Disposal Methods for Dewatered Sludge at DSD Sites

The spreading of dewatered sludge (20 percent solids or more) is similar to that of solid or semisolid fertilizer, lime, or animal manure. The dewatered sludge can be spread with bulldozers, front end loaders, graders, or box spreaders, and then incorporated into the soil by plowing or discing. The box spreader is commonly used, but the other types of equipment are often used for high sludge spreading rates typical of DSD sites. Dewatered sludge cannot be pumped or sprayed. The spiked tooth harrows used for normal farming operations may be too light to adequately bury the sludge; heavy-duty mine disks or disk harrows may be required.

The principal advantages of using dewatered sludge include reduced sludge hauling and storage costs and higher sludge disposal rates (compared to liquid sludge) per pass of equipment. Potential disadvantages of disposing dewatered rather than liquid sludge at DSD sites include the need for substantial modification of conventional spreading equipment and more equipment repairs, compared to many liquid sludge systems.

Figures 7-34 and 7-35 illustrate the specially designed trucks used to spread dewatered sludge. For small quantities of dewatered sludge, tractor-drawn conventional farm manure spreaders may be adequate (Loehr

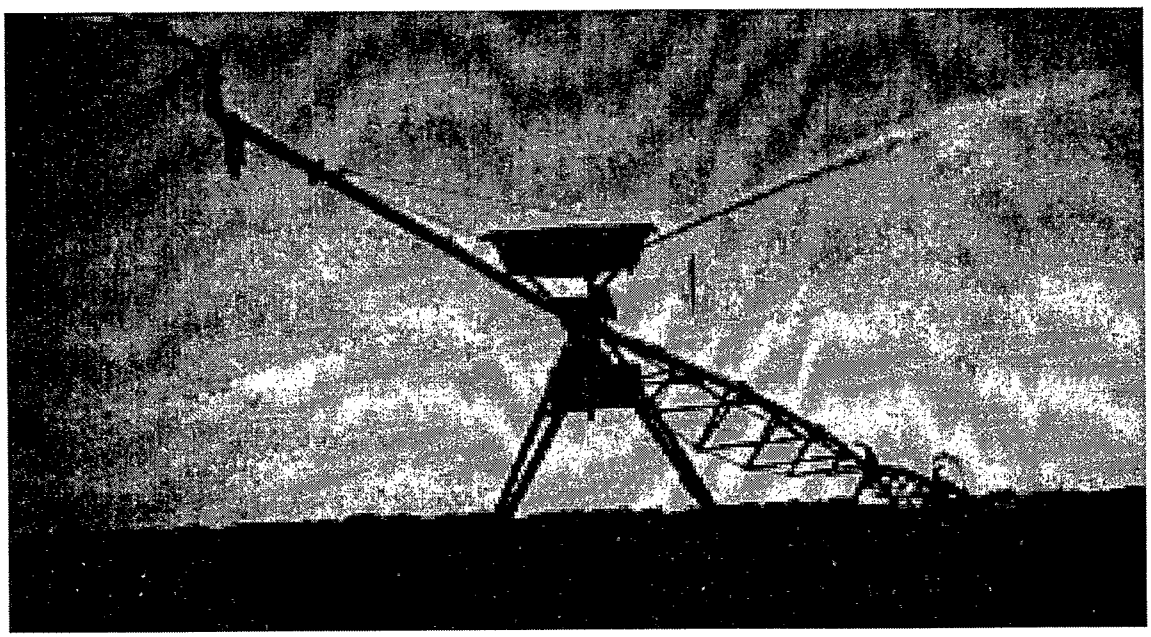


Figure 7-32. Venter pivot spray application system (Valmont Ind. Inc.).

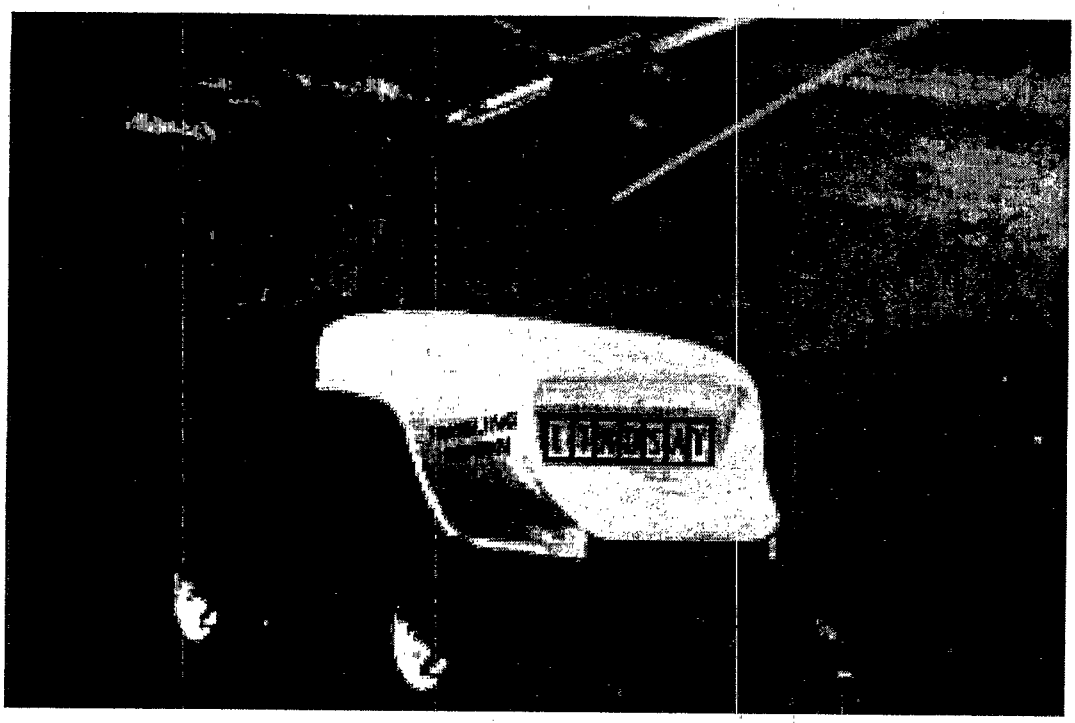


Figure 7-33. Traveling gun sludge sprayer (Lindsay Mfg. Co.).

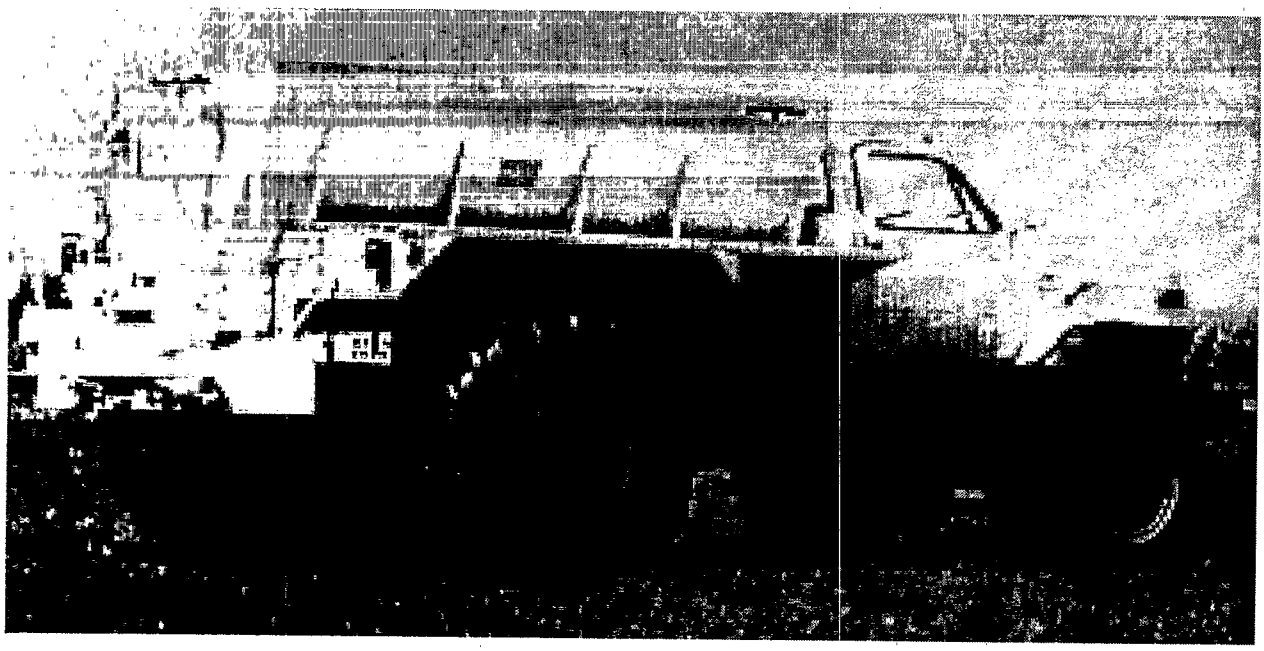


Figure 7-34. 7.2 cubic yard dewatered sludge spreader (Big Wheels, Inc.).

et al., 1979). Surface spreading of dewatered sludge on tilled land is usually followed by incorporation of the sludge in the soil. Standard agricultural discs or other tillage equipment pulled by a tractor or bull dozer can incorporate liquid or dewatered sludge into soil, such as the disk tiller, disk plow, and disk harrow shown in Figures 7-36 and 7-37 (U.S. EPA 1978b).

7.7.3.3 Disposal Methods Not Recommended

Land spreading of sewage sludge by gravity irrigation/flooding has generally not been successful where attempted and is discouraged by regulatory agencies and experienced designers. Problems with this method include difficulty in achieving uniform sludge spreading

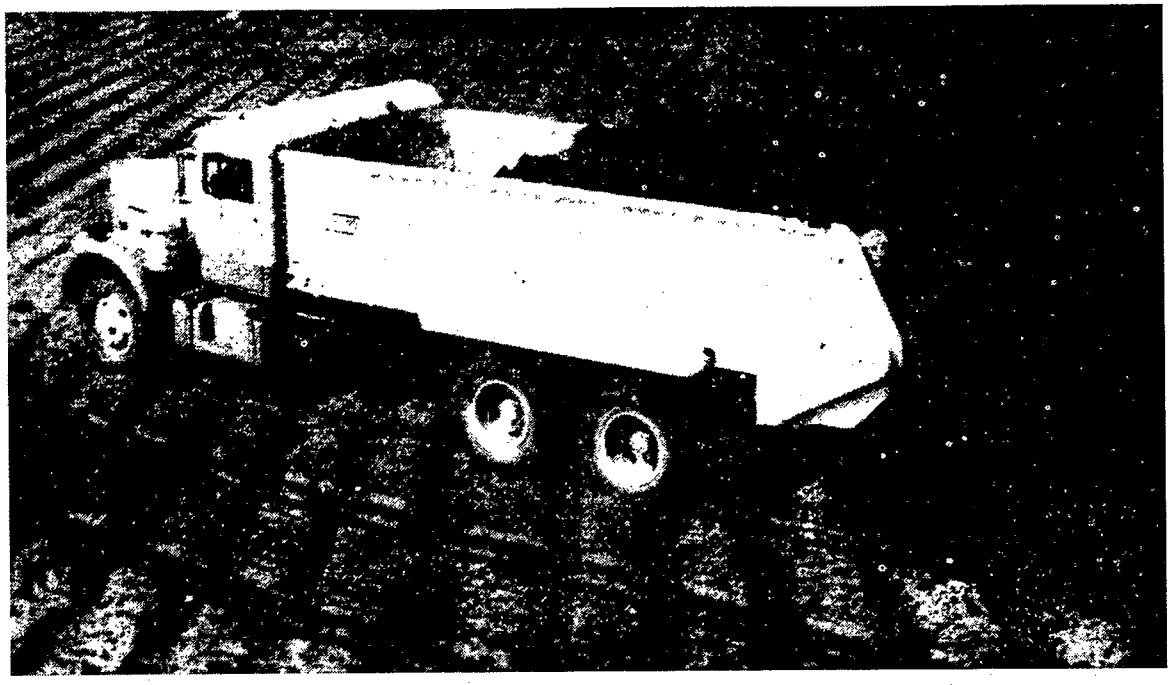


Figure 7-35. Large dewatered sludge spreader (BJ Mfg. Co.).

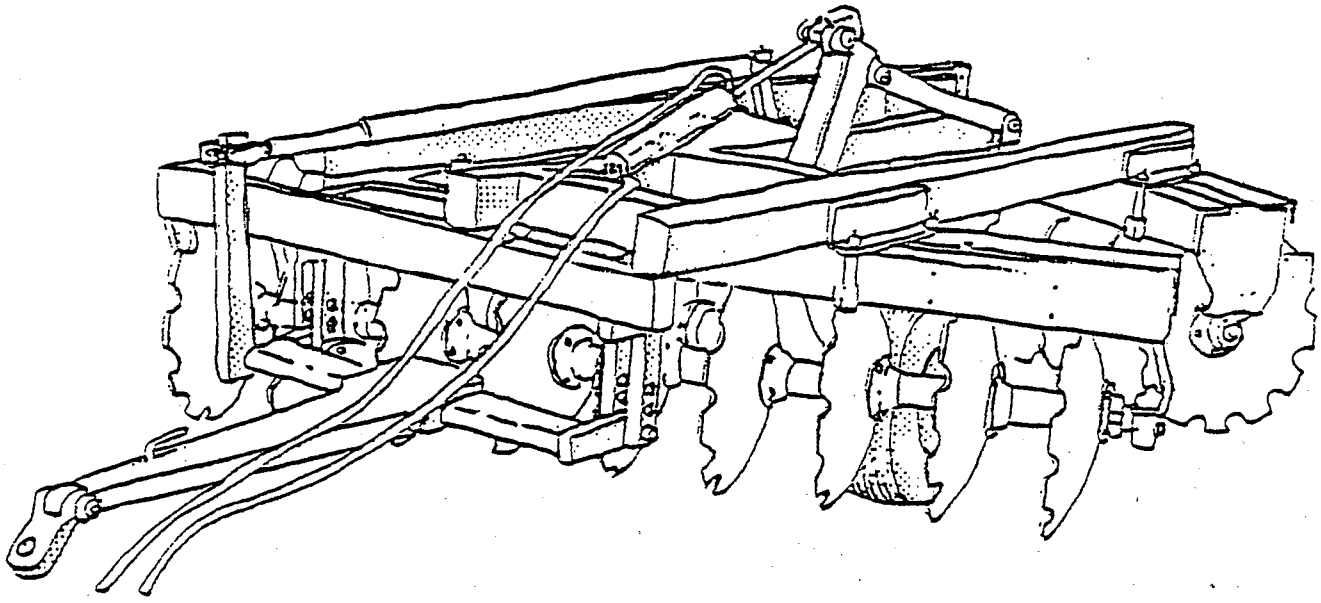


Figure 7-36. Example of disc tiller.

rates; clogging of soil pores; and tendency of the sewage sludge to turn septic with resulting odors.

7.7.4 Sludge Disposal Rates at DSD Sites

Well managed DSD projects can be environmentally acceptable even with high disposal rates if properly sited, designed, and operated. The disposal rate of sewage sludge to DSD sites, as defined in this manual and in Part 503, is limited by the following factors:

- Part 503 pollutant limits in sewage sludge for surface disposal sites if the site does not have a liner and leachate collection system. Representative samples of sewage sludge must be tested for arsenic, chromium, and nickel as required by Part 503 (see

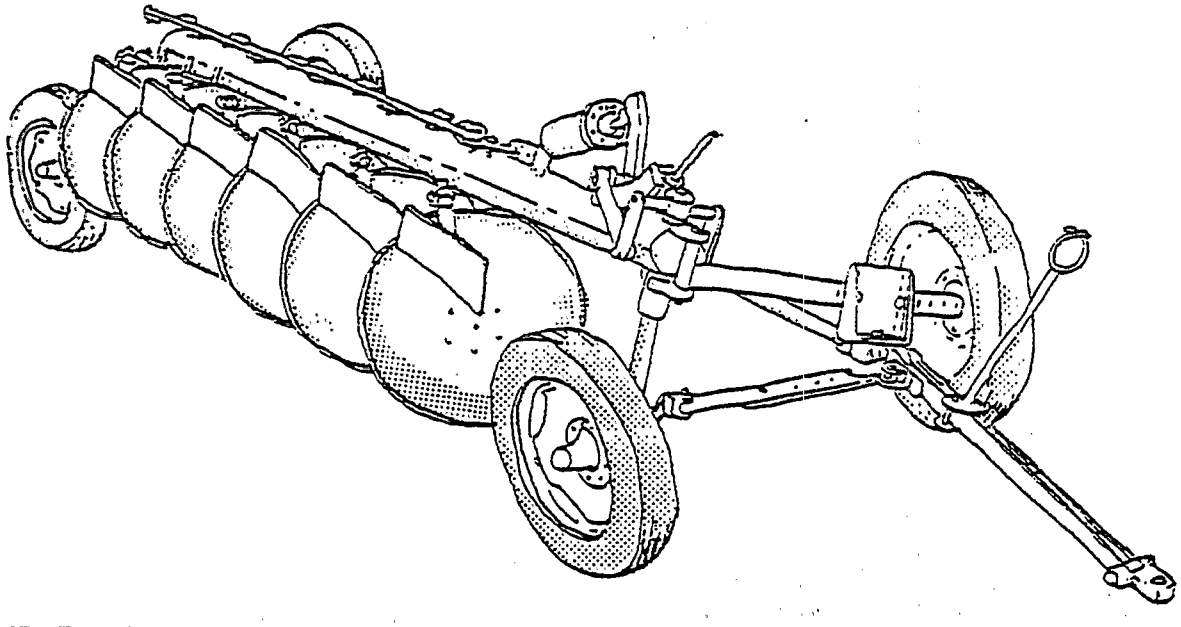


Figure 7-37. Example of disk plow.

Chapter 3) if the site does not have a liner and leachate collection system.

If monitoring results show that the sludge meets Part 503 pollutant limits, or if a liner and leachate collection system are onsite, then the other factors listed below should then also be considered.

- The rate of sludge which can be disposed during each spreading activity while still maintaining aerobic conditions in the soil. The method of sludge disposal, soil drainage, soil characteristics, sludge moisture content, and climatic conditions all influence this factor.
- The number of days during the year when sludge can be disposed, as dictated by weather conditions, ability of the sludge spreading equipment to operate with existing soil conditions, and equipment breakdown and maintenance requirements.
- Evaporation rates of sludge liquids.

Annual sludge disposal rates at DSD sites range from 50 to 2,000 T/ac. The higher disposal rates are practiced at DSD sites which:

- Receive dewatered sludge.
- Mechanically incorporate the sludge into the soil.
- Have relatively low precipitation.
- Are not faced with problems of leachate contamination of ground water from site conditions or project design.

A conservative approach for calculating sludge disposal rates is to match sludge disposal and net soil evaporation rates. Sludge disposal will generally be intensive during warm and dry periods and reduced during wet or cold periods.

Net soil evaporation is calculated by the use of:

$$E_N = E_S - P$$

$$E_N = (f \times E_L) - P \qquad \text{(Eq. 7-1)}$$

Where:

E_N = net soil evaporation
E_S = gross soil evaporation
E_L = gross lake evaporation
P = precipitation
f = factor expressing the relationship of soil and lake evaporation (dimensionless)

Typically, gross soil evaporation in an area is estimated as a fraction (e.g., f = 0.70) of the lake evaporation. Estimates can be obtained from local agricultural information services. Table 7-16 illustrates the calculation of net soil evaporation on a monthly basis for Colorado Springs, Colorado (Brown and Caldwell, 1979).

Having estimated net soil evaporation (E_N) for each month, the sludge disposal rates on a monthly basis are calculated by matching the moisture in the disposed sludge against E_N, as shown below:

$$R_M = \frac{E_N \times TS \times C}{100 - TS} \qquad \text{(Eq. 7-2)}$$

Where:

R_M = monthly sludge disposal rate (dry mt/ha/mo or dry T/ac/mo)
E_N = net soil evaporation (cm/mo or in./mo)
TS = total solids content of the sludge (percent) by weight
C = conversion factor which equals 100 mt/cm or 113.3 T/in.

Table 7-16. Net Monthly Soil Evaporation at Colorado Springs, Colorado (Brown and Caldwell, 1979)

Month	Gross Soil Evaporation (cm)*	Precipitation (cm)	Net Soil Evaporation (cm)
January	-	1.80	-
February	-	1.85	-
March	-	3.96	-
April	9.16	4.85	4.31
May	11.45	5.44	6.01
June	13.55	5.49	8.06
July	14.69	7.62	7.07
August	12.43	5.89	6.54
September	9.58	3.94	5.64
October	7.34	2.82	4.52
November	-	2.41	-
December	-	1.70	-
Annual	78.20	47.78	42.15

* Estimated based on 70 percent lake evaporation.
† Gross soil evaporation less precipitation.
# 1 in = 2.54 cm.

Table 7-17 shows monthly sludge disposal rates for the Colorado Springs site based on a sludge with a 4.85 percent solids content and the net monthly soil evaporation rates shown in Table 7-16. Sample calculations for April would be:

$$\text{Metric} \quad \frac{4.31 \times 4.85 \times 100}{100 - 4.85} = 22 \text{ m/ha}$$

$$\text{English} \quad \frac{1.70 \times 4.85 \times 113.3}{100 - 4.85} = 9.8 \text{ T/ac}$$

Referring to Table 7-17, an annual average total of 215 mt/ha (95.8 T/ac) dry weight of sludge could be disposed at this site based on net soil evaporation.

The use of net soil evaporation as a basis for calculating sludge disposal rates at DSD sites is conservative since it makes no allowance for moisture removal from the sludge through infiltration into the soil. If infiltration is allowed, sludge disposal rates at DSD sites can be calculated by the following equation:

$$R_M = \frac{(E_N + I) \times TS \times C}{100 - TS}$$

Where:

I = infiltration rate (cm/mo or in./mo)

all other terms as in previous equations

7.7.5 *Drying Periods Between Sludge Spreading Activities*

Drying (rest) periods between each sludge spreading activity allow the soil to return to its natural aerobic condition. Disposal should be scheduled to prevent excessive moisture in the soil for long periods and to minimize odors and the breeding of vectors.

Table 7-17. Monthly Sludge Disposal Rates at Colorado Springs, Colorado, DSD Site (Brown and Caldwell, 1979)

Month	Monthly Application Rate* (dry mt/ha)†	(dry T/ac)†
January	-	-
February	-	-
March	-	-
April	22.0	9.8
May	30.7	13.7
June	41.1	18.3
July	36.1	16.1
August	33.4	14.8
September	28.8	12.8
October	23.1	10.3
November	-	-
December	-	-
Annual	215.0	95.8

* Total solid content in the sludge is assumed to be 4.85 percent.

† Using Equation (7-2) and data from Table 7-16.

It is difficult to provide exact guidelines for the length of the drying period because numerous factors are involved, including:

- Quantity and moisture content of sludge disposed.
- Method of sludge disposal.
- Net soil evaporation rate and precipitation occurring during the days following disposal.
- Soil texture and infiltration rate.

Generally, if dewatered sludge is disposed and/or the sludge is incorporated into the soil during disposal, drying periods between each spreading activity can be short (2 to 3 days), providing the weather is favorable. When liquid sludge is spread to the soil surface without soil incorporation, the drying periods should be longer

(5 to 20 days), depending upon the quantity applied, topography, soil properties, and weather. Figure 7-38 shows suggested periods between each sludge spreading activity as a function of the type of sludge (liquid or dewatered), whether the sludge is incorporated into the soil, and disposal rate. This figure is based on experience at a limited number of DSD sites reviewed and is provided for general guidance only.

Aerobic conditions in the soil are more easily maintained by lighter disposal of sludge at more frequent intervals. For example, referring to the upper curve in Figure 7-38 for liquid sludge that is not incorporated into the soil, disposal of 11 mt/ha (5 T/ac) at 7-day intervals are generally preferable to disposal of 31 mt/ha (14 T/ac) at 20-day intervals. The heavier sludge disposal is more likely to cause anaerobic soil conditions conducive to odors and vector breeding.

7.7.6 Land Area Needs

Availability of sufficient land area is an essential consideration in selecting a DSD site. Oftentimes, DSD sites are located on land owned by a municipality. The high sludge disposal rates at DSD sites minimize land requirements (compared to land application options, such as spreading sludge on agricultural land) by maximizing sludge disposal rates per hectare.

Land area needs for a DSD site include land needed for sludge disposal, sludge storage, buffer areas, surface runoff control, and supporting facilities. Each of these needs is discussed below. The prudent designer will incorporate appropriate factors into the design to allow for possible future expansion.

7.7.6.1 Land Needed for Sludge Disposal

Once the acceptable sludge disposal (spreading) rate has been determined (as discussed in Section 7.7.5 above), a simple calculation can be used to define the area needed for sludge disposal. The calculation involves dividing the annual disposal/spreading rate into the total estimated quantity of sludge (both present and future) to be disposed annually, as shown below:

Area required =

$$\frac{\text{Maximum estimated amount of sludge be disposed of annually (dry weight)}}{\text{Annual disposal/spreading rate (dry weight/unit area)}}$$

7.7.6.2 Land Needed for Sludge Storage

Sludge storage is virtually always required at DSD sites because adverse weather or other factors prevent the continuous spreading of sludge at the site. Storage may be located at the POTW, at the DSD site, or both. At a minimum, the sludge storage facilities should have sufficient capacity to retain all sludge generated during non-spreading periods. Liquid sludge is typically stored in lined lagoons or metal tanks. Dewatered sludge is typically stored by mounding in areas protected from runoff. Odor controls are often needed for sludge lagoons, as

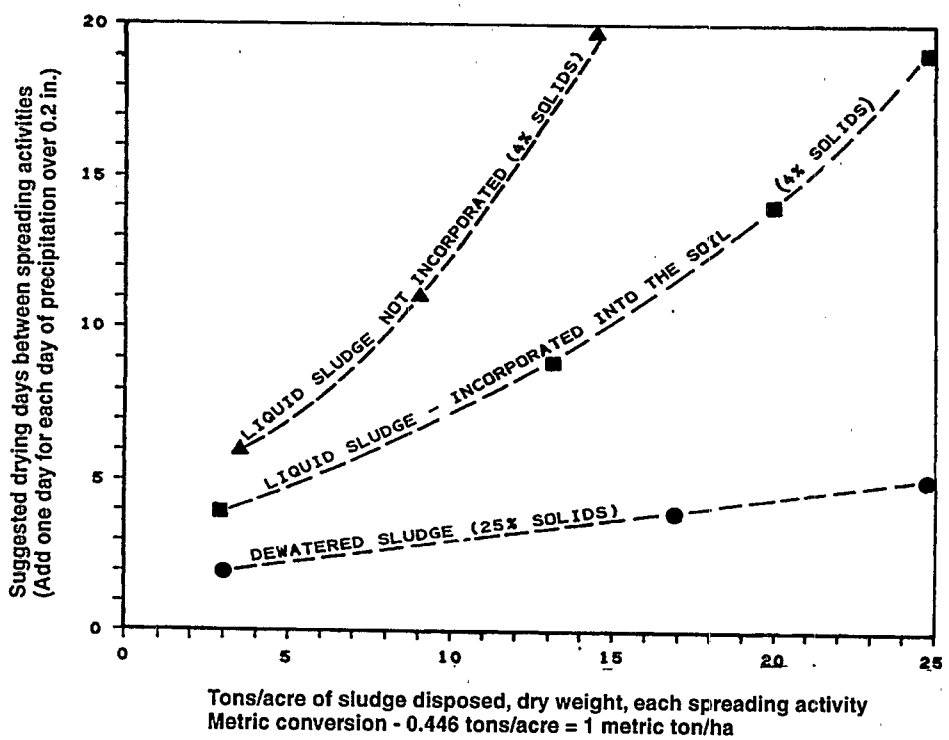


Figure 7-38. Suggested drying days between sludge activities at DSD sites for average soil conditions and periods of net evaporation <2 in./mo.

discussed in the section on "Aesthetics at DSD Site" in Chapter 9.

If sludge is stored for less than two years, the area is not considered to be final disposal and is not covered under Part 503. If, however, sludge is placed on an area of land for more than two years, that land area is considered a final surface disposal site, and, in addition to the area on which sludge is spread on the land, this "storage" area must also meet the Part 503 surface disposal requirements. Often the relevant regulatory agency will stipulate the minimum number of days for which sludge storage must be provided at a site (e.g., one-month or two-month storage).

One method for estimating the storage capacity needed for sewage sludge involves estimating the maximum volume of sewage sludge to be disposed each day at the DSD site, the percentage of solids the sludge contains, and the number of storage days to be provided. These estimations should include climatic and soil considerations (discussed later in this chapter) and a safety factor. The project designer should increase the minimum storage requirement by a safety factor of 20 to 50 percent to cover years with unusual weather and other contingencies. An example calculation for this approach is:

Assuming:

- The average rate of dry sludge solids to be disposed at the DSD site is 589 kg/day (1,300 lb/day).
- The sewage sludge contains 5 percent solids on the average.
- 100 days of storage are to be provided.

Then:

$$\frac{589 \text{ kg/day}}{0.05 (\% \text{ solids})} = 11{,}778 \text{ kg/day (26,000 lb/day) of liquid sludge to be stored.}$$

11,778 kg/day = 11,778 liters (l)/day (3,118 gal/day) of liquid sludge to be stored.

11,788 l/day x 100 days = 1.2 mil l (312,000 gal) of storage required.

A more sophisticated method of calculating sludge storage needed is to prepare a mass flow diagram of projected cumulative sludge generation and disposal at the DSD site, as shown in Figure 7-39. The figure shows that the minimum sludge storage requirement for the system is approximately 1.2×10^6 gal (4.54×10^6 l), which represents 84 days of sludge volume storage.

Even more accurate approaches can be used to calculate required sludge storage volume. For example, if open lagoons are used for sludge storage, the designer can calculate volume additions resulting from precipitation and volume subtractions resulting from evaporation from the storage lagoon surface.

Once the necessary storage volume has been established, the land area required for either liquid sludge lagoons or dewatered sludge stockpiles can be determined based on depth, height, freeboard, berm construction area, etc. As a rough approximation, the land area required equals three times the volume of the sludge to be stored divided by the depth (or height) of the material stored. For example, assume that one million L (35,310 ft^3) of liquid sludge storage is required and the liquid depth of the lagoon is 3 m (9.8 ft). The approximate area required equals 1,000 m^2 (10,800 ft^2).

Storage capacity can be provided by:

- Lagoons
- Tanks (open top or enclosed)
- Digesters
- Stockpiles

These sludge storage methods are summarized briefly below. For a more detailed discussion on sewage sludge storage options, see EPA's *Process Design Manual for Sludge Treatment and Disposal* (U.S. EPA, 1979).

Lagoons are usually the least expensive way to store sludge. With proper design, lagoon detention will also provide additional stabilization of the sludge and reduce pathogens. Several types of lagoons have been used for sludge storage, including:

- Facultative sludge lagoons
- Anaerobic liquid sludge lagoons
- Aerated storage basins
- Drying sludge lagoons

Various types of tanks also can be used to store sludge. In most cases, tanks are an integral part of the sludge treatment processes of the POTW and their design includes storage capabilities. Three common types of tanks used for sludge storage include:

- Imhoff and community septic tanks
- Holding tanks
- Unconfined hoppers and bins

Many sewage treatment plants do not have separate sludge retention capacity but rather rely on portions of the digester volume for storage. When available, an unheated sludge digester may provide short-term storage capacity. In anticipation of periods when sludge cannot be disposed on the DSD site, digester supernatant withdrawals can be accelerated to provide storage for several weeks of sludge volume (U.S. EPA, 1978a).

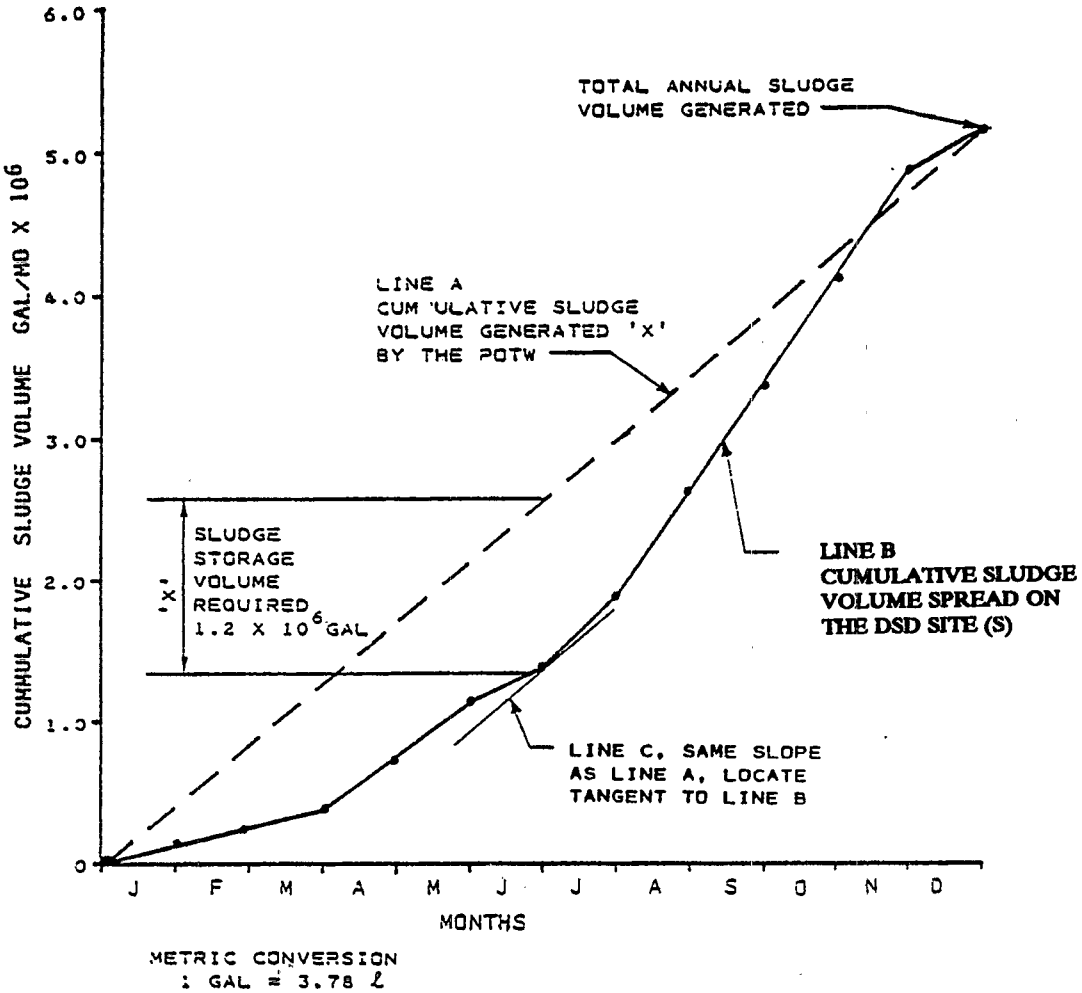


Figure 7-39. Example of mass flow diagram using cumulative generation and cumulative sludge spreading to estimate storage requirements at a DSD site.

Stockpiling is a temporary storage method for sludge that has been stabilized and dewatered or dried to a concentration (about 20 to 60 percent solids) suitable for mounding with bulldozers or loaders. The sludge is mounded into stockpiles 2 to 5 m (6 to 15 ft) high, depending on the quantity of sludge and the available land area. Periodic turning of the sludge helps to promote drying and maintain aerobic conditions. The process is most applicable in arid and semiarid regions, unless the stockpiles are covered to protect against rain. Enclosure of stockpiles may be necessary to control runoff.

7.7.6.3 Land Needed for Buffer Zone

If the DSD site is meeting the Part 503 pollutant limits for arsenic, chromium, and nickel at surface disposal sites (rather than having a liner and leachate collection system onsite to meet this Part 503 requirement), then the distance of the actively used portions of the DSD site from the property boundary will determine the specific pollutant limits that must be met (see Chapter 4).

The desired width of an acceptable buffer zone will vary, depending on surrounding land use and the potential for odor, dust, and noise resulting from the site. A minimum buffer of 150 m (500 ft) is suggested around any DSD site. A minimum buffer of 600 m (2,000 ft) is suggested around DSD sites when one or more of the following conditions will exist:

- Liquid sludge is stored at the site in open lagoons.
- Liquid sludge is spread on the soil surface and is not quickly incorporated by discing.
- Liquid sludge is sprayed using a wide coverage spray device.
- Residential dwellings or other heavily used public areas are adjacent to the DSD site.
- Sludge disposal rates are high and it is anticipated that anaerobic soil conditions will periodically result.

While difficult to quantify, the desirable width of a buffer zone is also a function of the size of the operation (e.g.,

volume of sludge disposed and the disposal area). The larger the operation, the more buffer area is desirable simply because the magnitude of potential nuisance to surrounding property is greater.

7.7.7 Proximity to Community Infrastructure

Another important consideration in designing a DSD site is its location relative to local infrastructure, including:

- Availability of a sewerage system to manage surface runoff and/or leachate.
- Proximity to a treatment plant to maintain reasonable sludge transportation costs.
- Accessibility to transport (e.g., roads and/or pipelines).

7.7.8 Climate Considerations

Information on local climatic conditions is used in many aspects of the DSD site design, including:

- Designing surface runoff collection, storage, and control structures.
- Determining necessary sludge storage capacity.
- Determining the area requirements for sludge spreading.
- Determining any necessary leachate collection and storage systems.

The designer should obtain the following historical climatic information for the past 20 years:

- Precipitation, by month and year (average and maximum).
- 25-year storm intensity (for which control is required by Part 503); also 50- and 100-year storms.
- Evaporation rate from water surface, by month and year (average and minimum).
- Annual number of days of precipitation over 0.3 cm (0.1 in) (average and maximum).
- Annual number of days below freezing (average and maximum).

In addition, it is useful to know the local evaporation rate from soils (usually about 70 percent of the rate from water surfaces). This information may be available from local university agricultural extension services or federal agencies. Generally, a site located in a temperate, arid climate is preferable for its high net evaporation.

7.7.9 Design Considerations At Beneficial DSD Sites

Some DSD sites are considered beneficial DSD sites because vegetation is grown on the site. The Part 503 regulation states that no crop production or grazing can be conducted at any surface disposal site, including beneficial DSD sites, unless the owner/operator can demonstrate to the permitting authority that, through management practices, public health and the environment will be protected from any reasonably anticipated adverse effects of pollutants in sewage sludge when crops are grown or animals are grazed. Growing vegetation at a beneficial DSD site has both major advantages and disadvantages, as discussed in Table 7-18. Beneficial DSD sites are discussed further in Chapter 9.

7.8 Environmental Safeguards at Surface Disposal Sites

Ground-water protection is the most difficult and costly environmental control measure required at many sewage sludge surface disposal sites. Additionally, contamination of surface water and methane gas buildup must be avoided. Design concepts that minimize or prevent adverse environmental impacts from surface drainage and methane gas migration at surface disposal sites are presented below. Other environmental controls are discussed in Chapter 8, Operations, since their control is more a function of operation than design.

7.8.1 Leachate Controls

Leachate can be generated simply from the excess moisture in the sewage sludge received at a surface disposal facility. Rainfall on the surface of the disposal unit can add a limited amount of water to the interred sludge. The surface of the disposal unit should be

Table 7-18. Advantages and Disadvantages of Dedicated Beneficial Use Sites

Advantages	1. If surface soil is "tight" and drains poorly, the plant root structure may improve soil drainage.
	2. Plants will enhance water removal through evapotranspiration.
	3. Plants will help to reduce surface runoff volume from precipitation.
	4. Plants will take up a portion of the nitrogen, metals, and other sludge constituents applied by incorporating them during growth. If the plants are harvested and used or disposed in a controlled manner, the constituents incorporated in the plants are removed from the site.
	5. The DSD site will more closely resemble a normal farming operation and be more visually pleasing to the public.
	6. Some of the sludge nutrients will be recycled into vegetation and may serve as a positive public relations factor to many citizens.
	7. Harvesting of the plants and their sale may provide a monetary return.

Table 7-18. Advantages and Disadvantages of Dedicated Beneficial Use Sites (continued)

Disadvantages	1. Sludge spreading scheduling is more complex since it usually must operate around the seeding, cultivation, and harvesting operations. Planted areas may be "off limits" for high rate sludge disposal during many months, often the best months for sludge disposal from an operations viewpoint.
	2. Planting, cultivation, and harvesting of plants can be labor and equipment intensive. Capital equipment and operating costs are increased over those for a DSD site that does not grow and harvest vegetation. Management is more complex since agronomic considerations are added to the primary mission of sludge management.
	3. The area required for a DSD site may be larger with vegetation involvement than for a project with no vegetation.
	4. Planted areas attract animals that could become a nuisance or serve as vectors.
	5. Planted areas may result in more unauthorized public entry, e.g., children climbing fences.
	6. Harvested plants may contain metal concentrations too high for human or animal consumption necessitating controlled disposal.
	7. After years of heavy sludge disposal, the soil may become phytotoxic to plants effectively ending any potential for agricultural operations at the site.

sloped enough to cause most of the rainfall to drain. Other stormwater runoff must be diverted around the disposal unit, and the unit must be located above historically high ground-water elevations. These positive controls will minimize the quantity of leachate generated.

Leachate may enter into the water system essentially through two pathways:

- Percolation of the leachate, laterally or vertically, through soil into the ground-water aquifers.
- Runoff of leachate outcroppings into surface waters.

Careful site selection and attention to design considerations can prevent or minimize leachate contamination of ground water and surface water. The control of leachate may be accomplished through:

- Natural conditions and attenuation (Section 6.4 and 6.5).
- Imported soils or soil amendments used as liners and/or cover (Section 7.5.6.1).
- Membrane liners (Section 7.5.6.2).
- Collection and treatment (Section 7.5.7).

7.8.2 Run-on/Runoff Controls

The purpose of a run-on control system is to collect and redirect surface waters to minimize the amount of surface water entering active sewage sludge units. Run-on control can be accomplished by constructing berms and swales above the filling area that will collect and redirect the water to the stormwater control structures.

Surface water management also is necessary at surface disposal sites to minimize erosion damage to earthen containment structures. Design of a surface water management system requires a knowledge of local precipitation patterns, surrounding topographic features, geologic conditions, and facility design. Surface water management systems do not have to be expensive or complex to be effective. The equipment and materials used for construction of the surface water management system are the same as those used for general earthwork and foundation construction. Construction may include excavation of a series of shallow channels to direct surface water flow, or in some cases, installation of basins to retain rainfall accumulation from sudden, intense storms. Surface water management systems are required for all surface disposal sites. This section provides a general discussion of design criteria for those systems and describes the types of system components. For more information on the materials and construction techniques that may be employed to control run-on/runoff at surface disposal sites, see the reference U.S. EPA (1988a).

The management practices of the Part 503 regulation require the owner/operator of surface disposal units to operate and maintain runoff and run-on management systems capable of collecting and controlling at least the water volume resulting from a 24-hour, 25-year storm.

7.8.2.1 Design Overview

The standard design approach for a surface water control system is to:

- Identify the intensity of the design storm.
- Determine the peak discharge rate.
- Calculate the runoff volume during peak discharge.
- Determine the control system design criteria and the required capacity for the control systems.
- Design the control system.

Identify Design Storm

Information on the 24-hour, 25-year recurring storm can be obtained from Technical Paper 40 *Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 years*, prepared by the Weather Bureau under the Department of Commerce.

Determining Peak Discharge Rate/Calculating Runoff

The two methods commonly recommended by EPA for use in designing surface water management structures are the Soil Conservation Service (SCS) method and the rational method.

SCS Method. A method that is most often appropriate for estimating run-on/runoff and peak discharge rate from a storm's rainfall is the SCS method. This method was originally designed to determine runoff volumes for small agricultural watersheds where insufficient long-term stream flow and precipitation data had been collected, but where soil types, topography, vegetative cover, and agricultural practices had been documented. The SCS method estimates runoff volume from accumulated rainfall and then applies the runoff volume to a simplified triangular unit hydrograph for peak discharge estimation and total runoff hydrograph (U.S. EPA, 1993b). A discussion of the development and use of this method is available in the reference U.S. Department of Agriculture, Soil Conservation Service (1986).

Rational Method. The rational method can be applied when determining peak discharge rates for significantly urbanized areas with largely impervious surface covers. The method is based on the premise that maximum runoff resulting from steady, uniformly intense precipitation will occur when the entire watershed, upstream of the site location, contributes to the discharge (U.S. EPA, 1985a). The method generally is used for areas of less than 200 acres. A discussion of the rational method can be found in U.S. EPA (1988a).

Control System Structures

Surface water management plans can incorporate several structures, both temporary and permanent, into the system design. Table 7-19 provides a list of the most frequently used structures.

Dikes/Berms. Dikes and berms are well-compacted earthen ridges or ledges constructed immediately upslope from or along the perimeter of the intended area of protection. A typical dike design is shown in Figure 7-40. Dikes are intended to provide short-term protection of critical areas by intercepting storm runoff and diverting the flow to natural or man-made drainage channels, man-made outlets, or sediment basins. Typically, dikes and berms should be expected to maintain their integrity for about 1 year, after which they should be rebuilt. Dikes are generally classified into two groups: interceptor dikes, designed to reduce slope length; and diversion dikes, designed to divert surface flow and to reduce slope length. Dikes can also prevent mixing of incompatible wastes and can reduce the amount of leachate produced in a landfill cell by diverting the water available to infiltrate the soil cover. Due to their temporary nature, dikes and berms are designed for runoff from no larger than a 5-acre watershed (U.S. EPA, 1985b).

Swales, Channels, and Waterways. Channels are excavated ditches that are generally wide and shallow with trapezoidal, triangular, or parabolic cross sections. A typical channel design is shown in Figure 7-41. Diversion channels are used primarily to intercept runoff or reduce slope length. Channels stabilized with vegetation or stone rip-rap are used to collect and transfer diverted water off site or to onsite storage or treatment. Applications and limitations of channels and waterways differ depending upon their specific design (U.S. EPA, 1988a).

Swales are placed along the perimeter of a site to keep offsite runoff from entering the site and to carry surface runoff from a land disposal unit. They are distinguished from earthen channels by side slopes that are less steep and have vegetative cover for erosion control (U.S. EPA, 1985b).

The specific design for channels, swales, and waterways must consider local drainage patterns, soil permeability, annual precipitation, area land use, and other pertinent characteristics of the contributing watershed. To comply with the Part 503 regulation, channels and waterways should accommodate the maximum rainfall expected in a 25-year period. Manning's formula for steady uniform flow in open channels is used to design channels and waterways (U.S. EPA, 1985b).

Terraces. Terraces are embankments constructed along the contour of very long or very steep slopes to intercept

Table 7-19. Surface Water Diversion and Collection Structures (U.S. EPA, 1988a)

Technology	Duration of Normal Use
Dikes and berms	Temporary
Channels (earthen and CMP)	Temporary
Waterways	Permanent
Terraces and benches	Temporary and permanent
Chutes	Permanent
Downpipes	Temporary
Seepage ditches and basins	Temporary
Sedimentation basins	Temporary

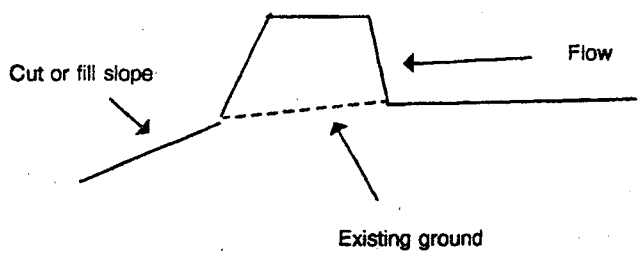


Figure 7-40. Typical temporary diversion dike (U.S. EPA, 1988a).

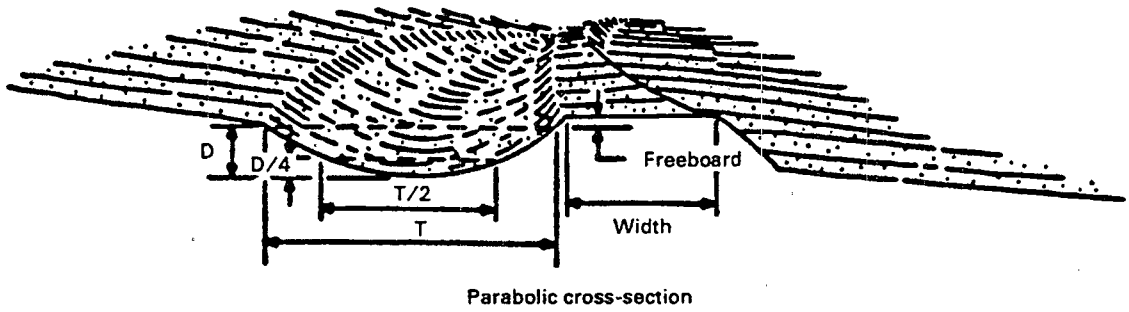


Figure 7-41. Typical channel design (U.S. EPA, 1988a).

and divert flow of surface water and to control erosion of slopes by reducing slope length. A typical terrace design is shown in Figure 7-42. Terraces may function to hydrologically isolate sites, control erosion of cover materials on sites that have been capped, or collect sediments eroded from disposal areas. For disposal sites undergoing final grading, construction terraces may be included as part of the site closure plan (U.S. EPA, 1985b).

Chutes and Downpipes. Chutes and downpipes are usually temporary structures that can play an important role in preventing erosion while monofill and surface impoundment covers are "stabilizing" with vegetation. A typical chute design is shown in Figure 7-43. Chutes are excavated earthen channels lined with non-erodible materials such as bituminous concrete or grouted rip-rap. Downpipes are constructed of rigid piping or flexible tubing and installed with prefabricated inlet sections. As a general rule, chutes should not be used when hydraulic heads are expected to be more than 18 ft (U.S. EPA, 1988a). Downpipes should not be used when the drainage basin is estimated to be larger than 5 acres (U.S. EPA, 1985b).

Seepage Basins and Ditches. Seepage basins and ditches are used to discharge water collected from surface water diversions, ground-water pumpings, or leachate treatment. They also may be used as part of an in situ treatment process to force treatment reagents into the subsurface. A typical seepage basin design is shown in Figure 7-44. They are most effective in highly permeable soils where recharge can occur. Typically, they are used in areas with shallow ground-water tables. Seepage ditches distribute water over a larger area than achievable with basins. They can be used for all soil where permeability exceeds about 0.9 in. per day (U.S. EPA, 1985b).

A seepage basin typically consists of the actual basin, a sediment trap, a bypass for excess flow, and an emergency overflow. A considerable amount of recharge occurs through the sidewalls of the basin, and therefore it is preferable that these be constructed of pervious material such as packed gravel (U.S. EPA, 1985b).

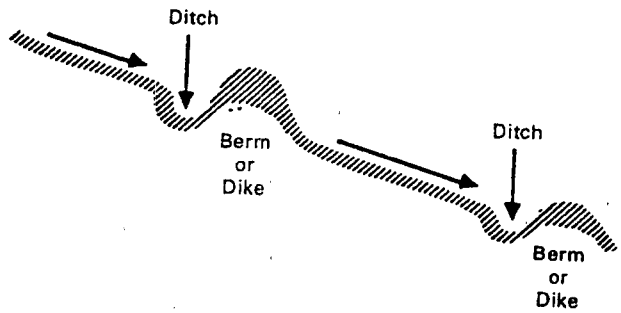


Figure 7-42. Typical terrace design (U.S. EPA, 1988a).

Sedimentation Basins. Sedimentation basins are used to retard surface water flow such that suspended particulates can settle. Sedimentation basins serve as the final step in the control of diverted, uncontaminated surface runoff, prior to discharge. A typical basin design is shown in Figure 7-45. Basins are especially useful in areas where surface runoff has a high silt or sand content. The major components include a principal and emergency spillway, an anti-vortex device, and the basin. The principal spillway consists of a vertical pipe or riser joined to a horizontal pipe that extends through the dike and has an outlet beyond the impoundment. The riser is topped by the anti-vortex device and trash rack, which improves the flow of water into the spillway and prevents floating debris from being carried out of the basin (U.S. EPA, 1985b).

7.8.3 Explosive Gases Control

Under the Part 503 regulation, surface disposal sites that cover active sewage sludge units (either daily or at closure) must limit the concentration of methane gas in the air in any structure within the site, and in the air at the property line of the disposal site (see Section 7.2.1.3).

The accumulation of methane gas in surface disposal structures can potentially result in fire and explosions that can endanger employees, users of the disposal site, and occupants of nearby structures, or cause damage to containment structures. These hazards are preventable through monitoring and through corrective action

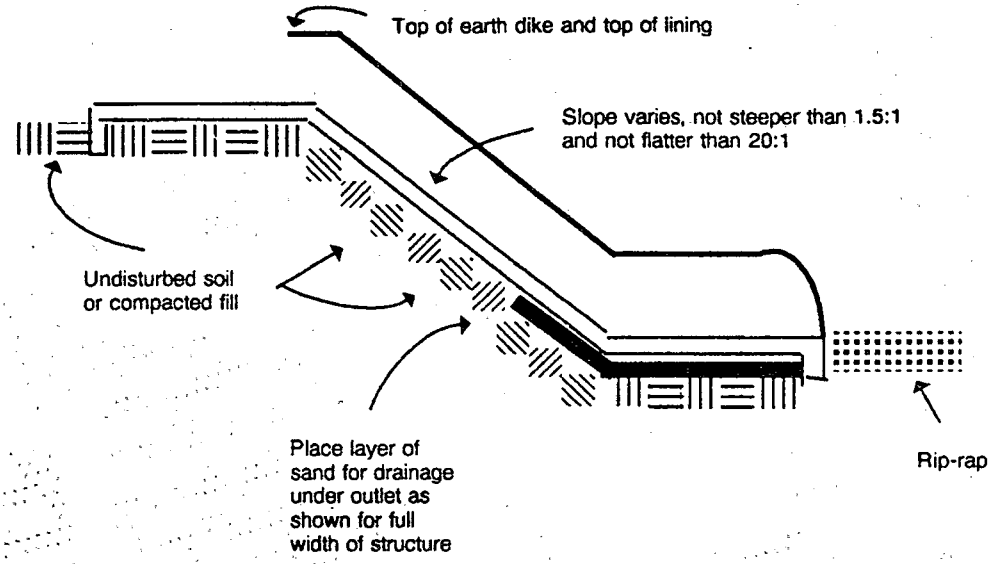


Figure 7-43. Typical paved chute design (U.S. EPA, 1988a).

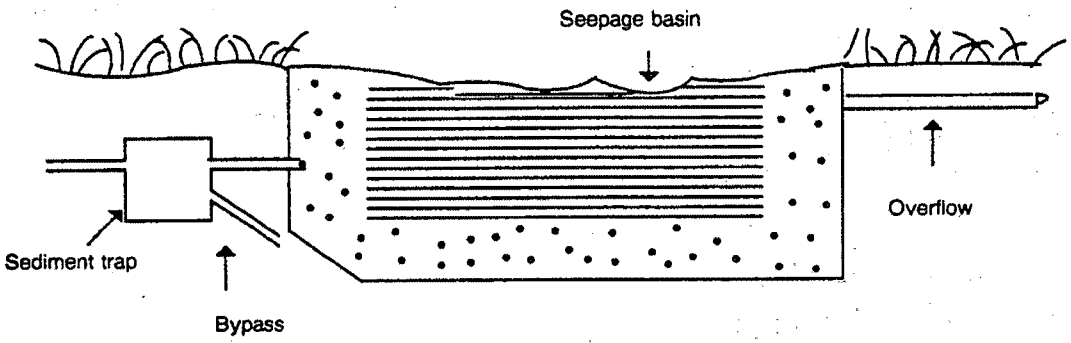


Figure 7-44. Typical seepage basin design (U.S. EPA, 1988a).

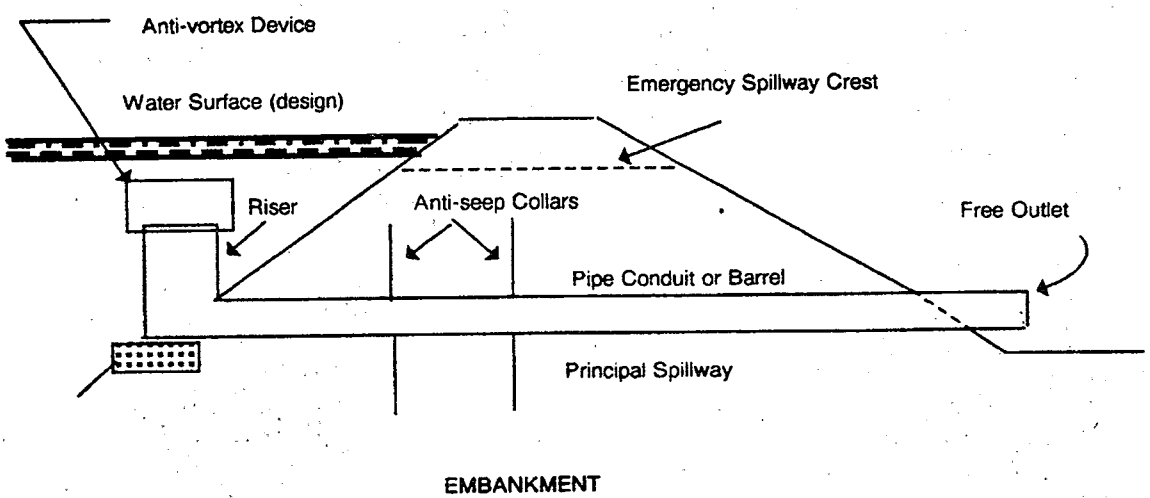


Figure 7-45. Typical sedimentation basin design (U.S. EPA, 1988a).

should methane gas levels exceed specified limits in the facility structures (excluding gas control or recovery system components), or at the facility property boundary.

To implement an appropriate plan for routine monitoring of methane in order to demonstrate compliance with allowable methane concentrations, the characteristics of gas production and migration at a disposal site should be understood. See the reference U.S. EPA (1993b) for a complete discussion of the characteristics of methane gas production.

7.8.3.1 Gas Monitoring

To demonstrate compliance with the Part 503 regulation, the owner/operator must sample air within facility structures where gas may accumulate and in soil at the property boundary. Other monitoring methods may include: sampling gases from probes within the surface disposal unit or from within the leachate collection system; or sampling gases from monitoring probes installed in soil between the surface disposal unit and either the property boundary or structures where gas migration may pose a danger. A typical gas monitoring probe installation is depicted in Figure 7-46 (U.S. EPA, 1993b).

The frequency of monitoring should be sufficient to detect methane gas migration based on subsurface conditions and the changing conditions within the disposal unit such as partial or complete capping, unit expansion, gas migration control system operation or failure, construction of new or replacement structures, and changes in landscaping or land use practices. The rate of methane gas migration as a result of these anticipated changes and the site-specific conditions, provides the basis for establishing a monitoring frequency (U.S. EPA, 1993b).

The number and location of gas probes is also site specific and highly dependent on subsurface conditions, land use, and location and design of facility structures. Monitoring for gas migration should be within the more permeable strata. Multiple or nested probes are useful in defining the vertical configuration of the migration pathway. Structures with basements or crawl spaces are more susceptible to landfill gas infiltration. Elevated structures are typically not at risk (U.S. EPA, 1993b).

Measurements are usually made in the field with a portable methane meter, explosimeter, or organic vapor analyzer. Gas samples also may be collected in glass or metal containers for laboratory analysis. Instruments with scales of measure in "percent of LEL" can be calibrated and used to detect the presence of methane. Instruments of the hot-wire Wheatstone bridge type (i.e., catalytic combustion) directly measure combustibility of the gas mixture withdrawn from the probe. The thermal conductivity type meter is susceptible to interference as the relative gas composition—and, thus, the thermal conductivity—changes. Field instruments should be calibrated prior to

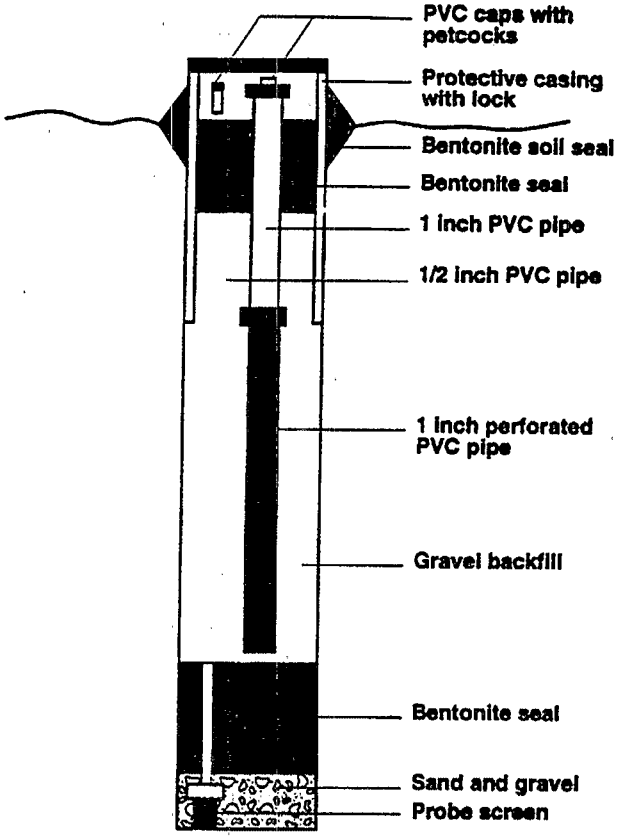


Figure 7-46. Typical gas monitoring probe (U.S. EPA, 1993b).

measurements and should be rechecked after each day's monitoring activity (U.S. EPA, 1993b).

Laboratory measurements with organic vapor analyzers or gas chromatographs may be used to confirm the identity and concentrations of gas. In addition to measuring gas composition, other indications of gas migration may be observed. These include odor (generally described as either a "sweet" or a rotten egg [hydrogen sulfide, or H_2S] odor), vegetation damage, septic soil, and audible or visual venting of gases, especially in standing water. Exposure to some gases can cause headaches and nausea.

If methane concentrations are in excess of 25 percent of the LEL in facility structures or exceed the LEL at the property boundary, the danger of explosion is imminent. Immediate action must be taken to protect human health from potentially explosive conditions. All personnel should be evacuated from the area immediately. Venting the building upon exit (e.g., leaving the door open) is desirable but should not replace evacuation procedures. See Section 10.4.4 for additional information on methane monitoring.

7.8.3.2 Gas Control Systems

Gas from covered surface disposal units may vent naturally or be purposely vented to the atmosphere by verti-

cal and/or lateral migration controls. Systems used to control or prevent gas migration are categorized as either passive or active systems. Passive systems provide preferential flow paths by means of natural pressure, concentration, and density gradients. Passive systems are primarily effective in controlling convective flow and have limited success controlling diffusive flow. Active systems are effective in controlling both types of flow. Active systems use mechanical equipment to direct or control landfill gas by providing negative or positive pressure gradients. Suitability of the systems is based on the design and age of the surface disposal unit, and on the soil, hydrogeologic, and hydraulic conditions of the facility and surrounding environment. Because of these variables, both systems have had varying degrees of success (U.S. EPA, 1993b).

Passive systems may be used in conjunction with active systems. An example of this may be the use of a low-permeability passive system for the closed portion of a monofill unit (for remedial purposes) and the installation of an active system in the active portion of the monofill unit (for future use).

Selection of construction materials for either type of gas control system should consider the elevated temperature conditions within a covered surface disposal unit as compared to the ambient air or soil conditions in which gas control system components are constructed. Because ambient conditions are typically cooler, water containing corrosive waste constituents may be expected to condense. This condensate should be considered in selecting construction materials. Provisions for managing this condensate should be incorporated to prevent accumulation and possible failure of the collection system.

Passive Systems

Passive gas control systems rely on natural pressure and convection mechanisms to vent methane gas to the atmosphere. Passive systems typically use "high-permeability" or "low-permeability" techniques at a site, either singularly or in combination. High-permeability systems use conduits such as ditches, trenches, vent wells, or perforated vent pipes surrounded by coarse soil to vent landfill gas to the surface and the atmosphere (see Figure 7-47). Low-permeability systems block lateral migration through barriers such as synthetic membranes and high-moisture-containing fine-grained soils (U.S. EPA, 1993b).

Passive systems may be incorporated into a surface disposal unit or may be used for remedial or corrective purposes at both closed and active surface disposal units. They may be installed within a surface disposal unit along the perimeter, or between the unit and the disposal facility property boundary. A detailed discussion of passive systems for remedial or corrective purposes may be found in U.S. EPA (1985b).

A passive system may be incorporated into the final cover system of a surface disposal unit closure design and may consist of perforated gas collection pipes, high-permeability soils, or high-transmissivity geosynthetics located just below the low-permeability gas and hydraulic barrier or infiltration layer in the cover system. These systems may be connected to vent pipes that vent gas through the cover system or that are connected to header pipes located along with perimeter of the surface disposal unit. The methane gas collection system also may be connected with a leachate collection system to vent gases in the headspace of leachate collection pipes (U.S. EPA, 1993b).

Some problems have been associated with passive systems. For example, snow and dirt may accumulate in vent pipes, preventing gas from venting. Vent pipes at the surface are also susceptible to clogging by vandalism.

Active Systems

Active gas control systems use mechanical means to remove gas from surface disposal units and consist of either positive pressure (air injection) or negative pressure (extraction) systems. Positive pressure systems induce a pressure greater than the pressure of the migrating gas and drive the gas out of the soil and/or back to the surface disposal unit in a controlled manner. Negative pressure systems extract gas from a surface disposal unit by using a blower to pull gas out of the unit. Negative pressure systems are more commonly used because they are more effective and offer more flexibility in controlling gas migration. The gas may be recovered for energy conversion, treated, or combusted in a flare system. Typical components of a flare system are shown in Figure 7-48. Negative pressure systems may be used as either perimeter gas control systems or interior gas collection/recovery systems. For more information regarding negative pressure gas control systems, refer to U.S. EPA (1985b).

An active gas extraction well is depicted in Figure 7-49. Gas extraction wells may be installed within the surface disposal unit or, as depicted in Figure 7-50a and Figure 7-50b, perimeter extraction trenches could be used. One possible configuration of an interior gas collection/recovery system is illustrated in Figure 7-51. The performance of active systems is not as sensitive to freezing or saturation of cover soils as that of passive systems. Although active gas systems are more effective in withdrawing gas from a surface disposal unit, capital, operation, and maintenance costs of such systems will be higher as these costs can be expected to continue throughout the post-closure period. At some future time, owners and operators may wish to convert

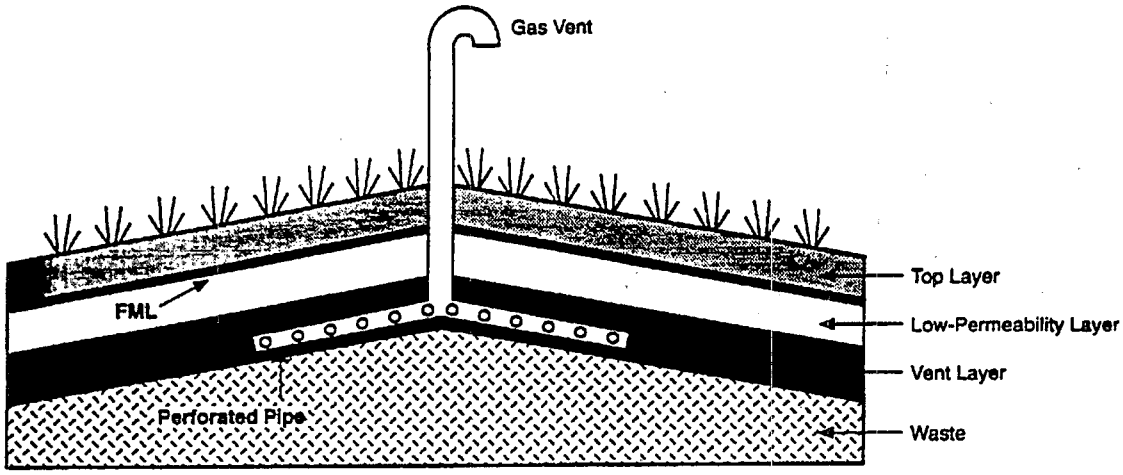


Figure 7-47. Passive gas control system (venting to atmosphere) (U.S. EPA, 1993b).

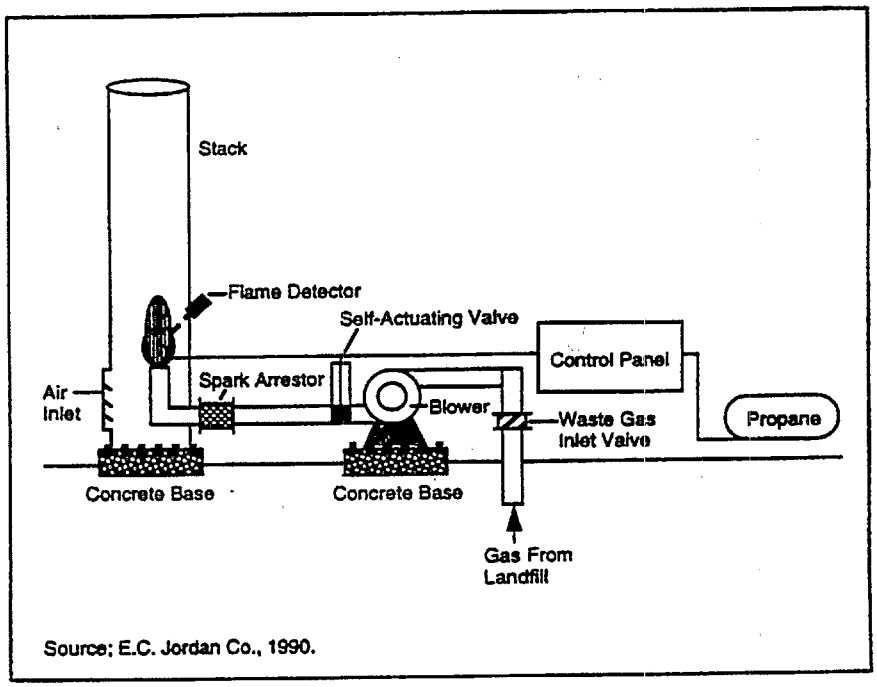


Figure 7-48. Example schematic diagram of a ground-based landfill gas flare (U.S. EPA, 1993b).

active gas controls into passive systems when gas production diminishes. The conversion option and its environmental effect (i.e., gas release causing odors, and health and safety concerns) should be addressed in the original design.

There are many benefits to recovering gas from surface disposal units. Monofill gas recovery systems can reduce monofill gas odor and migration, can reduce the danger of explosion and fire, and may be used as a source of revenue that may help to reduce the cost of closure. For more information on the benefits to recovering monofill gas, see the references U.S. EPA (1993b) and SWANA (1992).

7.9 Other Design Features

7.9.1 Access

At a minimum, a permanent road should be provided from the public road system to the site. For larger sites, the roadway should be 20 to 24 ft (6 to 7 m) wide for two-way traffic. For smaller operations a 15 ft (5 m) wide road can suffice. Additionally, the roadway should be gravel surfaced at the least, in order to provide access regardless of weather conditions. Grades should not exceed equipment limitations. For loaded vehicles, most uphill grades should be less than 7 percent and downhill grades less than 10 percent.

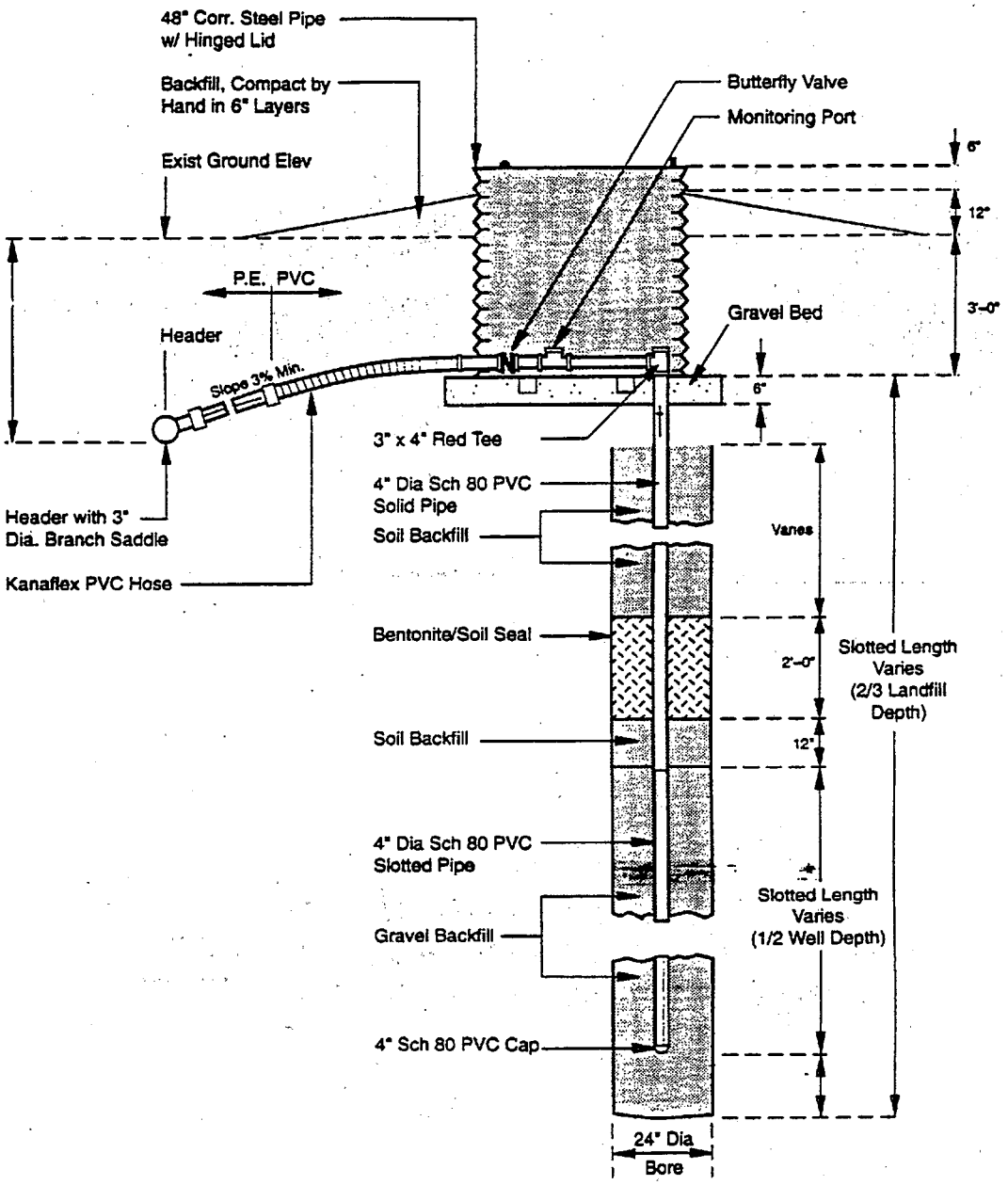


Figure 7-49. Example of a gas extraction well (U.S. EPA, 1993b).

Temporary roads are used to deliver sludge to the working area from the permanent road system. Temporary roads may be constructed by compacting the natural soil present and by controlling drainage, or by topping roads with a layer of gravel, crushed stone, cinders, crushed concrete, mortar, bricks, lime, cement, or asphalt binders to make the roads more serviceable.

Under the Part 505 regulation, access to surface disposal sites must be restricted (see Section 7.2.1.4). Fencing with gates that lock might be necessary to restrict access in densely populated areas. Natural barriers such as hedges, trees, embankments, or ditches, along with warning signs might be adequate in less-populated areas. In remote areas, it might be sufficient to post warning signs that say, "Do not enter," "No trespassing," or "Access restricted to authorized personnel only." Such posting also might be sufficient where there has been a low-rate application of sewage sludge.

7.9.2 Soil Availability

The quantity and adequacy of onsite soil for use as a bulking agent and for covering sludge will have been determined during the site selection process. The logistics of soil excavation, stockpiling, and consumption,

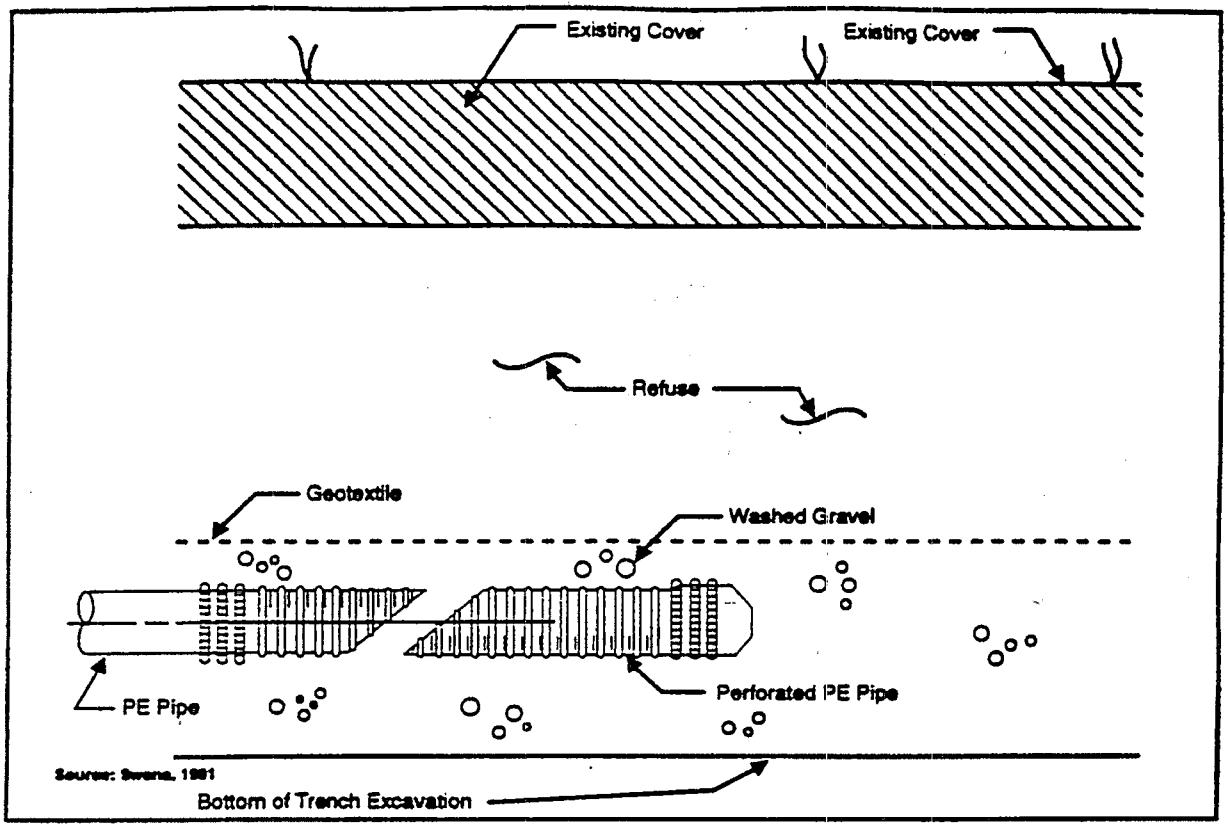


Figure 7-50a. Perimeter extraction trench system (U.S. EPA, 1993b).

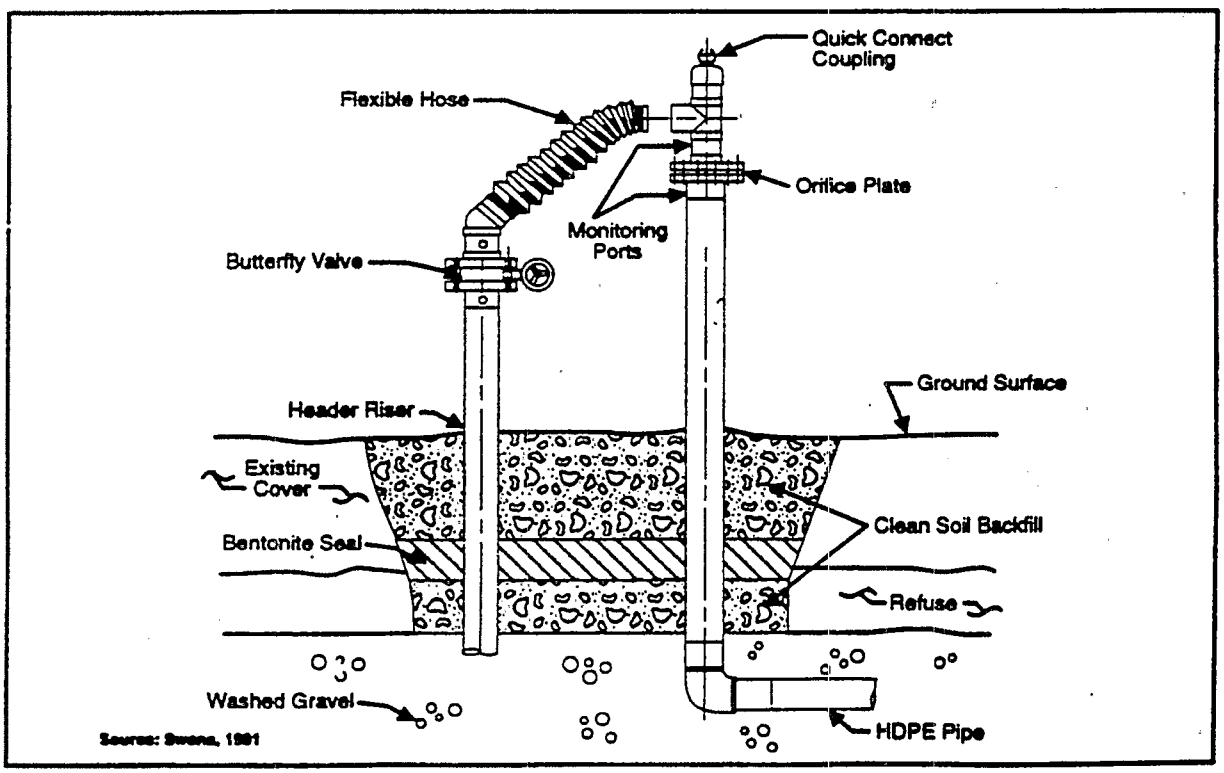


Figure 7-50b. Perimeter extraction trench system (U.S. EPA, 1993b).

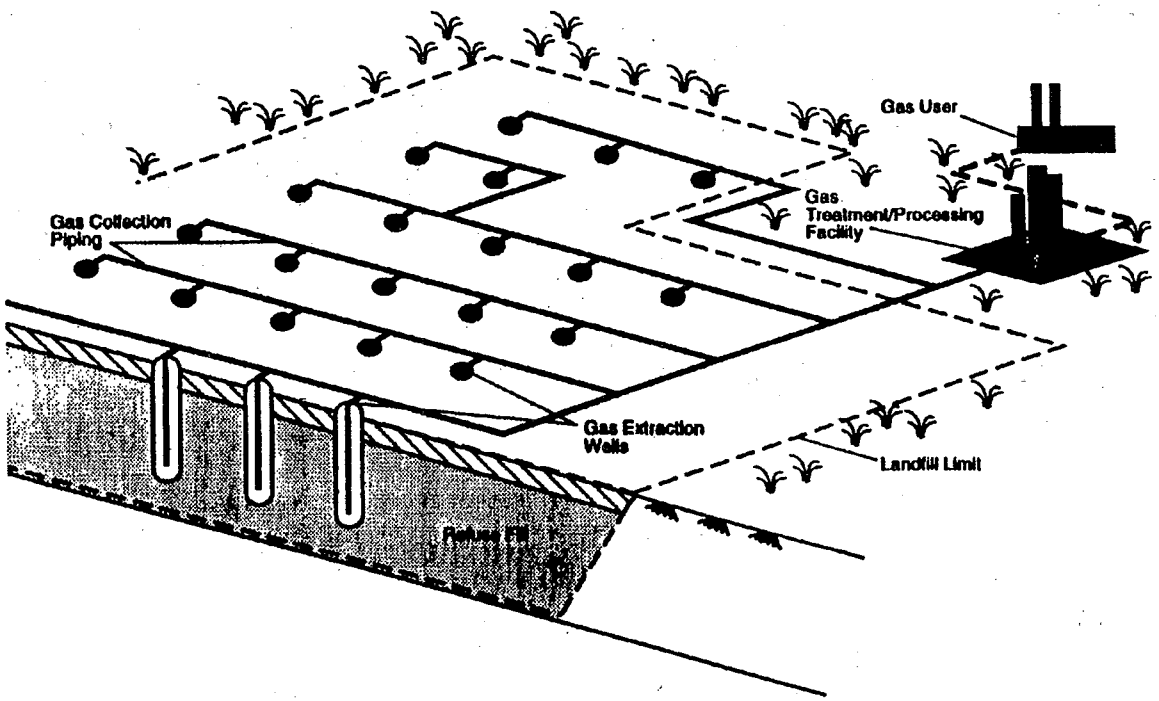


Figure 7-51. Example of an interior gas collection/recovery system (U.S. EPA, 1993b).

however, are more thoroughly evaluated during design. Excavation and stockpiling of soil must be closely coordinated with soil use for the following reasons:

- Soil determined to be suitable for use and readily excavated may be located in selected areas of the site. The excavation plan should designate that these areas be excavated before filling has proceeded atop them.
- Accelerated excavating programs may be desirable during warm weather to prevent the need to excavate frozen soil during cold weather.
- Soil stockpiles should be located so that runoff will not be directed into future adjacent excavations and/or sludge filling areas and to minimize erosion.

7.9.3 Special Working Areas

Special working areas should be designated on the site plan for inclement weather or other contingency situations. Access roads to these areas should be of all-weather construction and the area kept grubbed and graded. Arrangements for special working areas may include locating such areas closer to the surface disposal site entrance gate (Figure 7-52).

7.9.4 Buildings and Structures

At larger surface disposal sites or where climates are extreme, a building should be provided for office space and employee facilities. Since most surface disposal units operate year-round, regardless of weather, some protection from the elements should be provided for the employees. Sanitary facilities should be provided for both operation and hauling personnel. At a large site, a building might be provided for equipment storage and maintenance. At smaller sites, buildings cannot be justified, but trailers might be warranted.

Buildings on sites that will be used for less than 10 years can be temporary, mobile structures. The design and location of all structures should consider gas movement and differential settlement caused by decomposing sludge.

7.9.5 Utilities

Large surface disposal sites should have electrical, water, communication, 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 can be trucked in; and an electric generator can be used instead of having power lines run onto the site.

Water should be available for drinking, dust control, washing mud from haul vehicles before entering the public road, and employee sanitary facilities. A sewer line may be desirable, especially at large sites and at those where leachate is collected and treated with domestic wastewater. Telephone or radio communications may be necessary since accidents or spills

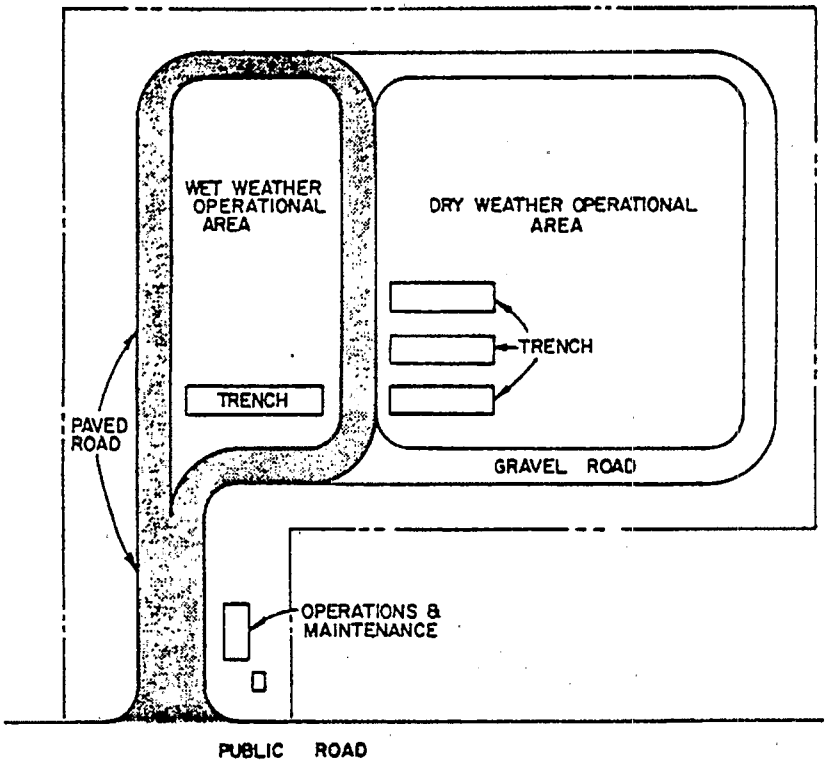


Figure 7-52. Special working area.

can occur that necessitate the ability to respond to calls for assistance.

7.9.6 Lighting

If dumping operations occur at night, portable lighting should be provided at the operating area. Alternatively, lights may be affixed to haul vehicles and onsite equipment. These lights should be situated to provide illumination to areas not covered by the regular headlights of the vehicle.

If the site has structures (e.g., employee facilities, administrative offices, equipment repair or storage sheds), or if there is an access road in continuous use, permanent security lighting might be desirable.

7.9.7 Wash Rack

For surface disposal units where operational procedures call for frequent contact of equipment with the sludge, a cleaning program should be implemented. Portable steam cleaning units or high-pressure washers may be used. A curbed wash pad and collection basin may be constructed to collect and contain contaminated wash water. The contaminated water may be either pumped to a septic tank/soil absorption system or dispersed with the sludge. The washing facility should be used to clean mud from haul vehicles, in order to keep sludge and mud off the highway.

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Chapter 8
Surface Disposal of Domestic Septage

Domestic septage is defined in the Part 503 regulation as the liquid or solid material removed from a septic tank, cesspool, portable toilet, Type III marine sanitation device, or a similar system that receives only domestic sewage (household, non-commercial, non-industrial sewage) (see Section 3.2.2). Table 3-2 in Chapter 3 lists some characteristic of septage.

The most common, and usually most economical, method of domestic septage disposal is land application (e.g., land spreading, irrigation, overland flow) which is not addressed in this manual. Disposal at an existing wastewater treatment plant is a viable and economical option if the plant is reasonably close to the source and has adequate processes and capacity to handle the domestic septage.

Surface disposal practices for domestic septage include placement in monofills (trenches), lagoons, and municipal solid waste landfills.

8.1 Regulatory Requirements for Surface Disposal of Domestic Septage

The regulatory requirements for the surface disposal of domestic septage are not as extensive as those for sewage sludge. Neither the pollutant limits nor the pathogen requirements of Part 503 apply if domestic septage is placed on an active sewage sludge unit. The regulation does, however, specify requirements for vector attraction reduction for domestic septage that is surface disposed.

Two alternatives are available for placing domestic septage on an active sewage sludge unit (see Options 9-12, Table 3-9 in Chapter 3). One alternative is to achieve vector attraction reduction by raising the pH of the domestic septage to 12 with alkali addition for 30 minutes, and maintaining the pH at 12 or greater for 30 minutes without adding more alkali. If pH reduction is used to achieve vector attraction reduction, each container of domestic septage must be monitored for compliance. The person who placed the domestic septage on the active sewage sludge unit must then certify that vector attraction reduction was achieved (see Figure 8-1) and develop a description of how it was achieved. The certification and the description must be kept for 5 years.

If vector attraction reduction is not achieved by alkali addition (as described above), the owner or operator of the surface disposal site must achieve vector attraction reduction by injecting or incorporating the domestic septage into the soil, or by covering it with soil daily. Certification that all these requirements have been met and a description of how they were met must be developed and maintained for 5 years. (Figure 8-1 shows the required certification statement.)

If domestic septage is placed in a monofill (such as a trench), surface impoundment, dedicated disposal site or other sludge-only surface disposal site, its disposal is covered by the requirements in the Part 503 regulation for such disposal sites (except for requirements for pollutant limits and pathogen reduction). These requirements are discussed further in Chapters 3, 4, 5, 7, 9, and 10.

If domestic septage is placed in a municipal solid waste landfill, its disposal is covered by the requirements of 40 CFR Part 258 for the disposal of non-hazardous waste. These requirements are discussed in Section 3.4.3. Note that because of the requirement that waste pass the Paint Filter Liquids Test (see Section 3.4.3), domestic septage must be dewatered so that it contains no free liquid before it can be placed in a municipal solid waste landfill.

Compliance with federal regulations governing domestic septage does not ensure compliance with state requirements. State programs may not define domestic septage the same way as the federal regulations. In addition, state requirements may be more restrictive or may be administered in a different manner from the federal regulation. It is important to check with the state septage coordinator to find out about state requirements.

8.2 Domestic Septage Disposal Lagoons

The use of lagoons for septage disposal is a common alternative in rural areas. As discussed in Section 7.5.3, if the lagoon is not part of the treatment process then these lagoons are considered surface disposal sites under the Part 503 rule.

An individual placing domestic septage on a surface disposal site must maintain the following certification statement for 5 years:

> "I certify, under penalty of law, that the vector attraction reduction requirements in §503.33(b)(12) have/have not been met. This determination has been made under my direction and supervision in accordance with the system designed to ensure that qualified personnel properly gather and evaluate the information used to determine that the vector attraction requirements have been met. I am aware that there are significant penalties for false certification, including the possibility of fine and imprisonment."

The owner or operator of the surface disposal site must maintain the following certification statement for 5 years:

> "I certify, under penalty of law, that the management practices in §503.24 and the vector attraction reduction requirements in [insert §503.33(b)(9) through §503.33(b)(11) when one of those requirements is met] have/have not been met. This determination has been made under my direction and supervision in accordance with the system designed to ensure that qualified personnel properly gather and evaluate the information used to determine that the management practices [and the vector attraction requirements, if appropriate] have been met. I am aware that there are significant penalties for false certification, including the possibility of fine and imprisonment."

Signature _____ Date _____

Figure 8-1. Certifications required when domestic septage is placed in a surface disposal site (U.S. EPA, 1994).

Domestic septage disposal lagoons are usually a maximum of 1.8 m (6 ft) deep and allow no effluent or soil infiltration. These lagoons require placement of domestic septage in small incremental lifts (15 to 30 cm, or 6 to 12 in.) and sequential loading of multiple lagoons for optimum drying. Most are operated in the unheated anaerobic or facultative stage. Odor problems may be reduced by placing the lagoon inlet pipe below liquid level and having water available for haulers to immediately wash any spills into the lagoon inlet line (U.S. EPA, 1994). Section 7.5.3 presents detailed information about lagoon design.

8.3 Monofills (Trenches) for Domestic Septage Disposal

Domestic septage is placed sequentially in multiple trenches in small lifts, 15 to 20 cm (6 to 8 in.), to minimize drying time. When the trench is filled with domestic septage, 0.6 m (2 ft) of soil should be placed as a final covering, and new trenches opened. An alternate management technique allows a filled trench to remain uncovered to permit as many solids to settle, as well as liquids to evaporate and leach out, as possible. Then the solids, as well as some bottom and sidewall material, are removed and the trench is reused (U.S. EPA, 1984).

Additional information on monofills is presented in Section 7.5.2.

8.4 Codisposal at Municipal Solid Waste Landfill Unit

Design information for codisposal at a municipal solid waste landfill is presented in Section 7.6; codisposal operation is discussed in Section 9.3.3.

8.5 References

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Chapter 9
Operation

9.1 Purpose and Scope

The purpose of this chapter is to introduce an approach for implementing a sewage sludge disposal operation. The operation of a sewage sludge surface disposal site can be viewed as an ongoing construction project. As with any construction project, it must proceed according to detailed plans. Unlike conventional construction, however, the operating parameters of a sewage sludge surface disposal site often change and may require innovative alterations and contingency plans. An effective operation requires a detailed operational plan and a choice of equipment compatible with the sludge characteristics, the site conditions, and the selected active sewage sludge unit.

9.2 Regulations

9.2.1 Part 503

9.2.1.1 Management Practices That Affect the Operation of Surface Disposal Sites

The Part 503 rule includes management practices that affect the daily operation of surface disposal sites. These management practices must be followed when sewage sludge is placed on a surface disposal site because they help protect human health and the environment from the reasonably anticipated adverse effects of pollutants in sewage sludge (U.S. EPA, 1994). The following management practices are addressed in Chapter 7:

- Collection of Runoff (Section 7.2.1.1 and Section 7.8.2).
- Collection of Leachate (Section 7.2.1.2 and Section 7.5.7).
- Limitations on Methane Gas Concentrations (Section 7.2.1.3 and Section 7.8.3).
- Restrictions of Public Access (Section 7.2.1.4 and Section 7.9.1).
- Protection of Ground Water (Section 7.2.1.5).

The following management practices required under Part 503 also impact the operation of a surface disposal site (U.S. EPA, 1994):

- *Restrictions on Crop Production.* Food, feed, or fiber crops may not be grown on an active sewage sludge unit unless approved by the permitting authority. The owner or operator of the surface disposal site must demonstrate to the permitting authority through management practices that public health and the environment are protected if crops are grown. If the owner/operator wishes to grow crops on the site, he or she must obtain permission from the regulatory agency. If permission is granted the owner/operator will be required to implement certain management practices to ensure that unsafe levels of pollutants are not taken up by crops that are eaten by people. These special management practices might include testing crops for the presence of pollutants and testing animal tissue for the presence of pollutants if animal feed is produced on the site, or setting a monitoring schedule for the crops and any animal feed products derived from the site.
- *Restrictions on Grazing.* Animals must not be allowed to graze on an active sewage sludge unit unless approved by the permitting authority. The owner/operator of a surface disposal site must demonstrate to the permitting authority that public health and the environment are protected if animals are allowed to graze. If the owner/operator wishes to graze animals on the site, he or she must obtain a permit. The permit would require specified management practices, such as monitoring the concentration of pollutants in any animal product (dairy or meat). This restriction on grazing helps ensure that unsafe levels of pollutants do not find their way into animals from which people obtain food.

A site on which the production of crops and/or grazing is allowed is considered a dedicated beneficial use site. (Operational considerations at beneficial TINE sites are discussed in Section 9.3.4.3 of this chapter.)

9.2.1.2 Operational Standards for Pathogen and Vector Attraction Reduction

Pathogens are disease-causing organisms, such as certain bacteria and viruses, that might be present in sewage sludge. Vectors are animals, such as rats, or

insects, such as flies, that might be attracted to sewage sludge and can spread disease after coming into contact with sewage sludge. The Part 503 rule includes requirements concerning the control of pathogens and the reduction of vector attraction for sewage sludge placed on an active sewage sludge unit site. Sewage sludge can be placed in an active sewage sludge unit only if the pathogen and vector attraction reduction requirements are met (see Section 3.4.2.2, Section 3.4.2.3, and Table 3-9).

To meet pathogen and vector attraction reduction requirements under Part 503 the following daily operation should take place (U.S. EPA, 1994):

- For pathogen reduction, either the sewage sludge placed on an active sewage sludge unit must meet Class A or Class B pathogen requirements, or a cover (soil or other material) must be placed on the active sewage sludge unit at the end of each day. If a daily cover is placed on the active sewage sludge unit, no other pathogen reduction requirements apply (see Section 3.4.2.2).
- For vector attraction reduction, one of several options listed in Table 3-4 must be met. These include placing a daily cover on the active sewage sludge unit, or, injecting or incorporating the sewage sludge into the soil (see Section 3.4.2.3).

In most cases, owners or operators of surface disposal sites will place a daily cover on the active sewage sludge unit to meet pathogen and vector attraction reduction requirements (U.S. EPA, 1994).

Regarding vector attraction reduction, if the method used to place sewage sludge at a TINE site is subsurface injection or incorporation (see Section 7.7.4), then the site can meet the Part 503 requirement for vector attraction reduction (Options 9 or 10) if the sewage sludge is injected or incorporated within a specified time frame after the sewage sludge has undergone a pathogen reduction process, as described in Section 3.4.2.2 and Section 3.4.2.3. If a method other than subsurface injection or incorporation is used, then the other options of achieving vector attraction reduction described in Section 3.4.2.3 must be used (see Section 9.3.4.3).

9.2.1.3 Other Requirements Under Part 503 Affecting Operation

The following requirements under part 503 also impact daily operations at sewage sludge surface disposal sites but have been addressed elsewhere in this document:

- Frequency of monitoring requirements (see Section 10.2)
- Reporting requirements (see Section 11.2)
- Recordkeeping requirements (see Section 11.2)

9.3 Method-Specific Operational Procedures

For the purposes of this chapter, the site operation may be viewed in two parts: the first part (Section 9.3) concerns operational procedures that are specific to the chosen active sewage sludge unit; the second part (Section 9.4) concerns general operational procedures that are independent of the active sewage sludge unit.

9.3.1 Operational Procedures for Monofilling

Operations dependent on the type of monofill include:

- Site preparation
- Sludge unloading
- Sludge handling and covering

Because these operations vary for each monofill, they will be discussed as functions of the monofills introduced in Chapter 2.

9.3.1.1 Trench

For trenches, subsurface excavation is required so that sludge can be placed entirely below the original ground surface. In trench applications, the sludge is usually dumped directly into the trench from haul vehicles. Soil is not used as a sludge bulking agent. Soil is used as cover, usually in a single, final application.

Two kinds of trenches have been identified including (1) narrow trench and (2) wide trench. Narrow trenches have widths less than 10 ft (3.0 m). Wide trenches have widths greater than 10 ft (3.0 m). Section 2.3.1 and Section 7.5.2.1 should be consulted for specific design criteria.

Site Preparation

Site preparation includes all tasks required prior to the receipt of sludge. Tasks include clearing and grubbing, grading the site, constructing access roads, and excavating trenches.

The location of access roads depends on the topography and the land utilization rate. Narrow trenches use land rapidly and require more extensive road construction. Wider and/or longer trenches may require vehicle access roads along both sides of the trench.

Prior to grading, the area should be cleared and grubbed. Grading should be done on the site (1) to control runoff and (2) to provide grades compatible with equipment to be used. For example, drag lines and trenching machines operate more efficiently on level surfaces. Narrow trenches may require less grading due to their applicability to hilly terrain.

Progressive trench construction is the most efficient procedure for a narrow trench operation. The initial trench is constructed using appropriate equipment and the soil either (1) piled along the length of the trench, or (2) stockpiled in a designated area, or (3) graded to ground level. Soil is often piled on the uphill side of the trench and used to prevent runoff from entering the trench. Succeeding trenches are constructed parallel to the initial trench. The trench dimensions and the distance between the trenches should follow design specifications.

Trenches may require dikes positioned intermittently across the width of the trench, especially if such trenches are long. The dikes should be of sufficient height to contain the sludge and attendant liquids and allow proper trench filling and covering. Equipment may be used inside wide trenches to construct dikes.

On-going site preparation is critical for proper execution of a trenching operation. Depending on the quantity of sludge received, a designated trench volume should always be maintained in advance of filling operations. Ideally, trenches should be prepared at least one week ahead of the current landfilling operation.

Sludge Unloading

Signs should be placed to designate which trench is the active sewage sludge unit. Sludge is usually unloaded from haul vehicles via direct dumping. Metal extension chutes or pumping, however, may also be employed. If direct dumping is employed, an appropriately sized area should be prepared at the lip of the trench so that transport vehicles can safely back up to the trench edge for unloading. Sludge unloading can occur along the length of both sides of the trench if necessary. The entire unloading area should be kept clear of discharged sludge and periodically regraded to facilitate safe unloading operations.

Sludge Handling and Covering

Sludge should be uniformly distributed throughout the trench. Otherwise, depressions that could cause ponding are likely to occur as the fill settles. Narrow and wide trenches should be filled only to a level where a sludge overflow will not occur due to displacement during cover application. Markers on trench sidewalls can be used for this purpose. The appropriate level for sludge filling can best be established via experimentation using test loads.

Concurrent excavation, filling, and covering of trenches is a sequential operation that requires a coordination of effort. When the sludge has filled the trench to the designated level, cover material should be applied using either soil freshly excavated from a parallel trench or soil stockpiled during excavation of the trench being filled. Depending upon the solids content of the sludge and the width of the trench, cover application should proceed as follows:

If the sludge has a solids content from 15 to 20 percent, the width of the trench should be 2 or 3 ft (0.6 to 0.9 m). Cover application should be via equipment based on solid ground adjacent to the trench. Covering equipment may include a backhoe with loader, excavator, or trenching machine.

If the sludge has a solids content from 20 to 28 percent, the width of the trench is technically unlimited. It is limited, however, by the requirement that cover be applied by equipment based on solid ground. Covering equipment may include a backhoe with loader, excavator, track loader, or dragline.

If the sludge has a solids content of 28 percent or above, the width of the trench is unlimited. Cover application can be via equipment which proceeds out over the trench pushing cover over the sludge. Covering equipment usually is a track dozer. In all cases, initial layers of cover should be carefully applied to minimize sludge displacement. (See Chapter 12 for information on final cover requirements for sewage sludge monofills.)

Operational Schematics

The preceding information has been included to generally describe the operation of trenches. Figures 9-1 through 9-4 illustrate specific trench operations.

9.3.1.2 Area Fill

For area fills, sludge is usually placed above the original ground surface. In area fill applications, soil is usually mixed with the sludge as a bulking agent. Cover may be used in both intermediate and final applications.

Three kinds of area fills have been defined including (1) area fill mound, (2) area fill layer, and (3) diked containment. In area fill mound operations, sludge/soil mixtures are usually stacked into piles approximately 6 ft (1.8 m) high. In area fill layer operations, sludge/soil mixtures are spread evenly in layers 0.5 to 3 ft (0.15 to 0.9 m) thick. In diked containment operations, sludge (with or without bulking soil) is dumped into pits contained by dikes constructed above the ground surface. Section 2.3.2 and Section 7.5.2.2 should be consulted for specific design criteria.

Area Fill Mounds

Area fill mounds may be employed in a variety of topographies. Usually such operations are conducted on level ground. Mound monofills, however, are also well suited to construction against a hillside that can provide containment on one or more sides.

Site Preparation. The first step is to prepare the subgrade. Depending on design specifications this may

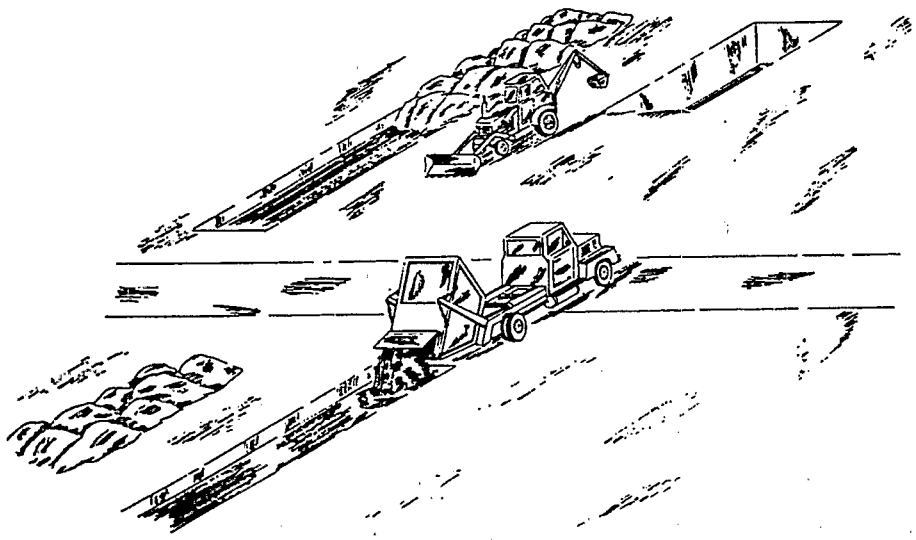

Figure 9-1. Narrow trench operation.

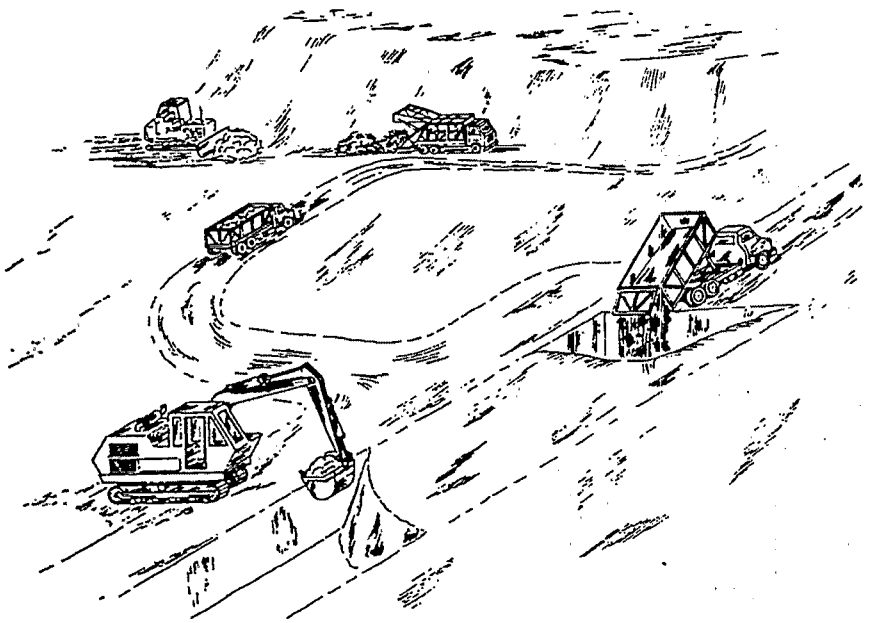

Figure 9-2. Wide trench operation at solid waste landfill.

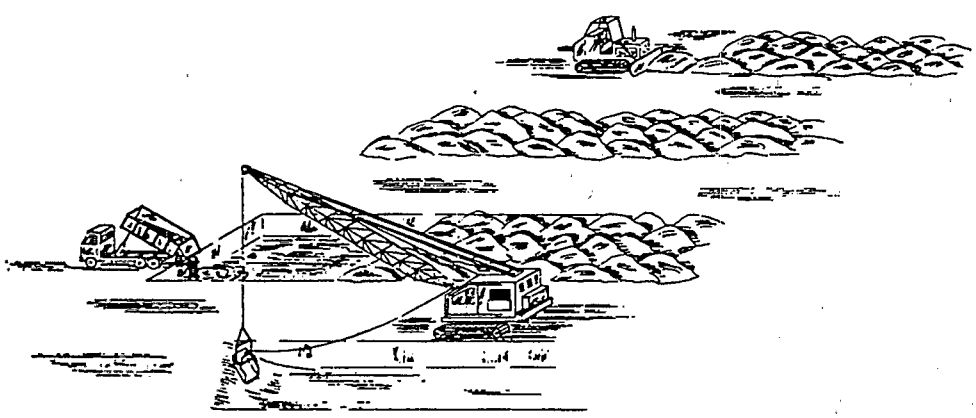

Figure 9-3. Wide trench operation with dragline.

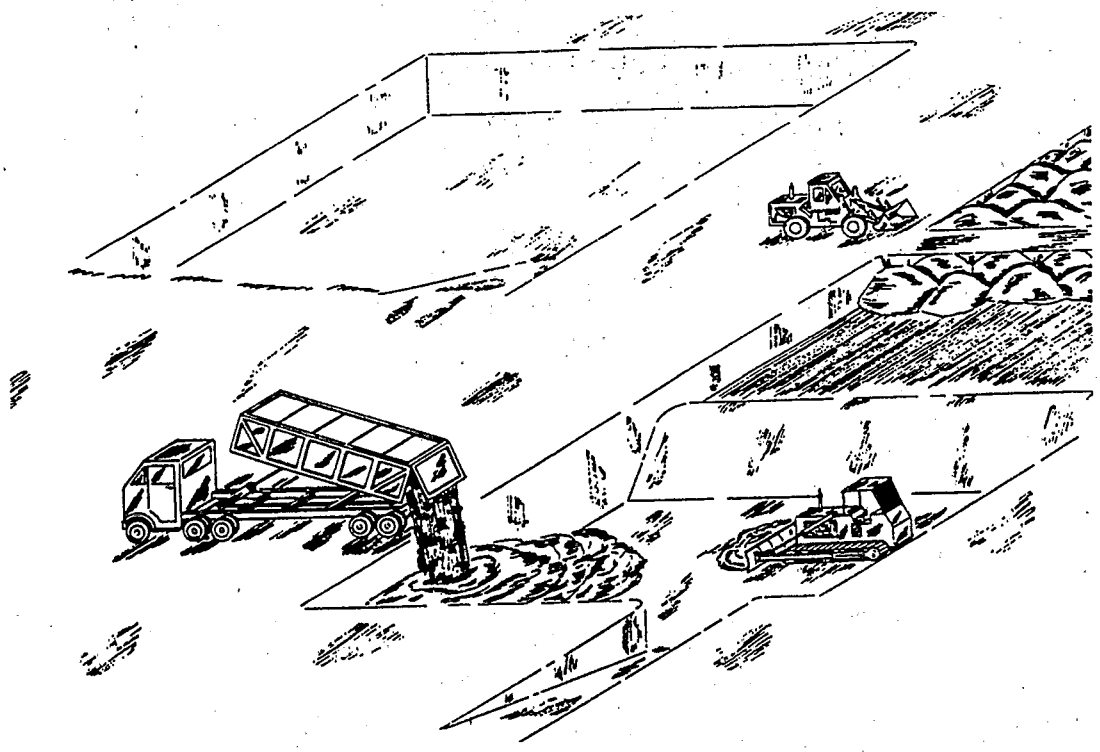

Figure 9-4. Wide trench operation with interior dikes.

include underdrains and/or liners for leachate collection. Due to the large amount of soil required for proper operation of area fill mounds, emphasis should be placed on securing sufficient soil material. Accordingly, the fill should be confined to a small area and proceed vertically to the maximum extent possible. This will reduce the areal extent of the monofill and consequently reduce erosion and silt-laden runoff from denuded areas, provided the slope does not become excessive.

The excavation can be carried out in phases to take advantage of soil differences. Any soil that has to be stockpiled for use as a sludge bulking agent should be placed in compacted, sloping piles. To keep the soil dry, piles may be covered with tarpaulins. Wet soils, because they are not suitable for sludge bulking, should not be stockpiled. Soil that is stockpiled should be placed as close as possible to points of eventual use and access to stockpiles provided.

Sludge Unloading. The sludge may be unloaded either in the filling area or in the designated unloading and mixing area near the bulking agent stockpile. The unloading area should be clean and relatively level for safe passage of trucks. Haul vehicles should not drive over completed sludge filling areas.

Sludge Handling and Covering. Operational procedures should be provided to specify what soils are to be mixed with sludge, where they are to be obtained, and how they are to be mixed and/or placed over the sludge. The amount of material required for each function is determined by site design specifications that take into account soil and sludge characteristics. Preliminary trial and error tests to determine sludge/soil ratios that produce sludge with appropriate consistencies should be attempted during initial operations.

Construction of area fill mounds requires that the sludge/soil mixture be relatively stable. Sludge/soil mounds are generally applied in a series of lifts with each lift containing one level of mounds. When completed, the lift should be covered with a layer of soil sufficient to safely support on-site operating equipment. (See Chapter 12 for information on final cover requirements for sewage sludge monofills.)

Area Fill Layer

Area fill layers may also be employed in a variety of topographies. Layer operations consist of a series of sludge layers with intermediate and final cover applications.

Site Preparation. As with area fill mounds, the first step is to prepare the subgrade. Again, liners and/or subdrain systems may be utilized depending on hydrogeological conditions. Fill areas for layer operations should be nearly level. Although the soil requirements of such operations are less than those of area fill mounds, it may be necessary to import soil. In any case, soil stockpiles should be established, both for use as bulking agents and cover soils. Areas should be excavated only as they are used, to the maximum extent possible. This will reduce the amount of denuded area subject to erosion.

Sludge Unloading. Specific unloading and sludge/soil mixing areas may be maintained or sludge can be placed directly in the fill area. An effective method in layer operations is to maintain soil stockpiles on the fill area itself. Bulldozers then mix and layer the sludge in one operation. Again, storage areas should be located away from traffic.

Sludge Handling and Covering. In general, design specifications based on sludge characteristics will give some indication of the required amounts of bulking agent. Nevertheless, it is always advisable to conduct preliminary trial and error tests to determine bulking ratios appropriate for supporting equipment. The depth of intermediate and final cover can also be determined in this manner. (See Chapter 12 for information on final cover requirements for sewage sludge monofills.)

Diked Containment

Diked containments are essentially aboveground wide trenches and, as such, use similar procedures and equipment. The design and construction of dikes is more complex. Diked containments are generally used at sites with high ground-water tables or bedrock, and/or where a sewage sludge with a low solids content is being disposed.

Site Preparation. The first step in preparing the site for diked containment is to provide a suitable subgrade or a liner, if necessary. (See Chapter 7 for information on foundations, liner and leachate collection systems, and, slope stability analyses.) The dike base is then constructed maintaining design dimensions and slopes (generally from 2H:1V to 3H:1V for sideslopes). Succeeding layers are then applied and each layer compacted by passing equipment over it. Alternatively, the containment area may be constructed against one or more steep sideslopes. A ramp should be provided for unloading vehicles.

Sludge Unloading. Sludge may be unloaded from the top of the dike or in an area designated for sludge/soil mixing. Slopes and grades of access roads should be maintained to design specifications. Provisions should be made for inclement weather (e.g., stockpiled soil kept dry).

Sludge Handling and Covering. The containment area is filled with sludge in layers, usually with intermediate soil or gravel cover provided at predetermined heights. Draglines are frequently used to apply intermediate and final cover. (See Chapter 12 for information on final cover requirements for sewage sludge monofills.)

Operational Schematics

The preceding information has been included to generally describe the operation of area fills. Figures 9-5 through 9-8 illustrate specific area fill operations.

9.3.2 Operational Procedures for Lagoons

Facultative sludge lagoons and sludge drying lagoons are used for surface disposal of sewage sludge.[1] Section 2.5 and Section 7.5.3 should be consulted for specific design criteria for these active sewage sludge units.

9.3.2.1 Facultative Sludge Lagoons

Operational considerations for facultative sludge lagoons include the loading or placement of sludge into the FSLs and routine operation.

Start-up and Loading

FSLs should be initially filled with effluent. Ideally, that effluent should then have about three to six weeks for development of an aerobic surface layer prior to the introduction of digested sludge. All FSLs should be loaded daily, with the loading distributed equally between FSLs. Loadings should be held below 20 pounds VS per 1,000 square feet per day (1.0 t VS/ha-d) on an average annual basis. As indicated earlier, considerable flexibility does exist. Loads can vary from day to day, and batch or intermittent loading of once every four days or less is acceptable. Shock loadings, such as with digester cleanings, should be distributed to all operating FSLs in proportion to the quantity of sludge they possess. FSLs should be loaded during periods of favorable atmospheric conditions, particularly just above ground surface, to maximize odor dispersion. The fixed and volatile sludge solids loadings to the FSLs and their volatile contents should be monitored quarterly.

Daily Routine

Surface mixers should operate for a period of between 6 and 12 hours. Operation should not coincide with FSL loading and should always be during the hours of minimum human exposure (usually midnight to 5 a.m.) and during periods of favorable atmospheric conditions. FSL supernatant return to the wastewater treatment process should be regulated to minimize shock loadings of high ammonia. Supernatant return flows should be monitored so that their potential impact on the liquid treatment process can be discerned. The sludge blanket in a lagoon should not be allowed to rise higher than 2 feet below the operating water surface.

9.3.2.2 Operations for Sludge Drying Lagoons

Operating procedures for drying lagoons used for final disposal include:

- Pumping liquid sludge, over a period of several months or more, into the lagoon. The pumped sludge

[1] As discussed in Sections 2.5 and 7.5.3, the surface disposal provisions of the Part 503 rule do not apply when sludge is **treated** in a lagoon. Section 1.1 provides more information on differentiation between sludge disposal, storage and treatment.

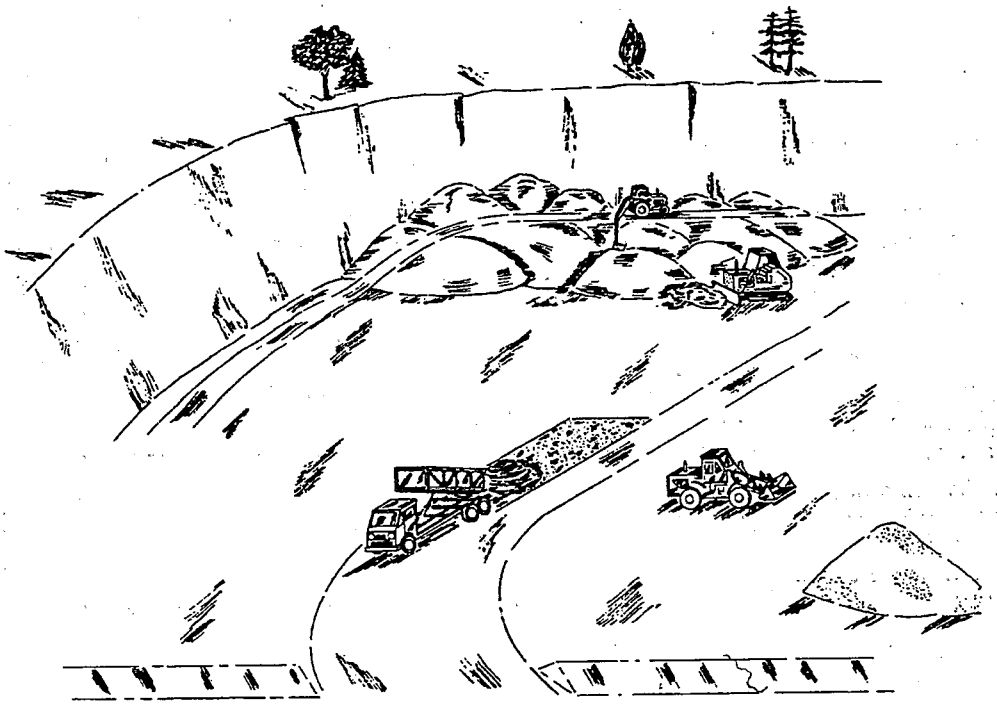

Figure 9-5. Area fill mound operation.

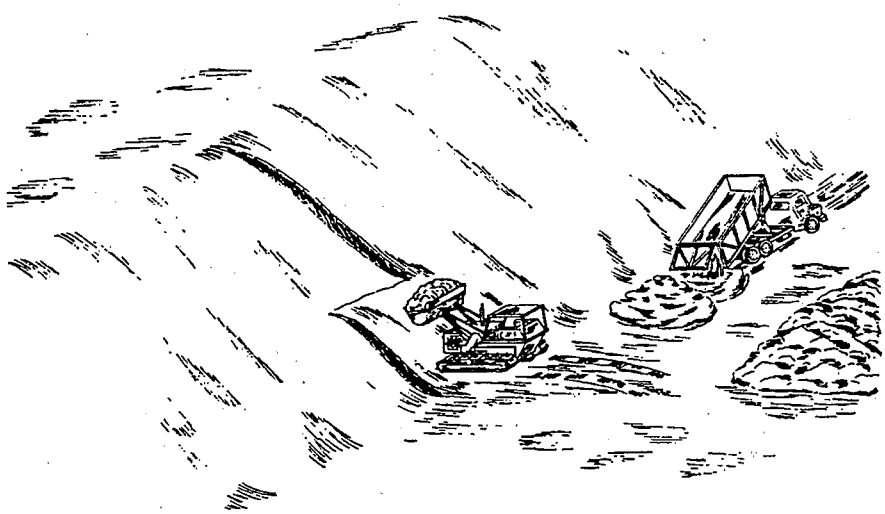

Figure 9-6. Area fill layer operation.

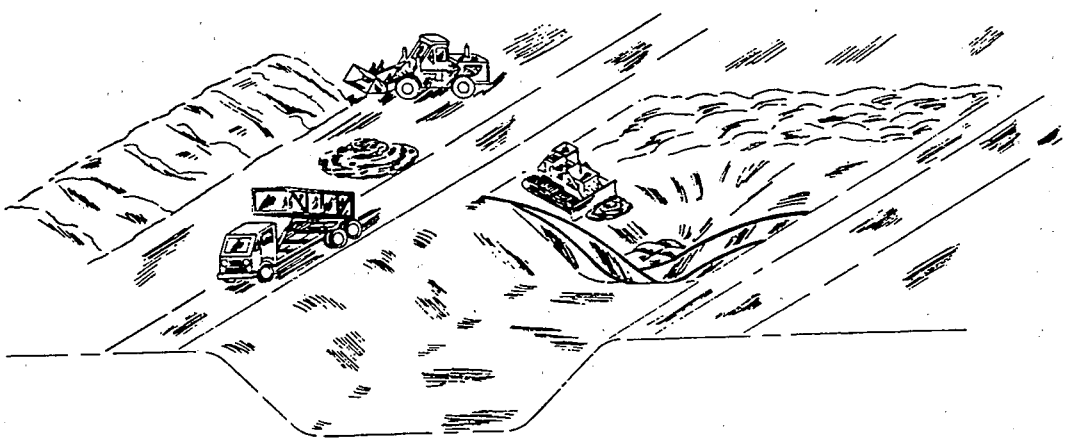

Figure 9-7. Area fill operation inside trench.

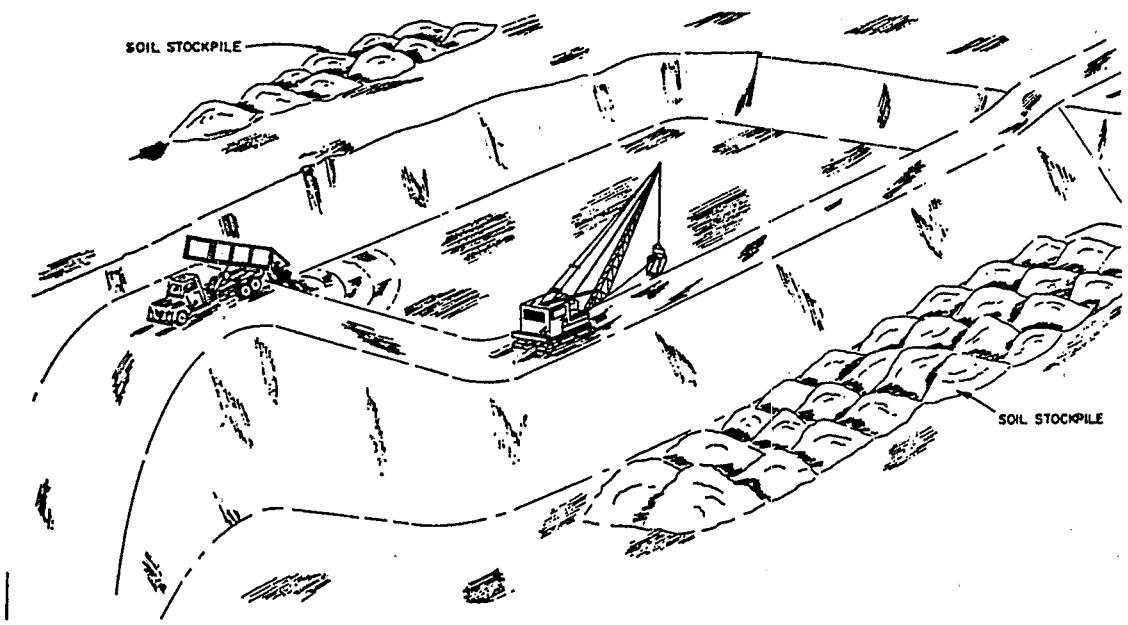

Figure 9-8. Diked containment operation.

is normally stabilized prior to application. The sludge is usually applied until a lagoon depth of 24 to 48 inches (0.7 to 1.4 m) is achieved.

- Decanting supernatant, either continuously or intermittently, from the lagoon surface and returning it to the wastewater treatment plant.
- Filling the lagoon to a desired sludge depth and then permitting it to dewater. Depending on the climate and the depth of applied sludge, a solids content of between 20 to 40 percent will be obtained in 3 to 12 months.

9.3.3 Operational Procedures for Codisposal

In codisposal operations, sludge is disposed of at an MSW landfill. Two kinds of codisposal operations have been identified including (1) sludge/solid waste mixture and (2) sludge/soil mixture. For sludge/solid waste mixtures, sludge is mixed directly with solid waste and landfilled at the working face. For sludge/soil mixtures, sludge is mixed with soil and used as cover over completed refuse fill areas. Section 2.7 and Section 7.6 should be consulted for specific design criteria.

9.3.3.1 Sludge/Solid Waste Mixture

At the landfill, once sludge receipt has begun, every effort should be made to take full advantage of the absorptive capacity of the solid waste. Consequently, the sludge should be mixed with the solid waste as thoroughly as possible. One procedure employed calls for solid waste to be dumped at the bottom of the working face, and subsequently pushed, spread, and compacted by equipment working up the working face.

Under these circumstances, sludge can be handled in two alternative ways. The first way includes:

1. Dump the solid waste at the bottom of the working face.
2. Dump the sludge atop the solid waste pile.
3. Thoroughly mix the sludge and solid waste.
4. Push, spread, and compact the sludge/solid waste mixture up the working face.

The second method can be accomplished in the following way:

1. Dump the solid waste at the bottom of the working face.
2. Push, spread, and compact the solid waste up the working face.
3. Dump the sludge at the top of the working face.
4. Push the sludge down the working face, spreading it evenly across the solid waste.

If small quantities of sludge are received at MSW landfills (i.e., less than 5 percent) it may be desirable to confine sludge dumping to a selected location on the working face. This approach is useful in MSW landfills that are sufficiently large to ensure that solid waste dumping proceeds simultaneously along a wide working face.

Precautions should be taken to contain any sludge that escapes from the working face. Containment can be achieved either by (1) landfilling the sludge in a small depression or (2) constructing a refuse or soil berm at the bottom of the working face.

Another factor to be considered at MSW landfills receiving sewage sludge is the increased potential for odor

problems to occur. Appropriate steps can be taken to control odors including more frequent application of cover and spot addition of lime.

9.3.3.2 Sludge/Soil Mixture

Another option for handling sludge at MSW landfills is mixing the sludge with soil and then applying the mixture as cover material over solid waste filled areas. Although this technically is not sludge landfilling, it is a viable alternative, is particularly useful in promoting vegetative growth in completed fill areas, and is performed at numerous MSW landfills.

If a sludge/soil mixture is determined to be a suitable material for the erosion layer of the final cover, the mixture can be applied as follows:

1. Spread sludge as received uniformly over the ground surface in a 3 to 6 in. (8 to 15 cm) thickness in an area designated for this purpose.
2. Disc the sludge into the soil. The resulting mixture of sludge to soil should be about 1:1.
3. If necessary, spread lime or a masking agent over the sludge/soil mixture for odor control.
4. After a period ranging from 1 to 8 weeks (depending on rainfall and climate) scrape up the sludge/soil mixture and spread it over the clay infiltration layer.

9.3.3.3 Operational Schematics

The preceding information has been included to generally describe the operation of MSW landfills. Figures 9-9 through 9-11 illustrate specific codisposal operations.

9.3.4 Operational Procedures at Dedicated Surface Disposal Sites

Important operational considerations at DSD sites include aesthetics (i.e., community concerns), labor, and issues related specifically to beneficial DSD sites. Each of these operational considerations for DSD sites are discussed below. Design considerations affecting operations at DSD sites, such as determining the most appropriate sludge placement method to use and calculating the acceptable sludge disposal rate, are addressed in Section 7.7.

9.3.4.1 Aesthetics at DSD Sites

The major community concern at most DSD sites is odor. If the DSD site is located on a treatment plant site that is remote from public areas, odor may not present a problem. But DSD sites may need to be located in populated areas if that is where land is available, especially in urban areas.

Generally, odor problems from sludge are the result of anaerobic (septic) conditions. When disposing large quantities of liquid sludge at DSD sites, the soil should be maintained in an aerated condition via surface drainage that precludes ponding of water on the site's surface and includes subsurface drainage and/or tillage (if necessary). Subsurface injection by sludge spreading vehicles provides another means of reducing odors.

Liquid sludge storage lagoons at DSD sites are a potential source of odor. Use of a lagoon, if properly designed, will reduce the potential for odors. If the sludge is well stabilized, odor problems are usually infrequent but may occur (e.g., during a spring thaw after extended cold weather or during a major disturbance of the sludge lagoon as would occur during bottom sediment cleanout). Typical attempts at controlling odors from sludge lagoons involve:

- Locating the sludge lagoon as far from public access areas as possible.
- Providing as large a buffer area around the site as possible.
- Adding lime to the lagoon.
- If the POTW sludge treatment process is having problems (e.g., a sour digester), if possible the resulting poorly stabilized sludge should not be added to the DSD site storage lagoon.

Dust and noise levels from use of heavy equipment (e.g., tractors, subsurface injector vehicles) at DSD sites may be a concern in some communities. In an agricultural area, dust and noise should be no worse than expected from normal farming operations and should create no problems. In an urban area, use of buffer zones and vegetative screening (trees and shrubs around the site) may be necessary to mitigate public impact.

9.3.4.2 Labor

Labor needs for DSD sites can vary widely, from one hour of operator time weekly for smaller sites using spray methods to 11 persons needed for one-half year each (where climate limits sludge spreading to certain seasons) at sites with larger operations using the subsurface injection method, based on reports from individual DSD sites. The 11-person operation included one person for each dredger, one person for each injector, and one person for each tiller tractor. Two people were hired as relief personnel for the injector and tractor operators, and one person served as supervisor of the crew (U.S EPA, 1984). Additional personnel will be needed at dedicated beneficial use sites where crops are grown (e.g., for seeding and harvesting).

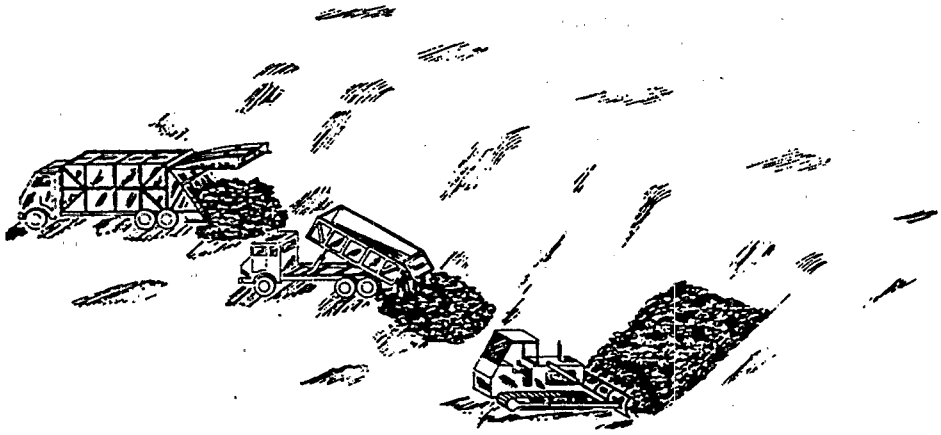

Figure 9-9. Sludge/solid waste mixture operation.

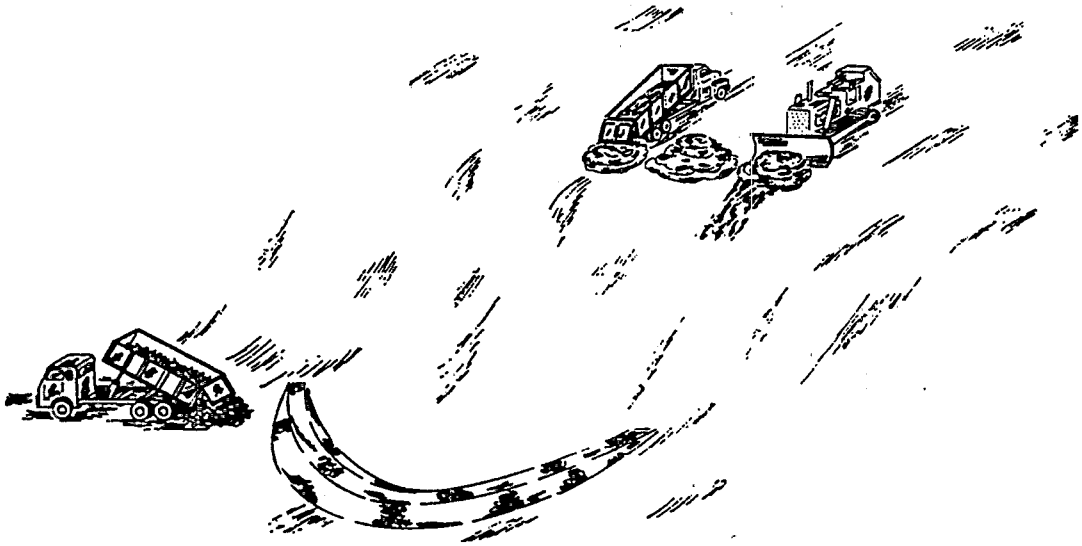

Figure 9-10. Sludge/solid waste mixture with dikes.

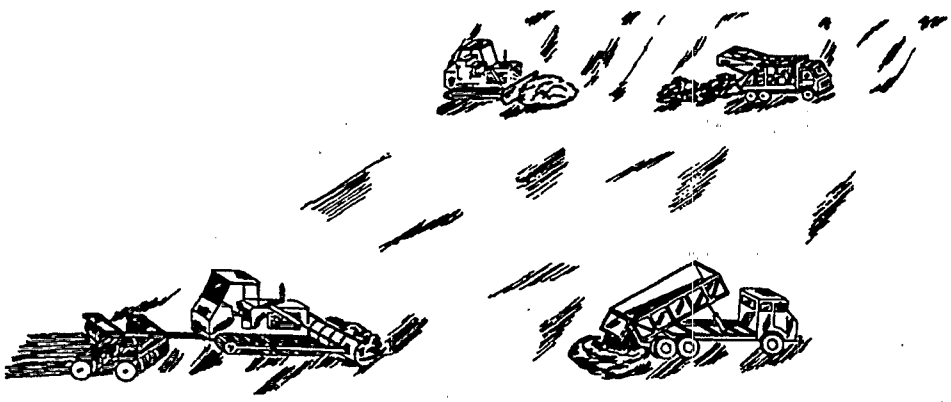

Figure 9-11. Sludge/soil mixture.

9.3.4.3 Operational Considerations at Dedicated Beneficial Use Sites

A POTW or other DSD site owner might choose to establish a beneficial DSD site if soil erosion or soil acidity are a problem at the site or if the facility is committed to a beneficial use policy. The sewage sludge increases the soil's productivity and can reduce soil erosion and acidity. The high disposal rates of sewage sludge placed on these sites can help supply nutrients that act as fertilizers, as well as organic matter that conditions the soil. Crops grown on beneficial DSD sites have been sold as animal feed or for use in the production of methanol or other alternative fuels (Lue-Hing, 1992).

Part 503 requires that an owner/operator of a beneficial DSD site must be able to demonstrate to the permitting authority that, by implementing certain management practices, public health and the environment will be protected if crops are grown or animals are grazed. The permitting authority may specify site-specific management practices to ensure that unsafe levels of pollutants are not taken up by crops that might be eaten by people (including animals that are allowed to graze on the site). Such management practices may include testing of crops or animal tissue (e.g., dairy or meat) for the presence of pollutants and specification of a monitoring schedule for the testing.

The crops chosen to be grown at a beneficial DSD site need to be compatible with the site's sludge disposal rate and the sludge disposal method used at the site (see Sections 7.7.4 and 7.7.5). Crops with high nutrient needs (e.g., nitrogen) will be able to tolerate higher sludge disposal rates and also can help reduce the amounts of nutrients that may be released as pollutants into surface runoff and leachate.

9.4 General Operational Procedures

9.4.1 Management Practices Required Under Part 503

Surface disposal site owners/operators must meet the Part 503 management practice for surface disposal related to operation of the surface disposal site. These address the operation of leachate collection systems, collection of surface water runoff, crop production and/or grazing of animals, access restrictions, and include monitoring requirements and pathogen and vector control requirements.

9.4.1.1 Leachate Collection System

If the surface disposal site owner chooses to have a liner and leachate collection system onsite (in lieu of meeting the Part 503 pollutant limits for surface disposal), then Part 503 requires that site owners operate the leachate collection system according to *design specifications and* must perform routine and other needed maintenance for the system. Chapter 7 includes a more detailed discussion of leachate collection at sewage sludge surface disposal sites.

9.4.1.2 Collection of Surface Water Runoff

A surface disposal site owner/operator must implement the management practices required for all surface disposal sites. One of the management practices requires that surface water runoff be collected from an active sewage sludge unit and that the runoff collection system must be capable of handling runoff from a 24-hour, 25-year storm event. Chapter 7 includes a more detailed discussion of collection of runoff at sewage sludge surface disposal sites.

9.4.1.3 Crop Production and/or Grazing of Animals

Part 503 management practices state that no crop production or grazing can be conducted at any surface disposal site, including beneficial DSD sites, unless the owner/operator can demonstrate to the permitting authority that, through management practices, public health and the environment will be protected from any reasonably anticipated adverse effects of pollutants—including pathogens—in sewage sludge when crops are grown or animals are grazed.

9.4.1.4 Access Restrictions

Under Part 503, public access to a surface disposal site must be restricted while an active sewage sludge unit is on the site and then for 3 years after the last active sewage sludge unit has been closed. Access restrictions are discussed in Section 7.9.1.

9.4.1.5 Monitoring Requirements

If a surface disposal site does not have a liner and leachate collection system, then the Part 503 pollutant limits for surface disposal must be met (see Chapter 3) and must also monitor ground water for nitrate. The owner/operator must then monitor the sewage sludge as required by Part 503 for the regulated pollutants. Surface disposal site owners must also monitor to ensure that certain pathogen and vector attraction reduction requirements are being met. In addition, air must be monitored for methane gas if sewage sludge placed on an active sewage sludge unit is covered either daily or at closure. Monitoring requirements are discussed in Chapter 10.

9.4.1.6 Pathogen and Vector Attraction Reduction

Sewage sludge at surface disposal sites must meet the Part 503 operational standards for pathogen and vector attraction reduction, as discussed in Chapter 3. Regarding pathogens, Part 503 requires that the pathogen density be reduced through certain processes and also contains management practices that help ensure that pathogens will not regrow.

9.4.2 General Operational Procedures for Sewage Sludge Surface Disposal Sites

Operational factors that are generally applicable to all sewage sludge disposal sites include:

- Environmental control practices
- Inclement weather practices
- Hours of operation

9.4.2.1 Environmental Control Practices

In many cases, environmental controls must be used at sewage sludge surface disposal sites. These environmental controls are described in the following sections and outlined in Table 9-1.

- *Spillage.* Enroute and on-site spillage of sludge must be cleaned up as soon as possible. Haul vehicles enroute to the disposal site should report even small spills to the operation supervisor, so emergency clean-up crews can take prompt action. On-site spills should be controlled as much as possible. It is a good policy to have lime on hand at all sludge disposal operations for spot application to spills if prompt clean-up is not feasible. The use of haul vehicles with baffles on them has been used effectively to limit spills.

- *Siltation and erosion.* The presence of silt-laden runoff from the site is often the result of improper grading. Grades of 2 to 5 percent should be maintained where feasible to promote overland surface drainage, while minimizing flow velocities. Denuded areas should be kept to a minimum during site operation. Ongoing construction and maintenance of sediment control devices (e.g., grass waterways, diversion ditches, riprap, sediment basins) are critical for an environmentally sound operation. During site completion, proper final grading, dressing, and seeding prevent long-term erosion and siltation problems.

- *Mud.* Mud is usually caused by improper drainage but can be a problem at any site during heavy rains or spring thaws. To minimize the effect of mud on operations, access roads should be constructed of gravel. If practical, a wash pad should be located near the exit gate to clean mud from transport vehicles.

Table 9-1. Environmental Control Practices

Environmental Problems	Safety Program	Maintain Washrooms for Personnel	Training of New Personnel	Use Safety Clamps on Truck Tailgates	Maintain Road Markings and Trench Barriers	Maintain Fencing	Maintain Buffer Areas and Grass	Proper Equipment Maintenance	Spray Water/Oil/Liquid Asphalt	Truck Wash Pad (to clean trucks)	Maintain Grass Waterways Diversion Ditches, Rip Ra	Final Grading of Disturbed Areas	Revegetation of Disturbed Areas	Chemical Masking Agent	Lime on Site	Workers Supplied with Aerators	Cover Sludge Daily	Water Diverted Away From Site
Spillage			X	X	X			X							X			
Siltation and Erosion			X				X				X	X	X					X
Mud			X				X		X	X	X		X					X
Dust			X				X		X	X			X			X		
Odors			X				X			X				X	X	X	X	
Noise			X				X	X										
Aesthetics			X			X	X				X	X	X				X	
Health		X	X												X	X	X	
Safety	X		X	X	X	X		X							X	X	X	

- *Dust.* Dust is usually caused by wind or the movements of haul vehicles and equipment. To minimize dust, access roads should be graveled. Also, areas that are covered with intermediate or final soil cover should be vegetated as soon after their completion as possible. As an alternative, water can be applied to dusty roads.

- *Odors.* Odors can be a serious problem at a sewage sludge surface disposal site unless preventive steps are taken. The sludge should be covered as frequently as necessary to minimize odor problems. Lime or chemical masking agents can be applied to reduce odor problems. An effective means of reducing odors is to limit storage of the sludge. Ideally, storage of sludge should be accomplished at the wastewater treatment plant.

- *Noise.* Noise sources at surface disposal sites include operating equipment and haul vehicles. Generally, the noise is similar to that generated by any heavy construction activity, and is confined to the site and the streets used to bring sludge to the site. To minimize the effect, every effort should be made to route traffic through the least populated areas. Further, the site can be isolated so that the noise cannot carry to nearby neighborhoods. The use of earthen berms and trees as noise barriers can be very effective. On the site, noise protection for employees will be governed by existing Occupational Safety and Health Act (OSHA) standards.

- *Aesthetics.* To make the surface disposal site publicly acceptable, every attempt should be made to keep the site compatible with its surroundings. During site preparation, it is important to leave as many trees as possible to form a visual barrier. Earthen berms can be similarly used. The use of architectural effects at the receiving area, the planting of trees along the property line, and confining dumping to designated areas will assist in the development of a sound operation. Additionally, every attempt should be made to minimize the size of the working area.

- *Worker health.* Although there is a possibility that pathogens will be present in sludge, particularly if undigested, no health problems have been reported by site operators. Nevertheless, personnel should use caution when transporting, handling, and covering sludge. Washing facilities should be located on or near the disposal site.

- *Worker safety.* As with any construction activity, safety methods must be implemented in accordance with OSHA guidelines. Work areas and access roads must be well marked to avoid on-site vehicle mishaps.

9.4.2.2 Inclement Weather Practices

Prolonged periods of rainy weather or freezing temperatures can impede routine operation of a sludge surface disposal site. Anticipating the operational problems and addressing contingency operations in the operation plan will promote efficient operations. A listing of potential inclement weather problems and solutions has been included in Table 9-2.

9.4.2.3 Hours of Operation

Hours of operation should coincide with hours of sludge receipt. In this way, personnel and equipment are available to direct trucks to the proper unloading location; assist if trucks become mired in sludge or mud; or cover the sludge quickly to minimize odors. If the operation plan calls for daily covering of sludge, hours of operation should continue at least 1/2 hr past the hours of sludge receipt to allow for cleanup activities. Sludge deliveries after hours at the surface disposal site should be discouraged.

9.5 Equipment

A wide variety of equipment is utilized at surface disposal sites. Equipment selected depends largely on (1) the disposal method and design dimensions employed and (2) quantity of sludge received.

Because equipment represents a large capital investment and accounts for a large portion of the operating cost, equipment selection should be based on a careful evaluation of the functions to be performed and the cost and ability of various machines to meet these needs. Contingency equipment for downtime and maintenance may be necessary at larger sites. These may be rented or borrowed from other municipal functions.

Table 9-3 provides guidance on the suitability of equipment to perform selected sludge disposal tasks. Table 9-4 provides typical equipment selections for seven operational schemes. These matrices are meant to give general guidance on the selection of sludge disposal equipment. It should be noted, however, that general recommendations on equipment selection can be misleading. In all cases, final selection should be based on site-specific considerations. Figures 9-12 through 9-15 illustrate typical equipment used at surface disposal facilities.

The importance of employing qualified and well-trained personnel at sludge surface disposal sites cannot be overstated. Qualified personnel often make the difference between a well-organized, efficient operation and a poor operation. Information on staffing and personnel for surface disposal sites is included in Chapter 11.

Table 9-2. Inclement Weather Problems and Solutions

Inclement Weather Conditions	Sludge Loading and Transport	Site Preparation	Sludge Unloading	Sludge Handling and Covering
Wet	Problem: If hauling great distances, wet weather conditions may increase liquid content of sludge. Solution: Cover transport vehicle.	Problem: Maneuverability of equipment hindered in mud. Solution: Plan to move operation to an accessible working area. Problem: Depressions accumulate water, may draw flies, mosquitos. Solution: Grade area to promote surface runoff. Use insecticides only when necessary.	Problem: Maneuverability of transport vehicles hindered in mud. Solution: Place sand or gravel in areas to improve traction. Increase depth of road material. Problem: Instability of trench walls may cause collapse while unloading. Solution: Have transport vehicle dump at trench lip and push sludge into trench with equipment. Problem: Mud and sludge accumulates on haul vehicles and equipment. Solution: A washing pad at the receiving area will clean vehicles.	Problem: When mixing sludge with refuse or soil, need more mixing material. Solution: Ensure sufficient supply of refuse or soil material. Problem: Ponded water collecting in trenches. Solution: Use potable pump to remove excess water.
Cold	Problem: Sludge freezes in haul vehicles. Solution: Line trucks with salt water, straw, sand or oil. Do not allow prolonged exposure to cold (park in garage). Use exhaust to heat the trailer.	Problem: Deep penetration of frost in trench areas. Solution: - Construct trenches during good weather and save for cold months. - Do not remove snow (acts as insulator) or allow vehicles to ride on trenching areas (causes frost to penetrate deeper into the ground). - Hydraulic rippers or jackhammers are to be used as a last resort.	Problem: Tailgates freeze. Solution: (1) Spray ethylene glycol on frozen parts. (2) use exhaust to heat frozen parts. Problem: Previously (fall season) muddy roads form severe ruts and chuck holes. Solution: Regrade and build before winter freeze.	Problem: Deep penetration of frost in cover supply areas. Solution: Accumulate stockpile in good weather. Ensure supply of cover material; insulate piles with tarpaulin or hay. Problem: Equipment freeze-up. Solution: Trucks or crawlers should be well cleaned of sludge and soil.

Table 9-3. Equipment Performance Characteristics

Equipment Name	TRENCH				AREA FILL										CODISPOSAL					
	Narrow Trench		Wide Trench		Mound					Layer					Diked Containment			Sludge/ Refuse		Sludge/ Soil			
	Trench Construction	Covering	Trench Construction	Covering	Soil Hauling	Mixing	Sludge Hauling	Mounding	Covering	Soil Hauling	Mixing	Sludge Hauling	Layering	Covering	Soil Hauling	Dike Construction	Covering	Spreading	Covering	Sludge Spreading	Mixing	Hauling	Covering
Trenching Machine	G	G	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Backhoe with Loader	G	G	-	-	F	F	F	G	F	F	F	F	-	-	F	-	-	-	-	-	-	-	-
Excavator	G	F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Track Loader	-	G	G	F	F	G	F	G	G	F	G	F	F	F	F	F	-	F	F	F	-	G	F
Wheel Loader	-	G	F	-	G	F	G	F	F	G	G	G	-	-	G	F	-	-	-	-	F	F	
Track Dozer[a]	-	G	G	G	-	G	-	F	G	-	G	-	G	G	-	G	G	G	G	G	F	-	G
Scraper	-	-	G	-	G	-	F	-	-	G	-	F	G	G	G	G	-	-	F	-	-	F	F
Dragline	G	G	G	G	-	-	-	-	G	-	-	-	-	-	-	-	G	-	-	-	-	-	-
Grader	-	-	-	-	-	-	-	-	-	-	-	-	G	G	-	-	-	-	-	F	-	-	-
Tractor with Disc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	G	-	-

LEGEND
G - Good. Fully capable of performing function listed. Equipment could be selected solely on basis of function listed.
F = Fair. Marginally capable of performing function listed. Equipment should be selected on basis of full capabilities in other function.
- = Not applicable. Cannot be used for function listed
a Caterpillar D-6 generally is the largest track dozer appropriate for a sludge landfill.

Table 9-4. Typical Equipment Selection Schemes

Equipment	Trench Method										Area Fill Method														Co-disposal Method[f]									
	Narrow Trench					Wide Trench					Mound					Layer					Diked Containment					Sludge/Refuse					Sludge/Soil				
	1[a]	2[b]	3[c]	4[d]	5[e]	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Trenching Machine				1	2																													
Backhoe with Loader	1	1		1*	1							1*	1*	1*	1																			
Excavator			1																															
Track Loader						1	1*	1		1*	1	1	1	1	1														1			1*	1*	2*
Wheel Loader														1	1					1*														
Track Dozer		1*	1	1	2*		1*	1	1	2*			1*	1	1	1	1	1	2*	2	1	1*	1*	1	2*			1*	1	1					
Scraper									1*	1			1*	1*	1		1*	1*	1*	1			1*	1	1										
Dragline																						1	1	1	1									
Grader																																	1*	1
Tractor with Disc																															1	1	1*	2*	2
Total	1	2	2	3	5	1	2	2	2	4	1	2	4	5	5	1	2	2	3	4	1	2	3	3	4	-	-	1	1	2	1	1	2	4	5

a Scheme 1 - 10 wet tons/day
b Scheme 2 - 50 wet tons/day
c Scheme 3 - 100 wet tons/day
d Scheme 4 - 250 wet tons/day
e Scheme 5 - 500 wet tons/day
f Additional equipment only

* May not receive 100% utilization

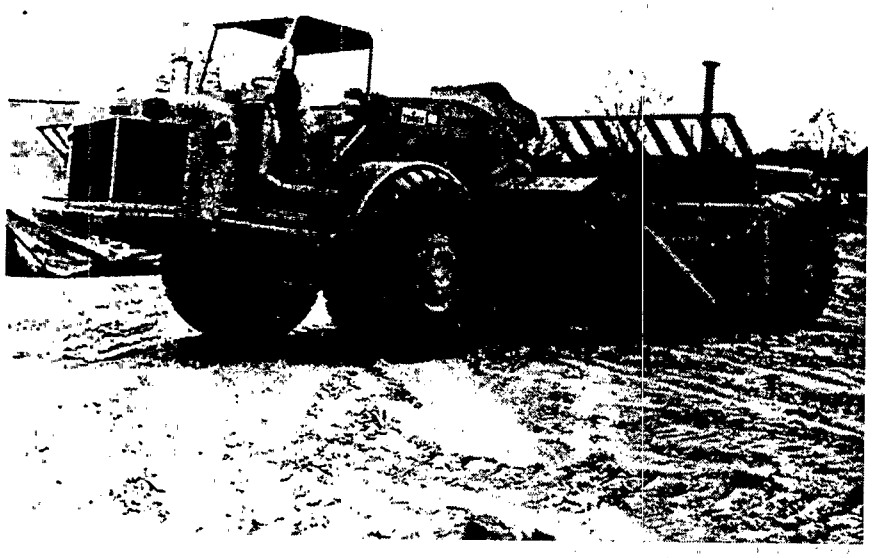

Figure 9-12. Scraper.

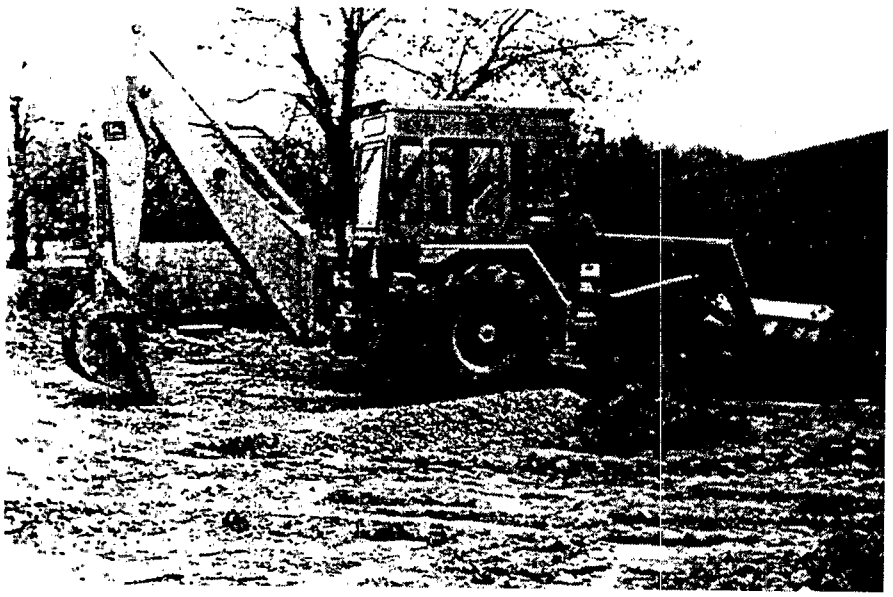

Figure 9-13. Backhoe with loader.

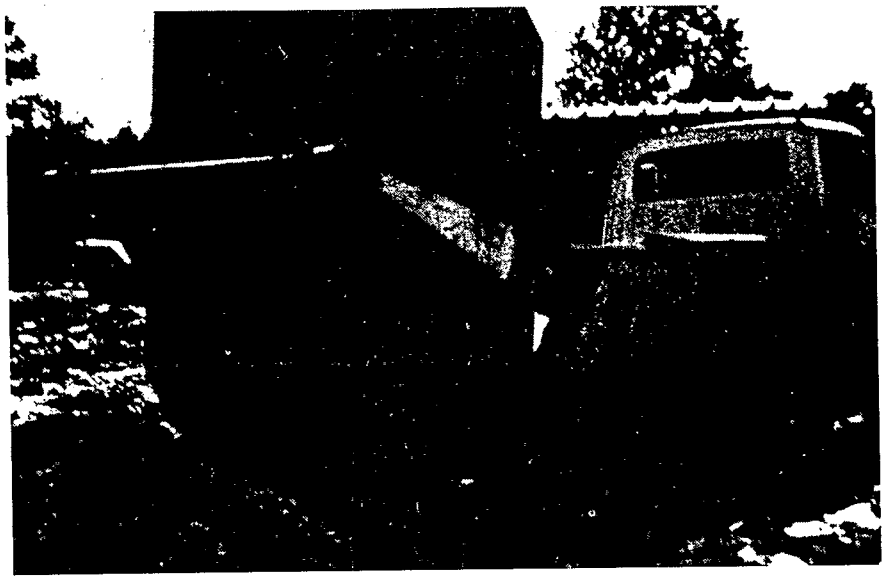

Figure 9-14. Load lugger.

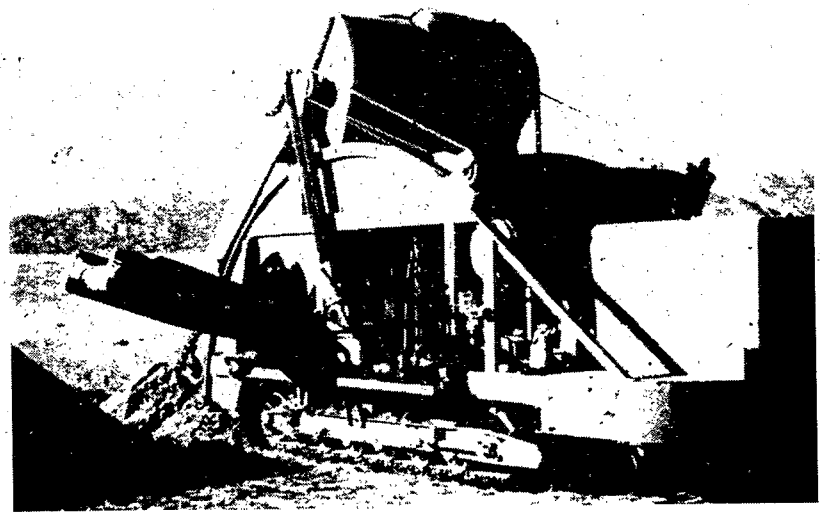

Figure 9-15. Trenching machine.

and air (outputs). The main concern with monitoring sewage sludge is ensuring that the nature and frequency of sampling adequately characterizes the concentration of pollutants in sludge. The main concern with environmental monitoring is ensuring that the number and location of sampling points are adequate to characterize background levels (for ground water) and that sampling is frequent enough to determine whether a particular requirement is met.

10.3.1 Parameters of Interest

As noted in Section 10.2.1, the main parameters of interest for monitoring at sewage sludge disposal sites include: (1) arsenic, chromium, and nickel, which have been identified as the main metals of concern in sludge; (2) pathogens and vector attraction reduction; (3) nitrates in the ground water; and (4) methane gas, which can reach explosive concentrations when sewage sludge is covered and anaerobic conditions develop in the subsurface. Where a treatment works is known to receive significant inputs of other types of pollutants from industrial sources, then the number of inorganic and organic species that must be monitored might be larger.

U.S. EPA (1992a) covers requirements for the monitoring, sampling, and analysis of pathogens and vector attraction reduction efforts under Part 503 in detail and should be consulted for further guidance. The remainder of this chapter focuses on other types of monitoring. Chapter 2 of U.S. EPA (1993a) also provides guidance on monitoring of sewage sludge for surface disposal.

At sites where leachate or runoff is collected and released to surface waters as a point source, NPDES permits may require monitoring of a number of parameters, such as chemical or biological oxygen demand (COD/BOD), turbidity, pH and selected chemical species. At sludge surface disposal sites arsenic, chromium, nickel, pathogens, and nitrates would be likely additional parameters for leachate and surface water monitoring, because they are monitored in other parts of the system.

10.3.2 Media To Be Sampled

Monitoring at sludge surface disposal sites may require sampling of all types of media: (1) solids or semisolids for sludge characterization, (2) liquids in the form of leachate, surface water, and ground water; and (3) air to detect presence of methane. Sewage has to be monitored if an active sewage sludge unit does not have a liner and leachate collection system, ground water has to be monitored unless a certification is made, and air has to be monitored if the unit is covered. Other special considerations for monitoring of specific media are addressed in Sections 10.4.2 (Ground Water), 10.4.3 (Leachate and Surface Water), and 10.4.4 (Methane).

10.3.3 Sampling Locations

Sampling locations will depend on the type of media being sampled. Sewage sludge can either be sampled during loading or on the ground after dumping or spreading.[1] Table 10-1 identifies recommended sampling points for various types of sewage sludge. In general, sampling locations should be as close to the stage before final disposal as possible. Domestic septage can be sampled from the container used to haul the domestic septage or after placement (the risk of penalties for being out of compliance after placement apply here as well). Section 10.4.1 addresses sampling of sludge in more detail. Ground-water monitoring wells (Section 10.4.3) should be located up- and down-gradient from the surface disposal site based on flow net analysis and other hydrogeologic information obtained during site investigations (Sections 6.4.3 and 6.5.2). Section 10.4.2 discusses monitoring well network design further. Leachate collection systems and ponds for collection of surface water runoff should be sampled at the point of discharge to surface waters. Methane gas monitoring devices, if required, should be placed in each structure within the surface disposal site bounda-

[1] Sampling after spreading poses the risk of penalties if samples exceed pollutant limits and should only be done if pollutants do not vary greatly in concentration and are known to fall well below pollutant limits.

Table 10-1. Chemical and Physical Parameters Typically Determined for Monitoring of Sewage Sludge Application Sites

Sample	Chemical and Physical Parameters
Ground Water	***Field Measured Parameters for Sampling***: pH, electrical conductivity, temperature, turbidity; ***Other Common Parameters:*** Total hardness, total dissolved solids, chlorides, sulfates, total organic carbon, nitrate nitrogen, total phosphorus, surfactants, selected metals (arsenic, chromium, nickel and others, if appropriate) or trace organics where applicable, pathogens/indicator organisms.
Surface Water	Fecal coliforms, total phosphorus, total nitrogen (Kjeldahl), dissolved oxygen, chemical/biological oxygen demand (COD/BOD), temperature, pH, suspended solids.
Soil	Exchangeable ammonium nitrogen and nitrate-nitrite nitrogen, available phosphorus, pH, electrical conductivity, organic carbon, exchangeable cations (calcium, magnesium, potassium, sodium), total and extractable metals—DTPA or 0.1 N HCl (arsenic, cadmium, chromium, copper, nickel, zinc), cation exchange capacity, particle size distribution (texture), other known or suspected contaminants.

Source: Adapted from Granato and Pietz (1992).

ries, and at site boundaries based on prevailing wind direction (Section 10.4.4).

10.3.4 Sampling Frequency

The Part 503 regulation establishes frequency of sampling to characterize sludge at surface disposal sites based on the amount of sludge placed on a site in a year (Table 10-2). If climatic conditions do not allow placement of the sludge year-round, the number of sampling events should be spaced over the period of active placement. For example, if placement of sludge only occurs 6 months of the year, and the minimum frequency is 6 times per year, then sampling would need to occur once a month during the period of active spreading. If no previous sampling data are available on the sludge to be disposed, it may be desirable to sample more frequently until enough data are collected to determine the minimum number of samples required to satisfy a 90 percent confidence limit for sample representativeness (Section 10.4.1).

Ground-water sampling is usually done on a quarterly basis, although specific state regulatory programs might specify different intervals. When leachate or surface runoff is discharged to surface water, the sampling interval will be specified in the NPDES permit, which again is typically four times a year. Air monitoring for methane gas, when required, should be continuous.

10.3.5 Sample Collection and Handling Procedures

Sample collection and handling procedures should be clearly defined and consistently followed to minimize sample errors attributable to the sampling process. This can be accomplished with a written sampling protocol that includes:

- Specification of personnel responsible for collecting samples, and training requirements to ensure that sampling protocols are correctly followed.

Table 10-2. Frequency of Monitoring for Surface Disposal of Sewage Sludge

Parameter	Validity of Analytical Data over Time and When Sampling/Analysis Must Occur
	METALS
Metals	Data remain valid for biosolids if no significant change in volatile solids. Determine monitoring frequency in accordance with monitoring frequency requirements.
	PATHOGENS CLASS A
Applies to All Class A Pathogen Reduction Alternatives (PRA): Fecal Coliform & *Salmonella* sp.	Because regrowth can occur, monitoring should be done: (a) sufficiently close to the time of biosolids use so data are available and no additional regrowth occurs before land application, or (b) when biosolids are prepared for sale or give-away in a bag or other container for land application, or (c) when biosolids are prepared to meet EQ requirements.
	Additional Information on Each Class A Pathogen Category
Class A PRA 1: Thermal Treatment, Moisture, Particle Size & Time Dependent	Data remain valid as long as biosolids remain dry before use. Time, temperature, and moisture content should be monitored continuously to ensure effectiveness of treatment.
Class A PRA 2: High pH, High Temperature	Monitor to ensure that pH 12 (at 25°C) is maintained for more than 72 hours.
Class A PRA 3: Enteric Virus & Viable Helminth Ova to Establish Process	Once destroyed, enteric virus or viable helminth ova does not regrow. To establish a process, determine with each monitoring episode until the process is shown to consistently achieve this status. Then continuously monitor process to ensure its validity.
Class A PRA 4: Enteric Virus & Viable Helminth Ova for Unknow Process	Once destroyed, enteric virus or viable helminth ova does not regrow. Monitor representative sample of biosolids material: (a) to be used or disposed, or (b) when prepared for sale or give-away in a bag or other container for land application, or (c) when prepared to meet EQ requirements.
Class A PRA 5: PFRP	Monitor continuously to show compliance with time and temperature or irradiation requirements.
Class A PRA 6: PFRP Equivalent	Monitor continuously to show compliance with PFRP or equivalent process requirements.

Table 10-2. Monitoring Considerations for Key Parameters (continued)

PATHOGENS CLASS B	
Class B PRA 1: Fecal Coliform	Measure the geometric mean of 7 samples when used or disposed sufficiently close to the time of use so that (i) data are available and (ii) no additional regrowth occurs before land application.
Class B PRA 2:	Continuously monitor to show that biosolids are meeting the PSRP requirements.
Class B PRA 3:	Continuously monitor to show that biosolids are meeting the equivalent PSRP requirements.
VECTOR ATTRACTION REDUCTION	
Vector Attraction Reduction (VAR) 1: 38% Volatile Solids Reduction (VSR)	Once achieved, no further attractiveness to vectors. If a batch process, determine VSR for each batch. If for a continuous process, determine VSR based on material being put in and withdrawn. Monitor continuously to verify that biosolids are meeting the necessary operating conditions.
VAR 2 for Anaerobic Digestion: If Cannot Meet VAR 1 Lab Test	
VAR 3 for Aerobic Digestion: If Cannot Meet VAR 1 Lab Test	Once achieved, no further attractiveness to vectors. If a batch process, determine VSR for each batch. If unable to show VSR, then conduct lab test. Monitor continuously to verify that biosolids are meeting the necessary operating conditions.
VAR 4: SOUR Test for Aerobic Processes	
VAR 5: Aerobic >40°C	Monitor continuously to show that biosolids are achieving the necessary temperatures over time.
VAR 6: Adding Alkaline Material	Determine pH over time for each batch. Data are valid as long as the pH does not drop such that putrefaction begins prior to land application.
VAR 7: Moisture Reduction No Unstabilized Primary Solids	To be achieved only by the removal of water. Data are valid as long as the moisture level remains below 30%.
VAR 8: Moisture Reduction Primary Unstabilized Solids	To be achieved only by the removal of water. Data are valid as long as the moisture level remains below 10%.
VAR 9: Injection into Soil	No significant amount of biosolids remains on soil surface within 1 hour after injection.
VAR 10: Incorporation into Soil	Biosolids must be incorporated into soil within 6 hours after being placed on the soil surface.
VAR 11: Covered with Soil Surface Disposal	Surface disposed biosolids must be covered daily.
VAR 12: Domestic Septage pH Adjustment	Preparer must ensure that pH is 12 for more than 30 minutes for each batch of domestic septage treated with alkaline material.

- Specification of safety precautions, such as use of gloves when handling or sampling untreated or treated sewage sludge and cleaning of sampling equipment, containers, protective clothing, and hands before delivering samples to others.

- Identification of the type of sampling device. For dewatered sludge, soil sampling devices, such as scoops, trier samplers, augers, or probes can be used. Stainless steel materials are best; chrome-plated samplers should be avoided. For leachate and surface water, sample containers can be filled directly at the points of discharge or dippers used to transfer liquid to the container. For ground water, a wide variety of sampling devices are available. Because nitrate is the only monitoring parameter specified in the Part 503 regulation, bailers will probably be the simplest and least expensive sampling device for ground-water sampling.

- Description of sample mixing and subsampling procedures when grab samples of sludge are composited and only part of the composite sample is used for analysis. This usually requires use of a mixing bowl or bucket (stainless steel or Teflon) or a disposable plastic sheet in or on which samples can be mixed and from which a smaller sample can be taken.
- Specification of the size and material of sample containers. Table 10-3 identifies suitable containers and minimum volume requirements for sludge sampling. Sample containers can often be obtained from the person or laboratory responsible for doing the sample analysis.
- Specification of sample preservation procedures and sample holding times. Table 10-3 identifies these requirements for sludge samples. Unless analysis is done in the field or in an onsite laboratory, sludge samples are usually cooled to 4°C (i.e., packed in ice). Holding times vary with the constituent being analyzed. For example, the maximum holding time for nitrate is 24 hours unless the sample is acidified, in which case the holding time is a maximum of 28 days (U.S. EPA. 1991c). The appropriate regulatory agency, in coordination with the testing laboratory, should be contacted to identify any specific sample preservation procedures and holding times for all specific constituents being monitored.
- Specification of sample equipment cleaning procedures to ensure that cross-contamination of samples does not occur. ASTM D5088 (Standard Practice for Decontamination of Field Equipment Used at Nonradioactive Waste Sites) provides guidance on these procedures.
- Specification of types and frequency of quality assurance/quality control (QA/QC) samples. Again, the appropriate regulatory agency should be contacted to determine which types of QA/QC samples may be required for the site.
- Description of sample chain-of-custody procedures to ensure that the integrity of samples is maintained during transport and analysis of samples.

Table 10-3. Sampling Points for Sewage Sludge

Biosolids Type	Sampling Point
Anaerobically Digested	Collect sample from taps on the discharge side of positive displacement pumps.
Aerobically Digested	Collect sample from taps on discharge lines from pumps. If batch digestion is used, collect sample directly from the digester. Cautions: 1. If biosolids are aerated during sampling, air entrains in the sample. Volatile organic compounds may be purged with escaping air. 2. When aeration is shut off, solids separate rapidly in well-digested biosolids.
Thickened	Collect sample from taps on the discharge side of positive displacement pumps.
Heat Treated	Collect sample from taps on the discharge side of positive displacement pumps *after* decanting. Be careful when sampling heat-treated biosolids because of: 1. High tendency for solids separation. 2. High temperature of sample (temperature <60°C as sampled) can cause problems with certain sample containers due to cooling and subsequent contraction of entrained gases.
Dewatered, Dried, Composted, or Thermally Reduced	Collect sample from material collection conveyors and bulk containers. Collect sample from many locations within the biosolids mass and at various depths.
Dewatered by Belt Filter Press, Centrifuge, Vacuum Filter Press	Collect sample from biosolids discharge chute.
Dewatered by Biosolids Press (plate and frame)	Collect sample from the storage bin; select four points within the storage bin, collect equal amount of sample from each point and combine.
Dewatered by Drying Beds	Divide bed into quarters, grab equal amounts of sample from the center of each quarter and combine to form a composite sample of the total bed. Each composite sample should include the entire depth of the biosolids material (down to the sand).
Compost Piles	Collect sample directly from front-end loader while biosolids are being transported or stockpiled within a few days of use.

Note: The term biosolids will be replaced with "sewage sludge" in the final document.

Each type of media that is sampled should have a separate written sampling protocol, unless sampling procedures are the same for different media. U.S. EPA (1994a) provides detailed guidance on sampling procedure for sewage sludge. Most of the references cited in Table 6-7 in Chapter 6, address sample collection and handling procedures in more detail. Keith (1992) provides a useful general guide to development of environmental sampling protocols. Major sources that address soil sampling in greater detail include: U.S. EPA (1989b), U.S. EPA (1991b), Boulding (1994), and U.S. EPA (1992c). Ground-water sampling generally requires the most complex procedures because of the need to purge a well before sample collection (Section 10.4.2). Major sources that address ground-water sampling procedures include: U.S. EPA (1985), U.S. EPA (1991c), and U.S. EPA (1993b).

10.3.6 Sample Analysis Methods

Numerous procedures are available for chemical analysis of environmental samples. For example, there are five major series of U.S. EPA methods: (1) EPA CLP (contract laboratory program) for inorganic and organic analysis; (2) EPA 200 series for water and wastes; (3) EPA 500 series for organic compounds in drinking water; (4) EPA 600 series (identified in 40 CFR, Part 146), and (5) SW-846 methods for solid waste (U.S. EPA, 1986). The American Society for Testing and Materials (ASTM) publishes annually standard test methods for analysis of water (Volumes 11.01 and 11.02) and wastes (Volume 11.04). The American Pubic Health Association/ Water Environment Federation's compilation of methods for analyzing water and wastewater is in its 18th edition (APHA, 1992). Furthermore, the U.S. Geological Survey, as well as other federal agencies, also have developed standard methods for chemical analysis (mainly in its Techniques of Water Resource Investigations series). Also, state environmental agencies might specify their own methods for analysis of certain constituents. For example, New Jersey requires testing of sulfide reactivity of sewage sludge (personal communication, Cris Gaines, U.S. EPA Office of Water, April 1994).

Analytical methods in the context of environmental regulatory programs can be grouped into the following categories:

- *EPA-approved* methods have been published in the Federal Register as the benchmark method for a specified regulatory purpose (i.e. reporting for NPDES or drinking water programs). Typically, EPA-approved methods required sophisticated fixed laboratory facilities.
- *EPA-accepted* methods have been evaluated by EPA against an EPA-approved method and been found to be equivalent to the EPA-approved method. Manufacturer claims that a method is EPA-accepted should be documented with a letter from EPA stating that the method has been evaluated by EPA and found to be equivalent. EPA-accepted methods are not published in the Federal Register because additions and changes to this category are so frequent that it is simpler to let manufacturers provide the necessary documentation to users.
- *Other standard methods* involve clearly defined procedures and protocols defined by state regulatory programs, other federal agencies (such as the U.S. Geological Survey) or professional organizations (such as the American Society for Testing and Materials and the American Public Health Association). For specific purposes, EPA may specify or recommend particular methods from these sources (See Table 10-5).
- *Field screening methods* involve relatively simple qualitative (substance is present or absent in relation to a threshold level), semiquantitative (concentrations lie within a certain range), or quantitative methods that can be used in the field or a small laboratory. Chemical field screening methods tend to be less expensive than EPA-approved and EPA-accepted methods, but also less accurate. Potential uses for these methods are discussed later in this Section.

EPA-Specified Methods

Table 10-4 identifies analytical methods for pathogens, inorganic pollutants, and other sludge parameters that are required by the Part 503 regulation. Specific methods for sample preparation and analysis for the metals of interest for sewage sludge surface disposal are contained in U.S. EPA (1986) as follows: arsenic (EPA Methods 3050/3051 and 7060/7061); chromium (EPA Methods 3050/3051 and 6010/7191/7190); and nickel (EPA Methods 3050/3051 and 6010/7520). Although both methods for 7060 and 7061 can be used to analyze for arsenic, Method 7060 is often preferable because high concentrations of chromium, cobalt, copper, molybdenum, nickel, or silver can cause analytical interference in method 7061 (U.S. EPA, 1994b).

Other Standard Methods

Any state regulatory agency that has jurisdiction over a surface disposal site should be consulted to determine whether any additional analysis methods are required. If conditions at a particular site require analysis for constituents for which there are not EPA or state-specified methods, the appropriate ASTM or APHA/WEF method may be selected (see above).

Field Screening Methods

Key considerations in sample analysis include ensuring that the methods used for regulatory reporting are acceptable to the permitting authority and minimizing analytical costs. U.S. EPA-approved methods require

Table 10-4. Minimum Frequency of Monitoring for Surface Disposal of Sewage Sludge

Amount of Biosolids[a] (metric tons per 365-day period)	Amount of Biosolids (English units)		Minimum Frequency
	Ave. per day	per 365 days	
Greater than zero but less than 290	>0 to <0.85	>0 to <320	Once per year
Equal to or greater than 290 but less than 1,500	0.85 to <4.5	320 to <1,650	Once per quarter (four times per year)
Equal to or greater than 1,500 but less than 15,000	4.5 to <45	1,650 to 16,500	Once per 60 days (six times per year)
Equal to or greater than 15,000	≥45	≥16,500	Once per month (twelve times per year)
Methane gas in air			Continuously with methane monitoring device if biosolids unit is covered

[a] Amount of biosolids (other than domestic septage) placed on active biosolids units—dry-weight basis.

Table 10-5. Comparison of Selected Field Analytical Methods Potentially Applicable for Field Screening at Sewage Sludge Surface Disposal Sites (all detection limits in ppm)

Test Method/ Manufacturer[a]	Arsenic	Chromium[b]	Nickel	Nitrate	Required Other Equipment
COLORIMETRIC METHODS					
EM Science (liquid samples)					
EM Quant	0.1-3	3-100	10-500	10-500	None
Aquaquant	—	0.005-1.6	0.02-0.5	—	None
Microquant	—	0.01-10	0.5-10	5-90	None
Spectroquant	—	0.025-2.5	0.1-10	2-50	Photometer
Reflectoquant	—	1-45	pending	3-90	RQ Flex Meter
Hach Company					
NPDES[c]	yes	yes	yes	—	Digestion (As, Cr); spectrophotometer
Sludge	—	>4 ppm[d]	>4 ppm	—	Digestion, spectrophotometer
OTHER METHODS					
Ion-Selective Electrodes[e]					
ATI/Orion	—	—	—	0.1	Meter and reference electrode
Hach Co.	—	—	—	0.1	Meter and reference electrode
Solonet	—	—	—	0.1	Meter and reference electrode
TM Analytic	—	—	—	0.1	Meter and reference electrode

Note: Manufacturer should be contacted for current status and documentation for EPA approval or acceptance.
[a] See Appendix C for addresses and phone numbers of manufacturers.
[b] Quant tests measure chromate, HACH water test measures Cr(VI) and Hach sludge tests are for total chromium.
[c] EPA-accepted methods for NPDES reporting (water samples).
[d] EPA-approved method only if preceded by EPA-approved nitric acid digestion.
[e] EPA acceptance pending for NPDWR reporting.

extensive laboratory facilities, with relatively high capital and operating costs, which means that analytical costs tend to be high. Advances in the portability and accuracy of instrumentation and techniques for analyzing environmental samples are making chemical analysis in the field or in small onsite laboratories an option that should be carefully evaluated, ***in consultation with the appropriate regulatory authority,*** as a possible way to reduce costs associated with chemical analysis. Such methods can be used in two ways: (1) as an alternative to sending samples to a laboratory where EPA-approved or EPA-accepted methods can be used in the field or in an on-site laboratory, and (2) for process control.

Most standard methods for sampling metals require use of flame or graphite furnace atomic absorption spectroscopy or inductively coupled plasma (ICP) atomic emission spectrometry, which require specialized training for use. Laboratory analysis of arsenic, chromium, and nickel in a sample of sludge can be expected to cost as much as $80 to $85. In contrast, semiquantitative colorimetric tests, which often are able to detect concentrations in sub-ppm levels, are available for many metals at a cost of less than $1.00 per sample. Table 10-5 identifies detection limits for a number of colorimetric methods (field screening methods) for arsenic, chromium, nickel, and nitrate, the main inorganic pollutants of interest in sewage sludge placed on an active sewage sludge unit. The Quant tests all use test strips that change in color in response to a concentration of the analyte being tested. EM Quant, Aquaquant, and Microquant tests involve visual matching with color charts or wheels. Spectroquant and Reflectoquant tests give quantitative results using spectrophotometric measurements. Hach tests use chemical reagents, often in combination with digestion procedures, yield quantitative measurements using a spectrophotometer. Hach (1991, 1992) provides detailed information on test procedures for waste and water analysis, respectively.

Table 10-5 provides summary information on other types of field-portable instruments. Ion-selective electrodes (ISE) able to measure concentrations of nitrate down to concentrations of 0.1 ppm and approved by U.S. EPA for monitoring drinking water quality is planned for publication in the Federal Register by the end of 1994. Laboratory analysis of water samples for nitrate generally cost around $25 per sample. For an initial investment of $1,500 to $2,500 for a nitrate electrode, reference electrode, and meter, reagents for ISE tests can be expected to cost from $0.50 to $1.50 depending on whether buffering solutions and reagents to reduce interference from the presence of other species are used.

10.4 Media-Specific Monitoring Considerations

10.4.1 Sewage Sludge Characterization

Number of Samples. Monitoring of arsenic, chromium, and nickel is required when surface disposal of sludge is conducted without use of a liner and leachate collection system to protect ground water. The regulation under 40 CFR 503.23 establishes pollutant limits for these metals based on distance from the boundary of the active sewage sludge unit to the property line of the surface disposal site (see Table 3-5 in Chapter 3). Sampling of sludge is required at the frequency specified in Table 10-2, based on the annual amount of sludge disposed. The minimum number of samples required to show that concentrations of arsenic, chromium, and nickel comply with the applicable pollutant limits in Table 10-6 at a 90 percent confidence interval can be readily calculated if the average concentration and the standard deviation of the historical sample set is known. The following simple equations are used for this procedure:

(Eq. 10-1)

$$\text{Sample Mean } (X) = \frac{\text{Sum of Data Values}}{n}$$

(Eq. 10-2)

$$\text{Standard Deviation}(s) = \frac{n(\text{Sum of Squared Data Values}) - (\text{Sum of Data Values})^2}{n(n-1)}$$

(Eq. 10-3)

$$\text{Number of Samples} = \frac{(\text{Constant T})^2 s^2}{(\text{Regulatory Limit} - X)^2}$$

where:

n = number of data values
Constant T = appropriate value from Table 10-7
Pollutant Limit = applicable value in Table 10-6 or permit-specific value

The following steps are required to calculate the minimum number of samples in a year to demonstrate compliance with the pollutant limits for a sewage sludge:

Step 1. Calculate the mean and standard deviations for arsenic, chromium, and nickel using historical data using Equations 10-1 and 10-2. If historical data are not available, Table 10-8 can be used to provide initial values.

Step 2. Determine the Constant T from Table 10-7 based on the number of data values (n), and the appropriate

Table 10-6. Analytical Methods for Sewage Sludge

Sample Type	Method
Enteric Viruses	ASTM Designation: D 4994-89, Standard Practice for Recovery of Viruses from Wastewater Sludges, Annual Book of ASTM Standards: Section 11. Water and Environmental Technology, ASTM, Philadelphia, PA, 1992.
Fecal Coliform	Part 9221 E or Part 922 D, Standard Methods for the Examination of Water and Wastewater, 18th edition, American Public Health Association, Washington, DC, 1992.
Helminth Ova	Yanko, W.A., Occurrence of Pathogens in Distribution and Marketing Municipal Sludges, EPA/600/1-87/014, 1987. PB 88-154273/AS, National Technical Information Service, Springfield, VA; (800) 553-6847.
Inorganic Pollutants	Test Methods for Evaluating Solid Waste, Physical/ Chemical Methods, EPA Publication SW-846, 3rd edition (1986) with Revision I. 2nd edition. PB 87-120291, National Technical Information Service, Springfield, VA. 3rd edition Doc. No. 955-001-00000-1, Superintendent of Documents, Government Printing Office, Washington, DC.
***Salmonella* sp. Bacteria**	Part 9260 D, Standard Methods for Examination of Water and Wastewater, 18th edition, American Public Health Association, Washington, DC, 1992; or, Kenner, B.A. and H.P. Clark, Detection and Enumeration of *Salmonella* and *Pseudomonas aeruginosa*, J. Water Pollution Control Federation, 46(9):2163-2171, 1974.
Specific Oxygen Uptake Rate	Part 2710 B, Standard Methods for the Examination of Water and Wastewater, 18th edition, American Public Health Association, Washington, DC, 1992.
Total, Fixed, and Volatile Solids	Part 2540 G, Standard Methods for the Examination of Water and Wastewater, 18th edition, American Public Health Association, Washington, DC, 1992.
Percent Volatile Solids Reduction Calculation[b]	Environmental Regulations and Technology—Control of Pathogens and Vectors in Sewage Sludge, EPA/625/R-92/013, U.S. Environmental Protection Agency, Cincinnati, OH, 1992; (614) 292-6717.

[a] These analytical methods are required by the Part 503 rule.

[b] This analytical method is provided as guidance in the Part 503 rule.

pollutant limits for all three metals from Table 10-6 or site-specific values in the permit.

Step 3. Calculate the required number of samples for each pollutant using Equation 10-3. The highest number of the three should be used for purposes of sampling.

If the number of samples seems too high (which may be the case if the national values from Table 10-8 are used), several options may be available to reduce the number of samples: (1) during the design stage, it may be possible to increase the distance from the boundary of an active sewage sludge unit to the less stringent surface disposal site property line if the distance is less than 150 ft, allowing recalculation of Equation 10-3 with pollutant limits (Table 10-6); or (2) collect a number of samples at relatively short intervals (days or weeks) and repeat Steps 1 through 3 above to see if a larger historical sample size reduces the number of samples required as long as the frequency of monitoring in Part 503 is met.

As the difference between the average concentration of a pollutant and the pollutant limit decreases, the number of required samples to demonstrate compliance increases. When this difference is small, the number of required samples might be so large as to make monitoring prohibitive. In such cases, the use of a liner and leachate collection system should be evaluated. Also, if the historical data indicate the pollutant limits cannot be achieved (e.g., mean chromium values for 100 MGD facilities in Table 10-8 exceeds the maximum allowed pollutant concentration in Table 10-6), use of a liner and leachate collection system is likely to be required.

Sample Collection. For "dry" sewage sludge (40 percent solids) sampling is best done when it is being transferred, usually on conveyors. U.S. EPA (1993a, 1994a) provide more detailed guidance on specific sludge sample collection procedures. The most convenient and most accurate scheme for sampling sludge will generally be to sample haul truck loads at a frequency that obtains the minimum number of samples calculated using Equation 10-3 assuming the Part 503 frequency of monitoring requirement is met. This frequency can be determined by dividing the annual tonnage or cubic yards of sludge by the calculated number of samples to

Table 10-7. Tabulated Values of Constant T for Evaluating Sludge for 90 Percent Confidence Interval

Number of Sample Points (Data Points)	Tabulated Constant T Value
2	6.314
3	2.920
4	2.353
5	2.132
6	2.015
7	1.943
8	1.895
9	1.860
10	1.833
11	1.812
12	1.796
13	1.782
14	1.771
15	1.761
16	1.753
17	1.746
18	1.740
19	1.734
20	1.729
21	1.725
22	1.721
23	1.717
24	1.714
25	1.711
26	1.708
28	1.703
30	1.699
inf.	1.645

determine how often haul trucks or spreaders should be sampled. For example, if 250 cubic yards of sewage sludge are hauled to the site in a year, in haul trucks with a 25 cubic yard capacity, and ten samples are required, then a representative sample from each truck load would be required. If half that amount was hauled in a year, then two representative samples representing the front and back half of each truck would be required.

10.4.2 Ground-Water Monitoring

Monitoring for nitrates in ground water at sewage sludge surface disposal sites is required unless a certification is made by a ground-water scientist that ground water will not be contaminated by the disposal of sewage sludge at the site (usually an option only if the site has a liner and leachate collection system). If only nitrate must be monitored (i.e., based on sludge or site characteristics the regulatory authority does not require monitoring of other pollutants), it may be possible to use drive-point monitoring well installations that are less expensive than standard installations, as discussed later in this section. In-house sample analysis using nitrate ion-selective electrodes also may be an economically attractive alternative to sending samples to a laboratory for analysis (see Section 10.3.6). The discussion that follows assumes that only nitrate is being monitored for regulatory reporting purposes and that the site rep-

Table 10-8. Alternative Values for Calculating Required Number of Sludge Samples for Metals Monitoring

Pollutant	Flow Group (MGD)	Mean (mg/kg)	Standard Deviation	T
Arsenic	>100	7.71	5.58	1.708
	10 to 100	12.08	17.04	1.645
	1 to 10	9.72	10.91	1.645
	<1	9.93	20.24	1.645
Chromium	>100	461.41	682.09	1.708
	10 to 100	281.40	503.53	1.645
	1 to 10	160.57	286.16	1.645
	<1	102.77	338.99	1.645
Nickel	>100	90.30	113.19	1.708
	10 to 100	81.96	108.17	1.645
	1 to 10	48.36	49.23	1.645
	<1	39.90	101.25	1.645

Source: Table I-11, 55 FR 47229-47231, November 9, 1990.

resents a Type I hydrogeologic setting (Section 6.4.3). If additional pollutants must be monitored, or aquifer materials are not suitable for drive-point installations, conventional monitoring well design should be followed, as covered in ASTM (1990), U.S. EPA (1991a), Nielsen and Schalla (1991), and references in Table 6-7 in Chapter 6. Use of drive-point installations for permanent monitoring wells is still a relatively new concept in regulatory applications, so the appropriate regulatory authorities should be consulted and provided any necessary additional information to demonstrate that such installations are an acceptable alternative to conventional monitoring well installations.

Monitoring Network Design. Figure 10-1 summarizes the process for designing a ground-water monitoring system. The flow net analysis described in Section 6.5.2 provides a basis for selecting locations for background monitoring wells and downgradient wells for detection monitoring. For a simple Type I hydrogeologic setting, monitoring wells would be set in the unconfined aquifer with a minimum of two upgradient background monitoring wells (Figure 10-2), with the location and number of downgradient monitoring wells depending on flow paths and the size of the site and any specific regulatory requirements addressing the number of wells. Flow net analysis will guide the depth of monitoring wells and the length of well screen to be used. As noted in Section 6.5.2, failure to use flow net analysis for placement of monitoring wells and determining screened intervals can easily result in samples that miss any pollutant plume that develops.

Monitoring Well Installation. Typical monitoring well installations in unconsolidated materials are drilled using a hollow-stem auger and constructed of PVC pipe and well screen with filter-pack and grouting to seal the annular space around the well pipe (ASTM,1990). If nitrate is the only analyte of interest for ground-water monitoring, as specified in the Part 503 regulation, then alternative, less-expensive approaches might be able to satisfy monitoring requirements. Sample bias as a result of sorption or leaching of well screen and casing materials is not a concern with nitrate because it is an anion, which means that small-diameter (typically 1 inch or less outer diameter) metal drive points and casing materials can be used for installation of monitoring wells in unconsolidated materials. Basic elements of such an installation include: (1) a slotted drive point (stainless steel is generally preferable for permanent installations because it is more resistant to corrosion); (2) a metal casing that is either cut to length or added as extensions until the desired depth is reached; and (3) a cap and protective containment structure to prevent accidental damage to the aboveground portion of the installation. Possible additional elements of the installation many include: (1) filter material, such as Vyon, to prevent soil particles from entering the openings in the drive point or use of porous stainless steel (10 to 20 micron opening), and (2) tubing that runs inside to the casing of the well point to eliminate contact between sample water and the casing.

Methods of installation include the methods and equipment described in Section 6.4.3 in Chapter 6 for installation of piezometers: (1) handheld power driver (Figure 6-2), (2) hydraulic probes (Figure 6-3), (3) hand-operated weighted drivers (Figure 6-8a), and (4) crank-driven drivers (Figure 6-8b). In addition, vibratory drive methods that adapt high-frequency hammer drill technology can be used for very rapid installation of pre-cut riser sections up to a maximum length of 21 ft (Figure 10-3). Depths of 30 ft can often be attained in nongravelly unconsolidated materials using the methods described

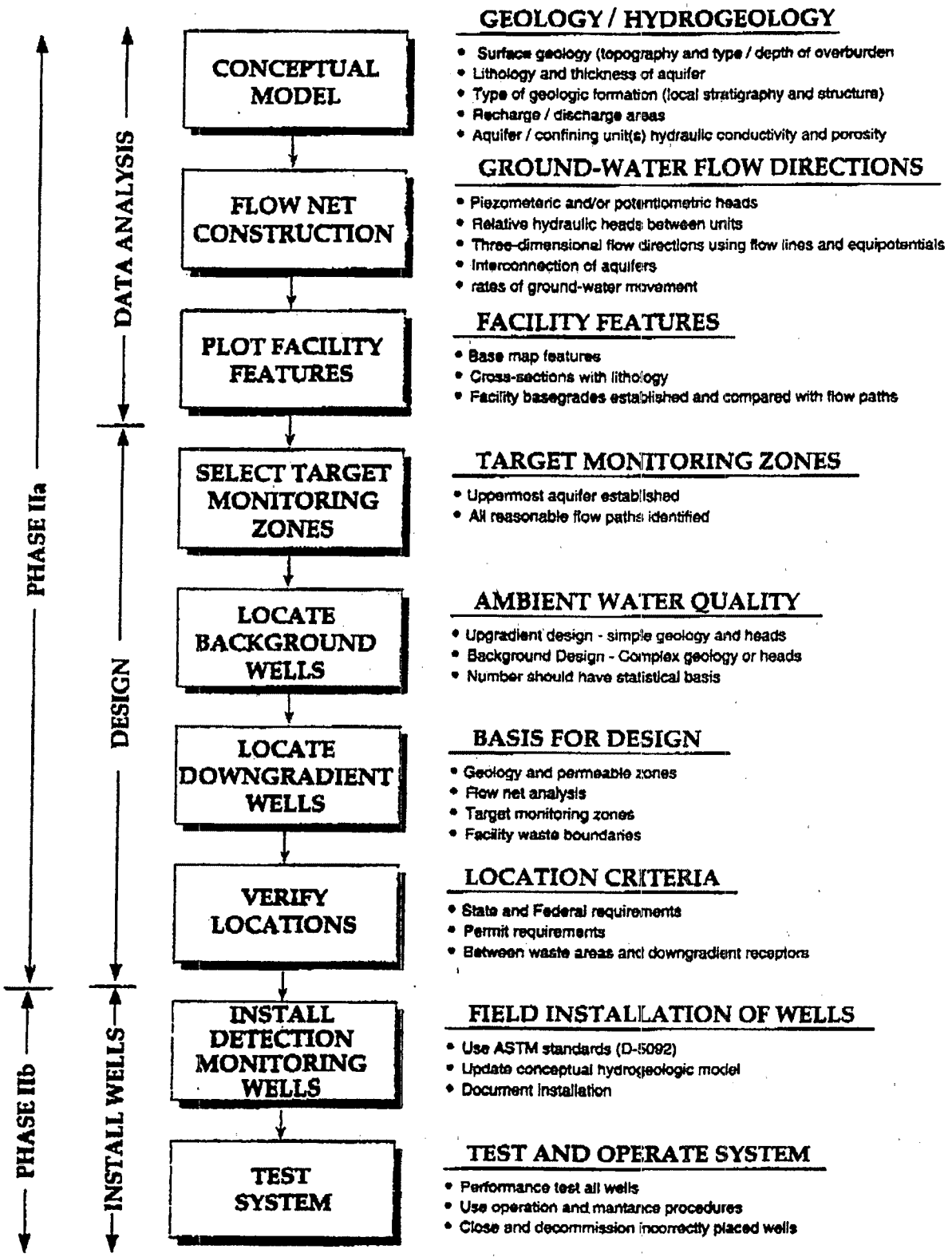

Figure 10-1. Flow diagram of monitoring system design (Sara, 1994).

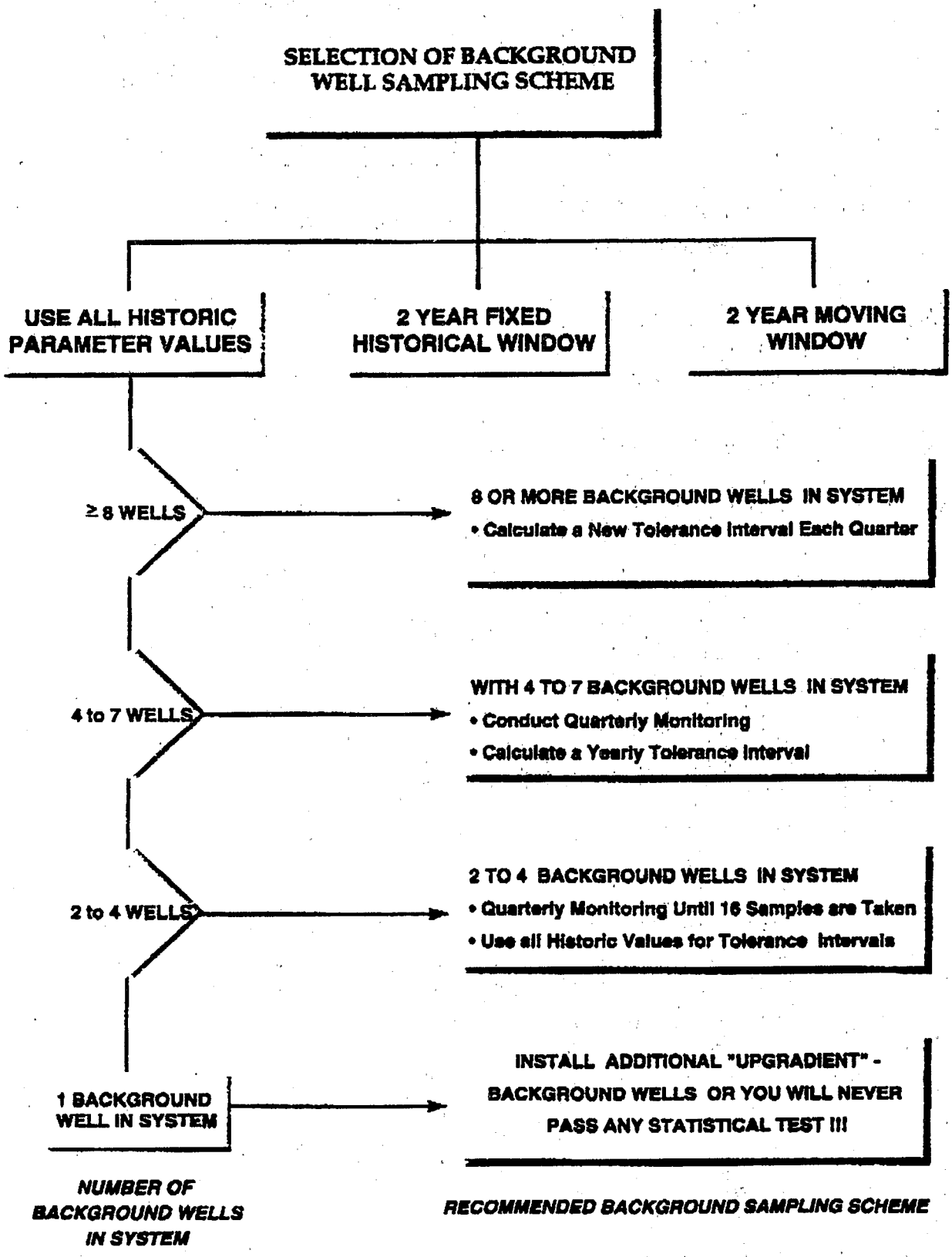

Figure 10-2. Guidelines for background well sampling based on number of wells (Sara, 1994).

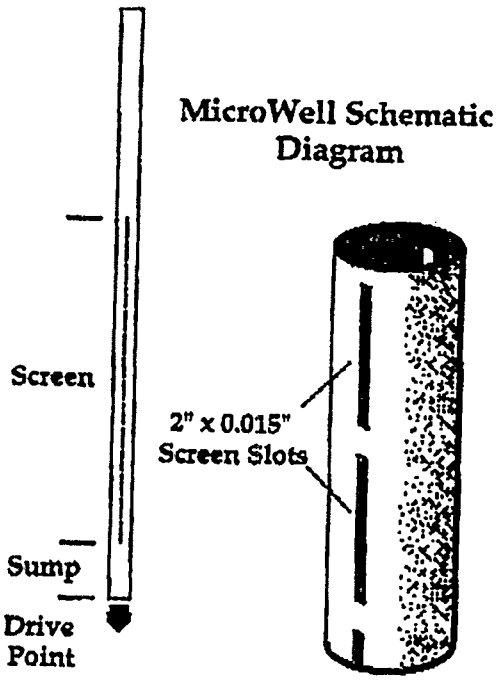

Figure 10-3. Micro Well schematic diagram; standard pipe is 0.62 inches internal diameter and 0.82 inches outer diameter (courtesy of Pine & Swallow Associates).

above. In unconfined sandy aquifers, depths of 100 ft are readily obtainable. Vibratory drive installations have penetrated to a maximum depth of 180 ft (personal communication, John Swallow, Pine & Swallow Associates, Groton, MA, April 1994). Solinst Canada's product literature reports that a Waterloo drive-point piezometer using a power-driven drive-hammer has been installed at a depth of 275 ft in lacustrine clay in New Mexico. Costs of drive-point monitoring well installations can be expected to range from 30 to 50 percent lower than conventional hollow-stem auger monitoring well installations. Table C-1 in Appendix C identifies manufacturers and distributors of well and piezometer drive points and drive equipment.

Sample Collection. The narrow diameter of the above monitoring well installations restricts sample collection to two main methods: (1) peristaltic suction lift pump for depths of 25 or 30 ft; (2) WaTerra inertial pump to depths of 100 ft (depths up to 250 feet can be sampled in 2- to 4-in. wells); (3) portable Solinst triple tube gas-drive sampler to depths up to 150 ft; and (4) small-diameter bailers (any depth). Specialized sampling techniques include (1) the BAT system, which uses evacuated sample containers and a disposable double-ended hypodermic needle for sample collection, and (2) the Waterloo drive-point double valve pump, which includes a dedicated positive displacement gas-drive sampler inside the drive point device.

Because drive-point installation results in minimal disturbance of the aquifer materials, if any, well development is required before samples are collected. If the drive point includes filter material, then well development should not be necessary. If the drive point is open slotted, then some soil grains less than the diameter of the slotting can enter the point, especially if vibratory drilling is used. For shallow installations (less than 25 ft) this material can be removed by using a peristaltic pump and inserting polyethylene tubing to the sediment/water interface. Deeper installations will require use of a bailer or WaTerra type inertial pump and surging action to suspend the sediment for collection in the bailer.

The narrow diameter of the drive pipe (generally less than 1 inch) means that drive-point installations will have less stagnant water in the well between sampling events, and the lack of filter pack or grout means that aquifer chemistry outside the well is minimally affected compared to conventional monitoring well installations. Consequently the amount of time required for purging before a sampling event also will be reduced. While purging, pH, conductance, and temperature should be monitored until they reach a consistent endpoint (no upward or downward trend), at which point the sample should be taken. Table C-1 in Appendix C identifies sources of field instrumentation for ground-water sampling. If nitrate ion-selective electrodes are used to analyze samples, multiparameter instruments are available that would allow monitoring of purge parameters and measuring nitrate concentration with the same meter.

10.4.3 Leachate and Surface Water Monitoring

If a liner and leachate collection system are used to prevent migration of pollutants into the ground water, the disposition of the leachate will determine what kind of monitoring will be required. Discharge as a point source to surface waters will require an NPDES permit, with the permit specifying what parameters must be monitored. Table 10-1 identifies commonly monitored parameters. As discussed in Section 10.3.6, depending on the parameters that must be monitored, use of wet chemistry field test kits or a small onsite laboratory may be a cost-effective alternative to sending samples to an outside laboratory. For example, there are 6 Hach methods that are U.S. EPA approved, and 35 Hach methods that are accepted by U.S. EPA for purposes of NPDES reporting (Hach Company, 1989).[2] The appropriate regulatory authority should always be consulted to determine whether a specific proposed method would be accepted for regulatory reporting. If leachate is discharged to a

[2] As noted in Section 10.3.6, the manufacturer test kits and equipment should be contacted for information on the current status of EPA acceptance or approval and asked to provide the appropriate documentation.

POTW, some monitoring might be required or appropriate for process control. Because precise measurements are usually not required for this purpose, use of colorimetric test strips as described in Section 10.3.6 might be a useful option.

Surface runoff from the sludge surface disposal site that is collected and discharged as a point source will require an NPDES permit. As with leachate, the permit will specify what parameters are to be monitored. It may be desirable to monitor any surface runoff from the active sewage sludge unit that is not controlled as a point source to see if pollutants of concern are moving offsite. Use of Quant test strips (Table 10-5) would be a relatively inexpensive way to determine the concentration of arsenic, chromium, nickel, and nitrate in surface runoff.

10.4.4 Monitoring Air for Methane Gas

Whenever sewage sludge placed on an active sewage sludge unit is covered daily or at closure, continuous monitoring of air for methane gas is required in all structures within the site properly line and at site property lines. Methane gas concentrations within any structure must be less than 25 percent of the lower explosive limit (LEL), which is the lowest percentage by volume of methane gas in air that supports a flame at 25°C and atmospheric pressure. For methane, the LEL is 5 percent. At the site property line, the LEL is the regulatory limit (i.e., concentrations are not allowed to exceed the LEL in air at the property line). (See Section 7.8.2 for additional information on control of explosive gases controls.)

Two main technologies are available for methane gas monitoring: (1) metal oxide sensors (MOS), also called catalytic oxidation, semiconductor, or solid state detectors; and (2) Pellistor/Wheatstone Bridge sensors. The first type tend to cost less but are less accurate (i.e., usually do not provide quantitative readings of concentrations), more difficult to calibrate, and are quite sensitive to changes in humidity. Pellistor/Wheatstone Bridge sensors are recommended for use when monitoring methane gas concentrations in air inside a structure. The electrical response of the Wheatstone bridge is linear with concentration, which allows accurate measurement at low concentrations. Sensors with a 4 to 20 milliamp (mA) signal range are recommended. Calibrating the sensor so that 4 mA equals zero provides assurance that the sensor is operating because any power failure will result in a negative reading.

There are several rules of thumb for determining how many sensors are required for a building. Smaller buildings with multiple rooms generally should have a sensor for every 1,500 cu ft of volume. For larger, open buildings, spacing of sensors 100 to 150 ft on center will generally be adequate. Sensors should be mounted on the highest point of a ceiling, and if outside air circulates through the structures, they should tend to be offset toward the downwind side of the structure (generally the east side). Sensors will provide maximum safety if they are installed so that methane concentrations of 10 percent LEL will cause a fan with a timer to automatically turn on to improve air circulation (the timer prevents the fan from being turned on and off repeatedly if concentrations fluctuate around 10 percent LEL). The sensor should be designed to sound a horn or turn on a warning light if methane concentrations reach 20 percent LEL so that action can be taken to reduce methane levels before the 25 percent limit in the Part 503 regulation is reached. Pellistor/ Wheatstone Bridge sensors should be calibrated every 30 to 90 days to ensure proper functioning. The installed cost of indoor installations for Pellistor/Wheatstone Bridge sensors can be expected to fall in the range of $1,000 to $1,500 per sensor.

Because methane gas is considerably less dense than air (specific gravity 0.5 percent) outdoor methane gas releases will tend to rise rather than travel laterally to site property lines unless there are exceptionally strong winds. It is highly unlikely that methane gas concentrations will reach anything approaching the LEL at sewage sludge surface disposal site property lines, but the most likely place to measure maximum concentrations would be downwind (generally east) of the area where sludge amounts are thickest. Initially, a single installation at the downwind point at which methane gas concentrations are expected to be highest should be adequate. The sensor should be set at about 6 ft above ground level and will require electrical service unless the site is very remote, in which case rechargeable batteries would be required. The sensor should be set to sound an audible alarm if methane gas concentrations reach 20 percent LEL. If site property line sensor readings repeatedly exceed 10 percent LEL, some consideration should be given to installing additional sensors along the downwind perimeter.

Table C-1 in Appendix C provides a selective list of manufacturers of gas monitoring instruments. The March 1994 issue of *Pollution Equipment News* (8650 Babcock Blvd., Pittsburgh, PA 15237-9915; 800/245-3182) provides a more detailed listing with information on gas detection equipment available from more than 90 manufacturers. The gas detection selection chart, which is updated annually, can be obtained by contacting Rimbach Publishing at the location and phone number given above.

10.5 Analysis and Interpretation of Sample Data

10.5.1 Sewage Sludge Characterization Data

When arsenic, chromium, and nickel concentrations are monitored, each new set of sample results should first be checked against the applicable limits in Table 10-8.

Assuming that analytical results fall within acceptable levels, the only other type of analysis is that at least once a year the procedures described in Section 10.4.1 should be repeated adding in the previous year's analytical results to recalculate sampling frequency for the upcoming year.

10.5.2 Ground-Water Sampling Data

As shown in Figure 10-2 a minimum of two background monitoring wells are required for valid statistical comparison of background and downgradient monitoring results. If fewer than four background monitoring wells are used, typically the case at sewage sludge surface disposal sites, quarterly monitoring until 16 samples have been taken is required before monitoring data results in downgradient wells can be properly interpreted (Sara, 1994). The types of statistical tests to determine whether nitrate has entered the ground-water system as a result of sludge disposal would be the same as for a RCRA facility and are described in U.S. EPA (1989a). U.S. EPA's GRITS/STAT software (U.S. EPA, 1992b) can be used to store monitoring data and run the statistical tests recommended in U.S. EPA (1989a). The required response if nitrate contamination is detected will depend on the background ground-water quality and policies of the permitting agency.

10.5.3 Other Data

Leachate and surface water sampling data generally do not require statistical analysis. If sampling is used for NPDES reporting, then sample results are compared against the limits specified in the permit. Sampling of leachate for process control when discharged to a POTW, as discussed in Section 10.4.3 might require some simple statistical analysis to compute average values and the range of values examined to see whether they are within desired limits. Methane gas monitoring systems in structures should be designed to be self-regulating, as described in Section 10.4.4, and will not normally require collection or analysis of sensor readings.

10.6 References

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Chapter 11
Recordkeeping, Reporting, and Management for Surface Disposal

11.1 General

This chapter describes the recordkeeping and reporting requirements when sewage sludge is placed on a surface disposal site under the Part 503 rule, including records of costs and activities. Regulatory requirements for recordkeeping are covered in Section 11.2. This discussion covers requirements for owners/operators of active sewage sludge units with, and without, liners and leachate collection systems, and for preparers of sewage sludge. The U.S. EPA document, *Surface Disposal of Sewage Sludge: A Guide for Owners/Operators of Surface Disposal Sites on the Monitoring, Recordkeeping, and Reporting Requirements of the Federal Standards for the Use or Disposal of Sewage Sludge 40 CFR, Part 503* (1994a), and U.S. EPA (1993b) outline additional information on the recordkeeping requirements for operators of active sewage sludge units and preparers of sewage sludge, respectively.

This chapter also discusses the management of surface disposal sites, including management organization and staffing/personnel. The management system required for a surface disposal site will be influenced by such factors as the type of active sewage sludge unit, the volume and type of sludge received, and site conditions. The goals of the manager of a sewage disposal site should be to operate the site in a manner that is economically sound and adequately protects public health and the environment. These goals must be carefully balanced as regulations become more stringent and operating costs increase.

The management of a surface disposal site involves a wide range of activities. The site manager is responsible for:

- Day-to-day operation
- Equipment maintenance and replacement
- Regulatory compliance
- Site security
- Public relations
- Personnel management and training
- Recordkeeping
- Fiscal management

11.2 Regulatory Requirements for Recordkeeping

11.2.1 Part 503 Recordkeeping Requirements for Owners/Operators of Active Sewage Sludge Units With Liners and Leachate Collection Systems

Owners/operators of active sewage sludge units are required to keep records of management practices and applicable vector attraction reduction requirements. They must also keep a certification statement as shown in Figure 11-1. The records must be maintained for 5 years and be readily available to State and EPA inspectors. The owners/operators should be aware that failure to keep adequate records is a violation of the Part 503 regulation and subject to penalty under the Clean Water Act (CWA).

11.2.1.1 Records of Management Practices

Owners/operators must ensure that the management practices (requirements for the siting, design, and operation of active sewage sludge units to ensure protection of human health and the environment) are met at each active sewage sludge unit. In addition, compliance with these practices must be documented in detailed records and kept for 5 years. Compliance with siting and design requirements must be documented only once. Compliance with the operating requirements must be recorded on a continual basis, the frequency of which depends on the specific requirements.

Some of the information gathered to support one management practice may overlap with the information required for others. For example, geotechnical investigations are required to demonstrate compliance with the requirements for three management practices: seismic impact zone, fault zones, and unstable areas. Geotechnical investigations, which are necessary for any construction project, evaluate foundation soils and bedrock and characterize the hydrogeology of a site. Maps or drawings should be obtained or produced as part of compliance with the management practices. A combination of

"I certify, under penalty of law, that the management practices in §503.24 and the vector attraction reduction requirement in [insert one of the requirements in §503.33(b)(9) through §503.33(b)(11), if one of those requirements is met] have/have not been met. This determination has been made under my direction and supervision in accordance with the system designed to ensure that qualified personnel properly gather and evaluate the information used to determine that the management practices [and the vector attraction reduction requirements, if appropriate] have been met. I am aware that there are significant penalties for false certification, including the possibility of fine and imprisonment."

Signature _____ Date _____

Figure 11-1. Certification statement required for recordkeeping: Owner/Operator of surface disposal site (U.S. EPA, 1994b).

commercially available and customized maps and plans can help demonstrate compliance.

Endangered or Threatened Species

Part 503 prohibits the placement of sewage sludge on an active sewage sludge unit if it is likely to adversely affect an endangered or threatened species or its designated critical habitat (see Section 4.2.1.1). The owner/operator should retain all documentation to demonstrate that the site was evaluated for potential effects on endangered or threatened species and their habitat and that necessary protective measures were identified and implemented. For example, this documentation should list endangered or threatened species in the area or document that none exists and briefly describe how the endangered or threatened species and its critical habitat are protected.

Usually, documentation will need to be performed only once. If the active sewage sludge unit begins to pose a risk to endangered or threatened species, however, the owner/operator should contact the permitting authority or the Fish and Wildlife Service.

Base Flood Flow Restrictions

Part 503 prohibits an active sewage sludge unit from restricting the flow of a base flood (see Section 4.2.1.2). The following types of information may be used to describe how this management practice is met:

- A flood plain insurance rate map (available from the Federal Emergency Management Agency) with the site location accurately marked to demonstrate whether it is within the 100-year floodplain. Other sources of this information include the U.S. Army Corps of Engineers, the U.S. Geological Survey (USGS), Bureau of Land Management, Tennessee Valley Authority, and local and State agencies.
- If the unit is in the 100-year floodplain, the design details and management practices that will prevent restriction of the flow of the base flood, including a plan view, a cross section of the unit, and calculations used to determine that the site will not restrict the base flood flow.
- If the unit is in the 100-year floodplain, evaluation of the impact of the unit based on predictive models, such as the HEC series generated by the U.S. Army Corps of Engineers.

Seismic Impact Zones

Part 503 requires active sewage sludge units located in seismic impact zones to be designed to withstand the maximum recorded ground level acceleration (see Section 4.2.1.3). The following types of information can be used to help demonstrate compliance with the seismic impact zone management practice:

- A seismic map, available from State or local agencies, with the site location marked on the map.
- Reports from State or local agencies on earthquake activity, including the maximum recorded horizontal ground level acceleration (as a percentage of the acceleration due to gravity (g), g=9.8 m/s^2) (this information is probably contained in any reports on earthquake activity obtained from State or local agencies).
- A site inspection that focuses on slopes that may have had the toe removed, water seeps from the base of a slope, less resistant strata at the base of a slope, posts and fences that are not aligned, utility poles with sagging or too tight wires, leaning trees, cracks in walls and streets, etc.
- If the active sewage sludge unit is located in a seismic impact zone, documentation on design specifications to accommodate the ground motion from earthquakes, such as shallower unit side slopes, more conservative design of dikes and runoff controls, and contingency plans for leachate collection systems.
- Design plans for the unit indicating the maximum ground motion that unit components are designed to withstand, including foundations, embankments,

leachate collection systems, liners (if installed), and any ancillary equipment that could be damaged from seismic shocks.

- Certification by an engineer with seismic design and geotechnical experience that the unit is designed to withstand the maximum recorded horizontal ground level acceleration.

Fault Zones

Part 503 prohibits locating an active sewage sludge unit within 60 meters of a fault that has had displacement (i.e., movement) during Holocene time (typically within the last 11,000 years) (see Section 4.2.1.3). Documentation to support this management practice may include the following:

- A Holocene fault map (available from local planning or State geological agencies or the USGS) with the site location marked. In 1978, the USGS published a map series identifying the location of Holocene faults in the United States *(Preliminary Young Fault Maps* [USGS, 1978]. For areas along Holocene faults, an investigation of the site and surrounding areas should be performed to determine if movement has occurred since 1978.
- A report on the area investigation of the site, emphasizing the location of faults, lineaments, or other features associated with fault movement, such as offset streams, cracked culverts and foundations, shifted curbs, escarpments, or other linear features.
- A geotechnical report on the site indicating the presence or absence of any faults or lineaments.

Unstable Areas

Part 503 also prohibits locating active sewage sludge units in unstable areas (see Section 4.2.1.3). The following information may be used to demonstrate that an individual active sewage sludge unit is not located in an unstable area:

- A one-time detailed geotechnical and geological evaluation of the stability of foundation soils, adjacent manmade and natural embankments, and slopes (may include both in situ and laboratory test evaluations).
- A one-time evaluation of the ability of the subsurface to support the active sewage sludge unit adequately, without damage to the structural components. If the evaluation indicates that an active sewage sludge unit is located in an unstable area, the unit must close.

Wetlands

Part 503 prohibits the location of an active sewage sludge unit in a wetland, unless a permit is issued pursuant to either Section 402 or 404 of the Clean Water Act, as amended (see Section 4.2.1.4). The following types of information may be necessary to demonstrate compliance with wetland restrictions:

- The location of the site on a wetlands delineation map, such as a National Wetlands Inventory map, Soil Conservation Service soil map, or a wetlands inventory map prepared locally.
- A permit or permit application for a Section 402 or 404 permit.
- A description of a wetlands assessment conducted by a qualified and experienced, multidisciplinary team, including a soil scientist and a botanist or biologist.

Storm Water Runoff

Part 503 requires that runoff from an active sewage sludge unit be collected and disposed of in accordance with National Pollutant Discharge Elimination System (NPDES) requirements and any other applicable requirements (see Section 7.2.1.1). In addition, the runoff collection system must be designed to handle the runoff from a 24-hour, 25-year storm event. The following types of information may be used to support compliance with this management practice:

- Copies of the NPDES permit and any other permits.
- A description of the design of the system used to collect and control runoff, including plan view, drawing details, cross sections, and calculations showing that the system has the capacity to collect the runoff volume anticipated from a 24-hour, 25-year storm event.
- A calculation of peak runoff flow, including data sources and methods used to calculate the peak runoff flow from a 24-hour, 25-year storm event.
- A description of inspection and maintenance required for the system.
- A description of the procedures for managing liquid discharges and complying with NPDES and other requirements.

Leachate Collection and Control

If an active sewage sludge unit has an appropriate liner and leachate collection system, the owner/operator must document that the leachate collection system is properly operated and maintained while the unit is active and for 3 years after closure of the sewage sludge unit (see Section 7.2.1.2). Documentation must also indicate that the leachate is disposed of properly. The following types of information may be used to demonstrate compliance with this management practice:

- Detailed material specifications for the liner, including drainage layer, filter layer, piping, and sumps.

- A description of the leachate collection system design, leak detection capability, and capacity for removal of leachate and liquid from the system.
- Design details, including layout of system and components shown in plan view and cross section and spacing and configuration of pipes, sumps, pumps, drainage plans.
- Test results demonstrating system compatibility with sewage sludge and leachates for all system components and materials.
- A description of inspection and maintenance schedules and procedures.
- An operational plan describing the method of treatment and disposal of leachate and schedules for disposal.
- Records of collection, treatment and disposal activities that demonstrate compliance with applicable requirements. For example, volume collected, monitoring data on treated leachate, volume disposed of (where and when).

Monitoring Air for Methane Gas

Air must be monitored continuously for methane gas when an active sewage sludge unit is covered daily (see Section 10.4.4). When a final cover is placed on a sewage sludge unit, air must be monitored continuously for methane gas for 3 years after closure of the sewage sludge unit. The following types of information may be used to demonstrate compliance with this management practice:

- A description of the system design, including plan drawing and calculations showing that the system can monitor air for methane gas concentrations.
- Design details of the site, including gas monitoring locations, spacing, and layout.
- Descriptions of air monitoring, alarm systems, emergency procedures, emergency contingency plans, system maintenance schedules, and any known methane gas mitigation.
- Results of methane gas monitoring, including the maximum and average levels recorded.

Food/Feed/Fiber Crops Prohibition

Growing food, feed, or fiber crops on any active sewage sludge unit is prohibited, unless explicitly authorized by the permitting authority (see Section 9.2.1.1). The following types of information can be used to demonstrate compliance with this management practice:

- Approval by the permitting authority if crops are being grown on the site.
- A listing of any vegetation on the unit.
- A description of procedures to ensure adherence to the crop use restrictions.

Grazing Prohibition

Part 503 prohibits grazing of animals on active sewage sludge units, unless specifically authorized by the permitting authority (see Section 9.2.1.1). The types of information that can be used to demonstrate compliance with the grazing restriction include the following:

- Approval by permitting authority if animals are being grazed at the site.
- If the location of the surface disposal site and the land use of surrounding properties exclude or limit grazing, then the only necessary documentation or records may be the certification statement required by the regulation that the management practices are being met.
- If the owner/operator has to install animal restriction devices (such as grates at gate entrances or electric fencing), records should be kept on the design, installation, and maintenance of the devices and a site map showing the locations of the devices.

Public Access Restrictions

Part 503 requires the owner/operator to restrict public access to active sewage sludge units and to closed units for 3 years after closure (see Section 7.2.1.4). The following types of information can be used to demonstrate compliance with the public access restrictions:

- A site map, showing the access control locations (e.g., placement of signs, fences and gates, and natural barriers).
- A description of access restriction measures, such as placement of vehicle barriers, signs, and construction plans for the placement and configuration of fences and gates.
- Language on warning signs.
- An inspection schedule for the access controls and repair procedures.
- Schedules for security guard postings or security inspections.

Prohibition of Ground-Water Contamination

Part 503 states that sewage sludge placed on an active sewage sludge unit cannot contaminate an aquifer (see Section 4.2.1.6). Compliance with this management practice may be demonstrated in either of the following two ways:

- Certification by a qualified ground-water scientist that sewage sludge placed on the active sewage sludge unit does not contaminate the aquifer. This should

include a report demonstrating that the design, construction, and operation of the liner/leachate collection system or the geology of the site is sufficient to retard liquid flow during the active life and post-closure period.

- Providing ground-water monitoring data. These data should include both baseline monitoring data on the aquifer obtained prior to placing sewage sludge in the unit, and ground-water monitoring data collected periodically throughout the life of the active sewage sludge unit.

The regulation requires this management practice to be met by either certification of a qualified ground-water scientist or the results of a ground-water monitoring program. The scientist must have a bachelor or post-graduate degree in the natural sciences or engineering and have sufficient training and experience (as demonstrated by State registration or professional certification) in ground-water monitoring, pollutant fate and transport, and corrective actions.

11.2.1.2 Part 503 Recordkeeping Requirements for Vector Attraction Reduction

As discussed in Section 3.4.2.3, there are 11 options to comply with the vector attraction reduction requirements. Options 1 through 8 are performed by the person who prepares the sewage sludge (see Section 11.2.3). Options 9 though 11 are performed by the owner/operator of the surface disposal site. Whenever one of options 9 through 11 is used, the owner/operator must certify whether the vector attraction reduction requirement is met. In addition, the owner/operator must keep records containing a description of how vector attraction reduction is met. The description should be supported by documentation of any activity used to achieve the vector attraction reduction. Records of the certification and description must be kept for at least 5 years.

Option 9—Sewage Sludge Injected Below Surface of the Land

Option 9 requires that the sewage sludge be injected below the surface of the land and that no significant amount of sewage sludge be visible within 1 hour of injection. If the sewage sludge meets the Class A pathogen reduction requirements, injection must take place within 8 hours after being discharged from the pathogen reduction process. Documentation on compliance could include a field notebook with entries describing how sewage sludge is injected below the land surface, the class of pathogen reduction achieved, how much time elapses between the pathogen reduction process and injection (if Class A), and observations on the amount of sewage sludge present on the land surface 1 hour after sewage sludge was injected.

Option 10—Sewage Sludge Incorporated Into the Soil

If sewage sludge is going to be incorporated into the soil for vector attraction reduction, the sewage sludge must be incorporated within 6 hours of placement on the active sewage sludge unit. If the sewage sludge is Class A, it has to be placed on the unit within 8 hours after being discharged from the pathogen reduction process and then incorporated into the soil within six hours after placement. There is no time period requirement for Class B sewage sludge. Documentation on compliance could include a field notebook with entries describing how the sewage sludge was incorporated and the class of pathogen reduction achieved. If the sewage sludge is Class A, notes should include the date and time (hour of day) the sewage sludge was discharged from the pathogen reduction process and the date and time (hour of day) the sewage sludge was incorporated into the soil.

Option 11—Sewage Sludge Covered With Soil or Suitable Material

Under option 11, the sewage sludge is covered with soil or other material at the end of each operating day. Option 11 meets vector attraction reduction requirements and pathogen reduction requirements. In contrast, when options 9 or 10 are used, either the Class A or Class B pathogen reduction requirements have to be met. Documentation on compliance with option 11 could include a field notebook describing when and how the soil or another material is placed over the sewage sludge at the end of each operating day, the thickness of the cover, and the type of cover material used.

11.2.1.3 Records of Pathogen Reduction

Part 503 does not impose recordkeeping requirements for pathogen reduction on the site owner/operator. Because the preparer is responsible for pathogen reduction, the preparer must document compliance (see Section 11.2.3).

11.2.2 Part 503 Recordkeeping Requirements for Owners/Operators of Active Sewage Sludge Units Without Liners and Leachate Collection Systems

Owners/operators of active sewage sludge units without liners and leachate collection systems must comply with all of the Part 503 recordkeeping requirements for the management practices that encompass design, siting, and operation, as well as for vector attraction reduction, as described in Section 11.2.1 above. In addition, the Part 503 regulation requires owners/operators of active sewage sludge units without liners and leachate collection systems to maintain records documenting the concentration of pollutants (arsenic, chromium, and nickel) in the sewage sludge if the active sewage sludge unit

boundary is less than 150 meters from the property line of the surface disposal site or if site-specific pollutants have been approved by the permitting authority. Documentation of sampling and analysis for pollutant concentrations should include the following information:

- Date and time of sample collection, sampling location, sample type, sample volume, name of sampler, type of sample container, and methods of preservation (including cooling).
- Date and time of sample analysis, name of analyst, and analytical methods used.
- Laboratory bench sheets indicating all raw data used in analyses and calculation of results.
- Sampling and analytical QA/QC procedures.
- Analytical results expressed in dry weight.

11.2.3 Part 503 Recordkeeping Requirements for the Preparer of Sewage Sludge for Placement on a Surface Disposal Site

The preparer of sewage sludge placed on an active sewage sludge unit must develop and keep the following information for 5 years (U.S. EPA, 1994b):

- The concentrations of arsenic, chromium, and nickel in sewage sludge for active sewage sludge disposal units with boundaries that are 150 meters or more from the surface disposal site's property line.
- A certification statement, as worded in Figure 11-2.
- A description of how certain pathogen and vector attraction reduction requirements are met.

Table 11-1 outlines a summary of pathogen and vector attraction reduction recordkeeping requirements for surface disposal of sewage sludge (U.S. EPA, 1992).

11.2.4 Recordkeeping Requirements for Surface Disposal of Domestic Septage

For sites where domestic septage is surface disposed, the recordkeeping requirements are dependent on the manner in which vector attraction reduction is achieved as follows (U.S. EPA, 1994b):

- If vector attraction reduction is achieved by adjusting the pH of the domestic septage, the person who placed the domestic septage on the surface disposal site must certify to this (see Figure 11-3) and develop a description of how vector attraction reduction was achieved. The certification and the description must be kept for 5 years.

OR

- If vector attraction reduction is achieved by injecting or incorporating the domestic septage into the soil, or by covering it with soil daily, all management practices for surface disposal of sewage sludge must be met. Certification that all these requirements have been met and a description of how they were met must be developed and maintained for 5 years. (Figure 8-1 in Chapter 8 shows an example of the required certification statement.)

11.2.5 Part 258 Recordkeeping Requirements

Under Part 258, all documentation and recordkeeping requirements are the responsibility of the owner/operator of the MSW landfill. A complete discussion of the recordkeeping and reporting requirements for MSW landfills regulated under Part 258 is beyond the scope of this manual. For more information on this subject, the reader is referred to U.S. EPA (1993a).

11.2.6 Other Recordkeeping Requirements

Other federal, state, and local agencies may require specific records to be maintained to comply with permits or regulations. These include:

"I certify, under penalty of law, that the pathogen requirements in [insert §503.32(a), §503.32(b)(2), §503.32(b)(3), or §503.32(b)(4) when one of these requirements is met] and the vector attraction reduction requirements in [insert one of the vector attraction reduction requirements in §503.32(b)(1) through §503.32(b)(8) when one of these requirements is met] have/have not been met. This determination has been made under my direction and supervision in accordance with the system designed to ensure that qualified personnel properly gather and evaluate the information used to determine that the [pathogen requirements and vector attraction reduction requirements if appropriate] have been met. I am aware that there are significant penalties for false certification, including the possibility of fine and imprisonment."

Signature _____ Date _____

Figure 11-2. Certification statement required for recordkeeping: Preparer of sewage sludge placed on surface disposal site (U.S. EPA, 1994b).

Table 11-1. Certification statement required for recordkeeping: Owner/Operator of surface disposal site (U.S. EPA, 1994b)

Who Must Keep Records?	Required Records: Description of How Class A or B Pathogen Requirement Was Met	Required Records: Description of How Vector Attraction Reduction Requirement Was Met	Required Records: Certification Statement That the Requirement Was Met
Sewage Sludge—Pathogen Requirements			
Person preparing the sewage sludge	✔		✔
Sewage Sludge—Vector Attraction Reduction Requirements			
Person preparing sewage sludge that meets one of the treatment-related vector attraction reduction requirements (Options 1-8)		✔	✔
Owner/operator of the surface disposal site if a barrier-related option (Options 9-11) is used to meet the vector attraction reduction requirement		✔	✔
Domestic Septage			
Person who places domestic septage on the surface disposal site if the domestic septage meets Option 12 for vector attraction reduction		✔	✔
Owner/operator of the surface disposal site if a barrier-related option (Options 9-11) is used to meet the vector attraction reduction requirement		✔	✔

- *Water Quality.* As part of the monitoring program for a discharge permit, such as from a leachate collection or treatment system.
- *OSHA and/or State Workplace Safety Requirements.* Information on jobsite safety and safety training and education. This includes maintenance of a file of Material Safety Data Sheets for all potentially hazardous materials used by employees.

11.3 Cost and Activity Recordkeeping

11.3.1 General

It is important for the surface disposal site manager to maintain an efficient recordkeeping system. Records must be maintained for administrative use (i.e., payroll, personnel management, purchasing, etc.), management decisions (planning and cost control), as well as compliance with regulatory requirements (see Section 11.2). The specific records to be maintained will depend on factors such as the type and size of the site, the management structure (privately owned, municipal facility, etc.), the source of operating funds (user fees, sewer fees, general revenue, etc.), and the requirements of the regulatory agencies.

11.3.2 Cost Recordkeeping

A primary concern of a surface disposal site owner/operator is to control costs. Maintaining accurate records of income and expenditures allows the site manager to determine unit costs for the site, maintain cost control, and predict future financial requirements. Costs may be computed on the basis of time, or units of sludge, such as wet tons, dry tons, or cubic yards. Based on this information, the income requirements for the site can be determined.

Effective cost control requires timely recognition of excessive costs and identification of the reason for such cost overruns. The increasing costs and complexities of sludge disposal operations require the use of more sophisticated cost control tools than have been used in the past. Use of cost accounting systems at surface disposal sites are recommended for management to control costs.

Because user fees are generally not charged at surface disposal sites (reducing the need for accountability) and surface disposal sites are not separate enterprises, but merely a secondary facet of a larger operation, cost records at many such sites are either nonexistent or poorly maintained.

The installation of a cost accounting system has several benefits, as listed below:

- The system facilitates orderly and efficient accumulation and transmission of relevant data. Much of the recommended data either should be or is already collected. Hence, the added cost of installing the system is minimal.
- The data can be grouped in standard accounting classifications. This simplifies interpretation of results and comparison with data from previous years or other operations. It also supports analysis of relative performance and operational changes.

An individual placing domestic septage on a surface disposal site must maintain the following certification statement for 5 years:

> "I certify, under penalty of law, that the vector attraction reduction requirements in §503.33(b)(12) have/have not been met. This determination has been made under my direction and supervision in accordance with the system designed to ensure that qualified personnel properly gather and evaluate the information used to determine that the vector attraction requirements have been met. I am aware that there are significant penalties for false certification, including the possibility of fine and imprisonment."

The owner or operator of the surface disposal site must maintain the following certification statement for 5 years:

> "I certify, under penalty of law, that the management practices in §503.24 and the vector attraction reduction requirements in [insert §503.33(b)(9) through §503.33(b)(11) when one of those requirements is met] have/have not been met. This determination has been made under my direction and supervision in accordance with the system designed to ensure that qualified personnel properly gather and evaluate the information used to determine that the management practices [and the vector attraction requirements, if appropriate] have been met. I am aware that there are significant penalties for false certification, including the possibility of fine and imprisonment."

Signature _____ Date _____

Figure 11-3. Certifications required when domestic septage is placed in a surface disposal site (U.S. EPA, 1994b).

- The system can account for all relevant costs of construction and operation.
- Accumulated data from the system can be used to identify which costs are high and the reasons for these high costs. These data can then be used to develop standards of performance and efficiency to mitigate inefficient and costly operations.
- The system includes automatic provisions for accountability. Cost control becomes more effective when the individual responsible for cost increases can be ascertained.
- Use of the collected data aids in short- and long-term forecasting of capital and operating budgets. Future requirements for equipment, manpower, cash, etc., can be accurately estimated. This, in turn, aids planning at all levels of management.
- The system can be flexible enough to meet the management requirements associated with different types of surface disposal sites, different types of operations, and different sludge quantities and types.

11.3.3 Activity Records

The recordkeeping system should include complete records of the activity at a surface disposal site. A daily report should be completed by the operator on site. This information can be used by the site manager for billing purposes, administrative use, equipment maintenance, material purchases, and management analysis of the site.

The activity record should include such information as:

- Quantity and type of sludge received by truckload
- Cover material utilization
- Personnel and equipment hours
- Miscellaneous expenses
- Sludge placement locations

Some of this information may be available from the treatment works, and some or all will be recorded at the site. Figure 11-3 is a sample form that could be used to record the quantity of sludge received from each incoming truck on a single day. The daily sludge quantity can be totaled at the bottom of the daily form and transferred to the monthly summary included as Figure 11-4. The monthly summary can be used to record the sludge quantity received, as well as cover soil utilization, personnel and machine hours, and miscellaneous expenses.

11.4 Part 503 Reporting Requirements

11.4.1 General

In general, the owner/operator of a surface disposal site will not be required to report unless specifically notified that the site has been designated as a "Class I sludge management facility" by the EPA Regional Administrator or the State Director of an approved sewage sludge management program. If a surface disposal site is designated as Class I, the types of information that will need to be reported will be the same information as kept for the recordkeeping requirements. Annual reports cover information generated during the calendar year (January 1 through December 31). Owners/operators would be expected to submit data collected during the course of the year. They are not expected to resubmit the

Site: _____

Month: _____

Completed By: _____

Day	Sludge		Cover material				Man hrs.	Machine hrs.		Expense		Site hrs.
	Loads	Tons	Begin	Rec'd	Used	Remain		Use	Down	$	Type	
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												
21												
22												
23												
24												
25												
26												
27												
28												
29												
30												
31												
Totals												

1 ton = 0.907 Mg

Figure 11-4. Monthly activity form.

one-time documentation on siting and design conditions. Annual reports should be submitted to the EPA Regional Water Compliance Branch Chief. The address for each Branch Chief is provided on the inside of the back cover of this document. The map on the inside of the front cover shows the EPA Region in which each State is located.

In addition, owners/operators who are also preparers of sewage sludge are required to submit an annual report if they are a Class I sludge management facility or if they are publicly owned treatment works (POTWs) with a design flow rate equal to or greater than 1 million gallons per day or POTWs that serve 10,000 people or more. Class I sludge management facilities are defined as POTWs required to have a pretreatment program under 40 CFR 403.8(a), including any POTW located in a State that has elected to assume local pretreatment program responsibilities under 40 CFR 403.10(e). The EPA Regional Administrator has the authority to designate additional facilities, including surface disposal sites as Class I. Preparers include persons who generate sewage sludge and persons who derive a material from sewage sludge. Any owner/operator of a surface disposal site who is also a preparer should refer to U.S. EPA (1993b) for a full discussion of the preparers' responsibilities.

11.4.2 Reporting Requirements in the Event of Closure

Owner/operators of surface disposal sites that have active sewage sludge units that will close are required to submit a written closure and post-closure plan to the permitting authority 180 days prior to the closure date. The plan must include the following elements:

- Discussion of how the leachate collection system will be operated and maintained for 3 years after the sewage sludge unit closes (for units with liners and leachate collection systems, only).
- Description of the system used to continuously monitor, for 3 years after the unit closes, methane gas in the air in any structures within the surface disposal site and in the air at the property line of the surface disposal site (for units with covers only).

- Discussion of how public access to the surface disposal site will be restricted for 3 years after closure of the last sewage sludge unit in the surface disposal site.

In addition, the owner of the surface disposal site must provide written notification to the subsequent owner of the site that sewage sludge was placed on the land. The notification should include:

- Map of the surface disposal site clearly showing the locations of sewage sludge units and their dimensions.
- Amount and quality of sewage sludge placed on each unit.
- Results of methane gas monitoring, if conducted.
- Type of liner and leachate collection system installed, if appropriate, and the volume and characteristics of leachate collected.
- Copy of the written closure and post-closure plan.
- Warnings, as appropriate, that for three years after closure air must be monitored for methane gas if a final cover is placed on any closed sewage sludge unit; that leachate has to be collected and disposed of properly if a closed unit has a liner and leachate collection system; and, that public access has to be restricted.

11.5 Management Organization

11.5.1 General

Surface disposal sites are managed by either public or private entities. Public management may be by municipal or county government, or by a quasi-governmental organization such as a sanitary district.

11.5.2 Municipal Operation

Most surface disposal sites operating today are municipal operations. In these cases, operation and management is usually by either the sewer department or the department of public works. Sewer departments often manage the disposal site because it is used to dispose of the sludge generated at the department's treatment works. Also, because sludge disposal is part of the overall wastewater treatment process, it is usually supported by the same budget and/or fee structure. Disposal sites are often located adjacent to the treatment works on land owned by the municipality.

Management by public works departments is becoming increasingly common. This arrangement is usually more appropriate for management of larger sites or those located some distance from the treatment plant. Operation of these sites requires construction-type activities, making the management requirements more suited to the experience and resources of a public works department.

11.5.3 County Operation

Management of surface disposal sites by county governments is less prevalent than that by municipal governments. As with municipal governments, county-operated sites are often managed by either a sewer department or public works department. County sites, however, typically serve larger populations and geographic areas. In these cases the economies of scale and greater availability of land for the site favor county-operated sites.

The choice between municipal or county operation is usually determined by which government operates the sewer department. This should not be the only determining factor, however, as county-wide management of sludge disposal can be a favorable option even when wastewater treatment is conducted by individual municipalities.

11.5.4 Sanitary District Operation

Sanitary districts are usually responsible for managing surface disposal sites when no alternate authority is available. Financing for sites managed by sanitary districts is often easier to secure because they usually have the power to levy special taxes or user fees. Because these districts generally service greater populations and may serve several municipal jurisdictions, they often are better financed and equipped to operate surface disposal sites due to the economies of scale.

11.5.5 Private Operation

Next to municipal operations, private management is the most prevalent type of site management. Sites may be operated under contract, franchise, or permit arrangement. In contract operations, the government agency contracts with the private operator to dispose of its sludge for a fixed lump sum fee, or a unit charge (per ton, cubic yard, or truckload). If a unit charge is the basis of the contractual arrangement, the government agency usually guarantees a specified minimum dollar amount to the contractor. Franchises typically grant the operator permission to dispose of sludge from specified areas and to charge fees that are usually regulated. Permits allow the operator to accept sludge for disposal without regard to source.

Private operations are advantageous for government agencies with limited capital available for construction and initial operation of a disposal site. Private operators are often able to operate at a lower cost than government facilities. Precautions should be taken, however, to ensure that private operators provide adequate environmental safeguards and comply with all regulations. For this reason, contract arrangements are usually the

most advantageous option for the government because operating and performance standards can be written into the contract.

11.6 Staffing and Personnel

11.6.1 General

Staffing requirements for a surface disposal site depends on the size and type of the site. Estimates of the size of the staff required should be developed during the design process and then refined into a formal staffing plan for the site. The staffing plan will provide information for estimating operating costs and serve as a guide for personnel hiring and management.

11.6.2 Personnel Descriptions

- *Equipment operator.* At many surface disposal sites, equipment operators are the only onsite personnel required. Tasks performed are mostly those of equipment operation. Other tasks, however, may include routine equipment maintenance and directing sludge unloading operations. A sample equipment inspection form to be completed daily by equipment operators is included as Figure 11-5.

Truck Ident.	Time*	Sludge		Sludge Weight or Volume
		Source†	Type‡	
Totals				

Instructions: To be completed for each truck, each time it makes a delivery.

* Only record time at 15-minute intervals
† Sources: Code for Contributing Treatment Plant
‡ Types: G = grit; DI = digested; CT = chemically treated

Figure 11-5. Daily waste receipt form.

- *Superintendent/Foreman/Supervisor.* This position involves overseeing all aspects of the disposal site operation, including maintaining daily records of operation, personnel supervision, and managing the daily activities at the site. Depending on the size of the site, this person may serve other functions such as equipment operator.
- *Mechanic.* Major equipment maintenance and repair should be performed by qualified mechanics. Mechanics or maintenance teams, however, are usually not needed full-time on the site. They usually come to the site on a regular schedule or as needed.
- *Laborer.* Larger surface disposal sites may need one or more persons to maintain control systems (e.g., leachate collection and treatment odor control, truck washing station, mud and dust control, etc.). The duties may also include maintaining the fencing and access roads.

In addition to the above listed personnel on site, offsite support personnel may also be required for efficient operation of a surface disposal site. Such personnel may include any of the following:

- *Clerical.* Clerical personnel maintain the records for the site, process personnel actions, and perform daily administrative duties.
- *Engineering consultant.* A technical consultant should be available to advise the site manager on the design and operational aspects of the site and its activities. The consultant would assist in identifying and solving any technical problems that may arise, assisting with regulatory compliance issues, and planning and implementing changes to the site, such as expansion or closure.
- *Management consultant.* A management consultant can provide assistance on administrative and financial issues for the site manager. The consultant can provide advice on the administration of the site, and on financing options for obtaining funds for capital and operating expenses.
- *Legal consultant.* A legal consultant can provide legal services for issues such as permitting and regulatory compliance, public hearings, contract review, and planning for activities such as post-closure use.

11.6.3 Training and Safety

It is important to employ well-trained personnel. Qualified personnel can be the difference between a well-organized, efficient operation and a poor operation. New employees should not only learn the tasks required for their positions, but also understand the purposes and importance of the overall disposal operation. Except for the larger operations, comprehensive training programs are not likely to be designed or conducted by the site

management. Training programs have been developed by the U.S. Environmental Protection Agency, professional organizations such as the American Public Works Association, and some educational associations. Because many of the procedures employed at municipal solid waste landfills are similar or identical to those employed at some types of sludge surface disposal sites, such programs may also be useful. Programs may consist of guideline information on training activities to be conducted by the employer, or classes conducted by these agencies. Equipment manufacturers are another source of information on training procedures.

Managers of surface disposal sites have an obligation to maintain safe and secure working conditions for all personnel. It is important that safety rules are written, published, distributed to all employees, and enforced. A safety training program, covering all aspects of site safety and proper equipment operation, as required by OSHA or State safety programs, should be conducted on a regular basis.

For safety reasons, it is desirable to have two or more persons working on site at any time. This can easily be accomplished at large surface disposal sites where more than one person is needed for daily operation. On small sites requiring only one operator, a second person should visit the site daily or the single operator should phone or check in at the end of the shift.

At a large site, a foreman and subordinate supervisors may be required. A multi-shift operation will require a supervisor for each shift as well as an overall manager. No matter what the size of the operation, one person should be responsible for safety on site, and be familiar with OSHA and State regulations and procedures.

A safety checklist prepared by the National Solid Waste Management association is included as Figure 11-6.

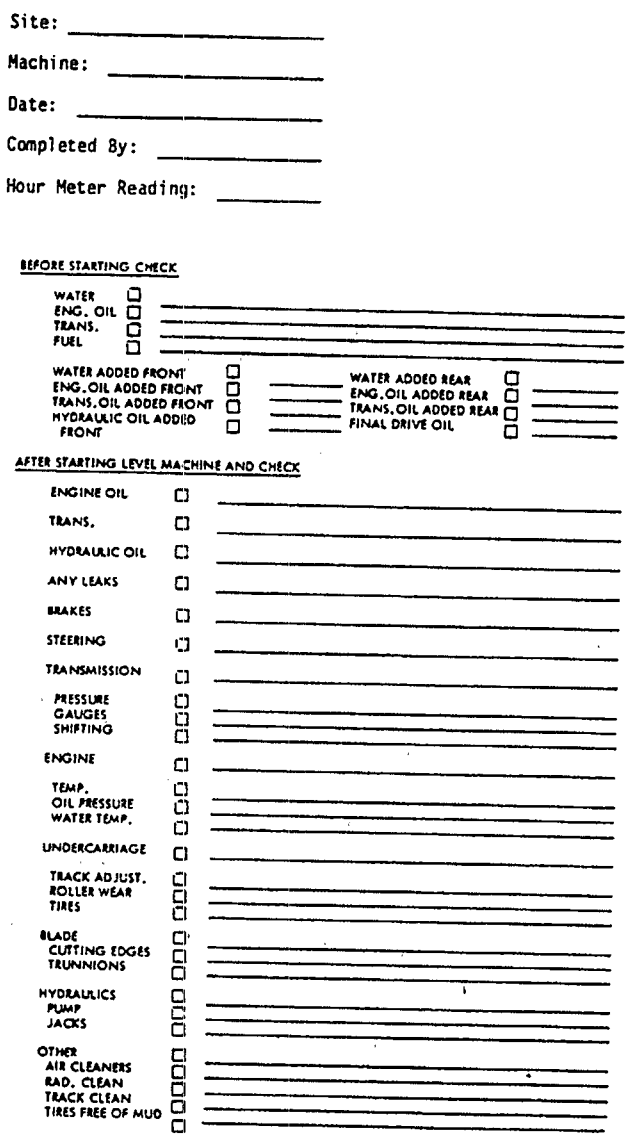

Figure 11-6. Equipment inspection form.

11.7 References

1. U.S. EPA. 1994a. Surface disposal of sewage sludge: A guide for owners/operators of surface disposal facilities on the monitoring, recordkeeping, and reporting requirements of the federal standards for the use or disposal of sewage sludge, 40 CFR Part 503. EPA/831/B-93/002c. Washington, DC (May).

2. U.S. EPA. 1994b. A plain English guide to the EPA 503 biosolids rule. EPA/832/R-93/003.

3. U.S. EPA. 1993a. Solid waste disposal facility criteria, technical manual. EPA/530/R-93/017 (NTIS PB94-100-450). Washington, DC (November).

4. U.S. EPA. 1993b. Preparing sewage sludge for land application or surface disposal—A guide for preparers of sewage sludge on the monitoring, recordkeeping, and reporting requirements of the federal standards for the use or disposal of sewage sludge, 40 CFR Part 503. EPA/831/B-93/002a. Washington, DC.

5. U.S. EPA. 1992. Environmental regulations and technology: Control of pathogens and vector attraction in sewage sludge (including domestic septage) under 40 CFR Part 503. EPA/625/R-92/013. Cincinnati, OH (December).

	BUILDING EXITS (OSHA 1910.35 - 1910.37)
	1. Doors swing with exit travel
	2. Marked with lighted signs
	3. Not locked so that they may be used from the inside at all times
	4. Keep free of obstructions
	5. Non-exit doors which can be mistaken as an exit as an exit are marked "No Exit"
	6. Single exits are allowed for rooms containing less than 25 people
	Combustible, Oxidizing, and Flammable Agents, When Using (OSHA 1910.101-1910.116)
	7. Electrical installation and static electricity are controlled or maintained
	8. Heating appliances are controlled or maintained in a safe manner
	9. "Hot" work (welding) controlled or maintained in a safe manner
	10. At least one 20 pound Class B fire extinguisher is within 25 feet of a storage area
	11. ICC approved metal drums are used for storage from 5-60 gallons
	12. Not more than required for one day or shift stored outside storage cabinet
	COMPRESSED AND LIQUIFIED GASES (OSHA 1910.101-1910.116)
	13. Charged and empty cylinders are separated
	14. Cylinders are grouped by type and stored in vertical positions
	15. Cylinders are not stored near other combustible material
	16. Cylinders are supported so that they cannot be tipped over
	17. Cylinder caps are in place on all cylinders which are not in use
	18. Oxygen cylinders are not stored within 20 feet of other types of gases
	DRAINAGE
	19. Drains are vented to prevent collection of combustible gases
	20. Grease and oil prevented from entering public sewage systems
	ELECTRICAL EQUIPMENT (OSHA 1910.308-1910.309)
	21. All outlet and junction boxes are properly covered
	22. All portable electrical tools and appliances are properly grounded
	23. Records maintained for inspection or portable electrical tools and appliances
	24. Electrical cabinet doors with exposed conductors of 50 volts or more are securely fastened
	25. Enclosures around high voltage electrical equipment are marked
	26. Frayed cords, cables, and loose wires regularly removed from service
	27. Switch boxes are identified as to equipment they control
	EMERGENCY LIGHTING
	28. Exits and necessary ways to exits are illuminated
	29. Exit signs are illuminated to at least 5 foot candles
	FIRE EXTINGUISHER EQUIPMENT (OSHA 1910.157)
	30. Extinguishers are inspected monthly for physical damage
	31. Inspection records are kept indicating inspector
	32. Maintenance performed yearly; hydrotested every 5 years, if required
	33. Inspection tags marked by month and year
	34. Extinguishers conspicuously installed and properly marked for use by type of fire (A,B,CorD)
	35. The top of portable extinguishers (less than 40 lbs) mounted no more than 5' above the floor
	36. The top of portable extinguishers (40 lbs or more) mounted no more than 3-1/2' above the floor
	FIRST AID (OSHA 1910.151)
	37. An approved first aid kit is available
	38. Emergency numbers of company-approved doctors and hospitals posted in appropriate locations
	39. Trained personnel available
	HAND AND PORTABLE TOOLS (OSHA 1910.241-1910.247)
	40. All useable tools have guards properly installed
	41. All portable electrical tools are tested monthly for ground
	42. Records kept of inspection (item 41)
	43. All tools in safe operating condition are free from worn or defective parts
	44. Jacks and hoists are legibly marked with the load rating
	HOUSEKEEPING
	45. Material on walls/shelves stored in a safe and orderly manner
	46. Facility is in a clean, orderly, and sanitary condition
	47. Hoses, welding leads, drop lights, etc. are rolled and properly stored
	48. Permanent aisles and passageways are free of obstructions
	49. Permanent aisles and passageways are permanently marked
	ILLUMINATION
	50. Sufficient quantity (20 foot candles or greater)
	51. Uniform distribution
	52. Well directed
	INDUSTRIAL SANITATION (OSHA 1910.141)
	53. Clean, available drinking fountains
	54. Facilities are maintained in a clean and stocked condition
	55. Hot water available
	56. Individual towels and drinking cups available
	57. Toilet facilities are within 200 feet of working area for each sex
	INDUSTRIAL TRUCK: FORKLIFT (OSHA 1910.178)
	58. Brakes in good operating condition
	59. Guard behind fork is in place (to guard from load falling to the rear)
	60. Load capacity of truck marked
	61. No one except operator permitted to ride
	62. No one stands or walks under raised forks
	63. Overhead guard to protect against falling objects
	64. Recharging/refueling done in a "No Smoking" isolated area
	65. Training program for operators
	66. Warning devices (horn) working
	LADDERS (OSHA 1910.25-1910.28)
	67. Anti-slip safety steps used on portable ladders
	68. Caution exercised when metal ladders used in electric current areas
	69. Caution exercised when metal ladders used with portable electric tools
	70. Ladders inspected monthly with inspection records kept
	71. Straight ladders properly secured

Figure 11-7. Safety checklist.

		LIQUID PETROLEUM GASES (OSHA 1910.110)
	72.	Bulk storage (126 to 500 gallons) at least 10 feet from building
	73.	Bulk storage (501 to 2,000 gallons) at least 25 feet from building
	74.	Bulk storage (251 to 2,000 gallons) at least three feet separation between tanks
	75.	Containers labeled by size (in pounds or gallons)
	76.	Containers labeled with pressure in "gauge psi"
	77.	Containers labeled by type of L.P.G.
	78.	Containers have safety relief and shut-off valves
	79.	Containers stored away from exits
	80.	Distance between L.P.G. containers and flammable liquid containers is 20 feet
	81.	No containers are stacked one above the other
	82.	Containers are stored in a "No Smoking" area
		MACHINE GUARDING (OSHA 1910.211-1910.222)
	83.	Abrasive wheels in accordance with type of work
	84.	Abrasive wheels in good condition
	85.	Abrasive wheels labeled and in accordance with rpm ratings
	86.	Abrasive wheels uniform in diameters
	87.	Air nozzles used for cleaning meet 30 psi limit
	88.	All rotating, cutting shearing, screw and worm, blending, and forming motions guarded
	89.	Safety precautions understood and used by shop employees
	90.	Steady rests on grinders meet 1/8" adjustment to wheel requirement
		PERSONAL PROTECTIVE EQUIPMENT (OSHA 1910.95, 1910.132-1910.140)
	91.	All protective equipment maintained in safe working condition
	92.	Ear protection worn when noise dBA greater than 90 for 8 hours
	93.	Ear protection worn when noise dBA greater than 95 for 4 hours
	94.	Ear protection worn when noise dBA greater than 100 for 2 hours
	95.	Ear protection worn when noise dBA greater than 105 for 1 hour
	96.	Ear protection worn when noise dBA greater than 110 for 1/2 hour
	97.	Ear protection worn when noise dBA greater than 115 for 1/4 hour
	98.	Eye and face protection provided where reasonable probability of injury exists
	99.	Respiratory protective equipment worn when air is contaminated (dust, gases, etc.)
	100.	Safety shoes, caps, gloves worn when necessary
		STAIRS (OSHA 1910.21-1910.24)
	101.	Angle of rise is between 30 to 50 degrees
	102.	Fixed stairs have at least a 22" width
	103.	Fixed stairs have at least a 1000 lbs. load strength
	104.	Non-slip treads are present
	105.	Stair railings are 30-34" from top rail surface to forward edge of step
	106.	Stairways less than 44" wide (both sides enclosed) have at least one handrail
	107.	Stairways less than 44" wide (one side open) have at least one stair railing on open side
	108.	Stairways over 44" wide (both sides open) have two railings
	109.	Standard railings are 42" nominally from top surface of floor
	110.	Wood railing posts at least 2" x 4" stock spaced not to exceed 6 feet
	111.	Pipe railings and posts at least 1-1/2" nominal diameter
	112.	Pipe railing posts spaced not to exceed 8 feet
	113.	Structural steel railings and posts at least 2" x 2"
	114.	Structural steel railing posts spaced not to exceed 8 feet
		VENTILATION (OSHA 1910.94)
	115.	Exhaust system for removal of toxic fumes and dust from work area
		WALKING, WORKING SURFACES (OSHA 1910.21-1910.32)
	116.	Aisles and passageways unobstructed
	117.	Permanent walkways marked
	118.	Floor hole openings guarded and marked
	119.	Floor surfaces in good condition and uncluttered
		WELDING, CUTTING, HEATING OR BRAZING (OSHA 1910.251-1910.254)
	120.	Acetylene not used at pressures greater than 15 psig
	121.	Eye protection worn, where required by extent of hazard
	122.	During welding operations, appreciable combustibles more than 35 feet away
	123.	During welding operations, floor swept clean of combustibles within 35 feet
	124.	Fire watch practiced, where necessary
	125.	Frame of electric welding machine grounded
		HEAVY EQUIPMENT SAFETY REQUIREMENTS
	126.	Each piece of equipment has roll-over protection (see Section X-"Roll Over Protection Schedule")
	127.	Each piece of equipment has fire extinguisher (20 lbs. ABC Minimum)
	128.	All heavy equipment is equipped with backup alarm
	129.	All machines operating at night equipped with headlights
	130.	Seat belts are on all equipment with roll-over protection
		MEDICAL AND FIRST AID
	131.	Medical personnel available for advice and consultation
	132.	Suitable place to render first aid
		ROADS
	133.	Adjacent road (City, State, etc.) is clear of debris and mud
	134.	Where possible, warning sign or light, "TRUCK ENTRANCE"
	135.	Landfill road crowned and proper drainage
	136.	Landfill road kept properly cleaned of debris
	137.	Landfill road has proper dust control by means of a water wagon or water truck
	138.	Traffic Control Signs (Landfill) - Stop sign (for vehicle leaving landfill before entering public street)
	139.	Traffic Control Signs (Landfill) - Speed limit signs
	140.	Traffic Control Signs (Landfill) - No parking signs
		LANDFILL SITE
	141.	All underground cables, pipes, etc., are clearly marked and identified
	142.	Utility wires are of sufficient height to allow clearance for all equipment using landfill
	143.	Security fences and landfill site is kept free as possible of blowing paper and debris

Figure 11-7. Safety checklist (continued).

Chapter 12
Closure and Post-Closure Care

12.1 General

Closure is the procedure through which a surface disposal site is closed after sewage sludge is no longer placed on the land. Issues to be addressed during closure include:

- Covering the sludge to control odors and vectors (insects, animals).
- Proper leachate management to prevent contamination of ground water or surface water.
- Prevention of methane gas accumulation.
- Maintaining a stable and secure site throughout the post-closure period.
- Selection of and preparation for the final end use of the site.

12.2 Regulatory Requirements

12.2.1 Part 503

The requirements for closure of a surface disposal site regulated under Part 503 are specified in Section 503.22. These requirements pertain to closing active sewage sludge units in a surface disposal site. Under these requirements:

- *Closure is required if an active sewage sludge unit is located in certain types of areas.* If an active sewage sludge unit is located within 60 meters of a fault, in an unstable area, or in a wetland, the unit must close by March 22, 1994. There are two exceptions to this requirement: (1) if the permitting authority has indicated that the location of a specific unit within 60 meters of a fault is acceptable, or (2) if a permit was issued under the Clean Water Act that allows the unit to be located in a wetland (U.S. EPA, 1994).
- *If an active sewage sludge unit closes, the permitting authority must be notified.* If an active sewage sludge unit is about to be closed, the owner/operator of the unit must provide the permitting authority with a written plan that describes closure and post-closure activities. At a minimum, the following information must be included in the plan: (1) how the leachate collection system will be operated and maintained for 3 years after closure (if the unit has such a system); (2) a description of the system used to monitor air for methane gas for 3 years after closure (if the active sewage sludge units are covered); and (3) how public access will be restricted for 3 years after closure. This information must be provided to the permitting authority 180 days before the unit closes (U.S. EPA, 1994).

The permitting authority may determine that the closure plan must include provisions for methane gas monitoring or leachate collection for more than 3 years. For example, if the sewage sludge placed in the active sewage sludge unit was not stabilized, it may be necessary to monitor air for methane gas and restrict access for a longer period to protect public health. Also, in areas of high rainfall, the permitting authority may determine it necessary to collect leachate for a longer period to ensure that the integrity of the liner is maintained (U.S. EPA, 1994).

Under the general requirements of Part 503:

- *Any subsequent landowner must be notified that the land was a surface disposal site.* The owner of a surface disposal site must provide the subsequent owner with written notification that sewage sludge were placed on the land (U.S. EPA, 1994).

The notification required for the subsequent owner of a surface disposal site will vary depending on when the land was sold and the provisions of the closure plan. For instance, if a surface disposal site was covered, had a liner, and was sold 1 year after closure, the notification would inform the next owner that the property was used to dispose of sewage sludge and that the new owner must operate the leachate collection system, monitor air for methane gas, and restrict public access for an additional 2 years (U.S. EPA, 1994).

12.2.2 Part 258

The requirements for closure and post-closure care of a municipal solid waste (MSW) landfill are regulated under Section 258.60 of Part 258. This regulation also requires the owner/operator of the MSW landfill to prepare a written closure plan. A complete discussion of the

closure requirements under the Part 258 regulation is beyond the scope of this manual. The reader is referred to U.S. EPA (1993) for additional information on these requirements.

12.3 Closure

12.3.1 Closure Plan

The closure plan is the document that specifies the criteria and procedures to be followed during closure and the post-closure period. The closure plan should be developed during the site selection and design process, because issues that occur at these stages can ultimately impact closure and the end use of the site. Also, by integrating the final site plans into the preliminary design, the ultimate value and cost of developing the final site can be enhanced.

The closure plan should be reviewed and updated as necessary during the operational life of the facility. The objectives of a closure plan include:

- Designating the design criteria and operational procedures for closure.
- Identifying operational and maintenance requirements of the post-closure site.

The contents of a closure plan varies depending on a number of factors, such as the type of surface disposal site, the regulations controlling the site (i.e., Part 503 or Part 258), specific features of the site, the concerns of the public, and the requirements of the regulating authority. The contents of a closure plan may include:

- Cover system design
- Vegetative cover design
- Stormwater management controls
- Inspection and maintenance procedures
- Leachate management controls
- Methane gas management controls
- Other environmental controls
- Plans for site access restriction and security
- Management and recordkeeping requirements
- Financial requirements

Figure 12-1 outlines a sample closure and postclosure plan for an active sewage sludge unit (U.S. EPA, 1994).

12.3.2 Cover for Monofills or MSW Landfills

The design criteria for landfill closure focus on two central themes: (1) the need to establish low-maintenance cover systems and (2) the need to design a final cover that minimizes the infiltration of precipitation into the waste. Landfill closure technology, design, and maintenance procedures continue to evolve as new geosynthetic materials become available, as performance requirements become more specific, and as performance history becomes available for the relatively small number of landfills that have been closed using current procedures and materials. Critical technical issues that must be faced by the designer include (U.S. EPA, 1993):

- Degree and rate of postclosure settlement and stresses imposed on soil liner components.
- Long-term durability and survivability of cover system.
- Long-term waste decomposition and management of landfill leachate and gases.
- Environmental performance of the combined bottom liner and final cover system.

Much information has been developed on final cover systems for landfills. The reader is referred to the reference U.S. EPA (1988) and U.S. EPA (1993) for further information on landfill cover systems.

12.3.2.1 General

The cover system is a physical barrier placed over the sewage sludge unit consisting of layers of soil and geomembrane material that isolate the sludge. The design criteria for a final cover system should be selected to (U.S. EPA, 1993):

- Minimize infiltration of precipitation into the sludge
- Promote good surface drainage
- Resist erosion
- Restrict gas migration and/or enhance recovery
- Isolate the sludge from vectors
- Improve aesthetics
- Minimize long-term maintenance

Reduction of infiltration in a well-designed final cover system is achieved through good surface drainage and runoff with minimal erosion, transpiration of water by plants in the vegetative cover and root zone, and restriction of percolation through earthen material (U.S. EPA, 1993).

Each element of a cover system consists of a layer of soil or other material selected to meet the requirements of a specific design criteria. Each element should be selected and designed based on the requirements of the specific site and the applicable regulations. The elements of a cover system are the erosion layer, the drainage layer, the infiltration layer, and the gas venting layer. Figure 7-24 in Chapter 7 illustrates the minimum requirements for the final cover system (U.S. EPA, 1993).

Owner/Operator Name:
Mailing Address:
Telephone Number:
Address of Active Sewage Sludge Unit Location:

I. ACTIVE SEWAGE SLUDGE UNIT CONDITIONS

A. General information

1. Size of active sewage sludge unit (hectares or acres)
2. Description of liner, if applicable
3. Description of leachate collection system, if applicable
4. Copy of NPDES permit if there are discharges to U.S. waters

B. Schedule of final closure (milestone chart)

1. Final date of sewage sludge accepted
2. Date all onsite disposal completed
3. Date final cover completed
4. Final date vegetation planted or other material placed
5. Final date closure completed
6. Total time required to close the site

II. DISPOSING OF SEWAGE SLUDGE

A. Total volume of sewage sludge to be disposed of on the active sewage sludge unit (m^3 or yd^3)

B. Description of procedures for disposing of sewage sludge

1. Size of surface disposal site, number of active sewage sludge units, and size of units necessary for disposing of sewage sludge (include site map of disposal area)

2. Design and construction of active sewage sludge units

Figure 12-1. Outline of sample closure and post-closure plan (U.S. EPA, 1994).

III. COVER AND VEGETATION

A. Final cover, if applicable

1. Total area to be covered (m^2 or yd^2)
2. Characteristics of final cover

    a. Type(s) of material(s)
    b. Depth of material(s)
    c. Total amount of material(s) required

3. Final cover design
    a. Slope of cover
    b. Length of run of slope
    c. Type of drainage and diversion structures

B. Vegetation (if vegetation is to be planted)

1. Total area requiring vegetation (hectares or acres)
2. Name or type of vegetation (e.g., rye grass)

C. Erosion Control (if vegetation is not to be planted)

1. Procedures and materials for controlling cover erosion
2. Justification for procedures and materials used

IV. GROUND-WATER MONITORING (if applicable)

A. Analyses required

1. Number of ground-water samples to be collected
2. Ground-water monitoring schedule (e.g., quarterly, semi-annually)
3. Details of ground-water monitoring program

B. Maintenance of ground-water monitoring equipment

V. COLLECTION, REMOVAL, AND TREATMENT OF LEACHATE

A. Description of leachate collection system (i.e., pumping and collecting procedures)

1. Description of the leachate sampling and analysis plan
2. Estimated volume of leachate collected per month

Figure 12-1. Outline of sample closure and post-closure plan (continued).

B. Description of leachate treatment process, if on-site

   a. Design objectives
   b. Materials and equipment required

C. Disposal of leachate

   1. If discharged to surface waters, include copy of NPDES permit
   2. If hauled offsite, provide final destination

D. Maintenance of equipment

   1. Repairs and replacements required
   2. Regular maintenance required over the duration of closure and post-closure periods

VI. METHANE MONITORING (if applicable)

A. Monitoring requirements

   1. Monitoring locations
   2. Types of samples
   3. Number of samples
   4. Analytical methods used
   5. Frequency of analyses

B. Maintenance of monitoring equipment

C. Planned responses to exceedances of limits

VII. MAINTENANCE ACTIVITIES

A. Surface disposal site inspections

   1. List all structures, areas, and monitoring systems to be inspected
   2. Frequency of inspections for each

B. Planned responses to probable occurrences (including those listed below)

   1. Loss of containment integrity
   2. Severe storm erosion
   3. Drainage failure

Figure 12-1. Outline of sample closure and post-closure plan (continued).

C. Maintenance of cover and/or vegetation

1. Cover maintenance activities and schedule
2. Mowing schedule
3. Reseeding and mulching schedule
4. Soil replacement

   a. Labor requirements
   b. Soil requirements

5. Fertilizing schedule
6. Sprinkling schedule
7. Rodent and insect control program

D. Control of erosion

1. Maintenance program for drainage and diversion system
2. Activities required to repair expected erosive damage
3. Replacement cover soil

   a. Amount to be stored onsite during the post-closure period
   b. Specification of alternative sources of cover soil, if applicable (i.e., offsite purchase agreement or onsite excavation)

VIII. INSTALLATION OR MAINTENANCE OF THE FENCE

A. If a fence already exists, describe required maintenance at closure to ensure it is in good condition

B. If fence is to be installed, specify:

1. Area to be enclosed
2. Type of materials used
3. Dimensions of fence

C. Security and public access practices planned for the post-closure period

1. Description of security system
2. Maintenance schedule

IX. CLOSURE SCHEDULE

A. Schedule for closure procedures
B. Schedule of periodic inspections

Figure 12-1. Outline of sample closure and post-closure plan (continued).

12.3.2.2 The Infiltration Layer

The infiltration layer is a low permeability layer consisting of a low permeability soil and/or a geomembrane. The infiltration layer must be at least 18 inches thick and composed of earthen material that has a hydraulic conductivity (K) less than or equal to the hydraulic conductivity of any bottom liner system or natural subsoils (U.S. EPA, 1993). The permeability of the infiltration layer should be less than or equal to the permeability of any liner system or natural soils present to prevent a "bathtub effect." Figure 12-2 presents an example of a final cover with a hydraulic conductivity equal to the hydraulic conductivity of the bottom liner system.

In no case can the final cover have a hydraulic conductivity greater than 1×10^{-5} cm/sec regardless of the permeability of underlying liners or natural subsoils (U.S. EPA, 1993). If a synthetic membrane is in the bottom liner, there must be a flexible membrane liner (FML) in the final cover to achieve a permeability that is less than or equal to the permeability of the bottom liner. Currently, it is not possible to construct an earthen liner with a permeability less than or equal to a synthetic membrane (U.S. EPA, 1993).

For units that have a composite liner with an FML, or naturally occurring soils with very low permeability (e.g., 1×10^{-8} cm/sec), the Agency anticipates that the infiltration layer in the final cover will include a synthetic membrane as part of the final cover (U.S. EPA, 1993). A final cover system for a landfill unit with an FML combined with a soil liner and leachate collection system is presented in Figure 12-3a. Figure 12-3b shows a final cover system for a landfill that has both a double FML and double leachate collection system.

The soil material used for the infiltration layer should be free of rocks, clods, debris, cobbles, rubbish and roots that may increase the hydraulic conductivity by creating preferential flow paths. The surface of the compacted soil should have a slope between 3 percent and 5 percent after settlement. It is critical that side slopes, which are frequently greater than 5 percent be evaluated for erosion potential (U.S. EPA, 1993).

The infiltration layer should be placed below the maximum depth of frost penetration to avoid freeze-thaw effects (U.S. EPA, 1989b). Freeze-thaw effects may cause the development of microfractures or realignment of intersticial fines that can increase the hydraulic conductivity of clays by as much as an order of magnitude. Infiltration layers may be subject to desiccation depending on the climate and soil water retention in the erosion layer. Fracturing and shrinking of the clay due to water loss can increase the hydraulic conductivity of the infiltration layer (U.S. EPA, 1993). Information regarding the maximum depth of frost penetration for a particular area can be obtained from the Soil Conservation Service, local utilities, construction companies, and local universities.

The infiltration layer is designed and constructed in a manner similar to that used for soil liners, with the following differences (U.S. EPA, 1993):

- The cover is generally not subject to large overburden loads, so the issue of compressive stresses is less critical unless post-closure land use will exert large loads.
- The soil cover is subject to loadings from settlement of underlying materials. The extent of settlement anticipated should be evaluated and a post-closure maintenance plan designed to compensate for the effects of settlement.
- Direct shear tests performed on construction materials should be conducted at lower shear stresses than those used for liner system designs.

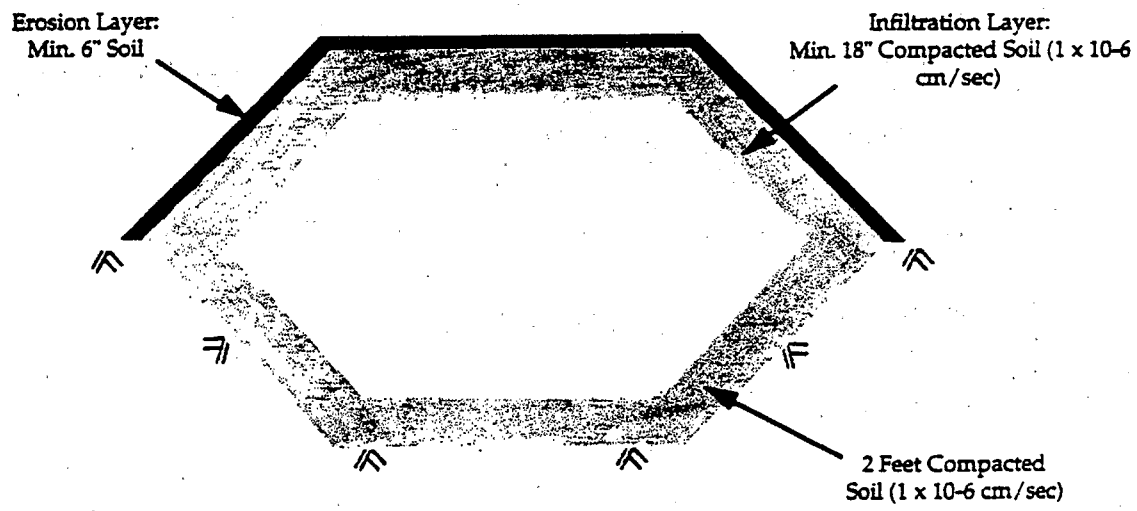

Figure 12-2. Example of final cover with hydraulic conductivity (K) ≤ K of liner (U.S. EPA, 1993).

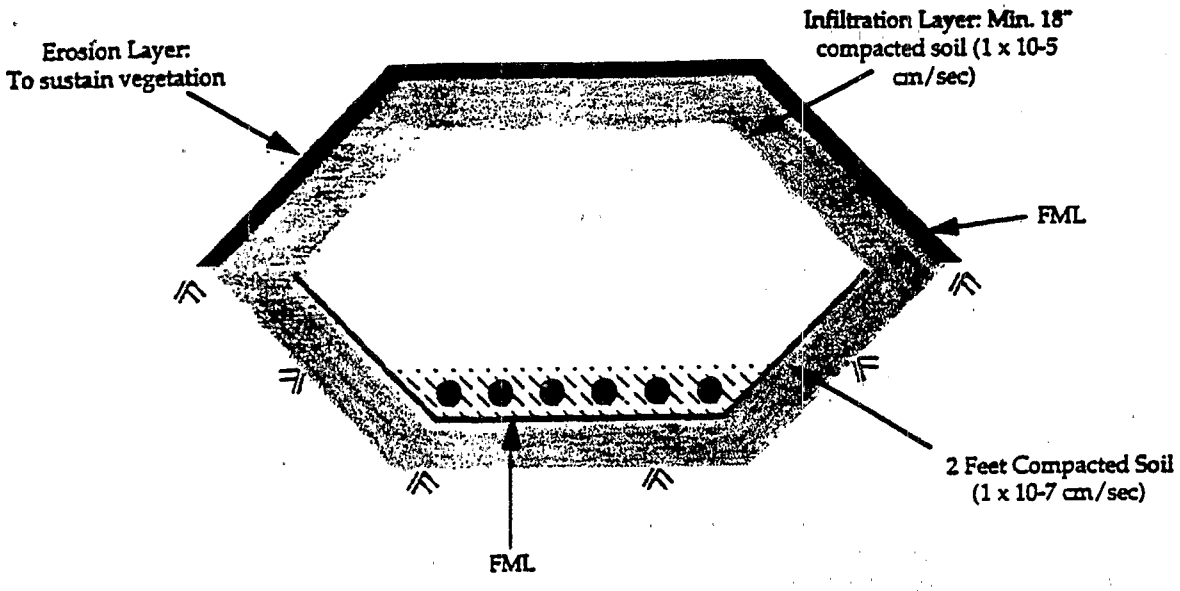

Figure 12-3a. Example of final cover design for an MSWLF unit with an FML and leachate collection system (U.S. EPA, 1993).

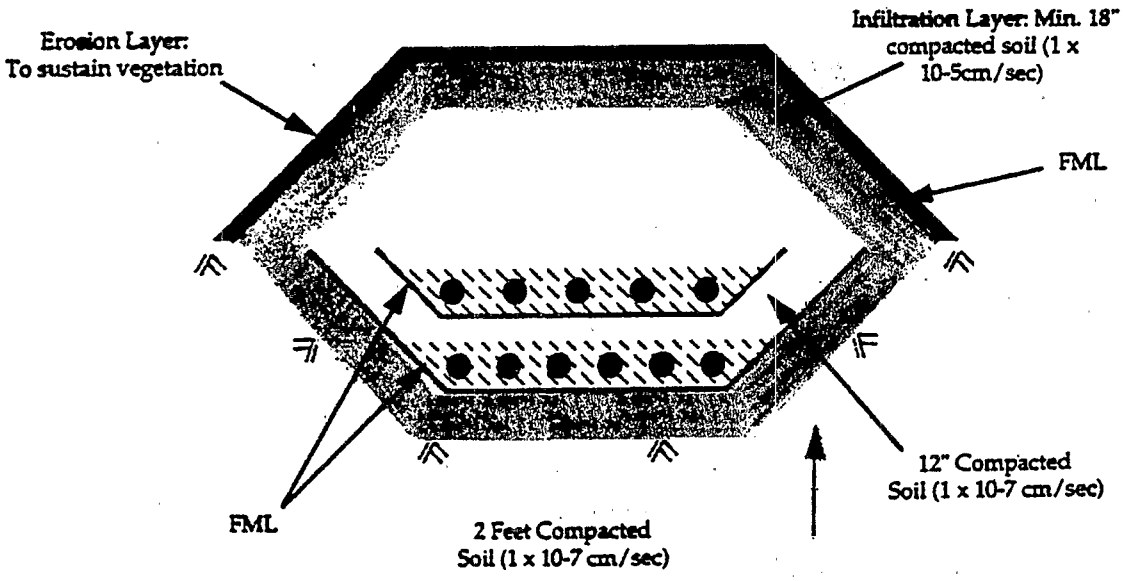

Figure 12-3b. Example of final cover design for an MSWLF unit with a double FML and leachate collection system (U.S. EPA, 1993).

Geomembranes

If a geomembrane is used as an infiltration layer, the geomembrane should be at least 20 mils (0.5 mm) in thickness, although some geomembrane materials may need to be a greater thickness (e.g., a minimum thickness of 60 mils is recommended for HDPE because of the difficulties in making consistent field seams in thinner material) (U.S. EPA, 1993).

12.3.2.3 The Erosion Layer

The erosion layer protects the cover system from erosion due to water and wind. It also functions as the growing medium for the vegetative cover. Selection of the soil for the erosion layer should consider both its ability to protect the underlying layers and to support the vegetative cover. The erosion layer also protects the infiltration layer from the impacts of freeze thaw cycles.

Soil erosion can reduce the performance of the surface soil layer of a unit by impairing the vegetative growth or causing rills that require maintenance and repair. Extreme erosion may lead to the exposure of the infiltration layer or the sludge, or may cause slope instability (U.S. EPA, 1988). Eroded soil can clog stormwater drains resulting in increased maintenance requirements.

Anticipated erosion due to surface water runoff for a given design may be approximated using the USDA Universal Soil Loss Equation (Eq. 12-1) as shown below (U.S. EPA, 1989a). By evaluating erosion loss,

the design may be optimized to reduce damage through selection of optimum slopes, and best available soil and plant materials, or by allowing excess soil to increase the time between required maintenance (U.S. EPA, 1993).

$$X = RKSLCP \qquad \text{(Eq. 12-1)}$$

where:

X = Soil loss (tons/acre/year)
R = Rainfall erosion index
K = Soil erodibility index
S = Slope gradient factor
L = Slope length factor
C = Crop management factor
P = Erosion control practice

Values for these parameters are available from the U.S. Soil Conservation Service (SCS) technical guidance document entitled *Predicting Rainfall Erosion Losses, Guidebook 537 (1978), available at local SCS offices throughout the country.*

Figure 12-4 can be used to find the soil loss ratio due to the slope of the site as used in the Universal Soil Loss Equation. Loss from wind erosion can be determined by the following equation (U.S. EPA, 1989a):

$$X' = I'K'C'L'V' \qquad \text{(Eq. 12-2)}$$

where:

X' = Annual wind erosion
I' = Field roughness factor
K' = Soil erodibility index
C' = Climate factor
L' = Field length factor
V' = Vegetative cover factor

12.3.2.4 The Vegetative Cover

The vegetative cover protects the uppermost soil layer from wind, water and mechanical erosion, and removes soil water from the site through evapotranspiration. The vegetative cover is also important because it improves the appearance of the site.

In selecting plant species for the vegetative cover, the following criteria should be considered (U.S. EPA, 1989b):

- Plants should be locally adapted perennials that are resistant to drought and temperature extremes.

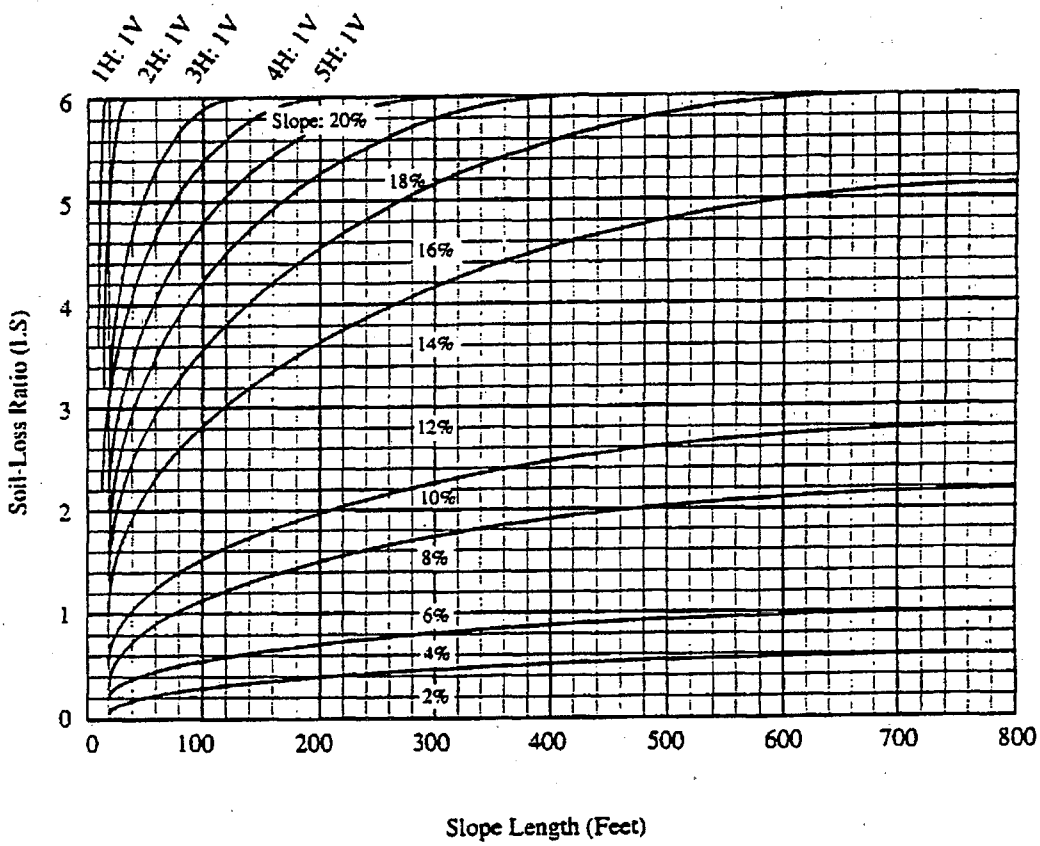

Figure 12-4. Soil erosion due to slope (U.S. EPA, 1993).

- If part of a cover system, the plants should not have root systems that will disrupt underlying drainage and infiltration layers.
- The plants should be able to thrive in low-nutrient soil conditions with minimum nutrient additions.
- There should be sufficient plant density to minimize soil cover erosion.
- Plants should require little or no maintenance.
- Sufficient variety of plant species to continue to achieve these characteristics and specifications over time.

Information on suitable species for a specific site is available from the USDA Soil Conservation Service, the Cooperative Extension Service, or local universities.

Typically, planting or seeding should be conducted in the fall or early spring to permit seedlings time to become established before winter freeze or summer drought occurs. Fast-growing temporary cover crops such as winter rye can provide a temporary vegetative cover over winter until conditions for permanent plantings are favorable (U.S. EPA, 1993).

Surface water runoff should be properly controlled to prevent excessive erosion and soil loss. Establishment of a healthy vegetative layer is key to protecting the cover from erosion. However, consideration also must be given to selecting plant species that are not deeply rooted because they could damage the underlying infiltration layer (U.S. EPA, 1993).

12.3.2.5 Alternate Final Cover Design

An alternative material and/or an alternative thickness may be used for an infiltration layer. For example, another method for controlling erosion is the use of an armored surface as the outer layer of a final cover system. An armored surface or hardened cap is generally used in arid regions or on steep slopes where the establishment and maintenance of vegetation would be difficult (U.S. EPA, 1993).

An armored surface (comprised of cobble-rich soils or soils rich in weathered rock fragments) should have the following characteristics (U.S. EPA, 1989b):

- Capable of remaining in place and minimizing erosion of the armored layer and underlying material during extreme weather events of rainfall and/or wind.
- Capable of accommodating settlement of the underlying material without compromising the component.
- Designed with a surface slope approximately the same as the underlying soil.
- Capable of controlling the rate of erosion.

Asphalt and concrete may also be used to construct an armored layer. These materials, however, deteriorate due to thermal expansion and deformation caused by subsidence. Crushed rock may be spread over the cover in areas where weather conditions such as wind, heavy rain, or temperature conditions commonly cause deterioration of vegetative covers (U.S. EPA, 1989b).

On sites subject to Part 258 regulations, armored surfaces are considered an alternative final cover design and may be employed in approved states only and with the permission of the regulating authority (40 CFR 258.60 (b)).

12.3.2.6 Other Components for Final Cover Systems

Other components that may be used in the final cover system include a drainage layer, a gas vent layer, and a biotic barrier layer. These components are shown in Figure 12-5.

The Drainage Layer

The drainage layer is a permeable layer constructed of soil or geosynthetic drainage material between the erosion layer and the infiltration layer. The drainage layer conveys water that has percolated through the erosion layer away from contact with the infiltration layer, thus reducing the potential for leachate generation (U.S. EPA, 1993).

A typical drainage layer consisting of soil material is at least 12 in. (30 cm) thick with a hydraulic conductivity between 10^{-2} and 10^{-3} cm/sec. The layer should be sloped between two percent and five percent after settling. The soil material should be no coarser than 3/8 in. (0.95 cm), classified according to the Universal Soil Classification System (USCS) as type SP, smooth and rounded, and free of debris that could damage an underlying geomembrane. Crushed stone is generally not appropriate because of the sharpness of the particles (U.S. EPA, 1993).

If geosynthetic materials are used as a drainage layer, the fully saturated effective transmissivity should be the equivalent of 1 foot of soil (30 cm) with a hydraulic conductivity range of 10^{-2} to 10^{-3} cm/sec. Transmissivity is calculated as the hydraulic conductivity multiplied by the drainage layer thickness (U.S. EPA, 1993).

A filter layer composed of a low nutrient soil or a geosynthetic material (such as a non-woven needle punch fabric) should be placed above the drainage layer. The purpose of this layer is to prevent clogging of the drainage layer by roots and by the downward migration of particles with the water.

The Gas Venting Layer

Sites with impermeable covers must have a system to collect or disperse the combustible gas (methane) and other harmful gases (such as hydrogen sulfide) that may be generated during biodegradation of the sludge. The

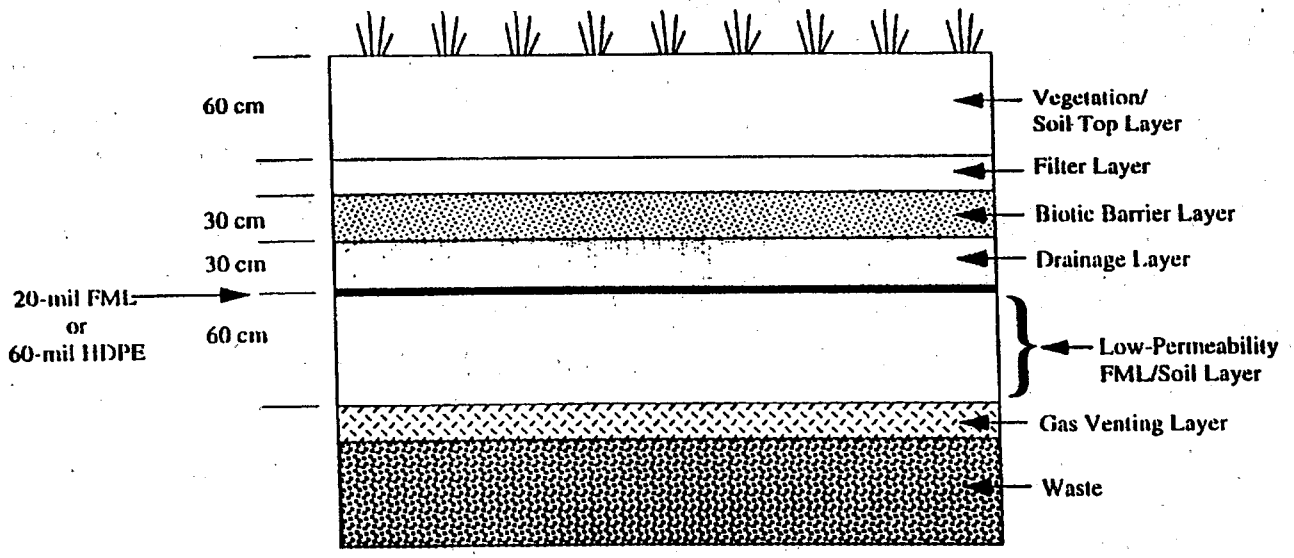

Figure 12-5. Example of alternative final cover design incorporating other components that may be used in final cover systems (U.S. EPA, 1993).

gas is collected in the gas vent layer. The gas vent layer is usually 12 in. (30 cm) thick and should be located between the infiltration layer and the sludge. Material used in construction of the gas vent layer should be medium to coarse-grained porous materials such as those used in the drainage layer (U.S. EPA, 1993).

A system of horizontal pipes located throughout the gas vent layer conveys the gases to vertical riser pipes or lateral headers that penetrate the infiltration layer. If riser pipes are used, they should be located at high points in the cross-section. Design of the horizontal pipes should incorporate some means to drain condensate that will form in the pipes. If not drained, the condensate can cause blockage of the pipes at low points. A more detailed discussion concerning gas at active sewage sludge units, including the use of active and passive collection systems is provided in Section 7.8.2.

Gas vent pipe penetrations through the cover can cause problems if settlement occurs. Settlement can cause concentrated stresses at these points damaging the cover and/or the vent pipes. If a geomembrane is used in the cover, adequate flexibility and slack material should be provided at these points. If an active gas collection system is used, penetrations may be made through the sides of the cover directly above the liner anchor trenches where effects of settlement would be less pronounced (U.S. EPA, 1993).

The Biotic Layer

Deep plant routes or burrowing animals (collectively called biointruders) may disrupt the drainage and the low hydraulic conductivity layers, thereby interfering with the drainage capability of the layers. A 30-cm (12-in.) biotic barrier of cobbles directly beneath the erosion layer may stop the penetration of some deep-rooted plants and the invasion of burrowing animals. Most research on biotic barriers has been done in, and is applicable to arid areas (U.S. EPA, 1993).

12.3.2.7 Other Design Issues

Hydrology

A computer model has been developed to assist designers in evaluating the hydraulic performance of a cover system. The Hydraulic Evaluation of Landfill Performance (HELP) Model was developed by the U.S. Army Corps of Engineers for the EPA. This model is generally accepted for use in designing landfill cover systems (U.S. EPA, 1988).

The HELP program calculates daily, average, and peak estimates of water movement across, into, through, and out of landfills. Input parameters include soil properties, climatological data, vegetation type, and site design data. Output from the model includes precipitation, runoff, percolation through the base of each cover layer subprofile, evapotranspiration, and lateral drainage from each profile. The model also calculates the maximum head on the barrier soil layer of each subprofile and the maximum and minimum soil moisture content of the evaporative zone (U.S. EPA, 1993). (See Section 7.5.7.1 for more information on the HELP Model.)

Settlement

Excessive settlement and subsidence caused by decomposition, dewatering and consolidation of the sludge can impair the integrity of the cover system. Specifically, settlement can contribute to (U.S. EPA, 1993):

- Ponding of surface water

- Disruption of gas collection pipe systems
- Fracturing of the infiltration layer
- Failure of geomembranes

Long-term settlement of disposal units should be analyzed on the basis of the deformation of the waste layers. Settlement due to deformation of the waste layers is most likely to occur after closure of the land disposal unit and final placement of the cover. Therefore, this type of settlement has more potential to cause subsidence damage to the cover than consolidation settlement, much of which can occur or can be made to occur prior to closure (U.S. EPA, 1987a).

Settlement can occur within a few days of sludge placement or extend over several years. Experience has indicated that sites may require regrading up to five years after closure. The rate and extent of settlement are controlled by several variables including:

- Sludge characteristics
- Disposal method
- Soil characteristics

Of these, the characteristics of the sludge have the greatest impact. Relevant sludge characteristics include:

- Solids content
- Volatile solids content
- Particle size and configuration

Sludge with a low solids content (15 to 20 percent solids) can be expected to settle more than sludge with a higher solids content (28 percent solids). Sludge may dewater due to evaporation, infiltration (into surrounding soils), or separation. Dewatering results in an increase in pore space and loss in volume, and consequent settling. Sludge with a low solids content disposed in trenches can stratify into liquid and solid phases. When this occurs, the solid phase is subject to rapid settlement.

Other factors that influence the stability of the active sewage sludge unit are the volatile solids content and the size and configuration of the sludge particles. Sludges with higher volatile solids content will biodegrade more and result in a greater loss of volume and increased settlement. Sludges with poorly sorted particles also settle to a greater extent.

Type of active sewage sludge units influence the potential for settlement. For example, landfill units in which the sludge is bulked with soil will settle in a different fashion from monofills.

Area fill disposal (where the sludge is not completely contained) may experience horizontal movement or creeping. Area fill sites are also susceptible to variable climatic conditions that may affect site stability.

Soil characteristics also affect settlement. The amount of interim and final cover applied will influence the degree of settlement by applying a surcharge to the sludge enhancing percolation of the liquid into the surrounding soil. The ability of the cover material to bear weight, inhibit water infiltration, and hold vegetation is important when predicting settlement.

For co-disposal sites, good records regarding the type, quantity, and location of solid waste materials disposed will aid in estimating the amount of settlement expected. Settlement due to consolidation may be minimized by compacting the waste during daily operations of the landfill or by landfilling baled waste (U.S. EPA, 1993).

If settlement is anticipated, several design options are possible. For example, the cover thickness can be designed such that after displacement occurs, surface drainage is still adequate. Figure 12-6 illustrates this design compensation method (U.S. EPA, 1988).

Slope Stability

Another potential cause of cover failure is displacement due to slope instability. Slope stability analyses should be performed to assess the potential for slope failure by various failure modes (e.g., rotational, sliding, wedge) as appropriate, based on the slope configuration. To adequately perform stability analyses, the properties of the cover system components, the sludge, and the foundation soils must be known as well as seepage conditions (U.S. EPA, 1988). A discussion of slope stability can be found in Section 7.5.5.

12.3.3 The Stormwater Management System

Control of stormwater on site is important in the control of erosion and surface water run-on and run-off. During closure the site should be graded so there is no ponding of surface water, and there is no run-on of precipitation from off-site areas. Final grades of the site should be designed so that after any settling has occurred, surface slopes are between 2 and 5 percent. Drainage pipes and ditches should convey all stormwater collected away from the site.

12.4 Post-Closure Maintenance

12.4.1 Inspection Program

A program of regular maintenance is necessary to maintain the site in proper condition during the post-closure period. The closure plan should contain an inspection schedule and a list of maintenance activities to be performed. Records of inspections detailing observations should be maintained to record and monitor changes in the site and its systems. These records also provide a continuity of the inspection process regardless of changes in the personnel conducting the inspections.

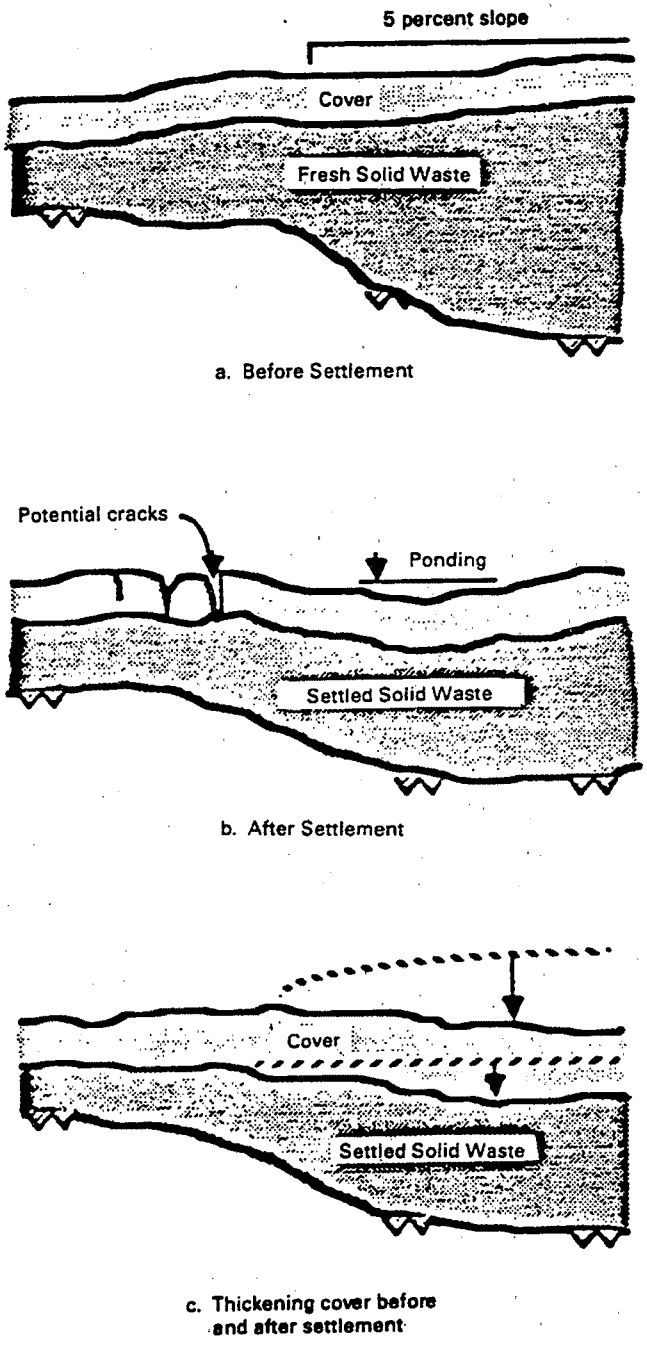

Figure 12-6. Thickened cover for tolerance of settlement (U.S. EPA, 1988).

Table 12-1 contains a list of typical inspection activities for a surface disposal site.

Site inspections consist of a walkover to inspect the systems and appurtenances and to look for evidence of any developing problems at the site. Aerial photography can be useful, especially on larger sites to identify and document the extent of any settlement or vegetative stress. Aerial photography should be used in conjunction with, rather than as a replacement for site walkovers. Optical topographic surveys can be used to quantify and record the extent of settlement on the site.

12.4.2 Maintenance

A maintenance program must be developed to ensure the continued integrity and effectiveness of the cover. Preventative maintenance work should be scheduled periodically for 2 to 3 years after cover installation to prevent loss of vegetation and gully development. Maintenance inspections should be regularly scheduled to provide early warning of more serious problems developing that would impact the cover's integrity such as cover subsidence, slope failure, leachate or upward gas migration, or deterioration of the drainage system. Figure 12-7 provides a brief overview of the elements of a typical maintenance program (U.S. EPA, 1988). The references U.S. EPA (1987b) and U.S. EPA (1982) provide detailed guidance on development of a post-closure maintenance program.

12.4.2.1 Stormwater Management System

The stormwater management system should be inspected to ensure it has not become blocked or damaged by subsidence. Drainage pipes should be inspected and, as necessary, cleaned. Surface drainage features should be cleared of unwanted vegetation, silt, rocks, and other debris. Appurtenances such as manholes and catch basins should be inspected for damage and blockage.

12.4.2.2 Regrading

Regrading should be performed as necessary to maintain the integrity of the erosion layer. Inspections should look for signs of soil erosion and settlement to be repaired by regrading. Erosion can cause formation of rills that, if not repaired, can lead to exposure of the infiltration layer or the sludge. Settlement can cause depressions and ponding of surface water or changes in stormwater flow patterns.

12.4.2.3 Vegetation

Regular maintenance of the vegetative cover is important to promote the growth of the desired vegetation. The vegetation should be mowed at least twice a year to suppress weeds and brush. Fertilizer and pesticides should be applied as necessary to promote the desired growth and to reduce pest damage.

The growth of undesirable plants can impair the vegetative cover. Deep rooted plants can penetrate and damage underlying drainage and infiltration layers. If such plants have become established, they should be completely removed and the remaining hole repaired. If the roots are left in place, they can begin to grow again, causing the problem to continue. Dead roots, as they

Table 12-1. Checklist for Surface Disposal Site Inspection

Cover System	• Look for formation of rills or other soil erosion damage. • Look for indications of settlement such as depressions in the surface or ponding of stormwater. • Look for indications of slope instability on steeper sideslopes. • Look for signs of leachate outcrops. • Check the condition of the vegetation for indications of subsurface problems. • Note the presence of any invader plant species. • Look for any animal burrows.
Stormwater Management System	• Be sure surface drainage features are clear and undamaged. • Be sure catch basins, manholes, and pipes are clean and unblocked.
Leachate Collection System	• Be sure pipes are unblocked and undamaged by settlement.
Gas Vents	• Be sure pipes are unblocked and undamaged by soil movement. • Be sure the infiltration layer is intact and properly sealed around vent pipes.
Gas Monitoring System	• Test the gas monitoring equipment.
Other Facilities	• Inspect roads, buildings, fences, etc., for signs of wear, damage, or vandalism.

PREVENTATIVE MAINTENANCE (2 to 3 years)

Cover System Component	Frequency	Task
Vegetation	twice per year annual	mowing (weed and brush) fertilization
Topsoil	as needed	soil reconditioning (supplemental fertilization, aeration)

PROBLEM IDENTIFICATION/CORRECTION

Cover System Component	Problem	Repair
Cover System	gully development	backfill to original grade with stone of narrow size range regrade cover replant vegetation
	subsidence	backfill with additional cover soil (care should be taken to maintain continuity of low permeable soil layer, geomembrane and drainage layer)
	slope instability	reconstruct cover flatten slopes add toe berm along base of slope
	gas migration that causes cracking	upgrade or install gas venting system install perimeter vents
Run-off Control System	erosion, siltation	placement of stone riprap or concrete modify channel alignment and/or gradients

Figure 12-7. Typical elements of maintenance program (U.S. EPA, 1988).

decay, can provide a preferential pathway for rainwater through the soil to the underlying layers.

Undesirable vegetation can provide a favorable habitat for burrowing animals. If a site inspection reveals the presence of animal burrows, they should be filled with rocks and soil as a deterrent.

Site inspections should also monitor for signs of vegetative stress. This can be an indication of subsurface problems that are otherwise undetectable. Unhealthy, dying or dead plants can be indicators of settlement, or leachate or gas leakage through the cover or liner.

12.4.2.4 The Leachate Collection System

On all active sewage sludge units that have liners and leachate collection systems, the leachate collection system must be maintained for 3 years during the post-closure period. Monitoring of the leachate quality should be conducted as required by permits. The permitting authority might require that ground water and the drainage from under the liner must be monitored to ensure the performance of the liner system. Under Part 258, if the owner/operator of an MSW landfill can show that the leachate generated is no longer potentially harmful, permission may be obtained to cease leachate monitoring.

The leachate collection system should be checked to ensure that it is functioning properly. The pipes should be inspected and cleaned regularly to prevent blockages from forming. Leachate outcrops are an indication of a rupture in the liner or the infiltration layer allowing precipitation to enter and leachate to escape. Failure of the infiltration layer may be due to settlement, burrowing animals, deep-rooted plants, or severe soil erosion.

12.4.2.5 Gas Monitoring and Collection System

Provisions must be made to monitor the concentration of methane gas in air at the site for 3 years during the post-closure period. Air must be monitored for methane gas in any structure on the site and at the site property line. Concentrations may not exceed 25 percent of the Lower Explosive Level (LEL) in air in any structure within the property line, and may not exceed the LEL in air at the property line. For safety purposes, it should be possible to measure methane levels within a structure without entering it.

The gas collection system should be inspected to check that it is working properly. Vent risers should be checked to ensure that they are not clogged with foreign matter such as dirt or rocks. The gas collection pipes should be flushed and pressure cleaned as necessary. (See Chapter 10 for additional information on monitoring for methane gas.)

12.4.2.6 Site Access and Security

Public access to surface disposal sites must be restricted for 3 years during the post-closure period. Other sites may require some security measures to prevent vandalism to structures, gas vents or other exposed appurtenances. Traffic control devices may be required to limit vehicles to areas where they will not damage a cover system or other features of the site. The closure plan should describe the security measures to be employed (fences, traffic barriers, signs, etc.).

Fences, traffic barriers, signs, etc., should be inspected regularly. Site inspections should look for damage to the site from vandalism and traffic, authorized or unauthorized. Additional security measures should be added as necessary. Any obvious health and safety hazards should be remedied immediately.

12.5 References

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Chapter 13
Costs of Surface Disposal of Sewage Sludge

This section presents typical costs for sewage sludge hauling, placement in a monofill or dedicated disposal site, and placement in a municipal solid waste (MSW) landfill. Costs for waste piles and surface impoundments are not discussed. Cost curves are presented for sewage sludge hauling, monofilling, and dedicated disposal, and are in terms of cost per wet ton vs. sludge quantity received. Typical costs are presented for: (1) annualized site capital costs, (2) site operating costs, and (3) total site costs (combined annualized capital and operating).

These curves can be useful in the early stages of sludge surface disposal site planning. Typical costs should be used only in preliminary work, however. Actual costs vary considerably with specific sludge and site conditions. Therefore, use of these curves for computing specific project costs is not recommended. Site-specific cost investigations should be made in each case.

13.1 Hauling Costs

Typical costs for hauling dewatered sewage sludge are presented in Figure 13-1. As shown, costs are given in dollars per wet ton as a function of the wet tons of sludge delivered to the site each day. Costs are presented for alternative distances of 5, 10, 20, 30, 40, and 50 mi (8.0, 16.1, 32.2, 48.3, 64.4, and 80.4 km) hauls.

"Principals and Design Criteria for Sewage Sludge Application on Land" (U.S. EPA, 1978) and "Transport of Sewage Sludge" (U.S. EPA, 1976) were the primary sources of information for data and procedures in developing these hauling costs. Other references (U.S. EPA, 1975; Los Angeles/Orange County Metropolitan Area, 1977; Spray Waste, Inc., 1974) are available and also were consulted and utilized. Sludge hauling costs were originally prepared for the year 1975 but were updated to reflect 1994 costs.

The hauling costs shown in Figure 13-1 reflect not only transportation costs, but also the cost of sludge loading and unloading facilities. For a treatment works generating wet tons (9.1 Mg) per day of a dewatered sludge and a 5-mi (8.0-km) haul, sludge loading and unloading facilities were found to contribute 60 percent of the total hauling costs. For a treatment works generating approximately 250 wet tons (227 Mg) per day of dewatered sludge and a 40-mi (64.4-km) haul, loading and unloading facilities contributed less than 10 percent of the total hauling costs.

Because of the differing bases for cost computations, certain assumptions on sludge volumes and unit costs were utilized to produce the hauling cost curve. These assumptions include:

1. The sludge was dewatered and had a solids content of approximately 20 percent. It was hauled by a 15 yd^3 (11.5 m^3), 3-axle dump truck.
2. Hauling was performed 8 hrs per day, 7 days per week.
3. Overhead and administrative costs were 25 percent of the operating cost.
4. Capital costs were annualized. A rate of 7 percent over 6 years was used for the trucks with a salvage value of 15 percent. A rate of 7 percent over 25 years was used for loading and unloading facilities with no salvage value.

If conditions other than the above-stated conditions prevail at a given site, the hauling costs in Figure 13-1 should be revised upward or downward appropriately. As an example, if 10 yd^3 (7.6 m^3) 2-axle dump trucks are used, costs should be higher by factors ranging from 1.3 for a treatment works generating 250 wet tons (227 Mg) per day with a 50-mi (80-km) haul, to 1.0 for a plant generating 10 wet tons (9.1 Mg) per day with a 5-mi (8.0-km) haul. Alternatively, if a 30 yd^3 (23.9 m^3) dump truck is used, costs should be lower by factors ranging from 0.6 to 1.0 for the aforementioned sludge quantities and haul distances.

13.2 Monofills and MSW Landfills

13.2.1 Site Costs

Typical site costs for monofilling sewage sludges are presented in Figure 13-2, 13-3, and 13-4. As shown, costs are given in dollars per wet ton of sewage sludge received as a function of the wet ton of sewage sludge delivered to the site each day. Costs are presented for each of the alternative monofills regulated under Part

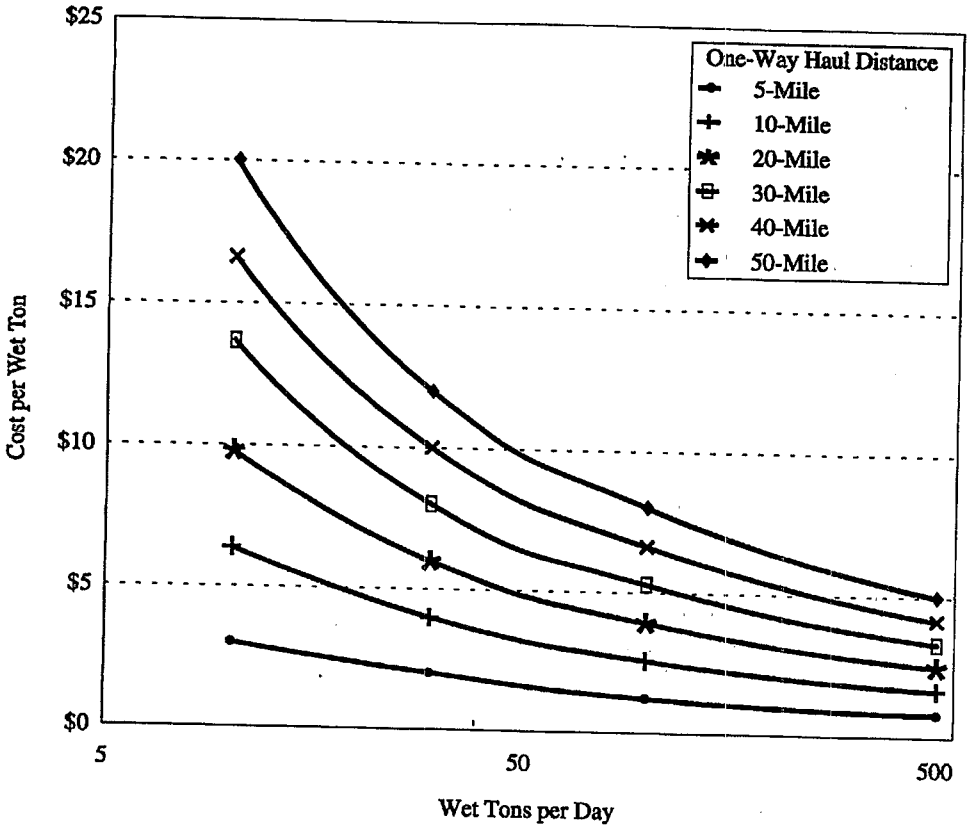

Figure 13-1. Typical Costs for Hauling Dewatered Sludge.

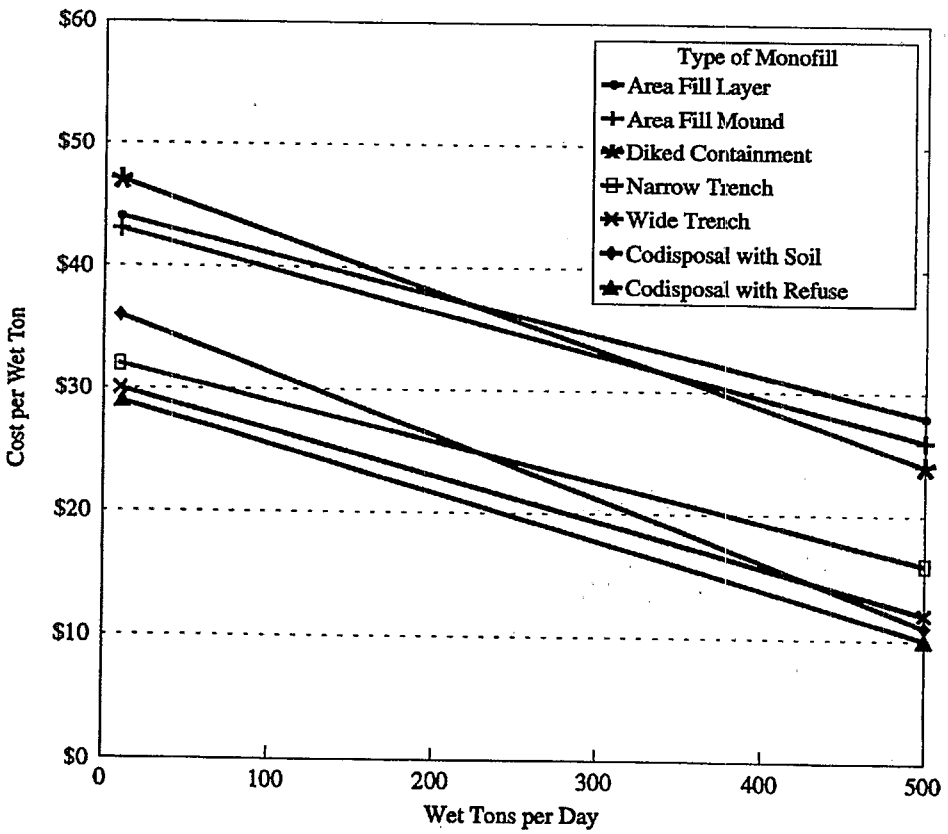

Figure 13-2. Capital Costs for Sludge Monofills and MSW Landfills.

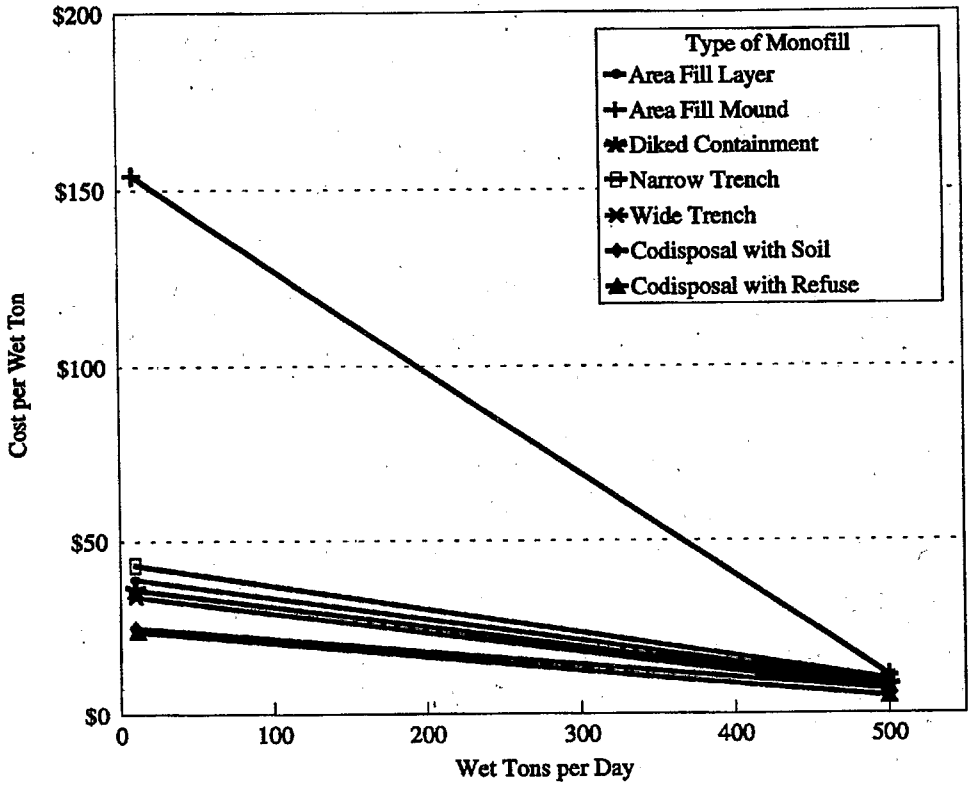

Figure 13-3. Operating Costs for Sludge Monofills and MSW Landfills.

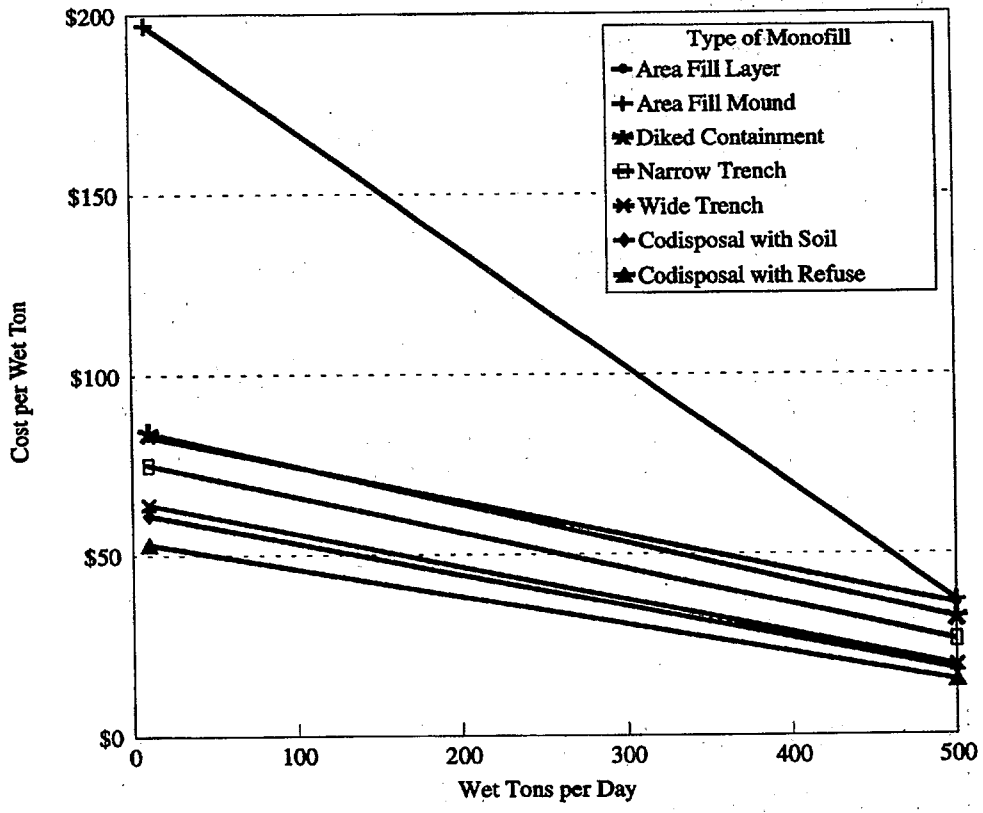

Figure 13-4. Total Costs for Sludge Monofills and MSW Landfills.

Table 13-1. Cost Scenarios for Alternative Landfilling Methods

Identification			Site Preparation				Sludge Bulking			Sludge Filling			Sludge Covering			Miscellaneous	
Scenario No.	Landfilling method	Sludge Solids Content (%)	Width (ft)	Depth (ft)	Length (ft)	Spacing (ft)	Bulking Performed	Bulking agent	Bulking ratio (bulking agent: sludge)[a]	Sludge depth per lift (ft)	No. of lifts	Sludge application rate (yd^3/acre)	Cover applied	Cover Thickness Interim (ft)	Cover Thickness Final (ft)	Imported soil required	Primary equipment
1	Narrow trench[a]	22	6	6	100	9	No	—	—	4	1	2,580	Yes	—	4	No	Backhoe with loader, track dozer, excavator
2	Wide trench[b]	32	60	8	600	30	No	—	—	4	1	4,100	Yes	—	5	No	Track loader, scraper, track dozer
3	Area fill mound[b]	30	—	—	—	—	Yes	Soil	1:1	6	2	9,680	Yes	3	1	Yes	Track loader, backhoe, track dozer, scraper, wheel loader
4	Area fill layer[b]	30	—	—	—	—	Yes	Soil	0.5:1	2	2	4,300	Yes	0.5	1	Yes	Track dozer, scraper, grader, wheel loader
5	Diked containment[a]	25	50	30	100	30	Yes	Soil	0.5:1	6	4	12,410	Yes	1	3	Yes	Dragline, track dozer, scraper
6	Sludge/refuse[b] mixture	20	—	—	—	—	Yes	Refuse	7 tons:1 wet ton	6	3	2,520	Yes	0.5	2	No	Track dozer, truck loader
7	Sludge/soil[b] mixture	20	—	—	—	—	Yes	Soil	1:1	1	1	1,600	No	—	—	No	Tractor with disc, grader, track loader

[a] Land-based
[b] Sludge-based

1 ft = 0.305 m
1 yd^3 = 0.765 m^3
1 acre = 0.405 ha

design dimensions and application rates were devised for the purposes of these cost calculations. These scenarios are summarized in Table 13-1. The cost curve for each method was plotted from computations that assumed alternative quantities of 10, 100, and 500 wet tons per day of sludge for each scenario.

Capital costs are summarized in Figure 13-2. Capital cost items included:

1. Land.
2. Site preparation (clearing and grubbing, surface water control ditches and ponds, monitoring wells, soil stockpiles, roads, and facilities).
3. Equipment purchase.
4. Engineering.

Capital costs were then annualized at 7 percent interest over 5 years (the life of the site) and divided by the sludge quantity delivered to the site in one year to get the capital cost per wet ton.

Operating costs are summarized in Figure 13-3. Operating cost items included:

1. Labor
2. Equipment fuel, maintenance and parts
3. Utilities
4. Laboratory analysis of water samples
5. Supplies and materials
6. Miscellaneous and other

Operating costs (see Figure 13-3) for one year were then divided by the annual sludge quantity delivered to the site to get the operating cost per wet ton.

The costs shown, which were derived from a variety of published information sources (Equipment Guide Book Company, 1977 and 1976; Robert Snow Means Company, 1978) and case study investigations, have been revised upward to reflect 1994 prices. Several assumptions were employed in producing these cost curves. These assumptions include:

1. Life of the surface disposal site was 5 years.
2. Actual fill areas (including inter-trench spaces) consumed 50 percent of the total surface disposal site area.
3. Engineering was 6 percent of the total capital cost.

It should be noted that the site costs shown for codisposal operations were derived by dividing the additional annualized capital cost and additional operating cost by the sludge quantity received. Actual unit costs for typical MSW landfills not receiving sludge may be expected to be less.

Figure 13-4 shows the total costs for monofills and MSW units in which sewage sludge is placed.

13.3 Dedicated Disposal of Sewage Sludge

Surface disposal on a dedicated surface disposal site differs from land application programs in that the site is used primarily or exclusively for the disposal of sewage sludge. Sludge disposal rates are much higher for dedicated disposal sites than for land application sites. Sewage sludge is often placed on a dedicated disposal site throughout the year, except during inclement weather.

Figures 13-5 through 13-7 present base capital costs, base annual operating and maintenance costs, and total costs for sewage sludge disposed at a dedicated disposal site. The assumptions used in developing these curves are as follows:

1. The sludge has a solids content of approximately 5 percent.
2. Daily disposal period is 7 hours per day.
3. Annual disposal period is 200 days per year.
4. Fraction of land required in addition to disposal area is 0.4 of the total surface disposal site.
5. The disposal rate is 30 to 50 dmt/ha/year.

13.4 Cost Analysis

As stated previously, the cost curves in this chapter should not be used for site-specific cost compilations performed during design. They can be useful, however, in the preliminary planning stages of a surface disposal site. In addition, they are useful in developing some general conclusions about sludge surface disposal costs. For instance:

1. Hauling costs ranged from less than $1 per wet ton (less than $1 per Mg) for a 5-mi (8.1-km) haul of 500 wet tons (453 Mg) per day to $20 per wet ton ($22 per Mg) for a 50-mi (80.4-km) haul of 10 wet tons (9.1 Mg) per day.
2. Annualized site capital costs ranged from $10 per wet ton ($11 per Mg) for a sludge/solid waste codisposal operation receiving 500 wet tons (453 Mg) per day to $47 per wet ton ($52 per Mg) for a diked containment operation receiving 10 wet tons (9.1 Mg) per day.
3. Site operating costs ranged from $5 per wet ton ($6 per Mg) for a sludge/solid waste codisposal operation receiving 500 wet tons (453 Mg) per day to $154 per wet ton ($169 per Mg) for an area fill mound operation receiving 10 wet tons (9.1 Mg) per day.

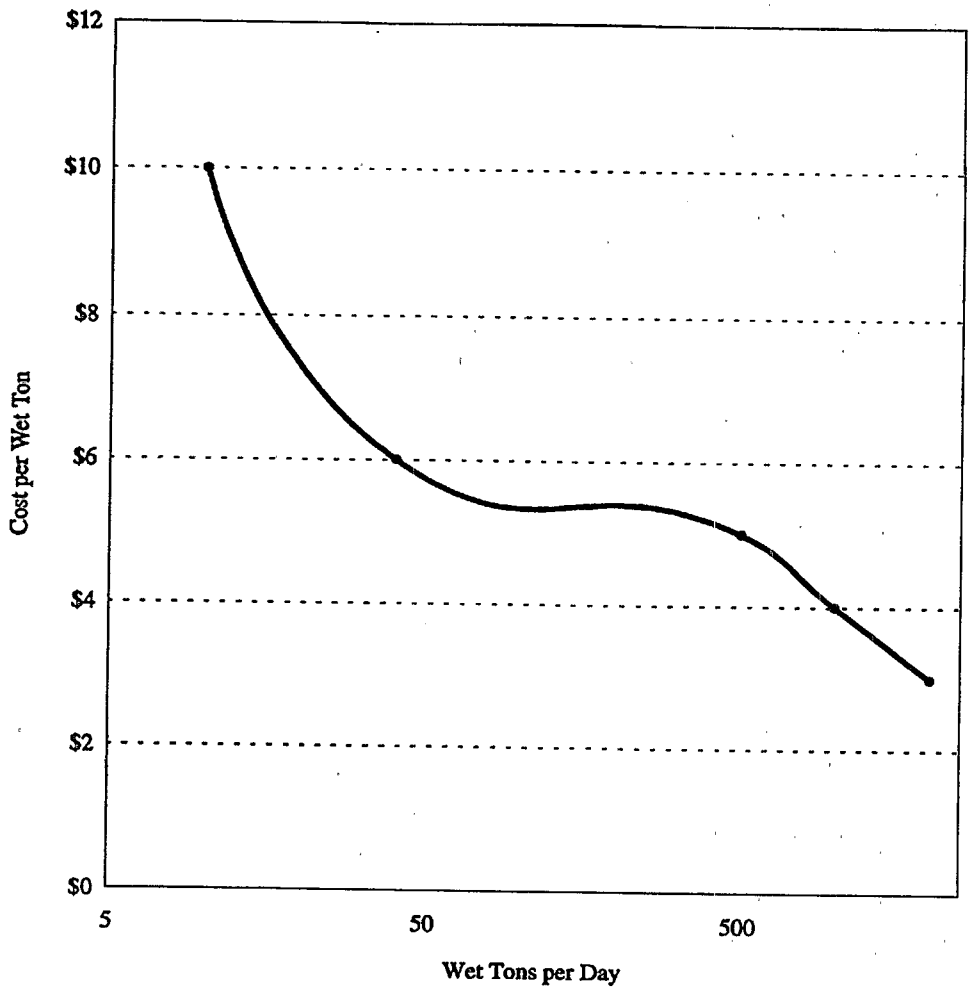

Figure 13-5. Capital Costs for Dedicated Surface Disposal Site.

4. Combined site costs ranged from $15 per wet ton ($17 per Mg) for a sludge/solid waste codisposal operation receiving 500 wet tons (453 Mg) per day to $197 per wet ton ($217 per Mg) for an area fill mound operation receiving 10 wet tons (9.1 Mg) per day.

Also, an assessment can be made of the relative costs of alternative types of sewage sludge units. A prioritized list of these methods based on total site costs (see Figures 13-4 and 13-7) with lowest costs first is as follows:

1. Codisposal with sludge/solid waste mixture
2. Codisposal with sludge/soil mixture
3. Wide trench
4. Dedicated surface disposal site
5. Narrow trench
6. Diked containment
7. Area fill layer
8. Area fill mound

The cost of an active sewage sludge unit is determined by the efficiency of the operation in terms of manpower, equipment, and land use. Other factors, such as haul distances play a role in the cost effectiveness of a given site but are the same for the various methods.

As indicated, codisposal and wide trench methods tend to be the most economical landfilling methods. Codisposal operations tend to be larger and benefit from the economies of scale. In addition, the availability of "free" bulking material in the form of solid waste reduces labor costs. Wide trenches have high application rates and are land and labor efficient. It should be noted, however, that the relatively high solids content required for effective utilization of wide trenches will increase the cost of sludge handling at the treatment plant.

Narrow trenches have relatively higher labor requirements and are intensive, contributing to high capital and operating costs. Area fill mounds and layers are labor and equipment intensive.

Diked containment requires a relatively large operation before it becomes a cost-effective means of surface

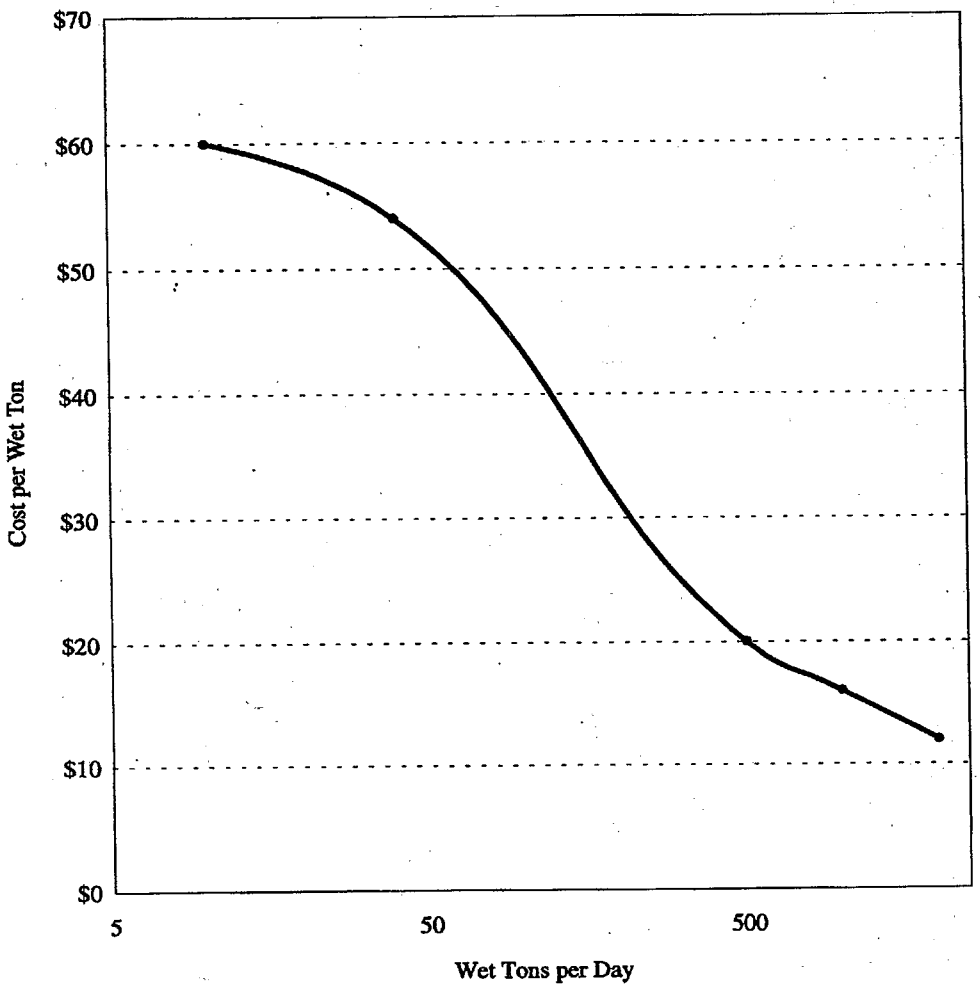

Figure 13-6. O&M Costs for Dedicated Surface Disposal Site.

disposal. This is a result of high initial labor and equipment requirements. Once established, however, diked containments are efficient in terms of operation and land use.

13.5 References

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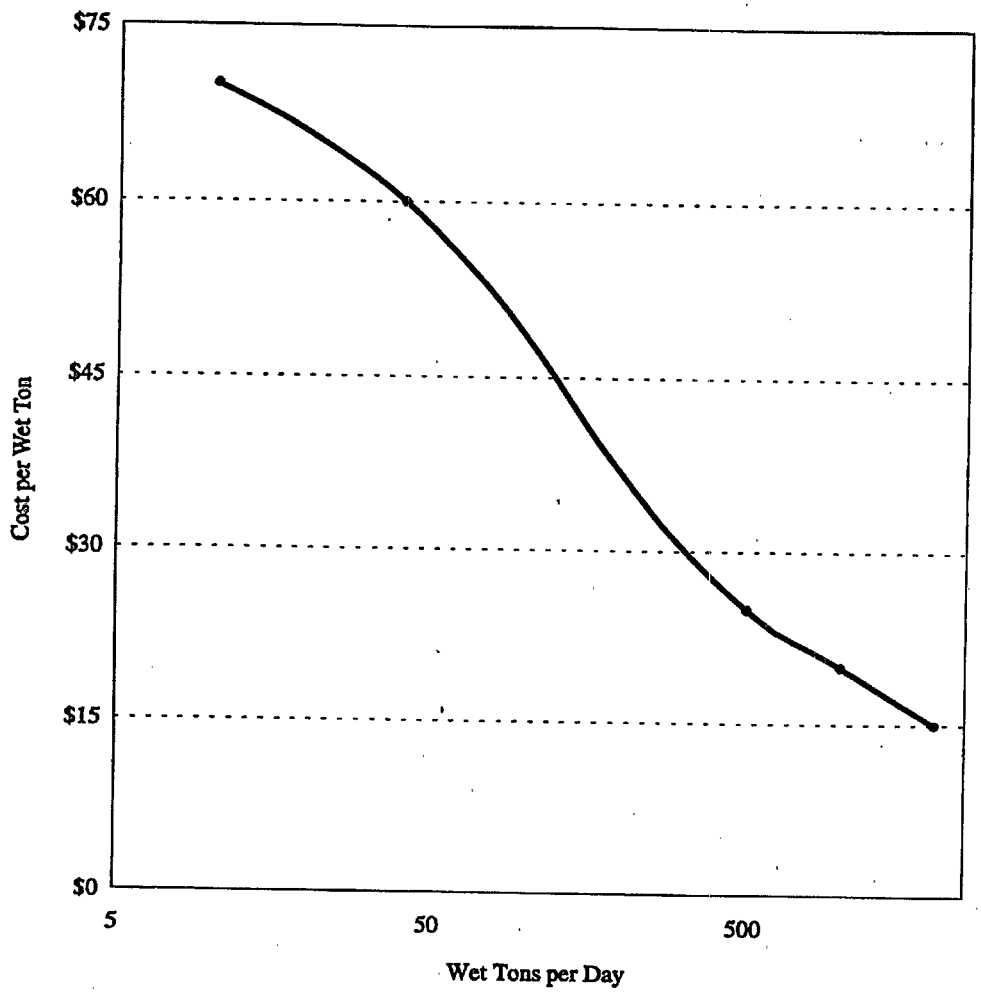


Figure 13-7. Total costs for dedicated surface disposal site.

Chapter 14
Design Examples

14.1 Introduction

The design of a surface disposal site is dependent on sludge characteristics and site conditions, such as percent solids, climate, soil, topography, and others. Consequently, no design example can be universal. Examples can be illustrative of the design and operating procedures that have been recommended in the preceding chapters, however.

This chapter contains three design examples. The approach in each of these examples is to present sludge characteristics and site conditions as given design data. The first example is for a large monofill receiving 25 percent solids sludge from a publicly owned treatment works (POTW) serving a population equivalent of 200,000. In this example, the type of monofill is selected early in the design process, and the design proceeds to (1) determine design dimensions, (2) prepare site development plans, (3) determine equipment and personnel requirements, (4) develop operational procedures, and (5) estimate costs. The second example is for a monofill receiving 35 percent solids sludge from a POTW serving a population equivalent of 50,000. In this example, two alternative monofills appear to be equally suitable at first. Alternate designs are performed for each before one monofill is selected on the basis of costs. The third design example is for a small POTW serving a population equivalent of only 5,000. POTW management is faced with a choice between monofilling their 34 percent solids sludge at the POTW site or disposing it at an existing MSW landfill.

It should be noted that the scope of this chapter is confined to design only. Siting and design considerations for active sewage sludge units and surface disposal sites influenced by regulatory requirements are discussed in Chapters 4 and 7, respectively. It should also be noted that the design described in this chapter is somewhat preliminary in nature. A final design should contain more detail and address other design considerations (such as sediment and erosion controls, roads, leachate control, etc.), which are not fully addressed herein.

14.2 Design Example No. 1

14.2.1 Statement of Problem

The problem is to design a monofill at a pre-selected site. The monofill is to receive a 35 percent solids sludge from a POTW that serves a population equivalent of 200,000. The recommended design has to be (1) in compliance with pertinent regulations, (2) environmentally safe, and (3) cost-effective.

14.2.2 Design Data

The following information is the given design data.

14.2.2.1 Treatment Plant Description

The POTW is a secondary treatment works. Further information on the POTW is as follows:

- Service population equivalent = 200,000
- Average daily flow rate = 20 MGD (0.86 m^3/sec)
- Industrial inflow rate = 10 percent of total flow rate
- Wastewater treatment processes:
  - Bar screen separation
  - Aerated grit tanks
  - Primary settling tanks
  - Secondary aeration tanks
  - Secondary settling tanks

14.2.2.2 Sludge Description

Sludge is generated primarily by two sources (primary and secondary settling tanks). The sludge is stabilized and dewatered. A more complete description is as follows:

- Sludge sources:
  - Primary settling tanks
  - Secondary settling tanks
- Sludge treatment:
  - Gravity Thickening
  - Mixing

- Anaerobic digestion
- Vacuum filtration

- Sludge characteristics (based on testing, review of records, and calculations)
  - Solids content = 25 percent.
  - Quantity on a dry weight basis = 13.0 dry tons/day (11.8 Mg/day).
  - Quantity on a wet weight basis = 52.0 wet tons/day (47.1 Mg/day).
  - Density = 1,700 lbs/yd^3 (1,009 kg/m^3).
  - Quantity on a wet volume basis = 61.2 yd^3/day (46.8m^3/day).

14.2.2.3 Climate

Significant climatological factors having an impact on monofilling are listed below:

- Preciptation = 32 in./yr (81 cm/yr).
- Evaporation = 28 in./yr (71 cm/yr).
- Number of days minimum temperature 32°F (0°C) and below = 60 days/yr.

As shown, the climate at the site is relatively mild with cold temperatures prevailing approximately two months per year. Precipitation exceeds evaporation by 4 in./yr (10 cm/yr)

14.2.2.4 General Site Description

Preliminary data were collected during the site selection process. It is summarized below:

- Size of property = 375 acre (152 ha)
- Property line frontage:
  - 5,200 ft (1,580 m) along country road
  - 4,700 ft (1,430 m) along residences
  - 4,600 ft (1,400 m) along grazing land
  - 1,200 ft (370 m) along woodland
- Slopes: Uniform slope of approximately 5 percent
- Vegetation:
  - 225 acres (91 ha) of woodland
  - 150 acres (60 ha) of grassland
- Surface water: None on site

A plan view of the site is presented in Figure 14-1. As shown, the site has good access along a county road. The site is located in a moderately developed residential area and abuts residences. Approximately 60 percent of the site is covered with woodland. The balance of the property is grass-covered.

14.2.2.5 Hydrogeology

Eight test borings were performed on the site to determine subsurface conditions. These were located as shown in Figure 14-1. Subsurface conditions generally are similar at all boring locations and can be summarized as follows:

Depth	Description
0-30	Clay
30-35	Silty sand
>35	Fractured crystalline rock

Ground water at the site is at a depth of 30 ft (9.0 m) and bedrock is at a depth of 35 ft (10.5 m). Samples of the clay were collected for analysis and the following determinations made:

- Texture = fine
- Permeability = 2 x 8 cm/sec
- Permeability class = very slow

14.2.3 Design

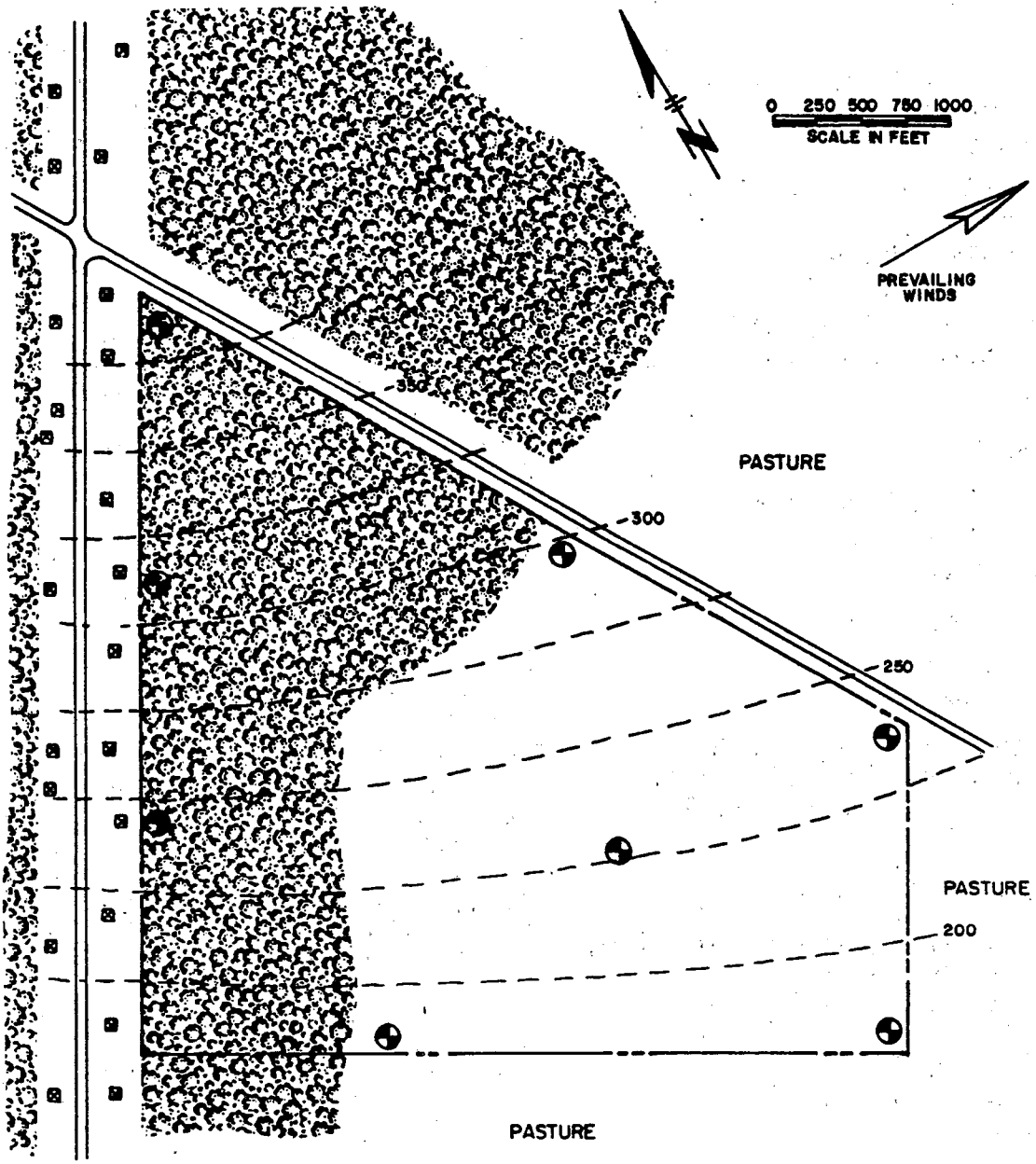
14.2.3.1 Selecting a Monofill Type

Table 2-1 in Chapter 2 should be consulted as a reference for this section. The sludge to be disposed at the site is stabilized. Because the ground slope is relatively flat at 5 percent, any of the monofill types discussed in Chapter 2 would be suitable for final disposal of this sludge. Because the sludge has a solids content of 25 percent, however, only narrow trenches and area fill layers are considered for selection. A narrow trench monofill was ultimately selected because ground water and bedrock at the site are deep. Cover application, if appropriate, would be via land-based equipment because of the solids content of the sludge (see Table 2-2 in Chapter 2). Soil should be used primarily for cover and is not required for bulking.

14.2.3.2 Design Dimensions

Table 7-2 in Chapter 7 should be consulted as a reference for this section. As shown in this table, the design dimensions to be determined for any trench operation include the following:

1. Excavation depth
2. Spacing
3. Width
4. Length
5. Orientation
6. Sludge fill depth
7. Cover thickness



LEGEND

PROPERTY BOUNDARY

ROAD

DWELLING

WOODS

200 CONTOURS

BORING

Figure 14-1. Plan view of site in example number 1.

The excavation depth is determined initially by the depth to ground water or bedrock.[1] A minimum separation of 2 to 5 ft (0.6 to 1.5 m) is usually provided between sludge deposits and the top of bedrock or ground water. In this case, a separation of 22 ft (6.6 m) was selected between the excavation and ground water. The excavation depth will be 8 ft (2.4 m).

Trench spacing is determined chiefly by sidewall stability. As a general rule, 1.0 to 1.5 ft (0.30 to 0.46 m) of spacing provided for every 1 ft (0.3 m) of trench depth. Because the soil type is relatively stable, 1.0 ft (0.3 m) of spacing for every 1 ft (0.3 m) of trench depth is adequate for this site and the total spacing at the site will be 8 ft (2.4 m).

Trench width is determined by sludge solids content and equipment considerations. Because the sludge is only 25 percent solids, a 2- to 3-ft (0.6- to 0.9-m) width should be used. At a width of 2 to 3 ft (0.6 to 0.9 m), the cover soil creates a bridging effect over the sludge receiving its support from solid ground on either side of the trench. A backhoe is the most efficient piece of equipment for excavations to an 8-ft (2.4-m) depth. For this site, a 2-ft (0.6-m) width is specified based on the equipment efficiency of the backhoe. The length for narrow trenches is limited only by the need to place containment within the trench to prevent low-solids sludge from flowing to one end of a trench. Trench length is set at 200 ft (61 m). Thus, at every 200 ft (61 m) the trench is discontinued for 5 ft (1.5 m) to provide containment. With regard to trench orientation, trenches should be kept parallel to one another to optimize land utilization. Because of the relatively flat slopes at the site, it is not necessary to orient the trenches parallel to topographic contours.

As shown in Table 7-2, for trench widths between 2 and 3 ft (0.6 and 0.9 m), the sludge fill depth should be within 1 to 2 ft (0.3 to 0.6 m) of the ground surface. Because the excavation depth is greater than usual for a trench of this width, sludge filling should proceed no closer than 2 ft (0.6 m) from the top. Cover application for a 2-ft (0.6-m) wide trench should be from 2 to 3 ft (0.6 to 0.9 m) thick. The chosen cover thickness for this site is 3 ft (0.9 m) due to the large sludge fill depth.

To test the practicality of these design dimensions, a full-scale test was performed at the site. Initially, a backhoe was used to excavate two parallel trenches at the previously-specified depth, width, and spacing. A 10 yd^3 (7.6 m^3) dump truck (to be used in sludge hauling) was then fully loaded with sludge and backed up to the trench. Because the trench sidewall withstood the load, the prescribed trench depth, width, and spacing were found to be sound. Subsequently, the sludge load was dumped into the trench, filling it to a 6-ft (1.8-m) depth. About 3 ft (0.9 m) of cover was then gently applied over the sludge by the backhoe. The cover was found to be adequately supported at this time. At an inspection of the test trenches several weeks later, no sludge had emerged; however, the cover had settled almost 1 ft (0.3 m). Because this settlement could cause ponding of rainwater over settled trenches in the future, the cover application thickness is increased to a total of 4 ft (1.2 m) or to 2 ft (0.6 m) above grade. The design can proceed based on the following design dimensions:

- Excavation depth = 8 ft (2.4 m).
- Spacing = 8 ft (2.4 m).
- Width = 2 ft (0.6 m).
- Length = 200 ft (61 m).
- Orientation = trenches parallel to each other but not necessarily parallel to contours.
- Sludge fill depth = 6 ft (1.8 m).
- Cover thickness = 4 ft (1.2 m).

14.2.3.3 Site Development

Site development is in accordance with the plan shown in Figure 14-2. Features of this plan included the following:

- A 300-ft (91-m) wooded buffer is maintained between the sludge fill area and residences. A 200-ft (61-m) buffer is maintained around the balance of the property.
- Trenches are installed along the downhill (southeastern) property line to collect storm water runoff.[2] A sedimentation pond is constructed to receive runoff collected by these trenches.
- In accordance with engineering judgment, one ground-water monitoring well is located upgradient from the fill area and five monitoring wells are located down-gradient from the fill area.
- The site is divided into nine active sewage sludge units so that the site can be cleared in phases. In this way, clearing can proceed approximately once each year in advance of sludge surface disposal operations.
- The active sewage sludge unit located nearest to the site entrance is designated for wet weather operations. The access road to this area is paved with asphalt.
- The remaining access roads are covered with gravel.
- After providing area for buffers, access roads, facilities, etc., approximately 156 acres (63 ha) remain for active sewage sludge units out of the entire 375 acres (152 ha) on the site.

[1] The Part 503 requirements related to contamination of ground water are discussed in Chapters 3, 6, and 7.

[2] These trenches are designed to have the capacity to handle runoff from a 24-hour, 25-year storm event in line with Part 503 requirements.

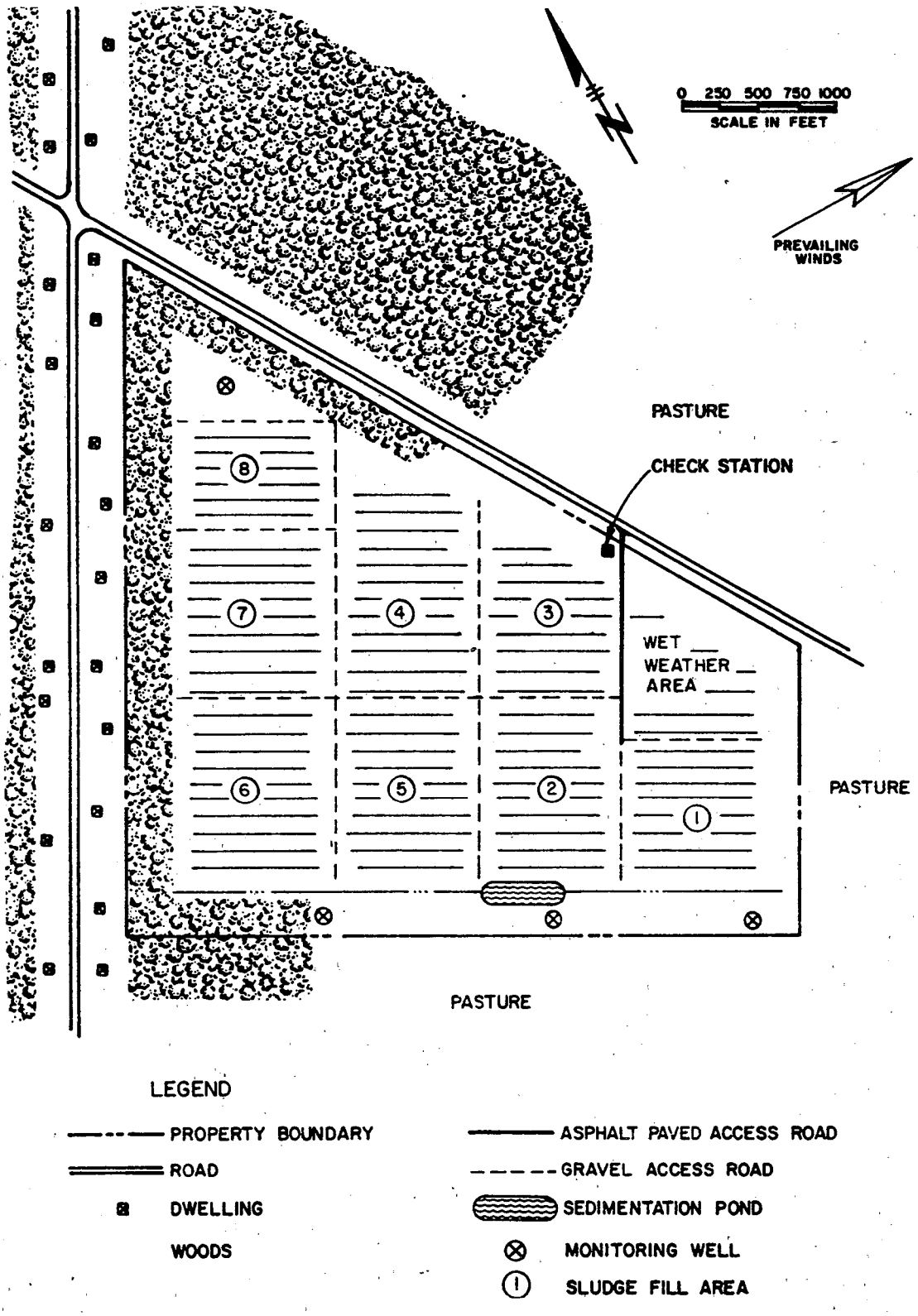


Figure 14-2. Site development plan for example number 1.

14.2.3.4 Calculations

Based on the design data and dimensions stated previously, calculations can be made of the (1) trench utilization rate, (2) sludge disposal rate, (3) land utilization rate, and (4) site life.

1. Trench utilization rate

$$= \frac{\text{sludge volume per day}}{\text{cross-sectional area of sludge in trench}}$$

$$= \frac{\text{sludge volume per day}}{(\text{trench fill depth}) \times (\text{trench width})}$$

$$= \frac{(61.2\ \text{yd}^3/\text{day}) \times (27\ \text{ft}^3/\text{yd}^3)}{(6\ \text{ft}) \times (2\ \text{ft})}$$

$$= 138\ \text{ft/day}\ (41.4\ \text{m/day})$$

2. Sludge disposal rate

$$= \frac{\text{cross-sectional area of sludge in trench}}{\text{width of trench} + \text{spacing}}$$

$$= \frac{(6\ \text{ft}) \times (2\ \text{ft})}{(2\ \text{ft}) + (8\ \text{ft})} = \frac{12\ \text{ft}^2}{10\ \text{ft}} = \frac{12\ \text{ft}^3}{10\ \text{ft}^2}$$

$$= \frac{(12\ \text{ft}^3)(1\ \text{yd}^3/27\ \text{ft}^3)}{(10\ \text{ft}^2)(1\ \text{acre}/43{,}506\ \text{ft}^2)}$$

$$= 1{,}936\ \text{yd}^3/\text{acre}\ (3{,}659\ \text{m}^3/\text{ha})$$

3. Land utilization rate

$$= \frac{\text{sludge volume per day}}{\text{sludge application rate}}$$

$$= \frac{61.2\ \text{yd}^3/\text{day}}{1{,}936\ \text{yd}^3/\text{acre}}$$

$$= 0.0316\ \text{acres}/0.0128\ \text{ha/day})$$

4. Site life =

$$= \frac{\text{usable fill area}}{\text{land utilization rate}}$$

$$= \frac{156\ \text{acres}}{0.0316\ \text{acres/day}} = \frac{4{,}937\ \text{days}}{365\ \text{days/year}}$$

$$= 13.5\ \text{years}$$

14.2.3.5 Equipment and Personnel

Table 9-4 in Chapter 9 should be consulted as a reference for this section. As shown, for a narrow trench operation receiving between 50 and 100 wet tons per day (45 and 91 Mg per day), the following equipment might be selected:

Description	Quantity	Hours per Week
Track backhoe with loader	1	15
Track dozer	1	15
Total	2	30

The use of a backhoe was already established during the selection of design dimensions. Therefore, the above suggested scheme was implemented. The duties and number of personnel are also established at this stage and include:

Description	Quantity	Hours per Week
Backhoe operator	1	40
Backhoe and dozer operator	1	40
Total	2	80

Operations are conducted at the site 8 hours per day and 7 days per week to coincide with sludge deliveries and avoid the added cost and odors often encountered with sludge storage facilities. The backhoe is operated 7 hours per day (plus 1 hour downtime per day for routine maintenance and cleanup) and 7 days per week. The dozer is operated 3 hours per day (plus 1 hour downtime per day for routine maintenance and cleanup) and 5 days per week. One full-time operator works 8 hours per day Monday through Friday. He is responsible for operating and maintaining the backhoe during these hours. The other operator works 8 hours per day Wednesday through Sunday; he is responsible for (1) operating and maintaining the backhoe for 8 hours each day on Saturday and Sunday, (2) operating and maintaining the dozer for 4 hours each day on Monday through Friday, and (3) performing miscellaneous functions such as check station attendant, compiling site records, etc.

14.2.3.6 Operational Procedures

Site preparation consisted of the following procedures:

1. Initially, active sewage sludge unit No. 1 and the inclement weather area are cleared and grubbed. Roads providing access to these areas are paved with asphalt or gravel (as shown in Figure 14-2). Several trenches are excavated in the inclement weather area and the soil stockpiled alongside each trench. Runoff, erosion, and sedimentation controls as well as monitoring wells are installed.

2. At least 1 month (but never more than 4 months) in advance of the fill operation, each new active sewage sludge unit is cleared and grubbed. Usually these operations occur once each year and are timed to avoid cold temperatures and frozen ground conditions. The work is performed by equipment and personnel brought in specifically for this task. Debris is disposed of on-site by burial and/or by producing wood chips.

On-going operations consist of the following:

1. Trenching begins in the corner of each active sewage sludge unit furthest removed from the access road and proceeds generally toward the road as it is completed.

vides contingency capacity for slightly more than one day's sludge receipt.

3. Trenches are excavated to design dimensions by the track backhoe as it straddles the excavation (see Figure 14-3).

4. Haul vehicles back-up to the previously excavated trench and dump sludge loads directly into the trench. Filling proceeds to approximately 2 ft (0.6 m) below the top of the trench. Because of its low solids content, sludge flows evenly throughout the trench and accumulations at one location are minimized.

5. Within 1 hour after sludge-filling has occurred in one location, the track backhoe excavates a new trench adjacent to the filled trench. Excavated material from the new trench is applied as cover over the adjacent sludge-filled trench. The cover is applied carefully from a low height at first to minimize the amount of cover sinking into sludge deposits. Subsequently, cover is applied less carefully. Ultimately, the cover extends to 2 ft (0.6 m) above grade.

Site completion consists of the following procedures:

1. Approximately 1 month after completion of each 1-acre (0.405-ha) portion of an active sewage sludge unit, the bulldozer is used to regrade the area to a smooth ground surface.

2. Immediately thereafter, the unit is hydroseeded (assuming weather conditions permit) and grasses soon take root.

14.2.3.7 Cost Estimates

Based on the site design, cost estimates were prepared for capital and operating costs in Tables 14-1 and 14-2, respectively. As shown, the total capital cost of the site is estimated at $3,474,945. Considering a site capacity of 260,000 wet tons (236,000 Mg) of sludge, the capital cost is $13.31 per wet ton (14.81 per Mg).

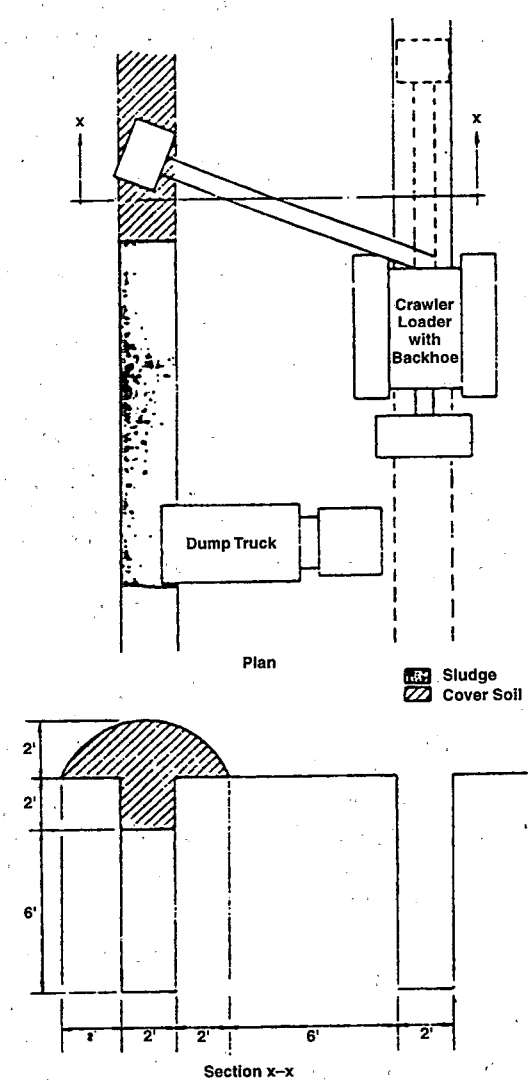


Figure 14-3. Operational procedures for example number 1.

Table 14-1. Estimate of Total Site Capital Costs for Example Number 1

Item	Quantity	Unit Cost	Total Cost
Land	375 acres	$7,500 /acre	$2,812,500
Site Preparation			
Clearing and Grubbing	45 acres	$1,250 /acre	56,250
Sodded Runoff Ditch	4,000 ft	$5 /ft	20,000
Pond	1 ea	$25,000 /ea	25,000
Monitoring Wells	6 ea	$2,000 /ea	12,000
Garage	1,600 sq ft	$30 /sq ft	48,000
Gravel Roads	1,500 ft	$25 /ft	37,500
Asphalt Roads	1,000 ft	$42 /ft	42,000
Miscellaneous			20,000
Equipment			
Backhoe	1 ea	$100,000 /ea	100,000
Dozer	1 ea	$95,000 /ea	95,000
Subtotal			3,268,250
Engineering at 6%			196,095
Total			3,464,345

Table 14-2. Estimate of Annual Operating Costs for Example Number 1

Item	Quantity	Unit Cost	Total Cost
Labor			
Backhoe Operator	2,080 hrs	$18 /hr	$37,440
Backhoe/Dozer Operator	2,080 hrs	$18 /hr	37,440
Equipment Fuel, Maintenance, Parts			
Backhoe	2,555 hrs	15.56 /hr	39,756
Dozer	780 hrs	10.18 /hr	7,940
Clearing and Grubbing	10 acres	$1,250 /acre	12,500
Gravel Roads	1,500 ft	$25 /ft	37,500
Office Trainer Rental	1 ea	$10,000 /ea	10,000
Utilities			10,000
Laboratory Analyses			14,400
Supplies and Materials			20,000
Miscellaneous			20,000
Total			246,976

As shown in Table 14-2, the annual operating cost is estimated at $246,976. Considering an annual receipt of 25,000 wet tons (22,700 Mg) of sludge, the unit operating cost is $9.88 per wet ton ($10.80 per Mg). Combined capital and operating costs are estimated at $23.25 per wet ton ($25.71 per Mg).

14.3 Design Example No. 2

14.3.1 Statement of Problem

The problem is to design a monofill at a pre-selected site. The monofill is to receive a 35 percent solids sludge from a proposed POTW that will serve a population equivalent of 50,000. The recommended design has to be (1) in compliance with pertinent regulations, (2) environmentally safe, and (3) cost-effective.

14.3.2 Design Data

The following information is the given design data.

14.3.2.1 Treatment Plant Description

The proposed POTW is a secondary treatment work. Further information on the POTW is as follows:

- Service population equivalent = 50,000

- Average flow = 5.0 Mgal/d (0.22 m^3/sec)
- Industrial inflow = 0 percent of total inflow
- Wastewater treatment processes:
  - Bar screen separation
  - Primary clarifier
  - Secondary clarifier
  - Sand filters
  - Chlorine contact tanks

14.3.2.2 Sludge Description

Sludge is to be generated primarily from two sources (primary and secondary clarifiers). The sludge will be anaerobically digested and dewatered. A more complete description is as follows:

- Sludge sources:
  - Primary clarifiers
  - Secondary clarifiers
- Sludge treatment:
  - Gravity thickening
  - Mixing
  - Anaerobic digestion
  - Dewatering via belt presses
- Sludge characteristics (based on treatment plant design report).
  - Solids content = 35 percent.
  - Quantity on a dry weight basis = 3.25 dry tons/day (2.95 Mg/day).
  - Quantity on a wet weight basis = 9.3 wet tons/day (8.5 Mg/day).
  - Density = 1,750 lbs/yd^3 (1,039 kg/m^3).
  - Quantity on a wet volume basis.

$$\frac{9.3 \text{ tons/day} \times (2{,}000 \text{ lbs/ton})}{1{,}750} = 10.6 \text{ yd}^3\text{/day } (8.1 \text{ m}^3\text{/day})$$

14.3.2.3 Climate

Significant climatological factors having an impact on surface disposal are listed below:

- Precipitation = 48 in./yr (122 cm/yr).
- Evaporation = 30 in./yr (76 cm/yr).
- Number of days minimum temperature 32°F (0°C) and below = 125 days/yr.

As shown, the climate is quite cold with freezing temperatures prevailing during 4 months of the year. Precipitation is high and evaporation exceeds precipitation by 18 in./yr (46 cm/yr).

14.3.2.4 General Site Description

Site data were collected from existing information sources as well as field investigations performed during the site selection process. These data are summarized below:

- Size of property = 12 acres
- Property line frontage:
  - 1,750 ft (533 m) along woodland.
  - 500 ft (152 m) along cropland.
  - 850 ft (259 m) along a county road with woodland on the other side.
- Slopes = relatively flat with slopes at approximately 2 percent.
- Vegetation:
  - 6.5 acres (2.6 ha) of woodland.
  - 5.5 acres (2.2 ha) of open space sparsely covered with grasses.
- Surface water = none on site; drainage on site via overland sheet flow into roadside ditch.

A plan view of the site is presented in Figure 14-4. As shown, the site has good access from a two-lane county road adjoining the property. Approximately one-half of the site is wooded; the balance is open space with some grasses. Cropland adjoins the property to the east. Other adjoining properties are undeveloped and wooded.

14.3.2.5 Hydrogeology

During the site selection phase, soil maps for the area were reviewed. In addition, logs of soil borings and wells drilled near the site were examined. Historical records compiled on nearby drinking water wells were reviewed for ground-water levels and seasonal fluctuations.

Subsequent to the site selection, four soil borings were performed at the site to verify subsurface conditions. These borings are located as shown in Figure 14-4. Subsurface conditions were found to be somewhat consistent at all boring locations and can be summarized as follows:

Depth	Description
0-5 ft (0-1.5 m)	Coarse sand with silty sand
>5 ft (>1.5 m)	Saturated coarse sand

The soil at the site is primarily a coarse sand; however, the sand had some layers of silty sand interspersed throughout. Ground water is at a depth of 5 ft (1.5 m). Due to the site's location on the coastal plain, bedrock is deep. Samples of the coarse sand were collected for analysis and the following determinations were made.

- Texture = coarse
- Permeability = 8×10^{-4} cm/sec
- Permeability class = moderately rapid

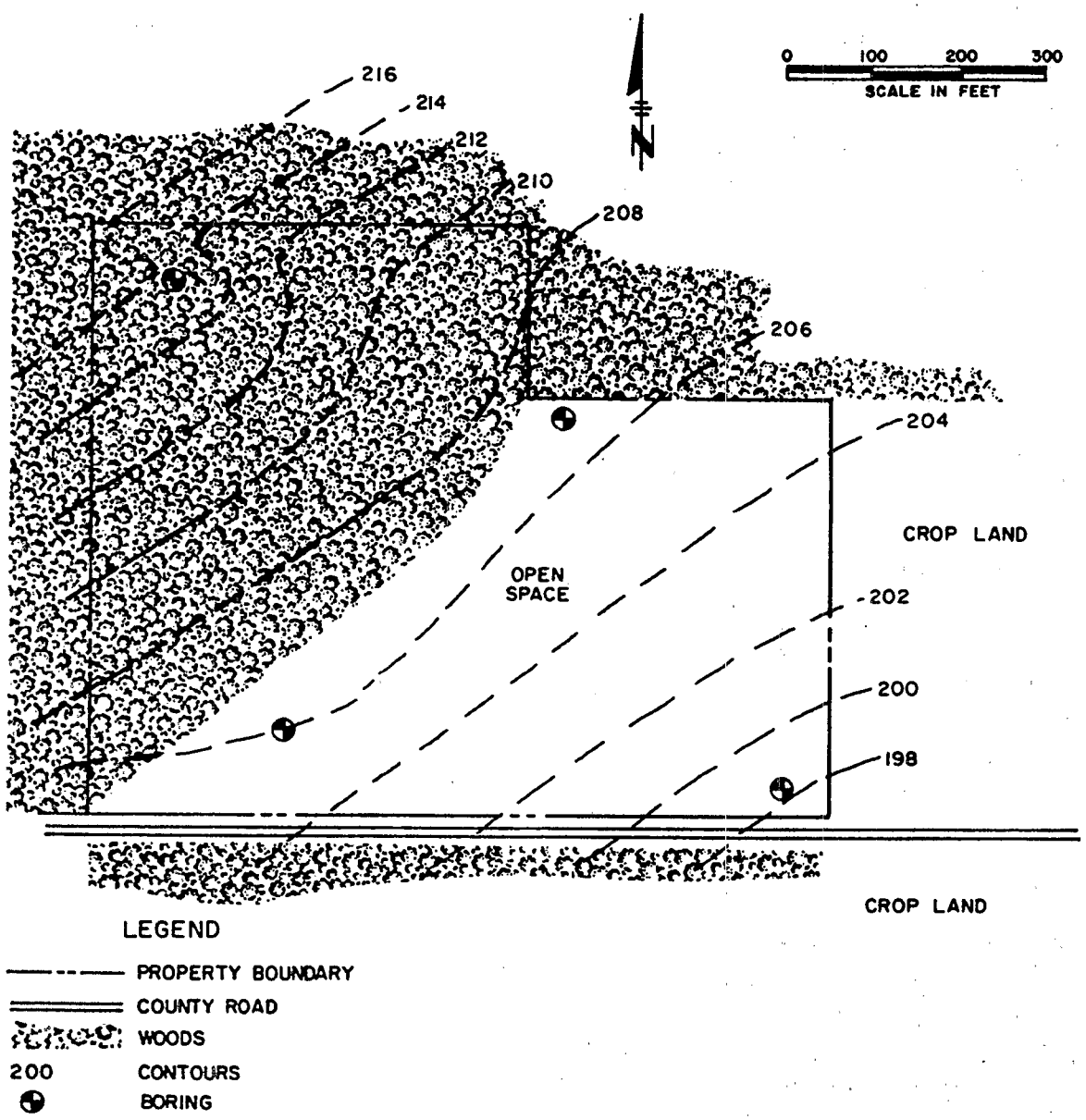


Figure 14-4. Site base map for example number 2.

14.3.3 Design

14.3.3.1 Selecting a Monofill Type

Table 2-1 in Chapter 2 should be consulted as a reference for this section. Because the sludge is stabilized and has a solids content of 35 percent, this sludge can be disposed in any of the types of monofill described in Table 2-1. None of these monofills are disqualified on the basis of sloping requirements, because the site is relatively flat (2 percent slopes).

Because the site is relatively small and a longer site life is desired, it becomes obvious early in the design process that a high sludge disposal rate is required. As shown in Table 2-2 in Chapter 2, the highest sludge disposal rates are attained with wide trenches, area fill mounds, and diked containments. Diked containment is ruled out because the high disposal rates sometimes achieved with this type of monofill are only possible for large diked containments (with high dikes) receiving large quantities of sludge. Wide trenches are initially selected based on the cost-effectiveness of this operation versus area fill mounds. Normally a 5-ft (1.5-m) depth to ground water is sufficient to allow trench excavation and still provide sufficient buffer soils. The soil's coarse texture and moderately rapid permeability at this site, however, indicated a strong potential for contaminant movement without a liner. Therefore, subsurface

placement of sludge in wide trenches lined with recompacted clay and geomembranes is one proposed monofill type.

Surface disposal of sludge in area fill mounds is retained as a possible disposal option even though area fill mounds have disadvantages in high precipitation areas such as at this site.

14.3.3.2 Design Dimensions

Preliminary designs are performed for each type of monofill still under consideration. The purpose of these designs is to provide a basis for the site life and cost for each method in order to select the best disposal method. Using Tables 7-2 and 7-4 in Chapter 7, dimensions are computed for each method as shown in Table 14-3.

14.3.3.3 Site Development

Site development is planned in accordance with Figures 14-5 and 14-6 for wide trench and area fill mound operations, respectively. Features included in both plans are as follows:

1. A buffer is maintained to all adjoining property. Where wooded areas exist along property frontages, a 100-ft (30-m) wide strip is maintained in its natural state. Where grassy open space areas exist along property frontages, a 150-ft (46-m) wide strip is undisturbed.
2. A sodded diversion ditch is included along the uphill side of the site to intercept upland drainage. Intercepted runoff is directed to existing roadside ditches.[3]
3. A sodded collection ditch was included along the downhill side of the site to intercept on-site drainage. Intercepted runoff was directed to a new sedimentation pond.

Features specific to the wide trench operation shown in Figure 14-4 included the following:

1. Trenches are laid out in accordance with design dimensions and make optimal use of available land.
2. Gravel roads are constructed as shown to provide access from the site entrance to individual trenches.
3. A liner system is installed including 2 ft of recompacted clay of 1 x 10^{-7} cm/sec permeability, plus 60 mil HDPE geomembrane along the bottom and sideslopes. A leachate collection system is installed on the floor above this.

Features specific to the area fill mound operation shown in Figure 14-5 included the following:

1. An asphalt-paved dumping/mixing pad and access road is specified.
2. A soil stockpile area is located near the dumping/mixing pad. Soil for this stockpile is imported once each year from another location incurring a 3-mile haul.
3. Most of the remaining site area is designated for surface disposal operations.

14.3.3.4 Calculations

Based on the design data and dimensions stated previously, calculations are performed for each of the proposed monofill types. Determinations made on the wide trench application include:

- Trench capacity = 1,481 yd^3/trench (1,132 m^3/trench).
- Number of trenches = 12
- Site capacity = 17,772 yd^3/trench (13,588 m^3)

[3]The dimensions of these drainage devices are checked to ensure they have the capacity to handle runoff from a 24-hour, 25-year storm event in line with Part 503 requirements.

Table 14-3. Design Considerations for Example Number 2

Design Consideration	Wide Trench	Area Fill Mound
Width	50 ft	--
Depth	8 ft	--
Length	200 ft	--
Spacing	20 ft	--
Bulking Performed	No	Yes
Bulking Agent	--	Soil
Bulking Ratio	--	1 Soil : 1 Sludge
Sludge Depth Per Lift	4 ft	6 ft
Number of Lifts	1	1
Cover Applied	Yes	Yes
Location of Equipment	Sludge–Based	Sludge–Based
Interim Cover Thickness	--	--
Final Cover Thickness	4 ft	3 ft
Imported Soil Required	No	Yes

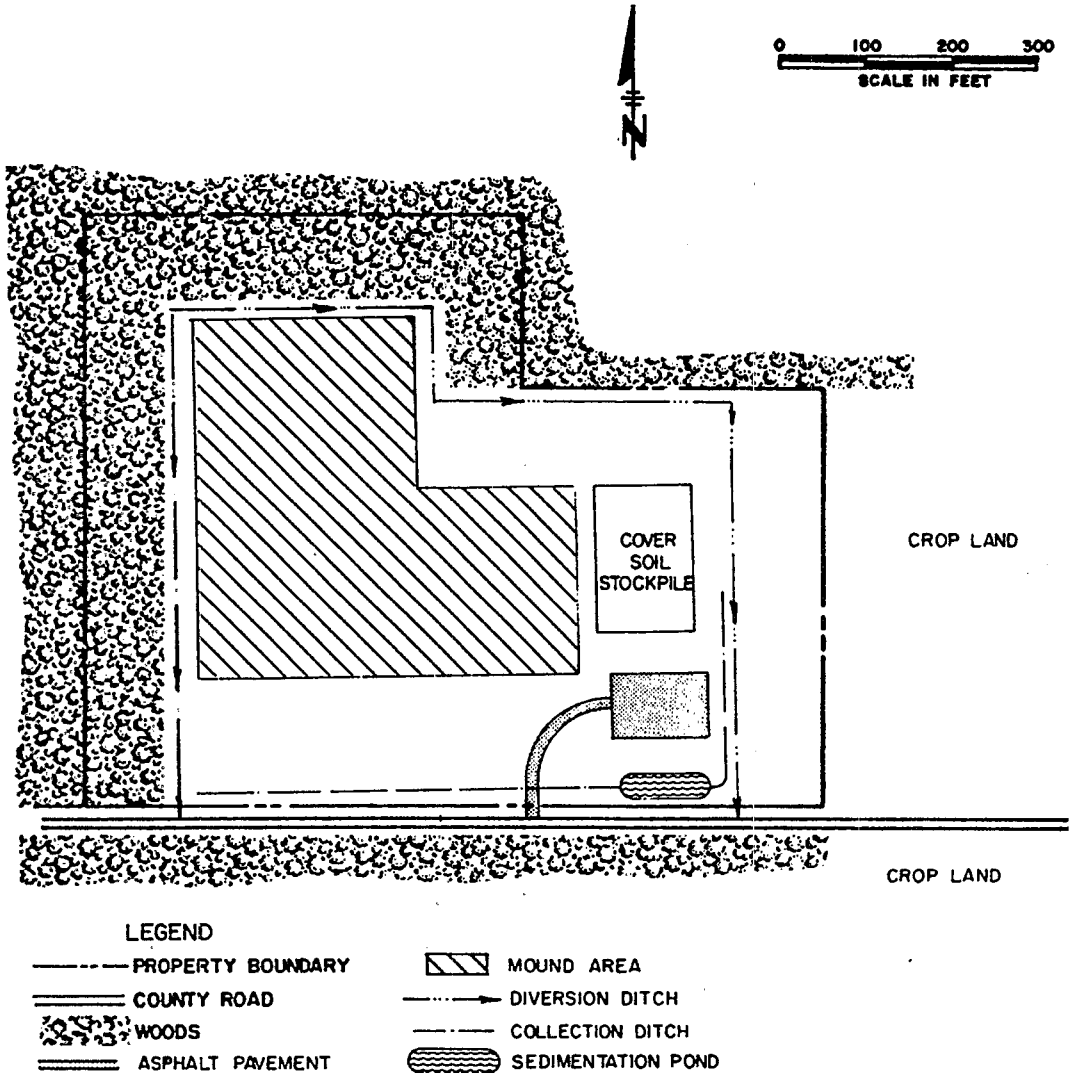


Figure 14-5. Site development plan for example number 2 area fill mound.

- Sludge volume received = 10.6 yd^3/day (8.1 m^3/day)
- Site life = 4.6 years

Determinations made on the area fill mound application include:

- Sludge application rate = 9,680 yd^3/acre (18,295 m^3/ha)
- Size of mounding area = 3 acres (1.22 ha)
- Site capacity = 29,040 yd^3 (22,204 m^3)
- Sludge volume received = 10.6 yd^3/day (8.1 m^3/day)
- Site life = 7.5 years

14.3.3.5 Equipment and Personnel

Using Table 9-4 in Chapter 9 as a reference, the following equipment and personnel were selected for use at the wide trench operation:

Description	Quantity	Hours per Week
Track Dozer	1	10
Track Dozer Operator	1	10

The following equipment and personnel were selected for use at the area fill mound operation:

Description	Quantity	Hours per Week
Track Loader	1	15
Track Loader Operator	1	20

14.3.3.6 Cost Estimates

Cost estimates were computed for each of the proposed monofill types. These estimates have been included as Tables 14-4 through 14-7. As shown, the annual operation cost of the wide trench operations is calculated at $55,334. The capital cost is calculated at $511,573.

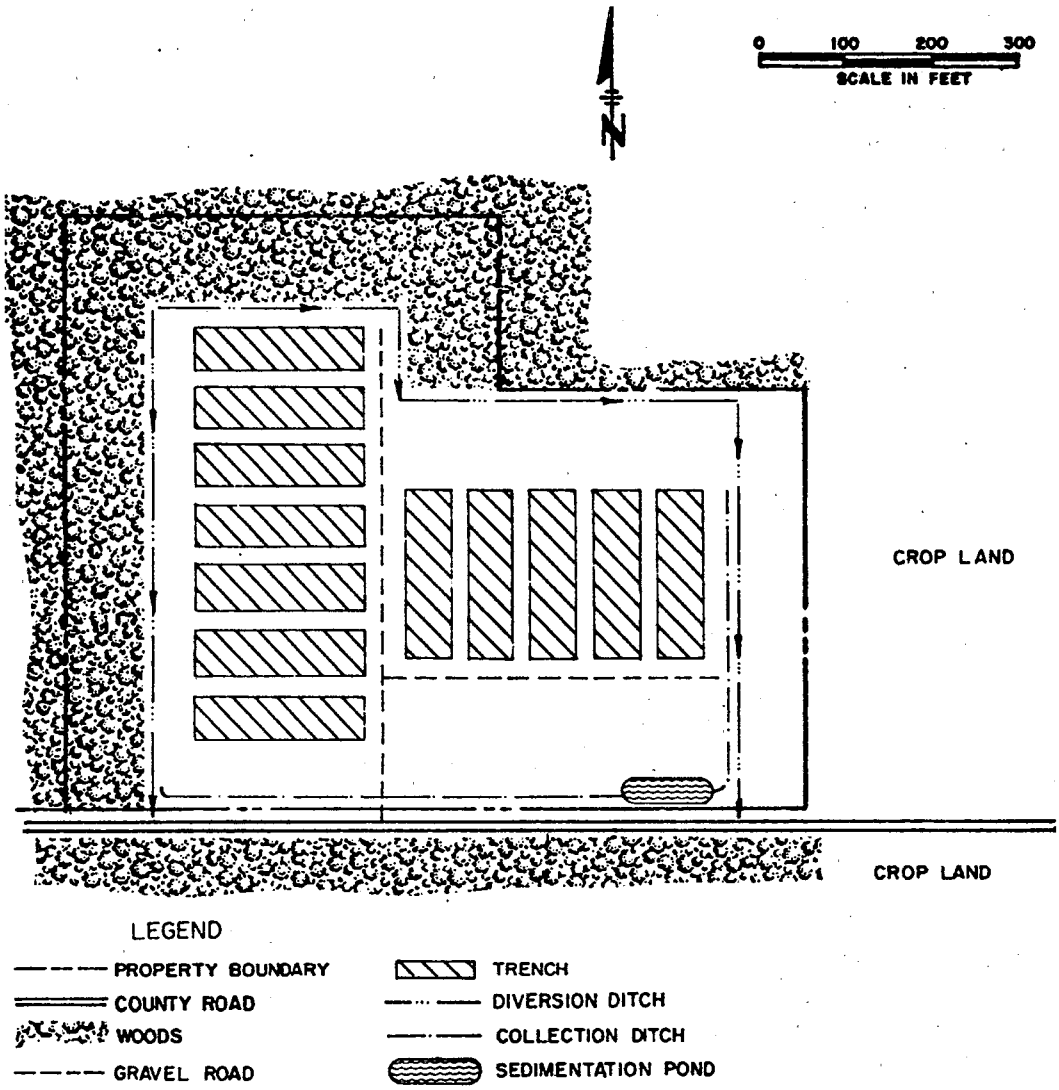


Figure 14-6. Site development plan for example number 2 wide fill trench.

The annual operating cost of the area fill mound is calculated at $70,570. The total capital cost is calculated at $514,276. Unit costs for each monofill are summarized below:

	Capital Cost	Operating Cost	Total Cost
Wide Trench	$36.94/wet ton ($40.74/Mg)	$13.54/wet ton ($14.93/Mg)	$50.48/wet ton ($55.67/Mg)
Area Fill Mound	$27.40/wet ton ($29.42/Mg)	$26.92/wet ton ($29.03/Mg)	$52.72/wet ton ($58.14/Mg)

14.3.3.7 Conclusion

An area fill mound is selected and utilized. Although the area fill mound actually costs more than the wide trench, the cost difference is not that substantial and the area fill mound's longer life makes it the clear-cut choice for the surface disposal site.

14.4 Design Example No. 3

14.4.1 Statement of Problem

The problem is to design a monofill on the site of a POTW serving a population equivalent of 5,000. The POTW had been disposing of their 34 percent solids sludge at an MSW landfill 8 miles (13 km) distant; however, landfill operators now are charging $60.00 per wet ton ($66.15 per Mg) for the sludge. Therefore, POTW operators are seeking the cost-savings that might be realized by surface disposal of the sludge themselves. The recommended design has to be (1) in compliance with pertinent regulations, (2) environmentally safe, and (3) cost-effective.

14.4.2 Design Data

The following information is the given design data.

Table 14-4. Estimate of Total Site Capital Costs for Example Number 2 Wide Trench

Item	Quantity	Unit Cost	Total Cost
Land	12 acres	$7,500 /acre	$90,000
Site Preparation			
Clearing and Grubbing	6 acres	$1,250 /acre	7,500
Sodded Division Ditch	1,750 ft	$5 /ft	8,750
Sodded Collection Ditch	850 ft	$5 /ft	4,250
Pond	1 ea	$10,000 /ea	10,000
Recompacted Clay Liner	9,680 cu yd	$7 /cu yd	67,760
Geomembrane	130,680 sq ft	$0.45 /sq ft	58,806
Leachate Collection	9,680 cu yd	$10 /cu yd	96,800
Monitoring Wells	5 ea	$2,000 /ea	10,000
Gravel Roads	950 ft	$25 /ft	23,750
Miscellaneous			10,000
Equipment			
Track Dozer	1 ea	$95,000 /ea	95,000
Subtotal			482,616
Engineering at 6%			28,957
Total			511,573

Table 14-5. Estimate of Annual Operating Costs for Example Number 2 Wide Trench

Item	Quantity	Unit Cost	Total Cost
Labor			
Dozer Operator	780 hrs	$18 /hr	$14,040
Equipment Fuel, Maintenance, Parts			
Track Dozer	520 hrs	10.18 /hr	5,294
Leachate Management	20,000 gallons	$0.20 /gallon	4,000
Laboratory Analyses			12,000
Other Supplies and Materials			10,000
Miscellaneous			10,000
Total			55,334

14.4.2.1 Treatment Plant Description

The POTW is a package plant. Further information on the POTW is as follows:

- Service population equivalent = 5,000
- Average flow = 0.5 Mgal/d (0.022 m^3/sec)
- Industrial inflow = 0 percent of total inflow
- Wastewater treatment processes:
  - Bar screen separation
  - Primary clarifier
  - Aeration tanks
  - Secondary clarifier

14.4.2.2 Sludge Description

Sludge from the secondary clarifier is recirculated to the primary clarifier. The sludge is stabilized and dewatered. A more complete description is as follows:

- Sludge sources—sludge from secondary clarifier recirculated to primary clarifier and withdrawn as mixture with primary sludge.
- Sludge treatment:
  - Aerobic digestion
  - Dewatering via sand drying beds
- Sludge characteristics (based on testing, review of records, and calculations).
  - Solids content = 34 percent.

Table 14-6. Estimate of Total Site Capital Costs for Example Number 2 Area Fill Mound

Item	Quantity	Unit Cost	Total Cost
Land	12 acres	$7,500 /acre	$90,000
Site Preparation			
Clearing and Grubbing	6 acres	$1,250 /acre	7,500
Sodded Division Ditch	1,750 ft	$5 /ft	8,750
Sodded Collection Ditch	850 ft	$5 /ft	4,250
Pond	1 ea	$10,000 /ea	10,000
Recompacted Clay Liner	9,680 cu yd	$7 /cu yd	67,760
Geomembrane	130,680 sq ft	$0.45 /sq ft	58,806
Leachate Collection	9,680 cu yd	$10 /cu yd	96,800
Monitoring Wells	5 ea	$2,000 /ea	10,000
Asphalt Paving	4,200 sq ft	$2 /sq ft	6,300
Miscellaneous			5,000
Equipment			
Track Dozer	1 ea	$120,000 /ea	120,000
Subtotal			485,166
Engineering at 6%			29,110
Total			514,276

Table 14-7. Estimate of Annual Operating Costs for Example Number 2 Area Fill Mound

Item	Quantity	Unit Cost	Total Cost
Labor			
Loader Operators	1,040 hrs	$18 /hr	$18,720
Equipment Fuel, Maintenance, Parts			
Track Dozer	780 hrs	20.32 /hr	15,850
Leachate Management	20,000 gallons	$0.20 /gallon	4,000
Laboratory Analyses			12,000
Other Supplies and Materials			10,000
Miscellaneous			10,000
Total			70,570

- Quantity on a dry weight basis = 0.33 dry tons/day (0.30 Mg/day).
- Quantity on a wet weight basis = 0.96 wet tons/day (0.87 Mg/day).
- Density = 1,850 lbs/yd^3/day (1,098 kg/m^3).
- Quantity on a wet volume basis = 1.03 yd^3/day (0.79 m^3/day).

14.4.2.3 Climate

Significant climatological factors having an impact on surface disposal are listed below:

- Precipitation = 32 in./yr (81.3 cm/yr).
- Evaporation = 34 in./yr (86.4 cm/yr).
- Number of days minimum temperature 32°F (0°C) and below = 40 days/yr.

The climate of the site is marked by mild temperatures. Precipitation is moderate and is exceeded slightly by evaporation.

14.4.2.4 General Site Description

The area to be used for a surface disposal site occupies a 3-acre (1.2-ha) portion of the 8-acre (3.2-ha) treatment plant property. It is located immediately adjacent to the POTW's sand drying beds. Other data concerning this 3-acre tract is summarized below:

- Adjoining properties:
  - 700 ft (210 m) abuts woodland which is privately owned.
  - 700 ft (210 m) abuts POTW.
- Slopes = evenly sloped at about 6 percent.
- Vegetation = all 3 acres (1.2 ha) had been previously cleared and are covered with grasses.
- Surface water = none of the 3-acre (1.2 ha) tract. A stream which receives effluent from the treatment facility is located 500 ft (150 m) away.

14.4.2.5 Hydrogeology

Site hydrogeological data was collected largely from information contained in the POTW report and drawings. Some additional information on soils, bedrock, and ground water was obtained from the sources listed in Chapter 6.

Subsurface conditions are summarized as follows:

Depth	Description
0-10 ft (0-3.0 m)	Silty clay with some clay lenses interspersed throughout
10-12 ft (3.0-3.7 m)	Saturated silty clay
12-15 ft (3.7-4.6 m)	Clay
15-26 ft (4.6-7.9 m)	Saturated silty clay
>26 ft (7.9 m)	Bedrock

The upper 10 ft (3.0-m) of soil was a dry silty clay and ground water was encountered at 10 ft (3.0 m). A 3-ft (0.9-m) thick tight clay seam protects the ground water located below it. Using Table 4-2 and Figures 4-8 and 4-9, the following determinations were made:

- Texture = fine
- Permeability = approximately 1 x 10^{-7} cm/sec
- Permeability class = very slow

14.4.3 Design

14.4.3.1 Selecting a Monofill Type

This site is conducive to subsurface placement of sludge because ground water and bedrock are relatively deep (at 10 and 26 ft [3.0 and 7.9 m], respectively), and the soils are tight enough to afford sufficient environmental protection. Because area fills are generally more manpower and equipment-intensive then are trenches, trenches should be selected in almost all instances where hydrogeologic conditions allow. In addition, wide trenches should be selected over narrow trenches for sludge with a solids content of 34 percent. An active sewage sludge unit liner is desirable (geomembrane only). Cover application, if appropriate, should be via sludge-based equipment. All of these considerations were established and utilized in the preliminary design.

14.4.3.2 Design Dimensions

The following design dimensions were established:

- Width = 20 ft (6.1 m)
- Depth = 8 ft (2.4 m)
- Length = 100 ft (30 m)
- Spacing = 30 ft (9.1 m)
- Sludge fill depth = 5 ft (1.5 m)
- Cover thickness = 4 ft (1.2 m)

Test trenches were then constructed on the site and operated under proposed conditions to ensure their effectiveness and practicality in a full-scale operation. The test was successful and the design proceeded based on the above dimensions.

14.4.3.3 Calculations

Based on the design data and dimensions stated previously, calculations were performed for each of the proposed monofills. Determinations made on the operation included:

- Trench capacity = 375 yd^3 (287 m^3)
- Number of trenches = 20
- Site capacity = 7,500 yd^3 (5,734 m^3)
- Sludge volume received = 1.03 yd^3/day (0.79 m^3/day)
- Site life = 20 years

14.4.3.4 Operational Procedures

Site preparation, on-going operations, and site completion consist of the following procedures:

1. Twice each year a contractor is employed to excavate sufficient trench capacity for a 6-month sludge quantity. The contractor uses a single front-end loader to excavate each 20-ft (6.1-m) wide trench to a depth of 8 ft (2.4 m). Excavated soil is stockpiled above and along both sides of the trench.
2. A liner (60 mil HDPE) is installed in each trench, with a leachate collection system placed atop it.
3. Once ready for operations, 6 months accumulation of sludge is removed from sand drying beds and loaded on a dump truck owned by the treatment plant.
4. The sludge is hauled the short distance to the trenching area. At that location, dump trucks back into the trenches from the open end of the trenches and deposit the sludge in 3- to 4-ft (0.9- to 1.2-m) high piles.

5. A bulldozer carefully enters the trench intermittently to push the sludge into a 5-ft (1.5-m) high accumulation.

6. After each trench is filled to completion, the bulldozer is employed to spread cover over the 20-ft (6.1-m) wide trench from the soil stockpiles located on either side. The cover is spread in a 4-ft (1.2-m) thick application to 1 ft (0.3 m) above grade.

7. The completed trench is then seeded to promote the growth of grasses.

8. Usually settlement of the trenches will not be severe due to the high solids content of the sludge and the cover thickness. Once each year the bulldozer employed for landfilling operations is used to regrade completed trenches from the previous year. These trenches are then reseeded.

14.4.3.5 Cost Estimates

The cost estimate prepared for this operation is presented in Table 14-8. As shown, the total cost is computed at $18,345 per year. Considering a sludge quantity of 379 wet tons per year (344 Mg per year), this equates to $48.40 per wet ton ($53.36 per Mg). This represents a savings of $11.60 per wet ton ($12.79 per Mg) when compared with the fee being charged by the local MSW landfill. Accordingly, plant operators will initiate the monofill disposal operation.

It should be noted that costs as low as $48.40 per wet ton ($53.36 per Mg) cannot be achieved by most treatment plants of this size. One of the reasons the cost is low in this case is because this plant is able to monofill 6 months of sludge in 1 or 2 days. Under these circumstances, this facility is able to achieve economies-of-scale usually found only at very large monofills.

Table 14-8. Estimate of Total Annual Cost for Example Number 3

Item	Quantity	Unit Cost	Total Cost
Mobilization			
Loader	2 /ea	500 /ea	$1,000
Dozer	2 /ea	500 /ea	1,000
Trench Excavation	600 cu yd	$2.50 /cu yd	1,500
Covering	230 cu yd	$1.50 /cu yd	345
Regrading	1 acre	$10,000 /acre	10,000
Seeding	1 acre	$4,500 /acre	4,500
Total			18,345

Chapter 15
Case Studies

These case studies were obtained from discussions with a number of state and regional authorities responsible for sludge management. They illustrate a range of surface disposal activities being conducted throughout the United States. Activities covered include surface disposal of sewage sludge in a monofill, at a dedicated disposal site, and at a dedicated beneficial use site, in addition to sludge storage in lagoons prior to final disposal.

15.1 Case Study 1: Surface Disposal in a Monofill Following Freeze-Thaw Conditioning in a Lagoon Impoundment

Anderson Septage Lagoon
Department of Public Works
Anderson, Alaska

15.1.1 General Site Information

The City of Anderson, about 75 miles southwest of Fairbanks, operates a lagoon impoundment for conditioning domestic septage, of which it receives about 400,000 gallons annually. In 1994, the city of 700 applied to the Alaska Department of Environmental Conservation (ADEC) for a permit to dispose of sludge recovered from its two storage lagoons in an onsite monofill.

The permit application seeks an exemption from 40 CFR Part 503 pollutant limit for sludge disposed within 25 m of a disposal site's boundary because Anderson's disposal unit is about 9 m (i.e., 30 ft) from the site's north boundary (Figure 15-1). (If "site-specific" limits are not set by the permitting authority, an alternative for disposal will have to be found.) Testing has determined that the city's sludge meets the pollution limits for solids that can be disposed of at least 150 m from a site's nearest boundary.

The domestic septage lagoon is located in a relatively remote area north of a U.S. Air Force landing strip and about 3 miles southeast of the Anderson (Figure 15-2). Moreover, the lagoon is restricted from receiving any hazardous or industrial waste or any municipal solid waste. All waste received at the lagoon must meet toxic characteristics leaching potential (TCLP) standards.

15.1.2 Site Characteristics

The Anderson lagoon is situated on a formation of glacial outwash and alluvial sediment estimated to extend to a depth of more than 20 ft, based on excavations in a nearby gravel quarry. The sediment has been classified as poorly graded sand mixed with silt and gravel, a geological material commonly referred to as pit run. The site's top layer of silt loam, which was removed during lagoon construction to take advantage of the frost-resistant characteristic of the sediment, was stockpiled on site for later use as a cover material.

Flood potential at the site has been deemed minimal, given average annual precipitation of only 12.7 in. Indeed, no flooding occurred in Anderson during August of 1967 when the region's heaviest rainfall on record (4.6 in.) caused localized flood-water problems. Although Anderson did experience flooding in 1978 during an unusually rapid thaw, it is believed that the lagoon, which was not operating at the time, would not have been affected.

The ground-water level at the site typically is more than 6 ft below the lagoon's percolation cell. Even during the summer of 1992, when ground water throughout the region rose to an unusually high level, the water table at the site was more than 4 ft below the percolation cell. Further, based in part on a 1983 engineering study, ground water flows from the lagoon impoundment in a north by northeast direction and generally away from Anderson (see Figure 15-2).

15.1.3 Domestic Septage Conditioning and Disposal

15.1.3.1 Lagoon Design

The Anderson domestic septage treatment works consists of a facultative cell flanked to the east and west by active primary lagoon cells and to the south by a third primary cell that is no longer in use. Adjoining the facultative cell to the north is a percolation cell, and beyond that the sludge disposal cell (see Figure 15-1). The

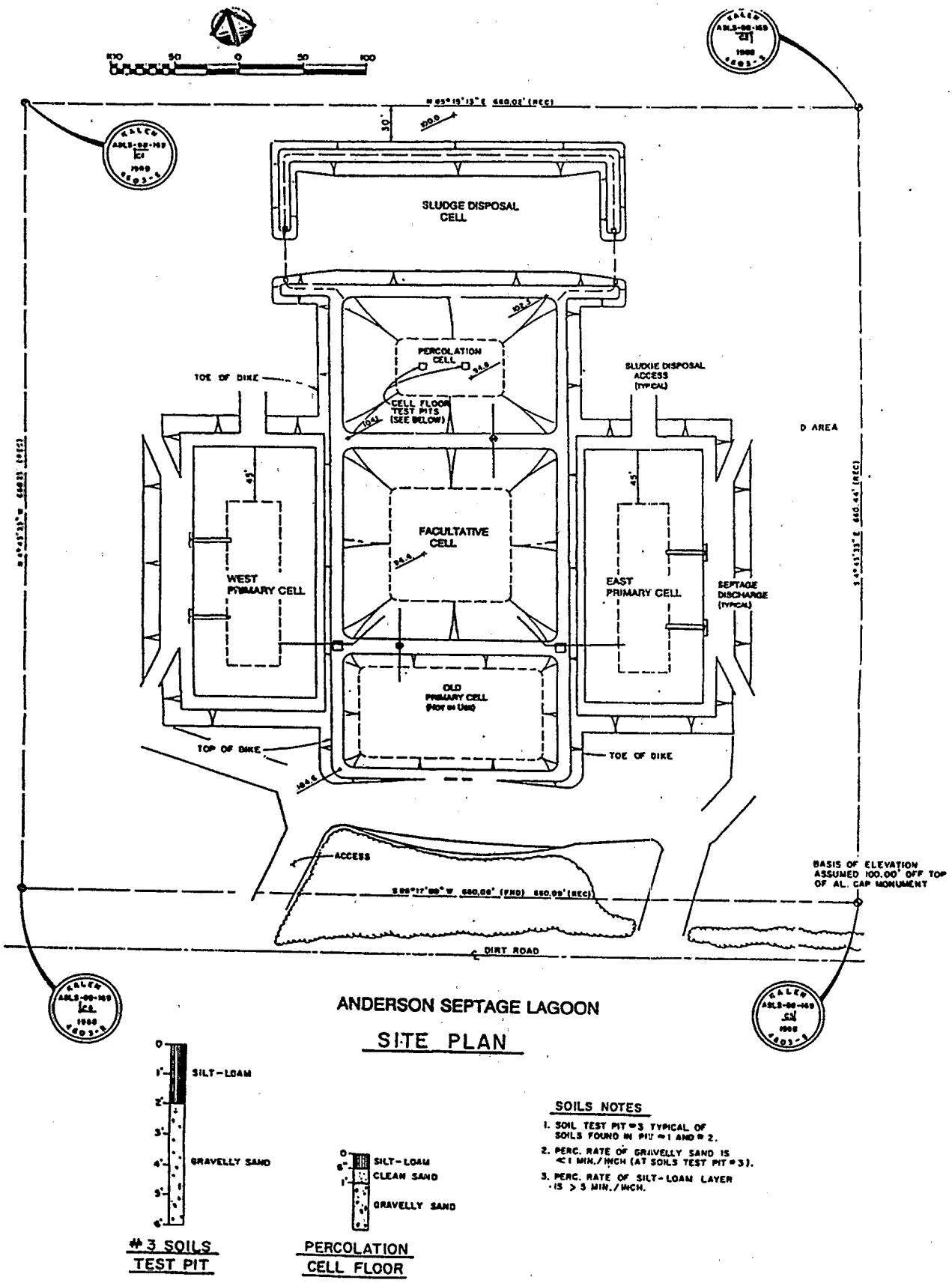


Figure 15-1. Anderson septage lagoon.

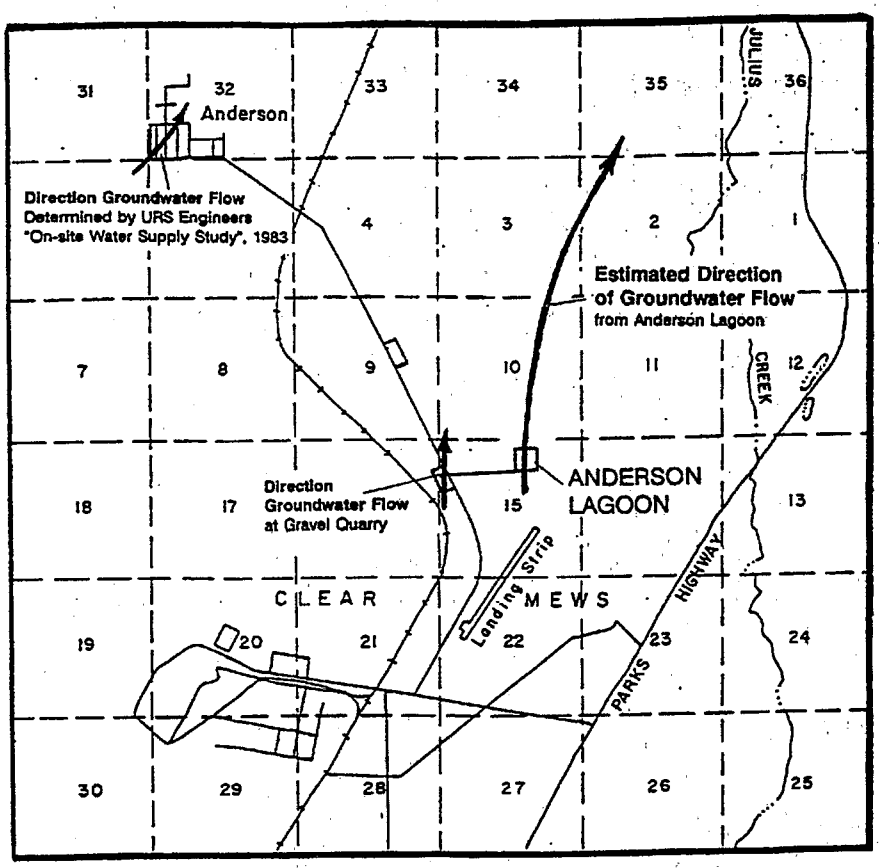


Figure 15-2. Site map of Anderson septage lagoon.

disposal cell (i.e., active sewage sludge unit) measures 90 x 200 ft in area and is surrounded by a 5-ft berm.

The lagoon cells measure 140 x 43 ft (6,000 sq ft) in area and 5.5 ft in depth to the top of the drain bed. Cell holding capacity is 450,000 gallons of liquid and 13,000 cu ft of sludge (at a depth of 2 ft). Cells are lined with a low-temperature arctic polyvinyl chloride (LTA PVC) material, which provides an impermeable barrier. At the bottom of each cell is a perforated high-density polyethylene (HDPE) pipe (10 ft on center) covered by 24 in. of sandy gravel, allowing the cell to function as a reverse drain field.

At the end of a storage period, liquid is siphoned off to the facultative cell. When initial transfer of liquid is carried out in the fall, a siphon alone is used because the liquid level is relatively high. In the spring, after freeze-thaw conditioning of the sludge has taken place and the liquid level is lower, a pump is used to prime the siphon; a pump manifold was constructed for this purpose.

The disposal cell is lined with pit run, which is separated from an 8-inch layer of silt by a geomembrane material. The gravelly layer functions as a French drain, with rainwater and snowmelt filtering through to the silt layer. From there the leachate drains into the percolation cell for gradual discharge to the ground through 6 in. of silt.

15.1.3.2 Conditioning and Disposal Process

The east and west primary cells receive domestic septage in alternating years. In the spring, at the end of a receiving year, liquid is siphoned off from the lagoon cell into the facultative cell, leaving only enough residual liquid to saturate the accumulated sludge (maximum liquid depth is 2 ft). The following spring, after the sludge has been conditioned through freezing and thawing, supernatant is siphoned off into the facultative cell. The sludge is then left to dry for about a week before it is moved to the disposal cell—using a bulldozer and dump truck—where it is spread onto a 6-inch layer of silt loam.

A typical load of dewatered sludge is spread against the berm and across a 20- x 30-ft area in a 2- to 3-ft layer, and the edge of the sludge pile is finished at no more than a 2:1 slope. To "encapsulate" the material so that pathogens and vector attraction are controlled, a 6-inch layer of loam is spread on top of the sludge followed by a layer of pit run. Once the cover is in place, the sludge pile is seeded, and then reseeded in the fall.

The ground cover that results from seeding the sludge pile contributes to leachate control through transpiration of rain water and snowmelt, while the loam cover reduces infiltration of water into the disposed sludge. The purpose of the pit-run layer is to minimize erosional

effects that can be caused by the harsh climate. Nonetheless, some liquid will inevitably reach the sludge layer. Thus, the base layer of loam and the percolation cell are intended to slow the discharge of leachate to the ground water to reduce concentrations of residual pollutants.

15.1.4 Operations Factors

15.1.4.1 Sludge Characteristics

The City of Anderson has applied for a permit that would allow disposal of sludge within 25 m of the treatment works' north boundary with the following maximum pollutant concentrations:

Arsenic	73 mg/dry kg
Chromium	600 mg/dry kg
Nickel	420 mg/dry kg

Under part 503, these concentrations are acceptable only for sludge placed in an active sewage sludge unit whose boundary is 150 meters from the surface disposal site property line. The city seeks "site-specific" pollutant limits, arguing that, despite the close proximity of the treatment works' border, minimal opportunity exists for humans or wildlife to come within 150 m of the disposal cell. The area is not accessible to humans except on foot, and it does not include any intermittent creek bottoms that might draw wildlife as well as hunters.

Additionally, when the city tested its sludge for TCLP, results indicated that pollutants are below regulatory levels.

15.1.4.2 Monitoring

In the spring, after freeze-thaw conditioning and transfer of supernatant and prior to disposal, sludge being held in a lagoon cell will be tested to determine if it meets permit requirements. Sludge will be analyzed for the parameters listed in Table 15-1. Testing will be performed on a composite sample made up of three grab samples, two collected from the base of the freeze-thaw bed bumper, opposite each domestic septage discharge culvert, and a third from the area of the culvert most used during the year (i.e., where the sludge is deepest). After collection and mixing, the sample will be iced and delivered to the testing lab within 1 day.

Table 15-1. Sludge Monitoring Parameters

parameter	units	method
Arsenic	mg/dry kg	EPA 7060
Chromium	mg/dry kg	EPA 7191
Nickel	mg/dry kg	EPA 6010
Total Solids	mg/l	SM[1] or EPA 160.3
Percent Solids	%	SM or EPA 160.3
Total Volatile Solids	%	SM or EPA 160.4
Fecal Coliform	#/dry gram	MPN, SM 9222C

1. SM = Standard Methods

The city has no plans to monitor ground water for nitrate. Therefore, under part 503 the city will be required to obtain a certification by a ground-water scientist that ground water will not be contaminated by the placement of sewage sludge on the active sewage sludge unit. During storage, lagoon cell liners will prevent nitrate from leaching out of sludge. Once disposed, ammonia in the sludge will not be able to oxidize into nitrate because the disposal cell provides an anaerobic environment.

All records concerning disposed sludge will be retained for 5 years.

15.1.5 Disposal Cell Capacity

The city estimates the site life of the disposal cell to be 20 years. This estimate assumes that 2,700 cu ft (100 yards) of sludge will be disposed each year. The assumption takes into account the 6 in. of silt that will be used to cover each year's load of sludge.

15.2 Case Study 2: Use of a Lagoon for Sewage Sludge Storage Prior to Final Disposal (Lagoon Impoundment in Clayey Soils)

Sludge Lagoon
Domestic and Industrial Wastewater Treatment Facility
Forest, Mississippi

15.2.1 General Site Information

In 1991, the City of Forest expanded and renovated its domestic and industrial wastewater treatment works to increase its liquid processing capabilities. As expected, given the increased effectiveness of improved operations, the sludge lagoon system soon approached its solids holding capacity. Thus, the city has submitted an application for a permit to construct two additional storage lagoon cells occupying about 5 acres.

The city's sludge handling process consists of treatment in aerobic digesters, followed by thickening and storage in a lagoon impoundment. During storage, the sewage sludge undergoes final disinfection, stabilization, and thickening in anticipation of final disposal.

Since the Forest mechanical-biological wastewater treatment works went into operation northeast of the city in 1977, the area set aside for lagoon impoundments has been expanded from 1.75 to 3.5 acres. The site of the proposed additional lagoon cells is a 52-acre parcel of open pastureland abutting two of the treatment works' existing lagoons (Figure 15-3). Because the parcel is

bounded to the north by a free-flowing stream and to the east and south by a similar stream, a portion of its boundary is characterized by wetland-type soils and vegetation; additionally, the land is considered to be in a 100-year flood zone. Nonetheless, a Phase I environmental site assessment concluded that no adverse recognized environmental conditions are present on the property and that any potential impacts to the surrounding properties related to lagoon construction can be minimized or appropriately mitigated.

15.2.2 Design Criteria

Data gathering for a geotechnical investigation of the site included 10 soil borings (see Figure 15-3), which found that near-surface soils in various locations consisted of expansive clays containing pockets of silty clays and sandy clays and silty clays that extend from the ground surface to depths that ranged from about 5 to 12 ft (Table 15-2). Underlying soils included sandy clays that extended to depths that ranged from about 13 to 16 ft as well as clays of the Yazoo Formation. Based on these findings, the geotechnical investigation concluded that the proposed lagoons could be constructed on the naturally deposited clay soils after proper site preparation (e.g., clearing, grubbing, and stripping of all organics). The investigation further concluded that the near-surface silty clay and clay soils could be used for embankment materials—although they are not the preferred materials for this purpose—providing special design and construction measures are adopted. For instance, the report recommended (1) the use of chemical stabilization of onsite soils to reduce plasticity and improve workability, and (2) the testing of each lift of fill material to provide some assurance that adequate and uniform densities are being obtained.

Tests to determine the permeability of in-place soils at the site—a characteristic that is critical to the location, design, and proper functioning of a sewage sludge lagoon—found seepage values to be well below the maximum allowable rate of 500 gallons per day per acre required by state regulations.

Concerning ground-water considerations, based on two soil borings that found free ground water at depths ranging from 8 to 13 ft, the geotechnical report concluded that problems might be encountered if construction excavations exceed depths of about 7 ft. Additionally, the report recommended that excavations should achieve slopes no steeper than 5 horizontal to 1 vertical to prevent the development of slough sides.

15.2.3 Sludge Collection and Disposal

15.2.3.1 Sludge-Collection Process Steps

The treatment works' impoundment lagoons receive sewage sludge from both industrial and domestic wastewater treatment streams. In the industrial stream, solids are collected in the following process steps:

- *Anaerobic Lagoons.* Influent raw wastewater is received and primary removal of solids plus anaerobic decomposition of carbonaceous biological oxygen demand take place, with solids settling to the bottom and accumulating over time.
- *Aerated Stabilization Basins (ASBs).* A pair of basins serve as complete-mix and partial-mix lagoons. Following significant decomposition of sludge through anaerobic and aerobic processes during residence in the partial-mix lagoon, floor drains and mechanical mixing capability allow for periodic removal of solids. If adequate digestion has occurred in the ASB, the solids can be transferred directly to storage lagoons.
- *Sequencing Batch Reactors (SBRs).* Effluent from the ASBs is pumped to the SBRs, where the waste undergoes an anoxic treatment promoting denitrification followed by an aerobic treatment including nitrification. The final phase of the batch treatment process involves settling and decanting, before solids are removed for mixing with other sludges.

Table 15-2. Laboratory Permeability Test Results

Laboratory Permeability Test Results									
Boring No.	Depth (ft)	Soil Type	Moisture Content (%)	In-Place Dry Unit Weight (pcf)	Liquid Limit	Plasticity Limit	Plasticity Index	Percent Passing the No. 200 Sieve (%)	k_v (cm/sec)
2	8-10	Clay	25.1	98.1	53	17	36	84.8	2.98×10^{-8}
2	13-15	Clay	24.8	94.8	69	19	50	89.2	1.00×10^{-8}
3	8-10	Silty Clay	22.7	105.5	49	11	38	76.8	1.25×10^{-8}
8	8-10	Silty Clay	32.4	99.7	48	15	33	69.5	1.27×10^{-8}
8	13-15	Sandy Clay	19.4	105.9	49	11	38	55.1	1.08×10^{-8}
9	8-10	Silty Clay	20.4	102.5	46	13	33	68.3	6.50×10^{-9}

In the domestic stream, solids are collected in the following process steps:

- *Primary Clarifiers.* After screening and degritting treatment, domestic flows are introduced to the primary clarifier, where sludge is collected by chain and flight in rectangular basins. From there, solids are delivered by telescoping valves to a sewage sludge pump wetwell.
- *First-Stage Clarifiers.* Effluent from the first-stage aeration basins is received by 12 clarifier basins that remove the settled solids using airlift pumping units. A portion of the sludge is returned to first-stage aera-

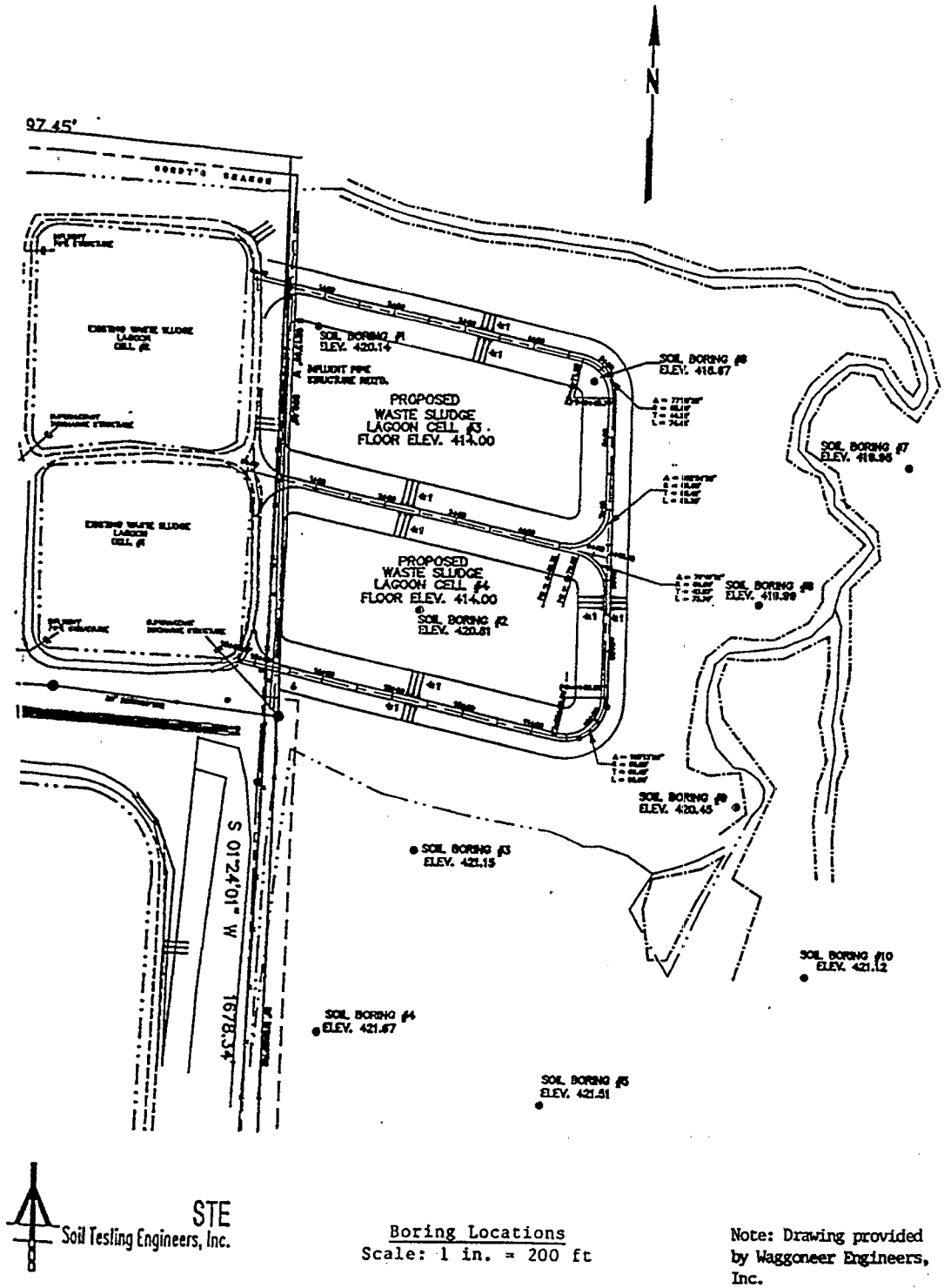


Figure 15-3. Site of proposed lagoon cells (Geotechnical Investigation Report).

tion as return-activated sludge and the remainder gravity flows to the wetwell as waste-activated sludge.

- *Second-Stage Clarifiers.* The second-stage aeration basin is followed by second-stage clarifiers, from which collected solids gravity flow to the second-stage return sludge pump wetwell. From there, the waste material is conveyed by lift pumps to a splitter box that diverts a portion of the sludge to the wetwell as waste-activated sludge.

Aerobic digesters receive all waste-activated sludge, with the exception of sludge from the anaerobic lagoon and from the ASB.

The two existing sludge lagoons have a total storage capacity of 1.2 million cu ft. One of the cells reached its capacity a number of years ago, while the other reached its capacity only recently. Cells were loaded at a rate of 17 pounds of volatile suspended solids per 1,000 sq ft per day, a rate that is well within the generally acceptable range.

15.2.3.2 Sludge-Disposal Alternatives

Operators of the Forest treatment works recognize that the Part 503 regulation makes disposal of sewage sludge an entirely different issue than storage. Given their immediate need for additional storage capacity, however, they are deferring any decision on disposal alternatives for the time being.

Two possible approaches for final disposal of the treatment works' sewage sludge include land application and placement in an MSW landfill. Land application would appear to be a less-attractive alternative because the sludge would need to meet specific Part 503 requirements that include limiting pathogens and metals. In contrast, landfilling would primarily require the sludge to be sufficiently dewatered. Operators recognize that disposing sewage sludges in MSW landfills, as required, has become significantly more expensive in recent years due to constraints on capacity. Nonetheless, a nearby, privately owned MSW landfill that was recently permitted might present a reasonably cost-effective disposal option for the Forest treatment works.

For the present, however, operators plan to expand their lagooning operation for storage of sludge in anticipation of eventual disposal. During storage in the lagoons, sewage sludge organics are gradually stabilized through aerobic and anaerobic processes, and the stabilized solids eventually settle to the bottom of the lagoon and accumulate.

Clayey soils that predominate at the treatment works site are conducive to providing a barrier of low permeability soils against ground-water contamination. Assuming that an active sewage sludge lagoon can effectively receive digested sludge and discharge a solids-free supernatant until the average solids concentration is 8 percent for the entire lagoon volume, the rate of waste sludge lagoon utilization will be approximately 1 acre per year for about the next 20 years.

If sewage sludge is stored on land (e.g., in a lagoon) for longer than 2 years, the person who prepares the sewage sludge must demonstrate to the permitting authority that the site is not an active sewage sludge unit. This includes an explanation of why sewage sludge needs to remain on the land for longer than 2 years prior to disposal and a projection of when the sludge finally will be used or disposed of. The surface disposal provisions of the Part 503 rule do not apply when sewage sludge is treated in a lagoon and treatment could be for an indefinite period.

15.2.4 Sludge Production Projections

Based on operating data, findings from a facility study, and the treatment works' long-term plan, operators have estimated quantities of sewage sludge that will be produced by the year 2005 (Table 15-3). For example, operators project that sewage sludge produced by ASBs for removal to lagoons will reach 4,097 pounds per day; this amount is calculated to decompose to about 2,538 pounds per day. Similarly, sludge produced by SRBs is expected to reach about 1,738 pounds per day.

In contrast, sewage sludge produced from domestic flows is expected to increase at the moderate annual rate of 1.5 percent, based on current population trends.

15.3 Case Study 3: Dedicated Surface Disposal in a Dry-Weather Climate

Solids Handling and Disposal Facility
Domestic Wastewater Treatment Facility
Colorado Springs, Colorado

15.3.1 General Site Information

The City of Colorado Springs operates processes for managing and disposing of sewage sludge generated at its POTW, which treats average flows of over 34 million gallons per day. Along with an anaerobic digestion complex for stabilization and an expanse of facultative sludge basins for additional long-term treatment of stabilized material, sewage sludge is disposed of on a dedicated surface disposal site.

The surface disposal site is located 18 miles south of the POTW at the city's Hanna Ranch property, which also is used for disposal of ash from the city's Ray Nixon Power Plant. A blend of primary and secondary sludge is conveyed from the POTW to Hanna Ranch via a pipeline—one of the longest pipelines in the country used to transport sewage sludge.

Minimal residential and commercial development has taken place near the Hanna Ranch site due to a limited

Table 15-3. Sewage Sludge Projections

Solids Category	1995 Digester Influent	1995 Lagoon Influent	1995 Final Disposal	2005 Digester Influent	2005 Lagoon Influent	2005 Final Disposal
ASB FSS (#/day)	--	578	578	--	730	730
ASB nVSS (#/day)	--	817	817	--	1,021	1,021
ASB VSS (#/day)	--	1,391	696	--	2,346	782
ASB TOTALS	--	2,786	2,091	--	4,097	2,533
SBR FSS (#/day)	481	481	481	757	757	757
SBR nVSS (#/day)	695	626	626	1,095	985	985
SBR VSS (#/day)	561	413	306	923	641	475
SBR TOTALS	1,737	1,520	1,413	2,775	2,383	2,217
DOM. PLANT FSS (#/day)	170	170	170	197	197	197
DOM. PLANT nVSS (#/day)	320	204	204	371	237	237
DOM. PLANT VSS (#/day)	361	238	95	419	276	110
DOM. TOTALS	851	612	469	987	710	544
TOTAL FSS (#/day)	651	1,229	1,229	955	1,684	1,684
TOTAL nVSS (#/day)	1,015	1,647	1,647	1,466	2,243	2,243
TOTAL VSS (#/day)	922	2,042	1,097	1,342	3,263	1,367
TOTAL SLUDGE SOLIDS	2,588	4,918	3,973	3,762	7,190	5,294

drinking water supply and the proximity of a military training range to the west. Given its relatively remote character, a portion of the ranch is set aside as a wildlife area, which is managed cooperatively by the state's Division of Wildlife and city utilities. Beyond merely monitoring the compatibility of operations with area wildlife, site managers have tested a habitat enhancement practice that involves growing feed crops within the disposal site for incidental grazing by antelope and waterfowl.

The soils at the Hanna Ranch site consist of verdos alluvium, piney creek alluvium, and a weather Pieere shale with low to very low permeabilities. Monthly average temperatures at the site range from 29°F to 71°F.

Public access to the surface disposal site is restricted by a fence that surrounds the Hanna Ranch and a uniformed security guard stationed 24 hours a day at the north entrance. Visitors are allowed limited access to the ranch for hunting and wildlife observation through a 3-ft opening in the fence at the site's south entrance, which is about 1.5 miles east of the active disposal units.

The site meets all of the Part 503 requirements. Characterization/management issues addressed in the site's state/county Certification of Designation include:

- A survey by the state's Division of Wildlife found that the disposal operations do not adversely affect a threatened or endangered species.
- Although no wetlands have been delineated in accordance with U.S. EPA or Corps of Engineers procedures, active sewage sludge units appear to be adjacent to one small (0.1 to 0.2 acres), isolated wetland in a creek drainage. Although disturbance of this wetland would be permitted under the nationwide permit for headwaters and isolated areas, current activities do no disturb the wetland.
- A site ground-water plan was recently rewritten by a qualified ground-water scientist to comply with 40 CFR Part 503. The plan includes 2 years of quarterly monitoring to determine ambient conditions, as required by the state, with a focus on total inorganic nitrogen and organic carbon concentrations.
- Modifications have been made to small sections of the active sewage sludge unit that were estimated to be special flood hazard areas that would be inundated by a 100-year flood. Runoff from a creek drainage (up to a 1,000-year flood) is contained for evaporation at a retention dam.
- A review of area geology confirmed that the surface disposal site is not in a seismic impact zone or in an unstable area.

15.3.2 Surface Disposal Approach

15.3.2.1 Process Description

At the solids handling and disposal facility, sewage sludge is gas mixed in four 1.5-million gallon anaerobic digesters. Once stabilized, the waste material is pumped to 30 acres of facultative sludge basins (FSBs, known in other states as facultative sludge lagoons) where it is treated under a 5-ft water cap for at least 3 years. After the digested sludge is removed from the bottom of the basins using a dredge equipped with a diesel-driven pump, they are conveyed through a floating, flexible pipe to a wet well in the control building. The sludge then is pumped from the wet well to a riser at each dedicated surface disposal (DSD) unit. From the riser, the sludge is loaded into the holding tank of a Terragator, a sludge dispersal vehicle equipped with flotation tires, and injected into the subsurface of the DSD units. The four DSD units at Hanna Ranch (Figure 15-4) total 180 acres.

The primary method of liquid disposal is through evaporation. Excess liquid from the facultative basins is pumped to supernatant lagoons for additional treatment, evaporation, and disposal.

In 1993, over 9,000 metric tons of sludge was disposed by subsurface injection at an average rate of 113 metric tons per hectare (124.3 tons per 2.5 acres). Disposal operations are limited to seasons when both the soil in the DSD units and the surface of the FSBs are not frozen. In 1993, disposal operations were conducted from March 16 to November 11.

15.3.2.2 Character of Sewage Sludge

The sludge produced at the POTW is of high quality. When surface disposed, however, the boundary of DSD units (i.e., active sewage sludge units) must be more than 100 m from the property line of the surface disposal site because of slightly elevated chromium concentrations (Table 15-4).

Steps taken to control pathogens and reduce vector attraction in the sewage sludge make the sludge appropriate for surface disposal. Relatively high concentrations of helminth ova, however, have prevented the sludge from meeting Class A criteria without significant additional treatment. Because the sludge is injected into the surface, further pathogen and vector reduction controls are not required by Part 503. The City of Colorado Springs has elected, however, to treat its sludge further. Pathogen reduction is carried out using high-rate anaerobic digestion to meet the requirements of a process to significantly reduce pathogens (PSRP). The process involves the anaerobic treatment of sludge for a specific mean cell residence time (MCRT) of about 20 days at a temperature of 96.8°F (36°C). Raw solids are fed

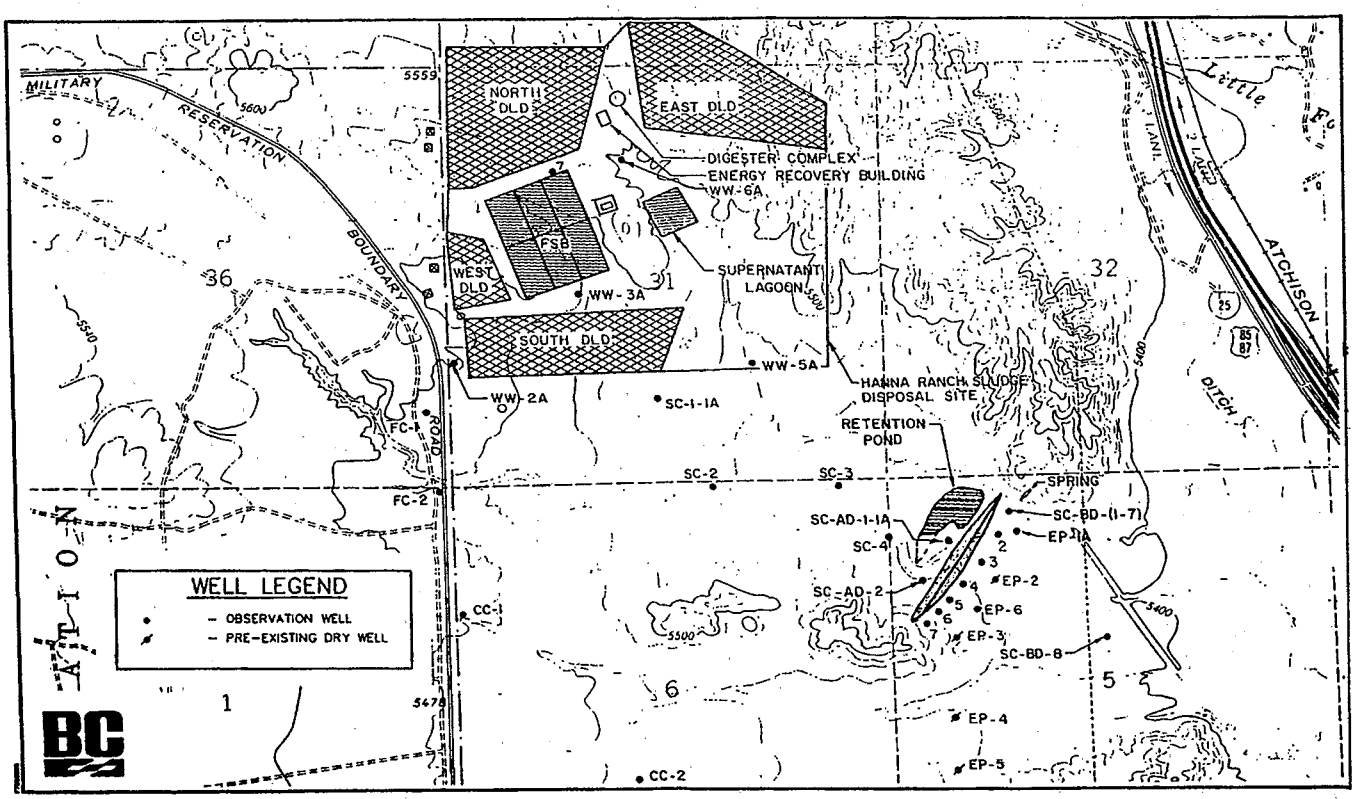


Figure 15-4. Topographic map of Hanna Ranch area.

Table 15-4. 1993 Sewage Sludge Monitoring Results

1993 Date	Arsenic mg/kg	Chromium mg/kg	Lead mg/kg	Mercury mg/kg	Moly mg/kg	Nickel mg/kg	Selenium mg/kg	Zinc mg/kg	Coliform [1] MPN/g	Helminth, #/4 g Observed [2]	Helminth, #/4 g Viable	Salmonella MPN/g	Enteric PFU/4 g
March 16									430,000				
March 23									230,000				
March 30									150,000				
April 6									40,000				
April 13 [3]	22 [4]		192	4.31	15		20	2,070	40,000				
April 20									65,600	2,000			
April 27									2,200	2,400			
May 4									5,900	8,000			
May 11									800 [5]	1,200	53 [4]	<0.2	<0.9
May 18									400	2,000			
May 25									1,100				
June 1									500				
June 8									800				
June 15									300				
June 22									500				
June 29									800				
July 20	<2.0	330				210			940	3,200			
July 27									2,020	4,400			
Aug 3									800	2,400			
Aug 10									130				
Aug 17	<2.0	290				190			50				
Aug 24									260	2,400			
Aug 31									110				
Sep 14									210				
Sep 21	<2.0	280				190			130				
Sep 28									700				
Oct 28	<2.0	310				210							
Nov 2	2.9	210				130							
1993 Avg	<5.6	284	192	4.31	15	186	20	2,070	0	3,111	53	<0.2	<0.9
1993 Max	29 [4]	330	243	5.26	18	210	30	2,510	430,000	8,000	53	<0.2	<0.9

notes:

1 : Method development was based on Standard Method 9221C Fecal Coliform MPN Prodecure based on Multiple-tube fermentation and Standard Method 2540B Total Solids Dried at 103-105 C

2 :Method based on Zinc Sulfate flotation according to Meyer, Miller and Kaneshiro, 1978, "Recovery of Ascaris Eggs from Sludge," Journal Parasitology 64:380-383.

3 : Metals data collected April 13, is an average of 9 samples collected on a cross section of FSB 6.

4 : Contract lab failed to correctly analyze quality control sample for this parameter.

5 : Contract lab duplicate result by methods SM 9221C and EPA 160.3 was 390.

6 : Contract lab result.

continuously into digesters, then removed sequentially from each of three digesters after 20 minutes in a 1-hour cycle. Although the POTW can operate utilizing all four digesters, the MCRT is achieved routinely using three digesters, while the fourth undergoes maintenance.

Sludge is heated to the desired temperature using a spiral counterflow-type heat exchanger at each digester fed by two low-pressure steam boilers. The boilers burn methane gas produced by the digesters as a primary fuel, but can also burn diesel fuel. Untreated sludge is mixed with recirculating solids before reaching the heat exchangers.

Although temperatures generally are controlled to within 1°C to ensure optimum operation and to avoid upsets, they occasionally drop—especially during startup. Nonetheless, at such times temperatures are kept within PSRP minimum standards (Table 15-5). Temperatures are measured before the heat exchangers electronically and mechanically, and operators and a computer monitoring system record temperatures every 2 hours. Recirculating pipe exterior temperature is measured with liquid-filled thermometers. Temperature gauges are calibrated quarterly.

Contract customers represent a secondary source of sewage sludge. Before sludge is accepted from contract customers for placement in the FSBs, however, the material is tested to ensure that fecal coliform concentrations are less than the 2 million most probable number (MPN) per gram of total solids.

Vector attraction reduction is achieved through volatile solids reduction, which is carried out in the digesters, and through subsurface injection of the sludge. Volatile

Table 15-5. PSRP Minimum Temperatures for Anaerobic Digestion

PSRP Minimum Temperatures for Anaerobic Digestion	
Mean Cell Residence Time (days)	Minimum Temperature (°C/° F)
15	35/95
16	35/95
17	34/93
18	34/93
19	34/93
20	33/91
21	33/91
22	33/91
23	32/90
24	32/90
25	32/90

solids reduction is a function of temperature and MCRT in the anaerobic digestion system. Thus, the same operational considerations (discussed above) for pathogen control ensure vector attraction reduction. In 1993, for example, average volatile solids reduction at the Hanna Ranch facility was 59 percent, well above the standard of 38 percent.

15.3.3 Operation and Maintenance

The surface disposal site is attended 10 hours a day by a crew of nine. It is linked by computer and microwave communications to the POTW in Colorado Springs to enable remote monitoring when operators are not on site.

15.4 Case Study 4: Dedicated Surface Disposal in a Temperate Climate

Sludge Surface Disposal Site
Metro Sanitary District
Springfield, Illinois

15.4.1 General Site Information

The Metro Sanitary District in Springfield, Illinois, has operated two sites for treatment and subsequent surface disposal of sewage sludge since 1973. At the district's Spring Creek surface disposal site, located north of the city in the vicinity of Capital Airport and the state fairgrounds (Figure 15-5), sludge is disposed on 80 acres of land following anaerobic digestion. Sludge received at the smaller, Sugar Creek surface disposal site, which is directly east of the city and roughly between two interchanges of Interstate 55 (Figure 15-6), is subjected to aerobic digestion before disposal on 30 acres.

In most years, livestock feed has been grown on a portion of one or both sites. Sludge is disposed only on the areas that are not cropped, which are alternated each year. Additionally, broadleaf weed killer is applied annually at both sites. The sites must meet the requirements for pathogen control and vector attraction control, including site restrictions, under the Part 503 rule.

Although the district has grown corn exclusively since the late 1980s, other feed crops have included alfalfa, sorghum, soybeans, and winter wheat. The disposal sites have been plowed and disked annually, except at the Sugar Creek surface disposal site between 1978 and 1987 when the district cultivated bluegrass and attempted to enter the sod market. As a result of the more stringent limits on nitrate in the Part 503 regulation, the district is switching at both sites from corn to canary grass, a hay crop that has higher nitrate requirements.

Samples from monitoring wells at the sites have shown that nitrate levels in ground water tend to be elevated at certain times of the year and during specific weather patterns. As a result, along with planning to change the feed crop at the site, the district has applied to the state environmental agency and the U.S. EPA for reclassification of the sites' ground water as Class II water. The district has assured authorities that it will be able to meet applicable state and federal requirements for the protection of ground water.

As a result of the pathogen control and vector attraction reduction requirements in Part 503, the district also plans to upgrade its aerobic treatment process at the Sugar Creek site (as described in Section 15.4.3.2).

15.4.2 Design Criteria

The western section of the Spring Creek surface disposal site, which began receiving sludge for disposal in October 1973, meets applicable design criteria for sludge disposal based on site features that include being:

- Situated 200 feet from any water well and above the 10-year flood plain.
- Constructed with a slope of less than 5 percent (except for a small section of the interior portion of the site).
- Bordered by a shallow berm and a restricted asphalt roadway to contain runoff.
- Characterized by a tight clay soil.

Important design features of the Spring Creek site's eastern section, which was put into service in March 1980, include being:

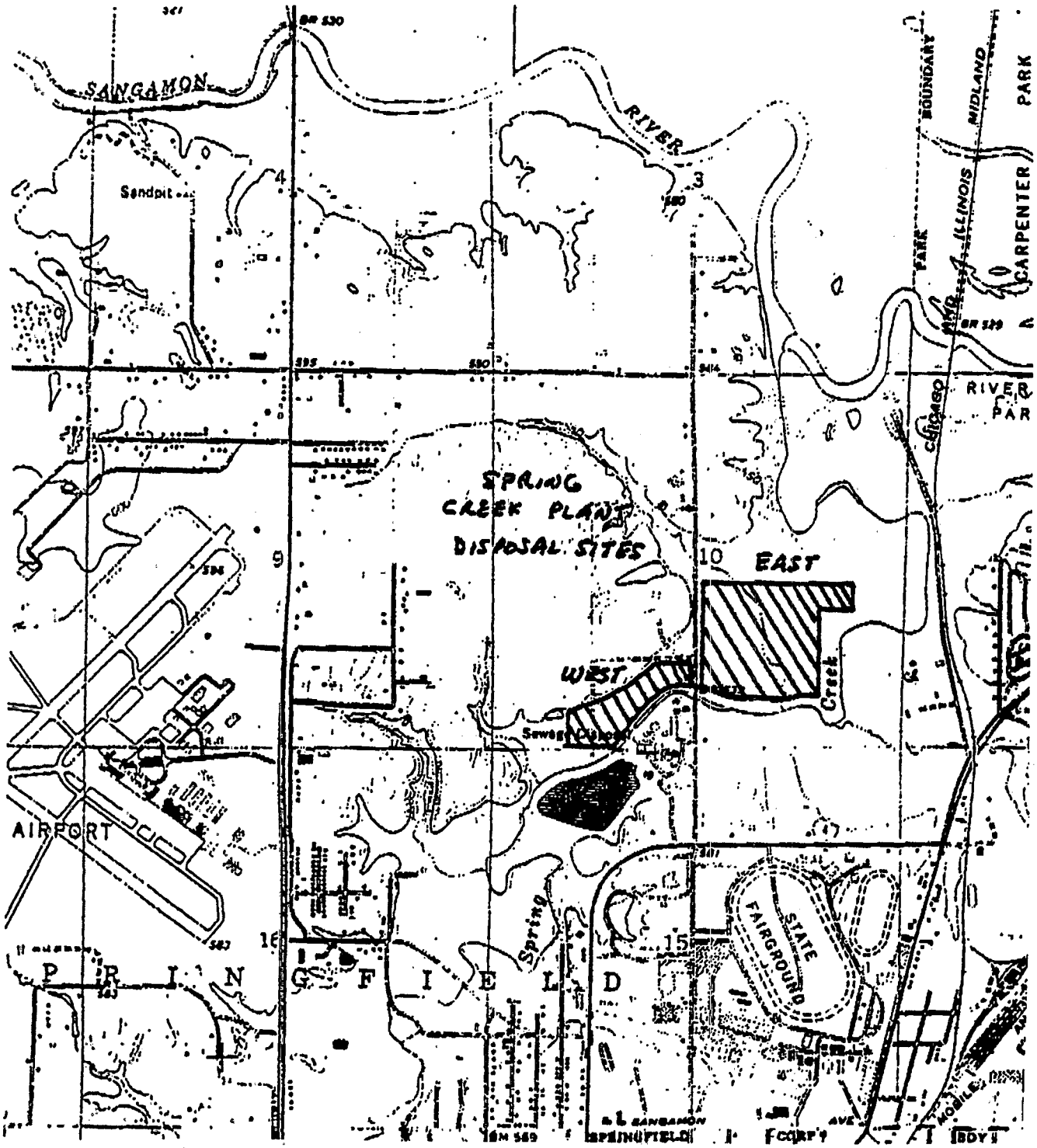


Figure 15-5. Spring Creek disposal site.

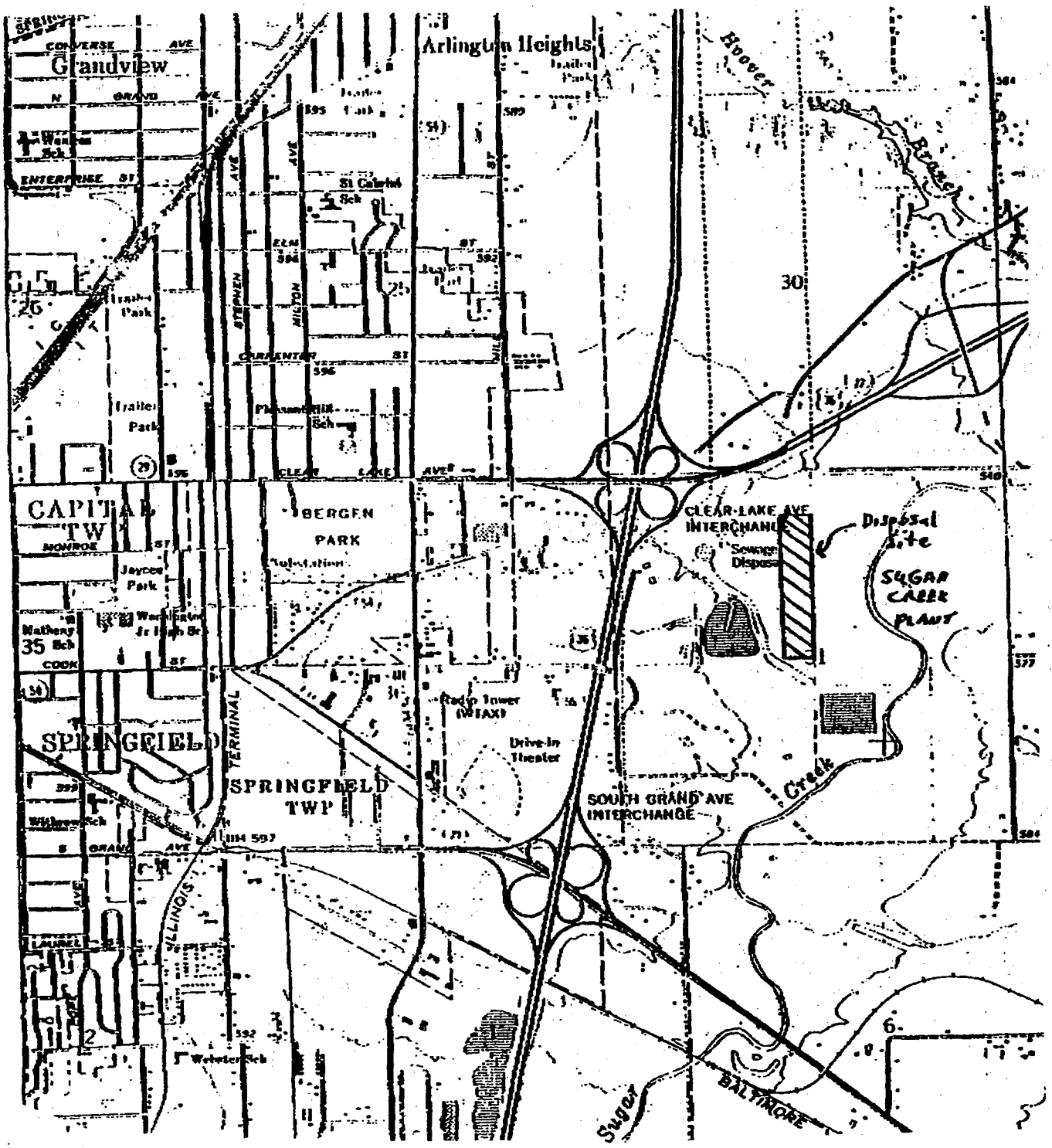


Figure 15-6. Sugar Creek disposal site.

- Situated 150 feet from any water well and 200 feet from any surface water.
- Constructed with a slope of less than 5 percent.
- Bordered by a berm (necessary because this section of the site is in a flood plain).
- Characterized by a sandy soil.

The district's Sugar Creek surface disposal site, which has been in use since October 1973, meets design criteria for sludge disposal based on site features that include being:

- Situated 150 feet from any water well and 200 feet from any surface water.
- Constructed with a slope of less than 5 percent.
- Characterized by a silty loam soil.

The site includes a 10-acre lagoon to catch runoff in the event of flooding. In the 20-plus years of operation, however, the site has not been subjected to a major flooding event.

Additionally, both the Spring Creek and Sugar Creek surface disposal sites are 200 feet from either an occupied dwelling or a public roadway.

15.4.3 Treatment and Surface Disposal Approach

15.4.3.1 Spring Creek Surface Disposal Site

Process Description. The primary and waste-activated sludge received at the Spring Creek surface disposal site undergoes primary anaerobic digestion, which involves heating and mixing of the material, followed by treatment in secondary digesters. By operating three primary digesters and six secondary units, on average about 28,000 gallons of sludge are processed each day. Operators also have attempted thickening waste-activated sludge in one of the six secondary digesters; one of the approaches included the use of a gravity-belt thickener.

Following the digestion process, the sludge is either (1) held in uncovered drying beds and spread on the surface disposal site after dewatering, or (2) it is sprayed onto the disposal site using fixed risers spaced 150 to 200 feet apart.

When spraying, pairs of risers operate in sequence dispersing 40,000 gallons of sludge with 50 psi of pressure across the area within their range. The edge of the spray pattern for the site's 92 risers is set at 110 to 180 feet from the surface of nearby Spring Creek. To minimize leaching of sludge into ground water, the entire disposal site is underdrained 6 to 9 feet below ground with 4- and 6-inch perforated pipe that is laterally spaced at 50 to 75 feet. Underdrains and forcemains are flushed after spraying, and collected sludge water is pumped to the effluent end of the primary treatment process.

The surface disposal site's 55,000 square feet of drying beds generally are used only during the colder months of winter, when spraying cannot be carried out, or when the spraying system is shut down for maintenance. Sludge placed in the beds in winter is allowed to dry until fall of that year, when it is hauled to the eastern section of the disposal site for spreading. The drying beds received 120,000 gallons of sludge in 1983 and almost 600,000 gallons in 1987, the only years to date when the beds were used.

Sludge residuals collected in the bottom of the site's secondary digesters are periodically pumped, using centrifugal pumps, to one of the disposal sites or is drawn by gravity to the drying beds. Water drained from the drying beds is pumped to the effluent end of the primary treatment works.

Character of Sewage Sludge. Sludge produced at the Spring Creek surface disposal site generally has a total solids content of 4.7 percent, volatile content of 41.2 percent, and a volatile acids concentration of 260 mg/L. Annual loading rates at the disposal site for nitrogen, phosphorus, and various metals are listed in Table 15-6.

15.4.3.2 Sugar Creek Surface Disposal Site

Process Description. The waste-activated sludge and floating scum materials (from secondary clarifiers) received at the Sugar Creek surface disposal site undergo staged treatment in a series of three aerobic digestion units. By operating units with a combined capacity of over 222,000 cubic feet (i.e., about 74,000 cubic feet each), on average about 25,000 gallons of sludge can be processed per day. On average 106,000 gallons of sludge (with a suspended solids content of about 8,000 mg/L) is sent to the digesters daily.

Each day, or as needed, the digestion system's airflow is shut down so that supernatant can be drawn into contact aeration tanks, making room for sludge inputs. Occasionally, surface scum is also removed and disposed along with other sludge. During the winter,

Table 15-6. Annual Pollutant Loading Rates at the Spring Creek Facility

Parameter	Annual Loading - lbs./Acre	
	West Site	East Site
Organic Nitrogen	910.0	1916.9
Phosphorus	532.3	1121.2
Lead	10.8	22.7
Zinc	41.3	87.0
Copper	24.8	52.3
Nickel	1.0	2.1
Cadmium	0.25	0.53
Manganese	28.1	59.3

[Loading Factor - 0.002 x 14.1 = 0.0282 (West)]
[Loading Factor - 0.002 x 29.7 = 0.0594 (East)]

Note: Average over 1983-1992.

sludge or scum is occasionally added to digestion tanks to control temperatures and ice formation.

Every 5 or 10 days, when the solids levels in the system reach about 15,000 to 25,000 mg/L or clear supernatant is no longer present, sludge is removed from the final digestion unit. The sludge material is removed in increments of 205,000 gallons and pumped, using centrifugal pumps, to the active sewage sludge unit. At the unit, the sludge is sprayed onto the surface from 30 risers each spaced about 200 feet apart. The spray system functions and is configured much like the system used at the Spring Creek site; it includes an underdrain system, and flushed sludge water is recycled to the treatment tanks. At this site, however, three risers operate in sequence, spraying 205,000 gallons of sludge within their range.

The site also includes two drying beds, covering 2,500 square feet, which to date operators have not needed to use in the sludge treatment process. Operators are considering the addition of a lime stabilization stage, however, as a final treatment step. Stabilization may be required during the winter months, when biological activity in the aerobic digesters slows, to meet Part 503 requirements for pathogen control and vector attraction reduction.

Character of Sewage Sludge. Sludge treated at the Sugar Creek site generally has a total solids content of 1.9 percent and volatile content of 50 percent. Annual loading rates at the disposal site for nitrogen, phosphorus, and various metals are listed in Table 15-7.

Table 15-7. Annual Pollutant Loading Rates at the Sugar Creek Facility

Parameter	Annual Loading - lbs/acre
Organic Nitrogen	1967.0
Phosphorus	969.4
Lead	21.2
Zinc	46.2
Copper	21.7
Nickel	1.9
Cadmium	0.43
Manganese	83.2

(Loading Factor = 0.002 x 24.3 = 0.0486)

Note: Average over 1983-1992.

APPENDIX A
Permit Application

Permits that are issued to publicly owned treatment works (POTWs) must include standards for sewage sludge use or disposal. In addition, EPA may issue sewage sludge permits to other "treatment works treating domestic sewage" (TWTDS) (i.e., other persons that generate, change the quality of, or dispose of sewage sludge).

The EPA's sewage sludge permit program regulations establish a framework for permitting sewage sludge use or disposal. The regulations require submission of a permit application that provides the permitting authority with sufficient information to issue an appropriate permit. A permit application must include information on the treatment work's identity, location, and regulatory status, as well as information on the quality, quantity, and ultimate use or disposal of the sewage sludge generated at the treatment works.

Because the sewage sludge permitting regulations were promulgated several years before the Part 503 standards, they describe the required application information in broad, almost generic terms. Currently, EPA is developing application forms and the Agency is planning to revise the permit application regulations to reflect specifically the Part 503 standards and to enable permit writers to tailor permit requirements to specific use or disposal practices.

The deadlines for submitting permit applications were revised in 1993 and are as follows:

- Applicants requiring site-specific pollutant limits in their permits (e.g., sewage sludge incinerators) and applicants requesting site-specific limits (e.g., some surface disposal sites) were required to submit applications by August 18, 1993.
- All other applicants with National Pollutant Discharge Elimination System (NPDES) permits are required to submit sewage sludge permit applications at the time of their next NPDES permit renewals.
- Sludge-only (non-NPDES) facilities that are not applying for site-specific limits, and not otherwise required to submit a full permit application, had to submit limited screening information by February 19, 1994.

The permit application information that must be submitted depends on the type of treatment works and which sewage sludge disposal practices are employed by the treatment works. Questions on permit applications should be directed to the appropriate State and EPA Regional Sewage Sludge Contacts listed in Appendix B.

Sludge-Only Facilities

The limited screening information submitted by a sludge-only facility typically will include the following:

- Facility name, contact person, mailing address, phone number, and location.
- Name and address of owner and/or operator.
- An indication of whether the facility is a POTW, privately owned treatment works, federally owned treatment works, blending or treatment operation, surface disposal site, or sewage sludge incinerator.
- The amount of sewage sludge generated and received, treated, and used or disposed.
- Available data on pollutant concentrations in the sewage sludge.
- Treatment to reduce pathogens and vector attraction properties of the sewage sludge.
- Identification of other persons receiving the sewage sludge for further processing or for use or disposal.
- Information on sites where the sewage sludge are used or disposed.

Treatment Works Submitting Full Permit Applications

A full permit application is much more comprehensive than the limited screening information described above for sludge-only facilities. A full permit application typically will include the following information:

General Information

- Name, contact person, mailing address, phone number, and location.
- Name and address of owner and/or operator.

- An indication of whether the facility is a POTW, privately owned treatment works, federally owned treatment works, blending or treatment operation, surface disposal site, or sewage sludge incinerator.
- Whether the facility is a Class I sludge management facility (i.e., a pretreatment POTW or another facility designated Class I by the permitting authority).
- The NPDES permit number (if any) and the number and type of any relevant Federal, State, or local environmental permits or construction approvals applied for or received.
- Whether any sewage sludge use or disposal occurs on Native American lands.
- A topographic map showing sewage sludge use or disposal sites and water bodies 1 mile beyond the property boundary and drinking water wells 1/4 mile beyond the property boundary.
- Results of hazardous waste testing for the sewage sludge, if any.
- Data on pollutant concentrations in the sewage sludge.

Information on Generation of Sewage Sludge or Preparation of a Material From Sewage Sludge

- The amount of sewage sludge generated.
- If sewage sludge is received from off site, the amount received, the name and address of person from whom the sewage sludge was received, and any treatment the sewage sludge have received.
- Description of any treatment to reduce pathogens and vector attraction properties of the sewage sludge.
- Description of any bagging and distribution activities for the sewage sludge.
- If sewage sludge is provided to another person for further treatment, the amount provided, the name and address of the receiving person, and a description of any subsequent treatment.

Information on Surface Disposal of Sewage Sludge (If Sewage Sludge Is Placed on a Surface Disposal Site)

- The amount of sewage sludge placed on surface disposal sites.
- The name, address, contact person, and permit number(s) for each surface disposal site, regardless of whether the applicant is the owner/operator.

In addition, the following information is required for each active sewage sludge unit that the applicant owns or operates:

- The amount of sewage sludge placed on the active sewage sludge unit.
- Whether the active sewage sludge unit has a liner and leachate collection system and, if so, a description of each.
- If sewage sludge is received from off site, the amount received, the name and address and permit number(s) of the person from whom the sewage sludge was received, and a description of any treatment the sewage sludge has received.
- Description of any processes used at the active sewage sludge unit to reduce vector attraction properties of the sewage sludge.
- Demonstration that the active sewage sludge unit will not contaminate an aquifer.
- If the applicant is requesting site-specific pollutant limits, information to support such a request.

All permit applications must be signed and certified. The permitting authority may request additional information to assess sewage sludge use or disposal practices, determine whether to issue a permit, or to identify appropriate permit requirements.

APPENDIX B
Federal Sewage Sludge Contacts

EPA Regional Sewage Sludge Contacts

REGION I

Thelma Hamilton (WMT-ZIN)
JFK Federal Building
One Congress Street
Boston, MA 02203
(617) 565-3569
Fax: (617) 565-4940

REGION 2

Alia Roufaeal
Water Management Division
26 Federal Plaza
New York, NY 10278
(212) 264-8663
Fax: (212) 264-9597

REGION 3

Ann Carkhuff (3WM55)
841 Chestnut Building
Philadelphia, PA 19107
(215) 597-9406
Fax: (215) 597-3359

REGION 4

Vince Miller
Water Division
345 Courtland Street, NE.
Atlanta, GA 30365
(404) 347-3012 (ext. 2953)
Fax: (404) 347-1739

REGION 5

Ash Sajjad (5WQP-16J)
Water Division
77 West Jackson Boulevard
Chicago, IL 60604-3590
(312) 886-6112
Fax: (312) 886-7804

REGION 6

Stephanie Kordzi (6-WPM)
Water Management Division
1445 Ross Avenue - Suite 1200
Dallas, TX 75202-2733
(214) 665-7520
Fax: (214) 655-6490

REGION 7

John Dunn
Water Management Division
726 Minnesota Avenue
Kansas City, KS 66101
(913) 551-7594
Fax: (913) 551-7765

REGION 8

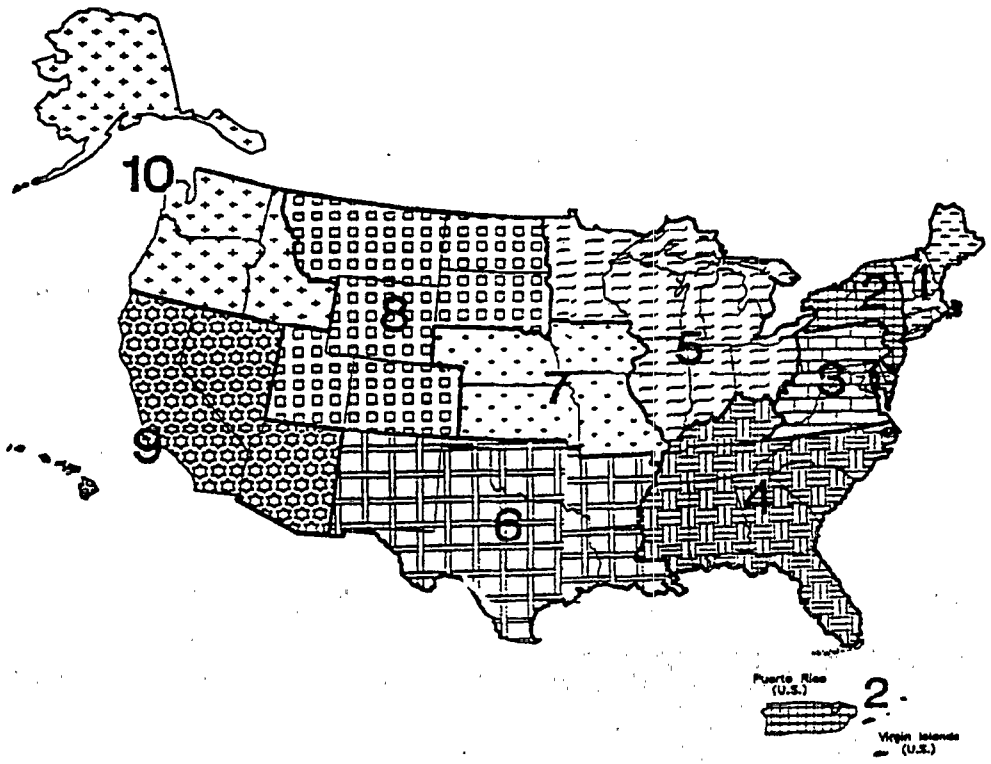
Bob Brobst (8WM-C)
Water Management Division
999 18th Street - Suite 500
Denver, CO 80202-2405
(303) 293-1627
Fax: (303) 294-1386

REGION 9

Lauren Fondahl
Permits Section
75 Hawthorne Street (W-5-2)
San Francisco, CA 94105
(415) 744-1909
Fax: (415) 744-1235

REGION 10

Dick Hetherington (WD-184)
Water Management Division
1200 Sixth Avenue
Seattle, WA 98101
(206) 553-1941
Fax: (206) 553-1775



ALPHABETICAL LISTING OF STATES

Region - State	Region - State	Region - State	Region - State
4 - Alabama	5 - Indiana	9 - Nevada	4 - Tennessee
10 - Alaska	7 - Iowa	1 - New Hampshire	6 - Texas
9 - Arizona	7 - Kansas	2 - New Jersey	8 - Utah
6 - Arkansas	4 - Kentucky	6 - New Mexico	1 - Vermont
9 - California	6 - Louisiana	2 - New York	3 - Virginia
8 - Colorado	1 - Maine	4 - North Carolina	10 - Washington
1 - Connecticut	3 - Maryland	8 - North Dakota	3 - West Virginia
3 - Delaware	1 - Massachusetts	5 - Ohio	5 - Wisconsin
3 - District of Columbia	5 - Michigan	6 - Oklahoma	8 - Wyoming
4 - Florida	5 - Minnesota	10 - Oregon	9 - American Samoa
4 - Georgia	4 - Mississippi	3 - Pennsylvania	9 - Guam
9 - Hawaii	7 - Missouri	1 - Rhode Island	2 - Puerto Rico
10 - Idaho	8 - Montana	4 - South Carolina	2 - Virgin Islands
5 - Illinois	7 - Nebraska	8 - South Dakota	

Figure B-1. Map of U.S. EPA Regions.

APPENDIX C
Manufacturers and Distributors of Equipment for Characterization and Monitoring of Sewage Sludge Surface Disposal Sites

In general, cost-effective equipment selection decisions require review of equipment specifications and costs from multiple sources. This appendix includes addresses and telephone numbers of more than 50 manufacturers and distributors of the types of equipment discussed in Chapter 6 (Field Investigations) and Chapter 10 (Monitoring). Table E-1 groups companies by the kinds of equipment they produce or distribute; Table E-2 provides addresses and telephone numbers for these sources. Inclusion of manufacturers and distributors in this appendix does not constitute U.S. EPA endorsement.

This appendix has been compiled from a variety of sources, and every effort has been made to make it comprehensive. Omission of any manufacturer or distributor of equipment in this appendix does not imply that that source is unsatisfactory.

Table C-1. Manufacturers and Distributors of Equipment for Characterization and Monitoring of Sewage Sludge Surface Disposal Sites

Topic	References
Soil Sampling Equipment	
Soil (Manual)	Associated Design & Manufacturing, Acker Drill Company, AMS, Ben Meadows, Christensen Boyles, CFE Equipment, Cole-Parmer Instrument, Concord, Drillers Services, Environmental Instruments, Forestry Suppliers, Geoprobe, Gilson Company, Hansen Machine Works, HAZCO Services, JMC/Clements Associates, Longyear U.S. Products, Oakfield Apparatus, Soiltest/ELE, Wheaton Environmental
Soil (Power-Driven)[1]	Acker Drill Company, AMS, Christensen Boyles, CFE Equipment, Concord, Forestry Suppliers, Geoprobe, Giddings Machine, Global Drilling Suppliers, KVA Analytical, Hogentogler, Longyear U.S. Products, Solinst Canada, Soiltest/ELE
Monitoring Equipment	
Piezometers	**Pneumatic:** Geokon, Longyear U.S. Products, Roctest, RST Instruments; **Electrical/Vibrating Wire:** Geokon, Longyear U.S. Products, Roctest, RST Instruments; **Small-Diameter Open-Tube:** Bartex, Solinst Canada, Soiltest/ELE, Slope Indicator, Timco
Direct Push Well Installations[2]	Applied Research Associates, Checkpoint Environmental (CheckWells), Geoprobe, Hogentogler (BAT© system), KVA Analytical, Pine and Swallow Associates (MicroWell© and VibraDrill©), Solinst Canada
Methane Monitoring	Biosystems, CEA Instruments, Dynamation, McNeill International, Neotronics, Sensidyne
Field/Small Laboratory Instrumentation	
GW Downhole Probes[3]	**Multiple-Parameter Probes:** Campbell Scientific (C/T), Design Analysis Associates (C/T), Geotech Environmental (C/T/pH/Eh/other), Horiba Instruments (C/T/pH/Tb), Hydrolab (C/T/ph/Eh/R/S/TDS/DO), In Situ (C/T), Martek Instruments (T/C/pH/Eh/DO); **Conductivity probes:** Solinst Canada, YSI; **ph Probes:** In SituGW Field Chemistry[3]
Sludge/Water Analysis	**Colorimetric Methods (Metals/NPDES Reporting):** EM Science, Hach Company; **Nitrate Ion-Selective Electrodes:** ATI/Orion, Hach Company, TM Analytic, Solomat; **Anodic Stripping Voltammetry:** Outokumpu; **X-Ray Fluorescence:** HNU Systems, Outokumpu, Spectrace.

[1] Sources of equipment small enough for transport or mounting in a van or pickup truck only.
[2] See also power-driven soil sampling equipment, which in most instances can also be used to drive well points.
[3] These instruments area usually used to monitor ground-water quality parameters during purging and sample collection.

Table C-2. Addresses and Telephone Numbers of Manufacturers and Distributors

Acker Drill Company, P.O. Box 830, Scranton, PA 18501; 800/752-2537. [Well drilling equipment, manual/power-driven/continuous soil samplers; purchased by Christensen Boyles Corporation in 1992]

ATI/Orion, The Schrafft Center, 529 Main St., Boston, MA 02129; 800/225-1480. [pH meters; nitrate and other ion selective electrodes]

Applied Research Associates, Inc., Waterman Rd. RFD 1, South Royalton, VT, 05068; 802/763-8348. [Direct-push ground-water sampler/well installation; cone penetration]

Art's Manufacturing and Supply (AMS), 105 Harrison, American Falls, ID 83211; 800/635-7330. [Manual/power-driven soil samplers (with liners); soil-gas samplers; surface water samplers (handle-grab); waste samplers (sludge grab sampler)]

Associated Design & Manufacturing Co., 814 N. Henry St., Alexandria, VA 22314; 703/549-5999 [Manual/subcore soil samplers]

Bartex, Inc., P.O. Box 3348, Annapolis, MD 21403; 301/261-2224. [Ground-water level measurement (acoustic/sonic); open-tube piezometer]

Ben Meadows Company, Inc., P.O. Box 80549, Atlanta (Chamblee), GA 30366; 800/241-6401. [Manual soil samplers (with liners)]

Biosystems, Inc., 5 Brookfield Drive, Middlefield, CT 06455; 203/344-1079. [Toxic/combustible gas detectors/sensors]

Campbell Scientific, Inc., 815 W. 1800 North, Logan, UT 84321; 801/750-9693. [Downhole temperature/conductivity probe]

CEA Instruments, Inc., 16 Chestnut St., Emerson, NJ 07630; 201/967-5660. [Toxic/combustible gas detectors/sensors]

C.F.E. Equipment, 9 South Peru Street, Plattsburgh, NY 12901; 800/665-6794. [Manual/power-driven soil (with liners)]

Checkpoint Environmental Science and Engineering, Acton, MA 01720; 508/369-8525. [Small-diameter wells installed with vibratory drill rig]

Christensen Boyles Corporation Products Division, 4446 West 1730 South, P.O. Box 30777, Salt Lake City, UT 84130; 800/453-8418, 801/974-5544. [Well drilling equipment (auger, rotary, core); manual/power-driven soil samplers]

Cole-Parmer Instrument Co., 7425 N. Oak Park Ave., Niles, IL 60714-9930; 800/323-4340; 708/647-7600. [Manual soil sampling (with liners); ground-water chemistry]

Concord, Inc., 2800 7th Ave. N., Fargo, ND 58102; 701/280-1260; [Manual/power-driven soil samplers (with liners)]

Design Analysis Associates, Inc., 75 W. 100 South, Logan, UT 84321; 801/753-2212. [Water level (pressure transducer)/temperature/conductivity probe]

Drillers Service, Inc., Environmental Products Division, 1972 Highland Ave. NE, P.O. Drawer 1407, Hickory, NC 28603; 800/334-2308. [Well drilling equipment; manual/power-driven soil samplers (with liners)]

Dynamation, 3784 Plaza Drive, Ann Arbor, MI 48108; 313/769-0573. [Portable toxic/combustible gas detectors]

EM Science, 480 Democrat Rd., P.O. Box 70, Gibbstown, NJ 08027; 800/222-0342, 609/354-9200. [Enzyme immunoassay for PCBs, TNT, RDX; wet chemistry colorimetric test kits for other constituents]

Environmental Instruments Co., 5650 Imhoff Drive, Suite A, Concord, CA 94520-5350; 800/648-9355. [Manual soil samplers (with liners); ground-water chemistry]

Forestry Suppliers, P.O. Box 8397, Jackson, MS 39284-8397; 800/647-5368. [Manual/power-driven soil samplers (with liners)]

Geokon, Inc., 48 Spencer St., Lebanon, NH 03766; 603/448-1562. [Ground-water level probes (electric); pneumatic/vibrating wire piezometers]

Geoprobe Systems, 607 Barney St., Salina, KS 67401; 913/825-1842. [Direct-push continuous soil/soil gas/ground-water (bailer) samplers and well installations]

Geotech Environmental Equipment, Inc., 1441 W. 46th Ave. #17, Denver, CO 80211; 303/433-7101. [Water chemistry (downhole C/T/pH/Eh probe, flow-through cell)]

Giddings Machine Company, 401 Pine Street, P.O. Box 2024, Fort Collins, CO 80522; 303/482-5586. [Hydraulic soil-core/auger samplers]

Gilson Company, Inc., P.O. Box 677, Worthington, OH 43085-0677; 800/444-1508. [Manual soil samplers (with liners); soil and ground-water chemistry]

Global Drilling Suppliers, Inc., 12101 Centron Place, Cincinnati, OH 45246; 800/356-6400. [Small portable auger and drilling unit; power-driven soil samplers]

Hach Company, P.O. Box 389, Loveland, CO 80539; 303/669-3050. [Colorimetric test kits for inorganics]

Hansen Machine Works, 1628 North C Street, Sacramento, CA 95814; 916/443-7755. [Veihmeyer soil probe]

HAZCO Services, Inc., 2006 Springboro West, Dayton, OH 45439; 800/332-0435. [Manual soil samplers (with liners); soil and ground-water chemistry]

HNU Systems, Inc., 160 Charlemont St., Newton, MA 02161-9987; 800/962-6032, 617/964-6690. [X-ray fluorescence; Hanby colorimetric field test kits]

Hogentogler & Co., Inc., P.O. Drawer 2219, Columbia, MD 21045; 800/638-8582. [Direct-push soil and ground-water samplers/well installations (BAT System)].

Table C-2. Addresses and Telephone Numbers of Manufacturers and Distributors (continued)

Horiba Instruments, Inc., 17671 Armstrong Ave., Irvine, CA 92714; 714/250-4811. [Ground-water chemistry (downhole C/T/pH/Tb probe, multiparameter/specific meters)]

Hydrolab Corp., P.O. Box 50116, Austin, TX 78763; 800/949-3766, 512/255-8841. [Ground-water chemistry (downhole C/T/ph/Eh/R/S/TDS/DO multiparameter probes)]

In Situ, Inc., 210 S. Third Street, P.O. Box 1, Laramie, WY 82070; 800/446-7488, 307/742-8213. [Water-level probes,; water chemistry (downhole pH and C/T probes, headspace)]

Isco Environmental Division, 531 Westgate Boulevard, Lincoln, NE 68528-1586; 800/228-4373, 402/474-4186. [Ground-water chemistry (flow-through cell)]

JMC/Clements Associates, Inc., RR 1 Box 186, Newton, IA 50208-9990; 800/247-6630. [Manual soil samplers (with liners)]

KVA Analytical Systems, P.O. Box 574, 281 Main St., Falmouth, MA 02541; 508/540-0561. [Direct push soil samplers/well installations; Division of K-V Associates, Inc.]

Longyear U.S. Products Group, Box 1959, Stone Mountain, GA 30086; 800/241-9468, 404/469-2720. [Hand/power-driven/continuous (GeoBarrel) soil samplers; pneumatic/vibrating wire piezometers; subsidiary of Longyear Company]

Martek Instruments, Inc., 6213-F Angus Dr., Raleigh, NC 27613; 800/722-2800, 919/781-8788. [Ground water chemistry (downhole T/C/pH/Eh/DO probes)

McNeill International, 7041 Hodgson Rd., Mentor, OH 44060; 800/MCNEILL. [Toxic/combustible gas detectors/sensors]

Neotronics, 2144 Hilton Drive SW, Gainesville, GA 30501-6153; 800/535-0606. [Toxic/combustible gas detectors/sensors]

Oakfield Apparatus Company, P.O. Box 65, Oakfield, WI 53065; 414/583-4114. [Manual soil samplers]

Outokumpu Electronics, Inc., 1900 N.E. Division St., Suite 204, Bend, OR 97701; 800/229-9209, 503/385-6748. [Field-portable X-ray fluorescence; anodic stripping voltammetry]

Pine & Swallow Associates, 867 Boston Road, Groton, MA 10450; 508/448-9511. [Small-diameter wells installed with vibratory drill rig; affiliated with ProTerra]

QED Ground-water Specialists, 6155 Jackson Rd., P.O. Box 3726, Ann Arbor, MI 48106; 800/624-2547, 313/995-2547 (MI), 415/930-7610 (CA). [Ground-water chemistry (flow-through cell)]

Roctest Inc., 7 Pond St. Plattsburgh, NY 12901-0118; 518/561-1192. [Pneumatic/vibrating wire piezometers]

RST Instruments, Inc., 241 Lynch Rd., Yakima, WA 98908; 509/965-1254. [Pneumatic/vibrating wire piezometers]

Sensidyne, 16333 Bay Vista Drive, Clearwater, FL 34620; 800/451-9444. [Toxic/combustible gas detectors/sensors; field chemistry test kits (hazardous chemicals, lead)]

Slope Indicator Co., P.O. Box 300316, Seattle, WA 98103-97316; 206/633-3073. [Vented piezometers]

Soiltest Products Division, ELE International, Inc., P.O. Box 8004, Lake Bluff, IL 60044; 800/323-1242. [Manual/power-driven soil samplers (with liners); open-tube piezometers; soil and water chemistry]

Solinst Canada, Ltd., 515 Main St., Glen Williams, Ontario L7G 3S9; 800/661-2023, 416/873-2255. [Power-driven thin-wall piston soil sampler (with liners); drive-point piezometers; ground-water chemistry (conductivity probe)]

Solomat-Neotronics, P.O. Box 370, Gainesville, GA, 30503; 800/765-6628. [Probes/datalogers (pH/C/DO/T/Tb/Eh/TDS/TSS, ion specific electrodes]

Spectrace Instruments, 345 East Middlefield Road, Mountain View, CA 94043; 414/967-0350. [Field-portable X-ray fluorescence]

Timco Mfg., Inc. P.O. Box 8, 851 Fifteenth St, Prairie du Sac, WI 53578; 800/236-8534, 608/643-8534. [Piezometers]

TM Analytic, Inc., 1106 N. Parsons Ave., Brandon, FL 33510; 813/684-2660. [Ion-specific electrodes]

Wheaton Environmental Products, 1301 North 10th Street, Millville, NY 08332-9854. 800/225-1437. [Manual soil samplers; ground-water chemistry]

YSI, Inc., Box 279, Yellow Springs, OH 45387; 800/765-4974, 513/767-7241. [Water chemistry (ground-water depth/conductivity probe, flow-through cell, multiparameter/specific meters/loggers: DO/T/C/pH/S/ammonia/Eh/Tb, DO, BOD)]

*U.S. GOVERNMENT PRINTING OFFICE: 1995-650-006/22073