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Solid Waste Disposal Facility Criteria

Technical Manual

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NOTICE

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TABLE OF CONTENTS

APPENDICES

INTRODUCTION

This manual was originally published in November, 1993 as a companion to the Criteria for Municipal Solid Waste Landfills (MSWLF Criteria) that were promulgated on October 9, 1991 as 40 CFR Part 258. Since that time the MSWLF Criteria have been modified several times due to statutory revisions and court decisions that are discussed below. Most of the modifications delayed the effective dates but all provisions are now effective. All changes to the rule are included in the text of the manual. The technical content of the manual did not require revision and only typographical errors were corrected.

The manual is now available in electronic format and can be accessed on the Environmental Protection Agency's (EPA) web site **<www.epa.gov/osw>**.

Purpose of This Manual

This technical manual has been developed to assist owners/operators of MSWLFs in achieving compliance with the revised MSWLF Criteria. This manual is not a regulatory document, and does not provide mandatory technical guidance, but does provide assistance for coming into compliance with the technical aspects of the revised landfill Criteria.

Implementation of the Landfill Criteria

The EPA fully intends that States and Tribes maintain the lead role in implementing and enforcing the revised Criteria. States will achieve this through approved State permit programs. Due to recent decisions by the courts, Tribes will do so using a case-by-case review process.[1] Whether in a State or in Indian Country, landfill owners/operators must comply with the revised[2] MSWLF Criteria.

Example of Technical and Performance Standards in 40 CFR Part 258: Liners

Technical standard:
MSWLFs must be built with a composite liner consisting of a 30 mil flexible membrane liner over 2 feet compacted soil with a hydraulic conductivity of no more than 1×10^{-7} cm/sec.

Performance standard:
MSWLFs must be built in accordance with a design approved by the Director of an approved State or as specified in 40 CFR § 258.40(e) for unapproved States. The design must ensure that the concentration values listed in Table 1 of 40 CFR § 258.40 will not be exceeded in the uppermost aquifer at the relevant point of compliance, as specified by the Director of an approved State under paragraph 40 CFR § 258.40(d).

State Process

The Agency's role in the regulation of MSWLFs is to establish national minimum standards that the states are to incorporate into their MSWLF permitting programs. EPA evaluates state

[1] The Agency originally intended to extend to Indian Tribes the same opportunity to apply for permit program approval as is available to States, but a court decision blocked this approach. See the **Tribal Process** section below for complete details.

[2] EPA finalized several revisions to 40 CFR Part 258 on October 1, 1993 (58 *FR* 51536) and issued a correction notice on October 14, 1993 (58 *FR* 53136). Questions regarding the final rule and requests for copies of the *Federal Register* notices should be made to the RCRA/Superfund Hotline at 800 424-9346.

MSWLF permitting programs under the procedures set out in 40 CFR Part 239, "Requirements for State Permit Program Determination of Adequacy," proposed on January 26, 1996 (61 *FR* 2584), to determine whether programs are adequate to ensure that MSWLF owners/operators comply with the federal standards. As of early 1998, 40 States and Territories had received full approval and another seven had received partial approval.

If their permitting programs have been approved by EPA, States can allow the use of flexible performance standards established in 40 CFR Part 258 in addition to the self-implementing technical standards for many of the Criteria. Approved States can provide owners/operators flexibility in satisfying the location restrictions, operating criteria, and requirements for liner design, ground-water monitoring, corrective action, closure and post-closure care, and financial assurance. This flexibility allows for the consideration of site-specific conditions in designing and operating a MSWLF at the lowest cost possible while ensuring protection of human health and the environment. In unapproved states, owners/operators must follow the self-implementing technical standards.

EPA continues to work with States toward approval of their programs and recommends that owners/operators stay informed of the approval status of the programs in their State. States may be in various stages of the program approval process. The majority of states have received full program approval and others have received "partial" program approval (i.e., only some portions of the State program are approved while the remainder of the program is pending approval). Regardless of a State's program approval status, landfill owners/operators must comply with the Criteria. States can grant flexibility to owners/operators only in the areas of their program that have been approved. For example, a state in which only the ground-water monitoring area of the permitting program has been approved by EPA cannot grant owners/operators flexibility to use alternative liner designs.

States are free to enact landfill regulations that are *more* stringent than the MSWLF Criteria. Certain areas of flexibility provided by the Criteria (e.g., the small landfill exemption) may not be reflected in a State program. In such instances, the owner/operator must comply with the more stringent provisions (e.g., no exemption). These regulations would be enforced by the State independently from the Criteria. **NOTE: The program requirements for approved States may differ from those described in this manual, which are based specifically on the Federal Criteria. Therefore, owners/operators are urged to work closely with their approved State in order to ensure that they are fully in compliance with all applicable requirements.**

State regulatory personnel will find this document helpful when reviewing permit applications for landfills. This manual presents technical information to be used in siting, designing, operating, and closing landfills, but does not present a mandatory approach for demonstrating compliance with the Criteria. This manual also outlines the types of information relevant to make the demonstrations required by the Criteria, including demonstrations for restricted locations and performance-based designs in approved States.

Tribal Process

From the beginning of EPA's development of the permitting program approval process, the Agency planned to offer permitting program approval to tribes as well as to states. In a 1996 court decision[3], however, the court ruled that EPA cannot approve tribal permitting programs. The Agency has therefore developed a site-specific rulemaking process to meet its goal of quickly and efficiently providing owners/operators in Indian Country[4] the same flexibility that is available to landfill owners/operators in states with EPA-approved MSWLF permitting programs. The process is described in *Site-Specific Flexibility Requests for Municipal Solid Waste Landfills in Indian Country—Draft Guidance* (EPA530-R-97-016).

Under this process, an owner or operator can request to use certain alternative approaches at a specific MSWLF site to meet the 40 CFR Part 258 performance standards. Unless the tribal government is the owner/operator, the tribal government should review the request for consistency with tribal law and policy and forward it to EPA with a recommendation. If EPA approves a request, it will issue a site-specific rule allowing the use of the requested alternative approaches. Owners/operators in Indian Country should therefore understand that when this manual refers to areas of flexibility that can be granted by a "State Director," they would instead seek such flexibility in the form of a site-specific rulemaking from EPA after tribal government review of their petition for rulemaking. Although tribes will not issue permits as EPA-approved permitting entities under the Criteria, they are free to enact separate tribal landfill regulations that are more stringent than the Criteria. Tribal regulations are enforced by the tribe independently of the Criteria.

The site-specific process encourages active dialogue among tribes, MSWLF owners/operators, EPA, and the public. The guidance is designed so that the Agency works in partnership with tribes. Because EPA recognizes tribal sovereignty, EPA will respect tribal findings concerning consistency of proposed approaches with tribal law and policy.

Revisions to Part 258

Some important changes have been made to Part 258 since its original promulgation. In addition, other regulations that affect solid waste management have been implemented.

Ground-Water Monitoring Exemption for Small, Dry, and Remote Landfills (40 CFR § 258.1(f)(1))

The Land Disposal Program Flexibility Act (LDPFA) of 1996 reestablished an exemption for ground-water monitoring for owners/operators of certain small MSWLFs. EPA revised 40 CFR § 258.1(f)(1) on September 25, 1996 (61 *FR* 50409) to codify the LDPFA ground-water monitoring exemption. To qualify for an exemption, owners/operators must accept less than 20 tons per day of MSW (based on an annual average), have no evidence of ground-water contamination, and be located in either a dry or remote location. This exemption eases the burden on certain small MSWLFs without compromising ground-water quality.[5]

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[3] *Backcountry Against Dumps v. EPA*, 100 F.3d 147 (D.C. Cir. 1996).

[4] This manual uses the term "Indian Country" as defined in 40 CFR § 258.2.

[5] In the original 40 CFR Part 258 rulemaking, promulgated October 9, 1991, the Agency provided an exemption from ground-water monitoring for small MSWLF units located in dry or remote locations. In 1993, the U.S. Court of Appeals for the District of Columbia set aside this ground-water monitoring exemption. *Sierra Club v. EPA*, 992 F.2d 337 (D.C. Cir. 1993).

New Flexibility for Small Landfills (40 CFR §§ 258.21, 258.23, 258.60)

In addition to reestablishing the ground-water exemption for small, dry, and remote MSWLFs, the LDPFA provided additional flexibility to approved states for any small landfill that receives 20 tons or less of MSW per day. EPA revised 40 CFR Part 258 to allow approved states to grant the use of alternative frequencies of daily cover, alternative frequencies of methane monitoring, and alternative infiltration layers for final cover (62 *FR* 40707 (July 29, 1997)). The LDPFA also authorized flexibility to establish alternative means for demonstrating financial assurance, and this flexibility was granted in another action. The additional flexibility will allow owners and operators of small MSWLFs the opportunity to reduce their costs of MSWLF operation while still protecting human health and the environment.

Added Financial Assurance Options (40 CFR § 258.74)

A revision to 40 CFR Part 258, published November 27, 1996 (61 *FR* 60328), provided additional options to the menu of financial assurance instruments that MSWLF owners/operators can use to demonstrate that adequate funds will be readily available for the costs of closure, post-closure care, and corrective action for known releases associated with their facilities. The existing regulations specify several mechanisms that owners and operators may use to make that demonstration, such as trust funds and surety bonds. The additional mechanisms are a financial test for use by local government owners and operators, and a provision for local governments that wish to guarantee the closure, post-closure, and corrective action costs for an owner or operator. These financial assurance options allow local governments to use their financial strength to avoid incurring the expenses associated with the use of third-party financial instruments. This action granted the flexibility to all owners and operators (including owners and operators of small facilities) to establish alternative means for demonstrating financial assurance as envisioned in the LDPFA.

Additionally, EPA promulgated a regulation allowing corporate financial tests and corporate guarantees as financial assurance mechanisms that private owners and operators of MSWLFs may use to demonstrate financial assurance (63 *FR* 17706 (April 10, 1998)). This test extends to private owners and operators the regulatory flexibility already provided to municipal owners or operators of MSWLFs. These regulations allow firms to demonstrate financial assurance by passing a financial test. For firms that qualify for the financial test, this mechanism will be less costly than the use of a third party financial instrument such as a trust fund or a surety bond.

<u>How to Use This Manual</u>

This document is subdivided into six chapters arranged to follow the order of the Criteria. The first chapter addresses the general applicability of the Part 258 Criteria; the second covers location restrictions; the third explains the operating requirements; the fourth discusses design standards; the fifth covers ground-water monitoring and corrective action; and the sixth chapter addresses closure and post-closure care. Each chapter contains an introduction to that section of the Criteria. This document does not include a section on the financial responsibility requirements;

questions regarding these requirements may be addressed to EPA's RCRA/Superfund Hotline at 800 424-9346.

Within each chapter, the Criteria have been subdivided into smaller segments. The *Statement of Regulation* section provides a verbatim recital of the regulatory language. The second section, entitled *Applicability*, provides a general explanation of the regulations and who must comply with them. Finally, for each segment of the regulation, a *Technical Considerations* section identifies key technical issues that may need to be addressed to ensure compliance with a particular requirement. Each chapter ends with a section entitled *Further Information*, which provides references, addresses, organizations, and other information that may be of use to the reader.

Limitations of This Manual

The ability of this document to provide current guidance is limited by the technical literature that was available at the time of preparation. Technology and product development are advancing rapidly, especially in the areas of geosynthetic materials and design concepts. As experience with new waste management techniques expands in the engineering and science community, an increase in published literature, research, and technical information will follow. The owners and operators of MSWLFs are encouraged to keep abreast of innovation through technical journals, professional organizations, and technical information developed by EPA. Many of the Criteria contained in Part 258 are performance-based. Future innovative technology may provide additional means for owners/operators to meet performance standards that previously could not be met by a particular facility due to site-specific conditions.

Deadlines and Effective Dates

The original effective date for the Criteria, October 9, 1993, was revised for several categories of landfills, in response to concerns that a variety of circumstances was hampering some communities' abilities to comply by that date. Therefore, the Agency provided additional time for certain landfills to come into compliance, especially small units and those that accepted waste from the 1993 Midwest floods. As the accompanying table indicates, the extended general effective dates for all MSWLF categories have passed, and all units should now be in compliance.

SUMMARY OF CHANGES TO THE EFFECTIVE DATES OF THE MSWLF CRITERIA

	MSWLF Units Accepting Greater than 100 TPD	**MSWLF Units Accepting 100 TPD or Less; Are Not on the NPL; and Are Located in a State That Has Submitted an Application for Approval by 10/9/93, or on Indian Lands or Indian Country**	**MSWLF Units That Meet the Small Landfill Exemption in 40 CFR §258.1(f)**	**MSWLF Units Receiving Flood-Related Waste**
General effective date.[1,2,3] This is the effective date for location, operation, design, and closure/post-closure.	October 9, 1993	April 9, 1994	October 9, 1997; exempt from the design requirements	Up to October 9, 1994 as determined by State
Date by which to install final cover if cease receipt of waste by the general effective date.[2,3]	October 9, 1994	October 9, 1994	October 9, 1998	Within one year of date determined by State; no later than October 9, 1995
Effective date of ground-water monitoring and corrective action.[2,3]	Prior to receipt of waste for new units; October 9, 1994 through October 9, 1996 for existing units and lateral expansions	October 9, 1993 for new units; October 9, 1994 through October 9, 1996 for existing units and lateral expansions	Exempt from the ground-water monitoring requirements.[5]	October 9, 1993 for new units; October 9, 1994 through October 9, 1996 for existing units and lateral expansions
Effective date of financial assurance requirements.[3,4]	April 9, 1997	April 9, 1997	October 9, 1997	April 9, 1997

[1] If a MSWLF unit receives waste after this date, the unit must comply with all of Part 258.
[2] See the final rule and preamble published on October 1, 1993 (58 FR 51536) for a full discussion of all changes and related conditions.
[3] See the final rule and preamble published on October 6, 1995 (60 FR 52337) for a full discussion of all changes and related conditions.
[4] See the final rule and preamble published on April 7, 1995 (60 FR 17649) for a discussion of this delay.
[5] See the final rule and preamble published on September 25, 1990 (61 FR 50409) for a discussion of the ground-water monitoring exemption.

CHAPTER 1

SUBPART A
GENERAL

CHAPTER 1
SUBPART A

TABLE OF CONTENTS

CHAPTER 1
SUBPART A
GENERAL

1.1 INTRODUCTION

Under the authority of both the Resource Conservation and Recovery Act (RCRA), as amended by the Hazardous and Solid Waste Amendments (HSWA) of 1984, and Section 405 of the Clean Water Act, the EPA issued "Solid Waste Disposal Facility Criteria" (40 CFR Part 258) on October 9, 1991. These regulations revise the "Criteria for Classification of Solid Waste Disposal Facilities and Practices," found in 40 CFR Part 257. Part 258 was established to provide minimum national criteria for all solid waste landfills that are not regulated under Subtitle C of RCRA, and that:

- Receive municipal solid waste; or
- Co-dispose sewage sludge with municipal solid waste; or
- Accept nonhazardous municipal waste combustion ash.

Part 257 remains in effect for all other non-hazardous solid waste facilities and practices.

Subpart A of the regulations defines the purpose, scope, and applicability of Part 258 and provides definitions necessary for proper interpretation of the requirements. In summary, the applicability of the Criteria is dependent on the operational status of the MSWLF unit relative to the date of publication of Part 258 and the effective date of the rule (October 9, 1993). An exemption from the design requirements is provided for small MSWLF units if specific operating, environmental, and location conditions are present. [The final rule as promulgated on October 9, 1991 exempted the owner/operators of small landfill units from both Subparts D and E. On May 7, 1993 the U.S. Court of Appeals for the District of Columbia Circuit issued an opinion that EPA did not have the authority to exempt these small landfills from the ground-water monitoring requirements (Subpart E), therefore, these small landfills can not be exempted from Subpart E. EPA is delaying the date of compliance for these units until October 9, 1995 (58 FR 51536). In addition, the Agency is investigating alternative ground-water monitoring procedures for these units.]

Owners or operators of MSWLF units that do not meet the Part 258 Criteria will be considered to be engaging in the practice of "open dumping" in violation of Section 4005 of RCRA. Similarly, owners and operators of MSWLF units that receive sewage sludge and do not comply with these Criteria will also be in violation of applicable sections of the Clean Water Act.

1.2 PURPOSE, SCOPE, AND APPLICABILITY 40 CFR §258.1 (a)(b)

1.2.1 Statement of Regulation

(a) The purpose of this part is to establish minimum national criteria under the Resource Conservation and Recovery Act (RCRA or the Act), as amended, for all municipal solid waste landfill (MSWLF) units and under the Clean Water Act, as amended, for municipal solid waste landfills that are used to dispose of sewage sludge. These minimum national criteria ensure the protection of human health and the environment.

(b) These Criteria apply to owners and operators of new MSWLF units, existing MSWLF units, and lateral expansions, except as otherwise specifically provided in this part; all other solid waste disposal facilities and practices that are not regulated under Subtitle C of RCRA are subject to the criteria contained in Part 257.

1.2.2 Applicability

Owners and operators of MSWLF units that receive municipal solid waste or that receive municipal waste combustion ash and are not currently regulated under Subtitle C of RCRA must comply with the Criteria. Furthermore, MSWLF units that receive and co-dispose sewage sludge must comply with Part 258 to be in compliance with Sections 309 and 405(e) of the Clean Water Act.

1.2.3 Technical Considerations

Criteria that define a solid waste disposal facility are contained within Part 257 of RCRA (Criteria for Classification of Solid Waste Disposal Facilities and Practices). Definitions pertaining to the revised Criteria are included in the definition section of Part 258. A MSWLF unit is defined as a discrete area of land or excavation that receives household waste, and that is not considered a land application unit, surface impoundment, injection well, or waste pile as those terms are defined under §257.2. An existing unit is a solid waste disposal unit that is receiving solid waste as of October 9, 1993. A lateral expansion is a horizontal expansion of the waste boundaries of an existing MSWLF unit. A new unit is a MSWLF unit that has not received waste before October 9, 1993.

In addition to household waste, a MSWLF unit may receive commercial waste, non-hazardous solid waste from industrial facilities including non-hazardous sludges, and sewage sludge from wastewater treatment plants. The terms commercial solid waste, industrial waste and household waste are defined in §258.2 (Definitions).

The types of landfills regulated under Part 257 include those facilities that receive:

- Construction and demolition debris only;
- Tires only; and
- Non-hazardous industrial waste only.

MSWLF units are not intended, nor allowed, to receive regulated quantities of hazardous wastes. Should a MSWLF owner/operator discover that a shipment contains regulated quantities of hazardous waste while still in the possession of the transporter, the owner/operator should refuse to accept the waste from the transporter. If regulated quantities of hazardous wastes are discovered after accepting the waste from the transporter, the owner/operator must return the shipment or manage the wastes in accordance with RCRA Subtitle C requirements.

Subtitle C of RCRA establishes procedures for making a hazardous waste determination. These procedures are summarized in Chapter 3 and Appendix B of this document.

1.3 PURPOSE, SCOPE, AND APPLICABILITY (cont.) 40 CFR §258.1 (c)-(e)

1.3.1 Statement of Regulation*

***[NOTE: EPA finalized several revisions to 40 CFR Part 258 on October 1, 1993 (58 FR 51536) and issued a correction notice on October 14, 1993 (58 FR 53136). These revisions delay the effective date for some categories of landfills. More detail on the content of the revisions is included in the introduction.]**

(c) These Criteria do not apply to municipal solid waste landfill units that do not receive waste after October 9, 1991.

(d) MSWLF units that receive waste after October 9, 1991 but stop receiving waste before October 9, 1993 are exempt from all the requirements of Part 258, except the final cover requirement specified in Section 258.60(a). The final cover must be installed within six months of last receipt of wastes. Owners or operators of MSWLF units described in this paragraph that fail to complete cover installation within this six month period will be subject to all the requirements of Part 258, unless otherwise specified.

(e) All MSWLF units that receive waste on or after October 9, 1993 must comply with all requirements of Part 258 unless otherwise specified.

1.3.2 Applicability

The applicability of Part 258, in its entirety or with exemptions to specific requirements, is based upon the operational status of the MSWLF unit relative to the date of publication, October 9, 1991, or the effective date of the rule, October 9, 1993 (see Figure 1-1). Three possible operational scenarios exist:

(1) The MSWLF unit received its last load of waste prior to October 9, 1991. These facilities are exempt from all requirements of the Criteria.

(2) The last load of waste was received after October 9, 1991, but before October 9, 1993. The owners and operators must comply only with the final cover requirements of §258.60(a). If the final cover is not installed within six (6) months of the last receipt of wastes, the owners and operators will be required to comply with all requirements of Part 258.

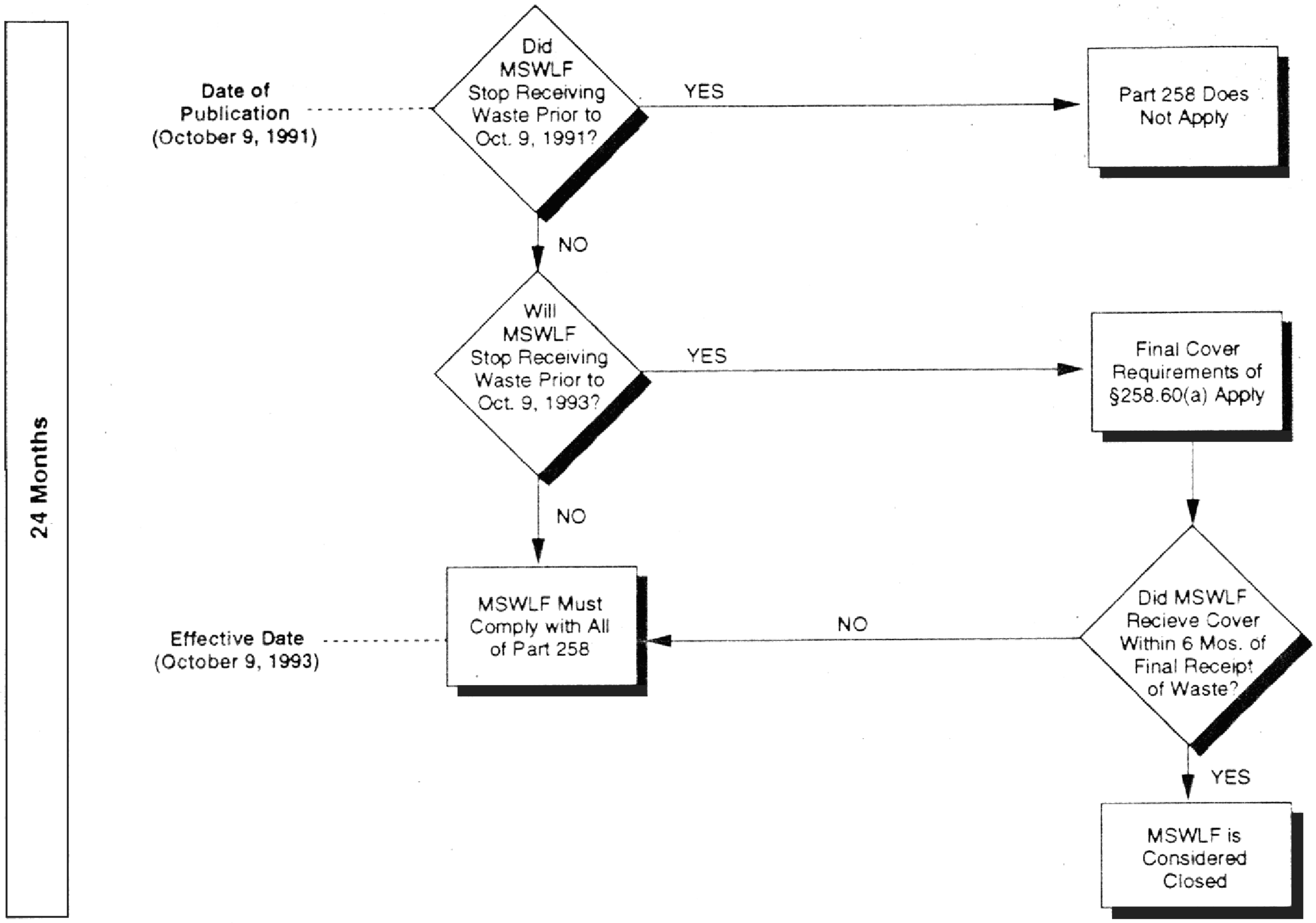


Figure 1-1
Applicability Flow Chart

(3) The MSWLF unit continues to receive waste after October 9, 1993. The owners or operators must comply with all requirements of Part 258, except where specified otherwise.

1.3.3 Technical Considerations

MSWLF units that receive the last load of waste between October 9, 1991 and October 9, 1993, must complete closure within six months of the last receipt of waste. Closure requirements are specified in Subpart F; however, these MSWLF units will be subject only to the closure requirements of §258.60(a) unless they fail to complete closure within the six-month period. The alternative cover design is not an option for MSWLF units in unapproved States.

The final cover system must be designed to minimize infiltration and erosion. The final cover must have a permeability that is 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. The system must be composed of an erosion layer that consists of at least six inches of an earthen material capable of sustaining native plant growth and an infiltration layer that is composed of at least 18 inches of an earthen material. However, if a MSWLF unit is constructed with a synthetic membrane in the liner system, it is anticipated that the final cover also will require a synthetic liner. Currently, it is not possible to construct an earthen liner with a permeability less than or equal to a synthetic membrane. Detailed technical considerations for the cover requirements under §258.60(a) are provided in Chapter 6.

1.4 SMALL LANDFILL EXEMPTIONS 40 CFR §258.1 (f)

1.4.1 Statement of Regulation

(f)(1) Owners or operators of new MSWLF units, existing MSWLF units, and lateral expansions that dispose of less than twenty (20) tons of municipal solid waste daily, based on an annual average, are exempt from subparts D ~~[and E]~~[*] of this Part, so long as there is no evidence of existing ground-water contamination from the MSWLF unit and the MSWLF unit serves:

(i) A community that experiences an annual interruption of at least three consecutive months of surface transportation that prevents access to a regional waste management facility, or

(ii) A community that has no practicable waste management alternative and the landfill unit is located in an area that annually receives less than or equal to 25 inches of precipitation.

(2) Owners or operators of new MSWLF units, existing MSWLF units, and lateral expansions that meet the criteria in (f)(1)(i) or (f)(1)(ii) must place in the operating record information demonstrating this.

(3) If the owner or operator of a new MSWLF unit, existing MSWLF unit, or lateral expansion has knowledge of ground-water contamination resulting from the unit that has asserted the exemption in (f)(1)(i) or (ii), the owner or operator must notify the State

Director of such contamination and, thereafter, comply with Subparts D [~~and E~~]* of this Part.

* [Note: On May 7, 1993 the U.S. Court of Appeals for the District of Columbia Circuit issued an opinion that EPA did not have the authority to exempt these small landfills from the ground-water monitoring requirements (Subpart E), therefore, these small landfills can not be exempted from Subpart E. EPA is delaying the date of compliance for these units until October 9, 1995 (58 FR 51536; October 1, 1993).]

1.4.2 Applicability

The exemption from Subpart D (Design) is applicable only to owners or operators of landfill units that receive, on an annual average, less than 20 tons of solid waste per day. The exemption is allowed so long as there is no evidence of existing ground-water contamination from the MSWLF unit. In addition, the MSWLF unit must serve a community that meets one of the following two conditions:

- For at least three consecutive months of the year, the community's municipal solid waste cannot be transported by rail, truck, or ship to a regional waste management facility; or

- There is no practicable alternative for managing wastes, and the landfill unit is located in an area that receives less than 25 inches of annual precipitation.

If either of the above two conditions is met, and there is no evidence of existing ground-water contamination, the landfill unit owner or operator is eligible for the exemption from the design, ground-water monitoring, and corrective action requirements. The owner or operator must place information documenting eligibility for the exemption in the facility's operating record. Once an owner or operator can no longer demonstrate compliance with any of the conditions of the exemption, the MSWLF facility must be in compliance with Subpart D.

1.4.3 Technical Considerations

The weight criterion of 20 tons does not have to be based on actual weight measurements but may be based on weight or volume estimates. If the daily waste receipt records, which include load weights, are not available for the facility, waste volumes can be estimated by using conversion factors of 1 ton = two to three cubic yards per ton depending on the type of compaction used at the MSWLF unit. Waste weights may be determined by counting the number of trucks and estimating an average weight for each.

To determine the daily waste received, an average may be used. If the facility is not open on a daily basis, the average number should reflect that fact. For example, if a facility is open four days per week (208 days/year) and accepts 25 tons each day, then the average daily amount of waste received can be calculated as follows:

Average Daily Waste Calculation

4 days/week x 52 weeks/year = 208 days/year; and

25 tons/day x 208 days/year = 5200 tons/year; then

5200 tons/year ÷ 365 days/year = 14.25 tons/day.

The facility would meet the criteria for receiving less than 20 tons per day.

Compliance with the 20 tons per day criterion should be based on all waste received, including household waste and agricultural or industrial wastes. As defined in the regulations, household waste includes any solid waste (including garbage, trash, and sanitary waste in septic tanks) derived from households (including single and multiple residences, hotels and motels, bunkhouses, ranger stations, crew quarters, campgrounds, picnic grounds, and day-use recreation areas).

The exemption from Subpart D requires that there be "no evidence of existing ground-water contamination" as a condition for eligibility. Evidence of contamination may include detected or known contamination of nearby drinking water wells, or physical evidence such as stressed vegetation that is attributable to the landfill.

One of two other conditions must be present for the exemption to apply. The first of these conditions is an annual interruption in transportation for at least three consecutive months. For example, some rural villages in Alaska may be restricted from transporting wastes to a regional facility due to extreme winter climatic conditions. These villages would find it impossible to transport wastes to a regional waste facility for at least three months out of the year due to snow and ice accumulation.

The second condition is composed of two requirements: (1) the lack of a practicable waste management alternative; and (2) a location that receives little rainfall. The exemption applies only to those areas that meet both requirements.

The determination of a "practicable waste management alternative" includes consideration of technical, economic, and social factors. For example, some small rural communities, especially in the western part of the United States, are located great distances from alternative waste management units (other MSWLF units, composting facilities, municipal waste combustors, transfer stations, etc.) making regionalization of waste management difficult.

Furthermore, many rural communities are located in arid areas that receive 25 inches or less of precipitation annually, which reduces the likelihood of ground-water contamination because of lessened leachate generation and contaminant migration. Rainfall information can be obtained from the National Weather Service, the National Oceanographic and Atmospheric Administration (NOAA), and the United States Geological Survey (USGS) Water Atlases.

1.5 APPLICABILITY
40 CFR §258.1 (g)-(j)

1.5.1 Statement of Regulation

(g) Municipal solid waste landfill units failing to satisfy these criteria are considered open dumps for purposes of State solid waste management planning under RCRA.

(h) Municipal solid waste landfill units failing to satisfy these criteria constitute open dumps, which are prohibited under Section 4005 of RCRA.

(i) Municipal solid waste landfill units containing sewage sludge and failing

to satisfy these Criteria violate sections 309 and 405(e) of the Clean Water Act.

(j) The effective date of this part is October 9, 1993, unless otherwise specified.*

***[NOTE: EPA finalized several revisions to 40 CFR Part 258 on October 1, 1993 (58 FR 51536) and issued a correction notice on October 14, 1993 (58 FR 53136). These revisions delay the effective date for some categories of landfills. More detail on the content of the revisions is included in the introduction.]**

1.5.2 Applicability

All MSWLF facilities that receive waste on or after the effective date must comply with all of Part 258 except where otherwise noted. MSWLF facilities that fail to comply with the Part 258 Criteria will be in violation of Section 4005 of RCRA and with Sections 309 and 405(e) of the Clean Water Act if the facility receives sewage sludge.

1.5.3 Technical Considerations

Failure to comply with the Part 258 Criteria will result in a MSWLF unit being categorized as an open dump under Section 4005 of RCRA. The practice of operating an open dump is prohibited.

If a MSWLF unit co-disposes sewage sludge with municipal solid waste and fails to comply with Part 258, it also will be in violation of Section 405(e) of the Clean Water Act (CWA), which requires that sewage sludge be disposed of in accordance with regulations established for such disposal. If found to be in violation, owners or operators may be liable for both civil and criminal actions enforced under Section 309 of the Clean Water Act.

1.6 DEFINITIONS
40 CFR §258.2

1.6.1 Statement of Regulation

Unless otherwise noted, all terms contained in this part are defined by their plain meaning. This section contains definitions for terms that appear throughout this Part; additional definitions appear in the specific sections to which they apply.

Active life means the period of operation beginning with the initial receipt of solid waste and ending at completion of closure activities in accordance with §258.60 of this Part.

Active portion means that part of a facility or unit that has received or is receiving wastes and that has not been closed in accordance with §258.60 of this Part.

Aquifer means a geological formation, group of formations, or portion of a formation capable of yielding significant quantities of ground water to wells or springs.

Commercial solid waste means all types of solid waste generated by stores, offices, restaurants, warehouses, and other non-manufacturing activities, excluding residential and industrial wastes.

<u>Director of an approved State</u> means the chief administrative officer of the State agency responsible for implementing the State municipal solid waste permit program or other system of prior approval that is deemed to be adequate by EPA under regulations published pursuant to section 4005 of RCRA.

<u>Existing MSWLF unit</u> means any municipal solid waste landfill unit that is receiving solid waste as of the effective date of this Part. Waste placement in existing units must be consistent with past operating practices or modified practices to ensure good management.

<u>Facility</u> means all contiguous land and structures, other appurtenances, and improvements on the land used for the disposal of solid waste.

<u>Ground water</u> means water below the land surface in a zone of saturation.

<u>Household waste</u> means any solid waste (including garbage, trash, and sanitary waste in septic tanks) derived from households (including single and multiple residences, hotels and motels, bunkhouses, ranger stations, crew quarters, campgrounds, picnic grounds, and day-use recreation areas).

<u>Industrial solid waste</u> means solid waste generated by manufacturing or industrial processes that is not a hazardous waste regulated under Subtitle C of RCRA. Such waste may include, but is not limited to, waste resulting from the following manufacturing processes: Electric power generation; fertilizer/agricultural chemicals; food and related products/by-products; inorganic chemicals; iron and steel manufacturing; leather and leather products; nonferrous metals manufacturing/foundries; organic chemicals; plastics and resins manufacturing; pulp and paper industry; rubber and miscellaneous plastic products; stone, glass, clay, and concrete products; textile manufacturing; transportation equipment; and water treatment. This term does not include mining waste or oil and gas waste.

<u>Lateral expansion</u> means a horizontal expansion of the waste boundaries of an existing MSWLF unit.

<u>Leachate</u> means a liquid that has passed through or emerged from solid waste and contains soluble, suspended, or miscible materials removed from such waste.

<u>Municipal solid waste landfill unit</u> means a discrete area of land or an excavation that receives household waste, and that is not a land application unit, surface impoundment, injection well, or waste pile, as those terms are defined under §257.2. A MSWLF unit also may receive other types of RCRA Subtitle D wastes, such as commercial solid waste, nonhazardous sludge, conditionally exempt small quantity generator waste, and industrial solid waste. Such a landfill may be publicly or privately owned. A MSWLF unit may be a new MSWLF unit, an existing MSWLF unit or a lateral expansion.

<u>New MSWLF unit</u> means any municipal solid waste landfill unit that has not received waste prior to the effective date of this Part.

Open burning means the combustion of solid waste without:

(1) Control of combustion air to maintain adequate temperature for efficient combustion,

(2) Containment of the combustion reaction in an enclosed device to provide sufficient residence time and mixing for complete combustion, and

(3) Control of the emission of the combustion products.

Operator means the person(s) responsible for the overall operation of a facility or part of a facility.

Owner means the person(s) who owns a facility or part of a facility.

Run-off means any rainwater, leachate, or other liquid that drains over land from any part of a facility.

Run-on means any rainwater, leachate, or other liquid that drains over land onto any part of a facility.

Saturated zone means that part of the earth's crust in which all voids are filled with water.

Sludge means any solid, semi-solid, or liquid waste generated from a municipal, commercial, or industrial wastewater treatment plant, water supply treatment plant, or air pollution control facility exclusive of the treated effluent from a wastewater treatment plant.

Solid waste means any garbage, or refuse, sludge from a wastewater treatment plant, water supply treatment plant, or air pollution control facility and other discarded material, including solid, liquid, semi-solid, or contained gaseous material resulting from industrial, commercial, mining, and agricultural operations, and from community activities, but does not include solid or dissolved materials in domestic sewage, or solid or dissolved materials in irrigation return flows or industrial discharges that are point sources subject to permit under 33 U.S.C. 1342, or source, special nuclear, or by-product material as defined by the Atomic Energy Act of 1954, as amended (68 Stat. 923).

State means any of the several States, the District of Columbia, the Commonwealth of Puerto Rico, the Virgin Islands, Guam, American Samoa, and the Commonwealth of the Northern Mariana Islands.

State Director means the chief administrative officer of the State agency responsible for implementing the State municipal solid waste permit program or other system of prior approval.

Uppermost aquifer means the geologic formation nearest the natural ground surface that is an aquifer, as well as lower aquifers that are hydraulically interconnected with this aquifer within the facility's property boundary.

Waste management unit boundary means a vertical surface located at the hydraulically downgradient limit of the unit. This vertical surface extends down into the uppermost aquifer.

1.6.2 Applicability

The definitions are applicable to all new, existing, and lateral expansions of existing MSWLF units regulated under 40 CFR §258. Additional definitions are provided within the body of the regulatory language and will apply to those particular sections. Definitions in Subpart A apply to all Sections of Part 258.

1.6.3 Technical Considerations

Selected definitions will be discussed in the following brief narratives.

Approved State: Section 4005(c) of RCRA requires that each State adopt and implement a State permit program. EPA is required to determine whether the State has developed an adequate program. States have primary responsibility for implementation and enforcement of the Criteria. EPA has the authority to enforce the Criteria in States where EPA has deemed the permit program to be inadequate. The Agency intended to extend to Indian Tribes the same opportunity to apply for permit program approval as is available to States. A federal court ruled, however, in *Backcountry Against Dumps v. EPA*, 100 F.3d 147 (D.C. Cir. 1996), that EPA cannot do so. The Agency therefore developed a site-specific rulemaking process to provide warranted flexibility to owners and operators of MSWLFs in Indian Country. Obtain the draft guidance document *Site-Specific Flexibility Requests for Municipal Solid Waste Landfills in Indian Country* (EPA 530-R-97-016) for further information.

Aquifer: An aquifer is a formation or group of formations capable of yielding a significant amount of ground water to wells or springs. To be an aquifer, a formation must yield enough water for ground-water monitoring samples. An unconfined aquifer is one where the water table is exposed to the atmosphere through openings in the overlying geologic formations. A confined aquifer is isolated from the atmosphere at the discharge point by impermeable geological units. A confined aquifer has relatively impermeable beds above and below.

Existing unit: Any MSWLF unit that is receiving household waste as of October 9, 1993 must continue to operate the facility in a manner that is consistent with both past operating practices and modified practices that continue or improve good waste management. Changes in operating practices intended to circumvent the purpose, intent, or applicability of any portions of Part 258 will not be considered in conformance with the Criteria. Facilities spreading a thin layer of waste over unused new areas will not be exempt from the design requirements for new units. The portion of a facility that is considered to be an existing unit will include the waste management area that has received waste prior to the effective date of Part 258. Existing units may expand vertically. However, vertical placement of waste over a closed unit would cause the unit to be considered a new unit and would subject the unit to the design requirements in Part 258.

Note: Not all units that have a valid State permit are considered existing units. To be an existing unit, the land surface must be covered by waste by October 9, 1993.

Lateral expansion: Any horizontal expansion of the waste boundary of a unit is a lateral expansion. This means that new land surface would be covered by waste after October 9, 1993. Expansions to the existing unit have to be consistent with past operating procedures or operating practices to ensure good management.

Spreading wastes over a large area to increase the size of an existing unit, prior to the effective date would not be consistent with good management practices. If a new land surface adjacent to an existing unit first receives waste after October 9, 1993, that area is classified as a lateral expansion and therefore, is subject to the new design standards. However, Part 258 regulations provide the flexibility for approved States to determine what would constitute a lateral expansion.

Municipal solid waste landfill unit: Municipal solid waste landfill units are units that receive household waste, such as that from single and multiple residences, hotels and motels, bunkhouses, ranger stations, crew quarters, campgrounds, picnic grounds and day-use recreation areas. Other Subtitle D wastes, such as commercial solid waste, nonhazardous sludge, and industrial solid waste, may be disposed of in a municipal solid waste landfill.

New municipal solid waste landfill unit: A new MSWLF unit is any unit that has not received waste prior to October 9, 1993. Lateral expansions are considered new MSWLF units for the purpose of location restrictions and design standards. New MSWLF units are subject to all requirements of Part 258.

1.7 CONSIDERATION OF OTHER FEDERAL LAWS 40 CFR §258.3

1.7.1 Statement of Regulation

The owner or operator of a municipal solid waste landfill unit must comply with any other applicable Federal rules, laws, regulations, or other requirements.

1.7.2 Applicability

Owners and operators of MSWLF units must comply with Federal regulations, laws, rules or requirements that are in effect at the time of publication of Part 258 or that may become effective at a later date.

1.7.3 Technical Considerations

Specific sections of Part 258 reference major Federal regulations that also may be applicable to MSWLF units regulated under Part 258. These regulations include the Clean Water Act (wetlands, sludge disposal, point and non-point source discharges), the Clean Air Act, other parts of RCRA (Subtitle C if the MSWLF unit inadvertently receives regulated hazardous waste), and the Endangered Species Act. Furthermore, additional Federal rules, laws, or regulations may need to be considered. The owner or operator of the MSWLF unit is responsible for deter-mining the conditions present at the facility that may require consideration of other Federal Acts, rules, requirements, or regulations. Careful review of the Part 258 Criteria will help to identify most of the major Federal laws that may be applicable to a particular MSWLF unit.

CHAPTER 2

SUBPART B
LOCATION CRITERIA

CHAPTER 2
SUBPART B

TABLE OF CONTENTS

CHAPTER 2
SUBPART B
LOCATION RESTRICTIONS

2.1 INTRODUCTION

Part 258 includes location restrictions to address both the potential effects that a municipal solid waste landfill (MSWLF) unit may have on the surrounding environment, and the effects that natural and human-made conditions may have on the performance of the landfill unit. These criteria pertain to new and existing MSWLF units and lateral expansions of existing MSWLF units. The location criteria of Subpart B cover the following:

- Airport safety;
- Floodplains;
- Wetlands;
- Fault areas;
- Seismic impact zones; and
- Unstable areas.

Floodplain, fault area, seismic impact zone, and unstable area restrictions address conditions that may have adverse effects on landfill performance that could lead to releases to the environment or disruptions of natural functions (e.g., floodplain flow restrictions). Airport safety, floodplain, and wetlands criteria are intended to restrict MSWLF units in areas where sensitive natural environments and/or the public may be adversely affected.

Owners or operators must demonstrate that the location criteria have been met when Part 258 takes effect. Components of such demonstrations are identified in this section. The owner or operator of the landfill unit must also comply with all other applicable Federal and State regulations, such as State wellhead protection programs, that are not specifically identified in the Criteria. Owners or operators should note that many States are now developing Comprehensive State Ground Water Protection Programs. These programs are designed to coordinate and implement ground-water programs in the States; they may include additional requirements. Owners or operators should check with State environmental agencies concerning Comprehensive State Ground Water Protection Program requirements. Table 2-1 provides a quick reference to the location standards required by the Criteria.

Table 2-1
Location Criteria Standards

Restricted Location	Applies to Existing Units	Applies to New Units and Lateral Expansions	Make Demonstration to "Director of an Approved State" OR Retain Demonstration in Operating Record	Existing Units Must Close if Demonstration Cannot be Made
Airport	Yes	Yes	Operating Record	Yes
Floodplains	Yes	Yes	Operating Record	Yes
Wetlands	No	Yes	Director	N/A
Fault Areas	No	Yes	Director	N/A
Seismic Impact Zones	No	Yes	Director	N/A
Unstable Areas	Yes	Yes	Operating Record	Yes

2.2 AIRPORT SAFETY 40 CFR §258.10

2.2.1 Statement of Regulation

(a) Owners or operators of new MSWLF units, existing MSWLF units, and lateral expansions that are located within 10,000 feet (3,048 meters) of any airport runway end used by turbojet aircraft or within 5,000 feet (1,524 meters) of any airport runway end used by only piston-type aircraft must demonstrate that the units are designed and operated so that the MSWLF unit does not pose a bird hazard to aircraft.

(b) Owners or operators proposing to site new MSWLF units and lateral expansions within a five-mile radius of any airport runway end used by turbojet or piston-type aircraft must notify the affected airport and the Federal Aviation Administration (FAA).

(c) The owner or operator must place the demonstration in paragraph (a) in the operating record and notify the State Director that it has been placed in the operating record.

(d) For purposes of this section:

(1) <u>Airport</u> means public-use airport open to the public without prior permission and without restrictions within the physical capacities of available facilities.

(2) <u>Bird hazard</u> means an increase in the likelihood of bird/aircraft collisions that may cause damage to the aircraft or injury to its occupants.

2.2.2 Applicability

Owners and operators of new MSWLF units, existing MSWLF units, and lateral expansions of existing units that are located near an airport, who cannot demonstrate that the MSWLF unit does not pose a bird hazard, must close their units.

This requirement applies to owners and operators of MSWLF units located within 10,000 feet of any airport runway end used by turbojet aircraft or within 5,000 feet of any airport runway end used only by piston-type aircraft. This applies to airports open to the public without prior permission for use, and where use of available facilities is not restricted. If the above conditions are present, the owner or operator must demonstrate that the MSWLF unit does not pose a bird hazard to aircraft and notify the State Director that the demonstration has been placed in the operating record. If the demonstration is not made, existing units must be closed in accordance with §258.16.

The regulation, based on Federal Aviation Administration (FAA) Order 5200.5A (Appendix I), prohibits the disposal of solid waste within the specified distances unless the owner or operator is able to make the required demonstration showing that the landfill is designed and operated so as not to pose bird hazards to aircraft. The regulation defines a "danger zone" within which particular care must be taken to ensure that no bird hazard arises.

Owners or operators proposing to site new units or lateral units within five miles of any airport runway end must notify both the affected airport and the FAA. This requirement is based on the FAA's position that MSWLF units located within a five mile radius of any airport runway end, and which attract or sustain hazardous bird movements across aircraft flight paths and runways, will be considered inconsistent with safe flight operations. Notification by the MSWLF owner/operator to the appropriate regional FAA office will allow FAA review of the proposal.

2.2.3 Technical Considerations

A demonstration that a MSWLF unit does not pose a bird hazard to aircraft within specified distances of an airport runway end should address at least three elements of the regulation:

- Is the airport facility within the regulated distance?;
- Is the runway part of a public-use airport?; and
- Does or will the existence of the landfill increase the likelihood of bird/aircraft collisions that may cause damage to the aircraft or injury to its occupants?

The first element can be addressed using existing maps showing the relationship of existing runways at the airport to the existing or proposed new unit or lateral expansion. Topographic maps (USGS 15-minute series) or State, regional, or local government agency maps providing similar or better accuracy would allow direct scaling, or measurement, of the closest distance from the end of a runway to the nearest MSWLF unit. The measurement can be made by drawing a circle of appropriate radius (i.e., 5,000 ft., 10,000 ft, or 5 miles, depending on the airport type) from the centerline of each runway end. The measurement only should be made between the end of the runway and the nearest MSWLF unit perimeter, not between any other boundaries.

To determine whether the runway is part of a public use airport and to determine whether all applicable public airports have been identified, the MSWLF unit owner/operator should contact the airport administration or the regional FAA office. This rule does not apply to private airfields.

The MSWLF unit design features and operational practices can have a significant effect on the likelihood of increased bird/aircraft collisions. Birds may be attracted to MSWLF units to satisfy a need for water, food, nesting, or roosting. Scavenger birds such as starlings, crows, blackbirds, and gulls are most commonly associated with active landfill units. Where bird/aircraft collisions occur, these types of birds are often involved due to their flocking, feeding, roosting, and flight behaviors. Waste management techniques to reduce the supply of food to these birds include:

- Frequent covering of wastes that provide a source of food;
- Shredding, milling, or baling the waste-containing food sources; and
- Eliminating the acceptance of wastes at the landfill unit that represent a food source for birds (by alternative waste management techniques such as source separation and composting or waste minimization).

Frequent covering of wastes that represent a food source for the birds effectively reduces the availability of the food supply. Depending on site conditions such as volume and types of wastes, waste delivery schedules, and size of the working face, cover may need to be applied several times a day to keep the inactive portion of the working face small relative to the area accessible to birds. By maintaining a small working face, spreading and compaction equipment are concentrated in a small area that further disrupts scavenging by the birds.

Milling or shredding municipal solid waste breaks up food waste into smaller particle sizes and distributes the particles throughout non-food wastes, thereby diluting food wastes to a level that frequently makes the mixture no longer attractive as a food supply for birds. Similarly, baling municipal solid waste reduces the surface area of waste that may be available to scavenging birds.

The use of varying bird control techniques may prevent the birds from adjusting to a single method. Methods such as visual deterrents or sound have been used with mixed success in an attempt to discourage birds from food scavenging. Visual deterrents include realistic models (still or animated) of the bird's natural predators (e.g., humans, owls, hawks, falcons). Sounds that have had limited success as deterrents include cannons, distress calls of the scavenger birds, and sounds of its natural predators. Use of physical barriers such as fine wires strung across or near the working face have also been successfully used (see Figure 2-1). Labor intensive efforts have included falconry and firearms. Many of these methods have limited long-term effects on controlling bird populations at landfill units/facilities, as the birds adapt to the environment in which they find food.

Proper design and operation also can reduce the attraction of birds to the landfill unit through eliminating scavenger bird habitat. For example, the use of the landfill unit as a source of water can be controlled by encouraging surface drainage and by preventing the ponding of water.

Birds also may be attracted to a landfill unit as a nesting area. Use of the landfill site as a roosting or nesting area is usually limited to ground-roosting birds (e.g., gulls). Operational landfill units that do not operate continuously often provide a unique roosting habitat due to elevated ground temperatures (as a result of waste decomposition within the landfill) and freedom from disturbance. Nesting can be minimized, however, by examining the nesting patterns and requirements of undesirable birds and designing controls accordingly. For example, nesting by certain species can be controlled through the mowing and maintenance schedules at the landfill.

In addition to design features and operational procedures to control bird populations, the demonstration should address the likelihood that the MSWLF unit may increase bird/aircraft collisions. One approach to addressing this part of the airport safety criterion is to evaluate the attraction of birds to the MSWLF unit and determine whether this increased population would be expected to result in a discernible increase in bird/aircraft collisions. The evaluation of bird attraction can be based on field observations at existing facilities where similar geographic location, design features, and operational procedures are present.

All observations, measurements, data, calculations and analyses, and evaluations should be documented and included in the demonstration. The demonstration must be placed in the operating record and the State Director must be notified that it has been placed in the operating record (see Section 3.11 in Chapter 3).

If an owner or operator of an existing MSWLF unit cannot successfully demonstrate compliance with §258.10(a), then the unit must be closed in accordance with §258.60 and post-closure activities must be conducted in accordance with §258.61 (see §258.16). Closure must occur by October 9, 1996. The Director of an approved State can extend the period up to 2 years if it is demonstrated that no available alternative disposal capacity exists and the unit poses no immediate threat to human health and the environment (see Section 2.8).

In accordance with FAA guidance, if an owner or operator is proposing to locate a new unit or lateral expansion of an existing MSWLF unit within 5 miles of the end of a public-use airport runway, the affected airport and the regional FAA office must be notified to provide an opportunity to review and comment on the site. Identification of public airports in a given area can be

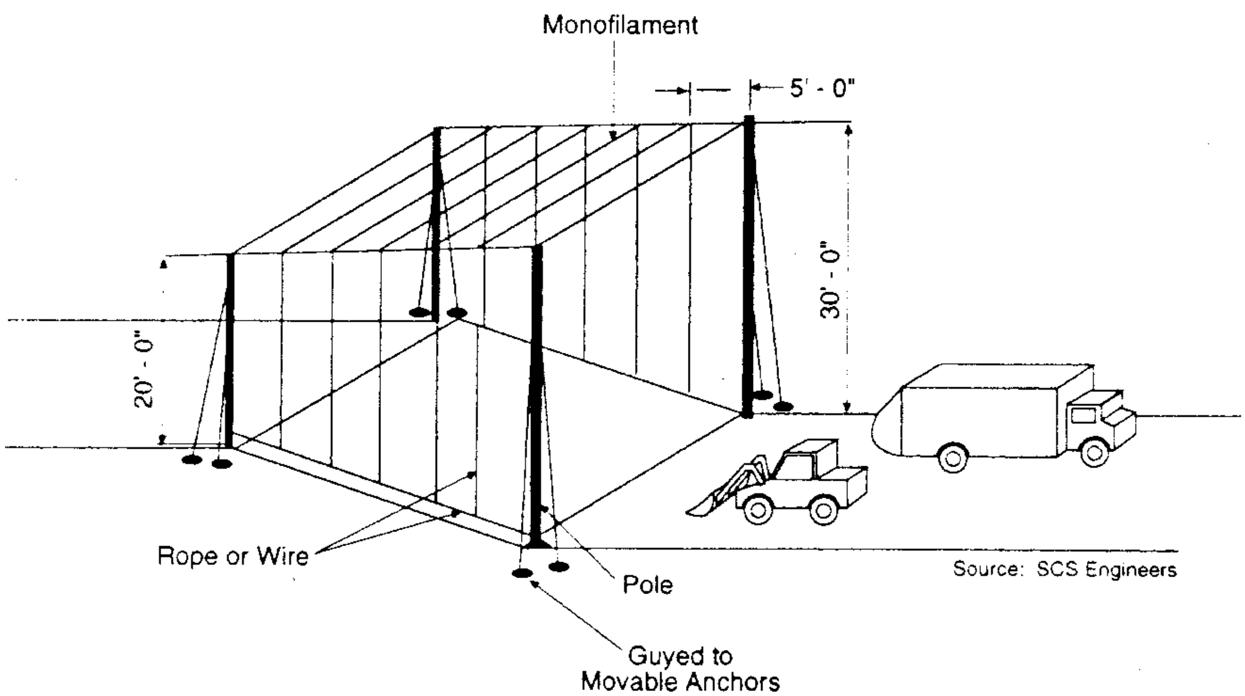


Figure 2-1.
Bird Control Device

requested from the FAA. Topographic maps (e.g., USGS 15-minute series) or other similarly accurate maps showing the relationship of the airport runway and the MSWLF unit should provide a suitable basis for determining whether the FAA should be notified.

2.3 FLOODPLAINS
40 CFR §258.11

2.3.1 Statement of Regulation

(a) Owners or operators of new MSWLF units, existing MSWLF units, and lateral expansions located in 100-year floodplains must demonstrate that the unit will not restrict the flow of the 100-year flood, reduce the temporary water storage capacity of the floodplain, or result in washout of solid waste so as to pose a hazard to human health and the environment. The owner or operator must place the demonstration in the operating record and notify the State Director that it has been placed in the operating record.

(b) For purposes of this section:

(1) Floodplain means the lowland and relatively flat areas adjoining inland and coastal waters, including flood-prone areas of offshore islands, that are inundated by the 100-year flood.

(2) 100-year flood means a flood that has a 1-percent or greater chance of recurring in any given year or a flood of a magnitude equaled or exceeded once in 100 years on the average over a significantly long period.

(3) Washout means the carrying away of solid waste by waters of the base flood.

2.3.2 Applicability

Owners/operators of new MSWLF units, existing MSWLF units, and lateral expansions of existing units located in a 100-year river floodplain who cannot demonstrate that the units will not restrict the flow of a 100-year flood nor reduce the water storage capacity, and will not result in a wash-out of solid waste, must close the unit(s). A MSWLF unit can affect the flow and temporary storage capacity of a floodplain. Higher flood levels and greater flood damage both upstream and downstream can be created and could cause a potential hazard to human health and safety. The rule does not prohibit locating a MSWLF unit in a 100-year floodplain; for example, the owner or operator is allowed to demonstrate that the unit will comply with the flow restriction, temporary storage, and washout provisions of the regulation. If a demonstration can be made that the landfill unit will not pose threats, the demonstration must be placed in the operating record, and the State Director must be notified that the demonstration was made and placed in the record. If the demonstration cannot be made for an existing MSWLF unit, then the MSWLF unit must be closed in 5 years in accordance with §258.60, and the owner or operator must conduct post-closure activities in accordance with §258.61 (see §258.16). The closure deadline may be extended for up to two years by the Director of an approved State if the owner or operator can demonstrate that no available alternative disposal capacity exists and there is no immediate threat to human health and the environment (see Section 2.8).

2.3.3 Technical Considerations

Compliance with the floodplain criterion begins with a determination of whether the MSWLF unit is located in the 100-year floodplain. If the MSWLF unit is located in the 100-year floodplain, then the owner or operator must demonstrate that the unit will not pose a hazard to human health and the environment due to:

- Restricting the base flood flow;
- Reducing the temporary water storage; and
- Resulting in the washout of solid waste.

Guidance for identifying floodplains and demonstrating facility compliance is provided below.

Floodplain Identification

River floodplains are readily identifiable as the flat areas adjacent to the river's normal channel. One hundred-year floodplains represent the sedimentary deposits formed by floods that have a one percent chance of occurrence in any given year and that are identified in the flood insurance rate maps (FIRMs) and flood boundary and floodway maps published by the Federal Emergency Management Agency (FEMA) (see Figure 2-2). Areas classified as "A" zones are subject to the floodplain location restriction. Areas classified as "B" or "C" zones are not subject to the restriction, although care should be taken to design facilities capable of withstanding some potential flooding.

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 may not be involved in the National Flood Insurance Program but which have FIRMs or Floodway maps published. Maps and other FEMA publications may be obtained from the FEMA Distribution Center (see Section 2.9.2 for the address). Areas not covered by the FIRMs or Floodway maps may be included in floodplain maps available through the U.S. Army Corps of Engineers, the U.S. Geological Survey, the U.S. Soil Conservation Service, the Bureau of Land Management, the Tennessee Valley Authority, and State, Tribal, and local agencies.

Many of the river channels covered by these maps may have undergone modification for hydropower or flood control projects and, therefore, the floodplain boundaries represented may not be accurate or representative. It may be necessary to compare the floodplain map series to recent air photographs to identify current river channel modifications and land use watersheds that could affect floodplain designations. If floodplain maps are not available, and the facility is located within a floodplain, then a field study to delineate the 100-year floodplain may be required. A floodplain delineation program can be based primarily on meteorological records and physiographic information such as existing and planned watershed land use, topography, soils and geologic mapping, and air photo interpretation of geomorphologic (land form) features. The United States Water Resource Council (1977) provides information for determining

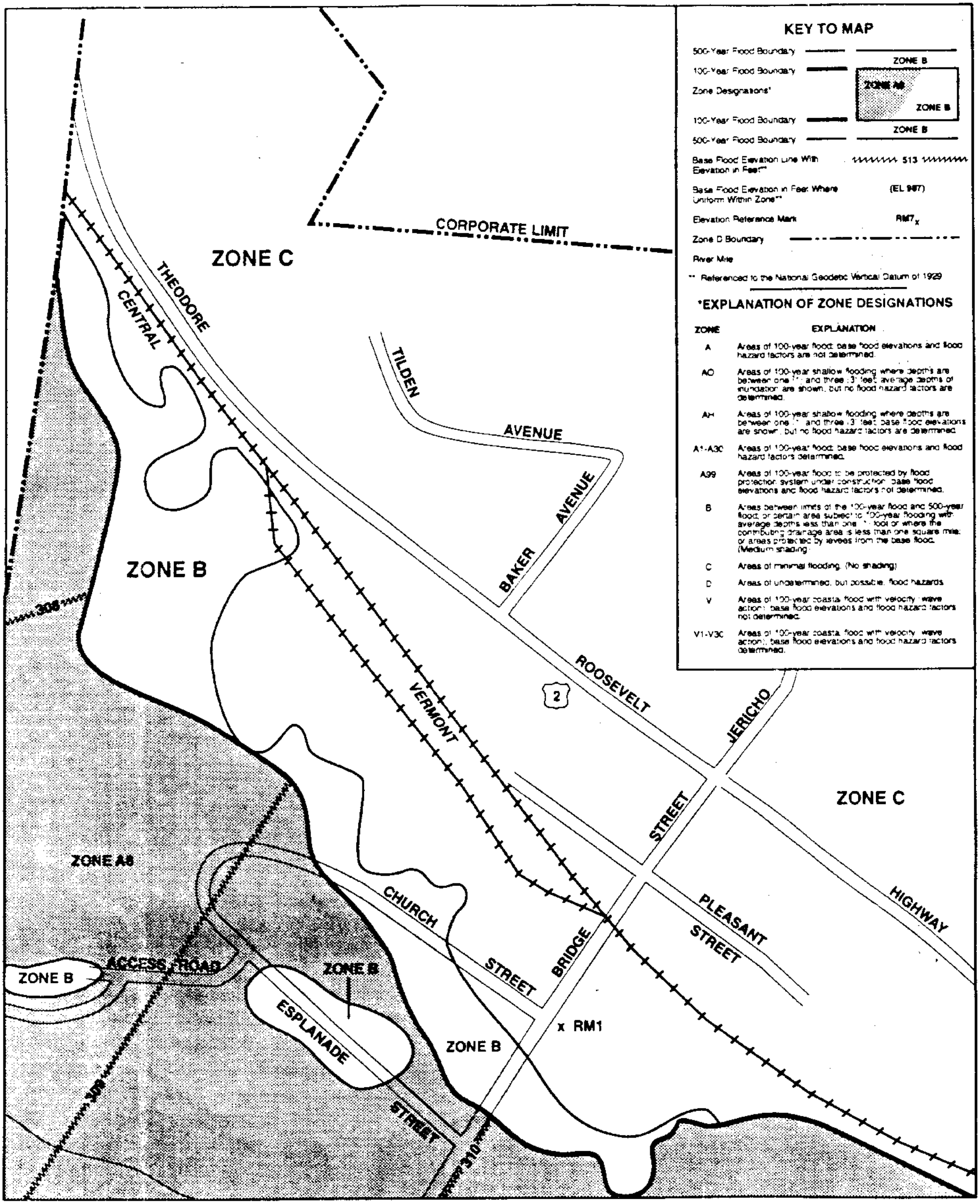


Figure 2-2
Example Section of Flood Plain Map

the potential for floods in a given location by stream gauge records. Estimation of the peak discharge also allows an estimation of the probability of exceeding the 100-year flood.

Engineering Considerations

If the MSWLF unit is within the 100-year floodplain, it must be located so that the MSWLF unit does not significantly restrict the base flood flow or significantly reduce temporary storage capacity of the floodplain. The MSWLF unit must be designed to prevent the washout of solid waste during the expected flood event. The rule requires that floodplain storage capacity, and flow restrictions that occur as the result of the MSWLF unit, do not pose a hazard to human health and the environment.

The demonstration that these considerations are met relies on estimates of the flow velocity and volume of floodplain storage in the vicinity of the MSWLF unit during the base flood. The assessment should consider the floodplain storage capacity and floodwater velocities that would likely exist in absence of the MSWLF unit. The volume occupied by a MSWLF unit in a floodplain may theoretically alter (reduce) the storage capacity and restrict flow. Raising the base flood level by more than one foot can be an indication that the MSWLF unit may reduce and restrict storage capacity flow.

The location of the MSWLF unit relative to the velocity distribution of floodwaters will greatly influence the susceptibility to washout. This type of assessment will require a conservative estimate of the shear stress on the landfill components caused by the depth, velocity, and duration of impinging river waters. Depending on the amount of inundation, the landfill unit may act as a channel side slope or bank or it may be isolated as an island within the overbank river channel. In both cases an estimate of the river velocity would be part of a proper assessment.

The assessment of flood water velocity requires that the channel cross section be known above, at, and below the landfill unit. Friction factors on the overbank are determined from the surface conditions and vegetation present. River hydrologic models may be used to simulate flow levels and estimate velocities through these river cross sections.

The Army Corps of Engineers (COE, 1982) has developed several numerical models to aid in the prediction of flood hydrographs, flow parameters, the effect of obstructions on flow levels, the simulation of flood control structures, and sediment transport. These methods may or may not be appropriate for a site; however, the following models provide well-tested analytical approaches:

HEC-1 Flood Hydrograph Package (watershed model that simulates the surface run-off response of a river basin to precipitation);

HEC-2 Water Surface Profiles (computes water surface profiles due to obstructions; evaluates floodway encroachment potential);

HEC-5 Simulation of Flood Control and Conservation Systems (simulates the sequential operation of a reservoir channel system with a branched network configuration; used to design routing that will minimize downstream flooding); and

HEC-6 Scour and Deposition in Rivers and Reservoirs (calculates water surface and sediment bed surface profiles).

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 run-off and peak flood hydrograph methods would be more appropriate for such conditions to predict the effects of severe flooding.

There are many possible cost-effective methods to protect the MSWLF unit from flood damage including embankment designs with rip-rap, geotextiles, or other materials. Guidelines for designing with these materials may be found in Maynard (1978) and SCS (1983). Embankment design will require an estimate of river flow velocities, flow profiles (depth), and wave activity. Figure 2-3 provides a design example for dike construction and protection of the landfill surface from flood water. It addresses height requirements to control the effects of wave activity. The use of alternate erosion control methods such as gabions (cubic-shaped wire structures filled with stone), paving bricks, and mats may be considered. It should be noted, however, that the dike design in Figure 2-3 may further decrease the water storage and flow capacities.

2.4 WETLANDS
40 CFR §258.12

2.4.1 Statement of Regulation

(a) New MSWLF units and lateral expansions shall not be located in wetlands, unless the owner or operator can make the following demonstrations to the Director of an approved State:

(1) Where applicable under section 404 of the Clean Water Act or applicable State wetlands laws, the presumption that a practicable alternative to the proposed landfill is available which does not involve wetlands is clearly rebutted;

(2) The construction and operation of the MSWLF unit will not:

(i) Cause or contribute to violations of any applicable State water quality standard,

(ii) Violate any applicable toxic effluent standard or prohibition under Section 307 of the Clean Water Act,

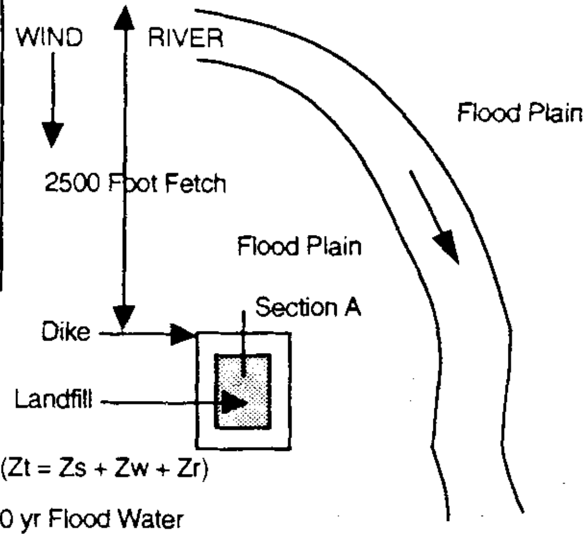
(iii) Jeopardize the continued existence of endangered or threatened species or result in the destruction or adverse modification of a critical habitat, protected under the Endangered Species Act of 1973, and

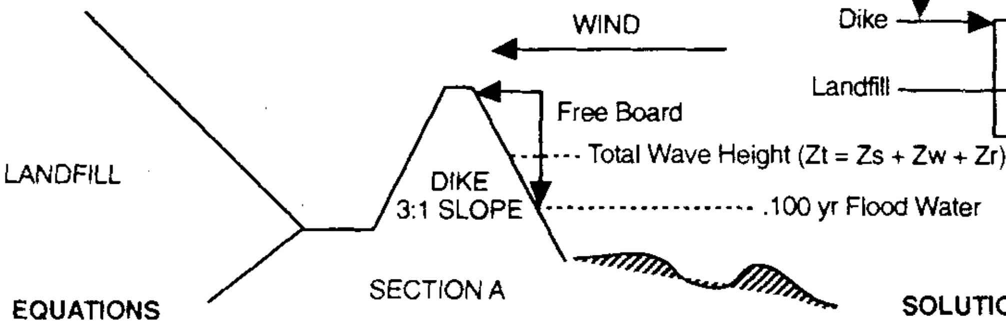
(iv) Violate any requirement under the Marine Protection, Research, and Sanctuaries Act of 1972 for the protection of a marine sanctuary;

ASSUMPTIONS:
- FETCH = 2500 FT
- WIND SPEED = 50 MPH
- AVE. WATER DEPTH ALONG FETCH = 5 FT
- OVERBANK WATER VELOCITY = 0.25 FT/S

DEFINITIONS

Zs = Wave Setup (tilting of water surface upward at downwind end)
Zw = Capillary Waves Height (developed by wind over water surface)
Zr = Wave Run-up (water run-up along dike from wave impact)





EQUATIONS

$$Zr = Zw(Zr/Zw)$$

$$\lambda = 5.12 tw^2$$

$$tw = 0.46 Vw^{0.44} F^{0.28}$$

where:
Zr = Wave run-up along dike
Zr/Zw = Relative run-up ratio from chart below
λ = Wavelength
tw = Wave period
Vw = wind speed (mph)
F = fetch (miles)

$$Zw = 0.034 Vw^{1.06} F^{0.47}$$

where:
Zw = ave. height of heighest 1/3rd of waves (ft)
F = fetch (miles)

$$Zs = \frac{Vw^2 F}{1400 d}$$

where:
Zs = rise above still water level (ft)
Vw = wind speed (mph)
F = fetch (miles)
d = water depth along fetch (ft)

$$W = \frac{K\gamma H^3}{1000(0.016\gamma - 1)^3(\cos\alpha - \sin\alpha)^3}$$

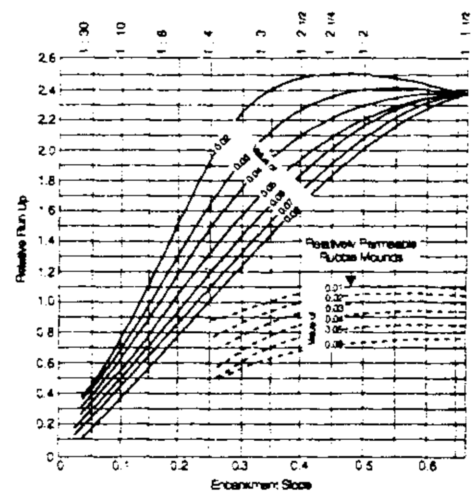
$$d = \left(\frac{6W}{\pi\gamma}\right)^{1/3}$$

where:
W = Rip - Rap stone weight (lbs)
d = Rip - Rap stone diameter
K = Coefficient (30)
γ = Stone Density (lb/cf)
H = height of design wave (ft)
α = bank slope (degrees)

SOLUTIONS

From the data provided in the assumptions at the beginning of the example:
Zs = 0.18 ft., Zw = 1.55 ft., Zr = 2.40 ft
Zt Design Height = 4.13 ft
Base 100 yr flood level = 5 ft
for Factor of Safety of 1.5
Dike Height = (1.5) (4.13 + 5) = 13.7 ft

For the Rip - Rap design given:
K = 30, γ = 120, H = 1.55 ft., a = 18°
For the protective stone on Dike
d = 0.5 ft., W = 12 lbs./stone



Wave run-up ratios vs. wave steepness and embankment slopes

Reference for Equations: U.S. Department of Interior, Bureau of Land Reclamation (1974)
Reference for Wave Run-up Chart: Linsley and Franzini (1972)

Figure 2-3. Example Floodplain Protection Dike Design

(3) The MSWLF unit will not cause or contribute to significant degradation of wetlands. The owner or operator must demonstrate the integrity of the MSWLF unit and its ability to protect ecological resources by addressing the following factors:

(i) Erosion, stability, and migration potential of native wetland soils, muds and deposits used to support the MSWLF unit;

(ii) Erosion, stability, and migration potential of dredged and fill materials used to support the MSWLF unit;

(iii) The volume and chemical nature of the waste managed in the MSWLF unit;

(iv) Impacts on fish, wildlife, and other aquatic resources and their habitat from release of the solid waste;

(v) The potential effects of catastrophic release of waste to the wetland and the resulting impacts on the environment; and

(vi) Any additional factors, as necessary, to demonstrate that ecological resources in the wetland are sufficiently protected.

(4) To the extent required under Section 404 of the Clean Water Act or applicable State wetland laws, steps have been taken to attempt to achieve no net loss of wetlands (as defined by acreage and function) by first avoiding impacts to wetlands to the maximum extent practicable as required by paragraph (a)(1) of this section, then minimizing unavoidable impacts to the maximum extent practicable, and finally offsetting remaining unavoidable wetland impacts through all appropriate and practicable compensatory mitigation actions (e.g., restoration of existing degraded wetlands or creation of man-made wetlands); and

(5) Sufficient information is available to make a reasonable determination with respect to these demonstrations.

(b) For purposes of this section, "wetlands" means those areas that are defined in 40 CFR §232.2(r).

2.4.2 Applicability

New MSWLF units and lateral expansions in wetlands are prohibited, except in approved States. The wetland restrictions allow existing MSWLF units located in wetlands to continue operations as long as compliance with the other requirements of Part 258 can be maintained.

In addition to the regulations listed in 40 CFR §258.12(a)(2), other Federal requirements may be applicable in siting a MSWLF unit in a wetland. These include:

- Sections 401, 402, and 404 of the CWA;
- Rivers and Harbors Act of 1989;
- National Environmental Policy Act;
- Migratory Bird Conservation Act;
- Fish and Wildlife Coordination Act;
- Coastal Zone Management Act;
- Wild and Scenic Rivers Act; and the
- National Historic Preservation Act.

As authorized by the EPA, the use of wetlands for location of a MSWLF facility may require a permit from the U.S. Army

Corps of Engineers (COE). The types of wetlands present (e.g., headwater, isolated, or adjacent), the extent of the wetland impact, and the type of impact proposed will determine the applicable category of COE permit (individual or general) and the permit application procedures. The COE District Engineer should be contacted prior to permit application to determine the available categories of permits for a particular site. Wetland permitting or permit review and comment can include additional agencies at the federal, state, regional, and local level. The requirements for wetland permits should be reviewed by the owner/operator to ensure compliance with all applicable regulations.

When proposing to locate a new facility or lateral expansion in a wetland, owners or operators must be able to demonstrate that alternative sites are not available and that the impact to wetlands is unavoidable.

If it is demonstrated that impacts to the wetland are unavoidable, then all practicable efforts must be made to minimize and, when necessary, compensate for the impacts. The impacts must be compensated for by restoring degraded wetlands, enhancing or preserving existing wetlands, or creating new wetlands. It is an EPA objective that mitigation activities result in the achievement of no net loss of wetlands.

2.4.3 Technical Considerations

The term wetlands, referenced in §258.12(b), is defined in §232.2(r). The EPA currently is studying the issues involved in defining and delineating wetlands. Proposed changes to the "Federal Manual for Identifying and Delineating Jurisdictional Wetlands," 1989, are still being reviewed. [These changes were proposed in the Federal Register on August 14, 1991 (56 FR 40446) and on December 19, 1991 (56 FR 65964).] Therefore, as of January 1993, the method used for delineating a wetland is based on a previously existing document, "Army Corps of Engineers Wetlands Delineation Manual," 1987. A Memorandum of Understanding between EPA and the Department of the Army, Corps of Engineers, was amended on January 4, 1993, to state that both agencies would now use the COE 1987 manual as guidance for delineating wetlands. The methodology applied by an owner/operator to define and delineate wetlands should be in keeping with the federal guidance in place at the time of the delineation.

Because of the unique nature of wetlands, the owner/operator is required to demonstrate that the landfill unit will not cause or contribute to significant degradation of wetlands. The demonstration must be reviewed and approved by the Director of an approved State and placed in the facility operating record. This provision effectively bans the siting of new MSWLF units or lateral expansions in wetlands in unapproved States.

There are several key issues that need to be addressed if an owner or operator proposes to locate a lateral expansion or a new MSWLF unit in a wetland. These issues include: (1) review of practicable alternatives, (2) evaluation of wetland acreage and function, (3) evaluation of impacts of MSWLF units on wetlands, and (4) offsetting impacts. Although EPA has an objective of no net loss of wetlands in terms of acreage and function, it recognizes that regions of the country exist where proportionally large areas are dominated by wetlands. In these regions, sufficient acreage and a suitable type of upland may not be present to allow construction of a new MSWLF unit or lateral expansion without wetland impacts. Wetlands evaluations may become an integral part of the siting, design, permitting, and environmental monitoring aspects of a landfill unit/facility (see Figure 2-4).

Practicable Alternatives

EPA believes that locating new MSWLF units or lateral expansions in wetlands should be done only where there are no less damaging alternatives available. Due to the extent of wetlands that may be present in certain regions, the banning of new MSWLF units or lateral expansions in wetlands could cause serious capacity problems. The flexibility of the rule allows owners or operators to demonstrate that there are no practicable alternatives to locating or laterally expanding MSWLF units in wetlands.

As part of the evaluation of practicable alternatives, the owner/operator should consider the compliance of the location with other regulations and the potential impacts of the MSWLF unit on wetlands and related resources. Locating or laterally expanding MSWLF units in wetlands requires compliance with other environmental regulations. The owner or operator must show that the operation or construction of the landfill unit will not:

- Violate any applicable State water quality standards;
- Cause or contribute to the violation of any applicable toxic effluent standard or prohibition;
- Cause or contribute to violation of any requirement for the protection of a marine sanctuary; and
- Jeopardize the continued existence of endangered or threatened species or critical habitats.

The MSWLF unit cannot cause or contribute to significant degradation of wetlands. Therefore, the owner/operator must:

- Ensure the integrity of the MSWLF unit, including consideration of the erosion, stability, and migration of native wetland soils and dredged/fill materials;
- Minimize impacts on fish, wildlife, and other aquatic resources and their habitat from the release of solid waste;
- Evaluate the effects of catastrophic release of wastes on the wetlands; and
- Assure that ecological resources in the wetlands are sufficiently protected, including consideration of the volume and chemical nature of waste managed in the MSWLF unit.

These factors were partially derived from Section 404(b)(1) of the Clean Water Act. These guidelines address the protection of the ecological resources of the wetland.

After consideration of these factors, if no practicable alternative to locating the landfill in wetlands is available, compensatory steps must be taken to achieve no net loss of wetlands as defined by acreage and

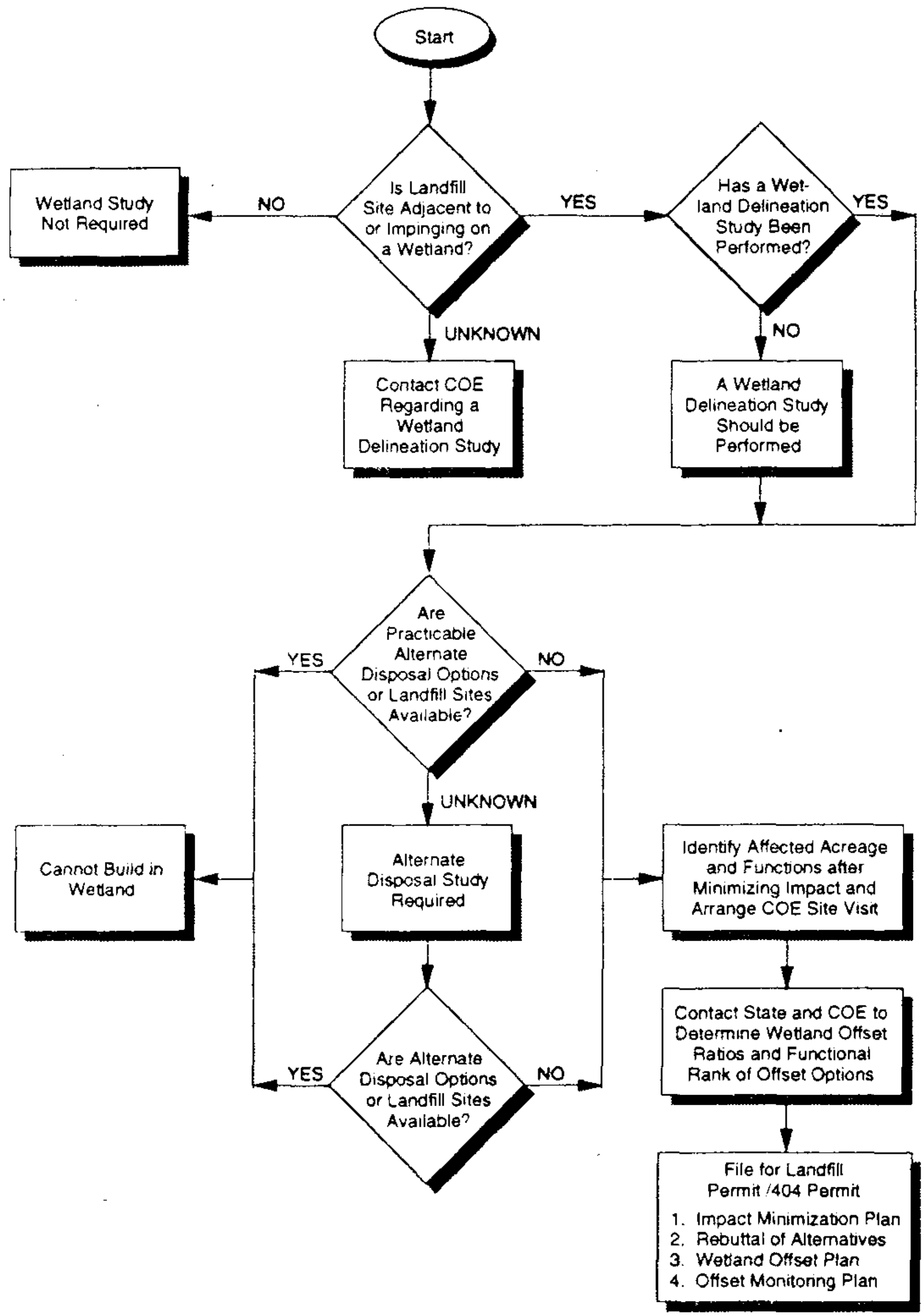


Figure 2-4
Wetlands Decision Tree for Owners/Operators in Approved States

function. The owner/operator must try to avoid and/or minimize impacts to the wetlands to the greatest extent possible. Where avoidance and minimization still result in wetland impacts, mitigation to offset impacts is required. Mitigation plans must be approved by the appropriate regulatory agencies and must achieve an agreed-upon measure of success. Examples of mitigation include restoration of degraded wetlands or creation of wetland acreage from existing uplands.

Part 258 presumes that practicable alternatives are available to locating landfill units in wetlands because landfilling is not a water-dependent activity. In an approved State, the owner or operator can rebut the presumption that a practicable alternative to the proposed landfill unit or lateral expansion is available. The term "practicable" pertains to the economic and social feasibility of alternatives (e.g., collection of waste at transfer stations and trucking to an existing landfill facility or other possible landfill sites). The feasibility evaluation may entail financial, economic, administrative, and public acceptability analyses as well as engineering considerations. Furthermore, the evaluations generally will require generation and assessment of land use, geologic, hydrologic, geographic, demographic, zoning, traffic maps, and other related information.

To rebut the presumption that an alternative practicable site exists generally will require that a site search for an alternative location be conducted. There are no standard methods for conducting site searches due to the variability of the number and hierarchy of screening criteria that may be applied in a specific case. Typical criteria may include:

- Distance from waste generation sources;
- Minimum landfill facility size requirements;
- Soil conditions;
- Proximity to ground-water users;
- Proximity of significant aquifers;
- Exclusions from protected natural areas;
- Degree of difficulty to remediate features; and
- Setbacks from roadways and residences.

Wetland Evaluations

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, and that under normal circumstances do support, a prevalence of vegetation adapted for life in saturated soil conditions. As defined under current guidelines, wetlands are identified based on the presence of hydric soils, hydrophytic vegetation, and the wetland hydrology. These characteristics also affect the functional value of a wetland in terms of its role in: supporting fish and wildlife habitats; providing aesthetic, scenic, and recreational value; accommodating flood storage; sustaining aquatic diversity; and its relationships to surrounding natural areas through nutrient retention and productivity exportation (e.g., releasing nutrients to downstream areas, providing transportable food sources).

Often, a wetland assessment will need to be conducted by a qualified and experienced multi-disciplinary team. The assessment should identify: (1) the limits of the wetland boundary based on hydrology, soil types and plant types; (2) the type and relative abundance of vegetation, including trees; and (3) rare, endangered, or otherwise protected species and their habitats (if any).

The current methods used to delineate wetlands are presented in "COE Wetlands Delineation Manual," 1987. In January 1993, EPA and COE agreed to use the 1987 Manual for purposes of delineation. The Federal Manual for Identifying and Delineating Jurisdictional Wetlands (COE, 1989) contains an extensive reference list of available wetland literature. For example, lists of references for the identification of plant species characteristic of wetlands throughout the United States, hydric soils classifications, and related wetland topics are presented. USGS topographic maps, National Wetland Inventory (NWI) maps, Soil Conservation Service (SCS) soil maps, wetland inventory maps, and aerial photographs prepared locally also may provide useful information.

After completion of a wetland study, the impact of the MSWLF unit on wetlands and its relationship to adjacent wetlands can be assessed more effectively. During the permitting process, local, State, and federal agencies with jurisdiction over wetlands will need to be contacted to schedule a site visit. It is usually advantageous to encourage this collaboration as early as possible in the site evaluation process, especially if the State program office that is responsible for wetland protection is different from the solid waste management office. Regulations will vary significantly from State to State with regard to the size and type of wetland that triggers State agency involvement. In general, the COE will require notification and/or consultation on any proposed impact on any wetland regardless of the actual degree of the impact. Other agencies such as the Fish and Wildlife Service and the SCS may need to be contacted in some States.

Evaluation of ecological resource protection may include assessment of the value of the affected wetland. Various techniques are available for this type of evaluation, and the most appropriate technique for a specific site should be selected in conjunction with applicable regulatory agencies. Available methods include analysis of functional value, the Wetland Evaluation Technique (WET), and the Habitat Evaluation Procedure (HEP).

The 1987 Manual does not address functional value in the detail provided by the 1989 manual. The methodology for conducting a functional value assessment should be reviewed by the applicable regulatory agencies. It is important to note that functional value criteria may become a standard part of wetland delineation following revision of the federal guidance manual(s). The owner or operator should remain current with the accepted practices at the time of the delineation/assessment.

The functional value of a given wetland is dependent on its soil, plant, and hydrologic characteristics, particularly the diversity, prevalence, and extent of wetland plant species. The relationship between the wetland and surrounding areas (nutrient sinks and sources) and the ability of the wetland to support animal habitats, or rare or endangered species, contributes to the evaluation of functional value.

Other wetland and related assessment methodologies include WET and HEP. WET allows comparison of the values and functions of wetlands before and after construction of a facility, thereby projecting the impact a facility may have on a wetland. WET was developed by the Federal Highway Administration and revised by the COE (Adamus *et al*., 1987). HEP was developed by the Fish and Wildlife Service to determine the quality and quantity of available habitat for selected species. HEP and WET may be used in conjunction with each other to provide an integrated assessment.

Impact Evaluation

If the new unit or lateral expansion is to be located in a wetland, the owner or operator must demonstrate that the unit will not cause or contribute to significant degradation of the wetland. Erosion potential and stability of wetland soils and any dredged or fill material used to support the MSWLF unit should be identified as part of the wetlands evaluation. Any adverse stability or erosion problems that could affect the MSWLF or contaminant effects that could be caused by the MSWLF unit should be resolved.

All practicable steps are to be taken to minimize potential impacts of the MSWLF unit to wetlands. A number of measures that can aid in minimization of impacts are available. Appropriate measures are site-specific and should be incorporated into the design and operation of the MSWLF unit. For example, placement of ground water barriers may be required if soil and shallow ground-water conditions would cause dewatering of the wetland due to the existence of underdrain pipe systems at the facility. In many instances, however, wetlands are formed in response to perched water tables over geologic material of low hydraulic conductivity and, therefore, significant drawdown impacts may not occur.

It is possible that the landfill unit/facility will not directly displace wetlands, but that adverse effects may be caused by leachate or run-off. Engineered containment systems for both leachate and run-off should mitigate the potential for discharge to wetlands.

Additional actions and considerations relevant to mitigating impacts of fill material in wetlands that may be appropriate for MSWLF facilities are provided in Subpart H (Actions to Minimize Adverse Effects) of 40 CFR §230 (Guidelines for Specification of Disposal Sites for Dredged or Fill Materials).

Wetland Offset

All unavoidable impacts must be "offset" or compensated for to ensure that the facility has not caused, to the extent practicable, any net loss of wetland acreage. This compensatory mitigation may take the form of upgrading existing marginal or lower-quality wetlands or creating new wetlands. Wetland offset studies require review and development on a site-specific basis.

To identify potential sites that may be proposed for upgrade of existing wetlands or creation of new wetlands, a cursory assessment of surrounding wetlands and uplands should be conducted. The assessment may include a study to define the functional characteristics and inter-relationships of these potential wetland mitigation areas. An upgrade of an existing wetland may consist of transplanting appropriate vegetation and importing low-permeability soil materials that would be conducive to forming saturated soil conditions. Excavation to form open water bodies or gradual restoration of salt water marshes by culvert expansions to promote sea water influx are other examples of compensatory mitigation.

Individual States may have offset ratios to determine how much acreage of a given functional value is required to replace the wetlands that were lost or impacted. Preservation of lands, such as through perpetual conservation easements, may be considered as a viable offset option. State offset ratios may require that for wetlands of an equivalent functional value, a larger acreage be created than was displaced.

Due to the experimental nature of creating or enhancing wetlands, a monitoring program to evaluate the progress of the effort should be considered and may be required as a wetland permit condition. The purpose of the monitoring program is to verify that the created/upgraded wetland is successfully established and that the intended function of the wetland becomes self-sustaining over time.

2.5 FAULT AREAS
40 CFR §258.13

2.5.1 Statement of Regulation

(a) New MSWLF units and lateral expansions shall not be located within 200 feet (60 meters) of a fault that has had displacement in Holocene time unless the owner or operator demonstrates to the Director of an approved State that an alternative setback distance of less than 200 feet (60 meters) will prevent damage to the structural integrity of the MSWLF unit and will be protective of human health and the environment.

(b) For the purposes of this section:

(1) Fault means a fracture or a zone of fractures in any material along which strata on one side have been displaced with respect to that on the other side.

(2) Displacement means the relative movement of any two sides of a fault measured in any direction.

(3) Holocene means the most recent epoch of the Quaternary period, extending from the end of the Pleistocene Epoch to the present.

2.5.2 Applicability

Except in approved States, the regulation bans all new MSWLF units or lateral expansions of existing units within 200 feet (60 meters) of the outermost boundary of a fault that has experienced displacement during the Holocene Epoch (within the last 10,000 to 12,000 years). Existing MSWLF units are neither required to close nor to retrofit if they are located in fault areas.

A variance to the 200-foot setback is provided if the owner or operator can demonstrate to the Director of an approved State that a shorter distance will prevent damage to the structural integrity of the MSWLF unit and will be protective of human health and the environment. The demonstration for a new MSWLF unit or lateral expansion requires review and approval by the Director of an approved State. If the demonstration is approved, it must be placed in the facility's operating record. The option to have a setback of less than 200 feet from a Holocene fault is not available in unapproved States.

2.5.3 Technical Considerations

Locating a landfill in the vicinity of an area that has experienced faulting in recent time has inherent dangers. Faulting occurs in areas where the geologic stresses exceed a geologic material's ability to withstand those stresses. Such areas also tend to be subject to earthquakes and ground failures (e.g., landslides, soil liquefaction) associated with seismic activity. A more detailed discussion of seismic activity is presented in Section 2.6.

Proximity to a fault can cause damage through:

- Movement along the fault which can cause displacement of facility structures,
- Seismic activity associated with faulting which can cause damage to facility structures through vibratory action (see Figure 2-5), and
- Earth shaking which can cause ground failures such as slope failures.

Consequently, appropriate setbacks from fault areas are required to minimize the potential for damage.

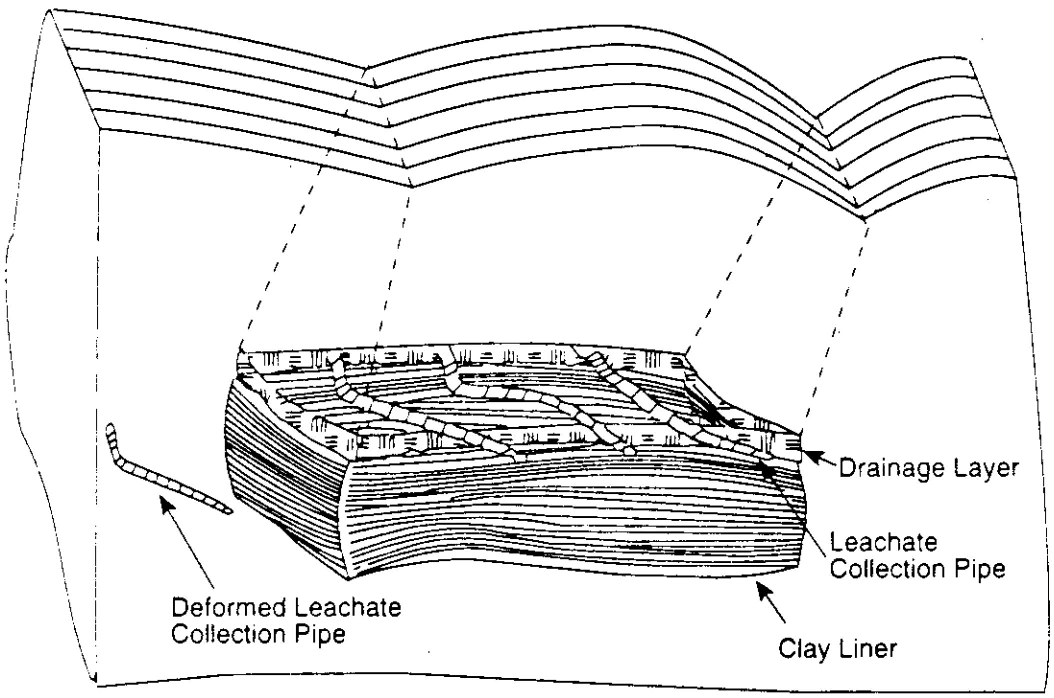
To determine if a proposed landfill unit is located in a Holocene fault area, U.S. Geological Survey (USGS) mapping can be used. A series of maps known as the "Preliminary Young Fault Maps, Miscellaneous Field Investigation (MF) 916" was published by the USGS in 1978. Information about these maps can be obtained from the USGS by calling 1-800-USA-MAPS, which reaches the USGS National Center in Reston, Virginia, or by calling 303-236-7477, which reaches the USGS Map Sales Center in Denver, Colorado.

For locations where a fault zone has been subject to movement since the USGS maps were published in 1978, a **geologic reconnaissance** of the site and surrounding areas may be required to map fault traces and to determine the faults along which movement has occurred in Holocene time. This reconnaissance also may be necessary to support a demonstration for a setback of less than 200 feet. Additional requirements may need to be met before a new unit or lateral expansion may be approved.

A **site fault characterization** is necessary to determine whether a site is within 200 feet of a fault that has had movement during the Holocene epoch. An investigation would include obtaining information on any lineaments (linear features) that suggest the presence of faults within a 3,000-foot radius of the site. The information could be based on:

- A review of available maps, logs, reports, scientific literature, or insurance claim reports;
- An aerial reconnaissance of the area within a five-mile radius of the site, including aerial photo analysis; or

Figure 2-5
Potential Seismic Effects



A schematic diagram of a landfill showing potential deformation of the leachate collection and removal system by seismic stresses.

Source: US EPA, 1992

- A field reconnaissance that includes walking portions of the area within 3,000 feet of the unit.

If the site fault characterization indicates that a fault or a set of faults is situated within 3,000 feet of the proposed unit, investigations should be conducted to determine the presence or absence of any faults within 200 feet of the site that have experienced movement during the Holocene period. Such investigations can include:

- Subsurface exploration, including drilling and trenching, to locate fault zones and evidence of faulting.

- Trenching perpendicular to any faults or lineaments within 200 feet of the unit.

- Determination of the age of any displacements, for example by examining displacement of surficial deposits such as glacial or older deposits (if Holocene deposits are absent).

- Examination of seismic epicenter information to look for indications of recent movement or activity along structures in a given area.

- Review of high altitude, high resolution aerial photographs with stereo-vision coverage. The photographs are produced by the National Aerial Photographic Program (NAPP) and the National High Altitude Program (NHAP). Information on these photos can be obtained from the USGS EROS Data Center in Sioux Falls, South Dakota at (605) 594-615

Based on this information as well as supporting maps and analyses, a qualified professional should prepare a report that delineates the location of the Holocene fault(s) and the associated 200-foot setback.

If requesting an alternate setback, a demonstration must be made to show that no damage to the landfill's structural integrity will result. Examples of engineering considerations and modifications that may be included in such demonstrations are as follows:

- For zones with high probabilities of high accelerations (horizontal) within the moderate range of 0.1g to 0.75g, seismic designs should be developed.

- Seismic stability analysis of landfill slopes should be performed to guide selection of materials and gradients for slopes.

- Where in-situ and laboratory tests indicate that a potential landfill site is susceptible to liquefaction, ground improvement measures like grouting, dewatering, heavy tamping, and excavation should be implemented.

- Engineering options include:

  — Flexible pipes,

  — Ground improvement measures (grouting, dewatering, heavy tamping, and excavation), and/or

  — Redundant precautionary measures (secondary containment system).

In addition, use of such measures needs to be demonstrated to be protective of human health and the environment. The types of engineering controls described above are similar to those that would be employed in areas that are likely to experience earthquakes.

2.6 SEISMIC IMPACT ZONES 40 CFR §258.14

2.6.1 Statement of Regulation

(a) New MSWLF units and lateral expansions shall not be located in seismic impact zones, unless the owner or operator demonstrates to the Director of an approved State that all containment structures, including liners, leachate collection systems, and surface water control systems, are designed to resist the maximum horizontal acceleration in lithified earth material for the site. The owner or operator must place the demonstration in the operating record and notify the State Director that it has been placed in the operating record.

(b) For the purposes of this section:

(1) Seismic impact zone means an area with a ten percent or greater probability that the maximum horizontal acceleration in lithified earth material, expressed as a percentage of the earth's gravitational pull (g), will exceed 0.10g in 250 years.

(2) Maximum horizontal acceleration in lithified earth material means the maximum expected horizontal acceleration depicted on a seismic hazard map, with a 90 percent or greater probability that the acceleration will not be exceeded in 250 years, or the maximum expected horizontal acceleration based on a site-specific seismic risk assessment.

(3) Lithified earth material means all rock, including all naturally occurring and naturally formed aggregates or masses of minerals or small particles of older rock that formed by crystallization of magma or by induration of loose sediments. This term does not include man-made materials, such as fill, concrete, and asphalt, or unconsolidated earth materials, soil, or regolith lying at or near the earth surface.

2.6.2 Applicability

New MSWLF units and lateral expansions in seismic impact zones are prohibited, except in approved States. A seismic impact zone is an area that has a ten percent or greater probability that the maximum expected horizontal acceleration in lithified earth material, expressed as a percentage of the earth's gravitational pull (g), will exceed 0.10g in 250 years.

The regulation prohibits locating new units or lateral expansions in a seismic impact zone unless the owner or operator can demonstrate that the structural components of the unit (e.g., liners, leachate collection systems, final cover, and surface water control systems) are designed to resist the maximum horizontal acceleration in lithified earth material at the site. Existing units are not required to be retrofitted. Owners or operators of new units or lateral expansions must notify the Director of an approved State and place the demonstration of compliance with the conditions of the restriction in the operating record.

2.6.3 Technical Considerations

Background on Seismic Activity

To understand seismic activity, it is helpful to know its origin. A brief introduction to the geologic underpinnings of seismic activity is presented below.

The earth's crust is not a static system. It consists of an assemblage of earthen masses that are in slow motion. As new crust is generated from within the earth, old edges of crust collide with one another, thereby causing stress. The weaker edge is forced to move beneath the stronger edge back into the earth.

The dynamic conditions of the earth's crust can be manifested as shaking ground (seismic activity), fracturing (faulting), and volcanic eruptions. Seismic activity also can result in types of ground failure. Landslides and mass movements (e.g., slope failures) are common on slopes; soil compaction or ground subsidence tends to occur in unconsolidated valley sediments; and liquefaction of soils tends to happen in areas where sandy or silty soils that are saturated and loosely compacted become in effect, liquefied (like quicksand) due to the motion. The latter types of phenomena are addressed in Section 2.7, Unstable Areas.

Information Sources on Seismic Activity

To determine the maximum horizontal acceleration of the lithified earth material for the site (see Figure 2-6), owners or operators of MSWLF units should review the seismic 250-year interval maps in U.S. Geological Survey Miscellaneous Field Study Map MF-2120, entitled "Probabilistic Earthquake Acceleration and Velocity Maps for the United States and Puerto Rico" (Algermissen et al., 1991). To view the original of the map that is shown in Figure 2-6 (reduced in size), contact the USGS office in your area. The original map (Horizontal Acceleration - Base modified from U.S.G.S. National Atlas, 1970, Miscellaneous Field Studies, Map MF 2120) shows county lines within each State. For areas not covered by the aforementioned map, USGS State seismic maps may be used to estimate the maximum horizontal acceleration. The National Earthquake Information Center, located at the Colorado School of Mines in Golden, Colorado, can provide seismic maps of all 50 states. The Center also maintains a database of known earthquakes and fault zones.

Information on the location of earthquake epicenters and intensities may be available through State Geologic Surveys or the Earthquake Information Center. For information concerning potential earthquakes in specific areas, the Geologic Risk Assessment Branch of USGS may be of assistance. Other organizations that study the effects of earthquakes on engineered structures include the National Information Service for Earthquake Engineering, the Building Seismic Safety Council, the National Institute of Science and Technology, and the American Institute of Architects.

Landfill Planning and Engineering in Areas of Seismic Activity

Studies indicate that during earthquakes, superficial (shallow) slides and differential displacement tend to be produced, rather than massive slope failures (U.S. Navy 1983). Stresses created by superficial failures can affect the liner and final cover

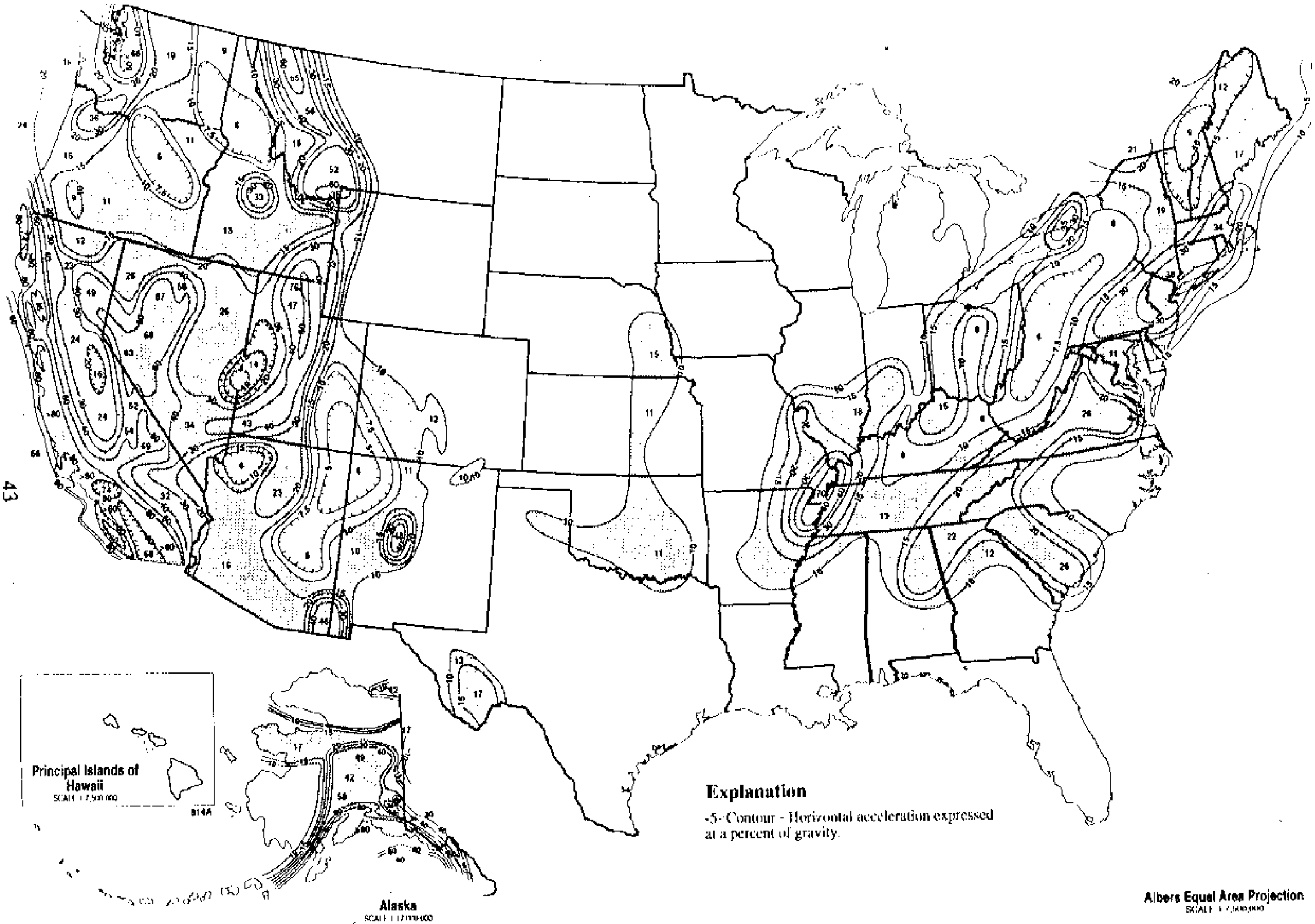


Figure 2-6. Seismic Impact Zones
(Areas with a 10% or greater probability that the maximum horizontal acceleration will exceed .10g in 250 years)

systems as well as the leachate and gas collection and removal systems. Tensional stresses within the liner system can result in fracturing of the soil liner and/or tearing of the flexible membrane liner. Thus, when selecting suitable sites from many potential sites during the siting process, the owner/operator should try to avoid a site with:

- Holocene fault zones,
- Sites with potential ground motion, and
- Sites with liquefaction potential.

If one of the above types of sites is selected, the owner/operator must consider the costs associated with the development of the site.

If, due to a lack of suitable alternatives, a site is chosen that is located in a seismic impact zone, a demonstration must be made to the Director of an approved State that the design of the unit's structural components (e.g., liners, leachate collection, final covers, run-on and run-off systems) will resist the maximum horizontal acceleration in lithified materials at the site. As part of the demonstration, owner/operators must:

- Determine the expected peak ground acceleration from a maximum strength earthquake that could occur in the area,

- Determine the site-specific seismic hazards such as soil settlement, and

- Design the facility to withstand the expected peak ground acceleration.

The design of the slopes, leachate collection system, and other structural components should have built-in conservative design factors. Additionally, redundant precautionary measures should be designed and built into the various landfill systems.

For those units located in an area with an estimated maximum horizontal acceleration greater than 0.1g, an evaluation of seismic effects should consider both foundation soil stability and waste stability under seismic loading. Conditions that may be considered for the evaluation include the construction phase (maximum open excavation depth of new cell adjacent to an existing unit), closure activities (prior to final consolidation of both waste and subsoil), and post-closure care (after final consolidation of both waste and foundation soil). If the maximum horizontal acceleration is less than or equal to 0.1g, then the design of the unit will not have to incorporate an evaluation of seismic effects unless the facility will be situated in an area with low strength foundation soils or soils with potential for liquefaction. The facility should be assessed for the effects of seismic activity even if the horizontal acceleration is expected to be less than 0.1g.

In determining the potential effects of seismic activity on a structure, an engineering evaluation should examine soil behavior with respect to earthquake intensity. When evaluating soil characteristics, it is necessary to know the soil strength as well as the magnitude or intensity of the earthquake in terms of peak acceleration. Other soil characteristics, including degree of compaction, sorting (organization of the soil particles), and degree of saturation, may need to be considered because of their potential influence on site conditions. For example, deposits of loose granular soils may be compacted by the ground vibrations induced by an earthquake. Such volume reductions could result in large uniform or differential settlements of the ground surface (Winterkorn and Fang, 1975).

Well-compacted cohesionless embankments or reasonably flat slopes in insensitive clay are less likely to fail under moderate seismic shocks (up to 0.15g and 0.20g acceleration). Embankments made of insensitive cohesive soils founded on cohesive soils or rock may withstand even greater seismic shocks. For earthen embankments in seismic regions, designs with internal drainage and core material most resistant to fracturing should be considered. Slope materials vulnerable to earthquake shocks are described below (U.S. Navy, 1983):

- Very steep slopes of weak, fractured and brittle rocks or unsaturated loess are vulnerable to transient shocks caused by tensional faulting;
- Loess and saturated sand may be liquefied by seismic shocks causing the sudden collapse of structures and flow slides;
- Similar effects are possible in sensitive cohesive soils when natural moisture exceeds the soil's liquid limit; and
- Dry cohesionless material on a slope at an angle of repose will respond to seismic shock by shallow sloughing and slight flattening of the slope.

In general, loess, deltaic soils, floodplain soils, and loose fills are highly susceptible to liquefaction under saturated conditions (USEPA, 1992).

Geotechnical stability investigations frequently incorporate the use of computer models to reduce the computational time of well-established analytical methods. Several computer software packages are available that approximate the anticipated dynamic forces of the design earthquake by resolving the forces into a static analysis of loading on design cross sections. A conservative approach would incorporate both vertical and horizontal forces caused by bedrock acceleration if it can be shown that the types of material of interest are susceptible to the vertical force component. Typically, the horizontal force caused by bedrock acceleration is the major force to be considered in the seismic stability analysis. Examples of computer models include PC-Slope by Geoslope Programming (1986), and FLUSH by the University of California.

Design modifications to accommodate an earthquake may include shallower waste sideslopes, more conservative design of dikes and run-off controls, and additional contingencies for leachate collection should primary systems be disrupted. Strengths of the landfill components should be able to withstand these additional forces with an acceptable factor of safety. The use of professionals experienced in seismic analysis is strongly recommended for design of facilities located in areas of high seismic risk.

2.7 UNSTABLE AREAS
40 CFR §258.15

2.7.1 Statement of Regulation

(a) Owners or operators of new MSWLF units, existing MSWLF units, and lateral expansions located in an unstable area must demonstrate that engineering measures have been incorporated into the MSWLF unit's

design to ensure that the integrity of the structural components of the MSWLF unit will not be disrupted. The owner or operator must place the demonstration in the operating record and notify the State Director that it has been placed in the operating record. The owner or operator must consider the following factors, at a minimum, when determining whether an area is unstable:

(1) On-site or local soil conditions that may result in significant differential settling;

(2) On-site or local geologic or geomorphologic features; and

(3) On-site or local human-made features or events (both surface and subsurface).

(b) For purposes of this section:

(1) Unstable area means a location that is susceptible to natural or human-induced events or forces capable of impairing the integrity of some or all of the landfill structural components responsible for preventing releases from a landfill. Unstable areas can include poor foundation conditions, areas susceptible to mass movements, and Karst terrains.

(2) Structural components means liners, leachate collection systems, final covers, run-on/run-off systems, and any other component used in the construction and operation of the MSWLF that is necessary for protection of human health and the environment.

(3) Poor foundation conditions means those areas where features exist which indicate that a natural or man-induced event may result in inadequate foundation support for the structural components of a MSWLF unit.

(4) Areas susceptible to mass movement means those areas of influence (i.e., areas characterized as having an active or substantial possibility of mass movement) where the movement of earth material at, beneath, or adjacent to the MSWLF unit, because of natural or man-induced events, results in the downslope transport of soil and rock material by means of gravitational influence. Areas of mass movement include, but are not limited to, landslides, avalanches, debris slides and flows, solifluction, block sliding, and rock fall.

(5) Karst terrains means areas where karst topography, with its characteristic surface and subterranean features, is developed as the result of dissolution of limestone, dolomite, or other soluble rock. Characteristic physiographic features present in karst terrains include, but are not limited to, sinkholes, sinking streams, caves, large springs, and blind valleys.

2.7.2 Applicability

Owners/operators of new MSWLF units, existing MSWLF units, and lateral expansions of units that are located in unstable areas must demonstrate the structural integrity of the unit. Existing units for which a successful demonstration cannot be made must be closed. The regulation applies to new units, existing units, and lateral expansions that are located on sites classified as unstable areas. Unstable areas are areas susceptible to natural or human-induced events or forces that are capable of impairing or destroying the integrity of some or all of the structural components. Structural components consist of liners, leachate collection systems, final cover systems, run-on and run-off control systems, and any other component necessary for protection of human health and the environment.

MSWLF units can be located in unstable areas, but the owner or operator must demonstrate that the structural integrity of the MSWLF unit will not be disrupted. The demonstration must show that engineering measures have been incorporated into the design of the unit to ensure the integrity of the structural components. Existing MSWLF units that do not meet the demonstration must be closed within 5 years in accordance with §258.60, and owners and operators must undertake post-closure activities in accordance with §258.61. The Director of an approved State can grant a 2-year extension to the closure requirement under two conditions: (1) no disposal alternative is available, and (2) no immediate threat is posed to human health and the environment.

2.7.3 Technical Considerations

Again, for the purposes of this discussion, natural unstable areas include those areas that have poor soils for foundations, are susceptible to mass movement, or have karst features.

- **Areas with soils that make poor foundations** have soils that are expansive or settle suddenly. Such areas may lose their ability to support a foundation when subjected to natural (e.g., heavy rain) or man-made events (e.g., explosions).

  — Expansive soils usually are clay-rich soils that, because of their molecular structure, tend to swell and shrink by taking up and releasing water and thus are sensitive to a variable hydrologic regime. Such soils include: smectite (montmorillonite group) and vermiculite clays; bentonite is a smectite-rich clay. In addition, soils rich in "white alkali" (sodium sulfate), anhydrite (calcium sulfate), or pyrite (iron sulfide) also may exhibit swelling as water content increases. Such soils tend to be found in the arid western states.

  — Soils that are subject to rapid settlement (subsidence) include loess, unconsolidated clays, and wetland soils. Loess, which is found in the central states, is a wind-deposited silt that is moisture-deficient and tends to compact upon wetting. Unconsolidated clays, which can be found in the southwestern states, can undergo considerable compaction when fluids such as water or oil are removed. Similarly, wetland soils, which by their nature are water-bearing, also tend to be subject to subsidence when water is withdrawn.

- Another type of unstable area is an **area that is subject to mass movement**. Such areas can be situated on steep or gradual slopes. They tend to 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 movements include avalanches, landslides, debris slides and flows, and rock slides.

- **Karst terrains** tend to be subject to extreme incidents of differential settlement, namely complete ground collapse. Karst is a term used to describe areas that are underlain by soluble bedrock, such as limestone, where solution of the rock by water creates subterranean drainage systems that may include areas of rock collapse. These areas tend to be characterized by large subterranean and surficial voids (e.g., caverns and sinkholes) and unpredictable surface and ground-water flow (e.g., sinking streams and large springs). Other rocks such as dolomite or gypsum also may be subject to solution effects.

Examples of human-induced unstable areas are described below:

- The presence of cut and/or fill slopes during construction of the MSWLF unit may cause slippage of existing soil or rock.

- Excessive drawdown of ground water increases the effective overburden on the foundation soils underneath the MSWLF unit, which may cause excessive settlement or bearing capacity failure on the foundation soils.

- A closed landfill as the foundation for a new landfill ("piggy-backing") may be unstable unless the closed landfill has undergone complete settlement of the underlying wastes.

As part of their demonstration to site a landfill in an unstable area, owners/operators must assess the ability of the soils and/or rock to serve as a foundation as well as the ability of the site embankments and slopes to maintain a stable condition. Once these factors have been evaluated, a MSWLF design should be developed that will address these types of concerns and prevent possible associated damage to MSWLF structural components.

In designing a new unit or lateral expansion or re-evaluating an existing MSWLF unit, a **stability assessment** should be conducted in order to avoid or prevent a destabilizing event from impairing the structural integrity of the landfill component systems. A stability assessment involves essentially three components: an evaluation of subsurface conditions, an analysis of slope stability, and an examination of related design needs. An evaluation of subsurface conditions requires:

- Assessing the stability of foundation soils, adjacent embankments, and slopes;

- Investigating the geotechnical and geological characteristics of the site to establish soil strengths and other engineering properties by performing standard penetration tests, field vane shear tests, and laboratory tests; and

- Testing the soil properties such as water content, shear strength, plasticity, and grain size distribution.

A stability assessment should consider (USEPA, 1988):

- The adequacy of the subsurface exploration program;
- The liquefaction potential of the embankment, slopes, and foundation soils;
- The expected behavior of the embankment, slopes, and foundation soils when they are subjected to seismic activity;
- The potential for seepage-induced failure; and
- The potential for differential settlement.

In addition, a qualified professional must assess, at a minimum, natural conditions (e.g., soil, geology, geomorphology) as well as human-made features or events (both subsurface and surface) that could cause differential settlement of ground. Natural conditions can be highly unpredictable and destructive, especially if amplified by human-induced changes to the environment. Specific examples of natural or human-induced phenomena include: debris flows resulting from heavy rainfall in a small watershed; the rapid formation of a sinkhole as a result of excessive local or regional ground water withdrawal in a limestone region; earth displacement by faulting activity; and rockfalls along a cliff face caused by vibrations resulting from the detonation of explosives or sonic booms.

Information on natural features can be obtained from:

- The USGS National Atlas map entitled "Engineering Aspects of Karst," published in 1984;
- Regional or local soil maps;
- Aerial photographs (especially in karst areas); and
- Site-specific investigations.

To examine an area for possible sources of human-induced ground instability, the site and surrounding area should be examined for activities related to extensive withdrawal of oil, gas, or water from subsurface units as well as construction or other operations that may result in ground motion (e.g., blasting).

Types of Failures

Failures occur when the driving forces imposed on the soils or engineered structures exceed the resisting forces of the material. The ratio of the resisting force to the driving force is considered the factor of safety (FS). At an FS value less than 1.0, failure will occur by definition. There is a high probability that, due to natural variability and the degree of accuracy in measurements, interpreted soil conditions will not be precisely representative of the actual soil conditions. Therefore, failure may not occur exactly at the calculated value, so factors of safety greater than 1.0 are required for the design. For plastic soils such as clay, movement or deformation (creep) may occur at a higher factor of safety prior to catastrophic failure.

Principal modes of failure in soil or rock include:

- Rotation (change of orientation) of an earthen mass on a curved slip surface approximated by a circular arc;
- Translation (change of position) of an earthen mass on a planar surface whose length is large compared to depth below ground;
- Displacement of a wedge-shaped mass along one or more planes of weakness;
- Earth and mud flows in loose clayey and silty soils; and
- Debris flows in coarse-grained soils.

For the purposes of this discussion, three types of failures can occur at a landfill unit: settlement, loss of bearing strength, and sinkhole collapse.

- If not properly engineered, a landfill in an unstable area may undergo extreme **settlement**, which can result in structural failure. Differential settlement is a particular mode of failure that generally occurs beneath a landfill in response to consolidation and dewatering of the foundation soils during and following waste loading.

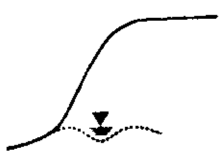
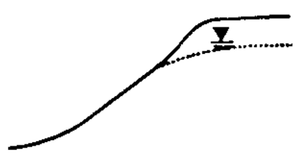
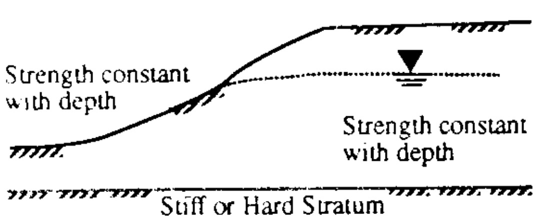
  Settlement beneath a landfill unit, both total and differential, should be assessed and compared to the elongation strength and flexure properties of the liner and leachate collection pipe system. Even small amounts of settlement can seriously damage leachate collection piping and sumps. The analysis will provide an estimate of maximum settlement, which can be used to aid in estimating differential settlement.

  Allowable settlement is typically expressed as a function of total settlement because differential settlement is more difficult to predict. However, differential settlement is a more serious threat to the integrity of the structure than total settlement. Differential settlement also is discussed in Section 6.3 of Chapter 6.

- **Loss of bearing strength** is a failure mode that tends to occur in areas that have soils that tend to expand, rapidly settle, or liquefy, thereby causing failure or reducing performance of overlying MSWLF components. Another example of loss of bearing strength involves failures that have occurred at operating sites where excavations for landfill expansions adjacent to the filled areas reduced the mass of the soil at the toe of the slope, thereby reducing the overall strength (resisting force) of the foundation soil.

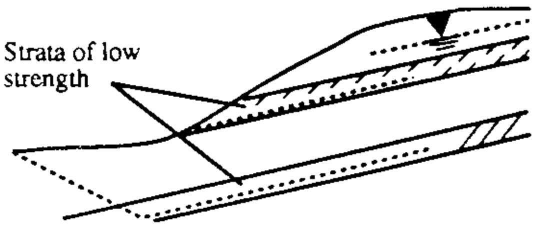
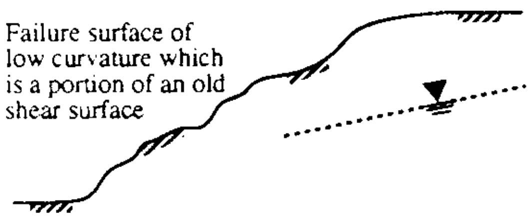
- **Catastrophic collapse in the form of sinkholes** is a type of failure that occurs in karst regions. As water, especially acidic water, percolates through limestone (calcium carbonate), the soluble carbonate material dissolves, forming cavities and caverns. Land overlying caverns can collapse suddenly, resulting in sinkhole features that can be 100 feet or more in depth and 300 feet or more in width.

Tables 2-2 and 2-3 provide examples of analytical considerations for mode of failure assessments in both natural and human-made slopes.

1. Slope in Coarse-Grained Soil with Some Cohesion *Low Groundwater* Failure of thin wedge, position influenced by tension cracks *High Groundwater* Failure at relatively shallow toe circles  	• With low groundwater, failure occurs on shallow, straight, or slightly curved surface. Presence of a tension crack at the top of the slope influences failure location. With high groundwater, failure occurs on the relatively shallow toe circle whose position is determined primarily by ground elevation. • Analyze with effective stress using strengths C' and Ø' from CD tests. Pore pressure is governed by seepage condition. Internal pore pressures and external water pressures must be included.
2. Slope in Coarse-Grained, Soil Cohesion *Low Groundwater* Stable slope angle = effective friction angle *High Groundwater* Stable slope angle = ½ effective friction angle  	• Stability depends primarily on groundwater conditions. With low groundwater, failures occur as surface sloughing until slope angle flattens to friction angle. With high groundwater, stable slope is approximately 1/2 friction angle. • Analyze with effective stress using strengths C' and Ø' from CD tests. Slight cohesion appearing in test envelope is ignored. Special consideration must be given to possible flow slides in loose, saturated fine sands.
3. Slope in Normally Consolidated or Slightly Preconsolidated Clay *Location of failure depends on variation of shear strength with depth.* 	• Failure occurs on circular arcs whose position is governed by theory. Position of groundwater table does not influence stability unless its fluctuation changes strength of the clay or acts in tension cracks. • Analyze with total stresses, zoning cross section for different values of shear strengths. Determine shear strength from unconfined compression test, unconsolidated undrained triaxial test or vane shear.

Source: Soil Mechanics, NAVFAC Design Manual 7.01

Table 2-2. Analysis of Stability of Natural Slopes

4. Slope in Stratified Soil Profile *Location of failure depends on relative strength and orientation of layers.*  	• Location of failure plane is controlled by relative strength and orientation of strata. Failure surface is combination of active and passive wedges with central sliding block chosen to conform to stratification. • Analyze with effective stress using strengths C' and Ø' for fine-grained strata and Ø' for cohesionless material.
5. Depth Creep Movements in Old Slide Mass *Bowl-shaped area of low slope (9 to 11%) bounded at top by old scarp.*  	• Strength of old slide mass decreases with magnitude of movement that has occurred previously. Most dangerous situation is in stiff, over-consolidated clay which is softened, fractured, or slickensided in the failure zone.

Source: Soil Mechanics, NAVFAC Design Manual 7.01

Table 2-2. Analysis of Stability of Natural Slopes (Continued)

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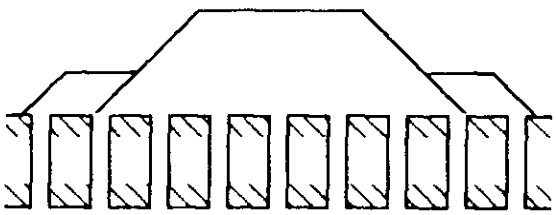
1. Failure of Fill on Soft Cohesive Foundation with Sand Drains



Location of failure depends on geometry and strength of cross section.

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- Usually, minimum stability occurs during placing of fill. If rate of construction is controlled, allow for gain in strength with consolidation from drainage.
- Analyze with effective stress using strengths C' and Ø' from CU tests with pore pressure measurement. Apply estimated pore pressures or piezometric pressures. Analyze with total stress for rapid construction without observation of pore pressures, use shear strength from unconfined compression or unconsolidated undrained triaxial.

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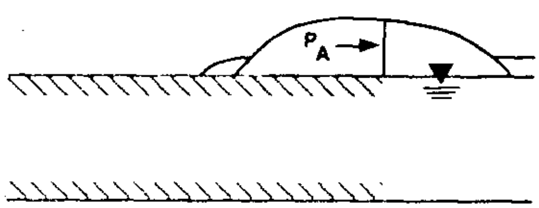
2. Failure of Stiff Compacted Fill on Soft Cohesive Foundation



Failure surface may be rotation on circular arc or translation with active and passive wedges.

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- Usually, minimum stability obtained at end of construction. Failure may be in the form of rotation or
translation, and both should be considered.
- For rapid construction ignore consolidation from drainage and utilize shear strengths determined from U or UU tests or vane shear in total stress analysis. If failure strain of fill and foundation materials differ greatly, safety factor should exceed one, ignoring shear strength of fill. Analyze long-term stability using C and Ø from CU tests with effective stress analysis, applying pore pressures of

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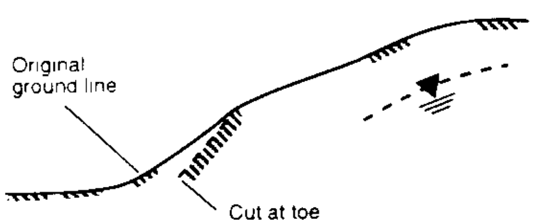
3. Failure Following Cut in Stiff Fissured Clay



Failure surface depends on pattern of fissures or depth of softening.

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- Release of horizontal stresses by excavation causes expansion of clay and opening of fissures, resulting in loss of cohesive strength.
- Analyze for short-term stability using C' and Ø' with total stress analysis. Analyze for long-term stability with C'_r and $Ø'_m$ based on residual strength measured in consolidated drained tests.

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Source: Soil Mechanics, NAVFAC Design Manual 7.01

Table 2-3. Analysis of Stability of Cut and Fill Slopes, Conditions Varying With Time

Subsurface Exploration Programs

Foundation soil stability assessments for non-catastrophic failure require field investigations to determine soil strengths and other soil properties. *In situ* field vane shear tests commonly are conducted in addition to collection of piston samples for laboratory testing of undrained shear strengths (biaxial and triaxial). Field vanes taken at depth provide a profile of soil strength. The required field vane depth intervals vary, based on soil strength and type, and the number of borings required depends on the variability of the soils, the site size, and landfill unit dimensions. Borings and field vane testing should consider the anticipated design to identify segments of the facility where critical cross sections are likely to occur. Critical sections are where factors of safety are anticipated to be lowest.

Other tests that are conducted to characterize a soil include determination of water content, Atterberg limits, grain size distribution, consolidation, effective porosity, and saturated hydraulic conductivity. The site hydrogeologic conditions should be assessed to determine if soils are saturated or unsaturated.

Catastrophic failures, such as sinkhole collapse in karst terrains or fault displacement during an earthquake, are more difficult to predict. Subsurface karst structures may have surface topographic expressions such as circular depressions over subsiding solution caverns. Subsurface borings or geophysical techniques may provide reliable means of identifying the occurrence, depth, and size of solution cavities that have the potential for catastrophic collapse.

Methods of Slope Stability Analysis

Slope stability analyses are performed for both excavated side slopes and aboveground embankments. The analyses are performed as appropriate to verify the structural integrity of a cut slope or dike. The design configuration is evaluated for its stability under all potential hydraulic and loading conditions, including conditions that may exist during construction of an expansion (e.g., excavation). Analyses typically performed are slope stability, settlement, and liquefaction. Factor of safety rationale and selection for different conditions are described by Huang (1983) and Terzaghi and Peck (1967). Table 2-4 lists recommended minimum factor of safety values for slopes. Many States may provide their own minimum factor of safety requirements.

There are numerous methods currently available for performing slope stability analyses. Method selection should be based on the soil properties and the anticipated mode of failure. Rationale for selecting a specific method should be provided.

The majority of these methods may be categorized as "limit equilibrium" methods in which driving and resisting forces are determined and compared. The basic assumption of the limit equilibrium approach is that the failure criterion is satisfied along an assumed failure surface. This surface may be a straight line, circular arc, logarithmic spiral, or other irregular plane. A free body diagram of the driving forces acting on the slope is constructed using assumed or known values of the forces. Next, the soil's shear resistance as it pertains to establishing equilibrium is calculated. This calculated shear resistance

Table 2-4

Recommended Minimum Values of Factor of Safety for Slope Stability Analyses

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, and logical picture of the strength characteristics.

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

Source: EPA Guide to Technical Resources for the Design of Land Disposal Facilities.

then is compared to the estimated or available shear strength of the soil to give an indication of the factor of safety (Winterkorn and Fang, 1975).

Methods that consider only the whole free body as a single unit include the Culmann method and the friction circle method. Another approach is to divide the free body into vertical slices and to consider the equilibrium of each slice. Several versions of the slice method are available; the best known are the Swedish Circle method and the Bishop method. Discussions of these and other methods may be found in Winterkorn and Fang (1975), Lambe and Whitman (1969), and U.S. Navy (1986).

A computer program that is widely used for slope stability analysis is PC STABL, a two-dimensional model that computes the minimum critical factors of safety between layer interfaces. This model uses the method of vertical slices to analyze the slope and calculate the factor of safety. PC STABL can account for heterogeneous soil systems, anisotropic soil strength properties, excess pore water pressure due to shear, static ground water and surface water, pseudostatic earthquake loading, surcharge boundary loading, and tieback loading. The program is written in FORTRAN IV and can be run on a PC. Figure 2-7 presents a typical output from the model.

Design for Slope Stabilization

Methods for slope stabilization are presented in Table 2-5 and are summarized below.

- The first illustration shows that stability can be increased by changing the slope geometry through reduction of the slope height, flattening the slope angle, or excavating a bench in the upper part of the slope.

- The second illustration shows how compacted earth or rock fill can be placed in the form of a berm at and beyond the slope's toe to buttress the slope. To prevent the development of undesirable water pressure behind the berm, a drainage system may be placed behind the berm at the base of the slope.

- The third illustration presents several types of retaining structures. These structures generally involve drilling and/or excavation followed by constructing cast-in-place concrete piles and/or slabs.

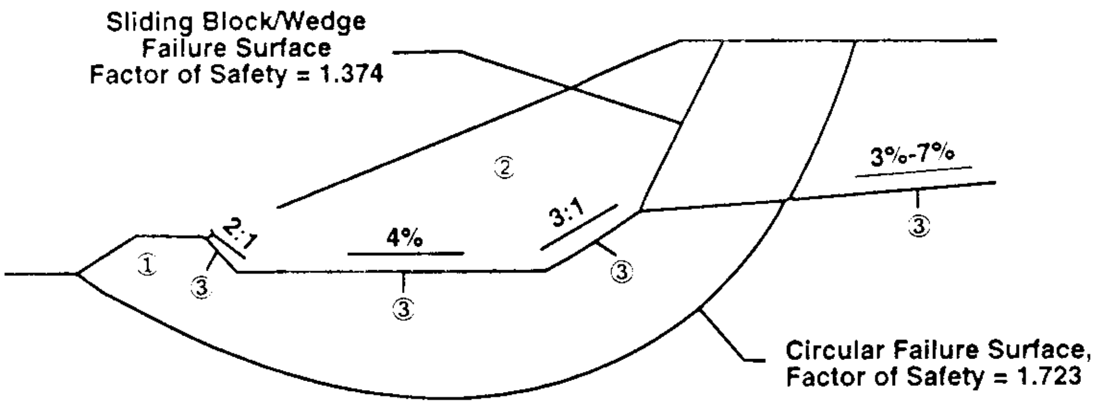
  — The T-shaped cantilever wall design enables some of the retained soil to contribute to the stability of the structure and is advisable for use on slopes that have vertical cuts.

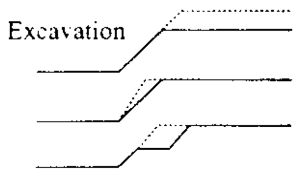
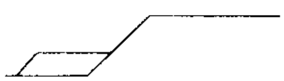
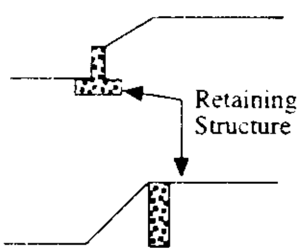
  — Closely-spaced vertical piles placed along the top of the slope area provide reinforcement against slope failure through a soil arching effect that is created between the piles. This type of retaining system is advisable for use on steeply cut slopes.

  — Vertical piles also may be designed with a tie back component at an angle to the vertical to develop a high resistance to lateral forces. This type of wall is recommended for use in areas

Figure 2-7
Sample Output from PC STABL Model

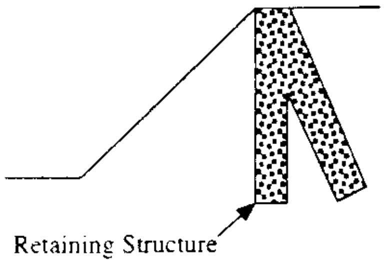
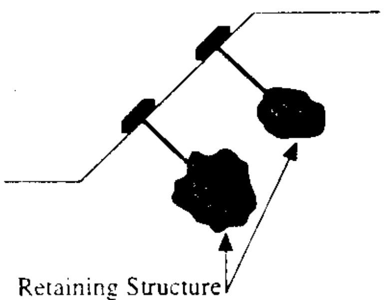
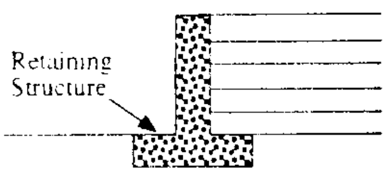
① Subgrade: Internal friction angle = 32 degrees
② Refuse: Internal friction angle of waste = 25 degrees
③ Refuse: Internal friction angle of waste = 25 degrees



Scheme	Applicable Methods	Comments
1. Changing Geometry 	1. Reduce slope height by excavation at top of slope 2. Flatten the slope angle. 3. Excavate a bench in upper part of slope.	1. Area has to be accessible to construction equipment. Disposal site needed for excavated soil. Drainage sometimes incorporated in this method.
2. Earth Berm Fill 	1. Compacted earth or rock berm placed at end beyond the toe. Drainage may be provided behind the berm.	1. Sufficient width and thickness of berm required so failure will not occur below or through the berm.
3. Retaining Structures 	1. Retaining wall: crib or cantilever type. 2. Drilled, cast-in-place vertical piles and/or slabs founded well below bottom slide plane. Generally 18 to 36 inches in diameter and 4- to 8-foot spacing. Larger diameter piles at closer spacing may be required in some cases with mitigate failures of cuts in highly fissured clays.	1. Usually expensive. Cantilever walls might have to be tied back. 2. Spacing should be such that soil can arch between piles. Grade beam can be used to tie piles together. Very large diameter (6 feet±) piles have been used for deep slide.

Source: Soil Mechanics, NAVFAC Design Manual 7.01

Table 2-5
Methods of Stabilizing Excavation Slopes

Scheme	Applicable Methods	Comments
	3. Drilled, cast-in-place vertical piles tied back with battered piles or a deadman. Piles founded well below slide plane. Generally, 12 to 30 inches in diameter and at least 4- to 8-foot spacing.	3. Space close enough so soil will arch between piles. Piles can be tied together with grade beam.
	4. Earth and rock anchors and rock bolts.	4. Can be used for high slopes, and in very restricted areas. Conservative design should be used, especially for permanent support. Use may be essential for slopes in rocks where joints dip toward excavation, and such joints daylight in the slope.
	5. Reinforced earth.	5. Usually expensive
4. Other methods	See TABLE 7, NAVFAC DM-7.2, Chapter 1	

Source: Soil Mechanics, NAVFAC Design Manual 7.01

Table 2-5 (continued)
Methods of Stabilizing Excavation Slopes

with steeply cut slopes where soil arching can be developed between the piles.

— The last retaining wall shown uses a cantilever setup along with soil that has been reinforced with geosynthetic material to provide a system that is highly resistant to vertical and lateral motion. This type of system is best suited for use in situations where vertically cut slopes must have lateral movement strictly controlled.

Other potential procedures for stabilizing natural and human-made slopes include the use of geotextiles and geogrids to provide additional strength, the installation of wick and toe drains to relieve excess pore pressures, grouting, and vacuum and wellpoint pumping to lower ground-water levels. In addition, surface drainage may be controlled to decrease infiltration, thereby reducing the potential for mud and debris slides in some areas. Lowering the ground-water table also may have stabilizing effects. Walls or large-diameter piling can be used to stabilize slides of relatively small dimension or to retain steep toe slopes so that failure will not extend back into a larger mass (U.S. Navy, 1986). For more detailed information regarding slope stabilization design, refer to Winterkorn and Fang (1975), U.S. Navy (1986), and Sowers (1979). Richardson and Koerner (1987) and Koerner (1986) provide design guidance for geosynthetics in both landfill and general applications.

Monitoring

During construction activities, it may be appropriate to monitor slope stability because of the additional stresses placed on natural and engineered soil systems (e.g., slopes, foundations, dikes) as a result of excavation and filling activities. Post-closure slope monitoring usually is not necessary.

Important monitoring parameters may include settlement, lateral movement, and pore water pressure. Monitoring for pore water pressure is usually accomplished with piezometers screened in the sensitive strata. Lateral movements of structures may be detected on the surface by surveying horizontal and vertical movements. Subsurface movements may be detected by use of slope inclinometers. Settlement may be monitored by surveying ground surface elevations (on several occasions over a period of time) and comparing them with areas that are not likely to experience changes in elevations (e.g., USGS survey monuments).

Engineering Considerations for Karst Terrains

The principal concern with karst terrains is progressive and/or catastrophic failure of subsurface conditions due to the presence of sinkholes, solution cavities, and subterranean caverns. The unpredictable and catastrophic nature of subsidence in these areas makes them difficult to develop as landfill sites. Before situating a MSWLF in a karst region, the subject site should be characterized thoroughly.

The first stage of demonstration is to characterize the subsurface. Subsurface drilling, sinkhole monitoring, and geophysical testing are direct means that can be used to characterize a site. Geophysical techniques include tests using electromagnetic conductivity, seismic refraction, ground-penetrating radar, gravity, and electrical resistivity. Interpretation and applicability of different geophysical techniques should be reviewed by a qualified geophysicist. Often more than one technique should be employed to confirm and correlate findings and anomalies. Subsurface drilling is recommended highly for verifying the results of geophysical investigations.

Additional information on karst conditions can come from remote sensing techniques, such as aerial photograph interpretation. Surface mapping of karst features can help to provide an understanding of structural patterns and relationships in karst terrains. An understanding of local carbonate geology and stratigraphy can aid in the interpretation of both remote sensing and geophysical techniques.

A demonstration that engineering measures have been incorporated into a unit located in a karst terrain may include both initial design and site modifications. A relatively simple engineering modification that can be used to mitigate karst terrain problems is ground-water and surface water control and conveyance. Such water control measures are used to minimize the rate of dissolution within known near-surface limestone. This means of controlling karst development may not be applicable to all karst situations. In areas where development of karst topography tends to be minor, loose soils overlying the limestone may be excavated or heavily compacted to achieve the needed stability. Similarly, in areas where the karst voids are relatively small and limited in extent, infilling of the void with slurry cement grout or other material may be an option.

In general, due to the unpredictable and catastrophic nature of ground failure in such areas, engineering solutions that try to compensate for the weak geologic structures by constructing manmade ground supports tend to be complex and costly. For example, reinforced raft (or mat) foundations could be used to compensate for lack of ground strength in some karst areas. Raft foundations are a type of "floating foundation" that consist of a concrete footing that extends over a very large area. Such foundations are used where soils have a low bearing capacity or where soil conditions are variable and erratic; these foundations are able to reduce and distribute loads. However, it should be noted that, in some instances, raft foundations may not necessarily be able to prevent the extreme type of collapse and settlement that can occur in karst areas. In addition, the construction of raft foundations can be very costly, depending on the size of the area.

2.8 CLOSURE OF EXISTING MUNICIPAL SOLID WASTE LANDFILL UNITS 40 CFR §258.16

2.8.1 Statement of Regulation

(a) Existing MSWLF units that cannot make the demonstration specified in §§258.10(a), pertaining to airports, 258.11(a), pertaining to floodplains, and 258.15(a), pertaining to unstable areas,

must close by October 9, 1996, in accordance with §258.60 of this part and conduct post-closure activities in accordance with §258.61 of this part.

(b) The deadline for closure required by paragraph (a) of this section may be extended up to two years if the owner or operator demonstrates to the Director of an approved State that:

(1) There is no available alternative disposal capacity;

(2) There is no immediate threat to human health and the environment.

2.8.2 Applicability

These requirements are applicable to all MSWLF units that receive waste after October 9, 1993 and cannot meet the airport safety, floodplain, or unstable area requirements. The owner or operator is required to demonstrate that the facility: (1) will not pose a bird hazard to aircraft under §258.10(a); (2) is designed to prevent washout of solid waste, will not restrict floodplain storage capacity, or increase floodwater flow in a 100-year floodplain under §258.11(a); and 3) can withstand damage to landfill structural component systems (e.g., liners, leachate collection, and other engineered structures) as a result of unstable conditions under §258.15(a). If any of these demonstrations cannot be made, the landfill must close by October 9, 1996. In approved States, the closure deadline may be extended up to two additional years if it can be shown that alternative disposal capacity is not available and that the MSWLF unit does not pose an immediate threat to human health and the environment.

2.8.3 Technical Considerations

The engineering considerations that should be addressed for airport safety, 100-year floodplain encroachment, and unstable areas are discussed in Sections 2.2, 2.3, and 2.7 of this chapter. Information and evaluations necessary for these demonstrations also are presented in these sections. If applicable demonstrations are not made by the owners or operators, the landfill unit(s) must be closed according to the requirements of section §258.60 by October 9, 1996.

For MSWLF units located in approved States, this deadline may be extended if there is no immediate threat to human health and the environment and no waste disposal alternative is available. The demonstration of no disposal alternative should consider all waste management facilities, including landfills, municipal waste combustors, and recycling facilities. The demonstration for the two-year extension should consider the impacts on human health and the environment as they relate to airport safety, 100-year floodplains, or unstable areas.

§§258.17-258.19 [Reserved].

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Winterhorn, H.F. and Fang, H.Y., (1975). "Foundation Engineering Handbook," Van Nostrand Reinhold, 1975.

2.9.2 Organizations

American Institute of Architects
Washington, D.C.
(202) 626-7300

Aviation Safety Institute (ASI)
Box 304
Worthington, OH 43085
(614) 885-4242

American Society of Civil Engineers
345 East 47th St.
New York, NY 10017-2398
(212) 705-7496

Building Seismic Safety Council
201 L Street, Northwest Suite 400
Washington, D.C. 20005
(202) 289-7800

Bureau of Land Management
1849 C St. N.W.
Washington, D.C. 20240
(202) 343-7220 (Locator)
(202) 343-5717 (Information)

Federal Emergency Management Agency
Flood Map Distribution Center
6930 (A-F) San Thomas Road
Baltimore, Maryland 21227-6227
1-800-358-9616

Federal Emergency Management Agency
(800) 638-6620 Continental U.S. only, except Maryland
(800) 492-6605 Maryland only
(800) 638-6831 Continental U.S., Hawaii, Alaska, Puerto Rico, Guam, and the Virgin Islands

Note: The toll free numbers may be used to obtain any of the numerous FEMA publications such as "The National Flood Insurance Program Community Status Book," which is published bimonthly.

To obtain Flood Insurance Rate Maps and other flood maps, the FEMA Flood Map Distribution Center should be contacted at 1-800-358-9616.

Federal Highway Administration
400 7th St. S.W.
Washington, D.C. 20590
(202) 366-4000 (Locator)
(202) 366-0660 (Information)

Hydrologic Engineering Center (HEC Models)
U.S. Army Corps of Engineers
609 Second St.
Davis, CA 95616
(916) 756-1104

National Information Service for Earthquake Engineering (NISEE)
University of California, Berkeley
404A Davis Hall
Berkeley, CA 94720
(415) 642-5113
(415) 643-5246 (FAX)

National Oceanic and Atmospheric Administration
Office of Legislative Affairs
1825 Connecticut Avenue Northwest
Room 627
Washington, DC 20235
(202) 208-5717

Tennessee Valley Authority
412 First Street Southeast, 3rd Floor
Washington, DC 20444
(202) 479-4412

U.S. Department of Agriculture
Soil Conservation Service
P.O. Box 2890
Washington, DC 20013-2890
(Physical Location: 14th and Independence Ave. N.W.)
(202) 447-5157

U.S. Department of the Army
U.S. Army Corps of Engineers
Washington, DC 20314-1000
(202) 272-0660

U.S. Department of the Interior
Fish and Wildlife Service
1849 C Street Northwest
Washington, DC 20240
(202) 208-5634

U.S. Department of Transportation
Federal Aviation Administration
800 Independence Ave., S.W.
Washington, D.C. 20591
(202) 267-3085

U.S. Geological Survey
12201 Sunrise Valley Drive
Reston, Virginia 22092
(800) USA-MAPS

U.S. Geological Survey
Branch of Geologic Risk Assessment
Stop 966 Box 25046
Denver, Colorado 80225
(303) 236-1629

U.S. Geological Survey
EROS Data Center
Sioux Falls, South Dakota 57198
(605) 594-6151

U.S. Geological Survey
National Earthquake Information Center
Stop 967 Box 25046
Denver Federal Center
Denver, Colorado 80225
(303) 236-1500

2.9.3 Models

Adamus, P.R., et al., (1987). "Wetland Evaluation Technique (WET); Volume II: Methodology"; Operational Draft Technical Report Y-87; U.S. Army Engineer Waterways Experiment Station; Vicksburg, MS.

COE, (1982). HEC-1, HEC-2, HEC-5, HEC-6 Computer Programs; Hydrologic Engineering Center (HEC); U.S. Army Corps of Engineers; Hydrologic Engineering Center; Davis California.

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APPENDIX I

FAA Order 5200.5A

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

5200.5A

l/31/90

SUBJ: WASTE DISPOSAL SITES ON OR NEAR AIRPORTS

1. PURPOSE. This order provides guidance concerning the establishment, elimination or monitoring of landfills, open dumps, waste disposal sites or similarly titled facilities on or in the vicinity of airports.

2. DISTRIBUTION. This order is distributed to the division level in the Offices of Airport Planning and Programming Airport Safety and Standards, Air Traffic Evaluations and Analysis Aviation Safety Oversight, Air Traffic Operations Service, and Flight Standards Service; to the division level in the regional Airports, Air Traffic, and Flight Standards Divisions; to the director level at the Aeronautical Center and the FAA Technical Center, and a limited distribution to all Airport District Offices, Flight Standards Field Offices, and Air Traffic Facilities.

3. CANCELLATION. Order 5200.5, FAA Guidance Concerning Sanitary Landfills On Or Near Airports, dated October 16, 1974, is canceled.

4. BACKGROUND. Landfills, garbage dumps, sewer or fish waste outfalls and other similarly licensed or titled facilities used for operations to process, bury, store or otherwise dispose of waste, trash and refuse will attract rodents and birds. Where the dump is ignited and produces smoke, an additional attractant is created. All of the above are undesirable and potential hazards to aviation since they erode the safety of the airport environment. The FM neither approves nor disapproves locations of the facilities above. Such action is the responsibility of the Environmental Protection Agency and/or the appropriate state and local agencies. The role of the FAA is to ensure that airport owners and operators meet their contractual obligations to the United States government regarding compatible land uses in the vicinity of the airport. While the chance of an unforeseeable, random bird strike in flight will always exist, it is nevertheless possible to define conditions within fairly narrow limits where the risk is increased. Those high-risk conditions exist in the approach and departure patterns and landing areas on and in the vicinity of airports. The number of bird strikes reported on aircraft is a matter of continuing concern to the FM and to airport management. Various observations support the conclusion that waste disposal sites are artificial attractants to birds. Accordingly, disposal sites located in the vicinity of an airport are potentially incompatible with safe flight operations. Those sites that are not compatible need to be eliminated. Airport owners need guidance in making those decisions and the FM must be in a position to assist. Some airports are not under the jurisdiction of the community or local governing body having control of land usage in the vicinity of the airport. In these areas, the airport owner should use its resources and exert its best efforts to close or control waste disposal operations within the general vicinity of the airport.

5. EXPLANATION OF CHANGES. The following list outlines the major changes to Order 5200.5:

a. Recent developments and new techniques of waste disposal warranted updating and clarification of what constitutes a sanitary landfill. This listing of new titles for waste disposal was outlined in paragraph 4.

b. Due to a reorganization which placed the Animal Damage Control Branch of the U.S. Department of Interior Fish and Wildlife Service under the jurisdiction of the U.S. Department of Agriculture an address addition was necessary

c. A zone of notification was added to the criteria which should provide the appropriate FM Airports office an opportunity to comment on the proposed disposal site during the selection process.

6. ACTION.

a. Waste disposal sites located or proposed to be located within the areas established for an airport by the guidelines set forth in paragraphs 7 a b, and c of this order should not be allowed to operate. If a waste disposal site is incompatible with an airport in accordance with guidelines of paragraph 7 and cannot be closed within a reasonable time, it should be operated in accordance with the criteria and instructions issued by Federal agencies such as the Environmental Protection Agency and the Department of Health and Human Services, and other such regulatory bodies that may have applicable requirements. The appropriate FM airports office should advise airport owners, operators and waste disposal proponents against locating, permitting or concurring in the location of a landfill or similar facility on or in the vicinity of airports.

(1) Additionally, any operator proposing a new or expanded waste disposal site within 5 miles of a runway end should notify the airport and the appropriate FM Airports office so as to provide an opportunity to review and comment on the site in accordance with the guidance contained in this order. FM field offices may wish to contact the appropriate State director of the United States Department of Agriculture to assist in this review. Also, any Air Traffic control tower manager or Flight Standards District Office manager and their staffs that become aware of a proposal to develop or expand a disposal site should notify the appropriate FM Airports office.

b. The operation of a disposal site located beyond the areas described in paragraph 7 must be properly supervised to ensure compatibility with the airport.

c. If at any time the disposal site, by virtue of its location or operation, presents a potential hazard to aircraft operations the owner should take action to correct the situation or terminate operation of the facility. If the owner of the airport also owns or controls the disposal facility and is subject to Federal obligations to protect compatibility of land uses around the airport, failure to take corrective action could place the airport owner in noncompliance with its commitments to the Federal government. The appropriate FM office should immediately evaluate the situation to determine compliance with federal agreements and take such action as may be warranted under the guidelines as prescribed in Order 5190.6, Airports Compliance Requirements, current edition.

(1) Airport owners should be encouraged to make periodic inspections of current operations of existing disposal sites near a federally obligated airport where potential bird hazard problems have been reported.

d. This order is not intended to resolve all related problems but is specifically directed toward eliminating waste disposal sites, landfills and similarly titled facilities in the proximity of airports, thus providing a safer environment for aircraft operations.

e. At airports certified under Federal Aviation Regulations, part 139, the airport certification manual/specifications should require disposal site inspections at appropriate intervals for those operations meeting the criteria of paragraph 7 that cannot be closed. These inspections are necessary to assure that bird populations are not increasing and that appropriate control procedures are being established and followed. The appropriate FAA airport offices should develop working relationships with state aviation agencies and state agencies that have authority over waste disposal and landfills to stay abreast of proposed developments and expansions and apprise them of the hazards to aviation that these present.

f. When proposing a disposal site, operators should make their plans available to the appropriate state regulatory agencies. Many states have criteria concerning siting requirements specific to their jurisdictions.

g. Additional information on waste disposal, bird hazard and related problems may be obtained from the following agencies:

U.S. Department of Interior Fish and Wildlife Service
18th and C Streets, NW
Washington, DC 20240

U.S. Department of Agriculture
Animal Plant Health Inspection Service
P.O. Box 96464
Animal Damage Control Program
Room 1624 South Agriculture Building
Washington, DC 20090-6464

U.S. Environmental Protection Agency
401 M Street, SW
Washington, DC 20460

U.S. Department of Health and Human Services
200 Independence Avenue, SW
Washington, DC 20201

7. CRITERIA. Disposal sites will be considered as incompatible if located within areas established for the airport through the application of the following criteria:

a. Waste disposal sites located within 10,000 feet of any runway end used or planned to be used by turbine powered aircraft

b. Waste disposal sites located within 5,000 feet of any runway end used only by piston powered aircraft.

c. Any waste disposal site located within a 5-mile radius of a runway end that attracts or sustains hazardous bird movements from feeding, water or roosting areas into, or across the runway and/or approach and departure patterns of aircraft.

Leonard E. Mudd
Director, Office of Airport Safety and Standards

CHAPTER 3

SUBPART C
OPERATING CRITERIA

CHAPTER 3
SUBPART C

TABLE OF CONTENTS

CHAPTER 3
SUBPART C
OPERATING CRITERIA

3.1 INTRODUCTION

The Solid Waste Disposal Facility Criteria contain a series of operating requirements pertaining to routine operation, management, and environmental monitoring at municipal solid waste landfill units (MSWLF units). The operating requirements pertain to new MSWLF units, existing MSWLF units, and lateral expansions of existing MSWLF units.

The operating requirements have been developed to ensure the safe daily operation and management at MSWLF units. The operating requirements include:

- The exclusion of hazardous waste;
- Cover material;
- Disease vector control;
- Explosive gases control;
- Air monitoring;
- Facility access;
- Run-on/run-off control systems;
- Surface water requirements;
- Liquid restrictions; and
- Recordkeeping requirements.

Any owner or operator of a MSWLF unit must comply with the operating requirements by October 9, 1993.

In specific cases, the operating requirements require compliance with other Federal laws. For example, surface water discharges from a MSWLF unit into the waters of the United States must be in conformance with applicable sections of the Clean Water Act. In addition, burning of municipal solid waste (MSW) is regulated under applicable sections of the Clean Air Act.

3.2 PROCEDURES FOR EXCLUDING THE RECEIPT OF HAZARDOUS WASTE 40 CFR §258.20

3.2.1 Statement of Regulation

(a) Owners or operators of all MSWLF units must implement a program at the facility for detecting and preventing the disposal of regulated hazardous wastes as defined in Part 261 of this title and polychlorinated biphenyls (PCB) wastes as defined in Part 761 of this title. This program must include, at a minimum:

(1) Random inspections of incoming loads unless the owner or operator takes other steps to ensure that incoming loads do not contain regulated hazardous wastes or PCB wastes;

(2) Records of any inspections;

(3) Training of facility personnel to recognize regulated hazardous waste and PCB wastes; and

(4) Notification of State Director of authorized States under Subtitle C of RCRA or the EPA Regional Administrator if in an unauthorized State if a regulated hazardous waste or PCB waste is discovered at the facility.

(b) For purposes of this section, regulated hazardous waste means a solid waste that is a hazardous waste, as defined in 40 CFR 261.3, that is not excluded from regulation as a hazardous waste under 40 CFR 261.4(b) or was not generated by a conditionally exempt small quantity generator as defined in §261.5 of this title.

3.2.2 Applicability

This regulation applies to all MSWLF units that receive wastes on or after October 9, 1993.

The owner or operator must develop a program to detect and prevent disposal of regulated hazardous wastes or PCB wastes at the MSWLF facility. Hazardous wastes may be gases, liquids, solids, or sludges that are listed or exhibit the characteristics described in 40 CFR Part 261. Household hazardous wastes are excluded from Subtitle C regulation, and wastes generated by conditionally exempt small quantity generators (CESQGs) are not considered regulated hazardous wastes for purposes of complying with §258.20; therefore, these wastes may be accepted for disposal at a MSWLF unit.

The MSWLF hazardous waste exclusion program should be capable of detecting and preventing disposal of PCB wastes. PCB wastes may be liquids or non-liquids (sludges or solids) and are defined at 40 CFR Section 761.60. PCB wastes do not include small capacitors found in fluorescent light ballast, white goods (e.g., washers, dryers, refrigerators) or other consumer electrical products (e.g., radio and television units).

The hazardous waste exclusion program is not intended to identify whether regulated hazardous waste or PCB waste was received at the MSWLF unit or facility prior to the effective date of the Criteria.

3.2.3 Technical Considerations

A solid waste is a regulated hazardous waste if it: (1) is listed in Subpart D of 40 CFR

Part 261 (termed a "listed" waste); (2) exhibits a characteristic of a hazardous waste as defined in Subpart C of 40 CFR Part 261; or (3) is a mixture of a listed hazardous waste and a non-hazardous solid waste. Characteristics of hazardous wastes as defined in Subpart C of 40 CFR Part 261 include ignitability, corrosivity, reactivity, and toxicity. The toxicity characteristic leaching procedure (TCLP) is the test method used to determine the mobility of organic and inorganic compounds present in liquid, solid, and multiphase wastes. The TCLP is presented in Appendix II of Part 261.

The MSWLF Criteria exclude CESQG waste (as defined in 40 CFR §261.5) from the definition of "regulated hazardous wastes." CESQG waste includes listed hazardous wastes or wastes that exhibit a characteristic of a hazardous waste that are generated in quantities no greater than 100 kg/month, or for acute hazardous waste, 1 kg/month. Under 40 CFR §261.5(f)(3)(iv) and (g)(3)(iv), conditionally exempt small quantity generator hazardous wastes may be disposed at facilities permitted, licensed, or registered by a State to manage municipal or industrial solid waste.

Other solid wastes are excluded from regulation as a hazardous waste under 40 CFR §261.4(b) and may be accepted for disposal at a MSWLF unit. Refer to §261.4(b) for a listing of these wastes.

PCBs are regulated under the Toxic Substances Control Act (TSCA), but PCB-containing wastes are considered hazardous wastes in some States. PCBs typically are not found in consumer wastes except for fluorescent ballast and small capacitors in white goods and electrical appliances.

These sources are not regulated under 40 CFR Part 761 and, therefore, are not part of the detection program required by §258.20. Commercial or industrial sources of PCB wastes that should be addressed by the program include:

- Mineral oil and dielectric fluids containing PCBs;
- Contaminated soil, dredged material, sewage sludge, rags, and other debris from a release of PCBs;
- Transformers and other electrical equipment containing dielectric fluids; and
- Hydraulic machines.

The owner or operator is required to implement a program to detect and exclude regulated hazardous wastes and PCBs from disposal in the landfill unit(s). This program must include elements for:

- Random inspections of incoming loads or other prevention methods;
- Maintenance of inspection records;
- Facility personnel training; and
- Notification to appropriate authorities if hazardous wastes or PCB wastes are detected.

Each of these program elements is discussed separately on the following pages.

Inspections

An inspection is typically a visual observation of the incoming waste loads by an individual who is trained to identify regulated hazardous or PCB wastes that would not be acceptable for disposal at the MSWLF unit. An inspection is considered satisfactory if the inspector knows the nature of all materials received in the load and is able to discern whether the materials are potentially regulated hazardous wastes or PCB wastes.

Ideally, all loads should be screened; however, it is generally not practical to inspect in detail all incoming loads. Random inspections, therefore, can be used to provide a reasonable means to adequately control the receipt of inappropriate wastes. Random inspections are simply inspections made on less than every load.

The frequency of random inspections may be based on the type and quantity of wastes received daily, and the accuracy and confidence desired in conclusions drawn from inspection observations. Because statistical parameters are not provided in the regulation, a reasoned, knowledge-based approach may be taken. A random inspection program may take many forms such as inspecting every incoming load one day out of every month or inspecting one or more loads from transporters of wastes of unidentifiable nature each day. If these inspections indicate that unauthorized wastes are being brought to the MSWLF site, then the random inspection program should be modified to increase the frequency of inspections.

Inspection frequency also can vary depending on the nature of the waste. For example, wastes received predominantly from commercial or industrial sources may require more frequent inspections than wastes predominantly from households.

Inspection priority also can be given to haulers with unknown service areas, to loads brought to the facility in vehicles not typically used for disposal of municipal solid waste, and to loads transported by previous would-be offenders. For wastes of unidentifiable nature received from sources other than households (e.g., industrial or commercial establishments), the inspector should question the transporter about the source/composition of the materials.

Loads should be inspected prior to actual disposal of the waste at the working face of the landfill unit to provide the facility owner or operator the opportunity to refuse or accept the wastes. Inspections can be conducted on a tipping floor of a transfer station before transfer of the waste to the disposal facility. Inspections also may occur at the tipping floor located near the facility scale house, inside the site entrance, or near, or adjacent to, the working face of the landfill unit. An inspection flow chart to identify, accept, or refuse solid waste is provided as Figure 3-1.

Inspections of materials may be accomplished by discharging the vehicle load in an area designed to contain potentially hazardous wastes that may arrive at the facility. The waste should be carefully spread for observation using a front end loader or other piece of equipment. Personnel should be trained to identify suspicious wastes. Some indications of suspicious wastes are:

- Hazardous placards or marking;
- Liquids;
- Powders or dusts;

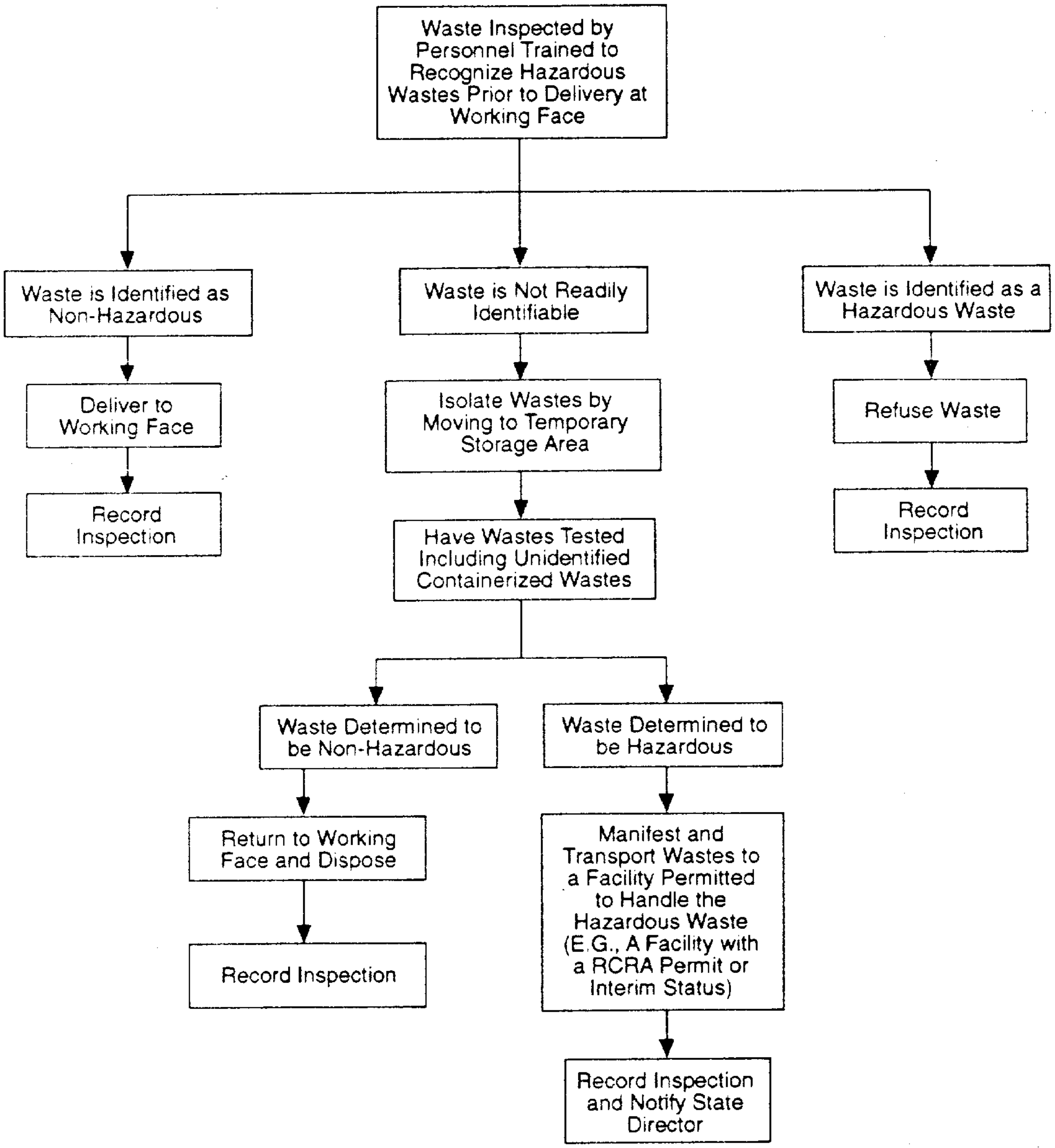

Figure 3-1
Hazardous Waste Inspection Decision Tree
Inspection Prior to Working Face

- Sludges;
- Bright or unusual colors;
- Drums or commercial size containers; or
- Chemical odors.

The owner or operator should develop specific procedures to be followed when suspicious wastes are discovered. The procedure should include the following points:

- Segregate the wastes;
- Question the driver;
- Review the manifest (if applicable);
- Contact possible source;
- Call the appropriate State or Federal agencies;
- Use appropriate protective equipment;
- Contact laboratory support if required; and
- Notify a response agency if necessary.

Containers with contents that are not easily identifiable, such as unmarked 55-gallon drums, should be opened only by properly trained personnel. Because these drums could contain hazardous waste, they should be refused whenever possible. Upon verifying that the solid waste is acceptable, it may then be transferred to the working face for disposal.

Some facilities may consider it reasonable to test unidentified waste, store it, and see that it is disposed of properly. Most facilities would not consider this reasonable.

Testing typically would include The Toxicity Characteristic Leaching Procedure (TCLP) and other tests for characteristics of hazardous wastes including corrosivity, ignitability, and reactivity. Wastes that are suspected of being hazardous should be handled and stored as a hazardous waste until a determination is made.

If the wastes temporarily stored at the site are determined to be hazardous, the owner or operator is responsible for the management of the waste. If the wastes are to be transported from the facility, the waste must be: (1) stored at the MSWLF facility in accordance with requirements of a hazardous waste generator, (2) manifested, (3) transported by a licensed transporter, and (4) sent to a permitted Treatment, Storage, or Disposal (TSD) facility for disposal. These requirements are discussed further in this section.

Alternative Methods for Detection and Prevention

While the regulations explicitly refer to inspections as an acceptable means of detecting regulated hazardous wastes and PCB wastes, preventing the disposal of these wastes may be accomplished through other methods. These methods may include receiving only household wastes and processed (shredded or baled) wastes that are screened for the presence of the excluded wastes prior to processing. A pre-acceptance agreement between the owner or operator and the waste hauler is another alternative method. An example of a pre-acceptance agreement is presented as Appendix I. The owner or operator should keep any such agreements concerning these alternatives in the operating record.

Recordkeeping

A record should be kept of each inspection that is performed. These records should be included and maintained in the facility operating record. Larger facilities that take large amounts of industrial and commercial wastes may use more detailed procedures than smaller facilities that accept household wastes. Inspection records may include the following information:

- The date and time wastes were received for inspection;
- Source of the wastes;
- Vehicle and driver identification; and
- All observations made by the inspector.

The Director of an approved State may establish alternative recordkeeping locations and requirements.

Training

Owners or operators must ensure that personnel are trained to identify potential regulated hazardous waste and PCB wastes. These personnel could include supervisors, designated inspectors, equipment operators, and weigh station attendants who may encounter hazardous wastes. Documentation of training should be placed in the operating record for the facility in accordance with §258.29.

The training program should emphasize methods to identify containers and labels typical of hazardous waste and PCB waste. Training also should address hazardous waste handling procedures, safety precautions, and recordkeeping requirements. This information is provided in training courses designed to comply with the Occupational Safety and Health Act (OSHA) under 29 CFR §1910.120. Information covered in these courses includes regulatory requirements under 40 CFR Parts 260 through 270, 29 CFR Part 1910, and related guidance documents that discuss such topics as: general hazardous waste management; identification of hazardous wastes; transportation of hazardous wastes; standards for hazardous waste treatment; storage and disposal facilities; and hazardous waste worker health and safety training and monitoring requirements.

Notification to Authorities and Proper Management of Wastes

If regulated quantities of hazardous wastes or PCB wastes are found at the landfill facility, the owner or operator must notify the proper authorities. Proper authorities are either the Director of a State authorized to implement the hazardous waste program under Subtitle C of RCRA, or the EPA Regional Administrator, in an unauthorized State.

If the owner or operator discovers regulated quantities of hazardous waste or PCB waste while it is still in the possession of the transporter, the owner or operator can refuse to accept the waste at the MSWLF facility, and the waste will remain the responsibility of the transporter. If the owner or operator is unable to identify the transporter who brought the hazardous waste, the owner or operator must ensure that the waste is managed in accordance with all applicable Federal and State regulations.

Operators of MSWLF facilities should be prepared to handle hazardous wastes that are inadvertently received at the MSWLF facility. This may include having containers such as 55-gallon drums available on-site and retaining a list of names and telephone numbers of the nearest haulers licensed to transport hazardous waste.

Hazardous waste may be stored at the MSWLF facility for 90 days, provided that the following procedures required by 40 CFR §262.34, or applicable State requirements, are followed:

- The waste is placed in tanks or containers;
- The date of receipt of the waste is clearly marked and visible on each container;
- The container or tank is marked clearly with the words "Hazardous Waste";
- An employee is designated as the emergency coordinator who is responsible for coordinating all emergency response measures; and
- The name and telephone number of the emergency coordinator and the number of the fire department is posted next to the facility phone.

Extensions to store the waste beyond 90 days may be approved pursuant to 40 CFR 262.34.

If the owner or operator transports the wastes off-site, the owner or operator must comply with 40 CFR Part 262 or the analogous State/Tribal requirements. The owner or operator is required to:

- Obtain an EPA identification number (EPA form 8700-12 may be used to apply for an EPA identification number; State or Regional personnel may be able to provide a provisional identification number over the telephone);
- Package the waste in accordance with Department of Transportation (DOT) regulations under 49 CFR Parts 173, 178, and 179 (The container must be labeled, marked, and display a placard in accordance with DOT regulations on hazardous wastes under 49 CFR Part 172); and
- Properly manifest the waste designating a permitted facility to treat, store, or dispose of the hazardous waste.

If the owner or operator decides to treat, store (for more than 90 days), or dispose of the hazardous waste on-site, he or she must comply with the applicable State or Federal requirements for hazardous waste treatment, storage, and disposal facilities. This may require a permit.

PCB wastes detected at a MSWLF facility must be stored and disposed of according to 40 CFR Part 761. The owner or operator is required to:

- Obtain an EPA PCB identification number;
- Properly store the PCB waste;
- Mark containers or items with the words "Caution: contains PCBs"; and

- Manifest the PCB waste for shipment to a permitted incinerator, chemical waste landfill, or high efficiency boiler (depending on the nature of the PCB waste) for disposal.

3.3 COVER MATERIAL REQUIREMENTS 40 CFR §258.21

3.3.1 Statement of Regulation

(a) Except as provided in paragraph (b) of this section, the owners or operators of all MSWLF units must cover disposed solid waste with six inches 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.

(b) Alternative materials of an alternative thickness (other than at least six inches of earthen material) may be approved by the Director of an approved State if the owner or operator demonstrates that the alternative material and thickness control disease vectors, fires, odors, blowing litter, and scavenging without presenting a threat to human health and the environment.

(c) The Director of an approved State may grant a temporary waiver from the requirement of paragraph (a) and (b) of this section if the owner or operator demonstrates that there are extreme seasonal climatic conditions that make meeting such requirements impractical.

3.3.2 Applicability

The regulation applies to all MSWLF units receiving waste after October 9, 1993. The regulation requires MSWLF unit owners and operators to cover wastes with a 6-inch layer of earthen material at the end of each operating day. More frequent application of soil may be required if the soil cover does not control:

- Disease vectors (e.g., birds, flies and other insects, rodents);
- Fires;
- Odors;
- Blowing litter; and
- Scavenging.

The Director of an approved State may allow an owner or operator to use alternative cover material of an alternative thickness or grant a temporary waiver of this requirement. An alternative material must not present a threat to human health and the environment, and must continue to control disease vectors, fires, odors, blowing litter, and scavenging. The only basis for a temporary waiver from the requirement to cover at the end of each operating day would be where extreme seasonal climatic conditions make compliance impractical.

3.3.3 Technical Considerations

Owners and operators of new MSWLF units, existing MSWLF units, and lateral expansions are required to cover solid waste at the end of each operating day with six inches of earthen material. This cover material requirement is not related to the final cover required under §258.60.

The placement of six inches of cover controls disease vectors (birds, insects, or rodents that represent the principal transmission pathway of a human disease) by preventing egress from the waste and by preventing access to breeding environments or food sources. Covering also reduces exposure of combustible materials to ignition sources and may reduce the spread of fire if the disposed waste burns. Odors and blowing litter are reduced by eliminating the direct contact of wind and disposed waste. Similarly, scavenging is reduced by removing the waste from observation. Should these unwanted effects of inadequate cover persist, the owner or operator may increase the amount of soil used or apply it more frequently. Any soil type can meet the requirements of the regulation when placed in a six-inch layer.

Approved States may allow demon-strations of alternative daily cover materials. The rule does not specify the time frame for the demonstration; usually the State decides. A period of six months should be ample time for the owner or operator to make the demonstra-tion. There are no numerical require-ments for the alternative cover; rather, the alternative cover must control disease vectors, fires, odors, blowing litter, and scavenging without presenting a threat to human health and the environment.

Demonstrations can be conducted in a variety of ways. Some suggested methods for demonstrating alternative covers are:

1) Side by side (six inches of earthen materials and alternative cover) test pads;

2) Full-scale demonstration; and

3) Short-term full-scale tests.

Alternative daily cover materials may include indigenous materials or commercially-available materials. Indigenous materials are those materials that would be disposed as waste; therefore, using these materials is an efficient use of landfill space. Examples of indigenous materials include (USEPA, 1992):

- Ash from municipal waste combustors and utility companies;
- Compost-based material;
- Foundry sand from the manufacturing process of discarding used dies;
- Yard waste such as lawn clippings, leaves, and tree branches;
- Sludge-based materials (i.e., sludge treated with lime and mixed with ash or soil);
- Construction and demolition debris (which has been processed to form a slurry);
- Shredded automobile tires;
- Discarded carpets; and
- Grit from municipal wastewater treatment plants.

Commercially developed alternatives have been on the market since the mid-1980s. Some of the commercial alternative materials require specially designed application equipment, while others use equipment generally available at most landfills. Some of the types of commercially available daily cover materials include (USEPA, 1992):

- Foam that usually is sprayed on the working face at the end of the day;
- Geosynthetic products such as a tarp or fabric panel that is applied at the end of the working day and removed at the beginning of the following working day; and
- Slurry products (e.g., fibers from recycled newspaper and wood chip slurry, clay slurry).

Other criteria to consider when selecting an alternative daily cover material include availability and suitability of the material, equipment requirements, and cost.

The temporary climatic waiver of the cover requirement is available only to owners or operators in approved States. The State Director may grant a waiver if the owner or operator demonstrates that meeting the requirements would be impractical due to extreme seasonal climatic conditions. Activities that may be affected by extreme seasonal climatic conditions include:

- Obtaining cover soil from a borrow pit;
- Transporting cover soil to the working face; or
- Spreading and compacting the soil to achieve the required functions.

Extremely cold conditions may prevent the efficient excavation of soil from a borrow pit or the spreading and compaction of the soil on the waste. Extremely wet conditions (e.g., prolonged rainfall, flooding) may prevent transporting cover soil to the working face and may make it impractical to excavate or spread and compact. The duration of waivers may be as short as one day for unusual rain storms, or as long as several months for extreme seasonal climatic conditions.

3.4 DISEASE VECTOR CONTROL 40 CFR §258.22

3.4.1 Statement of Regulation

(a) Owners or operators of all MSWLF units must prevent or control on-site populations of disease vectors using techniques appropriate for the protection of human health and the environment.

(b) For purposes of this section, <u>disease vectors</u> means any rodents, flies, mosquitoes, or other animals, including insects, capable of transmitting disease to humans.

3.4.2 Applicability

The regulation applies to existing MSWLF units, lateral expansions, and new MSWLF units. The owner or operator is required to prevent or control on-site disease vector populations of rodents, flies, mosquitoes, or other animals, including other insects. The techniques that may be used in fulfilling this requirement must be appropriate for the protection of human health and the environment.

3.4.3 Technical Considerations

Disease vectors such as rodents, birds, flies, and mosquitoes typically are attracted by putrescent waste and standing water, which act as a food source and breeding ground. Putrescent waste is solid waste that contains organic matter (such as food waste) capable of being decomposed by micro-organisms. A MSWLF facility typically accepts putrescent wastes.

Application of cover at the end of each operating day generally is sufficient to control disease vectors; however, other vector control alternatives may be required. These alternatives could include: reducing the size of the working face; other operational modifications (e.g., increasing cover thickness, changing cover type, density, placement frequency, and grading); repellents, insecticides or rodenticides; composting or processing of organic wastes prior to disposal; and predatory or reproductive control of insect, bird, and animal populations. Additional methods to control birds are discussed in Chapter 2 (Airport Safety).

Mosquitoes, for example, are attracted by standing water found at MSWLFs, which can provide a potential breeding ground after only three days. Water generally collects in surface depressions, open containers, exposed tires, ponds resulting from soil excavation, leachate storage ponds, and siltation basins. Landfill operations that minimize standing water and that use an insecticide spraying program ordinarily are effective in controlling mosquitoes.

Vectors may reach the landfill facility not only from areas adjacent to the landfill, but through other modes conducive to harborage and breeding of disease vectors. Such modes may include residential and commercial route collection vehicles and transfer stations. These transport modes and areas also should be included in the disease vector control program if disease vectors at the landfill facility become a problem. Keeping the collection vehicles and transfer stations covered; emptying and cleaning the collection vehicles and transfer stations; using repellents, insecticides, or rodenticides; and reproductive control are all measures available to reduce disease vectors in these areas.

3.5 EXPLOSIVE GASES CONTROL 40 CFR §258.23

3.5.1 Statement of Regulation

(a) Owners or operators of all MSWLF units must ensure that:

(1) The concentration of methane gas generated by the facility does not exceed 25 percent of the lower explosive limit for methane in facility structures (excluding gas control or recovery system components); and

(2) The concentration of methane gas does not exceed the LEL for methane at the facility property boundary.

(b) Owners or operators of all MSWLF units must implement a routine methane monitoring program to ensure that the standards of paragraph (a) of this section are met.

(1) The type and frequency of monitoring must be determined based on the following factors:

(i) Soil conditions;

(ii) The hydrogeologic conditions surrounding the facility;

(iii) The hydraulic conditions surrounding the facility; and

(iv) The location of facility structures and property boundaries.

(2) The minimum frequency of monitoring shall be quarterly.

(c) If methane gas levels exceeding the limits specified in paragraph (a) of this section are detected, the owner or operator must:

(1) Immediately take all necessary steps to ensure protection of human health and notify the State Director;

(2) Within seven days of detection, place in the operating record the methane gas levels detected and a description of the steps taken to protect human health; and

(3) Within 60 days of detection, implement a remediation plan for the methane gas releases, place a copy of the plan in the operating record, and notify the State Director that the plan has been implemented. The plan shall describe the nature and extent of the problem and the proposed remedy.

(4) The Director of an approved State may establish alternative schedules for demonstrating compliance with paragraphs (2) and (3).

(d) For purposes of this section, <u>lower explosive limit</u> (LEL) means the lowest percent by volume of a mixture of explosive gases in air that will propagate a flame at 25°C and atmospheric pressure.

<u>3.5.2 Applicability</u>

The regulation applies to existing MSWLF units, lateral expansions, and new MSWLF units. The accumulation of methane in MSWLF 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 landfill containment structures. These hazards are preventable through monitoring and through corrective action should methane gas levels exceed specified limits in the facility structures (excluding gas control or recovery system components), or at the facility property boundary. MSWLF facility owners and operators must comply with the following requirements:

- Monitor at least quarterly;
- Take immediate steps to protect human health in the event of methane gas levels exceeding 25% of the lower explosive limit (LEL) in facility structures, such as evacuating the building;
- Notify the State Director if methane levels exceed 25% of the LEL in facility structures or exceed the LEL at the facility property boundary;

- Within 7 days of detection, place in the operating record documentation that methane gas concentrations exceeded the criteria, along with a description of immediate actions taken to protect human health; and

- Within 60 days of detection, implement a remediation plan for the methane gas releases, notify the State Director, and place a copy of the remediation plan in the operating record.

The compliance schedule for monitoring and responding to methane levels that exceed the criteria of this regulation can be changed by the Director of an approved State.

3.5.3 Technical Considerations

To implement an appropriate routine methane monitoring program to demonstrate compliance with allowable methane concentrations, the characteristics of landfill gas production and migration at a site should be understood. Landfill gases are the result of microbial decomposition of solid waste. Gases produced include methane (CH_4), carbon dioxide (CO_2), and lesser amounts of other gases (e.g., hydrogen, volatile organic compounds, and hydrogen sulfide). Methane gas, the principal component of natural gas, is generally the primary concern in evaluating landfill gas generation because it is odorless and highly combustible. Typically, hydrogen gas is present at much lower concentra-tions. Hydrogen forms as decomposition progresses from the acid production phase to the methanogenic phase. While hydrogen is explosive and is occasionally detected in landfill gas, it readily reacts to form methane or hydrogen sulfide. Hydrogen sulfide is toxic and is readily identified by its "rotten egg" smell at a threshold concentration near 5 ppb.

Landfill gas production rates vary spatially within a landfill unit as a result of pockets of elevated microbial activity but, due to partial pressure gradients, differences in gas composition are reduced as the gases commingle within and outside the landfill unit. Although methane gas is lighter than air and carbon dioxide is heavier, these gases are concurrently produced at the microbial level and will not separate by their individual density. The gases will remain mixed and will migrate according to the density gradients between the landfill gas and the surrounding gases (i.e., a mixture of methane and carbon dioxide in a landfill unit or in surrounding soil will not separate by rising and sinking respectively, but will migrate as a mass in accordance with the density of the mixture and other gradients such as temperature and partial pressure).

When undergoing vigorous microbial production, gas pressures on the order of 1 to 3 inches of water relative to atmospheric pressure are common at landfill facilities, with much higher pressures occasionally reported. A barometric pressure change of 2 inches of mercury is equivalent to 27.2 inches of water. Relative gauge pressures at a particular landfill unit or portion of a landfill unit, the ability of site conditions to contain landfill gas, barometric pressure variations, and the microbial gas production rate control pressure-induced landfill gas migration. Negative gas pressures are commonly observed and are believed to occur as a result of the delayed response within a landfill unit to the passage of a high pressure system outside the landfill unit. Barometric highs will tend to introduce atmospheric oxygen into surface soils in shallow portions of the landfill unit, which may alter microbial activity, particularly methane production and gas composition.

Migration of landfill gas is caused by concentration gradients, pressure gradients, and density gradients. The direction in which landfill gas will migrate is controlled by the driving gradients and gas permeability of the porous material through which it is migrating. Generally, landfill gas will migrate through the path of least resistance.

Coarse, porous soils such as sand and gravel will allow greater lateral migration or transport of gases than finer-grained soils. Generally, resistance to landfill gas flow increases as moisture content increases and, therefore, an effective barrier to gas flow can be created under saturated conditions. Thus, readily drained soil conditions, such as sands and gravels above the water table, may provide a preferred flowpath, but unless finer-grained soils are fully saturated, landfill gases also can migrate in a "semi-saturated" zone. Figure 3-2 illustrates the potential effects of surrounding geology on gas migration.

While geomembranes may not eliminate landfill gas migration, landfill gas in a closed MSWLF unit will tend to migrate laterally if the final cover contains a geomembrane and if the side slopes of the landfill do not contain an effective gas barrier. Lateral gas migration is more common in older facilities that lack appropriate gas control systems. The degree of lateral migration in older facilities also may depend on the type of natural soils surrounding the facility.

Stressed vegetation may indicate gas migration. Landfill gas present in the soil atmosphere tends to make the soil anaerobic by displacing the oxygen, thereby asphyxiating the roots of plants. Generally, the higher the concentration of combustible gas and/or carbon dioxide and the lower the amount of oxygen, the greater the extent of damage to vegetation (Flowers, et. al, 1982).

Gas Monitoring

The owner or operator of a MSWLF unit/facility must implement a routine methane monitoring program to comply with the lower explosive limit (LEL) requirements for methane. Methane is explosive when present in the range of 5 to 15 percent by volume in air. When present in air at concentrations greater than 15 percent, the mixture will not explode. This 15 percent threshold is the Upper Explosive Limit (UEL). The UEL is the maximum concentration of a gas or vapor above which the substance will not explode when exposed to a source of ignition. The explosive hazard range is between the LEL and the UEL. Note, however, that methane concentrations above the UEL remain a significant concern; fire and asphyxiation can still occur at these levels. In addition, even a minor dilution of the methane by increased ventilation can bring the mixture back into the explosive range.

To demonstrate compliance, the owner/operator would sample air within facility structures where gas may accumulate and in soil at the property boundary. Other monitoring methods may include: (1) sampling gases from probes within the landfill unit or from within the leachate collection system; or (2) sampling gases

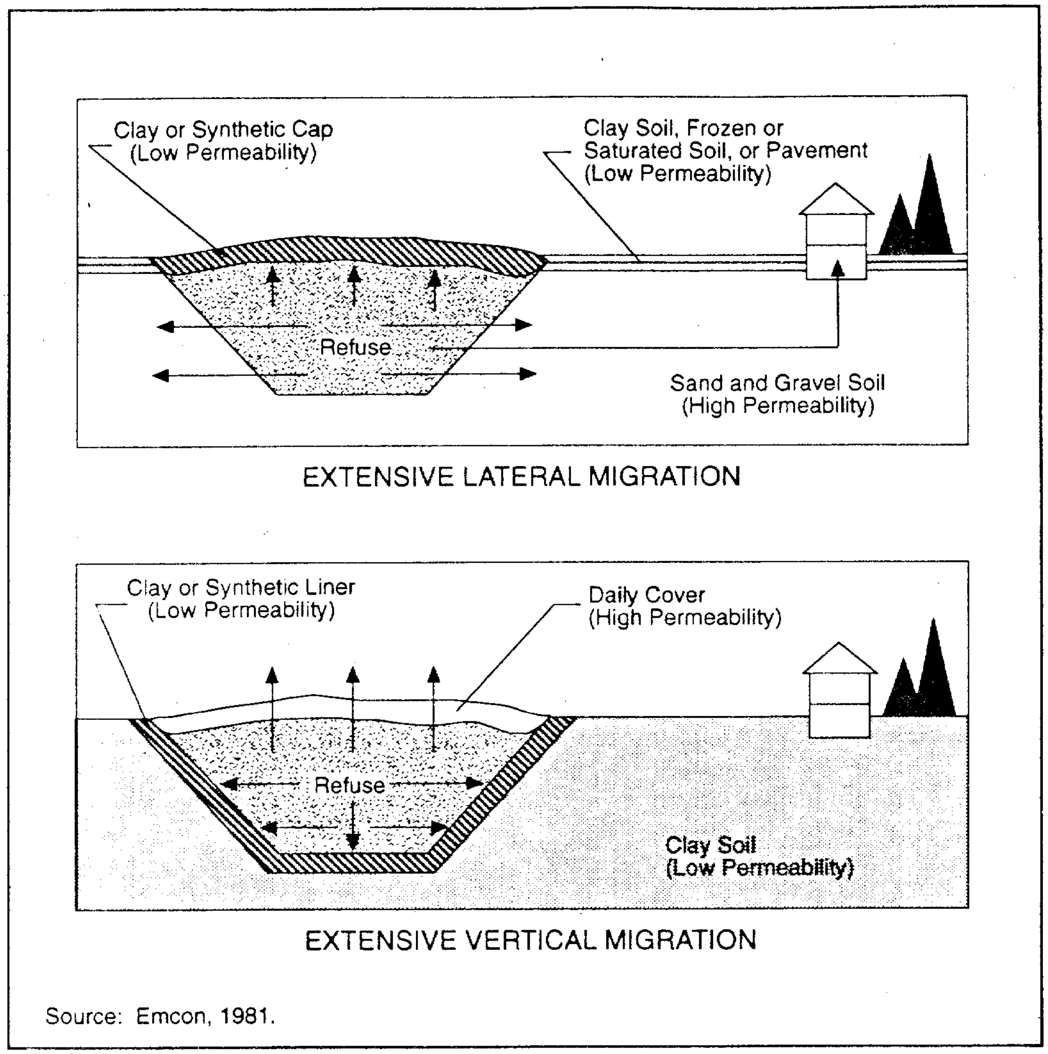

Figure 3-2
Potential Effects of
Surrounding Geology on Gas Migration

from monitoring probes installed in soil between the landfill 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 3-3.

Although not required by the regulations, collection of data such as water presence and level, gas probe pressure, ambient temperature, barometric pressure, and the occurrence of precipitation during sampling, provides useful information in assessing monitoring results. For example, falling barometric pressure may cause increased subsurface (gas) pressures and corresponding increased methane content as gas more readily migrates from the landfill. Gas probe pressure can be measured using a portable gauge capable of measuring both vacuum and pressure in the range of zero to five inches of water pressure (or other suitable ranges for pressure conditions); this pressure should be measured prior to methane measurement or sample collection in the gas probe. A representative sample of formation (subsurface) gases can be collected directly from the probe. Purging typically is not necessary due to the small volume of the probe. A water trap is recommended to protect instrumentation that is connected directly to the gas probe. After measurements are obtained, the gas probe should be capped to reduce the effects of venting or barometric pressure variations on gas composition in the vicinity of the probe.

The frequency of monitoring should be sufficient to detect landfill gas migration based on subsurface conditions and changing landfill conditions such as partial or complete capping, landfill 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 landfill gas migration as a result of these anticipated changes and the site-specific conditions provides the basis for establishing monitoring frequency. Monitoring is to be conducted at least quarterly.

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.

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, therefore, the thermal conductivity, changes. Field instruments should be calibrated prior to measurements and should be rechecked after each day's monitoring activity.

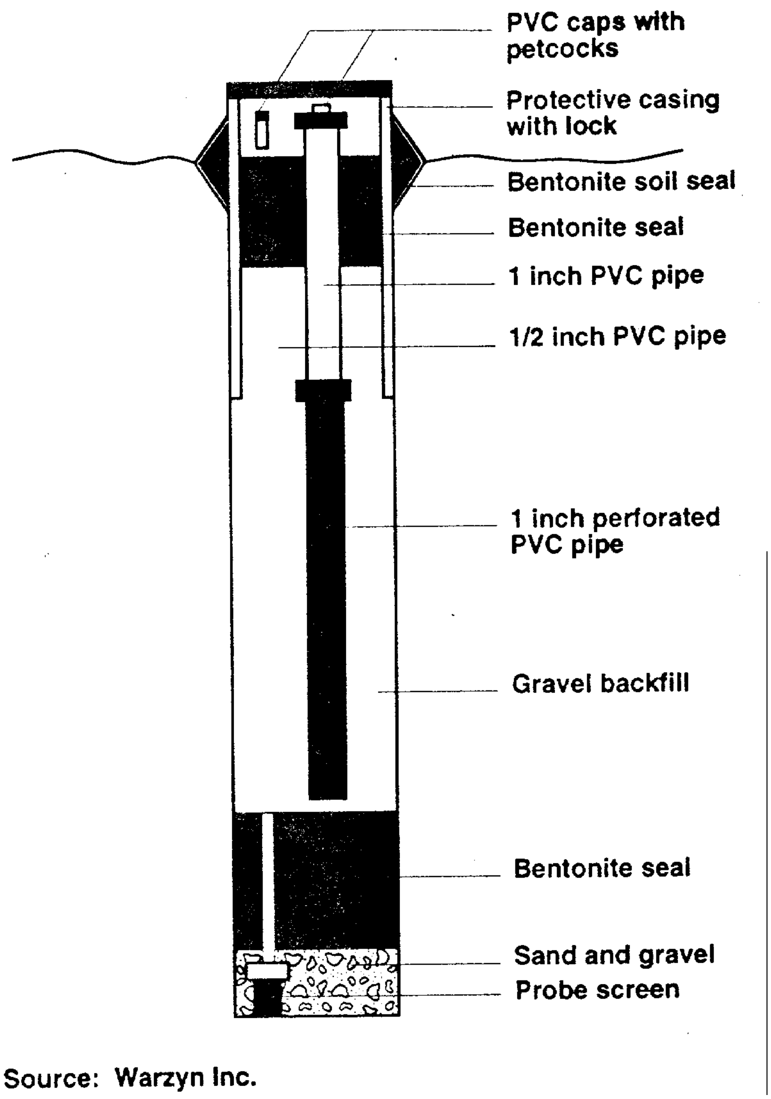

Figure 3-3
Typical Gas Monitoring Probe

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 (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.

Owners and operators in unapproved States have 60 days after exceeding the methane level to prepare and implement a remediation plan. The remediation plan should describe the nature and extent of the methane problem as well as a proposed remedy.

To comply with this 60-day schedule, an investigation of subsurface conditions may be needed in the vicinity of the monitoring probe where the criterion was exceeded. The objectives of this investigation should be to describe the frequency and lateral and vertical extent of excessive methane migration (that which exceeds the criterion). Such an investigation also may yield additional characterization of unsaturated soil within the area of concern. The investigation should consider possible causes of the increase in gas concentrations such as landfill operational procedures, gas control system failure or upset, climatic conditions, or closure activity. Based on the extent and nature of the excessive methane migration, a remedial action should be described, if the exceedance is persistent, that can be implemented within the prescribed schedule. The sixty-day schedule does not address the protection of human health and the environment. The owner or operator still must take all steps necessary to ensure protection of human health, including interim measures.

Landfill Gas Control Systems

Landfill gas may vent naturally or be purposely vented to the atmosphere by vertical 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 flowpaths 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 landfill 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.

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 landfill unit (for remedial purposes) and the installation of an active system in the active portion of the landfill unit (for future use).

Selection of construction materials for either type of gas control system should consider the elevated temperature conditions within a landfill 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 and possibly toxic 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. The condensate can be returned to the landfill unit if the landfill is designed with a composite liner and leachate collection system per §258.40(a)(2). See Chapter 4 for information regarding design. See Section 3.10 of this Chapter for information regarding liquids in landfills.

Additional provisions (under the Clean Air Act) were proposed on May 30, 1991 (56 FR 24468), that would require the owners/ operators of certain landfill facilities to install gas collection and control systems to reduce the emissions of nonmethane organic compounds (NMOCs). The proposed rule amends 40 CFR Parts 51, 52, and 60. For new municipal solid waste landfill units (those for which construction was begun after May 30, 1991), and for those units that have a design capacity greater than 111,000 tons, a gas collection and control system must be installed if emissions evaluations indicate that the NMOC emissions rate is 150 megagrams per year (167 tons per year) or greater. Allowable control systems include open and enclosed flares, and on-site or off-site facilities that process the gas for subsequent sale or use. EPA believes that, depending on landfill design, active collection systems may be more cost-effective than passive systems in ensuring that the system effectively captures the gas that is generated within the landfill unit. The provisions for new landfill units are self-implementing and will be effective upon promulgation of the rule.

In addition to the emissions standards for new municipal solid waste landfill units, the regulations proposed on May 30, 1991 establish guidelines for State programs for reducing NMOC emissions from certain existing municipal landfill units. These provisions apply to landfill units for which construction was commenced before May 30, 1991, and that have accepted waste since November 8, 1987 or that have remaining capacity. Essentially, the State must require the same kinds of collection and control systems for landfill units that meet the size criteria and emissions levels outlined above for new landfill units. The requirements for existing facilities will be effective after the State revises its State Implementation Plan and receives approval from EPA.

The rule is scheduled to be promulgated in late 1993; the cutoff numbers for landfill size and emission quantity may be revised in the final rule. EPA expects that the new regulations will affect less than 9% of the municipal landfill facilities in the U.S.

Passive Systems

Passive gas control systems rely on natural pressure and convection mechanisms to vent landfill gas to the atmosphere. Passive systems typically use "high-permeability" or "low-permeability" techniques, either singularly or in combination at a site. 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. Low-permeability systems block lateral migration through barriers such as synthetic membranes and high moisture-containing fine-grained soils.

Passive systems may be incorporated into a landfill design or may be used for remedial or corrective purposes at both closed and active landfills. They may be installed within a landfill unit along the perimeter, or between the landfill and the disposal facility property boundary. A detailed discussion of passive systems for remedial or corrective purposes may be found in U.S. EPA (1985).

A passive system may be incorporated into the final cover system of a landfill 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 the perimeter of the landfill unit. Figure 3-4 illustrates a passive system. The landfill gas collection system also may be connected with the leachate collection system to vent gases in the headspace of leachate collection pipes.

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 susceptible to clogging by vandalism. Biological clogging of the system is also more common in passive systems.

Active Systems

Active gas control systems use mechanical means to remove landfill gas 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 landfill unit in a controlled manner. Negative pressure systems extract gas from a landfill by using a blower to pull gas out of the landfill. 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 3-5. 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 (1985).

An active gas extraction well is depicted in Figure 3-6. Gas extraction wells may be installed within the landfill waste or, as depicted in Figure 3-7A and Figure 3-7B, perimeter extraction trenches could be used. One possible configuration of an interior gas collection/recovery system is illustrated in

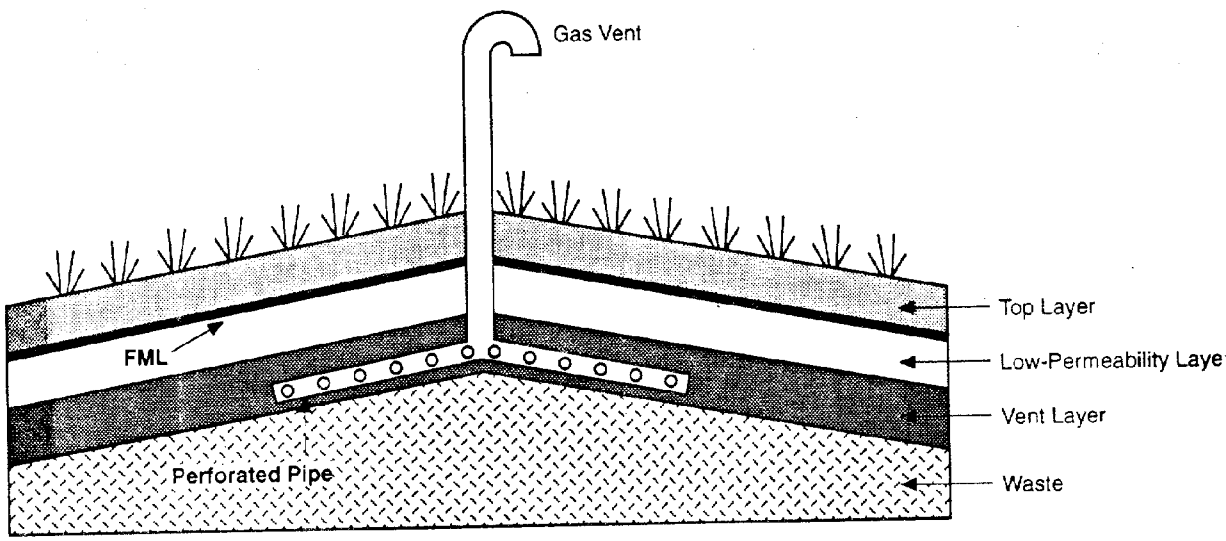

Figure 3-4
Passive Gas Control System
(Venting to Atmosphere)

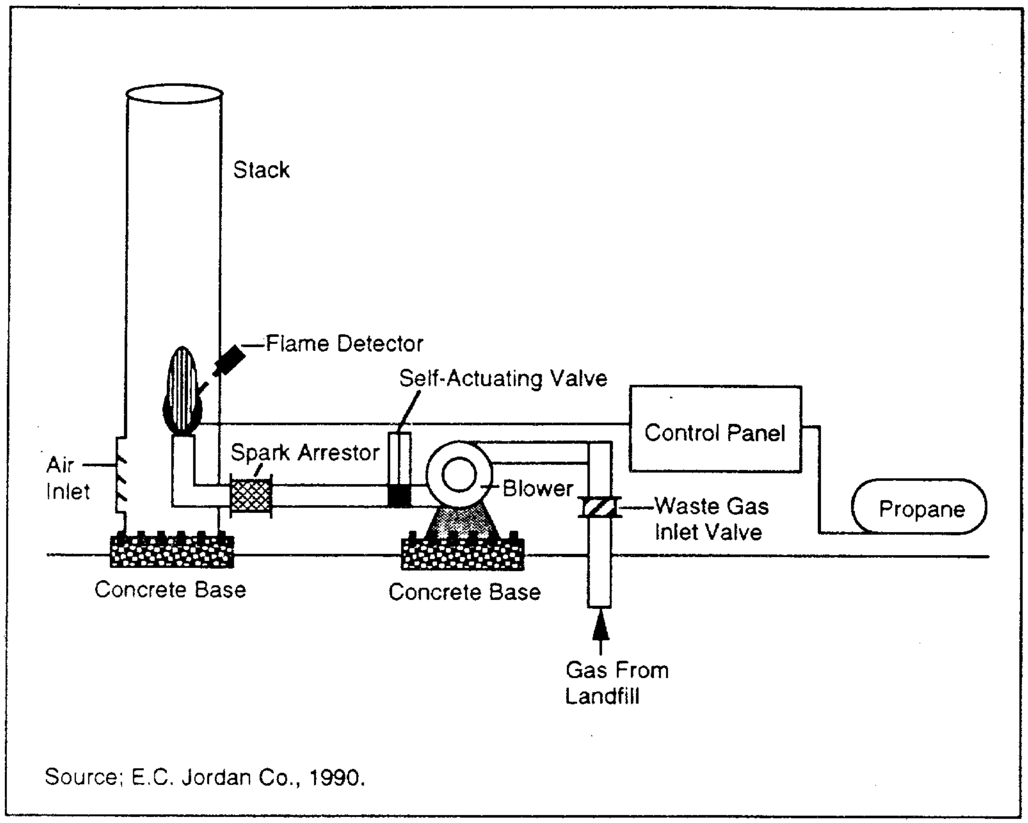

Figure 3-5. Example Schematic Diagram of a Ground-based Landfill Gas Flare

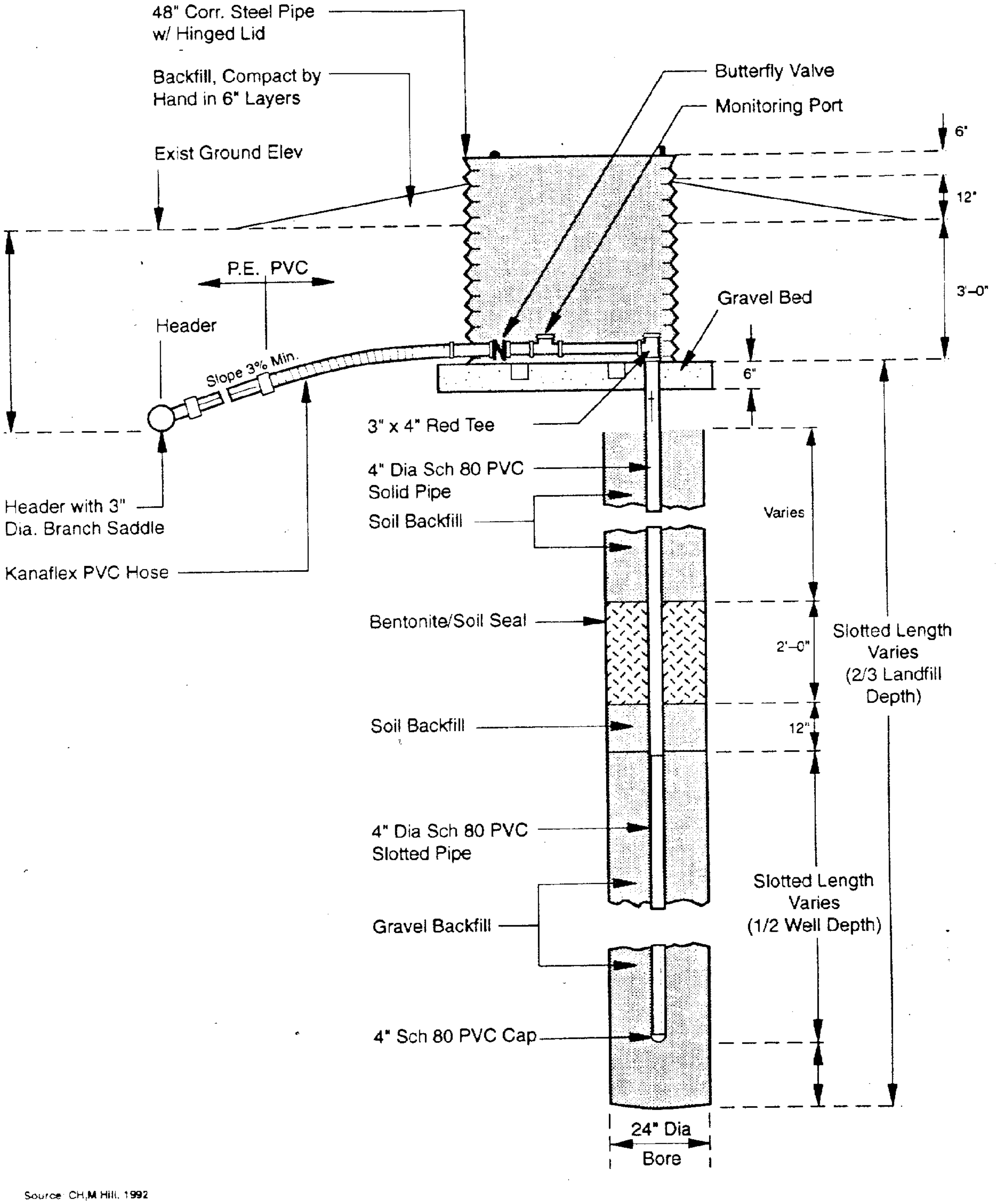

Figure 3-6 Example of a Gas Extraction Well

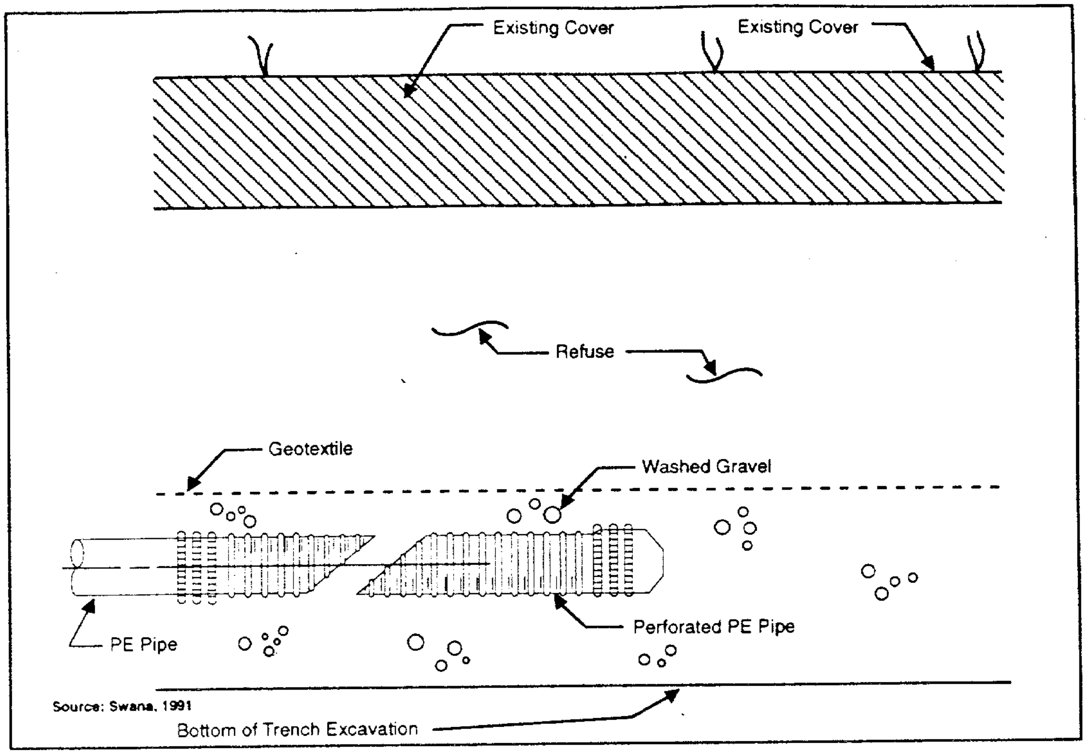

Figure 3-7A. Perimeter Extraction Trench System

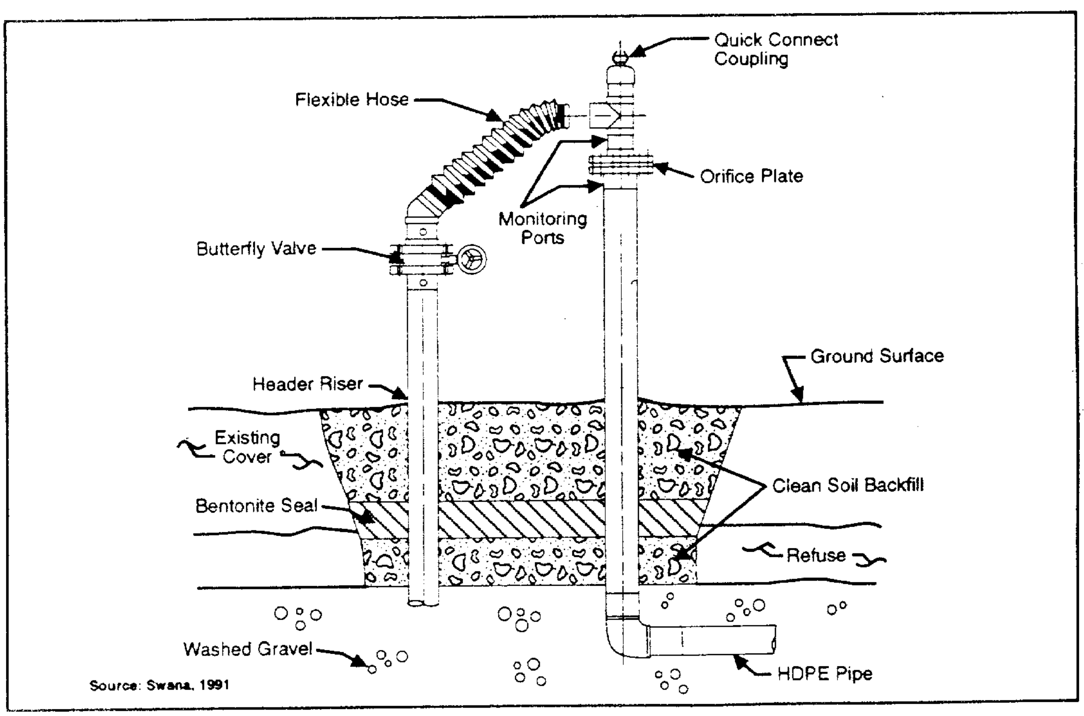

Figure 3-7B. Perimeter Extraction Trench System

Figure 3-8. 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 the landfill, capital, operation, and maintenance costs of such systems will be higher and these costs can be expected to continue throughout the post-closure period. At some future time, owners and operators may wish to convert 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 landfill gas. Landfill gas recovery systems can reduce landfill 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. Landfill gas can be used with a minimal amount of treatment or can be upgraded to pipeline standards (SWANA, 1992). An upgraded gas is one which has had the carbon dioxide and other noncombustible constituents removed.

Raw landfill gas may be used for heating small facilities and water, and may require removal of only water and particulates for this application. A slightly upgraded gas can be used for both water and space heating as well as lighting, electrical generation, cogeneration, and as a fuel for industrial boilers-burners. Landfill gas also may be processed to pipeline quality to be sold to utility companies and may even be used to fuel conventional vehicles. The amount of upgrading and use of landfill gas is dependent on the landfill size.

3.6 AIR CRITERIA 40 CFR §258.24

3.6.1 Statement of Regulation

(a) Owners or operators of all MSWLFs must ensure that the units do not violate any applicable requirements developed under a State Implementation Plan (SIP) approved or promulgated by the Administrator pursuant to section 110 of the Clean Air Act, as amended.

(b) Open burning of solid waste, except for the infrequent burning of agricultural wastes, silvicultural wastes, land-clearing debris, diseased trees, or debris from emergency clean-up operations, is prohibited at all MSWLF units.

3.6.2 Applicability

The regulation applies to existing MSWLF units, lateral expansions to existing MSWLF units, and new MSWLF units. Routine open burning of municipal solid waste is prohibited. Infrequent burning of agricultural and silvicultural wastes, diseased trees, or debris from land clearing or emergency clean-up operations is allowed when in compliance with any applicable requirements developed under a State Implementation Plan (SIP) of the Clean Air Act. Agricultural waste does not include empty pesticide containers or waste pesticides.

3.6.3 Technical Considerations

Air pollution control requirements are developed under a SIP, which is developed by the State and approved by the EPA Administrator. The owner or operator of a

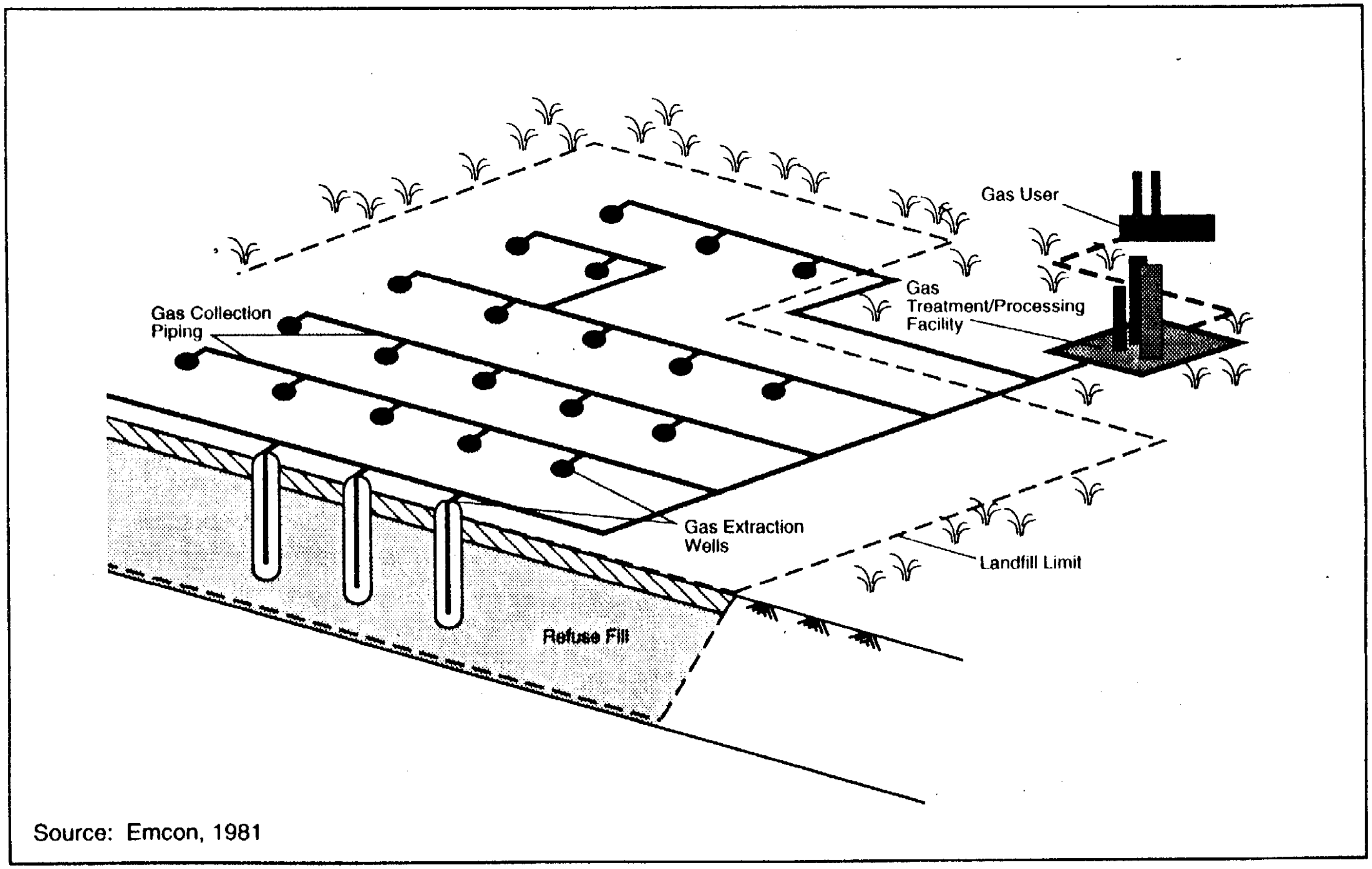

Figure 3-8
Example of an Interior Gas Collection/Recovery System

MSWLF unit should consult the State or local agency responsible for air pollution control to ascertain that the burning of wastes complies with applicable requirements developed under the SIP. The SIP may include variances, permits, or exemptions for burning agricultural wastes, silvicultural wastes, land-clearing debris, diseased trees, or debris from emergency clean-up operations. Routine burning of wastes is banned in all cases, and the SIP may limit burning of waste such as agricultural wastes to certain hours of the day; days of the year; designated burn areas; specific types of incinerators; atmospheric conditions; and distance from working face, public thoroughfares, buildings, and residences.

Requirements under the SIP also may include notifying applicable State or local agencies whose permits may: (1) restrict times when limited burning of waste may occur; (2) specify periods when sufficient fire protection is deemed to be available; or (3) limit burning to certain areas.

Open burning is defined under §258.2 as the combustion of solid waste: (1) without control of combustion air to maintain adequate temperature for efficient combustion; (2) without containment of the combustion reaction in an enclosed device to provide sufficient residence time and mixing for complete combustion; and (3) without the control of the emission of the combustion products. Trench or pit burners, and air curtain destructors are considered open burning units because the particulate emissions are similar to particulate emissions from open burning,
and these devices do not control the emission of combustion products.

[Note: The Agency plans to issue regulations under the Clean Air Act to control landfill gas emissions from large MSWLF units in 1993. These regulations are found at 40 CFR Parts 51, 52, and 60.]

3.7 ACCESS REQUIREMENT 40 CFR §258.25

3.7.1 Statement of Regulation

Owners or operators of all MSWLF units must control public access and prevent unauthorized vehicular traffic and illegal dumping of wastes by using artificial barriers, natural barriers, or both, as appropriate to protect human health and the environment.

3.7.2 Applicability

The regulation applies to existing MSWLF units, lateral expansions, and new MSWLF units. The owner or operator is required to prevent public access to the landfill facility, except under controlled conditions during hours when wastes are being received.

3.7.3 Technical Considerations

Owners and operators are required to control public access to prevent illegal dumping, public exposures to hazards at MSWLF units, and unauthorized vehicular traffic. Frequently, unauthorized persons are unfamiliar with the hazards associated with landfill facilities, and consequences of uncontrolled access may include injury and even death. Potential hazards are related to inability of equipment operators to see unauthorized individuals during operation of equipment and haul vehicles; direct exposure to waste (e.g., sharp objects and pathogens);

inadvertent or deliberate fires; and earth-moving activities.

Acceptable measures used to limit access of unauthorized persons to the disposal facility include gates and fences, trees, hedges, berms, ditches, and embankments. Chain link, barbed wire added to chain link, and open farm-type fencing are examples of fencing that may be used. Access to facilities should be controlled through gates that can be locked when the site is unsupervised. Gates may be the only additional measure needed at remote facilities.

3.8 RUN-ON/RUN-OFF CONTROL SYSTEMS 40 CFR §258.26

3.8.1 Statement of Regulation

(a) Owners or operators of all MSWLF units must design, construct, and maintain:

(1) A run-on control system to prevent flow onto the active portion of the landfill during the peak discharge from a 25-year storm;

(2) A run-off control system from the active portion of the landfill to collect and control at least the water volume resulting from a 24-hour, 25-year storm.

(b) Run-off from the active portion of the landfill unit must be handled in accordance with §258.27(a) of this Part.

3.8.2 Applicability

The regulation applies to existing MSWLF units, lateral expansions, and new MSWLF units. The owner or operator is required to prevent run-on onto the active portion of the landfill units and to collect and control run-off from the active portion for a 24-hour, 25-year storm. Management of run-off must comply with the point and non-point source discharge requirements of the Clean Water Act.

3.8.3 Technical Considerations

If stormwater enters the landfill unit and contacts waste (including water within daily cover), the stormwater becomes leachate and must be managed as leachate. The purpose of a run-on control system is to collect and redirect surface waters to minimize the amount of surface water entering the landfill unit. Run-on control can be accomplished by constructing berms and swales above the filling area that will collect and redirect the water to stormwater control structures.

As stated above, stormwater that does enter the landfill unit should be managed as leachate. Run-off control systems are designed to collect and control this run-off from the active portion of the landfill, including run-off from areas that have received daily cover, which may have contacted waste materials. Run-off control can be accomplished through stormwater conveyance structures that divert this run-off/leachate to the leachate storage device.

After a landfill unit has been closed with a final cover, stormwater run-off from this unit can be managed as stormwater and not leachate. Therefore, waters running off the final cover system of closed areas may not require treatment and generally can be combined with run-on waters. For landfills with steep side slopes, a bench system may provide the best solution for run-off control. A bench creates a break in the slope where the velocity of the stormwater run-off is expected to become erosive. The bench converts sheet flow run-off into channel flow. Benches typically are spaced 30 to 50 feet apart up the slope. An alternative to benches is a system of downchutes whereby stormwater is collected off the top of the landfill and conveyed down the slope through a pipe or channel. Caution should be taken not to construct downchutes with heavy material because of possible subsidence. Corrugated metal pipes or plastic-lined channels are examples of lightweight materials that can be used for downchute construction.

Run-on and run-off must be managed in accordance with the requirements of the Clean Water Act including, but not limited to, the National Pollutant Discharge Elimination System (NPDES). [See Section 3.9 of this chapter for further information on compliance with the Clean Water Act.]

Run-on and run-off control systems must be designed based on a 24-hour, 25-year 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. Alternatively, local meteorological data can be analyzed to estimate the criterion storm. To estimate run-on, the local watershed should be identified and evaluated to document the basis for run-on design flows.

The Soil Conservation Service (SCS) Method and/or the Rational Method are generally adequate for estimating storm flows for designing run-on and/or run-off control systems. The SCS method estimates run-off volume from accumulated rainfall and then applies the run-off volume to a simplified triangular unit hydrograph for peak discharge estimation and total run-off hydrograph. A discussion of the development and use of this method is available from the U. S. Department of Agriculture, Soil Conservation Service (1986).

The Rational Method approximates the majority of surface water discharge supplied by the watershed upstream from the facility. The Rational Method generally is used for areas of less than 200 acres. A discussion of the Rational Method may be found in U.S. EPA (1988).

Run-on/run-off control structures, both temporary and permanent, may be incorporated into the system design. Other structures (not mentioned above) most frequently used for run-on/run-off control are waterways, seepage ditches, seepage basins, and sedimentation basins. U.S. EPA (1985) provides an in-depth discussion for each of these structures.

3.9 SURFACE WATER REQUIREMENTS 40 CFR §258.27

3.9.1 Statement of Regulation

MSWLF units shall not:

(a) Cause a discharge of pollutants into waters of the United States, including

wetlands, that violates any requirements of the Clean Water Act, including, but not limited to, the National Pollutant Discharge Elimination System (NPDES) requirements, pursuant to section 402.

(b) Cause the discharge of a nonpoint source of pollution to waters of the United States, including wetlands, that violates any requirement of an area-wide or State-wide water quality management plan that has been approved under section 208 or 319 of the Clean Water Act, as amended.

3.9.2 Applicability

The regulation applies to existing MSWLF units, lateral expansions, and new MSWLF units. The owner or operator is required to comply with the Clean Water Act for any discharges to surface water or wetlands.

3.9.3 Technical Considerations

The owner or operator of a MSWLF facility should determine if the facility is in conformance with applicable requirements of water quality plans developed under Sections 208 and 319 of the Clean Water Act, and the National Pollutant Discharge Elimination System (NPDES) requirements under Section 402 of the Clean Water Act. The EPA and approved States have jurisdiction over discharge of pollutants (other than dredge and fill materials) in waters of the United States including wetlands. MSWLF units discharging pollutants or disposing of fill material into waters of the United States require a Section 402 (NPDES) permit. Discharge of dredge and fill material into waters of the United States is under the jurisdiction of the U.S. Army Corps of Engineers.

A MSWLF unit(s) that has a point source discharge must have a NPDES permit. Point source discharges for landfills include, but are not limited to: (1) the release of leachate from a leachate collection or on-site treatment system into the waters of the United States; (2) disposal of solid waste into waters of the United States; or (3) release of surface water (stormwater) run-off which is directed by a run-off control system into the waters of the United States. Leachate that is piped or trucked off-site to a treatment facility is not regarded as a point source discharge.

The Clean Water Act (CWA) provides clarifications of terms such as point source, waters of the United States, pollutants, and discharge of pollutants.

Owners/operators also should be aware that there are regulations promulgated pursuant to the CWA regarding stormwater discharges from landfill facilities. These regulations require stormwater discharge permit applications to be submitted by certain landfills that accept or have accepted specific types of industrial waste. See 40 CFR Section 122.26(a)-(c), which originally appeared in the Federal Register on November 16, 1990 (55 FR 47990).

In addition, EPA codified several provisions pursuant to the Intermodal Surface Transportation Efficiency Act of 1991 into the NPDES regulations. These regulations only affect the deadlines for submitting permit applications for stormwater discharges, and they apply to both uncontrolled and controlled sanitary landfills. "Uncontrolled sanitary landfills" are defined as landfills or open dumps that do not meet the requirements for run-on or run-off controls that are found in the

MSWLF Criteria, Section 258.25. "Controlled sanitary landfills" are those that do meet the run-on and run-off requirements. The NPDES regulations specify that **uncontrolled** sanitary landfills owned or operated by municipalities of less than 100,000 (population) must submit a NPDES permit application for their stormwater discharge or obtain coverage under a general permit. For **controlled** sanitary landfills owned or operated by a municipality with a population less than 100,000, there is no requirement to submit a stormwater discharge permit application (before October 1, 1992) unless a permit is required under Section 402(p)(2)(A) or (E) of the Clean Water Act. Other deadlines are set for municipalities with a population less than 250,000 that own or operate a municipal landfill. For further information contact the Stormwater Hotline (703) 821-4823. See the April 2, 1992 Federal Register (57 FR 11394), 40 CFR 122.26.

3.10 LIQUIDS RESTRICTIONS 40 CFR §258.28

3.10.1 Statement of Regulation

(a) Bulk or noncontainerized liquid waste may not be placed in MSWLF units unless:

(1) The waste is household waste other than septic waste; or

(2) The waste is leachate or gas condensate derived from the MSWLF unit and the MSWLF unit, whether it is an existing or new unit, is designed with a composite liner and leachate collection system as described in §258.40 (a)(2) of this part. The owner or operator must place the demonstration in the operating record and notify the State Director that it has been placed in the operating record.

(b) Containers holding liquid waste may not be placed in a MSWLF unit unless:

(1) The container is a small container similar in size to that normally found in household waste;

(2) The container is designed to hold liquids for use other than storage; or

(3) The waste is household waste.

(c) For purposes of this section:

(1) Liquid waste means any waste material that 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).

(2) Gas condensate means the liquid generated as a result of gas recovery process(es) at the MSWLF unit.

3.10.2 Applicability

The regulation applies to new MSWLF units, existing MSWLF units, and lateral expansions of existing MSWLF units. The owner or operator is prohibited from placing bulk or non-containerized liquid waste, or containerized liquid waste into the MSWLF unit. Liquids from households are exempt. Tank trucks of wastes are not exempt.

3.10.3 Technical Considerations

The restriction of bulk or containerized liquids is intended to control a source of liquids that may become a source of leachate. Liquid waste refers to any waste material that is determined to contain free liquids as defined by SW-846 (U.S. EPA, 1987) Method 9095 - Paint Filter Liquids Test. The paint filter test is performed by placing a 100 milliliter 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 five minutes. The apparatus used for performing the paint filter test is illustrated in Figure 3-9.

If the waste is considered a liquid waste, absorbent materials may be added to render a "solid" material (i.e., waste/absorbent mixture that no longer fails the paint filter liquids test). One common waste stream that may contain a significant quantity of liquid is sludge. Sludge is a mixture of water and solids that has been concentrated from, and produced during, water and wastewater treatment. Sludges may be produced as a result of providing municipal services (e.g., potable water supply, sewage treatment, storm drain maintenance) or commercial or industrial operations. Sewage sludge is a mixture of organic and inorganic solids and water, removed from wastewater containing domestic sewage. Sludge disposal is acceptable provided the sludge passes the paint filter test.

[NOTE: Additional Federal regulations restricting the use and disposal of sewage sludge were published on February 19, 1993 in the Federal Register (58 FR 9248). These regulations, however, do not establish additional treatment standards or other special management requirements for sewage sludge that is codisposed with solid waste.]

Owners and operators of MSWLF units may return leachate and gas condensate generated from a gas recovery process to the MSWLF, provided the MSWLF unit has been designed and constructed with a composite liner and leachate collection system in compliance with 40 CFR §258.40(a)(2). Approved States may allow leachate and landfill gas condensate recirculation in MSWLF units with alternative designs.

Recirculating leachate or landfill gas concentrate may require demonstrating that the added volume of liquid will not increase the depth of leachate on the liner to more than 30 cm.

Returning gas condensate to the landfill unit may represent a reasonable long-term solution for relatively small volumes of condensate. Gas condensate recirculation can be accomplished by pumping the condensate through pump stations at the gas recovery system and into dedicated drain fields (buried pipe) atop the landfill, or into other discharge points (e.g., wells).
Because gas condensate may be odorous, spray systems for recirculation are not used unless combined with leachate recirculation systems.

Leachate recirculation to a MSWLF unit has been used as a measure for managing leachate or as a means of controlling and managing liquid and solid waste decomposition. Leachate recirculation can be accomplished in the same manner as recirculation of landfill gas condensate. Because of the larger volume, however, discharge points may not be as effective as drainfields. In some cases, discharge points

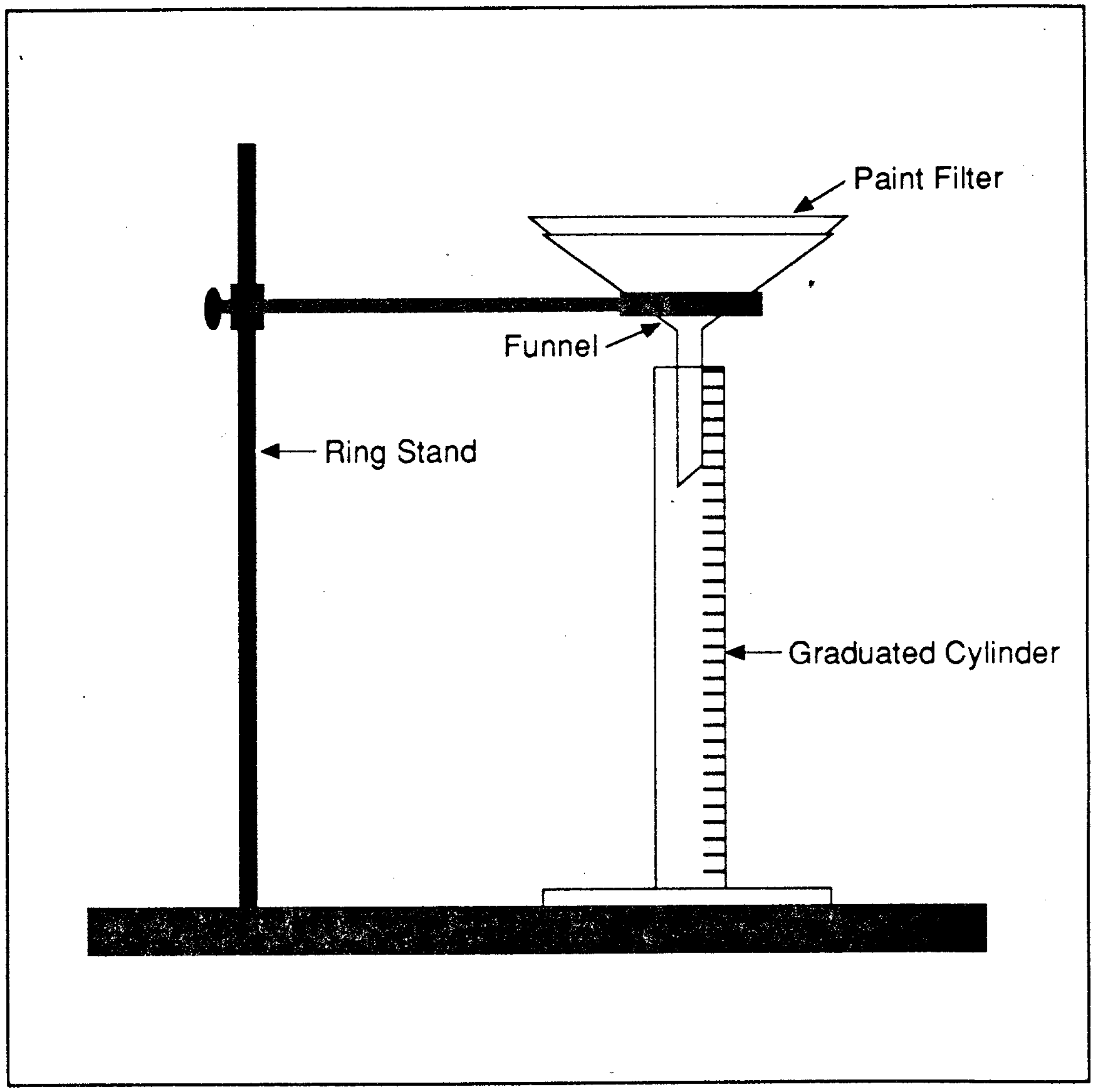

Figure 3-9. Paint Filter Test Apparatus

have been a source of odor. In addition, a discharge point may not allow for dissipation of the leachate. (For additional information regarding the effectiveness of using leachate recirculation to enhance the rate of organic degradation, see (Reinhart and Carson, 1993).)

3.11 RECORDKEEPING REQUIREMENTS 40 CFR §258.29

3.11.1 Statement of Regulation

(a) The owner or operator of a MSWLF unit must record and retain near the facility in an operating record, or in an alternative location approved by the Director of an approved state, the following information as it becomes available:

(1) Any location restriction demonstration required under Subpart B of this part;

(2) Inspection records, training procedures, and notification procedures required in §258.20 of this Part;

(3) Gas monitoring results from monitoring and any remediation plans required by §258.23 of this Part;

(4) Any MSWLF unit design documentation for placement of leachate or gas condensate in a MSWLF unit as required under §258.28 (a)(2) of this Part;

(5) Any demonstration, certification, finding, monitoring, testing, or analytical data required by Subpart E of this Part;

(6) Closure and post-closure care plans and any monitoring, testing, or analytical data as required by §§258.60 and 258.61 of this Part; and

(7) Any cost estimates and financial assurance documentation required by Subpart G of this Part.

(8) Any information demonstrating compliance with small community exemption as required by §258.1(f)(2).

(b) The owner/operator must notify the State Director when the documents from paragraph (a) of this section have been placed or added to the operating record, and all information contained in the operating record must be furnished upon request to the State Director or be made available at all reasonable times for inspection by the State Director.

(c) The Director of an approved State can set alternative schedules for recordkeeping and notification requirements as specified in paragraphs (a) and (b), except for the notification requirements in §258.10(b) and §258.55(g)(1)(iii).

3.11.2 Applicability

The regulation applies to existing MSWLF units, lateral expansions of existing MSWLF units, and new MSWLF units. The recordkeeping requirements are intended to be self-implementing so that owners/ operators in unapproved States can comply without State or EPA involvement. The owner or operator is required to maintain records of demonstrations, inspections, monitoring results, design documents, plans, operational procedures, notices, cost estimates, and financial assurance documentation.

3.11.3 Technical Considerations

The operating record should be maintained in a single location. The location may be at the facility, at corporate headquarters, or at city hall, but should be near the facility. Records should be maintained throughout the life of the facility, including the post-closure care period. Upon placement of each required document in the operating record, the State Director should be notified. The Director of an approved State may establish alternative requirements for recordkeeping, including using the State permit file for recordkeeping.

Recordkeeping at the landfill facility should include the following:

(a) Location restriction demonstrations: Demonstrations are required for any location restrictions under Subpart B. The location restrictions apply to:

- Airports;
- Floodplains;
- Wetla
- Fault areas;
- Seismic impact zones; and
- Unstable areas.

(b) Inspection records, training procedures, and notification procedures: Inspection records should include:

- Date and time wastes were received during the inspection;
- Names of the transporter and the driver;
- Source of the wastes;
- Vehicle identification numbers; and
- All observations made by the inspector.

Training records should include procedures used to train personnel on hazardous waste and on PCB waste recognition. Notification to EPA, State, and local agencies should be documented.

(c) Gas monitoring results and any remediation plans: If gas levels exceed 25 percent of the LEL for methane in any facility structures or exceed the LEL for methane at the facility boundary, the owner or operator must place in the operating record, within seven days, the methane gas levels detected, and a description of the steps taken to protect human health. Within 60 days of detection, the owner or operator must place a copy of the remediation plan used for gas releases in the operating record.

(d) MSWLF unit design documentation for placement of leachate or gas condensate in a MSWLF unit: If leachate and/or gas condensate are recirculated into the MSWLF unit, documentation of a composite liner and a leachate collection system capable of maintaining a maximum of 30 cm of leachate head in the MSWLF unit must be placed in the operating record.

(e) Demonstration, certification, monitoring, testing, or analytical finding required by the ground-water criteria: Documents to be placed in the operating record include:

- Documentation of design, installation, development, and decommission of any monitoring wells, piezometers, and other measurement, sampling, and analytical devices;

- Certification by a qualified ground-water scientist of the number, spacing, and depths of the monitoring systems;

- Documentation of sampling and analysis programs and statistical procedures;

- Notice of finding a statistically significant increase over background for one or more of the constituents listed in Appendix I of Part 258 (or alternative list in approved States) at any monitoring well at the waste management unit boundary (States with inadequate program) or the relevant point of compliance (approved States);

- Certification by a qualified ground-water scientist that an error in sampling, analysis, statistical evaluation, or natural variation in ground water caused an increase (false positive) of Appendix I constituents, or that a source other than the MSWLF unit caused the contamination (if appropriate);

- A notice identifying any Appendix II (Part 258) constituents that have been detected in ground water and their concentrations;

- A notice identifying the Part 258 Appendix II constituents that have exceeded the ground-water protection standard;

- A certification by a qualified ground-water scientist that a source other than the MSWLF unit caused the contamination or an error in sampling, analysis, statistical evaluation, or natural ground-water variation caused a statistically significant increase (false positive) in Appendix II (Part 258) constituents (if applicable);

- The remedies selected to remediate ground-water contamination; and

- Certification of remediation completion.

(f) Closure and post-closure plans and any monitoring, testing, or analytical data associated with these plans: The landfill facility owner or operator is required to place a copy of the closure plan, post-closure plan, and a notice of intent to close the facility in the operating record. Monitoring, testing, or analytical data associated with closure and post-closure information generated from ground-water and landfill gas monitoring must be placed in the operating record. A copy of the notation on the deed to the MSWLF facility property, as required following closure, along with certification and verification that closure and post-closure activities have been completed in accordance with their respective plans, also must be placed in the operating record.

(g) Estimates and financial assurance documentation required: The following documents must be placed in the operating record:

- An estimate of the cost of hiring a third party to close the largest area of all MSWLF units that will require final cover;

- Justification for the reduction of the closure cost estimate and the amount of financial assurance (if appropriate);

- A cost estimate of hiring a third party to conduct post-closure care;

- The justification for the reduction of the post-closure cost estimate and financial assurance (if appropriate);

- An estimate and financial assurance for the cost of a third party to conduct corrective action, if necessary; and

- A copy of the financial assurance mechanisms.

3.12 FURTHER INFORMATION

3.12.1 References

Flower, et al., (1982). "Vegetation Kills in Landfill Environs"; Franklin B. Flower, Ida A. Leone, Edward F. Gilman and John J. Arthur; Cook College, Rutgers University; New Brunswick, New Jersey 08903.

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U.S. Department of Agriculture Soil Conservation Service, (1986). "Urban Hydrology for Small Watersheds"; PB87-101580.

U.S. Department of Commerce, Weather Bureau, "Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years."

U.S. EPA, (1985). "Handbook - Remedial Action at Waste Disposal Sites"; EPA/625/6-85/006; U.S. EPA, Office of Research and Development; Cincinnati, Ohio 45268.

U.S. EPA, (1986). "Test Methods for Evaluating Solid Wastes: Physical/Chemical Methods"; Third Edition as amended by Updates I and II. U.S. EPA SW-846; Office of Solid Waste and Emergency Response; Washington, D.C.

U.S. EPA, (1988). "Guide to Technical Resources for the Design of Land Disposal Facilities"; EPA/625/6-88/018; U.S. EPA; Risk Reduction Engineering Laboratory and Center for Environmental Research Information; Cincinnati, Ohio 45268.

U.S. EPA, (1992). "Alternative Daily Cover Materials for Municipal Solid Waste Landfills;" U.S. EPA Region IX; San Francisco, California 94105.

3.12.2 Addresses

Solid Waste Association of North America (SWANA/GRCDA)
P.O. Box 7219
Silver Spring, MD 20910
(301) 585-2898

APPENDIX I

Special Waste Acceptance Agreement

Code#

Special Waste Acceptance Application

Generator Name: ____________________
Address: ____________________
____
Telephone: (   ) ____________________
Generator Contact: ____________________
General Material Description: ____________________

Originating Division: ____________________
Disposal Facility: ____________________
Location: ____________________
Waste Quantities: ____________ Units: Cubic Yds. ☐ Tons ☐
Frequency of Receipt: Daily ☐ Weekly ☐ Monthly ☐ One Time ☐
Other ____________________

Process Generating Waste: ____________________

Physical Properties: Physical State at 70°F: Solid ☐ Semisolid ☐ Liquid ☐ Density: _______ #/CY Color: ____________
Viscosity: Low ☐ Medium ☐ High ☐ Flash Point: _______ °F Odor: Yes ☐ No ☐
Water Content: _____ % by Weight Paint Filter Test: Passed ☐ Failed ☐
Reactive: No ☐ Yes ☐ With ____________________
Waste pH: _________ Infectious: Yes ☐ No ☐

Chemical Properties: (Concentrations in mg/l)

(TCLP)	Arsenic	____	m-Cresol	____	Hexachlorobenzene	____	Pyridine	____
	Barium	____	p-Cresol	____	Hexachlorobutadiene	____	Selenium	____
	Benzene	____	Cresol	____	Hexachloroethane	____	Silver	____
	Cadmium	____	2,4-D	____	Lead	____	Tetrachloroethylene	____
	Carbon Tetrachloride	____	1,4 Dichlorobenzene	____	Lindane	____	Toxaphene	____
	Chlordane	____	1,2 Dichloroethane	____	Mercury	____	Trichloroethylene	____
	Chlorobenzene	____	1,1-Dichloroethylene	____	Methoxychlor	____	2,4,5-Trichlorophenol	____
	Chloroform	____	2,4-Dinitrotoluene	____	Methyl Ethyl Ketone	____	2,4,6-Trichlorophenol	____
	Chromium	____	Endrin	____	Nitrobenzene	____	2,4,5-TP (Silvex)	____
	o-Cresol	____	Heptachlor	____	Pentachlorophenol	____	Vinyl Chloride	____

Other (list): ____________________
____

Other Information: Delivery Method: Bulk ☐ Other: ____________________
Regulatory Agency Approval Received: Yes ☐ No ☐ Permit Number: ____________________
Material Safety Data Sheet Provided: Yes ☐ No ☐

GENERATOR CERTIFICATION

To the best of my knowledge, the information provided above is accurate and the material is not classified as a hazardous waste in accordance with current regulations.

Authorized Representative
Signature ____________________
Name ____________________
Title ____________________
Date ____________________

FOR OFFICE USE ONLY

Conditions for Acceptance ____________________
____
____

1. Originating Division Manager ____________ Date ______
2. Disposal Facility Manager ____________ Date ______
3. District Manager ____________ Date ______
4. Regional Engineer ____________ Date ______

Recertification Frequency: BI Annual ☐ Annual ☐ Semi Annual ☐

First Page to Owner/Operator; Second Page to Customer; Third Page to Laboratory

Appendix I. Example Special Waste Acceptance Agreement

CHAPTER 4

SUBPART D
DESIGN CRITERIA

CHAPTER 4
SUBPART D

TABLE OF CONTENTS

CHAPTER 4
SUBPART D

DESIGN CRITERIA

4.1 INTRODUCTION

New MSWLF facilities and lateral expansions of existing units must comply with either a design standard or a performance standard for landfill design. The Federal Criteria do not require existing units to be retrofitted with liners. The design standard requires a composite liner composed of two feet of soil with a hydraulic conductivity of no more than 1 x 10^{-7} cm/sec, overlain by a flexible membrane liner (FML) and a leachate collection system. A performance-based design must demonstrate the capability of maintaining contaminant concentrations below maximum contaminant levels (MCLs) at the unit's relevant point of compliance. The performance standard has been established to allow design innovation and consideration of site-specific conditions; approved States may have adopted alternative design standards. Owners/operators are advised to work closely with State permitting agencies to determine the applicable design standard. Owners/operators in unapproved States may use the petition process (§258.40(c)) to allow for use of a performance-based design. This process is discussed in Section 4.5.

The technical considerations discussed in this chapter are intended to identify the key design features and system components for the composite liner and leachate collection system standards, and for the performance standard. The technical considerations include 1) design concepts, 2) design calculations, 3) physical properties, and 4) construction methods for the following:

1) Designs Based on the Performance Standard

- Leachate characterization and leakage assessment;
- Leachate migration in the subsurface;
- Leachate migration models; and
- Relevant point of compliance assessment.

2) Composite Liners and Leachate Collection Systems

- Soil liner component (soil properties lab testing, design, construction, and quality assurance/quality control testing);
- Flexible membrane liners (FML properties, design installation, and quality assurance/quality control testing);
- Leachate collection systems (strength and compatibility, grading and drainage, clogging potential, and filtration);

- Leachate removal systems (pumps, sumps, and standpipes); and
- Inspections (field observations and field and laboratory testing).

Designs based on the performance standard are described in Section 4.2. Requirements for composite liners are discussed in Section 4.3. These sections address the minimum regulatory requirements that should be considered during the design, construction, and operation of MSWLF units to ensure that they perform in a manner protective of human health and the environment. Additional features or procedures may be used to demonstrate conformance with the regulations or to control leachate release and subsequent effects. For example, during construction of a new MSWLF unit, or a lateral expansion of an existing MSWLF unit, quality control and quality assurance procedures and documentation may be used to ensure that material properties and construction methods meet the design specifications that are intended to achieve the expected level of performance. Section 4.4 presents methods to assess ground-water quality at the relevant point of compliance for performance-based designs. Section 4.5 describes the applicability of the petition process for States wishing to petition to use the performance standard.

4.2 PERFORMANCE-BASED DESIGN 40 CFR §258.40(a)(1)

4.2.1 Statement of Regulation

(a) New MSWLF units and lateral expansions shall be constructed:

(1) In accordance with a design approved by the Director of an approved State or as specified in §258.40(e) for unapproved States. The design must ensure that the concentration values listed in Table 1 will not be exceeded in the uppermost aquifer at the relevant point of compliance as specified by the Director of an approved State under paragraph (d) of this section, or

(2) *(See Statement of Regulation in Section 4.3.1 of this guidance document for the regulatory language for composite liner requirements).*

(b) *(See Statement of Regulation in Section 4.3.1 of this guidance document for the regulatory language for requirements pertaining to composite liner and leachate collection systems).*

(c) When approving a design that complies with paragraph (a)(1) of this section, the Director of an approved State shall consider at least the following factors:

(1) The hydrogeologic characteristics of the facility and surrounding land;

(2) The climatic factors of the area; and

(3) The volume and physical and chemical characteristics of the leachate.

(d) *(See Statement of Regulation in Section 4.4.1 of this guidance document for a discussion of the determination of the relevant point of compliance.)*

TABLE 1
(40 CFR 258.40; 56 FR 51022; October 9, 1991)

Chemical	MCL(mg/l)
Arsenic	0.05
Barium	1.0
Benzene	0.005
Cadmium	0.01
Carbon tetrachloride	0.005
Chromium (hexavalent)	0.05
2,4-Dichlorophenoxy acetic acid	0.1
1,4-Dichlorobenzene	0.075
1,2-Dichloroethane	0.005
1,1-Dichloroethylene	0.007
Endrin	0.0002
Fluoride	4.0
Lindane	0.004
Lead	0.05
Mercury	0.002
Methoxychlor	0.1
Nitrate	10.0
Selenium	0.01
Silver	0.05
Toxaphene	0.005
1,1,1-Trichloroethane	0.2
Trichloroethylene	0.005
2,4,5-Trichlorophenoxy acetic acid	0.01
Vinyl Chloride	0.002

4.2.2 Applicability

The Director of an approved State may approve a performance-based design for new MSWLF units and lateral expansions of existing units (see Section 4.3.2), if it meets the requirements specified in 40 CFR 258.40(a)(1). A performance-based design is an alternative to the design standard (composite liner with a leachate collection system). The composite design is required in unapproved States; however, if EPA does not promulgate procedures for State approval by October 9, 1993, the performance-based design may be available through the petition process (see Section 4.5).

4.2.3 Technical Considerations

Demonstration Requirements

For approval of landfill designs not conforming to the uniform design standard of a composite liner system and a leachate collection system (40 CFR §258.40(a)(2)), the owner or operator of the proposed MSWLF unit must demonstrate to the Director of an approved State that the design will not allow the compounds listed in Table 1 of §258.40 to exceed the MCLs in ground water at the relevant point of compliance. The demonstration should consider an assessment of leachate quality and quantity, leachate leakage to the subsurface, and subsurface transport to the relevant point of compliance. These factors are governed by site hydrogeology, waste characteristics, and climatic conditions.

The nature of the demonstration is essentially an assessment of the potential for leachate production and leakage from the landfill to ground water, and the anticipated fate and transport of constituents listed in Table 1 to the proposed relevant point of compliance at the facility. Inherent in this approach is the need to evaluate whether contaminants in ground water at the relevant point of compliance will exceed the concentration values listed in Table 1. If so, then the owner or operator needs to obtain sufficient site-specific data to adequately characterize the existing ground-water quality and the existing ground-water flow regime (e.g., flow direction, horizontal and vertical gradients, hydraulic conductivity, stratigraphy, and aquifer thickness).

An assessment should be made of the effect MSWLF facility construction will have on site hydrogeology. The assessment should focus on the reduced infiltration over the landfill area and altered surface water run-off patterns. Reduction of ground-water recharge and changes in surface water patterns resulting from landfill construction may affect ground-water gradients in some cases and may result in changes in lateral flow directions. One example of a hypothetical performance-based demonstration follows.

It is possible that a MSWLF unit located in an arid climatic zone would not produce leachate from sources of water (e.g., precipitation) other than that existing within the waste at the time of disposal. In such an environment, an owner or operator may demonstrate that significant quantities of leachate would not be produced. The demonstration should be supported by evaluating historic precipitation and evaporation data and the likelihood that the unit could be flooded as the result of heavy rains, surface run-off, or high water tables. It may be possible, through operational controls, to avoid exposing waste to precipitation or infiltration of water through overlying materials. If significant leachate production would not be expected, the regulatory authority, when reviewing the demonstration, should consider the hydrogeologic characteristics of the facility and the surrounding area, in addition to the expected volume of leachate and climatic factors.

Assuming leachate is produced, the demonstration should evaluate whether constituents listed in Table 1 can be expected to be present at concentrations greater than the MCLs. If such a demonstration is possible, it must address the hydrogeologic characteristics of the facility and the surrounding land to comply with §258.40(d). The following sections describe the various parts of a demonstration in greater detail.

Leachate Characterization

Leachate characterization should include an assessment and demonstration of the quantity and composition of leachate anticipated at the proposed facility. Discussion of this assessment follows.

Estimates of volumetric production rates of leachate are important in evaluating the fate and transport of the constituents listed in Table 1. Leachate production rates depend on rainfall, run-on, run-off, evapotranspiration, water table elevation relative to the bottom of the landfill unit, in-place moisture content of waste, and the prevention of liquid disposal at the site. Run-on, run-off, and water table factors can be managed traditionally through design and operational controls. The MSWLF Criteria prohibit bulk or containerized liquid disposal. Incident precipitation and evapotranspiration can be evaluated using models (e.g., HELP) or other methods of estimating site-specific leachate production (e.g., local historical meteorologic data).

If leachate composition data that are representative of the proposed facility are not available, then leachate data with a similar expected composition should be presented. Landfill leachate composition is influenced by:

(1) The annual infiltration of precipitation and rate of leaching;

(2) The type and relative amounts of materials in the waste stream; and

(3) The age and the biological maturity of the landfill unit, which may affect the types of organic and inorganic acids generated, oxidation/reduction potential (Eh), and pH conditions.

An existing landfill unit in the same region, with similar waste stream characteristics, may provide information that will allow the owner or operator to anticipate leachate composition of the proposed landfill unit. A review of existing literature also may be required to assess anticipated leachate composition if actual data are unavailable (see U.S. EPA, 1987b). A wide range of leachate concentrations are reported in the literature with higher concentrations of specific constituents typically reported for the initial leachate from laboratory or field experimental test fills or test cells. These "batch" one-day landfill tests do not account for the long-term climatic and meteorological influences on a full-scale landfill operation. Such high initial concentrations are not typical of full-scale operations (which are subject to the dilution effects of incidental rainfall on unused portions of the unit).

Assessment of Leakage Through Liners

An assessment of leakage (the volumetric release of leachate from the proposed performance-based design) should be based on analytical approaches supported by empirical data from other existing operational facilities of similar design, particularly those that have leak detection monitoring systems (see U.S. EPA, 1990b). In lieu of the existence or availability of such information, conservative analytical assumptions may be used to estimate anticipated leakage rates.

The transport of fluids and waste constituents through geomembranes differs in principle from transport through soil liner materials. The dominant mode of leachate transport through liner components is flow through holes and penetrations of the geomembrane, and Darcian flow through soil components. Transport through geomembranes where tears, punctures, imperfections, or seam failures are not involved is dominated by molecular diffusion. Diffusion occurs in response to a concentration gradient and is governed by Fick's first law. Diffusion rates through geomembranes are very low in comparison to hydraulic flow rates in soil liners, including compacted clays. For synthetic liners, the most significant factor influencing liner performance is penetration of the liner, including imperfect seams or pinholes caused by construction defects in the geomembrane (U.S. EPA, 1989).

A relatively new product now being used in liner systems is the geosynthetic clay liner (GCL). GCLs consist of a layer of pure bentonite clay backed by one or two geotextiles. GCLs exhibit properties of both soil liners and geomembranes, and have successfully substituted for the soil component in composite liner designs. GCLs are believed to transport fluids primarily through diffusion according to their low hydraulic conductivities (i.e., 1×10^{-9} cm/sec reported by manufacturers). Applications for GCLs are discussed further in the sections that follow.

Several researchers have studied the flow of fluids through imperfections in single geomembrane and composite liner systems. Further discussion of liner leakage rates can be found in Section 4.3.3 below. For empirical data and analytical methods the reader is referred to Jayawickrama et al. (1988), Kastman (1984), Haxo (1983), Haxo et al. (1984), Radian (1987), Giroud and Bonaparte (1989, Parts I and II), and Giroud et al. (1989). Leakage assessments also may be conducted with the use of the HELP model (U.S. EPA, 1988). Version 3.0 of the model is under revision and will include an updated method to assess leakage that is based on recent research and data compiled by Giroud and Bonaparte.

Leachate Migration in the Subsurface

Leachate that escapes from a landfill unit may migrate through the unsaturated zone and eventually reach the uppermost aquifer. In some instances, however, the water table may be located above the base of the landfill unit, so that only saturated flow and transport from the landfill unit need to be considered. Once leachate reaches the water table, contaminants may be transported through the saturated zone to a point of discharge (i.e., a pumping well, a stream, a lake, etc.).

The migration of leachate in the subsurface depends on factors such as the volume of the liquid component of the waste, the chemical and physical properties of the leachate constituents, the loading rate, climate, and the chemical and physical properties of the subsurface (saturated and unsaturated zones). A number of physical, chemical, and biological processes also may influence migration. Complex interactions between these processes may result in specific contaminants being transported through the subsurface at different rates. Certain processes result in the attenuation and degradation of contaminants. The degree of attenuation is dependent on the time that the contaminant is in contact with the subsurface material, the physical and chemical characteristics of the subsurface material, the distance that the contaminant has traveled, and the volume and characteristics of the leachate. Some of the key processes affecting leachate migration are discussed briefly here. The information is based on a summary in Travers and Sharp-Hansen (1991), who in turn relied largely on Aller et al. (1987), Keely (1987), Keely (1989), Lu et al. (1985), and U.S. EPA (1988a).

Physical Processes Controlling Contaminant Transport in the Subsurface

Physical processes that control the transport of contaminants in the subsurface include advection, mixing and dilution as a result of dispersion and diffusion, mechanical filtration, physical sorption, multi-phase fluid flow, and fracture flow. These processes, in turn, are affected by hydrogeologic characteristics, such as hydraulic conductivity and porosity, and by chemical processes.

Advection is the process by which solute contaminants are transported by the overall motion of flowing ground water. A non-reactive solute will be transported at the same rate and in the same direction as ground water flow (Freeze and Cherry, 1979). Advective transport is chiefly a function of the subsurface hydraulic conductivity distribution, porosity, and hydraulic gradients.

Hydrodynamic dispersion is a non-steady, irreversible mixing process by which a contaminant plume spreads as it is transported through the subsurface. Dispersion results from the effects of two components operating at the microscopic level: mechanical dispersion and molecular diffusion. Mechanical dispersion results from variations in pore velocities within the soil or aquifer and may be more significant than molecular diffusion in environments where the flow rates are moderate to high. Molecular diffusion occurs as a result of contaminant concentration gradients; chemicals move from high concentrations to low concentrations. At very slow ground-water velocities, as occur in clays and silts, diffusion can be an important transport mechanism.

Mechanical filtration removes from ground water contaminants that are larger than the pore spaces of the soil. Thus, the effects of mechanical filtration increase with decreasing pore size within a medium. Filtration occurs over a wide range of particle sizes. The retention of larger particles may effectively reduce the permeability of the soil or aquifer.

Physical sorption is a function of Van der Waals forces, and the hydrodynamic and electrokinetic properties of soil particles. Sorption is the process by which contaminants are removed from solution in ground water and adhere or cling to a solid surface. The distribution of a contaminant between the solution and the solid phase is called partitioning.

Multiphase fluid flow occurs because many solvents and oils are highly insoluble in water and may migrate in the subsurface as a separate liquid phase. If the viscosity and density of a fluid differ from that of water, the fluid may flow at a different rate and direction than the ground water. If the fluid is more dense than water it may reach the bottom of the aquifer (top of an aquitard) and alter its flow direction to conform to the shape and slope of the aquitard surface.

Hydraulic conductivity is a measure of the ability of geologic media to transmit fluids (USGS, 1987). It is a function of the size and arrangement of water-transmitting openings (pores and fractures) in the media and of the characteristics of the fluids (density, viscosity, etc.). Spatial variations in hydraulic conductivity are referred to as heterogeneities. A variation in hydraulic conductivity with the direction of measurement is referred to as anisotropy.

Variable hydraulic conductivity of the geologic formation may cause ground-water flow velocities to vary spatially. Variations in the rate of advection may result in non-uniform plume spreading. The changes in aquifer properties that lead to this variability in hydraulic conductivity may be three-dimensional. If the geologic medium is relatively homogeneous, it may be appropriate, in some instances, to assume that the aquifer properties also are homogeneous.

Secondary porosity in rock may be caused by the dissolution of rock or by regional fracturing; in soils, secondary porosity may be caused by desiccation cracks or fissures. Fractures or macropores respond quickly to rainfall events and other fluid inputs and can transmit water rapidly along unexpected pathways. Secondary porosity can result in localized high concentrations of contaminants at significant distances from the facility. The relative importance of secondary porosity to hydraulic conductivity of the subsurface depends on the ratio of fracture hydraulic conductivity to intergranular hydraulic conductivity (Kincaid et al., 1984a). For scenarios in which fracture flow is dominant, the relationships used to describe porous flow (Darcy's Law) do not apply.

Chemical Processes Controlling Contaminant Transport in the Subsurface

Chemical processes that are important in controlling subsurface transport include precipitation/dissolution, chemical sorption, redox reactions, hydrolysis, ion exchange, and complexation. In general, these processes, except for hydrolysis, are reversible. The reversible processes tend to retard transport, but do not permanently remove a contaminant from the system. Sorption and precipitation are generally the dominant mechanisms retarding contaminant transport in the saturated zone.

Precipitation/dissolution reactions can control contaminant concentration levels. The solubility of a solid controls the equilibrium state of a chemical. When the soluble concentration of a contaminant in leachate is higher than that of the equilibrium state, precipitation occurs. When the soluble concentration is lower than the equilibrium value, the contaminant exists in solution. The precipitation of a dissolved substance may be initiated by changes in pressure, temperature, pH, concentration, or redox potential (Aller et al., 1987). Precipitation of contaminants in the pore space of an aquifer can decrease aquifer porosity. Precipitation and dissolution reactions are especially important processes for trace metal migration in soils.

Chemical adsorption/desorption is the most common mechanism affecting contaminant migration in soils. Solutes become attached to the solid phase by means of adsorption. Like precipitation/dissolution, adsorption/desorption is a reversible process. However, adsorption/desorption generally occurs at a relatively rapid rate compared to precipitation reactions.

The dominant mechanism of organic sorption is the hydrophobic attraction between a chemical and natural organic matter that exists in some aquifers. The organic carbon content of the porous medium, and the solubility of the contaminant, are important factors for this type of sorption.

There is a direct relationship between the quantity of a substance sorbed on a particle surface and the quantity of the substance suspended in solution. Predictions about the sorption of contaminants often make use of sorption isotherms, which relate the amount of contaminant in solution to the amount adsorbed to the solids. For organic contaminants, these isotherms are usually assumed to be linear and the reaction is assumed to be instantaneous and reversible. The linear equilibrium approach to sorption may not be adequate for all situations.

Oxidation and reduction (redox) reactions involve the transfer of electrons and occur when the redox potential in leachate is different from that of the soil or aquifer environment. Redox reactions are important processes for inorganic compounds and metallic elements. Together with pH, redox reactions affect the solubility, complexing capacity, and sorptive behavior of constituents, and thus control the presence and mobility of many substances in water. Microorganisms are responsible for a large proportion of redox reactions that occur in ground water. The redox state of an aquifer, and the identity and quantity of redox-active reactants, are difficult to determine.

Hydrolysis is the chemical breakdown of carbon bonds in organic substances by water and its ionic species H^+ and OH^-. Hydrolysis is dependent on pH and Eh and is most significant at high temperatures, low pH, and low redox potential. For many biodegradable contaminants, hydrolysis is slow compared to biodegradation.

Ion exchange originates primarily from exchange sites on layered silicate clays and organic matter that have a permanent negative charge. Cation exchange balances negative charges in order to maintain neutrality. The capacity of soils to exchange cations is called the cation exchange capacity (CEC). CEC is affected by the type and quantity of clay mineral present, the amount of organic matter present, and the pH of the soil. Major cations in leachate (Ca, Mg, K, Na) usually dominate the CEC sites, resulting in little attenuation in soils of trace metals in the leachate.

A smaller ion exchange effect for anions is associated with hydrous oxides. Soils typically have more negatively charged clay particles than positively charged hydrous oxides. Therefore, the transport of cations is attenuated more than the transport of anions.

Complexation involves reactions of metal ions with inorganic anions or organic ligands. The metal and the ligand bind together to form a new soluble species called a complex. Complexation can either increase the concentration of a constituent in solution by forming soluble complex ions or decrease the concentration by forming a soluble ion complex with a solid. It is often difficult to distinguish among sorption, solid-liquid complexation, and ion exchange. Therefore, these processes are usually grouped together as one mechanism.

Biological Processes Controlling Contaminant Transport in the Subsurface

Biodegradation of contaminants may result from the enzyme-catalyzed transformation of organic compounds by microbes. Contaminants can be degraded to harmless byproducts or to more mobile and/or toxic products through one or more of several biological processes. Biodegradation of a compound depends on environmental factors such as redox potential, dissolved oxygen concentration, pH, temperature, presence of other compounds and nutrients, salinity, depth below land surface, competition among different types of organisms, and concentrations of compounds and organisms. The transformations that occur in a subsurface system are difficult to predict because of the complexity of the chemical and biological reactions that may occur. Quantitative predictions of the fate of biologically reactive substances are subject to a high degree of uncertainty, in part, because little information is available on biodegradation rates in soil systems or ground water. First-order decay constants are often used instead.

The operation of Subtitle D facilities can introduce bacteria and viruses into the subsurface. The fate and transport of bacteria and viruses in the subsurface is an important consideration in the evaluation of the effects of MSWLF units on human health and the environment. A large number of biological, chemical, and physical processes are known to influence virus and bacterial survival and transport in the subsurface. Unfortunately, knowledge of the processes and the available data are insufficient to develop models that can simulate a wide variety of site-specific conditions.

Leachate Migration Models

After reviewing the hydrogeologic characteristics of the site, the nature of liner leakage, and the leachate characteristics, it may be appropriate to use a mathematical model to simulate the expected fate and transport of the constituents listed in Table 1 to the relevant point of compliance. Solute transport and ground-water modeling efforts should be conducted by a qualified ground-water scientist (see Section 5.5). It is necessary to consider several factors when selecting and applying a model to a site. Travers and Sharp-Hansen (1991) provide a thorough review of these issues. The text provided below is a summary of their review.

Overview of the Modeling Process

A number of factors can influence leachate migration from MSWLF units. These include, but are not limited to, climatic effects, the hydrogeologic setting, and the nature of the disposed waste. Each facility is different, and no one generic model will be appropriate in all situations. To develop a model for a site, the modeling needs and the objectives of the study should be determined first. Next, it will be necessary to collect data to characterize the hydrological, geological, chemical, and biological conditions of the system. These data are used to assist in the development of a conceptual model of the system, including spatial and temporal characteristics and boundary conditions. The conceptual model and data are then used to select a mathematical model that accurately represents the conceptual model. The model selected should have been tested and evaluated by qualified investigators, should adequately simulate the significant processes present in the actual system, and should be consistent with the complexity of the study area, amount of available data, and objectives of the study.

First, an evaluation of the need for modeling should be made (Figure 4-1). When selecting a model to evaluate the potential for soil and ground-water contamination (Boutwell et al., 1986), three basic determinations must be made (Figure 4-2). Not all studies require the use of a mathematical model. This decision should be made at the beginning of the study, since modeling may require a substantial amount of resources and effort. Next, the level of model complexity required for a specific study should be determined (Figure 4-3). Boutwell et al. (1986) classify models as Level I (simple/analytical) and Level II (complex/numerical) models. A flowchart for determining the level of model complexity required is shown in Figure 4-3. Finally, the model capabilities necessary to represent a particular system should be considered (Figure 4-4). Several models may be equally suitable for a particular study. In some cases, it may be necessary to link or couple two or more computer models to accurately represent the processes at the site. In the section that follows, specific issues that should be considered when developing a scenario and selecting a model are described.

Models are a simplified representation of the real system, and as such, cannot fully reproduce or predict all site characteristics. Errors are introduced as a result of: 1) simplifying assumptions; 2) a lack of data; 3) uncertainty in existing data; 4) a poor understanding of the processes influencing the fate and transport of contaminants; and

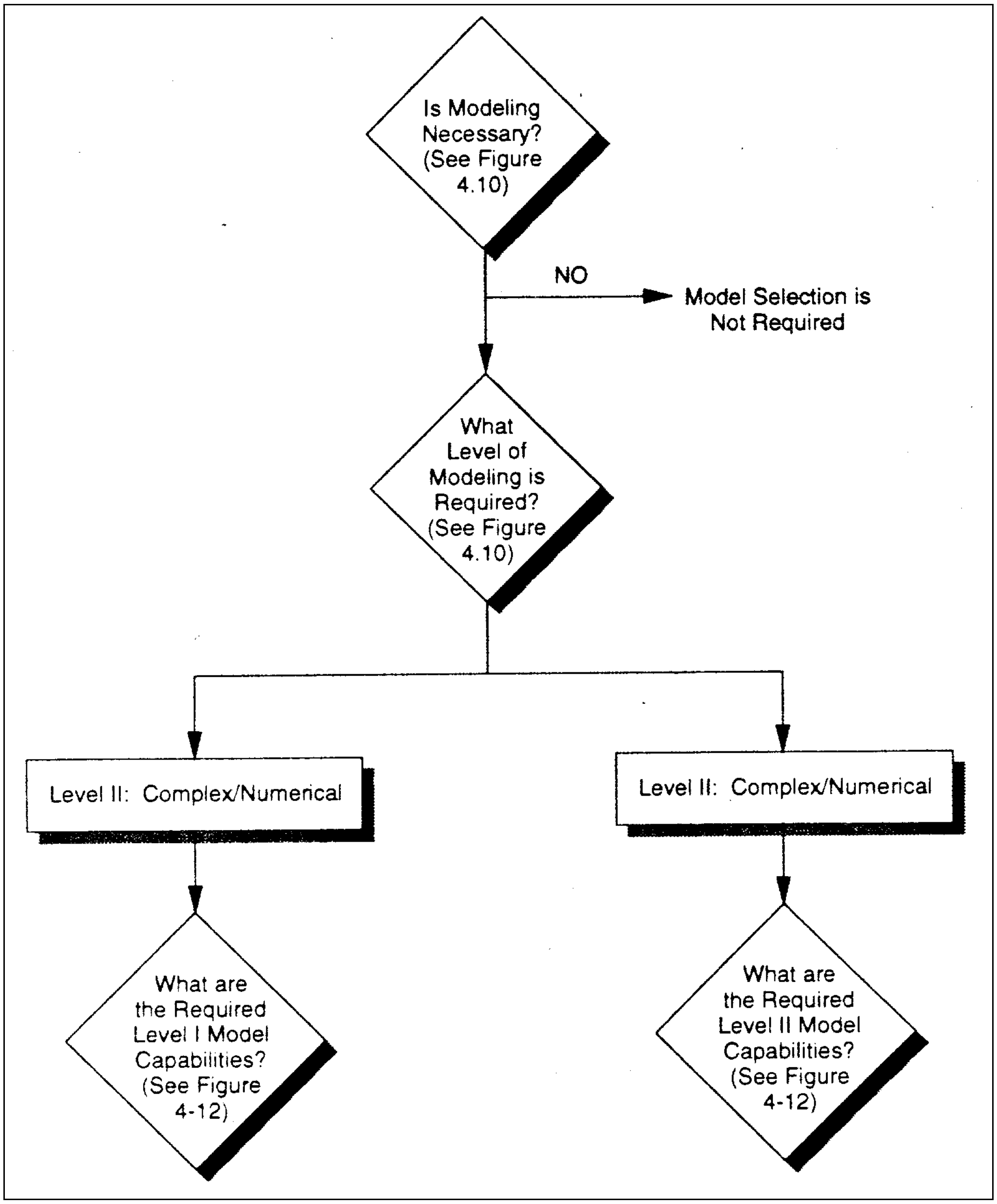


Figure 4-1
Three Basic Decisions in Model Selection
(Boutwell et. al., 1986)

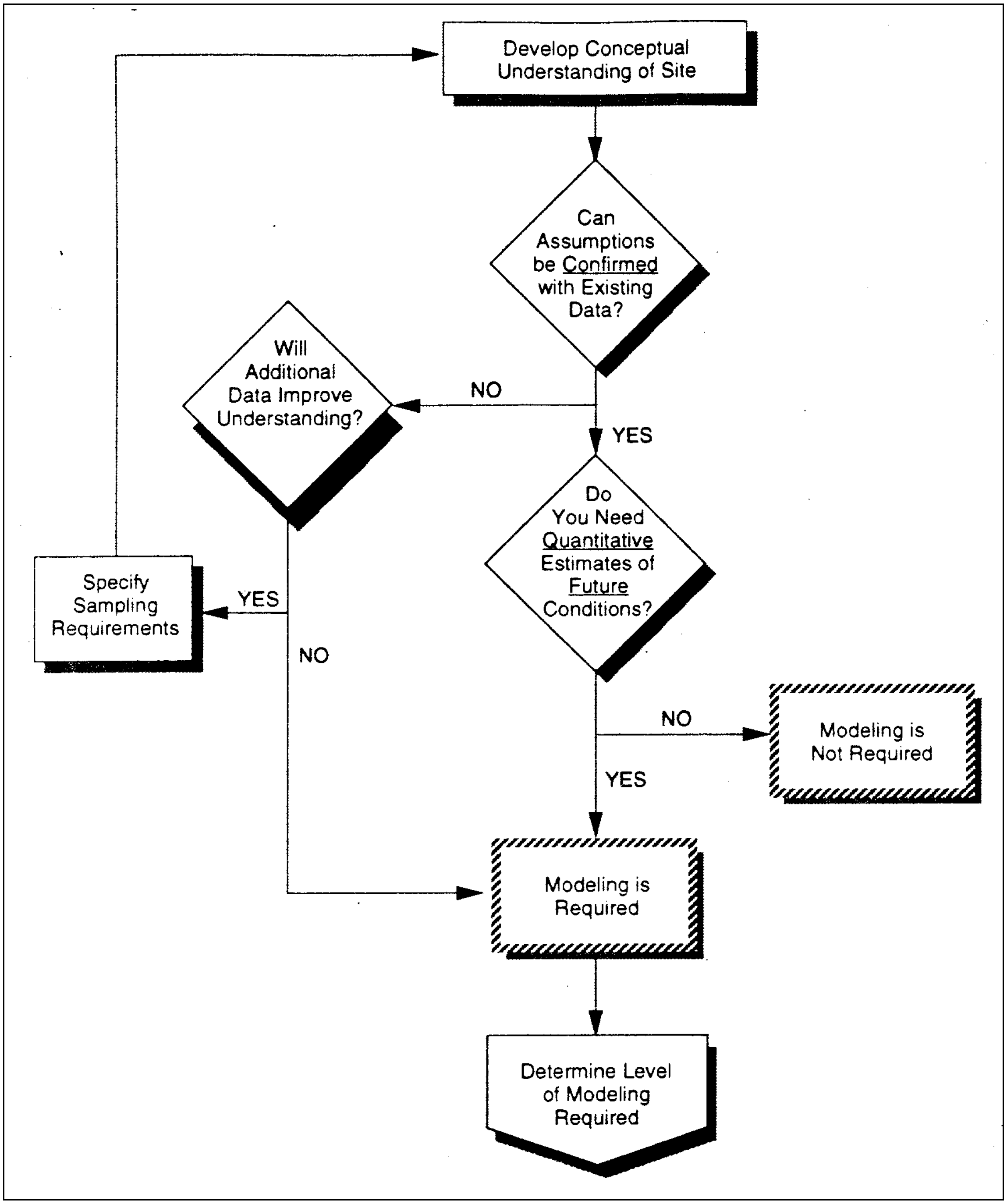


Figure 4-2
Flow Chart to Determine if Modeling is Required
(Boutwell et. al., 1986)

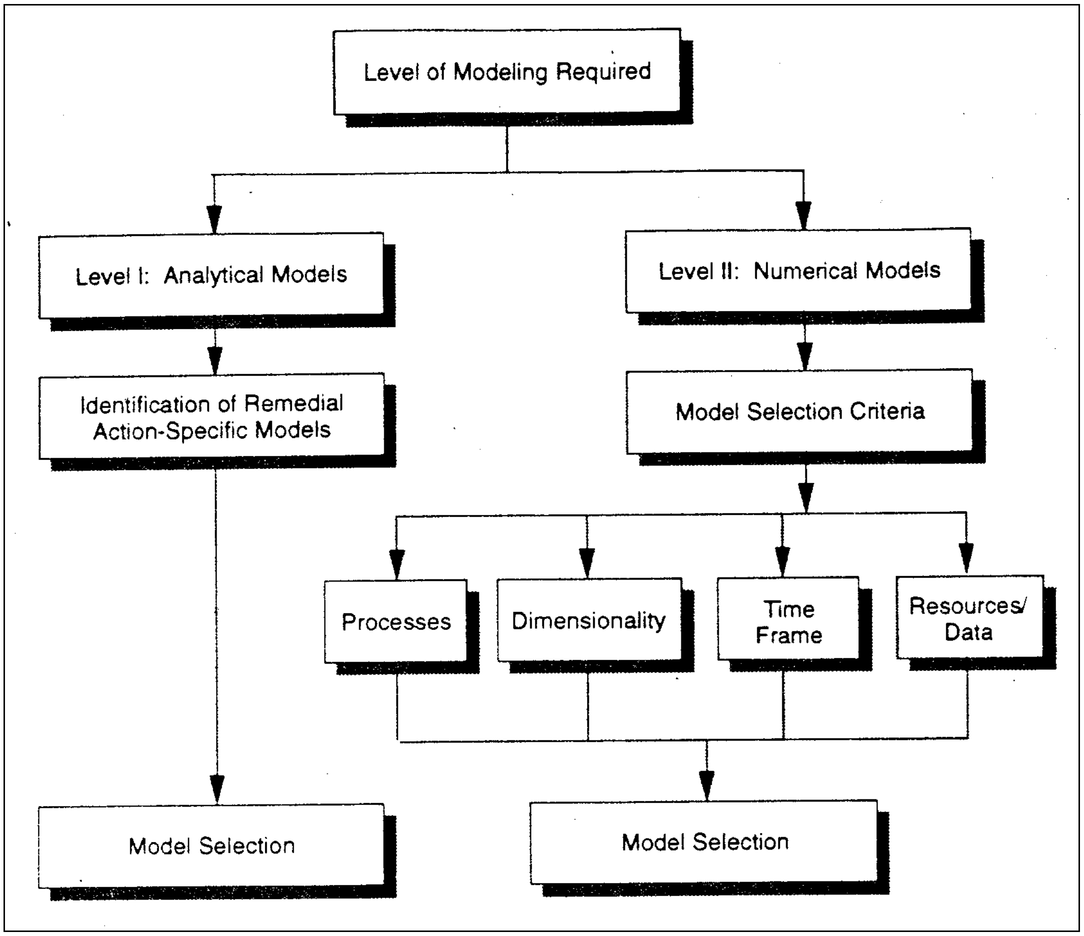


Figure 4-3
Flow Chart to Determine the Level of Modeling Required for Soil and Groundwater Systems
(Boutwell et. al., 1986)

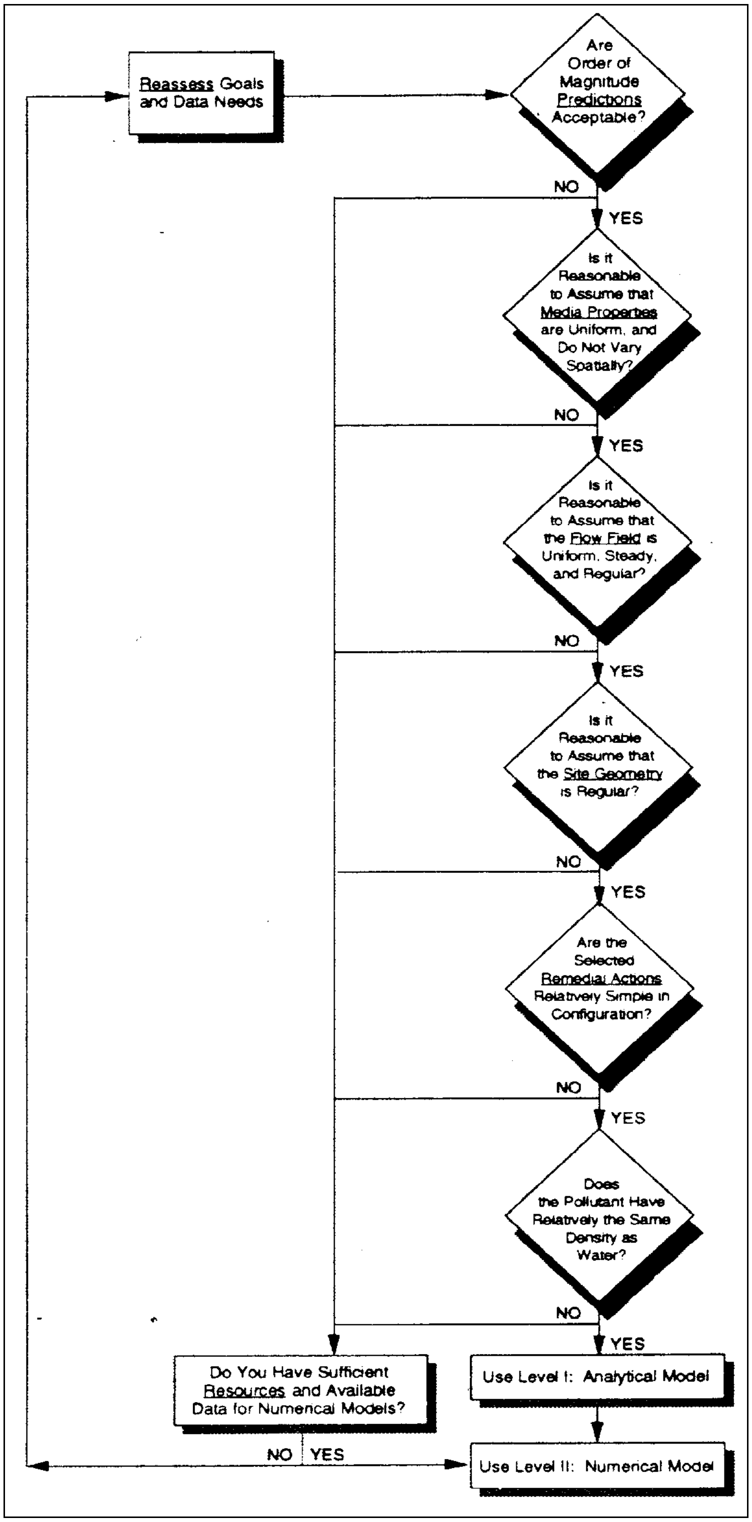


Figure 4-4
Flow Chart for Required Model Capabilities for Soil and Groundwater Systems
(Boutwell et. al., 1986)

5) limitations of the model itself. Therefore, model results should be interpreted as estimates of ground-water flow and contaminant transport. Bond and Hwang (1988) recommend that models be used for comparing various scenarios, since all scenarios would be subject to the same limitations and simplifications.

The quality of model results can depend to a large extent on the experience and judgement of the modeler, and on the quality of the data used to develop model input. The process of applying the model may highlight data deficiencies that may require additional data collection. The model results should be calibrated to obtain the best fit to the observed data. The accuracy of the results obtained from modeling efforts should then be validated. Model validation, which is the comparison of model results with experimental data or environmental data, is a critical aspect of model application, and is particularly important for site-specific evaluations.

Several recent reports present detailed discussions of the issues associated with model selection, application, and validation. Donigian and Rao (1990) address each of these issues, and present several options for developing a framework for model validation. EPA's Exposure Assessment Group has developed suggested recommendations and guidance on model validation (Versar Inc., 1987). A recent report by the National Research Council (1990) discusses the issues related to model application and validation, and provides recommendations for the proper use of ground-water models. Weaver et al. (1989) discuss options for selection and field validation of mathematical models.

Model Selection

Ground-water flow and solute transport models range from simple, analytical calculations to sophisticated computer programs that use numerical solutions to solve mathematical equations describing flow and transport. A sophisticated model may not yield an exact estimate of water quality at the relevant point of compliance for a given set of site conditions, but it may allow an estimate of the effects of complex physical and chemical processes. Depending on the complexity of site conditions and the appropriateness of the simplifying assumptions, a fairly sophisticated numerical model may provide useful estimates of water quality at the relevant point of compliance.

The following considerations should be addressed when selecting a model.

Analytical Versus Numerical Models

Mathematical models use either analytical, semi-analytical, or numerical solutions for ground-water flow and transport equations. Each technique has advantages and disadvantages. Analytical solutions are computationally more efficient than numerical simulations and are more conducive to uncertainty analysis (i.e., Monte Carlo techniques). Typically, input data for analytical models are simple and do not require detailed familiarity with the computer model or extensive modeling experience. Analytical solutions are typically used when data necessary for characterization of the site are sparse and simplifying assumptions are appropriate (Javandel et al., 1984). The limited data available in most field situations may not justify the use of a detailed numerical model; in some cases, results from simple analytical models may be appropriate

(Huyakorn et al., 1986). Analytical models require simplifying assumptions about the system. Therefore, complex interactions involving several fate and transport processes cannot be addressed in detail. Analytical models generally require a limited number of parameters that are often assumed to be constant in space and time (van der Heijde and Beljin, 1988).

Semi-analytical models approximate complex analytical solutions using numerical techniques (van der Heijde and Beljin, 1988). Semi-analytical methods allow for more complex site conditions than those that can be simulated with a purely analytical solution. Semi-analytical solution methods can consider multiple sources or recharging and discharging wells. However, they still require simplifying assumptions about the dimensionality and homogeneity of the system.

Numerical models are able to evaluate more complex site conditions than either analytical or semi-analytical models. Numerical models provide the user with a large amount of flexibility; irregular boundaries and spatial and temporal variations in the system can be considered. Numerical models require significantly more data than analytical models, and are typically more computationally intensive. Use of a numerical model requires an experienced modeler, and can involve a larger amount of computer time than simulations using an analytical or semi-analytical method.

To select an appropriate model, the complexity of the site hydrology and the availability of data should be considered. If data are insufficient, a highly sophisticated and complex model should not be used. In some situations, it is beneficial to use an analytical or semi-analytical model as a "screening level" model to define the range of possible values, and to use a numerical model when there are sufficient data.

A highly complex hydrogeologic system cannot be accurately represented with a simple analytical model. Heterogeneous or anisotropic aquifer properties, multiple aquifers, and complicated boundary conditions can be simulated using numerical models. In addition, sophisticated numerical models are available that can simulate processes such as fracture flow. Because each site is unique, the modeler should determine which conditions and processes are important at a specific site, and then select a suitable model.

Spatial Characteristics of the System

Although actual landfill units and hydrogeologic systems are three-dimensional, it is often desirable to reduce the number of dimensions simulated in a mathematical model to one or two. Two- and three-dimensional models are generally more complex and computationally expensive than one-dimensional models, and therefore require more data. In some instances, a one-dimensional model may adequately represent the system; the available data may not warrant the use of a multi-dimensional model. However, modeling a truly three-dimensional system using a two-dimensional model may produce results without adequate spatial detail. The choice of the number of dimensions in the model should be made for a specific site, based on the complexity of the site and the availability of data.

Steady-State Versus Transient Models

Models can simulate either steady-state or transient flow conditions. It may be appropriate to assume that some ground-water flow systems have reached approximate "steady-state" conditions, which implies that the system has reached equilibrium and no significant changes are occurring over time. The assumption of steady-state conditions generally simplifies the mathematical equations used to describe flow processes, and reduces the amount of input data required.

However, assuming steady-state conditions in a system that exhibits transient behavior may produce inaccurate results. For example, climatic variables, such as precipitation, vary over time and may have strong seasonal components. In such settings, the assumption of constant recharge of the ground-water system would be incorrect. Steady-state models also may not be appropriate for evaluating the transport of chemicals which sorb or transform significantly (Mulkey et al., 1989). The choice of simulating steady-state or transient conditions should be based on the degree of temporal variability in the system.

Boundary and Initial Conditions

The solution of differential equations describing flow and transport processes requires that initial and boundary conditions be specified. The initial conditions describe the conditions present in the system at the beginning of the simulation. In many ground-water flow and transport models, these conditions are related to the initial hydraulic conditions in the aquifer and the initial concentration of contaminants. Boundary conditions define the conditions present on the borders of the system, which may be steady-state or temporally variable. The initial and boundary conditions chosen to represent a site can significantly affect the results of the simulation.

One of the most significant boundary conditions in solute transport models is the introduction of a contaminant to the system. A source of ground-water contamination should be described in terms of its spatial, chemical, and physical characteristics, and its temporal behavior. Spatially, a source may be classified as a point source, line source, a distributed source of limited areal or three-dimensional extent, or as a non-point source of unlimited extent (van der Hjeide et al., 1988). Typically, temporal descriptions of the source term boundary conditions for models with analytical solutions are constant, constant pulse, and/or exponential decay (Mulkey et al., 1989). Numerical models typically handle a much wider range of source boundary conditions, allowing for a wide range of contaminant loading scenarios.

Homogeneous Versus Heterogeneous Aquifer/Soil Properties

The extent of the spatial variability of the properties of each aquifer will significantly affect the selection of a mathematical model. Many models assume uniform aquifer properties, which simplifies the governing equations and improves computational efficiency. For example, a constant value of hydraulic conductivity may be assumed at every point in the aquifer. However, this assumption may ignore the heterogeneity in the hydrogeologic system. Bond and Hwang (1988) present guidelines for determining whether the assumption of uniform aquifer properties is justified at a particular site. They state that the error associated with using an average value versus a spatial distribution is site-specific and extremely difficult to determine.

When site-specific data are limited, it is common to assume homogeneous and isotropic aquifer properties, and to develop a "reasonable worst-case" scenario for contaminant migration in the subsurface. However, as Auerbach (1984) points out, the assumption of homogeneous and isotropic aquifers often will not provide a "worst-case" scenario. For example, a continuous zone of higher hydraulic conductivity in the direction of ground-water flow can result in much higher rates of contaminant movement than would be predicted in a completely homogeneous aquifer. To develop a true "worst-case" model, information on the probable heterogeneity and anisotropy of the site should be collected.

The number of aquifers in the hydrogeologic system also will affect the selection of a mathematical model. Some systems include only a single unconfined or confined aquifer, which is hydraulically isolated from the surrounding layers. Some mathematical models, and in particular those with analytical solutions, can simulate only single layers. In other cases, the upper aquifer may be hydraulically connected to underlying aquifers. The MSWLF Criteria specify that MCLs not be exceeded at the relevant point of compliance within the uppermost aquifer. The uppermost aquifer includes not only the aquifer that is nearest the ground surface, but also all lower aquifers that are hydraulically connected to the uppermost aquifer within the vicinity of the facility.

Availability of Data

Although computer models can be used to make predictions about leachate generation and migration, these predictions are highly dependent on the quantity and quality of the available data. One of the most common limitations to modeling is insufficient data. Uncertainty in model predictions results from the inability to characterize a site in terms of the boundary conditions or the key parameters describing the significant flow and transport processes (National Research Council, 1990). The application of a mathematical model to a site typically requires a large amount of data. Inexperienced modelers may attempt to apply a model with insufficient data and, as a result, produce model results that are inconclusive.

To obtain accurate model results, it is essential to use data that are appropriate for the particular site being modeled. Models that include generic parameters, based on average values for similar sites, can be used to provide initial guidance and general information about the behavior of a system, but it is inappropriate to apply generic parameters to a specific hydrogeologic system. An excellent summary of the data required to model saturated and unsaturated flow, surface water flow, and solute transport is presented in Mercer et al. (1983). This report provides definitions and possible ranges of values for source terms, dependent variables, boundary conditions, and initial conditions.

Summary of Available Models

Several detailed reviews of ground-water models are available in the literature. A number of ground-water models, including saturated flow, solute transport, heat transport, fracture flow, and multiphase flow models, are summarized in van der Heijde et al. (1988). A report by van der Heijde and Beljin (1988) provides detailed descriptions of 64 ground-water flow and solute transport models that were selected for use in determining wellhead protection areas. A review of ground-water flow and transport models for the unsaturated zone is presented in Oster (1982). A large number of ground-water flow and transport models are summarized by Bond and Hwang (1988). Finally, Travers and Sharp-Hansen (1991) summarize models that may be applicable to problems of leachate generation and migration from MSWLF units. (See References supplied in Section 4.6.)

Table 4-1 (adapted from Travers and Sharp-Hansen (1991)) provides information on select leachate generation models. Tables 4-1a, b, and c list some of the available models that can be used to predict contaminant transport. The factors used to select these models include availability, documentation, uniqueness, and the size of the user community. These models are categorized by the techniques used to solve flow and transport equations. Table 4-1a lists analytical and semi-analytical models, and Tables 4-1b and 4-1c list numerical models that are solved by the finite-difference and the finite-element method, respectively.

The types of models that are available for application to the evaluation of MSWLF designs include leachate generation models and saturated and unsaturated zone flow and transport models. The level of sophistication of each of these types of models is based on the complexity of the processes being modeled. The majority of the models consider flow and transport based on advection dispersion equations. More complex models consider physical and chemical transformation processes, fracture flow, and multiphase fluid flow.

Leachate generation models predict the quantity and characteristics of leachate that is released from the bottom of a landfill. These models are used to estimate contaminant source terms and the releases of contaminants to the subsurface. Flow and transport models simulate the transport of contaminants released from the source to the unsaturated and saturated zones. Geochemical models are available that consider chemical processes that may be active in the subsurface such as adsorption, precipitation, oxidation/reduction, aqueous speciation, and kinetics.

Complex flow models have been developed to simulate the effects of nearby pumping and discharging wells, fracture flow, conduit flow in karst terrane, and multiphase flow for fluids that are less dense or more dense than water. However, the use of the more complex models requires additional data based on a thorough investigation of the subsurface characteristics at a site as well as well-trained users to apply the model correctly.

Most of the ground-water flow and solute transport models are deterministic. However, the use of stochastic models, which allow for characterization of spatial and temporal variability in systems, is increasing. A few of the models include a Monte Carlo capability for addressing the uncertainty inherent in the input parameters.

The EPA Multimedia Exposure Assessment Model (MULTIMED)

EPA has developed a modeling package to meet the needs of a large percentage of MSWLF unit owners and operators who will require fate and transport modeling as part of the performance-based design demonstration. This model, the Multimedia Exposure Assessment Model (MULTIMED), is intended for use at sites where certain simplifying assumptions can be made. MULTIMED can be used in

Table 4-1. Models for Application to Leachate Generation Problems (adapted from Travers and Sharp-Hansen, 1991)

Model Reference	Model Dimensions	Flow Conditions	Aquifer Conditions	Model Processes	Chemical Species	Additional Information
Bonazountas and Wagner (1984); SESOIL	1D/FD	Ss,Unsat	L,Hom,Iso	Ppt,Inf, RO,ET, Adv,Dif, Ads,Vol, Dec	single	Seasonal Soil Compartment Model. Simulates transport of water, sediment, and contaminants in soils. Includes affects of capillary rise, biological transformation, hydrolysis, cation exchange, complexation chemistry (metals by organic ligands). Hydrology based on generalized annual water balance dynamics model.
Carsel et al. (1984) PRZM	1D/FD	Usat,Ss,Tr	L,Hom,Iso	Adv,Dis, Dif,Dec, Rxn,ET, Vol,Inf	1,2, or 3	Pesticide Root Zone Model. Also includes plant uptake, leaching, runoff, management practices, and foliar washoff. Hydrologic flow solved by water routing scheme, chemical transport solved by finite difference scheme. Requires meteorological data. Water balance model.
EPRI (1981) UNSAT1D	1D/FD	Sat,Usat, Ss,Tr	Het,Hom,L Iso	Ppt,Inf, RO,ET	flow only	Solves one-dimensional Richard's equation. Accounts for capillary and gravitational effects. Requires landfill design data.
Knisel et al. (1989) GLEAMS	1D/FD	Usat,Tr,Ss	Hom,Iso,L	Inf,Dec,R O,ET,Ads	single	Groundwater Loading Effects of Agricultural Systems model. Developed by modifying CREAMS (Knisel, 1980) to add capability to estimate groundwater loadings. Simulates erosion. Water balance computations.
Schroeder et al. (1984) HELP	quasi-2D FD	Tr,Sat,Usat	L,Homo, Iso	ET,Ppt,In f,Dra,RO	flow only	A quasi-two-dimensional, deterministic water budget for landfills. Requires landfill design data. Model may be applied to open, partially open, and closed landfills. Requires meteorological data.

1D = One-dimensional	Sat = Saturated	Uc = Unconfined aquifer	In = Infiltration
2D = Two-dimensional	Usat = Unsaturated	Adv = Advection	ET = Evapotranspiration
3D = Three-dimensional	Hom = Homogeneous	Dis = Decay	Ppt = Precipitation
H = Horizontal	Het = Heterogeneous	Dif = Diffusion	RO = Runoff
V = Vertical	Iso = Isotropic	Dec = Decay	Rxn = Reaction
Ss = Steady-State	An = Anisotropic	Ads = Adsorption	W = Discharge or pumping wells
Tr = Transient	C = Confined Aquifer	Ret = Retardation	L = Layers

Table 4-1a. Analytical and Semi-Analytical Models for Application to Leachate Migration Problems (adapted from Travers and Sharp-Hansen, 1991)

Model Reference	Model Dimensions	Flow Conditions	Aquifer Conditions	Model Processes	Chemical Species	Additional Information
Beljin (1983) SOLUTE	ID(H), 2D(H) or 3D	Ss, Sat	C, Hom, Iso	Adv, Dis, Ads, Dec	single	A package of 8 analytical models for solute transport in groundwater. Also includes a program for unit conversion and error and function calculation.
Domenico and Palciauakes (1982) VHS	1D advection 2D dispersioh	Ss, Sat	C, Hom, Iso	Adv, Dis	single	Model for Vertical and Horizontal Spreading. Assumes infinite aquifer thickness. EPA considers VHS to be a conservative model since retardation, sorptions, precipitation, aquifer recharge not considered. Source is continuous constant strip source.
Domenico and Robbins (1985)	3D (transport)	Ss, Sat	C, Hom, Iso	Adv, Dis	single	Contaminant transport from a finite or continuous source in a continuous flow regimen. Assumes infinite thickness.
Huyakorn et al. (1987)	3D	Ss, Sat	C, Uc, Hom, Iso, An	Adv, Dis, Ads, Dec	single	Model allows for estimation of maximum concentration distribution along center line of a leachate plume. Gaussian vertical strip source.
Javandel et al. (1984) RESSQ	2D(H)	Ss, Sat	C, Hom, Iso	Adv, Ads	single	Calculate transport by advection and adsorption in a homogeneous, isotropic, uniform-thickness, confined aquifer. Uses semi-analytical solution methods.
Lindstrom and Boerams (1989) CXPHPH	1D(H)	Ss, Sat	C, Hom, Iso	Adv, Dis, Dec, Ads, Rxn	single	Analytical solutions of the general one-dimensional transport equation for confined aquifers, with several different initial and boundary conditions.
Nelson and Schur (1983) PATHS	2D(H)	Ss, Tr, Sat	C, Hom, Iso	Adv, Ads	single	Groundwater flow equations solved analytically, characteristic pathlines solved by Ruage-Kulls method.
Ostendorf et al. (1984)	1D(H,V)	Ss, Sat	Uc, Hom, Iso	Adv, Ads, Dec	single	Assumes transport of a simply reactive contaminant through a landfill and initially pure, underlying, shallow, aquifer with plane, sloping bottom.
Prakash (1984)	1D, 2D or 3D	Ss, Sat	C, Hom, Iso	Adv, Dis, Ads, Dec	single	Source boundary condition: instantaneous or finite-time release of contaminants from a point, line, plane, or parallel piped source.

Table 4-1a. Analytical and Semi-Analytical Models for Application to Leachate Migration Problems (adapted from Travers and Sharp-Hansen, 1991) (continued)

Model Reference	Model Dimensions	Flow Conditions	Aquifer Conditions	Model Processes	Chemical Species	Additional Information
Salhotre et al. (1990) MULTIMED	1D(vadose zone), 3D (transport in saturated zone)	Ss, Sat, Usat	Uc, Hom, Iso, L (Usat)	Adv, Dis, Ads, Dec, Vol	single	Model simulates movement of contaminants in saturated and unsaturated groundwater zones. In surface water and emissions to air. Includes Monte Carlo capability. Unsaturated zone transport solution is analytical, saturated zone is semi-analytical. Gaussian or patch source boundary condition.
Unge et al. (1986); Summers et al. (1989) MYGRT (Version 1.0, 2.0)	1,2(H,V)	Ss, Sat	Uc, Hom, Iso	Adv, Dis, Ret, Dec	single	Simulates migration of organic and inorganic solutes. Constant pulse source boundary condition. Proprietary code.
van Genuchten and Alves (1982)	1D(H,V)	Ss, Sat	C, Hom, Iso	Adv, Dis, Dif, Ads	single	Three types of source boundary conditions are considered: constant, exponential decay, and pulse step function.
Yeh (1981) AT123D	1D, 2D or 3D	Tr, Sat	C, Uc, Hom, Iso, An	Adv, Dis, Dif, Ads, Dec	single	Analytical, semi-analytical, solution techniques based on Green's function. Source boundary conditions include: constant, instantaneous pulse, or finite-time release from a point, line, area, or volume source

1D	=	One-dimensional	Sat	=	Saturated	Uc	=	Unconfined aquifer	Inf	=	Infiltration
2D	=	Two-dimensional	Usat	=	Unsaturated	Adv	=	Advection	ET	=	Evapotranspiration
3D	=	Three-dimensional	Hom	=	Homogeneous	Dis	=	Dispersion	Ppt	=	Precipitation
H	=	Horizontal	Het	=	Heterogeneous	Dif	=	Diffusion	RO	=	Run-off
V	=	Vertical	Iso	=	Isotropic	Dec	=	Decay	Rxn	=	Reaction
Ss	=	Steady-state	An	=	Anisotropic	Ads	=	Adsorption	W	=	Discharge or pumping wells
Tr	=	Transient	C	=	Confined aquifer	Ret	=	Retardation	L	=	Layers

Table 4-1b. Finite-Difference Models for Application to Leachate Migration Problems (adapted from Travers and Sharp-Hansen, 1991)

Model Reference	Model Dimensions	Flow Conditions	Aquifer Conditions	Model Processes	Chemical Species	Additional Information
Abriele and Pinder (1983)	1D	Ss, Tr, Sat, Usat	Uc, Iso, Hom	Dis, Dif	multiphase	Multiphase model for modeling aquifer contamination by organic compounds. Simulates simultaneous transport of contaminant in a nonaqueous phase, aqueous phase and as a mobile fraction of gas phase. Effects of capillarity, interphase mass transfer, diffusion, and dispersion considered.
Dillion et al. (1981; 1986) SWIFT/ SWIFT II	3D	Ss, Tr, Sat	C, Hom, Het, Iso, An	Adv, Dis, Dif, Dec, Rxn, W	single	Coupled groundwater flow, and heat or solute transport. Includes fracture flow, ion exchange, salt dissolution, in confined aquifer. SWIFT-II includes dual porosity for fractured media.
Erdogen and Heufeld (1983)	1D	Tr, Sat	Hom, Iso	Adv, Dis, Ads, Ppt	single	Model describes the desorption process using intraparticle and external file diffusion resistances as rate controlling mechanism (considers fluid velocity and particle size). Predicts leachate concentration profiles at the boundary of the landfill. Simulates precipitation with interrupted flow conditions.
GeoTrans (1985); Faust et al. (1989) SWAN-FLOW	3D	Ss, Tr, Sat, Usat	Uc, Hom, Het, Iso, An		multiphase	Faust (1989) extends SWANFLOW to include a solution technique which takes advantage of parallel computer processing.
Kipp (1987) NST3D	3D	Tr, Sat	C, Uc, Hom, Het, Iso, An	Adv, Dis, Dif, Ads, Dec, W	single	Simulates coupled density dependent groundwater flow and heat or mass transport in an anisotropic, heterogeneous aquifer.
Konikow and Bradshoeft (1985) USGS-NOC	2D (H,V)	Ss, Tr, Sat	C, Uc, Hom, Het, Iso, An	Adv, Dis, Dif, Ads, Dec, ET, W	single	Groundwater flow solved by finite difference, solute transport by the method of characteristics.

Table 4-1b. Finite-Difference Models for Application to Leachate Migration Problems (adapted from Travers and Sharp-Hansen, 1991) (continued)

Model Reference	Model Dimensions	Flow Conditions	Aquifer Conditions	Model Processes	Chemical Species	Additional Information
Harasimhan et al. (1986) DYNAMIX	3D	Ss, Tr, Sat	C, Uc, Hom, Het, Iso, An	Adv, Dis, Dif, Dec	multiple	Model couples a chemical specification model PHREEQE (Parkhurst et al, 1980) with a modified form of the transport code TRUMP (Edwards, 1969, 1972). Considers equilibrium reactions (see geochemical codes).
Prickett et al. (1981) RANDOM WALK or TRANS	1D or 2D(H)	Ss, Tr, Sat	C, Uc, Hom, Het, Iso, An, L	Adv, Dis, Ads, Dec, ET, W	single	Finite difference solution to groundwater flow, random walk approach used to simulate dispersion. Simulates random movement. Aquifer properties vary spatially and temporally.
Ruachel (1985) PORFLOW-II and III	2D(H,V) or 3D	Ss, Tr, Sat	C, Uc, Hom, Het, Iso, An, L	Adv, Dis, Dif, Ads, Dec, Rxn, W	single	Simulates density dependent flow, heat and mass transport. Aquifer and fluid properties may be spatially and temporally variable. Integrated finite difference solution. Includes phase change.
Travis (1984) TRACR3D	3D	Ss, Tr, Sat, Usat	C, Hom, Het, Iso, An	Adv, Dis, Dif, Ads, Dec	two-phase, multiple	Simulates transient two-phase flow and multi-component transport in deformable, heterogeneous, reactive, porous media.
Walton (1984) 35 Micro-computer Programs	1D, 2D(H) or 3D (radial, cyl)	Ss, Tr, Sat	C, Uc, Hom, Het, L	Adv, Dis, Ret	single	A series of analytical and simple numerical programs to analyze flow and transport of solutes in aquifers with simple geometry.

1D	=	One-dimensional	Sat	=	Saturated	Uc	=	Unconfined aquifer	Inf	=	Infiltration
2D	=	Two-dimensional	Usat	=	Unsaturated	Adv	=	Advection	ET	=	Evapotranspiration
3D	=	Three-dimensional	Hom	=	Homogeneous	Dis	=	Dispersion	Ppt	=	Precipitation
H	=	Horizontal	Het	=	Heterogeneous	Dif	=	Diffusion	RO	=	Run-off
V	=	Vertical	Iso	=	Isotropic	Dec	=	Decay	Rxn	=	Reaction
Ss	=	Steady-state	An	=	Anisotropic	Ads	=	Adsorption	W	=	Discharge or pumping wells
Tr	=	Transient	C	=	Confined aquifer	Ret	=	Retardation	L	=	Layers

Table 4-1c. Finite-Element Models for Application to Leachate Migration Problems (adapted from Travers and Sharp-Hansen, 1991)

Model Reference	Model Dimensions	Flow Conditions	Aquifer Conditions	Model Processes	Chemical Species	Additional Information
Cederberg et al. (1985) TRANQL	1 D, radial	Ss, Sat	C, Uc, Hom	Adv, Dis, Dif, Ads, Dec	multiple	Multicomponent transport model which links chemical equilibrium code MICROQL (Westfall, 1976) and transport code ISOQUAD (Pinder, unpublished manuscript, 1976). Includes a complexation in aqueous phase.
Dean et al. (1989) RUSTIC	1D(root zone, vadose zone); 2DH,V, radial (saturated zone)	Ss, Tr, Usat, Sat	C, Uc, Hom, Het, Iso, An, L	Adv, Dis, Ads, Dif, Dec, ET, W, Ppt, RO, Ret	1, 2, or 3	Simulates fate and transport of chemicals through three linked modules: root, values, and saturated zone. Includes PRZN (Carsel et al., 1984). RUSTIC is in Beta-testing phase. Includes Monte Carlo capability PRZN solution by finite difference.
Gupta et al. (1982) CFEST	2D(H,V) or 3D	Ss, Tr, Sat	C, Uc, Hom, Het, Iso, An, L	Adv, Dis, Dif, Ads, Dec, W	single	Solves coupled groundwater flow, solute and heat transport equations. Fluid may be heterogeneous.
Gureghian et al. (1980)	2D	Ss, Sat	C, Uc, Iso, An	Adv, Dis, Ads, Dec	single	Source boundary condition: Gaussian distributed source. Transport only.
Guvanssen (1986) NOTIF	1D, 2D, or 3D	Ss, Tr, Sat, Usat	C, Uc, Hom, Het, Iso, An	Adv, Dis, Dif, Ads, Dec	single	Groundwater flow and solute transport in fractured porous media.
Haji-Djafari and Wells (1982) GEOFLOW	3D	Ss, Tr, Sat	C, Uc, Hom, Het, Iso, An, L	Adv, Dis, Dif, Dec, Rxn, Ret, W	single	Simulation of areal configuration only. Proprietary code.
Huyakorn et al. (1984) SEFTRAN	1D or 2D(H,V)	Ss, Tr, Sat	C, Uc, Hom, Het, Iso, An, L	Adv, Dis, Dif, Ads, Dec, W	single	Proprietary code.
Huyakorn et al. (1986) TRAFRAP	2D(H,V)	Ss, Tr, Sat	C, Uc, Hom, Het, Iso, An	Adv, Dis, Dif, Ads, Dec, Rxn, W	single	Simulates groundwater flow and solute transport in fractured porous media. Includes precipitation.
Osborne and Sykes (1986) WSTIF	2D	Tr, Sat, Usat	Uc, Hom, Het, Iso, An, L		two-phase	Model simulates transport of immiscible organics in groundwater. Assumes no mass transport between phases.

Table 4-1c. Finite-Element Models for Application to Leachate Migration Problems (adapted from Travers and Sharp-Hansen, 1991) (continued)

Model Reference	Model Dimensions	Flow Conditions	Aquifer Conditions	Model Processes	Chemical Species	Additional Information
Theis et al. (1982) FIESTA	1D	Sat	Hom, Iso	Adv, Dis, Ads, Dec	multiple	Combinations of a component transport model, FEAP, and the chemical equilibrium speciation model NINEQL (Westfall et al. 1976). Simulates up to 6 chemical components, including all solution and sorbed phase complexes.
van Genuchten (1978) SUMATRA-I	1D(V)	Tr, Sat, Usat	C, Uc, Hom, Het, Iso, L	Adv, Dis, Ads, Dec, Ret	single	Simulates simultaneous flow of water and solutes in a one-dimensional, vertical soil profile.
Voss (1984) SUTRA	2D(H,V)	Ss, Tr, Sat, Usat	C, Uc, Hom, Het, Iso, An	Adv, Dis, Dif, Ads, Dec, Rxn, W	single	Fluid may be heterogeneous (density-dependent groundwater flow).
Yeh and Ward (1981) FEMWATER FEMWASTE	2D(H,V)	Ss, Tr, Sat, Usat	Uc, Hom, Het, Iso, An	Adv, Dis, Ads, Dec, Ppt, W	single	FEMWATER simulates groundwater flow. FEMWASTE simulates waste transport through saturated-unsaturated porous media. Simulates capillarity, infiltration, and recharge/discharge sources (e.g., lakes, reservoirs, and streams).
Yeh (1990) LEWASTE, 3DLEWASTE	2D/3D	Ss, Tr, Sat, Usat	Uc, C, Hom, Het, Iso, An	Adv, Dis, Ads, Dec, W	single	Transport codes based on the Lagrangian-Eulerian approach, can be applied to Peclet Numbers from 0 to infinity. LEWASTE is intended to simulate 2D local flow systems. 3DLEWASTE can simulate regional or local flow systems. The LEWASTE series replaces the FEMWASTE models.

1D = One-dimensional	Sat = Saturated	Uc = Unconfined aquifer	Inf = Infiltration
2D = Two-dimensional	Usat = Unsaturated	Adv = Advection	ET = Evapotranspiration
3D = Three-dimensional	Hom = Homogeneous	Dis = Dispersion	Ppt = Precipitation
H = Horizontal	Het = Heterogeneous	Dif = Diffusion	RO = Run-off
V = Vertical	Iso = Isotropic	Dec = Decay	Rxn = Reaction
Ss = Steady-state	An = Anisotropic	Ads = Adsorption	W = Discharge or pumping wells
Tr = Transient	C = Confined aquifer	Ret = Retardation	L = Layers

conjunction with a separate leachate source model, such as HELP (Schroeder et al., 1984). Output from HELP is then used in MULTIMED to demonstrate that either a landfill design or the specific hydrogeologic conditions present at a site will prevent contaminant concentrations in ground water from exceeding the concentrations listed in Table 1 of §258.40. (Refer to pp. 4-53 and 6-8 for further discussion of HELP.) A description of MULTIMED follows with guidance for determining if its use is appropriate for a given site.

[NOTE: Version 3.0 of the HELP model will be 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.]

Overview of the Model

The MULTIMED model consists of modules that estimate contaminant releases to air, soil, ground water, or surface water. General information about the model and its theory is provided in Salhotra *et al.* (1990). Additionally, information about the application of MULTIMED to MSWLF units (developed by Sharp-Hansen *et al.* [1990]) is summarized here. In MULTIMED, a steady-state, one-dimensional, semi-analytical module simulates flow in the unsaturated zone. The output from this module, which is water saturation as a function of depth, is used as input to the unsaturated zone transport module. The latter simulates transient, one-dimensional (vertical) transport in the unsaturated zone and includes the effects of dispersion, linear adsorption, and first-order decay. Output from the unsaturated zone modules is used as input to the semi-analytical saturated zone transport module. The latter considers three-dimensional flow because the effects of lateral or vertical dispersion may significantly affect the model results.

Therefore, reducing the dimensions to one in this module would produce inaccurate results. The saturated zone transport module also considers linear adsorption, first-order decay, and dilution as a result of ground-water recharge. In addition, MULTIMED has the capability to assess the impact of uncertainty in the model inputs on the model output (contaminant concentration at a specified point), using the Monte Carlo simulation technique.

The simplifying assumptions required to obtain the analytical solutions limit the complexity of the systems that can be evaluated with MULTIMED. The model does not account for site-specific spatial variability (e.g., aquifer heterogeneities), the shape of the land disposal facility, site-specific boundary conditions, or multiple aquifers and pumping wells. Nor can MULTIMED simulate processes, such as flow in fractures and chemical reactions between contaminants, that may have a significant effect on the concentration of contaminants at a site. In more complex systems, it may be beneficial to use MULTIMED as a "screening level" model to allow the user to obtain an understanding of the system. A more complex model could then be used if there are sufficient data.

Application of MULTIMED to MSWLF Units

Procedures have been developed for the application of MULTIMED to the design of MSWLF units. They are explained in Sharp-Hansen et al. (1990) and are briefly summarized here. The procedures are:

- Collect site-specific hydrogeologic data, including amount of leachate generated (see Section 4.3.3);
- Identify the contaminant(s) to be simulated and the point of compliance;
- Propose a landfill design and determine the corresponding infiltration rate; then
- Run MULTIMED and calculate the dilution attenuation factor (DAF) (i.e., the factor by which the concentration is expected to decrease between the landfill unit and the point of compliance); and
- Multiply the initial contaminant concentration by the DAF and compare the resulting concentration to the MCLs to determine if the design will meet the standard.

At this time, only contaminant transport in the unsaturated and/or saturated zones can be modeled, because the other options (i.e., surface water, air) have not yet been thoroughly tested. In addition, only steady-state transport simulations are allowed. No decay of the contaminant source term is permitted; the concentration of contaminants entering the aquifer system is assumed to be constant over time. The receptor (e.g., a drinking water well) is located directly downgradient of the facility and intercepts the contaminant plume; also, the contaminant concentration is calculated at the top of the aquifer.

The user should bear in mind that MULTIMED may not be an appropriate model for some sites. Some of the issues that should be considered before modeling efforts proceed are summarized in Table 4-2. A "no" answer to any of the questions in Table 4-2 may indicate that MULTIMED is not the most appropriate model to use. As stated above, MULTIMED utilizes analytical and semi-analytical solution techniques to solve the mathematical equations describing flow and transport. As a result, the representation of a system simulated by the model is simple, and little or no spatial or temporal variability is allowed for the parameters in the system. Thus, a highly complex hydrogeologic system cannot be accurately represented with MULTIMED.

The spatial characteristics assumed in MULTIMED should be considered when applying MULTIMED to a site. The assumption of vertical, one-dimensional unsaturated flow may be valid for facilities that receive uniform areal recharge. However, this assumption may not be valid for facilities where surface soils (covers or daily backfill) or surface slopes result in an increase of run-off in certain areas of the facility, and ponding of precipitation in others. In addition, the simulation of one-dimensional, horizontal flow in the saturated zone requires several simplifying assumptions. The saturated zone is treated as a single, horizontal aquifer with uniform properties (e.g., hydraulic conductivity). The effects of pumping or discharging wells on the ground-water flow system cannot be addressed with the MULTIMED model.

The MULTIMED model assumes steady-state flow in all applications. Some ground-water flow systems are in an approximate "steady-state," in which the amount of water entering the flow system equals the amount of water leaving the system. However, assuming steady-state conditions in a system that exhibits transient behavior may produce inaccurate results.

TABLE 4-2
ISSUES TO BE CONSIDERED
BEFORE APPLYING MULTIMED
(from Sharp-Hansen et al., 1990)

<u>Objectives of the Study</u>

- Is a "screening level" approach appropriate?
- Is modeling a "worst-case scenario" acceptable?

<u>Significant Processes Affecting Contaminant Transport</u>

- Does MULTIMED simulate all the significant processes occurring at the site?
- Is the contaminant soluble in water and of the same density as water?

<u>Accuracy and Availability of the Data</u>

- Have sufficient data been collected to obtain reliable results?
- What is the level of uncertainty associated with the data?
- Would a Monte Carlo simulation be useful? If so, are the cumulative probability distributions for the parameters with uncertain values known?

<u>Complexity of the Hydrogeologic System</u>

- Are the hydrogeologic properties of the system uniform?
- Is the flow in the aquifer uniform and steady?
- Is the site geometry regular?
- Does the source boundary condition require a transient or steady-state solution?

MULTIMED may be run in either a deterministic or a Monte Carlo mode. The Monte Carlo method provides a means of estimating the uncertainty in the results of a model, if the uncertainty of the input variables is known or can be estimated. However, it may be difficult to determine the cumulative probability distribution for a given parameter. Assuming a parameter probability distribution when the distribution is unknown does not help reduce uncertainty. Furthermore, to obtain a valid estimate of the uncertainty in the output, the model must be run numerous times (typically several hundred times), which can be time-consuming. These issues should be considered before utilizing the Monte Carlo technique.

4.3 COMPOSITE LINER AND LEACHATE COLLECTION SYSTEM 40 CFR §258.40

<u>4.3.1 Statement of Regulation</u>

(a) New MSWLF units and lateral expansions shall be constructed:

(1) *See Statement of Regulation in Section 4.2.1 of this guidance document for performance-based design requirements.*

(2) With a composite liner, as defined in paragraph (b) of this section and a leachate collection system that is designed and constructed to maintain less than a 30-cm depth of leachate over the liner,

(b) For purposes of this section, <u>composite liner</u> means a system consisting of two components; the upper component must consist of a minimum 30-mil flexible

membrane liner (FML), and the lower component must consist of at least a two-foot layer of compacted soil with a hydraulic conductivity of no more than 1 x 10^{-7} cm/sec. FML components consisting of high density polyethylene (HDPE) shall be at least 60-mil thick. The FML component must be installed in direct and uniform contact with the compacted soil component.

4.3.2 Applicability

New MSWLF units and expansions of existing MSWLF units in States without approved programs must be constructed with a composite liner and a leachate collection system (LCS) that is designed to maintain a depth of leachate less than 30 cm (12 in.) above the liner. A composite liner consists of a flexible membrane liner (FML) installed on top of, and in direct and uniform contact with, two feet of compacted soil. The FML must be at least 30-mil thick unless the FML is made of HDPE, which must be 60-mil thick. The compacted soil liner must be at least two feet thick and must have a hydraulic conductivity of no more than 1 x 10^{-7} cm/sec.

Owners and operators of MSWLF units located in approved States have the option of proposing a performance-based design provided that certain criteria can be met (see Section 4.2.2).

4.3.3 Technical Considerations

This section provides information on the components of composite liner systems including soils, geomembranes, and leachate collection systems.

Standard Composite Liner Systems

The composite liner system is an effective hydraulic barrier because it combines the complementary properties of two different materials into one system: 1) compacted soil with a low hydraulic conductivity; and 2) a FML (FMLs are also referred to as geomembranes). Geomembranes may contain defects including tears, improperly bonded seams, and pinholes. In the absence of an underlying low-permeability soil liner, flow through a defect in a geomembrane is essentially unrestrained. The presence of a low-permeability soil liner beneath a defect in the geomembrane reduces leakage by limiting the flow rate through the defect.

Flow through the soil component of the liner is controlled by the size of the defect in the geomembrane, the available air space between the two liners into which leachate can flow, the hydraulic conductivity of the soil component, and the hydraulic head. Fluid flow through soil liners is calculated by Darcy's Law, where discharge (Q) is proportional to the head loss through the soil (dh/dl) for a given cross-sectional flow area (A) and hydraulic conductivity (K) where:

$$Q = KA(dh/dl)$$

Leakage through a geomembrane without defects is controlled by Fick's first law, which describes the process of liquid diffusion through the membrane liner. The diffusion process is similar to flow governed by Darcy's law for soil liners except that diffusion is driven by concentration gradients and not by hydraulic head. Although diffusion rates in geomembranes are several orders of magnitude lower than comparable hydraulic flow rates in low-permeability soil liners, construction of a completely impermeable geomembrane is difficult. The factor that most strongly influences geomembrane performance is the presence of imperfections such as improperly bonded seams, punctures and pinholes. A detailed discussion of leakage through geomembranes and composite liners can be found in Giroud and Bonaparte (1989 (Part I and Part II)). A geomembrane installed with excellent control over defects may yield the equivalent of a one-centimeter-diameter hole per acre of liner installed (Giroud and Bonaparte, 1989 (Part I and Part II)). If the geomembrane were to be placed over sand, this size imperfection under one foot of constant hydraulic head could be expected to account for as much as 3,300 gal/acre/day (31,000 liters/hectare/ day) of leakage. Based upon measurements of actual leakage through liners at facilities that have been built under rigorous control, Bonaparte and Gross (1990) have estimated an actual leakage rate, under one foot of constant head, of 200 liters/hectare/day or about 21 gallons/acre/day for landfill units.

The uniformity of the contact between the geomembrane and the soil liner is extremely important in controlling the effective flow area of leachate through the soil liner. Porous material, such as drainage sand, filter fabric, or other geofabric, should not be placed between the geomembrane and the low permeability soil liner. Porous materials will create a layer of higher hydraulic conductivity, which will increase the amount of leakage below an imperfection in the geomembrane. Construction practices during the installation of the soil and the geomembrane affect the uniformity of the geomembrane/soil interface, and strongly influence the performance of the composite liner system.

Soil Liner

The following subsections discuss soil liner construction practices including thickness requirements, lift placement, bonding of lifts, test methods, prerequisite soil properties, quality control, and quality assurance activities.

Thickness

Two feet of soil is generally considered the minimum thickness needed to obtain adequate compaction to meet the hydraulic conductivity requirement. This thickness is considered necessary to minimize the number of cracks or imperfections through the entire liner thickness that could allow leachate migration. Both lateral and vertical imperfections may exist in a compacted soil. The two-foot minimum thickness is believed to be sufficient to inhibit hydraulic short-circuiting of the entire layer.

Lift Thickness

Soil liners should be constructed in a series of compacted lifts. Determination of appropriate lift thickness is dependent on the soil characteristics, compaction equipment, firmness of the foundation materials, and the anticipated compactive effort needed to achieve the required soil hydraulic conductivity. Soil liner lifts should be thin enough to allow adequate compactive effort to reach the lower portions of the lift. Thinner lifts also provide greater assurance that sufficient compaction can be achieved to provide good, homogeneous bonding between subsequent lifts. Adequate compaction of lift thickness between five and ten inches is possible if appropriate equipment is used (USEPA, 1988). Nine-inch loose lift thicknesses that will yield a 6-

inch soil layer also have been recommended prior to compaction (USEPA, 1990a).

Soil liners usually are designed to be of uniform thickness with smooth slopes over the entire facility. Thicker areas may be considered wherever recessed areas for leachate collection pipes or collection sumps are located. Extra thickness and compactive efforts near edges of the side slopes may enhance bonding between the side slopes and the bottom liner. In smaller facilities, a soil liner may be designed for installation over the entire area, but in larger or multi-cell facilities, liners may be designed in segments. If this is the case, the design should address how the old and new liner segments will be bonded together (U.S. EPA, 1988).

Bonding Between Lifts

It is not possible to construct soil liners without some microscopic and/or macroscopic zones of higher and lower hydraulic conductivity. Within individual lifts, these preferential pathways for fluid migration are truncated by the bonded zone between the lifts. If good bonding between the lifts is not achieved during construction, the vertical pathways may become connected by horizontal pathways at the lift interface, thereby diminishing the performance of the hydraulic barrier.

Two methods may be used to ensure proper bonding between lifts. Kneading or blending a thinner, new lift with the previously compacted lift may be achieved by using a footed roller with long feet that can fully penetrate a loose lift of soil. If the protruding rods or feet of a sheepsfoot roller are sufficient in length to penetrate the top lift and knead the previous lift, good bonding may be achieved. Another method includes scarifying (roughening), and possibly wetting, the top inch or so of the last lift placed with a disc harrow or other similar equipment before placing the next lift.

Placement of Soil Liners on Slopes

The method used to place the soil liner on side slopes depends on the angle and length of the slope. Gradual inclines from the toe of the slope enable continuous placement of the lifts up the slopes and provide better continuity between the bottom and sidewalls of the soil liner. When steep slopes are encountered, however, lifts may need to be placed and compacted horizontally due to the difficulties of operating heavy compaction equipment on steeper slopes.

When sidewalls are compacted horizontally, it is important to tie in the edges with the bottom of the soil liner to reduce the probability of seepage planes (USEPA, 1988). A significant amount of additional soil liner material will be required to construct the horizontal lifts since the width of the lifts has to be wide enough to accommodate the compaction equipment. After the soil liner is constructed on the side slopes using this method, it can be trimmed back to the required thickness. The trimmed surface of the soil liner should be sealed by a smooth-drum roller. The trimmed excess materials can be reused provided that they meet the specified moisture-density requirements.

Hydraulic Conductivity

Achieving the hydraulic conductivity standard depends on the degree of compaction, compaction method, type of clay, soil moisture content, and density of the soil during liner construction. Hydraulic conductivity is the key design parameter when evaluating the acceptability of the constructed soil liner. The hydraulic conductivity of a soil depends, in part, on the viscosity and density of the fluid flowing through it. While water and leachate can cause different test results, water is an acceptable fluid for testing the compacted soil liner and source materials. The effective porosity of the soil is a function of size, shape, and area of the conduits through which the liquid flows. The hydraulic conductivity of a partially saturated soil is 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 permeability. Hydraulic conductivity testing should be conducted on samples that are fully saturated to attempt to measure the highest possible hydraulic conductivity.

EPA has published Method 9100 in publication SW-846 (Test Methods for Evaluating Solid Waste) to measure the hydraulic conductivity of soil samples. Other methods appear in the U.S. Army Corps of Engineers Engineering Manual 1110-2-1906 (COE, 1970) and the newly published "Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter" (ASTM D-5084). To verify full saturation of the sample, this latter method may be performed with back pressure saturation and electronic pore pressure measurement.

Soil Properties

Soils typically possess a range of physical characteristics, including particle size, gradation, and plasticity, that affect their ability to achieve a hydraulic conductivity of 1×10^{-7} cm/sec. Testing methods used to characterize proposed liner soils should include grain size distribution (ASTM D-422), Atterberg limits (ASTM D-4318), and compaction curves depicting moisture and density relationships using the standard or modified Proctor (ASTM D-698 or ASTM D-1557), whichever is appropriate for the compaction equipment used and the degree of firmness of the foundation materials.

Liner soils usually have at least 30 percent fines (fine silt- and clay-sized particles). Some soils with less than 30 percent fines may be worked to obtain hydraulic conductivities below 1×10^{-7} cm/sec, but use of these soils requires greater control of construction practices and conditions.

The soil plasticity index (PI), which is determined from the Atterberg limits (defined by the liquid limit minus the plastic limit), should generally be greater than 10 percent. However, soils with very high PI, (greater than 30 percent), are cohesive and sticky and become difficult to work with in the field. When high PI soils are too dry during placement, they tend to form hard clumps (clods) that are difficult to break down during compaction. Preferential flow paths may be created around the clods allowing leachate to migrate at a relatively high rate.

Soil particles or rock fragments also can create preferential flow paths. For this reason, soil particles or rock fragments should be less than 3 inches in diameter so as not to affect the overall hydraulic performance of the soil liner (USEPA, 1989).

The maximum density of a soil will be achieved at the optimum water content, but this point generally does not correspond to the point at which minimum hydraulic conductivity is achieved. Wet soils, however, have low shear strength and high potential for desiccation cracking. Care should be taken not to compromise other engineering properties such as shear strengths of the soil liner by excessively wetting the soil liner. Depending on the specific soil characteristics, compaction equipment and compactive effort, the hydraulic conductivity criterion may be achieved at moisture values of 1 to 7 percent above the optimum moisture content.

Although the soil may possess the required properties for successful liner construction, the soil liner may not meet the hydraulic conductivity criterion if the construction practices used to install the liner are not appropriate and carefully controlled. Construction quality control and quality assurance will be discussed in a later section.

Amended Soils

If locally available soils do not possess properties to achieve the specified hydraulic conductivity, soil additives can be used. Soil additives, such as bentonite or other clay materials, can decrease the hydraulic conductivity of the native soil (USEPA, 1988b).

Bentonite may be obtained in a dry, powdered form that is relatively easy to blend with on-site soils. Bentonite is a clay mineral (sodium-montmorillonite) that expands when it comes into contact with water (hydration), by absorbing the water within the mineral matrix. This property allows relatively small amounts of bentonite (5 to 10 percent) to be added to a noncohesive soil (sand) to make it more cohesive (U.S. EPA, 1988b). Thorough mixing of additives to cohesive soils (clay) is difficult and may lead to inconsistent results with respect to complying with the hydraulic conductivity criterion.

The most common additive used to amend soils is sodium bentonite. The disadvantage of using sodium bentonite includes its vulnerability to degradation as a result of contact with chemicals and waste leachates (U.S. EPA, 1989).

Calcium bentonite, although more permeable than sodium bentonite, also is used as a soil amendment. Approximately twice as much calcium bentonite typically is needed to achieve a hydraulic conductivity comparable to that of sodium bentonite.

Soil/bentonite mixtures generally require central plant mixing by means of a pugmill, cement mixer, or other mixing equipment where water can be added during the process. Water, bentonite content, and particle size distribution must be controlled during mixing and placement. Spreading of the soil/bentonite mixture may be accomplished in the same manner as the spreading of natural soil liners, by using scrapers, graders, bulldozers, or a continuous asphalt paving machine (U.S. EPA, 1988).

Materials other than bentonite, including lime, cement, and other clay minerals such as atapulgite, may be used as soil additives (U.S. EPA, 1989). For more information concerning soil admixtures, the reader is referred to the technical resource document on the design and construction of clay liners (U.S. EPA, 1988).

Testing

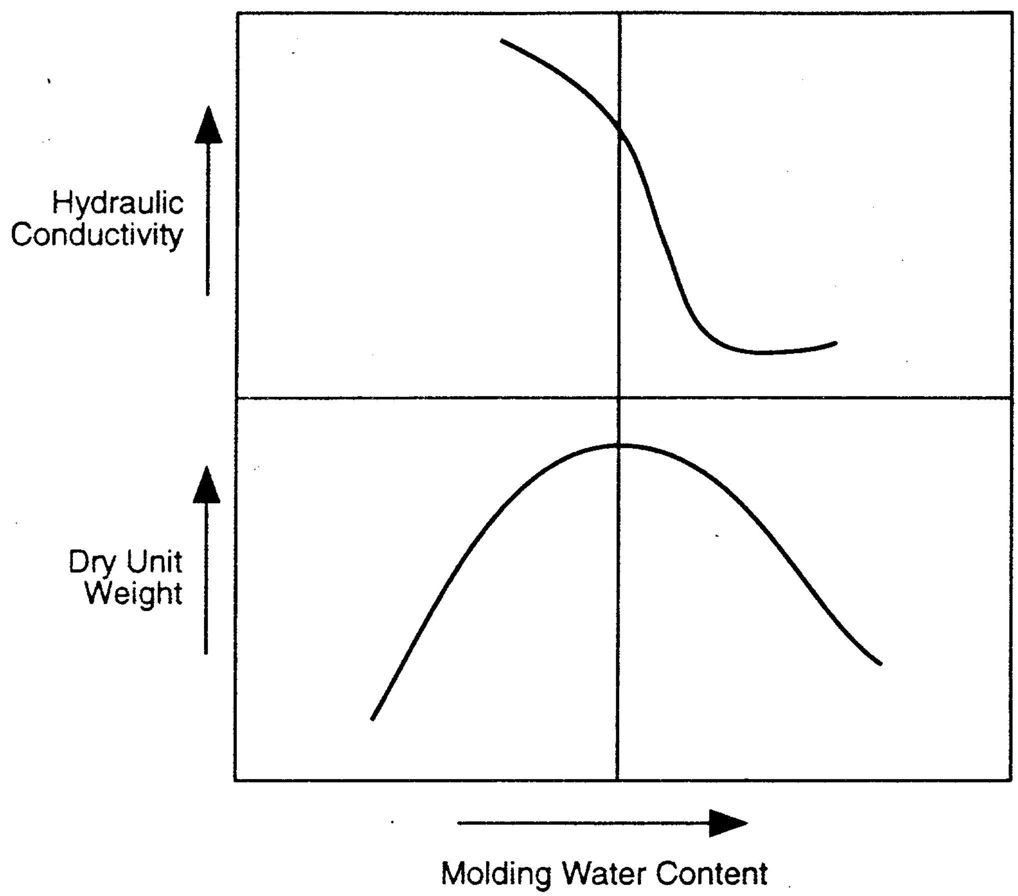
Prior to construction of a soil liner, the relationship between water content, density, and hydraulic conductivity for a particular soil should be established in the laboratory. Figure 4-5 shows the influence of molding water content (moisture content of the soil at the time of compaction) on hydraulic conductivity of the soil. The lower half of the diagram is a compaction curve and shows the relationship between dry unit weight, or dry density of the soil, and water content of the soil. The optimum moisture content of the soil is related to a peak value of dry density known as maximum dry density. Maximum dry density is achieved at the optimum moisture content.

The lowest hydraulic conductivity of compacted clay soil is achieved when the soil is compacted at a moisture content slightly higher than the optimum moisture content, generally in the range of 1 to 7 percent (U.S. EPA, 1989). When compacting clay, water content and compactive effort are the two factors that should be controlled to meet the maximum hydraulic conductivity criterion.

It is impractical to specify and construct a clay liner to a specific moisture content and a specific compaction (e.g., 5 percent wet of optimum and 95 percent modified Proctor density). Moisture content can be difficult to control in the field during construction; therefore, it may be more appropriate to specify a range of moisture contents and corresponding soil densities (percent compaction) that are considered appropriate to achieve the required hydraulic conductivity. Benson and Daniel (U.S. EPA, 1990) propose water content and density criteria for the construction of clay liners in which the moisture-density criteria ranges are established based on hydraulic conductivity test results. This type of approach is recommended because of the flexibility and guidance it provides to the construction contractor during soil placement. Figure 4-6 presents compaction data as a function of dry unit weight and molding water content for the construction of clay liners. The amount of soil testing required to determine these construction parameters is dependent on the degree of natural variability of the source material.

Quality assurance and quality control of soil liner materials involve both laboratory and field testing. Quality control tests are performed to ascertain compaction requirements and the moisture content of material delivered to the site. Field tests for quality assurance provide an opportunity to check representative areas of the liner for conformance to compaction specifications, including density and moisture content. Quality assurance laboratory testing is usually conducted on field samples for determination of hydraulic conductivity of the in-place liner. Laboratory testing allows full saturation of the soil samples and simulates the effects of large overburden stress on the soil, which cannot be done conveniently in the field (U.S. EPA, 1989).

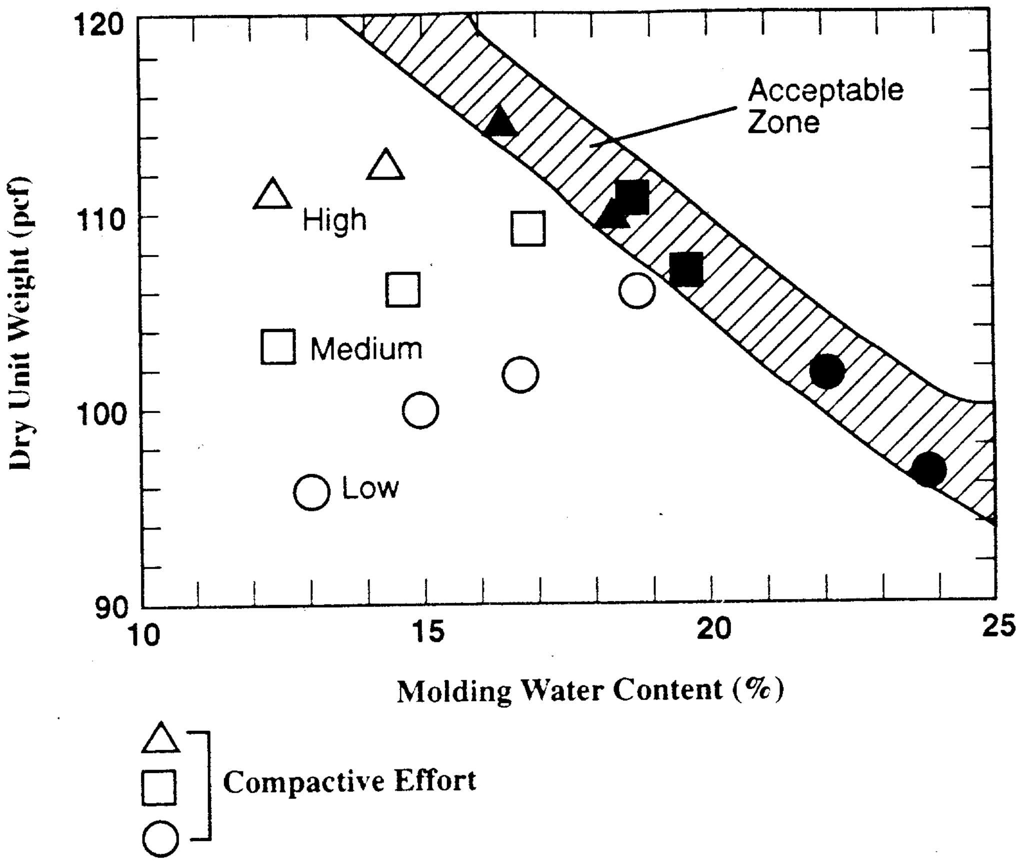
Differences between laboratory and field conditions (e.g., uniformity of material, control of water content, compactive effort, compaction equipment) may make it unlikely that minimum hydraulic conductivity values measured in the laboratory on remolded, pre-construction borrow source samples are the same as the values achieved during actual liner construction. Laboratory testing on remolded soil specimens does not account for operational problems that may result in desiccation, cracking, poor bonding of lifts, and inconsistent degree of compaction on sidewalls (U.S. EPA, 1988b). The relationship between field and laboratory hydraulic conductivity testing has been investigated by the U.S. Environmental



Source: U.S. EPA, 1989.

Note: The optimum moisture content occurs at the point at which maximum density is achieved. The lowest hydraulic conductivity generally occurs at water contents higher than optimum.

Figure 4-5
Hydraulic Conductivity and Dry Unit Weight as a Function of Molding Water Content



Compaction Data for a Silty Clay (from Mitchell et al., 1965). Solid symbols represent specimens with a hydraulic conductivity ≤ 1 x 10^{-7} cm/s and open symbols represent specimens with hydraulic conductivity > 1 x 10^{-7} cm/s.

Source: CERI 90-50 (USEPA, 1990)

Figure 4-6. Compaction Data for Silty Clay

Protection Agency using field case studies (U.S. EPA, 1990c).

In situ, or field, hydraulic conductivity testing operates on the assumption that by testing larger masses of soil in the field, one can obtain more realistic results. Four types of *in situ* hydraulic conductivity tests generally are used: borehole tests, porous probes, infiltrometer tests, and underdrain tests. A borehole test is conducted by drilling a hole, then filling the hole with water, and measuring the rate at which water percolates into the borehole. In the borehole test, water also can percolate through the sidewalls of the borehole. As a result, the measured hydraulic conductivity is usually higher than that measured by other one-dimensional field testings.

The second type of test involves driving or pushing a porous probe into the soil and pouring water through the probe into the soil. With this method, however, the advantage of testing directly in the field is somewhat offset by the limitations of testing such a small volume of soil.

A third method of testing involves a device called an infiltrometer. This device is embedded into the surface of the soil liner such that the rate of flow of a liquid into the liner can be measured. The two types of infiltrometers most widely used are open and sealed. Open rings are less desirable because, with a hydraulic conductivity of 10^{-7} cm/sec, it is difficult to detect a 0.002 inch per day drop in water level of the pond from evaporation and other losses.

With sealed rings, very low rates of flow can be measured. However, single-ring infiltrometers allow lateral flow beneath the ring, which can complicate the interpretation of test results. Single rings are also susceptible to the effects of temperature variation; as the water temperature increases, the entire system expands. As it cools down, the system contracts. This situation could lead to erroneous measurements when the rate of flow is small.

The sealed double-ring infiltrometer has proven to be the most successful method and is the one currently used. The outer ring forces infiltration from the inner ring to be more or less one-dimensional. Covering the inner ring with water insulates it substantially from temperature variation.

Underdrains, the fourth type of in situ test, are the most accurate in situ permeability testing device because they measure exactly what migrates from the bottom of the liner. However, under-drains are slow to generate data for low permeability liners, because of the length of time required to accumulate measurable flow. Also, underdrains must be installed during construction, so fewer underdrains are used than other kinds of testing devices.

Field hydraulic conductivity tests are not usually performed on the completed liner because the tests may take several weeks to complete (during which time the liner may be damaged by desiccation or freezing temperatures) and because large penetrations must be made into the liner. If field conductivity tests are performed, they are usually conducted on a test pad. The test pad should be constructed using the materials and methods to be used for the actual soil liner. The width of a test pad is usually the width of three to four construction vehicles, and the length is one to two times the width. Thickness is usually two to three feet. Test pads can be used as a means for verifying that the proposed materials and construction procedures will meet performance objectives. If a test pad is constructed, if tests verify that performance objectives have been met, and if the actual soil liner is constructed to standards that equal or exceed those used in building the test pad (as verified through quality assurance), then the actual soil liner should meet or exceed performance objectives.

Other than the four types of field hydraulic conductivity tests described earlier, ASTM D 2937 "Standard Test Method for Density of Soil in Place by the Drive-Cylinder Method" may be used to obtain in-place hydraulic conductivity of the soil liner. This test method uses a U.S. Army Corps of Engineers surface soil sampler to drive a thin-walled cylinder (typically 3-inch by 3-inch) into a completed lift of the soil liner to obtain relatively undisturbed samples for laboratory density and hydraulic conductivity testings. This test can provide useful correlation to other field and quality assurance testing results (e.g, Atterberg limits, gradation, in-place moisture and density of the soil liner) to evaluate the in-place hydraulic conductivity of the soil liner.

Soil Liner Construction

Standard compaction procedures are usually employed when constructing soil liners. The following factors influence the degree and quality of compaction:

- Lift thickness;
- Full scale or segmented lift placement;
- Number of equipment passes;
- Scarification between lifts;
- Soil water content; and
- The type of equipment and compactive effort.

The method used to compact the soil liner is an important factor in achieving the required minimum hydraulic conductivity. Higher degrees of compactive effort increase soil density and lower the soil hydraulic conductivity for a given water content. The results of laboratory compaction tests do not necessarily correlate directly with the amount of compaction that can be achieved during construction.

Heavy compaction equipment (greater than 25,000 lbs or 11,300 kg) is typically used when building the soil liner to maximize compactive effort (U.S. EPA, 1989). The preferred field compaction equipment is a sheepsfoot roller with long feet that fully penetrates loose lifts of soil and provides higher compaction while kneading the clay particles together. The shape and depth of the feet are important; narrow, rod-like feet with a minimum length of about seven inches provide the best results. A progressive change from the rod-like feet to a broader foot may be necessary in some soils after initial compaction, to allow the roller to walk out of the compacted soil. The sheepsfoot feet also aid in breaking up dry clods (see *Soil Properties* in this section). Mechanical road reclaimers, which are typically used to strip and re-pave asphalt, can be extremely effective in reducing soil clod size prior to compaction and in scarifying soil surfaces between lifts. Other equipment that has been used to compact soil includes discs and rototillers.

To achieve adequate compaction, the lift thickness (usually five to nine inches) may be decreased or the number of passes over the lift may be increased. Generally, compaction equipment should pass over the soil liner five to twenty times to attain the compaction needed to comply with the minimum hydraulic conductivity criterion (U.S. EPA, 1989).

Efforts made to reduce clod size during excavation and placement of the soil for the liner should improve the chances for achieving low hydraulic conductivity in several ways. Keeping clods in the soil liner material small will facilitate a more uniform water content. Macropores between clod remnants can result in unacceptably high field hydraulic conductivity.

Opinions differ on acceptable clod sizes in the uncompacted soil. Some suggest a maximum of one to three inches in diameter, or no larger than one-half the lift thickness. The main objective is to remold all clods in the compaction process to keep hydraulic conductivity values consistent throughout the soil liner (U.S. EPA, 1988).

Geomembranes

Geomembranes are relatively thin sheets of flexible thermoplastic or thermoset polymeric materials that are manufactured and prefabricated at a factory and transported to the site. Because of their inherent impermeability, use of geomembranes in landfill unit construction has increased. The design of the side slope, specifically the friction between natural soils and geosynthetics, is critical and requires careful review.

Material Types and Thicknesses

Geomembranes are made of one or more polymers along with a variety of other ingredients such as carbon black, pigments, fillers, plasticizers, processing aids, crosslinking chemicals, anti-degradants, and biocides. The polymers used to manufacture geomembranes include a wide range of plastics and rubbers differing in properties such as chemical resistance and basic composition (U.S. EPA, 1983 and U.S. EPA, 1988e). The polymeric materials may be categorized as follows:

- Thermoplastics such as polyvinyl chloride (PVC);
- Crystalline thermoplastics such as high density polyethylene (HDPE), very low density polyethylene (VLDPE), and linear low density polyethylene (LLDPE); and
- Thermoplastic elastomers such as chlorinated polyethylene (CPE) and chlorosulfonated polyethylene (CSPE).

The polymeric materials used most frequently as geomembranes are HDPE, PVC, CSPE, and CPE. The thicknesses of geomembranes range from 20 to 120 mil (1 mil = 0.001 inch) (U.S. EPA, 1983 and U.S. EPA, 1988e). The recommended minimum thickness for all geomembranes is 30 mil, with the exception of HDPE, which must be at least 60 mil to allow for proper seam welding. Some geomembranes can be manufactured by a calendering process with fabric reinforcement, called scrim, to provide additional tensile strength and dimensional stability.

Chemical and Physical Stress Resistance

The design of the landfill unit should consider stresses imposed on the liner by the design configuration. These stresses include the following:

- Differential settlement in foundation soils;

- Strain requirements at the anchor trench; and

- Strain requirements over long, steep side slopes.

An extensive body of literature has been developed by manufacturers and independent researchers on the physical properties of liners. Geosynthetic design equations are presented in several publications including Kastman (1984), Koerner (1990), and U.S. EPA (1988e).

The chemical resistance of a geomembrane to leachate has traditionally been considered a critical issue for Subtitle C (hazardous waste) facilities where highly concentrated solvents may be encountered. Chemical resistance testing of geomembranes may not be required for MSWLF units containing only municipal solid waste; EPA's data base has shown that leachate from MSWLF units is not aggressive to these types of materials. Testing for chemical resistance may be warranted considering the waste type, volumes, characteristics, and amounts of small quantity generator waste or other industrial waste present in the waste stream. The following guidance is provided in the event such testing is of interest to the owner or operator.

EPA's Method 9090 in SW-846 is the established test procedure used to evaluate degradation of geomembranes when exposed to hazardous waste leachate. In the procedure, the geomembrane is immersed in the site-specific chemical environment for at least 120 days at two different temperatures. Physical and mechanical properties of the tested material are then compared to those of the original material every thirty days. A software system entitled Flexible Liner Evaluation Expert (FLEX), designed to assist in the hazardous waste permitting process, may aid in interpreting EPA Method 9090 test data (U.S. EPA, 1989). A detailed discussion of both Method 9090 and FLEX is available from EPA.

It is imperative that a geomembrane liner maintain its integrity during exposure to short-term and long-term mechanical stresses. Short-term mechanical stresses include equipment traffic during the installation of a liner system, as well as thermal expansion and shrinkage of the geomembrane during the construction and operation of the MSWLF unit. Long-term mechanical stresses result from the placement of waste on top of the liner system and from subsequent differential settlement of the subgrade (U.S. EPA, 1988a).

Long-term success of the liner requires adequate friction between the components of a liner system, particularly the soil subgrade and the geomembrane, and between geosynthetic components, so 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 to evaluate:

- The ability of a geomembrane to support its own weight on the side slopes;

- The ability of a geomembrane to withstand down-dragging during and after waste placement;

- The best anchorage configuration for the geomembrane;

- The stability of a soil cover on top of a geomembrane; and
- The stability of other geosynthetic components such as geotextile or geonet on top of a geomembrane.

These requirements may affect the choice of geomembrane material, including polymer type, fabric reinforcement, thickness, and texture (e.g., smooth or textured for HDPE) (U.S. EPA, 1988). PVC also can be obtained in a roughened or file finish to increase the friction angle.

Design specifications should indicate the type of raw polymer and manufactured sheet to be used as well as the requirements for the delivery, storage, installation, and sampling of the geomembrane. Material properties can be obtained from the manufacturer-supplied average physical property values, which are published in the Geotechnical Fabrics Report's Specifier's Guide and updated annually. The minimum tensile properties of the geomembrane must be sufficient to satisfy the stresses anticipated during the service life of the geomembrane. Specific raw polymer and manufactured sheet specifications and test procedures include (U.S. EPA, 1988e, and Koerner, 1990):

Raw Polymer Specifications

- Density (ASTM D-1505);
- Melt index (ASTM D-1238);
- Carbon black (ASTM D-1603); and
- Thermogravimetric analysis (TGA) or differential scanning calorimetry (DSC).

Manufactured Sheet Specifications

- Thickness (ASTM D-1593);
- Tensile properties (ASTM D-638);
- Tear resistance (ASTM D-1004);
- Carbon black content (ASTM D-1603);
- Carbon black dispersion (ASTM D-3015);
- Dimensional stability (ASTM D-1204); and
- Stress crack resistance (ASTM D-1693).

Geomembranes may have different physical characteristics, depending on the type of polymer and the manufacturing process used, that can affect the design of a liner system. When reviewing manufacturers' literature, it is important to remember that each manufacturer may use more than one polymer or resin type for each grade of geomembrane and that the material specifications may be generalized to represent several grades of material.

Installation

Installation specifications should address installation procedures specific to the properties of the liner installed. The coefficient of thermal expansion of the geomembrane sheet can affect its installation and its service performance. The geomembrane should lie flat on the underlying soil. However, shrinkage and expansion of the sheeting, due to changes in temperature during installation, may result in excessive wrinkling or tension in the geomembrane. Wrinkles on the geomembrane surface will affect the uniformity of the soil-geomembrane interface and may result in leakage through imperfections. Excessive tautness of the geomembrane may affect its ability to resist rupture from localized stresses on the seams or at the toe of slopes where bridging over the subgrade may occur during installation. In addition to thermal expansion and contraction of the geomembrane, residual stresses from manufacturing remain in some geomembranes and can cause non-uniform expansion and contraction during construction. Some flexibility is needed in the specifications for geomembrane selection to allow for anticipated dimensional changes resulting from thermal expansion and contraction (U.S. EPA, 1988).

Technical specifications for geomembranes also should include: information for protection of the material during shipping, storage and handling; quality control certifications provided by the manufacturer or fabricator (if panels are constructed); and quality control testing by the contractor, installer, or a construction quality assurance (CQA) agent. Installation procedures addressed by the technical specifications include a geomembrane layout plan, deployment of the geomembrane at the construction site, seam preparation, seaming methods, seaming temperature constraints, detailed procedures for repairing and documenting construction defects, and sealing of the geomembrane to appurtenances, both adjoining and penetrating the liner. The performance of inspection activities, including both non-destructive and destructive quality control field testing of the sheets and seams during installation of the geomembrane, should be addressed in the technical specifications. Construction quality assurance is addressed in an EPA guidance document (USEPA, 1992).

The geomembrane sheeting is shipped in rolls or panels from the supplier, manufacturer, or fabricator to the construction site. Each roll or panel may be labeled according to its position on the geomembrane layout plan to facilitate installation. Upon delivery, the geomembrane sheeting should be inspected to check for damage that may have occurred during shipping. (U.S. EPA, 1992).

Proper storage of the rolls or panels prior to installation is essential to the final performance of the geomembrane. Some geomembrane materials are sensitive to ultraviolet exposure and should not be stored in direct sunlight prior to installation. Others, such as CSPE and CPE, are sensitive to moisture and heat and can partially crosslink or block (stick together) under improper storage conditions. Adhesives or welding materials, which are used to join geomembrane panels, also should be stored appropriately (U.S. EPA, 1992).

Visual inspection and acceptance of the soil liner subgrade should be conducted prior to installing the geomembrane. The surface of the subgrade should meet design specifications with regard to lack of protruding objects, grades, and thickness. Once these inspections are conducted and complete, the geomembrane may be installed on top of the soil liner. If necessary, other means should be employed to protect the subgrade from precipitation and erosion, and to prevent desiccation, moisture loss, and erosion from the soil liner prior to geomembrane placement. Such methods may include placing a plastic tarp on top of completed portions of the soil liner

(USEPA, 1992). In addition, scheduling soil liner construction slightly ahead of the geomembrane and drainage layer placement can reduce the exposure of the soil liner to the elements.

Deployment, or placement, of the geomembrane panels or rolls should be described in the geomembrane layout plan. Rolls of sheeting, such as HDPE, generally can be deployed by placing a shaft through the core of the roll, which is supported and deployed using a front-end loader or a winch. Panels composed of extremely flexible liner material such as PVC are usually folded on pallets, requiring workers to manually unfold and place the geomembrane. Placement of the geomembrane goes hand-in-hand with the seaming process; no more than the amount of sheeting that can be seamed during a shift or work day should be deployed at any one time (USEPA, 1988). Panels should be weighted with sand bags if wind uplift of the membrane or excessive movement from thermal expansion is a potential problem. Proper stormwater control measurements should be employed during construction to prevent erosion of the soil liner underneath the geomembrane and the washing away of the geomembrane.

Once deployment of a section of the geomembrane is complete and each section has been visually inspected for imperfections and tested to ensure that it is the specified thickness, seaming of the geomembrane may begin. Quality control/quality assurance monitoring of the seaming process should be implemented to detect inferior seams. Seaming can be conducted either in the factory or in the field. Factory seams are made in a controlled environment and are generally of high quality, but the entire seam length (100 percent) still should be tested non-destructively (U.S. EPA, 1988). Destructive testing should be done at regular intervals along the seam (see page 4-66).

Consistent quality in fabricating field seams is critical to liner performance, and conditions that may affect seaming should be monitored and controlled during installation. An inspection should be conducted in accordance with a construction quality assurance plan to document the integrity of field seams. Factors affecting the seaming process include (U.S. EPA, 1988):

- Ambient temperature at which the seams are made;
- Relative humidity;
- Control of panel lift-up by wind;
- The effect of clouds on the geomembrane temperature;
- Water content of the subsurface beneath the geomembrane;
- The supporting surface on which the seaming is bonded;
- The skill of the seaming crew;
- Quality and consistency of the chemical or welding material;
- Proper preparation of the liner surfaces to be joined;
- Moisture on the seam interface; and
- Cleanliness of the seam interface (e.g., the amount of airborne dust and debris present).

Depending on the type of geomembrane, several bonding systems are available for the construction of both factory and field seams. Bonding methods include solvents, heat seals, heat guns, dielectric seaming, extrusion welding, and hot wedge techniques. To ensure the integrity of the seams, a geomembrane should be seamed using the bonding system recommended by the manufacturer (U.S. EPA, 1988). EPA has developed a field seaming manual for all types of geomembranes (U.S. EPA, 1991a).

Thermal methods of seaming require cleanliness of the bonding surfaces, heat, pressure, and dwell time to produce high quality seams. The requirements for adhesive systems are the same as those for thermal systems, except that the adhesive takes the place of the heat. Sealing the geomembrane to appurtenances and penetrating structures should be performed in accordance with detailed drawings included in the design plans and approved specifications.

An anchor trench along the perimeter of the cell generally is used to secure the geomembrane during construction (to prevent sloughing or slipping down the interior side slopes). Run out calculations (Koerner, 1990) are available to determine the depth of burial at a trench necessary to hold a specified length of membrane, or combination of membrane and geofabric or geotextile. If forces larger than the tensile strength of the membrane are inadvertently developed, then the membrane could tear. For this reason, the geomembrane should be allowed to slip or give in the trench after construction to prevent such tearing. However, during construction, the geomembrane should be anchored according to the detailed drawings provided in the design plans and specifications (USEPA, 1988).

Geomembranes that are subject to damage from exposure to weather and work activities should be covered with a layer of soil as soon as possible after quality assurance activities associated with geomembrane testing are completed. Soil should be placed without driving construction vehicles directly on the geomembrane. Light ground pressure bulldozers may be used to push material out in front over the liner, but the operator must not attempt to push a large pile of soil forward in a continuous manner over the membrane. Such methods can cause localized wrinkles to develop and overturn in the direction of movement. Overturned wrinkles create sharp creases and localized stresses in the geomembrane that could lead to premature failure. Instead, the operator should continually place smaller amounts of soil or drainage material working outward over the toe of the previously placed material. Alternatively, large backhoes can be used to place soil over the geomembrane that can later be spread with a bulldozer or similar equipment. Although such methods may sound tedious and slow, in the long run they will be faster and more cost-effective than placing too much material too fast and having to remobilize the liner installer to repair damaged sections of the geomembrane. The QA activities conducted during construction also should include monitoring the contractor's activities on top of the liner to avoid damage to installed and accepted geomembranes.

Leachate Collection Systems

Leachate refers to liquid that has passed through or emerged from solid waste and contains dissolved, suspended, or immiscible materials removed from the solid waste. At MSWLF units, leachate is typically aqueous with limited, if any, immiscible fluids or dissolved solvents. The primary function of the leachate collection system is to collect and convey leachate out of the landfill unit and to control the depth of the leachate above the liner. The leachate collection system (LCS) should be designed to meet the regulatory performance standard of maintaining less than 30 cm (12 inches) depth of leachate, or "head," above the liner. The 30-cm head allowance is a design standard and the Agency recognizes that this design standard may be exceeded for relatively short periods of time during the active life of the unit. Flow of leachate through imperfections in the liner system increases with an increase in leachate head above the liner. Maintaining a low leachate level above the liner helps to improve the performance of the composite liner.

Leachate is generally collected from the landfill 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. LCS's should consist of the following components (U.S. EPA, 1988):

- A low-permeability base (in this case a composite liner);

- A high-permeability drainage layer, constructed of either natural granular materials (sand and gravel) or synthetic drainage material (e.g., geonet) placed directly on the FML, or on a protective bedding layer (e.g., geofabric) directly overlying the liner;

- Perforated leachate collection pipes within the high-permeability drainage layer to collect leachate and carry it rapidly to a sump or collection header pipe;

- A protective filter layer over the high permeability drainage material, if necessary, to prevent physical clogging of the material by fine-grained material; and

- Leachate collection sumps or header pipe system where leachate can be removed.

The design, construction, and operation of the LCS 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 systems materials is provided in the reference U.S. EPA (1989). The leachate head in the layer is a function of the liquid impingement rate, bottom slope, pipe spacing, and drainage layer hydraulic conductivity. The impingement rate is estimated using a complex liquid routing procedure. If the maximum leachate depth exceeds 30 cm for the system, except for short-term occurrences, the design should be modified to improve its efficiency by increasing grade, decreasing pipe spacing, or increasing the hydraulic conductivity (transmissivity) of the drainage layer (U.S. EPA, 1988).

Grading of Low-Permeability Base

The typical bottom liner slope is a minimum of two percent after allowances for settlement at all points in each system. A slope is necessary for effective gravity drainage through the entire operating and post-closure period. Settlement estimates of the foundation soils should set this two-percent grade as a post-settlement design objective (U.S. EPA, 1991b).

High-Permeability Drainage Layer

The high-permeability drainage layer is placed directly over the liner or its protective bedding layer at a slope of at least two percent (the same slope necessary for the composite liner). Often the selection of a drainage material is based on the on-site availability of natural granular materials. In some regions of the country, hauling costs may be very high for sand and gravel, or appropriate materials may be unavailable; therefore, the designer may elect to use geosynthetic drainage nets (geonets) or synthetic drainage materials as an alternative. Frequently, geonets are substituted for granular materials on steep sidewalls because maintaining sand on the slope during construction and operation of the landfill unit is more difficult (U.S. EPA, 1988).

Soil Drainage Layers

If the drainage layer of the leachate collection system is constructed of granular soil materials (e.g., sand and gravel), then it should be demonstrated that this granular drainage layer has sufficient bearing strength to support expected loads. This demonstration will be similar to that required for the foundations and soil liner (U.S. EPA, 1988).

If the landfill unit is designed on moderate-to-steep (15 percent) grades, the landfill design should include calculations demonstrating that the selected granular drainage materials will be stable on the most critical slopes (e.g., usually the steepest slope) in the design. The calculations and assumptions should be shown, especially the friction angle between the geomembrane and soil, and if possible, supported by laboratory and/or field testing (USEPA, 1988).

Generally, gravel soil with a group designation of GW or GP on the Unified Soils Classification Chart can be expected to have a hydraulic conductivity of greater than 0.01 cm/sec, while sands identified as SW or SP can be expected to have a coefficient of permeability greater than 0.001 cm/sec. The sand or gravel drains leachate that enters the drainage layer to prevent 30 cm (12 in) or more accumulation on top of the liner during the active life of the MSWLF unit LCS. The design of a LCS frequently uses a drainage material with a hydraulic conductivity of 1 x 10^{-2} cm/sec or higher. Drainage materials with hydraulic conductivities in this order of magnitude should be evaluated for biological and particulate clogging (USEPA, 1988). Alternatively, if a geonet is used, the design is based on the transmissivity of the geonet.

If a filter layer (soil or geosynthetic) is constructed on top of a drainage layer to protect it from clogging, and the LCS is designed and operated to avoid drastic changes in the oxidation reduction potential of the leachate (thereby avoiding formation of precipitates within the LCS), then there is no conceptual basis to anticipate that conductivity will decrease over time. Where conductivity is expected to decrease over time, the change in impingement rate also should be evaluated over the same time period because the reduced impingement rate and hydraulic conductivity may still comply with the 30 cm criterion.

Unless alternative provisions are made to control incident precipitation and resulting surface run-off, the impingement rate during the operating period of the MSWLF unit is usually at least an order of magnitude greater than the impingement rate after final closure. The critical design condition for meeting the 30 cm (12 in) criterion can therefore be expected during the operating life. The designer may evaluate the sensitivity of a design to meet the 30 cm (12 in) criterion as a result of changes in impingement rates, hydraulic conductivity, pipe spacing, and grades. Such sensitivity analysis may indicate which element of the design should be emphasized during construction quality monitoring or whether the design can be altered to comply with the 30 cm (12 in) criterion in a more cost-effective manner.

The soil material used for the drainage layer should be investigated at the borrow pit prior to use at the landfill. Typical borrow pit characterization testing would include laboratory hydraulic conductivity and grain size distribution. If grain size distribution information from the borrow pit characterization program can be correlated to the hydraulic conductivity data, then the grain size test, which can be conducted in a short time in the field, may be a useful construction quality control parameter. Compliance with this parameter would then be indicative that the hydraulic conductivity design criterion was achieved in the constructed drainage layer. This information could be incorporated into construction documents after the borrow pit has been characterized. If a correlation cannot be made between hydraulic conductivity and grain size distribution, then construction documents may rely on direct field or laboratory measurements to demonstrate that the hydraulic conductivity design criterion was met in the drainage layer.

Granular materials are generally placed using conventional earthmoving equipment, including trucks, scrapers, bulldozers, and front-end loaders. Vehicles should not be driven directly over the geosynthetic membrane when it is being covered. (U.S. EPA, 1988a).

Coarse granular drainage materials, unlike low-permeability soils, can be placed dry and do not need to be heavily compacted. Compacting granular soils tends to grind the soil particles together, which increases the fine material and reduces hydraulic conductivity. To minimize settlement following material placement, the granular material may be compacted with a vibratory roller. The final thickness of the drainage layer should be checked by optical survey measurements or by direct test pit measurements (U.S. EPA, 1988).

Geosynthetic Drainage Nets

Geosynthetic drainage nets (geonets) may be substituted for the granular layers of the LCRs on the bottom and sidewalls of the landfill cells. Geonets require less space than perforated pipe or gravel and also promote rapid transmission of liquids. They do, however, require geotextile filters above them and can experience problems with creep and intrusion. Long-term operating and performance experience of geonets is limited because the material and its application are relatively new (U.S. EPA, 1989).

If a geonet is used in place of a granular drainage layer, it must provide the same level of performance (maintaining less than 30 cm of leachate head above the liner). An explanation of the calculation used to compute the capacity of a geonet may be found in U.S. EPA (1987a). The transmissivity of a geonet can be reduced significantly by intrusion of the soil or a geotextile. A protective geotextile between the soil and geonet will help alleviate this concern. If laboratory transmissivity tests are performed, they should be done under conditions, loads, and configurations that closely replicate the actual field conditions. It is important that the transmissivity value used in the leachate collection system design calculations be selected based upon those loaded conditions (U.S. EPA, 1988). It is also important to ensure that appropriate factors of safety are used (Koerner, 1990).

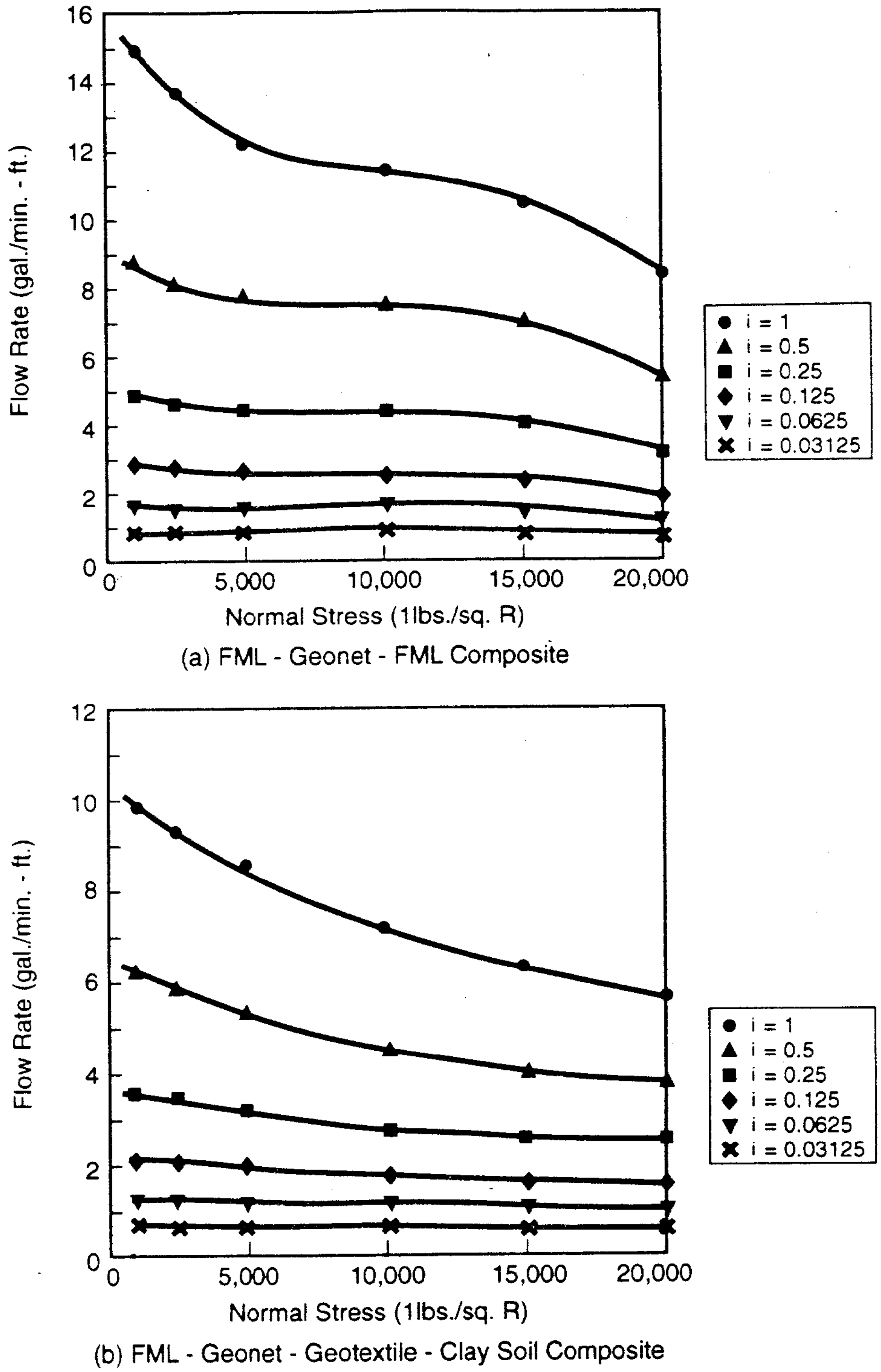
The flow rate or transmissivity of geonets may be evaluated by ASTM D-4716. This flow rate may then be compared to design-by-function equations presented in U.S. EPA (1989). In the ASTM D-4716 flow test, the proposed collector cross section should be modeled as closely as possible to actual field conditions (U.S. EPA, 1989).

Figure 4-7 shows the flow rate "signatures" of a geonet between two geomembranes (upper curves) and the same geonet between a layer of clay soil and a geomembrane (lower curves). The differences between the two sets of curves represent intrusion of the geotextile/clay into the apertures of the geonet. The curves are used to obtain a flow rate for the particular geonet being designed (U.S. EPA, 1989). Equations to determine the design flow rate or transmissivity are also presented in U.S. EPA (1989), Giroud (1982), Carroll (1987), Koerner (1990), and FHWA (1987).

Generally, geonets perform well and result in high factors of safety or performance design ratios, unless creep (elongation under constant stress) becomes a problem or adjacent materials intrude into apertures (U.S. EPA, 1989). For geonets, the most critical specification is the ability to transmit fluids under load. The specifications also should include a minimum transmissivity under expected landfill operating (dynamic) or completion (static) loads. The specifications for thickness and types of material should be identified on the drawings or in the materials section of the specifications, and should be consistent with the design calculations (U.S. EPA, 1988).

Geonets are often used on the sidewalls of landfills because of their ease of installation. They should be placed with the top ends in a secure anchor trench with the strongest longitudinal length extending down the slope. The geonets need not be seamed to each other on the slopes, only tied at the edges, butted, or overlapped. They should be placed in a loose condition, not stretched or placed in a configuration where they are bearing their own weight in tension. The construction specifications should contain appropriate installation requirements as described above or the requirements of the geonet manufacturer. All geonets need to be protected by a filter layer or geotextile to prevent clogging (U.S. EPA, 1988).

The friction factors against sliding for geotextiles, geonets, and geomembranes often can be estimated using manufacturers data because these materials do not exhibit the range of characteristics as seen in soil materials. However, it is important that the designer perform the actual tests using site materials and that the sliding stability calculations accurately represent the actual design configuration, site conditions, and the specified material characteristics (U.S. EPA, 1988).



Source: U.S. EPA. 1989.

Figure 4-7. Flow Rate Curves for Geonets in Two Composite Liner Configurations

Leachate Collection Pipes

All components of the leachate collection system must have sufficient strength to support the weight of the overlying waste, cover system, and post-closure loadings, as well as the stresses from operating equipment. The component that is most vulnerable to compressive strength failure is the drainage layer piping. Leachate collection system piping can fail by excessive deflection, which may lead to buckling or collapse (USEPA, 1988). Pipe strength calculations should include resistance to wall crushing, pipe deflection, and critical buckling pressure. Design equations and information for most pipe types can be obtained from the major pipe manufacturers. For more information regarding pipe structural strength, refer to U.S. EPA (1988).

Perforated drainage pipes can provide good long-term performance. These pipes have been shown to transmit fluids rapidly and to maintain good service lives. The depth of the drainage layer around the pipe should be deeper than the diameter of the pipe. The pipes can be placed in trenches to provide the extra depth. In addition, the trench serves as a sump (low point) for leachate collection. Pipes can be susceptible to particulate and biological clogging similar to the drainage layer material. Furthermore, pipes also can be susceptible to deflection. Proper maintenance and design of pipe systems can mitigate these effects and provide systems that function properly. Acceptable pipe deflections should be evaluated for the pipe material to be used (USEPA, 1989).

The design of perforated collection pipes should consider the following factors:

- The required flow using known percolation impingement rates and pipe spacing;
- Pipe size using required flow and maximum slope; and
- The structural strength of the pipe.

The pipe spacing may be determined by the Mound Model. In the Mound Model (see Figure 4-8), the maximum height of fluid between two parallel perforated drainage pipes is equal to (U.S. EPA, 1989):

$$h_{\max} = \frac{L\sqrt{c}}{2}\left[\frac{\tan^2\alpha}{c} + 1 - \frac{\tan\alpha}{c}\sqrt{\tan^2\alpha + c}\right]$$

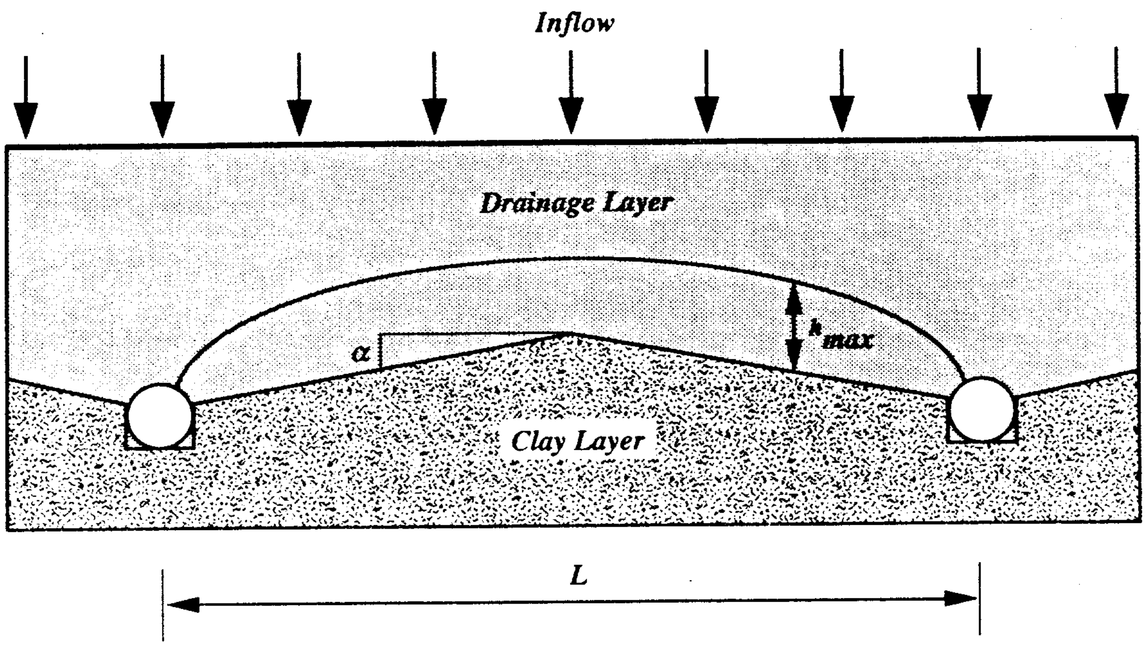
where c = q/k
k = permeability
q = inflow rate
α = slope.

The two unknowns in the equation are:

L = distance between the pipes; and
c = amount of leachate.

Using a maximum allowable head, h_{max}, of 30 cm (12 in), the equation is usually solved for "L" (U.S. EPA, 1989).

The amount of leachate, "c", can be estimated in a variety of ways including the Water Balance Method (U.S. EPA, 1989) and the computer model Hydrologic Evaluation of Landfill Performance (HELP). The HELP Model 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, run-off, infiltration, percolation, soil-moisture



Source: U.S. EPA, 1989

Figure 4-8. Definition of Terms for Mound Model Flow Rate Calculations

storage, evapotranspiration, and lateral drainage. The program estimates run-off drainage and leachate that are expected to result from a wide variety of landfill conditions, including open, partially open, and closed landfill cells. The model also may be used to estimate the depth of leachate above the bottom liner of the landfill unit. The results may be used to compare designs or to aid in the design of leachate collection systems (U.S. EPA, 1988).

Once the percolation and pipe spacing are known, the design flow rate can be obtained using the curve in Figure 4-9. The amount of leachate percolation at the particular site is located on the x-axis.

The required flow rate is the point at which this value intersects with the pipe spacing value determined from the Mound Model. Using this value of flow rate and the bottom slope of the site, the required diameter for the pipe can be determined (see Figure 4-10). Finally, the graphs in Figures 4-11 and 4-12 show two ways to determine whether the strength of the pipe is adequate for the landfill design. In Figure 4-11, the vertical soil pressure is located on the y-axis. The density of the backfill material around the pipe is not governed by strength, so it will deform under pressure rather than break. Ten percent is the absolute limiting deflection value for plastic pipe. Using Figure 4-11, the applied pressure on the pipe is located and traced to the trench geometry, and then the pipe deflection value is checked for its adequacy (U.S. EPA, 1989).

The LCS specifications should include (U.S. EPA, 1988):

- Type of piping material;
- Diameter and wall thickness;
- Size and distribution of slots and perforations;
- Type of coatings (if any) used in the pipe manufacturing; and
- Type of pipe bedding material and required compaction used to support the pipes.

The construction drawings and specifications should clearly indicate the type of bedding to be used under the pipes and the dimensions of any trenches. The specifications should indicate how the pipe lengths are joined. The drawings should show how the pipes are placed with respect to the perforations. To maintain the lowest possible leachate head, there should be perforations near the pipe invert, but not directly at the invert. The pipe invert itself should be solid to allow for efficient pipe flow at low volumes (U.S. EPA, 1988).

When drainage pipe systems are embedded in filter and drainage layers, no unplugged ends should be allowed. The filter materials in contact with the pipes should be appropriately sized to prevent migration of the material into the pipe. The filter media, drainage layer, and pipe network should be compatible and should represent an integrated design.

Protection of Leachate Collection Pipes

The long-term performance of the LCS depends on the design used to protect pipes from physical clogging (sedimentation) by the granular drainage materials. Use of a graded material around the pipes is most effective if accompanied by proper sizing of pipe perforations. The Army Corps of

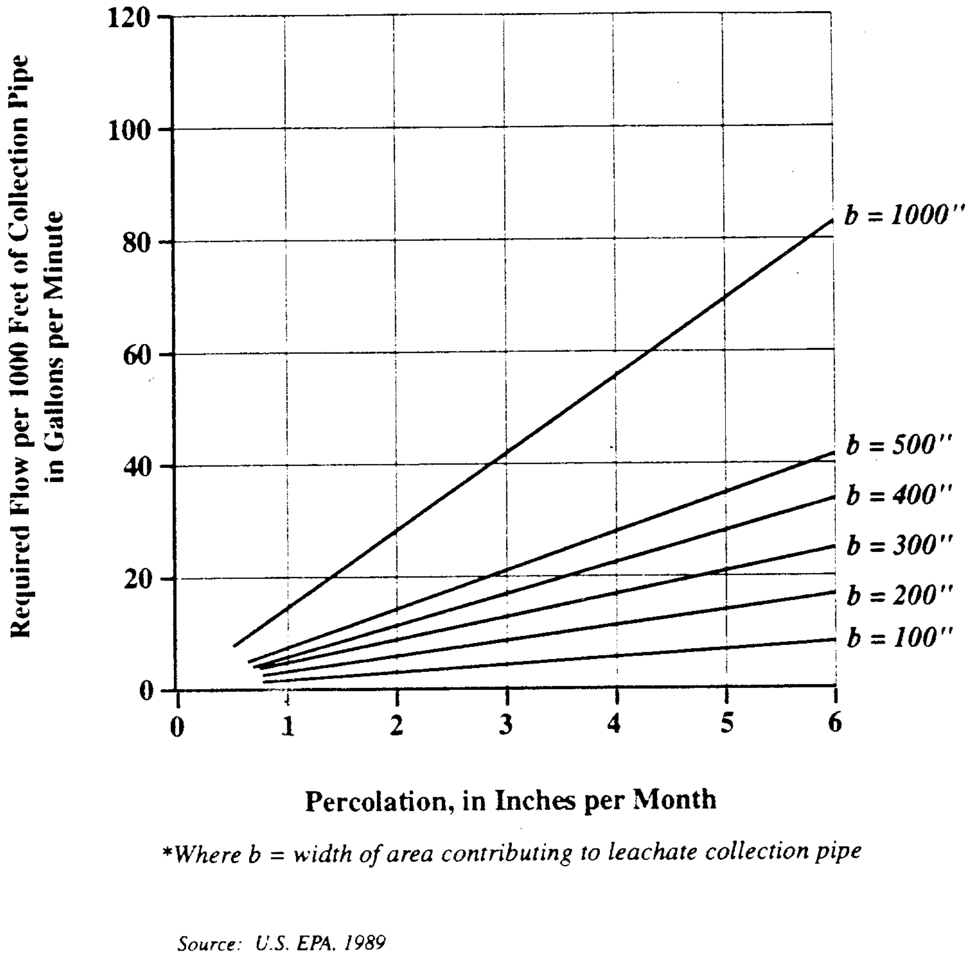


Figure 4-9. Required Capacity of Leachate Collection Pipe

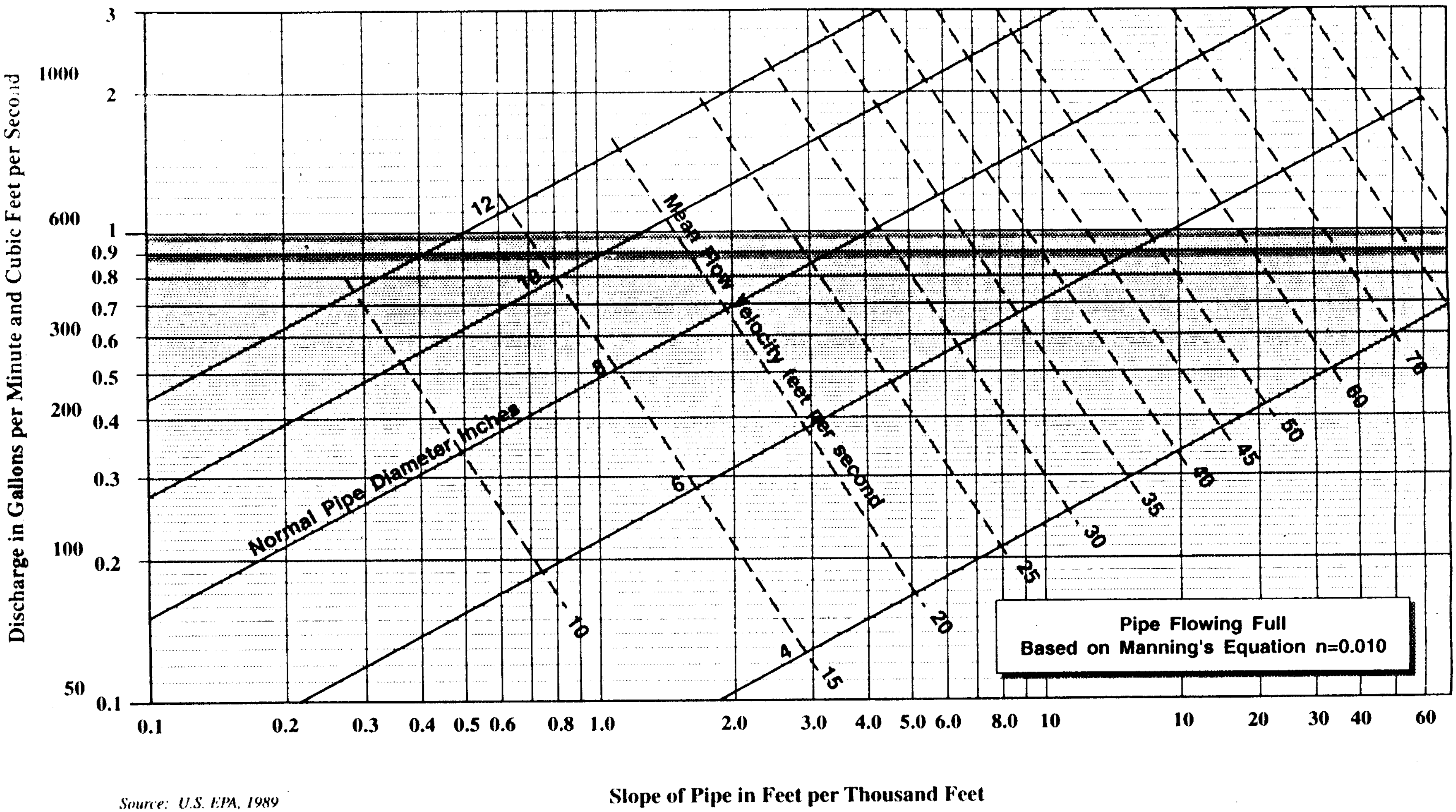
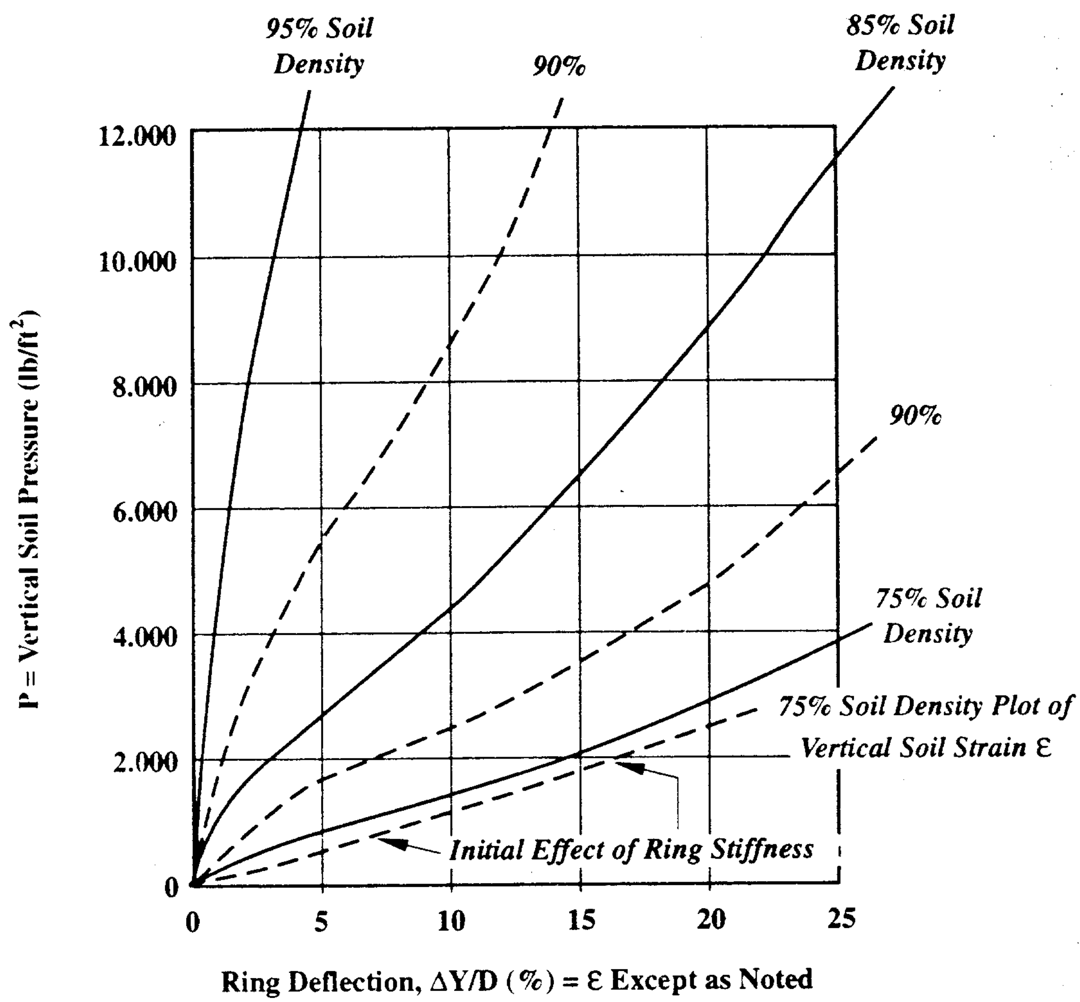
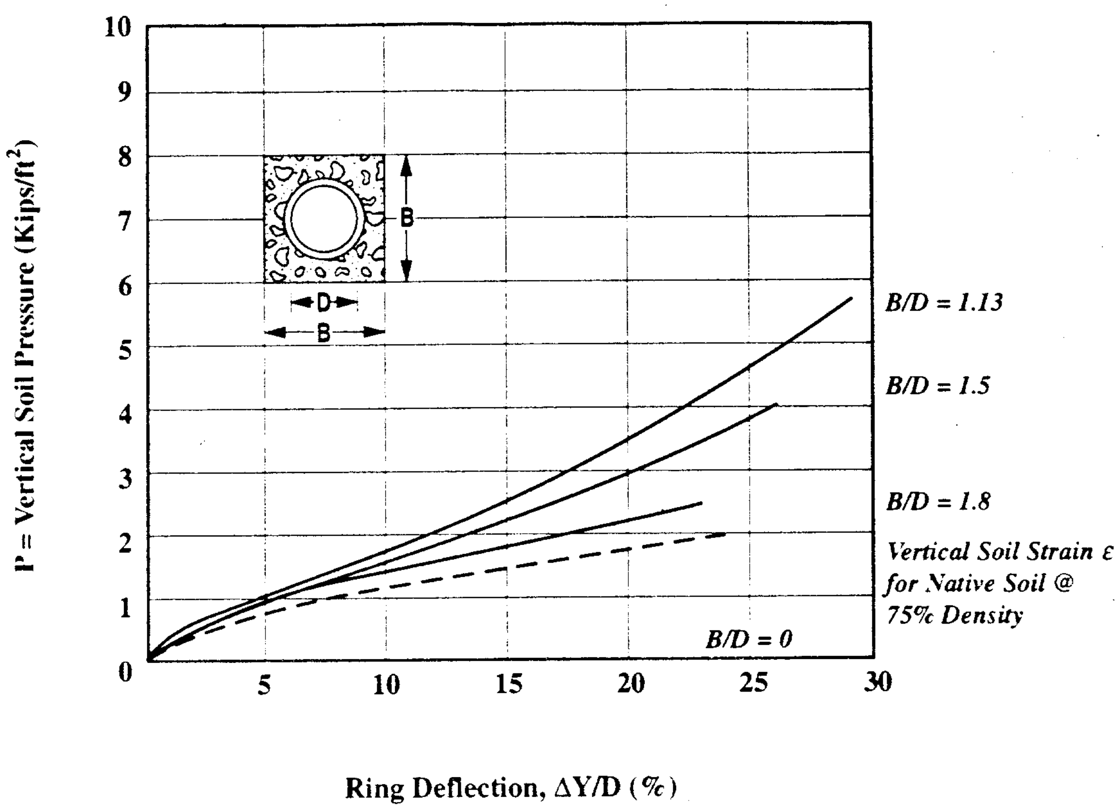


Figure 4-10. Leachate Collection Pipe Sizing Chart



Source: U.S. EPA. 1989

Figure 4-11. Vertical Ring Deflection Versus Vertical Soil Pressure for 18-inch Corrugated Polyethylene in High Pressure Soil Cell



Source: U.S. EPA, 1989

Figure 4-12. Example of the Effect of Trench Geometry and Pipe Sizing on Ring Deflection

Engineers (GCA Corporation, 1983) has established design criteria using graded filters to prevent physical clogging of leachate drainage layers and piping by soil sediment deposits. When installing graded filters, caution should be taken to prevent segregation of the material (USEPA, 1991a).

Clogging of the pipes and drainage layers of the leachate collection system can occur through several other mechanisms, including chemical and biological fouling (USEPA, 1988). The LCS should be designed with a cleanout access capable of reaching all parts of the collection system with standard pipe cleaning equipment.

Chemical clogging can occur when dissolved species in the leachate precipitate in the piping. Clogging can be minimized by periodically flushing pipes or by providing a sufficiently steep slope in the system to allow for high flow velocities for self-cleansing. These velocities are dependent on the diameter of the precipitate particles and on their specific gravity. ASCE (1969) discusses these relationships. Generally, flow velocities should be in the range of one or two feet per second to allow for self-cleansing of the piping (U.S. EPA, 1988).

Biological clogging due to algae and bacterial growth can be a serious problem in MSWLF units. There are no universally effective methods of preventing such biological growth. Since organic materials will be present in the landfill unit, there will be a potential for biological clogging. The system design should include features that allow for pipe system cleanings. The components of the cleaning system should include (U.S. EPA, 1991b):

- A minimum of six-inch diameter pipes to facilitate cleaning;
- Access located at major pipe intersections or bends to allow for inspections and cleaning; and
- Valves, ports, or other appurtenances to introduce biocides and/or cleaning solutions.

In its discussion of drainage layer protection, the following section includes further information concerning protection of pipes using filter layers.

Protection of the High-Permeability Drainage Layer

The openings in drainage materials, whether holes in pipes, voids in gravel, or apertures in geonets, must be protected against clogging by accumulation of fine (silt-sized) materials. An intermediate material that has smaller openings than those of the drainage material can be used as a filter between the waste and drainage layer. Sand may be used as filter material, but has the disadvantage of taking up vertical space (USEPA, 1989). Geotextiles do not use up air space and can be used as filter materials.

Soil Filter Layers

There are three parts to an analysis of a sand filter that is placed above drainage material. The first determines whether or not the filter allows adequate flow of liquids. The second evaluates whether the void spaces are small enough to prevent solids from being lost from the upstream materials. The third estimates the long-term clogging behavior of the filter (U.S. EPA, 1989).

The particle-size distribution of the drainage system and the particle-size distribution of the invading (or upstream) soils are required in the design of granular soil (sand filter) materials. The filter material should have its large and small size particles intermediate between the two extremes. Equations for adequate flow and retention are:

- Adequate Flow:
  $d_{85f} > (3 \text{ to } 5) d_{15d.s.}$

- Adequate Retention:
  $d_{15f} < (3 \text{ to } 5) d_{85w.f.}$

Where f = required filter soil;
d.s. = drainage stone; and
w.f. = water fines.

There are no quantitative methods to assess soil filter clogging, although empirical guidelines are found in geotechnical engineering references.

The specifications for granular filter layers that surround perforated pipes and that protect the drainage layer from clogging are based on a well-defined particle size distribution. The orientation and configuration of filter layers relative to other LCS components should be shown on all drawings and should be described, with ranges of particle sizes, in the materials section of the specifications (U.S. EPA, 1988a).

Thickness is an important placement criterion for granular filter material. Generally, the granular filter materials will be placed around perforated pipes by hand, forming an "envelope." The dimensions of the envelope should be clearly stated on the drawings or in the specifications. This envelope can be placed at the same time as the granular drainage layer, but it is important that the filter envelope protect all areas of the pipe where the clogging potential exists. The plans and specifications should indicate the extent of the envelope. The construction quality control program should document that the envelope was installed according to the plans and specifications (U.S. EPA, 1988).

A granular filter layer is generally placed using the same earthmoving equipment as the granular drainage layer. The final thickness should be checked by optical survey or by direct test pit measurement (U.S. EPA, 1988).

This filter layer is the uppermost layer in the leachate collection system. A landfill design option includes a buffer layer, 12 inches thick (30 cm) or more, to protect the filter layer and drainage layer from damage due to traffic. This final layer can be general fill, as long as it is no finer than the soil used in the filter layer (U.S. EPA, 1988). However, if the layer has a low permeability, it will affect leachate recirculation attempts.

Geotextile Filter Layers

Geotextile filter fabrics are often used. The open spaces in the fabric allow liquid flow while simultaneously preventing upstream fine particles from fouling the drain. Geotextiles save vertical space, are easy to install, and have the added advantage of remaining stationary under load. Geotextiles also can be used as cushioning materials above geomembranes (USEPA, 1989). Because geotextile filters are susceptible to biological clogging, their use in areas inundated by leachate (e.g., sumps, around leachate collection pipes, and trenches) should be avoided.

Geotextile filter design parallels sand filter design with some modifications (U.S. EPA, 1989). Adequate flow is assessed by comparing the material (allowable) permittivity to the design imposed permittivity. Permittivity is measured by the ASTM D-4491 test method. The design permittivity utilizes an adapted form of Darcy's law. The resulting comparison yields a design ratio, or factor of safety, that is the focus of the design (U.S. EPA, 1989):

$DR = ø_{allow}/ø_{reqd}$

where:

$ø_{allow}$ = permittivity from ASTM D-4491

$ø_{reqd} = (q/a)\ (1/h_{max})$

q/a = inflow rate per unit area

h_{max} = 12 inches

The second part of the geotextile filter design is determining the opening size necessary for retaining the upstream soil or particulates in the leachate. It is well established that the 95 percent opening size is related to particles to be retained in the following type of relationship:

O_{95} < fct. (d_{50}, CU, DR)

where:

O_{95} = 95% opening size of geotextile;

d_{50} = 50% size of upstream particles;

CU = Uniformity of the upstream particle size; and

DR = Relative density of the upstream particles.

The O_{95} size of a geotextile in the equation is the opening size at which 5 percent of a given value should be less than the particle size characteristics of the invading materials. In the test for the O_{95} size of the geotextile, a sieve with a very coarse mesh in the bottom is used as a support. The geotextile is placed on top of the mesh and is bonded to the inside so that the glass beads used in the test cannot escape around the edges of the geotextile filter. The particle-size distribution of retained glass beads is compared to the allowable value using any of a number of existing formulas (U.S. EPA, 1989).

The third consideration in geotextile design is long-term clogging. A test method for this problem that may be adopted by ASTM is called the Gradient Ratio Test. In this test, the hydraulic gradient of 1 inch of soil plus the underlying geotextile is compared with the hydraulic gradient of 2 inches of soil. The higher the gradient ratio, the more likely that a clog will occur. The final ASTM gradient ratio test will include failure criteria. An alternative to this test method is a long-term flow test that also is performed in a laboratory. The test models a soil-to-fabric system at the anticipated hydraulic gradient. The flow rate through the system is monitored. A long-term flow rate will gradually decrease until it stops altogether (U.S. EPA, 1989).

The primary function of a geotextile is to prevent the migration of fines into the leachate pipes while allowing the passage of leachate. The most important specifications are those for hydraulic conductivity and retention. The hydraulic conductivity of the geotextile generally should be at least ten times the soil it is retaining. An evaluation of the retention ability for loose soils is based on the average particle size of the soil and the apparent opening size (AOS) of the geotextile. The maximum apparent opening size, sometimes called equivalent opening size, is determined by the size of the soil that will be retained; a geotextile is then selected to meet that specification. The material specifications should contain a range of AOS values for the geotextile, and these AOS values should match those used in the design calculations (U.S. EPA, 1988).

One of the advantages of geotextiles is their light weight and ease of placement. The geotextiles are brought to the site, unrolled, and held down with sandbags until they are covered with a protective layer. They are usually overlapped, not seamed; however, on slopes or in other configurations, they may be sewn (U.S. EPA, 1988).

As with granular filter layers, it is important that the design drawings be clear in their designation of geotextile placement so that no potential route of pipe or drainage layer clogging is left unprotected. If geotextiles are used on a slope, they should be secured in an anchor trench similar to those for geomembranes or geonets (U.S. EPA, 1988).

Leachate Removal System

Sumps, located in a recess at the low point(s) within the leachate collection drainage layer, provide one method for leachate removal from the MSWLF unit. In the past, low volume sumps have been constructed successfully from reinforced concrete pipe on a concrete footing, and supported above the geomembrane on a steel plate to protect the geomembrane from puncture. Recently, however, prefabricated polyethylene structures have become available. These structures may be suitable for replacing the concrete components of the sump and have the advantage of being lighter in weight.

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. Low-volume sumps, however, can present operational problems. Because they may run dry frequently, there is an increased probability of the submersible pumps burning out. For this reason, some landfill operators prefer to have sumps placed at depths between 1.0 and 1.5 meters. While head levels of 30 cm or less are to be maintained on the liner, higher levels are acceptable in sumps. Alternatively, the sump may be designed with level controls and with a backup pump to control initiation and shut-off of the pumping sequence and to have the capability of alternating between the two pumps. The second pump also may be used in conjunction with the primary pump during periods of high flow (e.g., following storm events) and as a backup if the primary pump fails to function. A visible alarm warning light to indicate pump failure to the operator also may be installed.

Pumps used to remove leachate from the sumps should be sized to ensure removal of leachate at the maximum rate of generation. These pumps also should have a sufficient operating head 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, 1988).

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 landfill 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. The penetration should be designed and constructed in a manner that allows nondestructive quality control testing of 100 percent of the seal between the pipe and the geomembrane. If not properly constructed and fabricated, geomembrane penetrations can become a source of leakage through the geomembrane.

Other Design Considerations

The stability of the individual leachate collection system components placed on geomembrane-covered slopes should be considered. A method for calculating the factor of safety (FS) against sliding for soils placed on a sloped geomembrane surface is provided in Koerner (1990). This method considers the factors affecting the system, including the slope length, the slope angle, and the friction angle between the geomembrane and its cover soil. Generally, the slope angle is known and is specified on the design drawings. A minimum FS is then selected. 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 should be changed to produce an adequate design (U.S. EPA, 1988). For short slopes in a landfill unit, the FS can be as low as 1.1 to 1.2 if the slope will be unsupported (i.e., no waste will be filled against it) for only a short time, and if any failures that do occur can be repaired fairly easily. Longer slopes may require higher factors of safety due to the potential of sliding material to tear the geomembrane along the slope or near the toe of the slope.

Construction Quality Assurance and Quality Control

The following section is excerpted from U.S. EPA (1992). This section discusses quality assurance and quality control (QA/QC) objectives. For a more detailed discussion on QA/QC and specific considerations, refer to U.S. EPA (1992).

CQA/CQC Objectives

Construction quality assurance (CQA) consists of a planned series of observations and tests to ensure that the final product meets project specifications. CQA plans, specifications, observations, and tests are used to provide quantitative criteria with which to accept the final product.

On routine construction projects, CQA is normally the concern of the owner and is obtained using an independent third-party testing firm. The independence of the third-party inspection firm is important, particularly when the owner is a corporation or other legal entity that has under its corporate "umbrella" the capacity to perform the CQA activities. Although "in-house" CQA personnel may be registered professional engineers, a perception of misrepresentation may exist if CQA is not performed by an independent third party.

The CQA officer should fully disclose any activities or relationships with the owner that may impact his impartiality or objectivity. If such activities or relationships exist, the CQA officer should describe actions that have been or can be taken to avoid, mitigate, or neutralize the possibility they might affect the CQA officer's objectivity. Regulatory representatives can then evaluate whether these mechanisms are sufficient to ensure an acceptable CQA product.

Construction quality control (CQC) is an on-going process of measuring and controlling the characteristics of the product in order to meet manufacturer's or project specifications. CQC is a production tool that is employed by the manufacturer of materials and by the contractor installing the materials at the site. CQA, by contrast, is a verification tool employed by the facility owner or regulatory agency to ensure that the materials and installations meet project specifications. CQC is performed independently of the CQA Plan. For example, while a geomembrane liner installer will perform CQC testing of field seams, the CQA program will require independent CQA testing of those same seams by a third-party inspector.

The CQA/CQC plans are implemented through inspection activities that include visual observations, field testing and measurements, laboratory testing, and evaluation of the test data. Inspection activities typically are concerned with four separate functions:

- Quality Control (QC) Inspection by the Manufacturer provides an in-process measure of the product quality and its conformance with the project plans and specifications. Typically, the manufacturer will QC test results to certify that the product conforms to project plans and specifications.

- Construction Quality Control (CQC) Inspection by the Contractor provides an in-process measure of construction quality and conformance with the project plans and specifications, thereby allowing the contractor to correct the construction process if the quality of the product is not meeting the specifications and plans.

- Construction Quality Assurance (CQA) Testing by the Owner (Acceptance Inspection) performed by the owner usually through the third-party testing firm, provides a measure of the final product quality and its conformance with project plans and specifications. Due to the size and costs of a typical MSWLF unit construction project, rejection of the project at completion would be costly to all parties. Acceptance Inspections as portions of the project become complete allow deficiencies to be found and corrected before they become too large and costly.

- Regulatory Inspection often is performed by a regulatory agency to ensure that the final product conforms with all applicable codes and regulations. In some cases, the regulatory agency will use CQA documentation and the as-built plans or "record drawings" to confirm compliance with the regulations.

Soil Liner Quality Assurance/Quality Control

Quality control testing performed on materials used in construction of the landfill unit includes source testing and construction testing. Source testing defines material properties that govern material placement. Source testing commonly includes moisture content, soil density, Atterberg limits, grain size, and laboratory hydraulic conductivity. Construction testing ensures that landfill construction has been performed in accordance with the plans and technical specifications. Construction testing generally includes tests of soil moisture content, density, lift thickness, and hydraulic conductivity.

The method of determining compliance with the maximum hydraulic conductivity criterion should be specified in the QA/QC plan. Some methods have included the use of the criterion as a maximum value that never should be exceeded, while other methods have used statistical techniques to estimate the true mean. The sample collection program should be designed to work with the method of compliance determination. Selection of sample collection points should be made on a random basis.

Thin wall sampling tubes generally are used to collect compacted clay samples for laboratory hydraulic conductivity testing. It is important to minimize disturbance of the sample being collected. Tubes pushed into the soil by a backhoe may yield disturbed samples. A recommended procedure (when a backhoe is available during sample collection) is to use the backhoe bucket as a stationary support and push the tube into the clay with a jack positioned between the clay and the tube. The sample hole should be filled with bentonite or a bentonite clay mixture, and compacted using short lifts of material.

If geophysical methods are used for moisture and density measurements, it is recommended that alternative methods be used less frequently to verify the accuracy of the faster geophysical methods. Additional information on testing procedures can be found in U.S. EPA (1988b) and U.S. EPA (1990a).

Quality assurance testing for soil liners includes the same testing requirements as specified above for control testing. Generally, the tests are performed less frequently and are performed by an individual or an entity independent of the contractor. Activities of the construction quality assurance (CQA) officer are essential to document quality of construction. The CQA officer's responsibilities and those of the CQA officer's staff members may include:

- Communicating with the contractor;
- Interpreting and clarifying project drawings and specifications with the designer, owner, and contractor;
- Recommending acceptance or rejection by the owner/operator of work completed by the construction contractor;
- Submitting blind samples (e.g., duplicates and blanks) for analysis by the contractor's testing staff or one or more independent laboratories, as applicable;
- Notifying owner or operator of construction quality problems not resolved on-site in a timely manner;
- Observing the testing equipment, personnel, and procedures used by the construction contractor to check for detrimentally significant changes over time;
- Reviewing the construction contractor's quality control recording, maintenance, summary, and interpretations of test data for accuracy and appropriateness; and

- Reporting to the owner/operator on monitoring results.

Soil Liner Pilot Construction (Test Fill)

A pilot construction or test fill is a small-scale test pad that can be used to verify that the soil, equipment, and construction procedures can produce a liner that performs according to the construction drawings and specifications. An owner or operator may want to consider the option of constructing a test fill prior to the construction of the liner. A test pad is useful not only in teaching people how to build a soil liner, it also can function as a construction quality assurance tool. If the variables used to build a test pad that achieves a 1×10^{-7} cm/sec hydraulic conductivity are followed exactly, then the completed full-size liner should meet the regulatory requirements (U.S. EPA, 1989). A test fill may be a cost-effective method for the contractor to evaluate the construction methods and borrow source. Specific factors that can be examined/tested during construction of a test fill include (U.S. EPA, 1988b):

- Preparation and compaction of foundation material to the required bearing strength;

- Methods of controlling uniformity of the soil material;

- Compactive effort (e.g., type of equipment, number of passes) to achieve required soil density and hydraulic conductivity;

- Lift thickness and placement procedures to achieve uniformity of density throughout a lift and the absence of apparent boundary effects between lifts or between placements in the same lift;

- Procedures for protecting against desiccation cracking or other site- and season-specific failure mechanisms for the finished liner or intermediate lifts;

- Measuring the hydraulic conductivity on the test fill in the field and collecting samples of field-compacted soil for laboratory testing;

- Test procedures for controlling the quality of construction;

- Ability of different types of soil to meet hydraulic conductivity requirements in the field; and

- Skill and competence of the construction team, including equipment operators and quality control specialists.

Geomembrane Quality Assurance/ Quality Control Testing

As with the construction of soil liners, installation of geomembrane liners should be in conformance with a quality assurance/quality control plan. Tests performed to evaluate the integrity of geomembrane seams are generally considered to be either "destructive" or "non-destructive."

Destructive Testing

Quality control testing of geomembranes generally includes peel and shear testing of scrap test weld sections prior to commencing seaming activities and at periodic intervals throughout the day. Additionally, destructive peel and shear field tests are performed on samples from the installed seams.

Quality assurance testing generally requires that an independent laboratory perform peel and shear tests of samples from installed seams. The samples may be collected randomly or in areas of suspect quality. HDPE seams are generally tested at intervals equivalent to one sample per every 300 to 400 feet of installed seam for extrusion welds, and every 500 feet for fusion-welded seams. Extrusion seams on HDPE require grinding prior to welding, which can greatly diminish parent material strengths if excessive grinding occurs. Detailed discussion of polyethylene welding protocol can be found in U.S. EPA (1991a). For dual hot wedge seams in HDPE, both the inner and outer seam may be subjected to destructive shear tests at the independent laboratory. Destructive samples of installed seam welds are generally cut into several pieces and distributed to:

- The installer to perform construction quality control field testing;
- The owner/operator to retain and appropriately catalog or archive; and
- An independent laboratory for peel and shear testing.

If the test results for a seam sample do not pass the acceptance/rejection criteria, then samples are cut from the same field seam on both sides of the rejected sample location. Samples are collected and tested until the areal limits of the low quality seam are defined. Corrective measures should be undertaken to repair the length of seam that has not passed the acceptance/rejection criteria. In many cases, this involves seaming a cap over the length of the rejected seam or reseaming the affected area (U.S. EPA, 1988). In situations where the seams continually fail testing, the seaming crews may have to be retrained.

Non-Destructive Testing

Non-destructive test methods are conducted in the field on an in-place geomembrane. These test methods determine the integrity of the geomembrane field seams. Non-destructive test methods include the probe test, air lance, vacuum box, ultrasonic methods (pulse echo, shadow and impedance plane), electrical spark test, pressurized dual seam, electrical resistivity, and hydrostatic tests. Detailed discussion of these test methods may be found in U.S. EPA (1991a). Seam sections that fail appropriate, non-destructive tests must be carefully delineated, patched or reseamed, and retested. Large patches or reseamed areas should be subjected to destructive test procedures for quality assurance purposes. The specifications should clearly describe the degree to which non-destructive and destructive test methods will be used in evaluating failed portions of non-destructive seam tests.

Geomembrane Construction Quality Assurance Activities

The responsibilities of the construction quality assurance (CQA) personnel for the installation of the geomembrane are generally the same as the responsibilities for the construction of a soil liner with the following additions:

- Observation of liner storage area and liners in storage, and handling of the liner as the panels are positioned in the cell;

- Observation of seam overlap, seam preparation prior to seaming, and material underlying the liner;
- Observation of destructive testing conducted on scrap test welds prior to seaming;
- Observation of destructive seam sampling, submission of the samples to an independent testing laboratory, and review of results for conformance to specifications;
- Observation of all seams and panels for defects due to manufacturing and/or handling and placement;
- Observation of all pipe penetration boots and welds in the liner;
- Preparation of reports indicating sampling conducted and sampling results, locations of destructive samples, locations of patches, locations of seams constructed, and any problems encountered; and,
- Preparation of record drawings of the liner installation, in some cases.

The last responsibility is frequently assigned to the contractor, the owner's representative, or the engineer.

Leachate Collection System Construction Quality Assurance

The purpose of leachate collection system CQA is to document that the system construction is in accordance with the design specifications. Prior to construction, all materials should be inspected to confirm that they meet the construction plans and specifications. These include (U.S. EPA, 1988):

- Geonets;
- Geotextiles;
- Pipe size, materials, and perforations;
- Granular material gradation and prefabricated structures (sumps, manholes, etc.);
- Mechanical, electrical, and monitoring equipment; and
- Concrete forms and reinforcement.

The leachate collection system foundation (geomembrane or low permeability soil liner) should be inspected and surveyed upon its completion to ensure that it has proper grading and is free of debris and liquids (U.S. EPA, 1988).

During construction, the following activities, as appropriate, should be observed and documented (U.S. EPA, 1988):

- Pipe bedding placement including quality, thickness, and areal coverage;
- Granular filter layer placement including material quality and thickness;
- Pipe installation including location, configuration, grades, joints, filter layer placement, and final flushing;
- Granular drainage layer placement including protection of underlying liners, thickness, overlap with filter

fabrics and geonets if applicable, and weather conditions;

- Geonet placement including layout, overlap, and protection from clogging by granular material carried by wind or run-off during construction;

- Geotextile/geofabric placement including coverage and overlap;

- Sumps and structure installation; and

- Mechanical and electrical equipment installation including testing.

In addition to field observations, actual field and laboratory testing may be performed to document that the materials meet the design specifications. These activities should be documented and should include the following (U.S. EPA, 1988):

- Geonet and geotextile sampling and testing;

- Granular drainage and filter layer sampling and testing for grain size distribution; and

- Testing of pipes for leaks, obstructions, and alignments.

Upon completion of construction, each component should be inspected to identify any damage that may have occurred during its installation, or during construction of another component (e.g., pipe crushing during placement of granular drainage layer). Any damage that does occur should be repaired, and these corrective measures should be documented in the CQA records (U.S. EPA, 1988).

4.4 RELEVANT POINT OF COMPLIANCE 40 CFR §258.40(d)

4.4.1 Statement of Regulation

(a) *(See Statement of Regulation in Section 4.2.1 of this guidance document for the regulatory language for performance-based design requirements.)*

(b) *(See Statement of Regulation in Section 4.3.1 of this guidance document for the regulatory language for requirements pertaining to composite liner and leachate collection systems.)*

(c) *(See Statement of Regulation in Section 4.2.1 of this guidance document for the regulatory language for performance-based design requirements.)*

(d) The relevant point of compliance specified by the Director of an approved State shall be no more than 150 meters from the waste management unit boundary and shall be located on land owned by the owner of the MSWLF unit.

In determining the relevant point of compliance, the State Director shall consider at least the following factors:

(1) The hydrogeologic characteristics of the facility and surrounding land;

(2) The volume and physical and chemical characteristics of the leachate;

(3) The quantity, quality, and direction of flow of ground water;

(4) The proximity and withdrawal rate of the ground-water users;

(5) The availability of alternative drinking water supplies;

(6) The existing quality of the ground water, including other sources of contamination and their cumulative impacts on the ground water and whether the ground water is currently used or reasonably expected to be used for drinking water;

(7) Public health, safety, and welfare effects; and

(8) Practicable capability of the owner or operator.

4.4.2 Applicability

In States with approved permit programs, owners/operators may have the opportunity to employ an alternative liner design, as per §258.40(a)(1). In these situations, some flexibility is allowed in terms of establishing a relevant point of compliance. The relevant point of compliance may be located a maximum of 150 meters from the waste management unit boundary; however, the location must be on property owned by the MSWLF unit owner or operator.

In unapproved States the relevant point of compliance is set at the waste management unit boundary. The waste management unit boundary is defined as the vertical surface located at the hydraulically downgradient limit of the unit. This vertical surface extends down into and through the entire thickness of the uppermost aquifer.

4.4.3 Technical Considerations

At least eight factors should be considered in establishing the relevant point of compliance for any design under §258.40. The factors provide information needed to determine if the alternative boundary is sufficiently protective of human health and the environment and if the relevant point of compliance is adequate to measure the performance of the disposal unit.

Site Hydrogeology

The first factor to be considered when determining the relevant point of compliance is site hydrogeology. Site hydrogeologic characteristics should be used to identify additional information required to set the relevant point of compliance. The site data should be sufficient to determine the lateral well-spacing required to detect contaminant releases to the uppermost aquifer. Hydrogeologic information required to fully characterize a site is presented in greater detail in Section 5.6.3.

Leachate Volume and Physical Characteristics

Data on leachate volume and quality are needed to make a determination of the "detectability" of leakage from the facility at the relevant point of compliance. The net concentration at any given point resulting from the transport of contaminants from the landfill is a function of contaminant type, initial contaminant concentration, and leakage rate. Assessment of leachate volume is discussed in Sections 4.2 and 4.3. The assessment of contaminant fate and transport was discussed in Section 4.3.

Quality, Quantity and Direction of Ground-Water Flow

The hydrogeologic data collected should provide information to assess the ground-water flow rate, ground-water flow direction, and the volume of ground-water flow. Background ground-water quality data should be used to establish baseline concentrations of the monitoring constituents. This information will be required as input to determine if contaminants from the landfill unit have been released and have migrated to the relevant point of compliance.

Ground-Water Receptors

The goal of establishing the relevant point of compliance is to ensure early detection of contamination of the uppermost aquifer. The distance to the relevant point of compliance should allow sufficient time for corrective measures to be implemented prior to the migration of contaminants to private or public water supply wells.

Existing users of ground water immediately downgradient from the facility should be identified on a map. Users located at a downgradient point where contaminants might be expected to migrate during the active life and post-closure care period of the facility should be identified.

Alternative Drinking Water Supplies

Consideration should be given to the availability of alternate drinking water supplies in the event of a ground-water contamination problem. If the uppermost aquifer is the sole water supply source available, all reasonable efforts should be made to locate the relevant point of compliance as close as possible to the actual waste management unit boundary.

Existing Ground-Water Quality

The existing ground-water quality, both upgradient and downgradient of the MSWLF unit, should be determined prior to establishing the relevant point of compliance (see Section 5.6.3). The performance standard for landfill design requires that landfill units be designed so that the concentrations listed in Table 1 are not exceeded at a relevant point of compliance. Issues for approved States to consider are whether the ground water is currently used or is reasonably expected to be used as a drinking water source when setting a relevant point of compliance. If the ground water is not currently or reasonably expected to be used for drinking water, the State may allow the relevant point of compliance to be set near the 150-meter limit.

Public Health, Welfare, Safety

Consideration should be given to the potential overall effect on public health, welfare, and safety of the proposed relevant point of compliance. Issues that should be considered include:

- Distance to the nearest ground-water user or potentially affected surface water;
- The response time (based on the distance to the proposed relevant point of compliance) required to identify and remediate or otherwise contain ground water that may become impacted and potentially affect downgradient water supplies; and
- The risk that detection monitoring data may not be representative of a worst case release of contaminants to ground water.

Practicable Capability of the Owner or Operator

If the relevant point of compliance is placed farther from the waste management unit boundary, the volume of water requiring treatment, should the ground water become contaminated, will increase. One or more of the following conditions could affect the owner's or operator's practicable capability (technical and financial) to remediate contaminant releases:

- Area of impact, remedial costs, scope of remedial investigation, and site characterization;
- Increased response time due to higher costs and increased technical scope of selected remedial method;
- A reduction of the removal efficiency of treatment technologies; and
- Increased difficulty in ground-water extraction or containment if these technologies are chosen.

The Director may require some indication of financial capability of the owner or operator to maintain a longer and more costly remedial program due to the longer detection time frame associated with a relevant point of compliance located at a greater distance from the waste management unit boundary. Additional information on remedial actions for ground water is provided in this document in Chapter 5.

4.5 PETITION PROCESS 40 CFR §258.40(e)

4.5.1 Statement of Regulation

(a) - (d) *(See Statement of Regulation in Sections 4.2.1, 4.3.1, and 4.4.1 of this guidance document for regulatory language.)*

(e) If EPA does not promulgate a rule establishing the procedures and requirements for State compliance with RCRA Section 4005(c)(1)(B) by October 9, 1993, owners and operators in unapproved States may utilize a design meeting the performance standard in §258.40(a)(1) if the following conditions are met:

(1) The State determines the design meets the performance standard in §258.40(a)(1);

(2) The State petitions EPA to review its determination; and

(3) EPA approves the State determination or does not disapprove the determination within 30 days.

[Note to Subpart D: 40 CFR Part 239 is reserved to establish the procedures and requirements for State compliance with RCRA Section 4005(c)(1)(B).]

4.5.2 Applicability

If EPA does not promulgate procedures and requirements for state approval by October 9, 1993, owners and operators of MSWLF units located in unapproved States may be able to use an alternative design (in compliance with §258.40(a)(1)) under certain circumstances.

Owners or operators of MSWLF units should contact the municipal solid waste regulatory department in their State to determine if their State has been approved by the U.S. EPA.

4.6 FURTHER INFORMATION

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4.6.3 Models

List of Contacts for Obtaining Leachate Generation and Leachate Migration Models

Center for Exposure Assessment Modeling (CEAM), U.S. EPA, Office of Research and Development, Environmental Research Laboratory, Athens, Georgia 30605-2720, Model Distribution Coordinator (706) 546-3549, Electronic Bulletin Board System (706) 546-3402: MULTIMED, PRZM, FEMWATER/FEMWASTE, LEWASTE/3DLEWASTE

Electric Power Research Institute, Palo Alto, California, (214) 655-8883: MYGRT, FASTCHEM

Geo-Trans Inc., 46050 Manekin Plaza, Suite 100, Sterling, VA 20166, (703) 444-7000: SWANFLOW, SWIFT, SWIFT II, SWIFT III, SWIFT/386.

Geraghty & Miller, Inc., Modeling Group, 10700 Parkridge Boulevard, Suite 600 Reston, VA 22091: MODFLOW[386], MODPATH[386], MOC[386], SUTRA[386], Quickflow,

International Groundwater Modeling Center, Colorado School of Mines, Golden, Colorado (303) 273-3103: SOLUTE, Walton35, SEFTRAN, TRAFRAP,

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CHAPTER 5

SUBPART E
GROUND-WATER MONITORING
AND CORRECTIVE ACTION

CHAPTER 5
SUBPART E

TABLE OF CONTENTS

CHAPTER 5
SUBPART E
GROUND-WATER MONITORING AND CORRECTIVE ACTION

5.1 INTRODUCTION

The Criteria establish ground-water monitoring and corrective action requirements for all existing and new MSWLF units and lateral expansions of existing units except where the Director of an approved State suspends the requirements because there is no potential for migration of leachate constituents from the unit to the uppermost aquifer. The Criteria include requirements for the location, design, and installation of ground-water monitoring systems and set standards for ground-water sampling and analysis. They also provide specific statistical methods and decision criteria for identifying a significant change in ground-water quality. If a significant change in ground-water quality occurs, the Criteria require an assessment of the nature and extent of contamination followed by an evaluation and implementation of remedial measures.

Portions of this chapter are based on a draft technical document developed for EPA's hazardous waste program. This document, "RCRA Ground-Water Monitoring: Draft Technical Guidance" (EPA/530-R-93-001), is undergoing internal review, and may change. EPA chose to incorporate the information from the draft document into this chapter because the draft contained the most recent information available.

5.2 APPLICABILITY
40 CFR §258.50 (a) & (b)

5.2.1 Statement of Regulation

(a) The requirements in this Part apply to MSWLF units, except as provided in paragraph (b) of this section.

(b) Ground-water monitoring requirements under §258.51 through §258.55 of this Part may be suspended by the Director of an approved State for a MSWLF unit if the owner or operator can demonstrate that there is no potential for migration of hazardous constituents from that MSWLF unit to the uppermost aquifer (as defined in §258.2) during the active life of the unit and the post-closure care period. This demonstration must be certified by a qualified ground-water scientist and approved by the Director of an approved State, and must be based upon:

(1) Site-specific field collected measurements, sampling, and analysis of physical, chemical, and biological processes affecting contaminant fate and transport, and

(2) Contaminant fate and transport predictions that maximize contaminant migration and consider impacts on human health and environment.

5.2.2 Applicability

The ground-water monitoring requirements apply to all existing MSWLF units, lateral expansions of existing units, and new MSWLF units that receive waste after October 9, 1993. The requirements for ground-water monitoring may be suspended if the Director of an approved State finds that no potential exists for migration of hazardous constituents from the MSWLF unit to the uppermost aquifer during the active life of the unit, including closure or post-closure care periods.

The "no potential for migration" demonstration must be based upon site-specific information relevant to the fate and transport of any hazardous constituents that may be expected to be released from the unit. The predictions of fate and transport must identify the maximum anticipated concentrations of constituents migrating to the uppermost aquifer so that a protective assessment of the potential effects to human health and the environment can be made. A successful demonstration could exempt the MSWLF unit from requirements of §§258.51 through 258.55, which include installation of ground-water monitoring systems, and sampling and analysis for both detection and assessment monitoring constituents. *Preparing No-Migration Demonstrations for Municipal Solid Waste Disposal Facilities-Screening Tool* is a guidance document describing a process owners/ operators can use to prepare a no-migration demonstration (NMD) requesting suspension of the ground-water monitoring requirements.

5.2.3 Technical Considerations

All MSWLF units that receive waste after the effective date of Part 258 must comply with the ground-water monitoring requirements. The Director of an approved State may exempt an owner/operator from the ground-water monitoring requirements at §258.51 through §258.55 if the owner or operator demonstrates that there is no potential for hazardous constituent migration to the uppermost aquifer throughout the operating, closure, and post-closure care periods of the unit. Owners and operators of MSWLFs not located in approved States will not be eligible for this waiver and will be required to comply with all ground-water monitoring requirements. The "no-migration" demonstration must be certified by a qualified ground-water scientist and approved by the Director of an approved State. It must be based on site-specific field measurements and sampling and analyses to determine the physical, chemical, and biological processes affecting the fate and transport of hazardous constituents. The demonstration must be supported by site-specific data and predictions of the maximum contaminant migration. Site-specific information must include, at a minimum, the information necessary to evaluate or interpret the effects of the following properties or processes on contaminant fate and transport:

Physical Properties or Processes:

- Aquifer Characteristics, including hydraulic conductivity, hydraulic gradient, effective porosity, aquifer thickness, degree of saturation, stratigraphy, degree of fracturing and secondary porosity of soils and bedrock, aquifer heterogeneity, ground-water discharge, and ground-water recharge areas;

- Waste Characteristics, including quantity, type, and origin (e.g., commercial, industrial, or small quantity generators of unregulated hazardous wastes);

- Climatic Conditions, including annual precipitation, leachate generation estimates, and effects on leachate quality;

- Leachate Characteristics, including leachate composition, solubility, density, the presence of immiscible constituents, Eh, and pH; and

- Engineered Controls, including liners, cover systems, and aquifer controls (e.g., lowering the water table). These should be evaluated under design and failure conditions to estimate their long-term residual performance.

Chemical Properties or Processes:

- Attenuation of contaminants in the subsurface, including adsorption/ desorption reactions, ion exchange, organic content of soil, soil water pH, and consideration of possible reactions causing chemical transformation or chelation.

Biological Processes:

- Microbiological Degradation, which may attenuate target compounds or cause transformations of compounds, potentially forming more toxic chemical species.

The alternative design section of Chapter 5.0 discusses these and other processes that affect contaminant fate and solute transport.

When owners or operators prepare a no-migration demonstration, they must use predictions that are based on maximum contaminant migration both from the unit and through the subsurface media. Assumptions about variables affecting transport should be biased toward over-estimating transport and the anticipated concentrations. Assumptions and site specific data that are used in the fate and transport predictions should conform with transport principles and processes, including adherence to mass-balance and chemical equilibria limitations. Within these physicochemical limitations, assumptions should be biased toward the objective of assessing the maximum potential impact on human health and the environment. The evaluation of site-specific data and assumptions may include some of the following approaches:

- Use of the upper bound of known aquifer parameters and conditions that will maximize contaminant transport (e.g., hydraulic conductivity, effective porosity, horizontal and vertical gradients), rather than average values

- Use of the lower range of known aquifer conditions and parameters that tend to attenuate or retard contaminant transport (e.g., dispersivities, decay coefficients, cation exchange capacities, organic carbon contents, and recharge conditions), rather than average values

- Consideration of the cumulative impacts on water quality, including both existing water quality data and cumulative health risks posed by hazardous constituents likely to migrate from the MSWLF unit and other potential or known sources.

A discussion of mathematical approaches for evaluating contaminant or solute transport is provided in Chapter 5.

5.3 COMPLIANCE SCHEDULE 40 CFR § 258.50 (c)

5.3.1 Statement of Regulation*

***[NOTE: EPA finalized several revisions to 40 CFR Part 258 on October 1, 1993 (58 FR 51536), and these revisions delay the effective date for some categories of landfills. More detail on the content of the revisions is included in the introduction.]**

(c) Owners and operators of MSWLF units must comply with the ground-water monitoring requirements of this part according to the following schedule unless an alternative schedule is specified under paragraph (d):

(1) Existing MSWLF units and lateral expansions less than one mile from a drinking water intake (surface or subsurface) must be in compliance with the ground-water monitoring requirements specified in §§258.51 - 258.55 by October 9, 1994;

(2) Existing MSWLF units and lateral expansions greater than one mile but less than two miles from a drinking water intake (surface or subsurface) must be in compliance with the ground-water monitoring requirements specified in §§258.51 - 258.55 by October 9, 1995;

(3) Existing MSWLF units and lateral expansions greater than two miles from a drinking water intake (surface or subsurface) must be in compliance with the ground-water monitoring requirements specified in §§258.51 - 258.55 by October 9, 1996;

(4) New MSWLF units must be in compliance with the ground-water monitoring requirements specified in §§258.51 - 258.55 before waste can be placed in the unit.

5.3.2 Applicability

The rule establishes a self-implementing schedule for owners or operators in States with programs that are deemed inadequate or not yet approved. As indicated in the Statement of Regulation, this schedule depends on the distance of the MSWLF unit from drinking water sources. Approved States may specify an alternative schedule under §258.50 (d), which is discussed in Section 5.4.

Existing units and lateral expansions less than one mile from a drinking water intake must be in compliance with the ground-water monitoring requirements by October 9, 1994. If the units are greater than one mile but less than two miles from a drinking water intake, they must be in compliance by October 9, 1995. Those units located more than two miles from a drinking water intake must be in compliance by October 9, 1996 (see Table 5-1).

New MSWLF units, defined as units that have not received waste prior to October 9, 1993, must be in compliance with these requirements before receiving waste regardless of the proximity to a water supply intake.

5.3.3 Technical Considerations

For most facilities, these requirements will become applicable 3 to 5 years after the promulgation date of the rule. This period

Table 5-1. Compliance Schedule for Existing Units and Lateral Expansions in States with Unapproved Programs

Distance From Water Supply Intake	Time to Comply From October 9, 1991
One mile or less	3 Years
More than one mile but less than two miles	4 Years
More than two miles	5 Years

should provide sufficient time for the owner or operator to conduct site investigation and characterization studies to comply with the requirements of 40 CFR §258.51 through §258.55. For those facilities closest to drinking water intakes, the period provides 2 to 3 years to assess seasonal variability in ground-water quality. A drinking water intake includes water supplied to a user from either a surface water or ground-water source.

5.4 ALTERNATIVE COMPLIANCE SCHEDULES 40 CFR 258.50 (d)(e) & (g)

5.4.1 Statement of Regulation

(d) The Director of an approved State may specify an alternative schedule for the owners or operators of existing MSWLF units and lateral expansions to comply with the ground-water monitoring requirements specified in §§258.51 - 258.55. This schedule must ensure that 50 percent of all existing MSWLF units are in compliance by October 9, 1994 and all existing MSWLF units are in compliance by October 9, 1996. In setting the compliance schedule, the Director of an approved State must consider potential risks posed by the unit to human health and the environment. The following factors should be considered in determining potential risk:

(1) Proximity of human and environmental receptors;

(2) Design of the MSWLF unit;

(3) Age of the MSWLF unit;

(4) The size of the MSWLF unit;

(5) Types and quantities of wastes disposed, including sewage sludge; and

(6) Resource value of the underlying aquifer, including:

(i) Current and future uses;

(ii) Proximity and withdrawal rate of users; and

(iii) Ground-water quality and quantity.

(e) Once established at a MSWLF unit, ground-water monitoring shall be conducted throughout the active life and post-closure care period of that MSWLF unit as specified in §258.61.

(f) ***(See Section 5.5 for technical guidance on qualifications of a ground-water scientist.)***

(g) The Director of an approved State may establish alternative schedules for demonstrating compliance with §258.51(d)(2), pertaining to notification of placement of certification in operating record; § 258.54(c)(1), pertaining to notification that statistically significant increase (SSI) notice is in operating record; § 258.54(c)(2) and (3), pertaining to an assessment monitoring program; § 258.55(b), pertaining to sampling and analyzing Appendix II constituents; §258.55(d)(1), pertaining to placement of notice (Appendix II constituents detected) in record and notification of notice in record; § 258.55(d)(2), pertaining to sampling for Appendix I and II; § 258.55(g), pertaining to notification (and placement of notice in record) of SSI above ground-water protection standard; § 258.55(g)(1)(iv) and § 258.56(a), pertaining to assessment of corrective measures; § 258.57(a), pertaining to selection of remedy and notification of placement in record; § 258.58(c)(4), pertaining to notification of placement in record (alternative corrective action measures); and § 258.58(f), pertaining to notification of placement in record (certification of remedy completed).

5.4.2 Applicability

The Director of an approved State may establish an alternative schedule for requiring owners/operators of existing units and lateral expansions to comply with the ground-water monitoring requirements. The alternative schedule is to ensure that at least fifty percent of all existing MSWLF units within a given State are in compliance by October 9, 1994 and that all units are in compliance by October 9, 1996.

In establishing the alternative schedule, the Director of an approved State may use site-specific information to assess the relative risks posed by different waste management units and will allow priorities to be developed at the State level. This site-specific information (e.g., proximity to receptors, proximity and withdrawal rate of ground-water users, waste quantity, type, containment design and age) should enable the Director to assess potential risk to the uppermost aquifer. The resource value of the aquifer to be monitored (e.g., ground-water quality and quantity, present and future uses, and withdrawal rate of ground-water users) also may be considered.

Once ground-water monitoring has been initiated, it must continue throughout the active life, closure, and post-closure care periods. The post-closure period may last up to 30 years or more after the MSWLF unit has received a final cover.

In addition to establishing alternative schedules for compliance with ground-water monitoring requirements, the Director of an approved State may establish alternative schedules for certain sampling and analysis requirements of §§258.54 and 258.55, as well as corrective action requirements of §§258.56, 258.57, and 258.58. See Table 5-2 for a summary of notification requirements for which approved States may establish alternative schedules.

5.4.3 Technical Considerations

The rule allows approved States flexibility in establishing alternate ground-water monitoring compliance schedules. In setting an alternative schedule, the State will consider potential impacts to human health and the environment. Approved States have the option to address MSWLF units that have environmental problems immediately. In establishing alternative schedules for installing ground-water monitoring systems at existing MSWLF units, the Director of an approved State may consider information including the age and design of existing facilities. Using this type of information, in conjunction with a knowledge of the wastes disposed, the Director should be able to qualitatively assess or rank facilities based on their risk to local ground-water resources.

5.5 QUALIFICATIONS
40 CFR 258.50 (f)

5.5.1 Statement of Regulation

(f) For the purposes of this Subpart, a qualified ground-water scientist is a scientist or engineer who has received a baccalaureate or post-graduate degree in

Table 5-2. Summary of Notification Requirements

Section	Description
§258.51(d)(2)	14 day notification period after well installation certification by a qualified ground-water scientist (GWS)
§258.54(c)(1)	14 day notification period after finding a statistical increase over background for detection parameter(s)
§258.55(d)(1)	14 day notification period after detection of Appendix II constituents
§258.57(a)	14 day notification period after selection of corrective measures
§258.58(c)(4)	14 day notification period prior to implementing alternative measures
§258.58(f)	14 day notification period after remedy has been completed and certified by GWS

the natural sciences or engineering and has sufficient training and experience in ground-water hydrology and related fields as may be demonstrated by State registration, professional certifications, or completion of accredited university programs that enable that individual to make sound professional judgements regarding ground-water monitoring, contaminant fate and transport, and corrective action.

5.5.2 Applicability

The qualifications of a ground-water scientist are defined to ensure that professionals of appropriate capability and judgement are consulted when required by the Criteria. The ground-water scientist must possess the fundamental education and experience necessary to evaluate ground-water flow, ground-water monitoring systems, and ground-water monitoring techniques and methods. A ground-water scientist must understand and be able to apply methods to solve solute transport problems and evaluate ground-water remedial technologies. His or her education may include undergraduate or graduate studies in hydrogeology, ground-water hydrology, engineering hydrology, water resource engineering, geotechnical engineering, geology, ground-water modeling/ground-water computer modeling, and other aspects of the natural sciences. The qualified ground-water scientist must have a college degree but need not have professional certification, unless required at the State or Tribal level. Some States/Tribes may have certification programs for ground-water scientists; however, there are no recognized Federal certification programs.

5.5.3 Technical Considerations

A qualified ground-water scientist must certify work performed pursuant to the following provisions of the ground-water monitoring and corrective action requirements:

- No potential for migration demonstration (§258.50(b))
- Specifications concerning the number, spacing, and depths of monitoring wells (§258.51(d))
- Determination that contamination was caused by another source or that a statistically significant increase resulted from an error in sampling, analysis, or evaluation (§§258.54 (c)(3) and 258.55 (g)(2))
- Determination that compliance with a remedy requirement is not technically practicable (§258.58(c)(1))
- Completion of remedy (§258.58(f)).

The owner or operator must determine that the professional qualifications of the ground-water specialist are in accordance with the regulatory definition. In general, a certification is a signed document that transmits some finding (e.g., that monitoring wells were installed according to acceptable practices and standards at locations and depths appropriate for a given facility). The certification must be placed in the operating record of the facility, and the State Director must be notified that the certification has been made. Specific details of these certifications will be addressed in the order in which they appear in this guidance document.

Many State environmental regulatory agencies have ground-water scientists on staff. The owner or operator of a MSWLF unit or facility is not necessarily required to obtain certification from an independent (e.g., consulting) ground-water scientist and may, if agreed to by the Director in an approved State, obtain approval by the Director in lieu of certification by an outside individual.

5.6 GROUND-WATER MONITORING SYSTEMS 40 CFR §258.51 (a)(b)(d)

5.6.1 Statement of Regulation

(a) A ground-water monitoring system must be installed that consists of a sufficient number of wells, installed at appropriate locations and depths, to yield ground-water samples from the upper-most aquifer (as defined in §258.2) that:

(1) Represent the quality of background ground water that has not been affected by leakage from a unit. A determination of background quality may include sampling of wells that are not hydraulically upgradient of the waste management area where:

(i) Hydrogeologic conditions do not allow the owner or operator to determine what wells are hydraulically upgradient; or

(ii) Sampling at other wells will provide an indication of background ground-water quality that is as representative or more representative than that provided by the upgradient wells; and

(2) Represent the quality of ground water passing the relevant point of compliance specified by the Director of an approved State under §258.40(d) or at the waste management unit boundary in unapproved States. The downgradient monitoring system must be installed at the relevant point of compliance specified by the Director of an approved State under §258.40(d) or at the waste management unit boundary in unapproved States that ensures detection of ground-water contamination in the uppermost aquifer. When physical obstacles preclude installation of ground-water monitoring wells at the relevant point of compliance at existing units, the down-gradient monitoring system may be installed at the closest practicable distance hydraulically down-gradient from the relevant point of compliance or specified by the Director of an approved State under §258.40 that ensures detection of ground-water contamination in the uppermost aquifer.

(b) The Director of an approved State may approve a multi-unit ground-water monitoring system instead of separate ground-water monitoring systems for each MSWLF unit when the facility has several units, provided the multi-unit ground-water monitoring system meets the requirement of §258.51(a) and will be as protective of human health and the environment as individual monitoring systems for each MSWLF unit, based on the following factors:

(1) Number, spacing, and orientation of the MSWLF units;

(2) Hydrogeologic setting;

(3) Site history;

(4) Engineering design of the MSWLF units; and

(5) Type of waste accepted at the MSWLF units.

(c) (See Section 5.7 for technical guidance on monitoring well design and construction.)

(d) The number, spacing, and depths of monitoring systems shall be:

(1) Determined based upon site-specific technical information that must include thorough characterization of:

(i) Aquifer thickness, ground-water flow rate, ground-water flow direction including seasonal and temporal fluctuations in ground-water flow; and

(ii) Saturated and unsaturated geologic units and fill materials overlying the uppermost aquifer, materials comprising the uppermost aquifer, and materials comprising the confining unit defining the lower boundary of the uppermost aquifer; including, but not limited to: thicknesses, stratigraphy, lithology, hydraulic conductivities, porosities and effective porosities.

(2) Certified by a qualified ground-water scientist or approved by the Director of an approved State. Within 14 days of this certification, the owner or operator must notify the State Director that the certification has been placed in the operating record.

5.6.2 Applicability

The requirements for establishing a ground-water monitoring system pursuant to §258.51 apply to all new units, existing units, and lateral expansions of existing units according to the schedules identified in 40 CFR §258.50. A ground-water monitoring system consists of both background wells and wells located at the point of compliance or waste management unit boundary (i.e., downgradient wells). The ground-water monitoring network must be capable of detecting a release from the MSWLF unit. A sufficient number of monitoring wells must be located downgradient of the unit and be screened at intervals in the uppermost aquifer to ensure contaminant detection. Generally, upgradient wells are used to determine background ground-water quality.

The downgradient wells must be located at the relevant point of compliance specified by the Director of an approved State, or at the waste management unit boundary in States that are not in compliance with regulations. If existing physical structures obstruct well placement, the downgradient monitoring system should be placed as close to the relevant point of compliance as possible. Wells located at the relevant point of compliance must be capable of detecting contaminant releases from the MSWLF unit to the uppermost aquifer. As discussed earlier in the section pertaining to the designation of a relevant point of compliance (Section 4.4), the point of compliance must be no greater than 150 meters from the unit boundary.

The Director of an approved State may allow the use of a multi-unit ground-water monitoring system. MSWLF units in

States that are deemed not in compliance with the regulations must have a monitoring system for each unit.

A qualified ground-water scientist must certify that the number, spacing, and depths of the monitoring wells are appropriate for the MSWLF unit. This certification must be placed in the operating records. The State Director must be notified within 14 days that the certification was placed in the operating record.

5.6.3 Technical Considerations

The objective of a ground-water monitoring system is to intercept ground water that has been contaminated by leachate from the MSWLF unit. Early contaminant detection is important to allow sufficient time for corrective measures to be developed and implemented before sensitive receptors are significantly affected. To accomplish this objective, the monitoring wells should be located to sample ground water from the uppermost aquifer at the closest practicable distance from the waste management unit boundary. An alternative distance that is protective of human health and the environment may be granted by the Director of an approved State. Since the monitoring program is intended to operate through the post-closure period, the location, design, and installation of monitoring wells should address both existing conditions and anticipated facility development, as well as expected changes in ground-water flow.

Uppermost Aquifer

Monitoring wells must be placed to provide representative ground-water samples from the uppermost aquifer. The uppermost aquifer is defined in §258.2 as "the geologic formation nearest to the natural ground surface that is an aquifer, as well as lower aquifers that are hydraulically interconnected with this aquifer within the facility property boundary." These lower aquifers may be separated physically from the uppermost aquifer by less permeable strata (having a lower hydraulic conductivity) that are often termed aquitards. An aquitard is a less permeable geologic unit or series of closely layered units (e.g., silt, clay, or shale) that in itself will not yield significant quantities of water but will transmit water through its thickness. Aquitards may include thicker stratigraphic sequences of clays, shales, and dense, unfractured crystalline rocks (Freeze and Cherry, 1979).

To be considered part of the uppermost aquifer, a lower zone of saturation must be hydraulically connected to the uppermost aquifer within the facility property boundary. Generally, the degree of communication between aquifers is evaluated by ground-water pumping tests. Methods have been devised for use in analyzing aquifer test data. A summary is presented in *Handbook: Ground Water*, Vol. II (USEPA, 1991). The following discussions under this section (5.6.3) should assist the owner or operator in characterizing the uppermost aquifer and the hydrogeology of the site.

Determination of Background Ground-Water Quality

The goal of monitoring-well placement is to detect changes in the quality of ground water resulting from a release from the MSWLF unit. The natural chemical composition of ground water is controlled primarily by the mineral composition of the geologic unit comprising the aquifer. As ground water moves from one geologic unit to another, its chemical composition may change. To reduce the probability of detecting naturally occurring differences in ground-water quality between background and downgradient locations, only ground-water samples collected from the same geologic unit should be compared.

Ground-water quality in areas where the geology is complex can be difficult to characterize. As a result, the rule allows the owner or operator flexibility in determining where to locate wells that will be used to establish background water quality.

If the facility is new, ground-water samples collected from both upgradient and downgradient locations prior to waste disposal can be used to establish background water quality. The sampling should be conducted to account for both seasonal and spatial variability in ground-water quality.

Determining background ground-water quality by sampling wells that are not hydraulically upgradient may be necessary where hydrogeologic conditions do not allow the owner or operator to determine which wells are hydraulically upgradient. Additionally, background ground-water quality may be determined by sampling wells that provide ground-water samples as representative or more representative than those provided by upgradient wells. These conditions include the following:

- The facility is located above an aquifer in which ground-water flow directions change seasonally.
- The facility is located near production wells that influence the direction of ground-water flow.
- Upgradient ground-water quality is affected by a source of contamination other than the MSWLF unit.
- The proposed or existing landfill overlies a ground-water divide or local source of recharge.
- Geologic units present at downgradient locations are absent at upgradient locations.
- Karst terrain or fault zones modify flow.
- Nearby surface water influences ground-water flow directions.
- Waste management areas are located close to a property boundary that is upgradient of the facility.

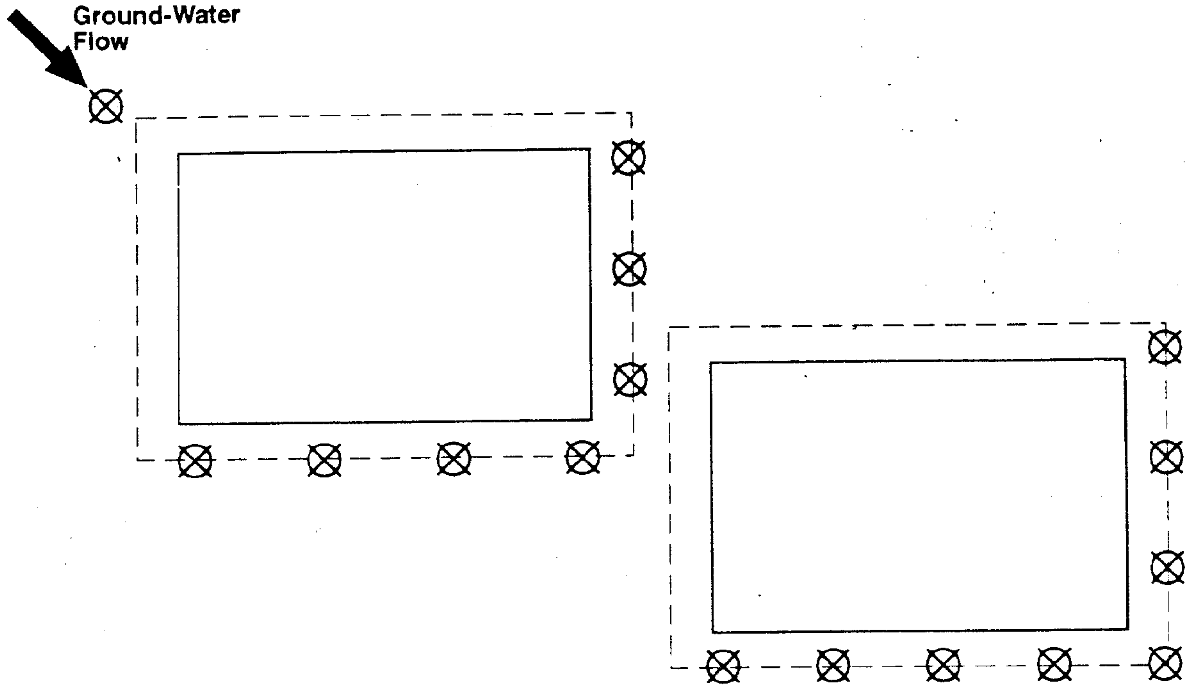
Multi-Unit Monitoring Systems

A multi-unit ground-water monitoring system does not have wells at individual MSWLF unit boundaries. Instead, an imaginary line is drawn around all of the units at the facility. (See Figure 5-1 for a comparison of single unit and multi-unit systems.) This line constitutes the relevant point of compliance. The option to establish a multi-unit monitoring system is restricted to facilities located in approved States. A multi-unit system must be approved by the Director of an approved State after consideration has been given to the:

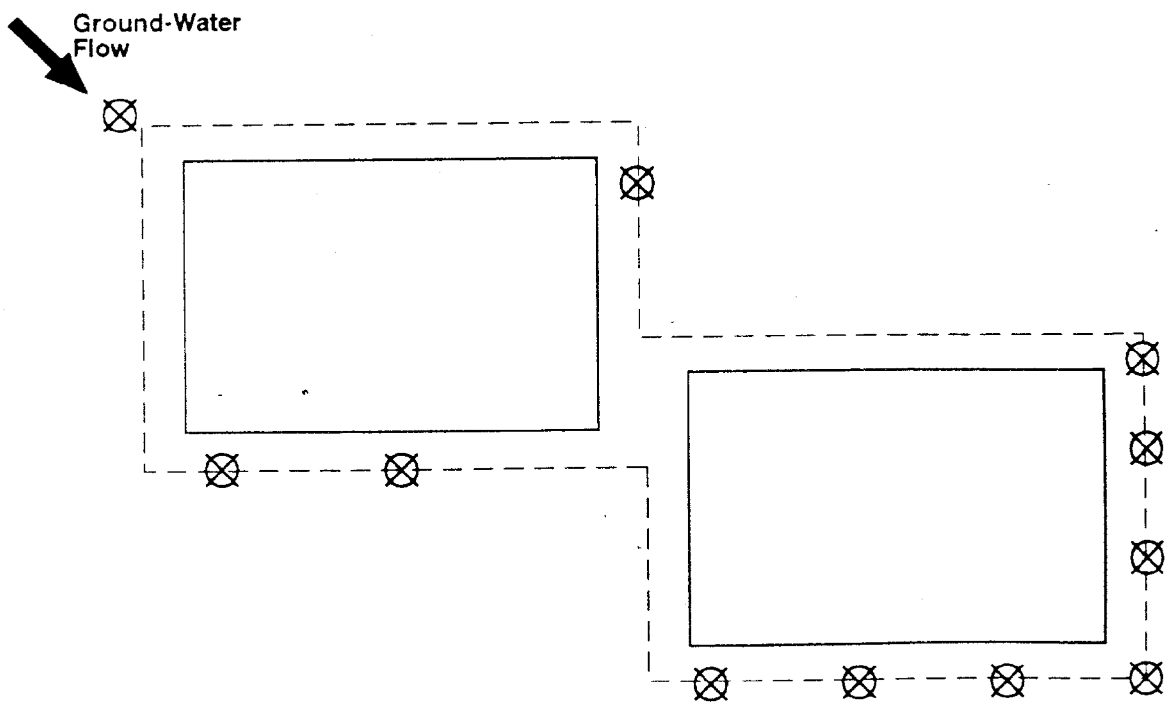
- Number, spacing, and orientation of the MSWLF units

Figure 5-1. Comparison of Single Unit and Multi-Unit Monitoring System

Single-Unit System



Multi-Unit System



- Hydrogeologic setting
- Site history
- Engineering design of the MSWLF units
- Type of wastes accepted at the facility.

The purpose of a multi-unit system is to reduce the number of monitoring wells that can provide the same information. The conceptual design of the multi-unit system should consider the use and management of the facility with respect to anticipated unit locations. In some cases, it may be possible to justify a reduction in the number of wells if the waste management units are aligned along the same flow path in the ground-water system.

The multi-unit monitoring system must provide a level of protection to human health and the environment that is comparable to monitoring individual units. The multi-unit system should allow adequate time after detection of contamination to develop and implement corrective measures before sensitive receptors are adversely affected.

Hydrogeological Characterization

Adequate monitoring-well placement depends on collecting and evaluating hydrogeological information that can be used to form a conceptual model of the site. The goal of a hydrogeological investigation is to acquire site-specific data concerning:

- The lateral and vertical extent of the uppermost aquifer
- The lateral and vertical extent of the upper and lower confining units/layers
- The geology at the owner's/operator's facility (e.g, stratigraphy, lithology, and structural setting)
- The chemical properties of the uppermost aquifer and its confining layers relative to local ground-water chemistry and wastes managed at the facility
- Ground-water flow, including:
  - The vertical and horizontal directions of ground-water flow in the uppermost aquifer
  - The vertical and horizontal components of the hydraulic gradient in the uppermost and any hydraulically connected aquifer
  - The hydraulic conductivities of the materials that comprise the upper-most aquifer and its confining units/layers
  - The average linear horizontal velocity of ground-water flow in the uppermost aquifer.

The elements of a program to characterize the hydrogeology of a site are discussed briefly in the sections that follow and are addressed in more detail in "RCRA Ground-Water Monitoring: Draft Technical Guidance" (USEPA, 1992a).

Prior to initiating a field investigation, the owner or operator should perform a preliminary investigation. The preliminary investigation will involve reviewing all available information about the site, which may consist of:

- Information on the waste management history of the site, including:
  - A chronological history of the site, including descriptions of wastes managed on-site
  - A summary of documented releases
  - Details on the structural integrity of the MSWLF unit and physical controls on waste migration
- A literature review, including:
  - Reports of research performed in the area of the site
  - Journal articles
  - Studies and reports available from local, regional, and State offices (e.g., geologic surveys, water boards, and environmental agencies)
  - Studies available from Federal offices, such as USGS or USEPA
- Information from file searches, including:
  - Reports of previous investigations at the site
  - Geological and environmental assessment data from State and Federal reports.

The documentation itemized above is by no means a complete listing of information available for a preliminary investigation. Many other sources of hydrogeological information may be available for review during the preliminary investigation.

Characterizing Site Geology

After the preliminary investigation is complete, the owner/operator will have information that he/she can use to develop a plan to characterize site hydrogeology further.

Nearly all hydrogeological investigations include a subsurface boring program. A boring program is necessary to define site hydrogeology and the small-scale geology of the area beneath the site. The program usually requires more than one iteration. The objective of the initial boreholes is to refine the conceptual model of the site derived from the preliminary investigation.

The subsurface boring program should be designed as follows:

- The initial number of boreholes and their spacing is based on the information obtained during the preliminary investigation.
- Additional boreholes should be installed as needed to provide more information about the site.
- Samples should be collected from the borings at changes in lithology. For boreholes that will be completed as monitoring wells, at least one sample should be collected from the interval that will be the screened interval. Boreholes that will not be completed as monitoring wells must be properly decommissioned.

Geophysical techniques, cone penetrometer surveys, mapping programs, and laboratory analyses of borehole samples can be used to plan and supplement the subsurface boring program. Downhole geophysical techniques include electric, sonic, and nuclear logging. Surface geophysical techniques include seismic reflection and refraction, as well as electromagnetic induction and resistivity.

The data obtained from the subsurface boring program should enable the owner or operator to identify:

- Lithology, soil types, and stratigraphy
- Zones of potentially high hydraulic conductivity
- The presence of confining formations or layers
- Unpredicted geologic features, such as fault zones, cross-cutting structures, and pinch-out zones
- Continuity of petrographic features, such as sorting, grain size distribution, and cementation
- The potentiometric surface or water table.

Characterizing Ground-Water Flow Beneath the Site

In addition to characterizing site geology, the owner/operator should characterize the hydrology of the uppermost aquifer and its confining layer(s) at the site. The owner or operator should install wells and/or piezometers to assist in characterizing site hydrology. The owner/operator should determine and assess:

- The direction(s) and rate(s) of ground-water flow (including both horizontal and vertical components of flow)
- Seasonal/temporal, natural, and artificially induced (e.g., off-site production well-pumping, agricultural use) short-term and long-term variations in ground-water elevations and flow patterns
- The hydraulic conductivities of the stratigraphic units at the site, including vertical hydraulic conductivity of the confining layer(s).

Determining Ground-Water Flow Direction and Hydraulic Gradient

Installing monitoring wells that will provide representative background and downgradient water samples requires a thorough understanding of how ground water flows beneath a site. Developing such an understanding requires obtaining information regarding both ground-water flow direction(s) and hydraulic gradient. Ground-water flow direction can be thought of as the idealized path that ground-water follows as it passes through the subsurface. Hydraulic gradient (i) is the change in static head per unit of distance in a given direction. The static head is defined as the height above a standard datum of the surface of a column of water (or other liquid) that can be supported by the static pressure at a given point (i.e., the sum of the elevation head and pressure head).

To determine ground-water flow directions and hydraulic gradient, owners and operators should develop and implement a water level-monitoring program. This program should be structured to provide precise water level measurements in a sufficient number of piezometers or wells at a sufficient frequency to gauge both seasonal average flow directions and temporal fluctuations in ground-water flow directions. Ground-water flow direction(s) should be determined from water levels measured in wells screened in the same hydro-stratigraphic position. In heterogeneous geologic settings (i.e., settings in which the hydraulic conductivities of the subsurface materials vary with location in the subsurface), long well screens can intercept stratigraphic horizons with different (e.g., contrasting) ground-water flow directions and different heads. In this situation, the resulting water levels will not provide the depth-discrete head measurements required for accurate determination of the ground-water flow direction.

In addition to evaluating the component of ground-water flow in the horizontal direction, a program should be undertaken to assess the vertical component of ground-water flow. Vertical ground-water flow information should be based, at least in part, on field data from wells and piezometers, such as multi-level wells, piezometer clusters, or multi-level sampling devices, where appropriate. The following sections provide acceptable methods for assessing the vertical and horizontal components of flow at a site.

Ground-Water Level Measurements

To determine ground-water flow directions and ground-water flow rates, accurate water level measurements (measured to the nearest 0.01 foot) should be obtained. Section 5.8 delineates procedures for obtaining water level measurements. At facilities where it is known or plausible that immiscible contaminants (i.e., non-aqueous phase liquids (NAPLs)) occur (or are determined to be potentially present after considering the waste types managed at the facility) in the subsurface at the facility, both the depth(s) to the immiscible layer(s) and the thickness(es) of the immiscible layer(s) in the well should be recorded.

For the purpose of measuring total head, piezometers and wells should have as short a screened interval as possible. Specifically, the screens in piezometers or wells that are used to measure head should generally be less than 10 feet long. In circumstances including the following, well screens longer than 10 feet may be warranted:

- Natural water level fluctuations necessitate a longer screen length.

- The interval monitored is slightly greater than the appropriate screen length (e.g., the interval monitored is 12 feet thick).

- The aquifer monitored is homogeneous and extremely thick (e.g., greater than 300 feet); thus, a longer screen (e.g., a 20-foot screen) represents a fairly discrete interval.

The head measured in a well with a long screened interval is a function of all of the different heads over the entire length of the screened interval. Care should be taken when interpreting water levels collected from wells that have long screened intervals (e.g., greater than 10 feet).

The water-level monitoring program should be structured to provide precise water level measurements in a sufficient number of piezometers or wells at a sufficient frequency to gauge both seasonal average flow directions and temporal fluctuations in ground-water flow directions. The owner/operator should determine and assess seasonal/temporal, natural, and artificially induced (e.g., off-site production well-pumping, agricultural use) short-term and long-term variations in ground-water elevations, ground-water flow patterns, and ground-water quality.

Establishing Horizontal Flow Direction and the Horizontal Component of Hydraulic Gradient

After the water level data and measurement procedures are reviewed to determine that they are accurate, the data should be used to:

- Construct potentiometric surface maps and water table maps based on the distribution of total head. The data used to develop water table maps should be from piezometers or wells screened across the water table. The data used to develop potentiometric surface maps should be from piezometers or wells screened at approximately the same elevation in the same hydrostratigraphic unit;

- Determine the horizontal direction(s) of ground-water flow by drawing flow lines on the potentiometric surface map or water table map (i.e., construct a flow net);

- Calculate value(s) for the horizontal and vertical components of hydraulic gradient.

Methods for constructing potentiometric surface and water table maps, constructing flow nets, and determining the direction(s) of ground-water flow are provided by USEPA (1989c) and Freeze and Cherry (1979). Methods for calculating hydraulic gradient are provided by Heath (1982) and USEPA (1989c).

A potentiometric surface or water table map will give an approximate idea of general ground-water flow directions. However, to locate monitoring wells properly, ground-water flow direction(s) and hydraulic gradient(s) should be established in both the horizontal and vertical directions and over time at regular intervals (e.g., over a 1-year period at 3-month intervals).

Establishing Vertical Flow Direction and the Vertical Component of Hydraulic Gradient

To make an adequate determination of the ground-water flow directions, the vertical component of ground-water flow should be evaluated directly. This generally requires the installation of multiple piezometers or wells in clusters or nests, or the installation of multi-level wells or sampling devices. A piezometer or well nest is a closely spaced group of piezometers or wells screened at different depths, whereas a multi-level well is a single device. Both piezometer/well nests and multi-level wells allow for the measurement of vertical variations in hydraulic head.

When reviewing data obtained from multiple placement of piezometers or wells in single boreholes, the construction details of the well should be carefully evaluated. Not only is it extremely difficult to seal several piezometers/wells at discrete depths within a single borehole, but sealant materials may migrate from the seal of one piezometer/well to the screened interval of another piezometer/well. Therefore, the design of a piezometer/well nest should be considered carefully. Placement of piezometers/wells in closely spaced boreholes, where piezometers/wells have been screened at different, discrete depth intervals, is likely to produce more accurate information. The primary concerns with the installation of piezometers/wells in closely spaced, separate boreholes are: 1) the disturbance of geologic and soil materials that occurs when one piezometer is installed may be reflected in the data obtained from another piezometer located nearby, and 2) the analysis of water levels measured in piezometers that are closely spaced, but separated horizontally, may produce imprecise information regarding the vertical component of ground-water flow. The limitations of installing multiple piezometers either in single or separate boreholes may be overcome by the installation of single multi-level monitoring wells or sampling devices in single boreholes. The advantages and disadvantages of these types of devices are discussed by USEPA (1989f).

The owner or operator should determine the vertical direction(s) of ground-water flow using the water levels measured in multi-level wells or piezometer/well nests to construct flow nets. Flow nets should depict the piezometer/well depth and length of the screened interval. It is important to portray the screened interval accurately on the flow net to ensure that the piezometer/well is actually monitoring the desired water-bearing unit. A flow net should be developed from information obtained from piezometer/ well clusters or nests screened at different, discrete depths. Detailed guidance for the construction and evaluation of flow nets in cross section (vertical flow nets) is provided by USEPA (1989c). Further information can be obtained from Freeze and Cherry (1979).

Determining Hydraulic Conductivity

Hydraulic conductivity is a measure of a material's ability to transmit water. Generally, poorly sorted silty or clayey materials have low hydraulic conductivities, whereas well-sorted sands and gravels have high hydraulic conductivities. An aquifer may be classified as either homogeneous or heterogeneous and either isotropic or anisotropic according to the way its hydraulic conductivity varies in space. An aquifer is homogeneous if the hydraulic conductivity is independent of location within the aquifer; it is heterogeneous if hydraulic conductivities are dependent on location within the aquifer. If the hydraulic conductivity is independent of the direction of measurement at a point in a geologic formation, the formation is isotropic at that point. If the hydraulic conductivity varies with the direction of measurement at a point, the formation is anisotropic at that point.

Determining Hydraulic Conductivity Using Field Methods

Sufficient aquifer testing (i.e., field methods) should be performed to provide representative estimates of hydraulic conductivity. Acceptable field methods include conducting aquifer tests with single wells, conducting aquifer tests with multiple wells, and using flowmeters. This section provides brief overviews of these methods, including two methods for obtaining vertically discrete measurements of hydraulic conductivity. The identified references provide detailed descriptions of the methods summarized in this section.

A commonly used test for determining horizontal hydraulic conductivity with a single well is the slug test. A slug test is performed by suddenly adding, removing, or displacing a known volume of water from a well and observing the time that it takes for the water level to recover to its original level (Freeze and Cherry, 1979). Similar results can be achieved by pressurizing the well casing, depressing the water level, and suddenly releasing the pressure to simulate the removal of water from the well. In most cases, EPA recommends that water not be introduced into wells during aquifer tests to avoid altering ground-water chemistry. Single-well tests are limited in scope to the area directly adjacent to the well screen. The vertical extent of the well screen generally defines the part of the geologic formation that is being tested.

A modified version of the slug test, known as the multilevel slug test, is capable of providing depth-discrete measurements of hydraulic conductivity. The drawback of the multilevel slug test is that the test relies on the ability of the investigator to isolate a portion of the aquifer using a packer. Nevertheless, multilevel slug tests, when performed properly, can produce reliable measurements of hydraulic conductivity.

Multiple-well tests involve withdrawing water from, or injecting water into, one well, and obtaining water level measurements over time in observation wells. Multiple-well tests are often performed as pumping tests in which water is pumped from one well and drawdown is observed in nearby wells. A step-drawdown test should precede most pumping tests to determine an appropriate discharge rate. Aquifer tests conducted with wells screened in the same water-bearing zone can be used to provide hydraulic conductivity data for that zone. Multiple-well tests for hydraulic conductivity characterize a greater proportion of the subsurface than single-well tests and, thus, provide average values of hydraulic conductivity. Multiple-well tests require measurement of parameters similar to those required for single-well tests (e.g., time, drawdown). When using aquifer test data to determine aquifer parameters, it is important that the solution assumptions can be applied to site conditions. Aquifer test solutions are available for a wide variety of hydrogeologic settings, but are often applied incorrectly by inexperienced persons. Incorrect assumptions regarding hydrogeology (e.g., aquifer boundaries, aquifer lithology, and aquifer thickness) may translate into incorrect estimations of hydraulic conductivity. A qualified ground-water scientist with experience in designing and interpreting aquifer tests should be consulted to ensure that aquifer test solution methods fit the hydrogeologic setting. Kruseman and deRidder (1989) provide a comprehensive discussion of aquifer tests.

Multiple-well tests conducted with wells screened in different water-bearing zones furnish information concerning hydraulic communication among the zones. Water levels in these zones should be monitored during the aquifer test to determine the type of aquifer system (e.g., confined, unconfined, semi-confined, or semi-unconfined) beneath the site, and their leakance (coefficient of leakage) and drainage factors (Kruseman and deRidder, 1989). A multiple-well aquifer test should be considered at every site as a method to establish the vertical extent of the uppermost aquifer and to evaluate hydraulic connection between aquifers.

Certain aquifer tests are inappropriate for use in karst terrains characterized by a well-developed conduit flow system, and they also may be inappropriate in fractured bedrock. When a well located in a karst conduit or a large fracture is pumped, the water level in the conduit is lowered. This lowering produces a drawdown that is not radial (as in a granular aquifer) but is instead a trough-like depression parallel to the pumped conduit or fracture. Radial flow equations do not apply to drawdown data collected during such a pump test. This means that a conventional semi-log plot of drawdown versus time is inappropriate for the purpose of determining the aquifer's transmissivity and storativity. Aquifer tests in karst aquifers can be useful, but valid determinations of hydraulic conductivity, storativity, and transmissivity may be impossible. However, an aquifer test can provide information on the presence of conduits, on storage characteristics, and on the percentage of Darcian flow. McGlew and Thomas (1984) provide a more detailed discussion of the appropriate use of aquifer tests in fractured bedrock and on the suitable interpretation of test data. Dye tracing also is used to determine the rate and direction of ground-water flow in karst settings (Section 5.2.4).

Several additional factors should be considered when planning an aquifer test:

- Owners and operators should provide for the proper storage and disposal of potentially contaminated ground water pumped from the well system.

- Owners and operators should consider the potential effects of pumping on existing plumes of contaminated ground water.

- In designing aquifer tests and interpreting aquifer test data, owners/operators should account and correct for seasonal, temporal, and anthropogenic effects on the potentiometric surface or water table. This is usually done by installing piezometers outside the influence of the stressed aquifer. These piezometers should be continuously monitored during the aquifer test.

- Owners and operators should be aware that, in a very high hydraulic conductivity aquifer, the screen size and/or filter pack used in the test well can affect an aquifer test. If a very small screen size is used, and the pack is improperly graded, the test may reflect the characteristics of the filter pack, rather than the aquifer.

- EPA recommends the use of a step-drawdown test to provide a basis for selecting discharge rates prior to conducting a full-scale pumping test. This will ensure that the pumping rate chosen for the subsequent pumping test(s) can be sustained without exceeding the available drawdown of the pumped wells. In addition, this test will produce a measurable drawdown in the observation wells.

Certain flowmeters recently have been recognized for their ability to provide accurate and vertically discrete measurements of hydraulic conductivity. One of these, the impeller flowmeter, is available commercially. More sensitive types of flowmeters (i.e., the heat-pulse flowmeter and electromagnetic flowmeter) should be available in the near future. Use of the impeller flowmeter requires running a caliper log to measure the uniformity of the diameter of the well screen. The well is then pumped with a small pump operated at a constant flow rate. The flowmeter is lowered into the well, and the discharge rate is measured every few feet by raising the flowmeter in the well. Hydraulic conductivity values can be calculated from the recorded data using the Cooper-Jacob (1946) formula for horizontal flow to a well. Use of the impeller flowmeter is limited at sites where the presence of low permeability materials does not allow pumping of the wells at rates sufficient to operate the flowmeter. The application of flowmeters in the measure of hydraulic conductivity is described by Molz et al. (1990) and Molz et al. (1989).

Determining Hydraulic Conductivity Using Laboratory Methods

It may be beneficial to use laboratory measurements of hydraulic conductivity to augment the results of field tests. However, field methods provide the best estimates of hydraulic conductivity in most cases. Because of the limited sample size, laboratory tests can fail to account for secondary porosity features, such as fractures and joints, and hence, can greatly underestimate overall aquifer hydraulic conductivities. Laboratory tests may provide valuable information about the vertical component of hydraulic conductivity of aquifer materials. However, laboratory test results always should be confirmed by field measurements, which sample a much larger portion of the aquifer. In addition, laboratory test results can be profoundly affected by the test method selected and by the manner in which the tests are carried out (e.g., the extent to which sample collection and preparation have changed the in situ hydraulic properties of the tested material). Special attention should be given to the selection of the appropriate test method and test conditions and to quality control of laboratory results. McWhorter and Sunada (1977), Freeze and Cherry (1979), and Sevee (1991) discuss determining hydraulic conductivity in the laboratory. Laboratory tests may provide the best estimates of hydraulic conductivity for materials in the unsaturated zone, but they are likely to be less accurate than field methods for materials in the saturated zone (Cantor et al., 1987).

Determining Ground-Water Flow Rate

The calculation of the average ground-water flow rate (average linear velocity of ground-water flow), or seepage velocity, is discussed in detail in USEPA (1989c), in Freeze and Cherry (1979), and in Kruseman and deRidder (1989). The average linear velocity of ground-water flow ($\bar{v}$) is a function of hydraulic conductivity (K), hydraulic gradient (i), and effective porosity (n_e):

$$\bar{v} = -\frac{Ki}{n_e}$$

Methods for determining hydraulic gradient and hydraulic conductivity have been presented previously. Effective porosity, the percentage of the total volume of a given mass of soil, unconsolidated material, or rock that consists of interconnected pores through which water can flow, should be estimated from laboratory tests or from values cited in the literature. (Fetter (1980) provides a good discussion of effective porosity. Barari and Hedges (1985) provide default values for effective porosity.) USEPA (1989c) provides methods for determining flow rates in heterogeneous and/or anisotropic systems and should be consulted prior to calculating flow rates.

Interpreting and Presenting Data

The following sections offer guidance on interpreting and presenting hydrogeologic data collected during the site characterization process. Graphical representations of data, such as cross sections and maps, are typically extremely helpful both when evaluating data and when presenting data to interested individuals.

Interpreting Hydrogeologic Data

Once the site characterization data have been collected, the following tasks should be undertaken to support and develop the interpretation of these data:

- Review borehole and well logs to identify major rock, unconsolidated material, and soil types and establish their horizontal and vertical extent and distribution.

- From borehole and well log (and outcrop, where available) data, construct representative cross-sections for each MSWLF unit, one in the direction of ground-water flow and one orthogonal to ground-water flow.

- Identify zones of suspected high hydraulic conductivity, or structures likely to influence contaminant migration through the unsaturated and saturated zones.

- Compare findings with other studies and information collected during the preliminary investigation to verify the collected information.

- Determine whether laboratory and field data corroborate and are sufficient to define petrology, effective porosity, hydraulic conductivity, lateral and vertical stratigraphic relationships, and ground-water flow directions and rates.

After the hydrogeologic data are interpreted, the findings should be reviewed to:

- Identify information gaps

- Determine whether the collection of additional data or reassessment of existing data is required to fill in the gaps

- Identify how information gaps are likely to affect the ability to design a RCRA monitoring system.

Generally, lithologic data should correlate with hydraulic properties (e.g., clean, well-sorted, unconsolidated sands should exhibit high hydraulic conductivity). Additional boreholes should be drilled and additional samples should be collected to describe the hydrogeology of the site if the investigator is unable to 1) correlate stratigraphic units between borings, 2) identify zones of potentially high hydraulic conductivity and the thickness and lateral extent of these zones, or 3) identify confining formations/layers and the thickness and lateral extent of these formation layers.

When establishing the locations of wells that will be used to monitor ground water in hydrogeologic settings characterized by ground-water flow in porous media, the following should be documented:

- The ground-water flow rate should be based on accurate measurements of hydraulic conductivity and hydraulic gradient and accurate measurements or estimates of effective porosity

- The horizontal and vertical components of flow should be accurately depicted in flow nets and based on valid data

- Any seasonal or temporal variations in the water table or potentiometric surface, and in vertical flow components, should be determined.

Once an understanding of horizontal and vertical ground-water flow has been established, it is possible to estimate where monitoring wells will most likely intercept contaminant flow.

Presenting Hydrogeologic Data

Subsequent to the generation and interpretation of site-specific geologic data, the data should be presented in geologic cross-sections, topographic maps, geologic maps, and soil maps. The Agency suggests that owners/operators obtain or prepare and review topographic, geologic, and soil maps of the facility, in addition to site maps of the facility and MSWLF units. In cases where suitable maps are not available, or where the information contained on available maps is not complete or accurate, detailed mapping of the site should be performed by qualified and experienced individuals. An aerial photograph and a topographic map of the site should be included as part of the presentation of hydrogeologic data. The topographic map should be constructed under the supervision of a qualified surveyor and should provide contours at a maximum of 2-foot intervals.

Geologic and soil maps should be based on rock, unconsolidated material, and soil identifications gathered from borings and outcrops. The maps should use colors or symbols to represent each soil, unconsolidated material, and rock type that outcrops on the surface. The maps also should show the locations of outcrops and all borings placed during the site characterization. Geologic and soil maps are important because they can provide information describing how site geology fits into the local and regional geologic setting.

Structure contour maps and isopach maps should be prepared for each water-bearing zone that comprises the uppermost aquifer and for each significant confining layer, especially the one underlying the uppermost aquifer. A structure contour map depicts the configuration (i.e., elevations) of the upper or lower surface or boundary of a particular geologic or soil formation, unit, or zone. Structure contour maps are especially important in understanding dense non-aqueous phase liquid (DNAPL) movement because DNAPLs (e.g., tetrachloroethylene) may migrate in the direction of the dip of lower permeability units. Separate structure contour maps should be constructed for the upper and lower surfaces (or contacts) of each zone of interest. Isopach maps should depict contours that indicate the thickness of each zone. These maps are generated from borings and geologic logs and from geophysical measurements. In conjunction with cross-sections, isopach maps may be used to help determine monitoring well locations, depths, and screen lengths during the design of the detection monitoring system.

A potentiometric surface map or water table map should be prepared for each water-bearing zone that comprises the uppermost aquifer. Potentiometric surface and water table maps should show both the direction and rate of ground-water flow and the locations of all piezometers and wells on which they are based. The water level measurements for all piezometers and wells on which the potentiometric surface map or water table map is based should be shown on the potentiometric surface or water table map. If seasonal or temporal variations in ground-water flow occur at the site, a sufficient number of potentiometric surface or water table maps should be prepared to show these variations. Potentiometric surface and water table maps can be combined with structure contour maps for a particular formation or unit. An adequate number of cross sections should be prepared to depict significant stratigraphic and structural trends and to reflect stratigraphic and structural features in relation to local and regional ground-water flow.

Hydrogeological Report

The hydrogeological report should contain, at a minimum:

- A description of field activities
- Drilling and/or well construction logs
- Analytical data
- A discussion and interpretation of the data
- Recommendations to address data gaps.

The final output of the site characterization phase of the hydrogeological investigation is a conceptual model. This model is the integrated picture of the hydrogeologic system and the waste management setting. The final conceptual model must be a site-specific description of the unsaturated zone, the uppermost aquifer, and its confining units. The model should contain all of the information necessary to design a ground-water monitoring system.

Monitoring Well Placement

This section separately addresses the lateral placement and the vertical sampling intervals of point of compliance wells. However, these two aspects of well placement should be evaluated together in the design of the monitoring system. Site-specific hydrogeologic data obtained during the site characterization should be used to determine the lateral placement of detection monitoring wells and to select the length and vertical position of monitoring well intakes. Potential pathways for contaminant migration are three-dimensional. Consequently, the design of a detection monitoring network that intercepts these potential pathways requires a three-dimensional approach.

Lateral Placement of Point of Compliance Monitoring Wells

Point of compliance monitoring wells should be as close as physically possible to the edge of the MSWLF unit(s) and should be screened in all transmissive zones that may act as contaminant transport pathways. The lateral placement of monitoring wells should be based on the number and spatial distribution of potential contaminant migration pathways and on the depths and thicknesses of stratigraphic horizons that can serve as contaminant migration pathways.

Point of compliance monitoring wells should be placed laterally along the downgradient edge of the MSWLF unit to intercept potential pathways for contaminant migration. The local ground-water flow direction and gradient are the major factors in determining the lateral placement of point of compliance wells. In a homogeneous, isotropic hydrogeologic setting, well placement can be based on general aquifer characteristics (e.g., direction and rate of ground-water flow), and potential contaminant fate and transport characteristics (e.g., advection, dispersion). More commonly, however, geology is variable and preferential pathways exist that control the migration of contaminants. These types of heterogeneous, anisotropic geologic settings can have numerous, discrete zones within which contaminants may migrate.

Potential migration pathways include zones of relatively high intrinsic (matrix) hydraulic conductivities, fractured/faulted zones, and subsurface material that may increase in hydraulic conductivity if the material is exposed to waste(s) managed at the site (e.g., a limestone layer that underlies an acidic waste). In addition to natural hydrogeologic features, human-made features may influence the ground-water flow direction and, thus, the lateral placement of point of compliance wells. Such human-made features include ditches, areas where fill material has been placed, buried piping, buildings, leachate collection systems, and adjacent disposal units. The lateral placement of monitoring wells should be based on the number and spatial distribution of potential contaminant migration pathways and on the depths and thicknesses of stratigraphic horizons that can serve as contaminant migration pathways.

In some settings, the ground-water flow direction may reverse seasonally (depending on precipitation), change as a result of tidal influences or river and lake stage fluctuations, or change temporally as a result of well-pumping or changing land use patterns. In other settings, ground water may flow away from the waste management area in all directions. In such cases, EPA recommends that monitoring wells be installed on all sides (or in a circular pattern) around the waste management area to allow for the detection of contamination. In these cases, certain wells may be downgradient only part of the time, but such a configuration should ensure that releases from the unit will be detected.

The lateral placement of monitoring wells also should be based on the physical/ chemical characteristics of the contaminants of concern. While the restriction of liquids in MSWLFs may limit the introduction of hazardous constituents into landfills, it is important to consider the physical/chemical characteristics of contaminants when designing the well system. These characteristics include solubility, Henry's Law constant, partition coefficients, specific gravity, contaminant reaction or degradation products, and the potential for contaminants to degrade confining layers. For example, contaminants with low solubilities and high specific gravities that occur as DNAPLs may migrate in the subsurface in directions different from the direction of ground-water flow. Therefore, in situations where the release of DNAPLs is a concern, the lateral placement of compliance point ground-water monitoring wells should not necessarily only be along the downgradient edge of the MSWLF unit. Considering both contaminant characteristics and hydrogeologic properties is important when determining the lateral placement of monitoring wells.

Vertical Placement and Screen Lengths

Proper selection of the vertical sampling interval is necessary to ensure that the monitoring system is capable of detecting a release from the MSWLF unit. The vertical position and lengths of well intakes are functions of (1) hydro-geologic factors that determine the distribution of, and fluid/vapor phase transport within, potential pathways of contaminant migration to and within the uppermost aquifer, and (2) the chemical and physical characteristics of contaminants that control their transport and distribution in the subsurface. Well intake length also is determined by the need to obtain vertically discrete ground-water samples. Owners and operators should determine the probable location, size, and geometry of potential contaminant plumes when selecting well intake positions and lengths.

Site-specific hydrogeologic data obtained during the site characterization should be used to select the length and vertical position of monitoring well intakes. The vertical positions and lengths of monitoring well intakes should be based on the number and spatial distribution of potential contaminant migration pathways and on the depths and thicknesses of stratigraphic horizons that can serve as contaminant migration pathways. Figure 5-2 illustrates examples of complex stratigraphy that would require multiple vertical monitoring intervals.

The depth and thickness of a potential contaminant migration pathway can be determined from soil, unconsolidated material, and rock samples collected during the boring program, and from samples collected while drilling the monitoring well. Direct physical data can be supplemented by geophysical data, available regional/local hydrogeological data, and other data that provide the vertical distribution of hydraulic conductivity. The vertical sampling interval is not necessarily synonymous with aquifer thickness. Monitoring wells are often screened at intervals that represent a portion of the thickness of the aquifer. When monitoring an unconfined aquifer, the well screen typically should be positioned so that a portion of the well screen is in the saturated zone and a portion of the well screen is in the unsaturated zone (i.e., the well screen straddles the water table). While the restriction of liquids in MSWLFs may limit the introduction of hazardous constituents into landfills, it is important to consider the physical/chemical characteristics of contaminants when designing the well system.

The vertical positions and lengths of monitoring well intakes should be based on the same physical/chemical characteristics of the contaminants of concern that influence the lateral placement of monitoring wells. Considering both contaminant characteristics and hydrogeologic properties is important when choosing the vertical position and length of the well intake. Some contaminants may migrate within very narrow zones. Of course, for well placement at a new site, it is unlikely that the owner or operator will be able to assess contaminant characteristics.

Different transport processes control contaminant migration depending on whether the contaminant dissolves or is immiscible in water. Immiscible

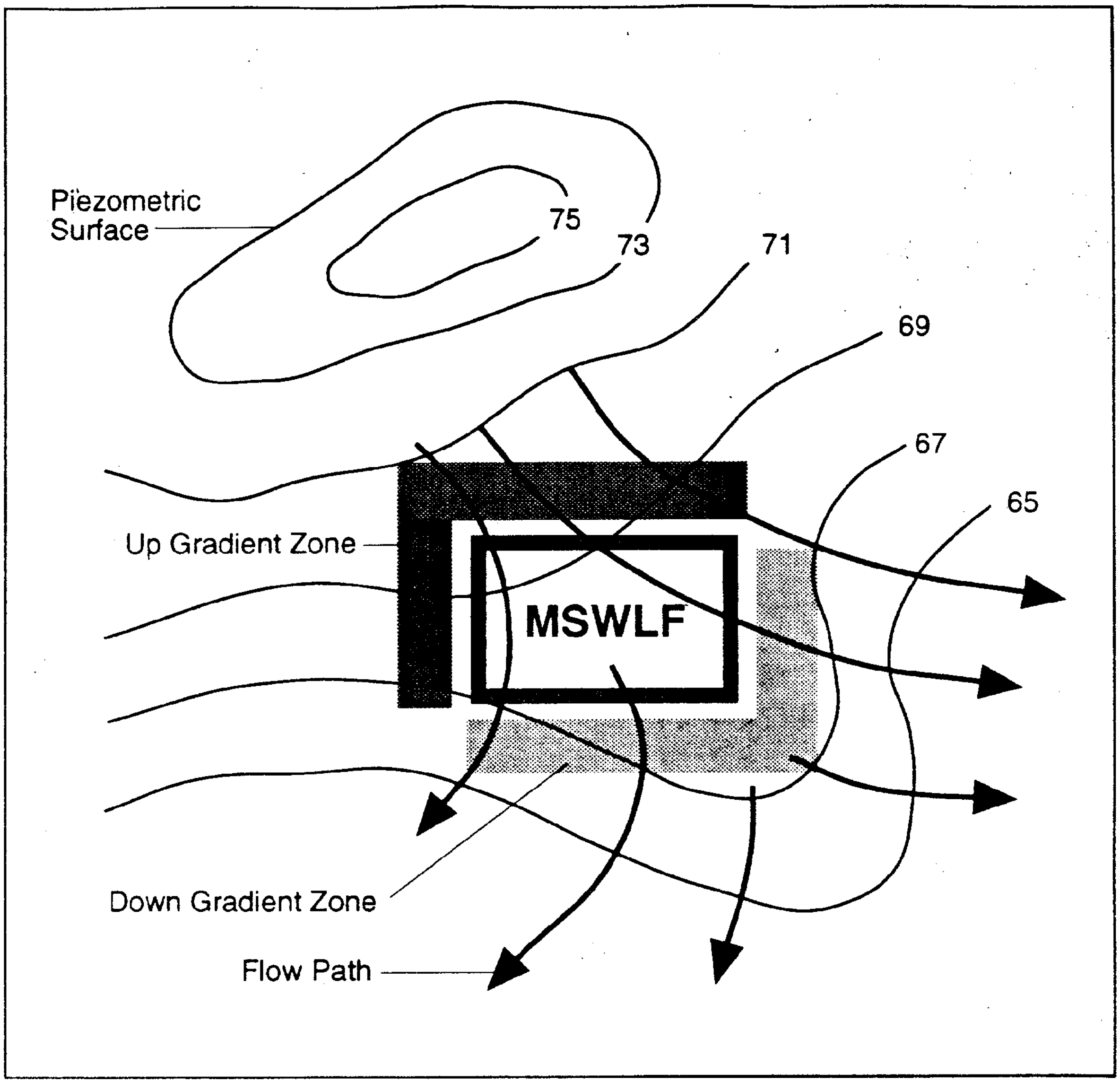


Figure 5-2
Upgradient and Downgradient
Designations for Idealized MSWLF

contaminants may occur as light non aqueous phase liquids (LNAPLs), which are lighter than water, and DNAPLs, which are denser than water. LNAPLs migrate in the capillary zone just above the water table. Wells installed to monitor LNAPLs should be screened at the water table/capillary zone interface, and the screened interval should intercept the water table at its minimum and maximum elevation. LNAPLs may become trapped in residual form in the vadose zone and become periodically remobilized and contribute further to aquifer contamination, either as free phase or dissolved phase contaminants, as the water table fluctuates and precipitation infiltrates the subsurface.

The migration of free-phase DNAPLs may be influenced primarily by the geology, rather than the hydrogeology, of the site. That is, DNAPLs migrate downward through the saturated zone due to density and then migrate by gravity along less permeable geologic units (e.g., the slope of confining units, the slope of clay lenses in more permeable strata, bedrock troughs), even in aquifers with primarily horizontal ground-water flow. Consequently, if wastes disposed at the site are anticipated to exist in the subsurface as a DNAPL, the potential DNAPL should be monitored:

- At the base of the aquifer (immediately above the confining layer)
- In structural depressions (e.g., bedrock troughs) in lower hydraulic conductivity geologic units that act as confining layers
- Along lower hydraulic conductivity lenses and units within units of higher hydraulic conductivity
- "Down-the-dip" of lower hydraulic conductivity units that act as confining layers, both upgradient and downgradient of the waste management area.

Because of the nature of DNAPL migration (i.e., along structural, rather than hydraulic, gradients), wells installed to monitor DNAPLs may need to be installed both upgradient and downgradient of the waste management area. It may be useful to construct a structure contour map of lower permeability strata and identify lower permeability lenses upgradient and downgradient of the unit along which DNAPLs may migrate. The wells can then be located accordingly.

The lengths of well screens used in ground-water monitoring wells can significantly affect their ability to intercept releases of contaminants. The complexity of the hydrogeology of a site is an important consideration when selecting the lengths of well screens. Most hydrogeologic settings are complex (heterogeneous and anisotropic) to a certain degree. Highly heterogeneous formations require shorter well screens to allow sampling of discrete portions of the formation that can serve as contaminant migration pathways. Well screens that span more than a single saturated zone or a single contaminant migration pathway may cause cross-contamination of transmissive units, thereby increasing the extent of contamination. Well intakes should be installed in a single saturated zone. Well intakes (e.g., screens) and filter pack materials should not interconnect, or promote the interconnection of, zones that are separated by a confining layer.

Even in hydrologically simple formations, or within a single potential pathway for contaminant migration, the use of shorter well screens may be necessary to detect contaminants concentrated at particular depths. A contaminant may be concentrated at a particular depth because of its physical/chemical properties and/or because of hydrogeologic properties. In homogeneous formations, a long well screen can permit excessive amounts of uncontaminated formation water to dilute the contaminated ground water entering the well. At best, dilution can make contaminant detection difficult; at worst, contaminant detection is impossible if the concentrations of contaminants are diluted to levels below the detection limits for the prescribed analytical methods. The use of shorter well screens allows for contaminant detection by reducing excessive dilution. When placed at depths of predicted preferential flow, shorter well screens are effective in monitoring the aquifer or the portion of the aquifer of concern.

Generally, screen lengths should not exceed 10 feet. However, certain hydrogeologic settings may warrant or necessitate the use of longer well screens for adequate detection monitoring. Unconfined aquifers with widely fluctuating water tables may require longer screens to intercept the water table surface at both its maximum and minimum elevations and to provide monitoring for the presence of contaminants that are less dense than water. Saturated zones that are slightly greater in thickness than the appropriate screen length (e.g., 12 feet thick) may warrant monitoring with longer screen lengths. Extremely thick homogeneous aquifers (e.g., greater than 300 feet) may be monitored with a longer screen (e.g., a 20-foot screen) because a slightly longer screen would represent a fairly discrete interval in a very thick formation. Formations with very low hydraulic conductivities also may require the use of longer well screens to allow sufficient amounts of formation water to enter the well for sampling. The importance of accurately identifying such conditions highlights the need for a complete hydrogeologic site investigation prior to the design and placement of detection wells.

Multiple monitoring wells (well clusters or multilevel sampling devices) should be installed at a single location when (1) a single well cannot adequately intercept and monitor the vertical extent of a potential pathway of contaminant migration, or (2) there is more than one potential pathway of contaminant migration in the subsurface at a single location, or (3) there is a thick saturated zone and immiscible contaminants are present, or are determined to be potentially present after considering waste types managed at the facility. Conversely, at sites where ground water may be contaminated by a single contaminant, where there is a thin saturated zone, and where the site is hydrogeologically homogeneous, the need for multiple wells at each sampling location is reduced. The number of wells that should be installed at each sampling location increases with site complexity.

The following sources provided additional information on monitoring well placement: USEPA (1992a), USEPA (1990), USEPA (1991), and USEPA (1986a).

5.7 GROUND-WATER MONITORING WELL DESIGN AND CONSTRUCTION 40 CFR §258.51 (c)

5.7.1 Statement of Regulation

(c) Monitoring wells must be cased in a manner that maintains the integrity of the monitoring well bore hole. This casing must be screened or perforated and packed with gravel or sand, where necessary, to enable collection of ground-water samples. The annular space (i.e., the space between the bore hole and well casing) above the sampling depth must be sealed to prevent contamination of samples and the ground water.

(1) The owner or operator must notify the State Director that the design, installation, development, and decommission of any monitoring wells, piezometers and other measurement, sampling, and analytical devices documentation has been placed in the operating record; and

(2) The monitoring wells, piezometers, and other measurement, sampling, and analytical devices must be operated and maintained so that they perform to design specifications throughout the life of the monitoring program.

§258.52 [Reserved].

5.7.2 Applicability

The requirements for monitoring well design, installation, and maintenance are applicable to all wells installed at existing units, lateral expansions of units, and new MSWLF units. The design, installation, and decommissioning of any monitoring well must be documented in the operating record of the facility and certified by a qualified ground-water scientist. Documentation is required for wells, piezometers, sampling devices, and water level measurement instruments used in the monitoring program.

The monitoring wells must be cased to protect the integrity of the borehole. The design and construction of the well directly affects the quality and representativeness of the samples collected. The well casing must have a screened or perforated interval to allow the entrance of water into the well casing. The annular space between the well screen and the formation wall must be packed with material to inhibit the migration of formation material into the well. The well screen must have openings sized according to the packing material used. The annular space above the filter pack must be sealed to provide a discrete sampling interval.

All monitoring wells, piezometers, and sampling and analytical devices must be maintained in a manner that ensures their continued performance according to design specifications over the life of the monitoring program.

5.7.3 Technical Considerations

The design, installation, and maintenance of monitoring wells will affect the consistency and accuracy of samples collected. The design must be based on site-specific information. The formation material (lithology and grain size distribution) will determine the selection of proper packing and sealant materials, and the stratigraphy will determine the screen length for the interval to be monitored. Installation practices should be specified and overseen to ensure that the monitoring well is installed as designed and will perform as intended. This section will discuss the factors that must be considered when designing monitoring wells. Each well must be tailored to suit the hydrogeological setting, the contaminants to be monitored, and other site-specific factors. Figure 5-3 depicts the components of a typical monitoring well installation.

The following sections provide a brief overview of monitoring well design and construction. More comprehensive discussions are provided in USEPA (1989f) and USEPA (1992a).

Selection of Drilling Method

The method chosen for drilling a monitoring well depends largely on the following factors (USEPA, 1989f):

- Versatility of the drilling method
- Relative drilling cost
- Sample reliability (ground-water, soil, unconsolidated material, or rock samples)
- Availability of drilling equipment
- Accessibility of the drilling site
- Relative time required for well installation and development
- Ability of the drilling technology to preserve natural conditions
- Ability to install a well of desired diameter and depth
- Relative ease of well completion and development, including the ability to install the well in the given hydrogeologic setting.

In addition to these factors, USEPA (1989f) includes matrices to assist in selecting an appropriate drilling method. These matrices list the most commonly used drilling techniques for monitoring well installation, taking into consideration hydrogeologic settings and the objectives of the monitoring program.

The following basic performance objectives should guide the selection of drilling procedures for installing monitoring wells:

- Drilling should be performed in a manner that preserves the natural properties of the subsurface materials.
- Contamination and/or cross-contamination of ground water and aquifer materials during drilling should be avoided.
- The drilling method should allow for the collection of representative samples of rock, unconsolidated materials, and soil.
- The drilling method should allow the owner/operator to determine when the appropriate location for the screened interval has been encountered.
- The drilling method should allow for proper placement of the filter pack and annular sealants. The borehole should be at least 4 inches larger in diameter than the nominal diameter of the well casing and screen to allow adequate

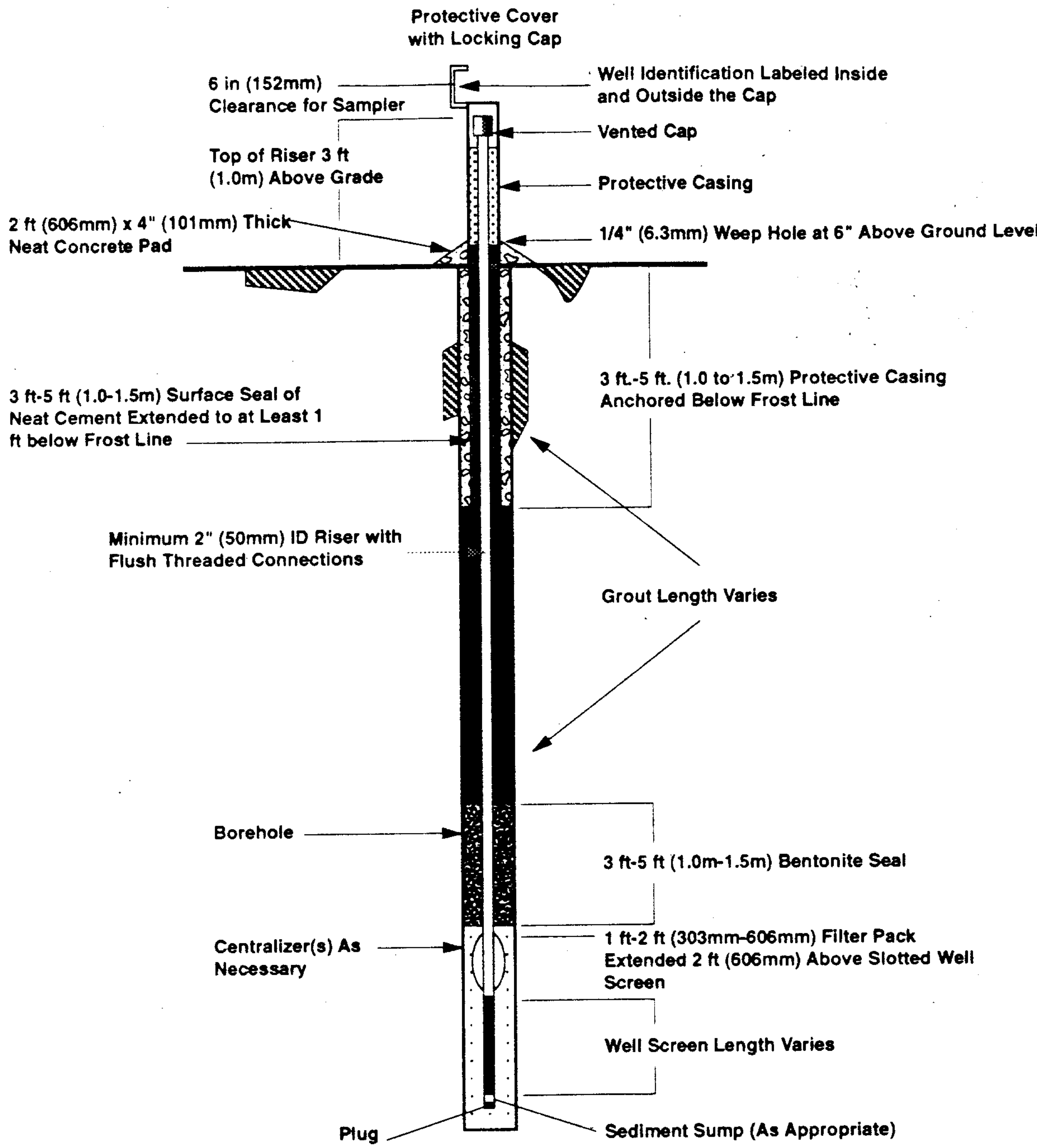


Figure 5.3. Example of a Monitoring Well Design-Single Cased Well

space for placement of the filter pack and annular sealants.

- The drilling method should allow for the collection of representative ground-water samples. Drilling fluids (including air) should be used only when minimal impact to the surrounding formation and ground water can be ensured.

The following guidelines apply to the use of drilling fluids, drilling fluid additives, and lubricants when drilling ground-water monitoring wells:

- Drilling fluids, drilling fluid additives, or lubricants that affect the analysis of hazardous constituents in ground-water samples should not be used.

- The owner/operator should demonstrate the inertness of drilling fluids, drilling fluid additives, and lubricants by performing analytical testing of drilling fluids, drilling fluid additives, and lubricants and/or by providing information regarding the composition of drilling fluids, drilling fluid additives, or lubricants obtained from the manufacturer.

- The owner/operator should consider the potential impact of drilling fluids, drilling fluid additives, and lubricants on the physical and chemical characteristics of the subsurface and on ground-water quality.

- The volume of drilling fluids, drilling fluid additives, and lubricants used during the drilling of a monitoring well should be recorded.

Monitoring Well Design

Well Casing

<u>Well Casing and Screen Materials</u>

A casing and well screen are installed in a ground-water monitoring well for several reasons: to provide access from the surface of the ground to some point in the subsurface, to prevent borehole collapse, and to prevent hydraulic communication between zones within the subsurface. In some cases, State or local regulations may specify the casing and material that the owner or operator should use. A comprehensive discussion of well casing and screen materials is provided in USEPA (1989f) and in USEPA (1992a). The following discussion briefly summarizes information contained in these references.

Monitoring well casing and screen materials may be constructed of any of several types of materials, but should meet the following performance specifications:

- Monitoring well casing and screen materials should maintain their structural integrity and durability in the environment in which they are used over their operating life.

- Monitoring well casings and screens should be resistant to chemical and microbiological corrosion and degradation in contaminated and uncontaminated waters.

- Monitoring well casings and screens should be able to withstand the physical forces acting upon them during and following their installation and during their use -- including forces due to suspension in the borehole, grouting, development, purging, pumping, and sampling and forces exerted on them by the surrounding geologic materials.

- Monitoring well casing and screen materials should not chemically alter ground-water samples, especially with respect to the analytes of concern, as a result of their sorbing, desorbing, or leaching analytes. For example, if chromium is an analyte of interest, the well casing or screen should not increase or decrease the amount of chromium in the ground water. Any material leaching from the casing or screen should not be an analyte of interest or interfere in the analysis of an analyte of interest.

In addition, monitoring well casing and screen materials should be relatively easy to install into the borehole during construction of the monitoring well.

The selection of the most suitable well casing and screen materials should consider site-specific factors, including:

- Depth to the water-bearing zone(s) to be monitored and the anticipated well depth

- Geologic environment

- Geochemistry of soil, unconsolidated material, and rock over the entire interval in which the well is to be cased

- Geochemistry of the ground water at the site, as determined through an initial analysis of samples from both background wells and downgradient wells and including:

  - Natural ground-water geochemistry

  - Nature of suspected or known contaminants

  - Concentration of suspected or known contaminants

- Design life of the monitoring well.

Casing materials widely available for use in ground-water monitoring wells can be divided into three categories:

1) <u>Fluoropolymer materials</u>, including polytetrafluoroethylene (PTFE), tetrafluoroethylene (TFE), fluorinated ethylene propylene (FEP), perfluoroalkoxy (PFA), and polyvinylidene fluoride (PVDF)

2) <u>Metallic materials</u>, including carbon steel, low-carbon steel, galvanized steel, and stainless steel (304 and 316)

3) <u>Thermoplastic materials</u>, including polyvinyl chloride (PVC) and acrylonitrile butadiene styrene (ABS).

In addition to these three categories of materials, fiberglass-reinforced plastic (FRP) has been used for monitoring applications. Because FRP has not yet been used in general application across the country, very little data are available on its characteristics and performance. All well construction materials possess strength-related characteristics and chemical resistance/chemical interference characteristics that influence their performance in site-specific hydrogeologic and contaminant-related monitoring situations.

The casing must be made of a material strong enough to last for the life of the well. Tensile strength is needed primarily during well installation when the casing is lowered into the hole. The joint strength will determine the maximum length of a section that can be suspended from the surface in an air-filled borehole.

Collapse strength is the capability of a casing to resist collapse by any external loads to which it is subjected both during and after installation. A casing is most susceptible to collapse during installation before placement of the filter pack or annular seal materials around the casing. Once a casing is installed and supported, collapse is seldom a concern. Several steps that can be taken to avoid casing collapse are:

1) Drilling a straight, clean borehole

2) Uniformly distributing filter pack materials at a slow, even rate

3) Avoiding use of quick-setting (high temperature) cements for thermoplastic casings installation.

Compressive strength of the casing is a measure of the greatest compressive stress that a casing can bear without deformation. Casing failure due to a compressive strength limitation generally is not an important factor in a properly installed well. This type of failure results from soil friction on unsupported casing.

Chemical resistance/interference characteristics must be evaluated before selecting monitoring well materials. Metallic casing materials are more subject to corrosion, while thermoplastic casing materials are more susceptible to chemical degradation. The geochemistry of the formation water influences the degree to which these processes occur. If ground-water chemistry affects the structural integrity of the casing, then the samples collected from the well are likely to be affected.

Materials used for monitoring well casing must not exhibit a tendency to sorb or leach chemical constituents from, or into, water sampled from the well. If a casing material sorbs constituents from ground water, those constituents may either not be detected during monitoring or be detected at a lower concentration. Chemical constituents also can be leached from the casing materials by aggressive aqueous solutions. These constituents may be detected in samples collected from the well. The results may indicate contamination that is due to the casing rather than the formation water. Casing materials must be selected with care to avoid degradation of the well and to avoid erroneous results.

In certain situations it may be advantageous to design a well using more than one material for well components. For example, where stainless steel or fluoropolymer materials are preferred in a specific chemical environment, costs may be saved by using PVC in non-critical portions of the well. These savings may be considerable, especially in deep wells where only the lower portion of the well is in a critical chemical environment and where tens of feet of lower-cost PVC may be used in the upper portion of the well. In a composite well design, dissimilar metallic components should not be used unless an electrically isolating design is incorporated (i.e., a dielectric coupling) (USEPA, 1986).

Coupling Procedures for Joining Casing

Only a limited number of methods are available for joining lengths of casing or casing and screen together. The joining method depends on the type of casing and type of casing joint.

There are generally two options available for joining metallic well casings: welding via application of heat, or threaded joints. Threaded joints provide inexpensive, fast, and convenient connections and greatly reduce potential problems with chemical resistance or interference (due to corrosion) and explosion potential. Wrapping the male threads with fluoropolymer tape prior to joining sections improves the watertightness of the joint. One disadvantage to using threaded joints is that the tensile strength of the casing string is reduced to approximately 70 percent of the casing strength. This reduction in strength does not usually pose a problem because strength requirements for small diameter wells (such as typical monitoring wells) are not as critical and because metallic casing has a high initial tensile strength.

Joints should create a uniform inner and outer casing diameter in monitoring well installations. Solvent cementing of thermoplastic pipe should never be used in the construction of ground-water monitoring wells. The cements used in solvent welding, which are organic chemicals, have been shown to adversely affect the integrity of ground-water samples for more than 2 years after well installation; only factory-threaded joints should be used on thermoplastic well material.

Well Casing Diameter

Although the diameter of the casing for a monitoring well depends on the purpose of the well, the casing size is generally selected to accommodate downhole equipment. Additional casing diameter selection criteria include the 1) drilling or well installation method used, 2) anticipated depth of the well and associated strength requirements, 3) anticipated method of well development, 4) volume of water required to be purged prior to sampling, 5) rate of recovery of the well after purging, and 6) anticipated aquifer testing.

Casing Cleaning Requirements

Well casing and screen materials should be cleaned prior to installation to remove any coatings or manufacturing residues. Prior to use, all casing and screen materials should be washed with a mild, non-phosphate, detergent/potable water solution and rinsed with potable water. Hot pressurized water, such as in steam cleaning, should be used to remove organic solvents, oils, or lubricants from casing and screens composed of materials other than plastic. At sites where volatile organic contaminants may be monitored, the cleaning of well casing and screen materials should include a final rinse with deionized water or potable water that has not been chlorinated. Once cleaned, casings and screens should be stored in an area that is free of potential contaminants. Plastic sheeting can generally be used to cover the ground in the decontamination area to provide protection from contamination. USEPA (1989f) describes the procedures that should be used to clean casing and screen materials.

Well Intake Design

The owner/operator should design and construct the intakes of monitoring wells to (1) accurately sample the aquifer zone that the well is intended to sample, (2) minimize the passage of formation materials (turbidity) into the well, and (3) ensure sufficient structural integrity to prevent the collapse of the intake structure. The goal of a properly completed monitoring well is to provide low turbidity water that is representative of ground-water quality in the vicinity of the well. Close attention to proper selection of packing materials and well development procedures for wells installed in fine-grained formations (e.g., clays and silty glacial tills) is important to minimize sample turbidity from suspended and colloidal solids. There may be instances where wells completed in rock do not require screens or filter packs; the State regulatory agency should be consulted prior to completion of unscreened wells.

The selection of screen length usually depends on the objective of the well. Piezometers and wells where only a discrete flow path is monitored (such as thin gravel interbedded with clays) are generally completed using short screens (2 feet or less). To avoid dilution, the well screens should be kept to the minimum length appropriate for intercepting a contaminant plume, especially in a high-yielding aquifer. The screen length should generally not exceed 10 feet. If construction of a water table well is the objective, either for defining gradient or detecting floating phases, then a longer screen is acceptable because the owner/operator will need to provide a margin of safety that will guarantee that at least a portion of the screen always contacts the water table regardless of its seasonal fluctuations. The owner or operator should not employ well intake designs that cut across hydraulically separated geologic units.

Well screen slot size should be selected to retain from 90 percent to 100 percent of the filter pack material (discussed below) in artificially filter packed wells. Well screens should be factory-slotted. Manual slotting of screens in the field should not be performed under any circumstances.

Filter Pack Design

The primary filter pack material should be a chemically inert material and well rounded, with a high coefficient of uniformity. The best filter pack materials are made from industrial grade glass (quartz) sand or beads. The use of other materials, such as local, naturally occurring clean sand, is discouraged unless it can be shown that the material is inert (e.g., low cation exchange capacity), coarse-grained, permeable, and uniform in grain size. The filter pack should extend at least 2 feet above the screened interval in the well.

Although design techniques for selecting filter pack size vary, all use the filter pack ratio to establish size differential between formation materials and filter pack materials. Generally, this ratio refers to either the average (50 percent retained) grain size of the formation material or to the 70 percent retained size of the formation material. Barcelona et al. (1985b) recommend using a uniform filter pack grain size that is three to five times the size of the 50 percent retained size of the formation material (USEPA, 1990).

Filter pack material should be installed in a manner that prevents bridging and particle-size segregation. Filter pack material installed below the water table should generally be tremied into the annular space. Allowing filter pack material to fall by gravity (free fall) into the annular space is only appropriate when wells are relatively shallow, when the filter pack has a uniform grain size, and when the filter pack material can be poured continuously into the well without stopping.

At least 2 inches of filter pack material should be installed between the well screen and the borehole wall. The filter pack should extend at least 2 feet above the top of the well screen. In deep wells, the filter pack may not compress when initially installed. Consequently, when the annular and surface seals are placed on the filter pack, the filter pack compresses sufficiently to allow grout into, or very close to, the screen. Consequently, filter packs may need to be installed as high as 5 feet above the screened interval in monitoring wells that are deep (i.e., greater than 200 feet). The precise volume of filter pack material required should be calculated and recorded before placement, and the actual volume used should be determined and recorded during well construction. Any significant discrepancy between the calculated volume and the actual volume should be explained.

Prior to installing the annular seal, a 1- to 2-foot layer of chemically inert fine sand may be placed over the filter pack to prevent the intrusion of annular or surface sealants into the filter pack. When designing monitoring wells, owners and operators should remember that the entire length of the annular space filled with filter pack material or sand is effectively the monitored zone. Moreover, if the filter pack/sand extends from the screened zone into an overlying zone, a conduit for hydraulic connection is created between the two zones.

Annular Sealants

Proper sealing of the annular space between the well casing and the borehole wall is required to prevent contamination of samples and the ground water. Adequate sealing will prevent hydraulic connection within the well annulus. The materials used for annular sealants should be chemically inert with the highest anticipated concentration of chemical constituents expected in the ground water at the facility. In general, the permeability of the sealing material should be one to two orders of magnitude lower than the least permeable part of the formation in contact with the well. The precise volume of annular sealants required should be calculated and recorded before placement, and the actual volume used should be determined and recorded during well construction. Any significant discrepancy between the calculated volume and the actual volume should be explained.

When the screened interval is within the saturated zone, a minimum of 2 feet of sealant material, such as raw (>10 percent solids) bentonite, should be placed immediately over the protective sand layer overlying the filter pack. Granular bentonite, bentonite pellets, and bentonite chips may be placed around the casing by means of a tremie pipe in deep wells (greater than approximately 30 feet deep), or by dropping them directly down the annulus in shallow wells (less than approximately 30 feet deep). Dropping the bentonite pellets down the annulus presents a potential for bridging (from premature hydration of the bentonite), leading to gaps in the seal below the bridge. In shallow monitoring wells, a tamping device should be used to prevent bridging from occurring.

A neat cement or shrinkage-compensated neat cement grout seal should be installed on top of the bentonite seal and extend vertically up the annular space between the well casing and the borehole wall to within a few feet of land surface. Annular sealants in slurry form (e.g., cement grout, bentonite slurry) should be placed by the tremie/pump (from the bottom up) method. The bottom of the placement pipe should be equipped with a side discharge deflector to prevent the slurry from jetting a hole through the protective sand layer, filter pack, or bentonite seal. The bentonite seal should be allowed to completely hydrate, set, or cure in conformance with the manufacturer's specifications prior to installing the grout seal in the annular space. The time required for the bentonite seal to completely hydrate, set, or cure will differ with the materials used and the specific conditions encountered, but is generally a minimum of 4 to 24 hours. Allowing the bentonite seal to hydrate, set, or cure prevents the invasion of the more viscous and more chemically reactive grout seal into the screened area.

When using bentonite as an annular sealant, the appropriate clay should be selected on the basis of the environment in which it is to be used, such as the ion-exchange potential of the sediments, sediment permeability, and compatibility with expected contaminants. Sodium bentonite is usually acceptable.

When the annular sealant must be installed in the unsaturated zone, neat cement or shrinkage-compensated neat cement mixtures should be used for the annular sealant. Bentonite is not recommended as an annular sealant in the unsaturated zone because the moisture available is insufficient to fully hydrate bentonite.

Surface Completion

Monitoring wells are commonly either above-ground completions or flush-to-ground completions. The design of both types must consider the prevention of infiltration of surface runoff into the well annulus and the possibility of accidental damage or vandalism. Completing a monitoring well involves installing the following components:

- Surface seal
- Protective casing
- Ventilation hole
- Drain hole
- Cap and lock
- Guard posts when wells are completed above grade.

A surface seal, installed on top of the grout seal, extends vertically up the well annulus to the land surface. To protect against frost heave, the seal should extend at least 1 foot below the frost line. The composition of the surface seal should be neat cement or concrete. In an above-ground completion, the surface seal should form at least a 2-foot wide, 4-inch thick apron.

A locking protective casing should be installed around the well casing to prevent damage or unauthorized entry. The protective casing should be anchored below the frost line (where applicable) into the surface seal and extend at least 18 inches above the surface of the ground. A 1/4-inch vent hole pipe is recommended to allow the escape of any potentially explosive gases that may accumulate within the well. In addition, a drain hole should be installed in the protective casing to prevent water from accumulating and, in freezing climates, freezing around the well casing. The space between the protective casing and the well casing may be filled with gravel to allow the retrieval of tools and to prevent small animal/insect entrance through the drain. A suitable cap should be placed on the well to prevent tampering or the entry of any foreign materials. A lock should be installed on the cap to provide security. To prevent corrosion or jamming of the lock, a protective cover should be used. Care should be taken when using such lubricants as graphite or petroleum-based sprays to lubricate the lock, as lubricants may introduce a potential for sample contamination.

To guard against accidental damage to the well from facility traffic, the owner/operator should install concrete or steel bumper guards around the edge of the concrete apron. These should be located within 3 or 4 feet of the well and should be painted orange or fitted with reflectors to reduce the possibility of vehicular damage.

The use of flush-to-ground surface completions should be avoided because this design increases the potential for surface water infiltration into the well. In cases where flush-to-ground completions are unavoidable, such as in active roadways, a protective structure, such as a utility vault or meter box, should be installed around the well casing. In addition, measures should be taken to prevent the accumulation of surface water in the protective structure and around the well intake. These measures should include outfitting the protective structure with a steel lid or manhole cover that has a rubber seal or gasket and ensuring that the bond between the cement surface seal and the protective structure is watertight.

<u>Well Surveying</u>

The location of all wells should be surveyed by a licensed professional surveyor (or equivalent) to determine their X-and-Y coordinates as well as their distances from the units being monitored and their distances from each other. A State Plane Coordinate System, Universal Transverse Mercator System, or Latitude/Longitude should be used, as approved by the Regional Administrator. The survey should also note the coordinates of any temporary benchmarks. A surveyed reference mark should be placed on the top of the well casing, not on the protective casing or the well apron, for use as a measuring point because the well casing is more stable than the protective casing or well apron (both the protective casing and the well apron are more susceptible to frost heave and spalling). The height of the reference survey datum, permanently marked on top of the inner well casing, should be determined within ±0.01 foot in relation to mean sea level, which in turn is determined by reference to an established National Geodetic Vertical Datum. The reference marked on top of inner well casings should be resurveyed at least once every 5 years, unless changes in ground-water flow patterns/direction, or damage caused by freeze/thaw or desiccation processes, are noted. In such cases, the Regional Administrator may require that well casings be resurveyed on a more frequent basis.

Well Development

All monitoring wells should be developed to create an effective filter pack around the well screen, to rectify damage to the formation caused by drilling, to remove fine particles from the formation near the borehole, and to assist in restoring the natural water quality of the aquifer in the vicinity of the well. Development stresses the formation around the screen, as well as the filter pack, so that mobile fines, silts, and clays are pulled into the well and removed. The process of developing a well creates a graded filter pack around the well screen. Development is also used to remove any foreign materials (drilling water, muds, etc.) that may have been introduced into the well borehole during drilling and well installation and to aid in the equilibration that will occur between the filter pack, well casing, and the formation water.

The development of a well is extremely important to ensuring the collection of representative ground-water samples. If the well has been properly completed, then adequate development should remove fines that may enter the well either from the filter pack or the formation. This improves the yield, but more importantly it creates a monitoring well capable of producing samples of acceptably low turbidity. Turbid samples from an improperly constructed and developed well may interfere with subsequent analyses.

When development is initiated, a wide range of grain sizes of the natural material is drawn into the well, and the well typically produces very turbid water. However, as development continues and the natural materials are drawn into the filter pack, an effective filter will form through a sorting process. Inducing movement of ground water into the well (i.e., in one direction) generally results in bridging of the particles. A means of inducing flow reversal is necessary to break down bridges and produce a stable filter.

The commonly accepted methods for developing wells are described in USEPA (1989f) and Driscoll (1986) and include:

- Pumping and overpumping

- Surging with a surge block

- Bailing.

USEPA (1989f) provides a detailed overview of well development and should be consulted when evaluating well development methods.

Documentation of Well Design, Construction, and Development

Information on the design, construction, and development of each well should be compiled. Such information should include (1) a boring log that documents well drilling and associated formation sampling and (2) a well construction log and well construction diagram ("as built").

Decommissioning Ground-Water Monitoring Wells and Boreholes

Ground-water contamination resulting from improperly decommissioned wells and boreholes is a serious concern. Any borehole that will not be completed as a monitoring well should be properly decommissioned. The USEPA (1975) and the American Water Works Association (1985) provide the following reasons, summarized by USEPA (1989f), as to why improperly constructed or unused wells should be properly decommissioned:

- To eliminate physical hazards
- To prevent ground-water contamination
- To conserve aquifer yield and hydrostatic head
- To prevent intermixing of subsurface water.

Should an owner or operator have a borehole or an improperly constructed or unused well at his or her facility, the well or borehole should be decommissioned in accordance with specific guidelines. USEPA (1989f) provides comprehensive guidance on performing well decommissioning that can be applied to boreholes. In addition, any State/Tribal regulatory guidance should be consulted prior to decommissioning monitoring wells, piezometers, or boreholes. Lamb and Kinney (1989) also provide information on decommissioning ground-water monitoring wells.

Many States require that specific procedures be followed and certain paperwork be filed when decommissioning water supply wells. In some States, similar regulations may apply to the decommissioning of monitoring wells and boreholes. The EPA and other involved regulatory agencies, as well as experienced geologists, geotechnical engineers, and drillers, should be consulted prior to decommissioning a well or borehole to ensure that decommissioning is performed properly and to ensure compliance with State law. If a well to be decommissioned is contaminated, the safe removal and proper disposal of the well materials should be ensured by the owner/operator. Appropriate measures should be taken to protect the health and safety of individuals when decommissioning a well or borehole.

5.8 GROUND-WATER SAMPLING AND ANALYSIS REQUIREMENTS 40 CFR §258.53

5.8.1 Statement of Regulation

(a) The ground-water monitoring program must include consistent sampling and analysis procedures that are designed to ensure monitoring results that provide an accurate representation of ground-water quality at the background and downgradient wells installed in compliance with §258.51(a) of this Part. The owner or operator must notify the State Director that the sampling and analysis program documentation has been placed in the operating record and the program must include procedures and techniques for:

(1) Sample collection;

(2) Sample preservation and shipment;

(3) Analytical procedures;

(4) Chain of custody control; and

(5) Quality assurance and quality control.

(b) The ground-water monitoring program must include sampling and analytical methods that are appropriate for ground-water sampling and that accurately measure hazardous constituents and other monitoring parameters in ground-water samples. Ground-water samples shall not be field-filtered prior to laboratory analysis.

(c) The sampling procedures and frequency must be protective of human health and the environment.

(d) Ground-water elevations must be measured in each well immediately prior to purging, each time ground water is sampled. The owner or operator must determine the rate and direction of ground-water flow each time ground water is sampled. Ground-water elevations in wells which monitor the same waste management area must be measured within a period of time short enough to avoid temporal variations in ground-water flow which could preclude accurate determination of ground-water flow rate and direction.

(e) The owner or operator must establish background ground-water quality in a hydraulically upgradient or background well(s) for each of the monitoring parameters or constituents required in the particular ground-water monitoring program that applies to the MSWLF unit, as determined under §258.54(a), or §258.55(a) of this Part. Background ground-water quality may be established at wells that are not located hydraulically upgradient from the MSWLF unit if it meets the requirements of §258.51(a)(1).

(f) The number of samples collected to establish ground-water quality data must be consistent with the appropriate statistical procedures determined pursuant to paragraph (g) of this section. The sampling procedures shall be those specified under §258.54(b) for detection monitoring, §258.55(b) and (d) for assessment monitoring, and §258.56(b) of corrective action.

5.8.2 Applicability

The requirements for sampling and analysis apply to all facilities required to conduct ground-water monitoring throughout the active life, closure, and post-closure periods of operation. Quality assurance and quality control measures for both field and laboratory activities must be implemented. The methods and procedures constituting the program must be placed in the operating record of the facility.

For the sampling and analysis program to be technically sound, the sampling procedures and analytical methods used should provide adequate accuracy, precision, and detection limits for the analyte determinations. Prior to sampling, the static ground-water elevations in the wells must be measured to allow determination of the direction of ground-water flow and estimates of rate of flow. The time interval between measurements at different wells must be minimized so that temporal changes in ground-water elevations do not cause an incorrect determination of ground-water flow direction.

Background ground-water quality must be established at all upgradient or background wells. The background water quality may be determined from wells that are not upgradient of the MSWLF unit, provided that the wells yield representative ground-water samples.

The sampling program must be designed in consideration of the anticipated statistical method applied by the owner or operator. The data objectives of the monitoring program, in terms of the number of samples collected and the frequency of collection, should be appropriate for the statistical method selected for data comparison.

5.8.3 Technical Considerations

The purpose of a ground-water sampling and analysis program is to establish a protocol that can be followed throughout the monitoring period of the site (operating, closure, and post-closure). The protocol is necessary so that data acquired can be compared over time and accurately represent ground-water quality. Sample collection, preservation, shipment, storage, and analyses should always be performed in a consistent manner, even as monitoring staff change during the monitoring period.

The owner's/operator's ground-water monitoring program must include a description of procedures for the following:

- Sample collection
- Sample preservation and shipment
- Analytical procedures
- Chain of custody control
- Quality assurance and quality control.

The ground-water monitoring program must be documented in the operating record of the facility.

The objectives of the monitoring program should clearly define the quality of the data required to detect significant changes in ground-water chemistry due to the operation of the solid waste disposal facility. These data quality objectives should address:

- Accuracy and precision of methods used in the analysis of samples, including field measurements
- Quality control and quality assurance procedures used to ensure the validity of the results (e.g., use of blank samples, record keeping, and data validation)
- Number of samples required to obtain a certain degree of statistical confidence
- Location and number of monitoring wells required.

Sample Collection

Frequency

The frequency of sample collection under detection monitoring should be evaluated for each site according to hydrogeologic conditions and landfill design. In States, the minimum sampling frequency should be semiannual. The background characterization should include four independent samples at each monitoring location during the first semi-annual event (i.e., during the first 6 months of monitoring). (See the discussion under Section 5.10.3 on collecting independent samples to determine background.) More frequent sampling may be selected. For example, quarterly sampling may be conducted to evaluate seasonal effects on ground-water quality.

The frequency of sample collection during assessment monitoring activities will depend on site-specific hydrogeologic conditions and contaminant properties. The frequency of sampling is intended to obtain a data set that is statistically independent of the previous set. Guidance to estimate this minimum time to obtain independent samples is provided in "Statistical Analysis of Ground-water Monitoring Data at RCRA Facilities - Interim Final Guidance" (USEPA, 1989).

Water Level Measurements

The ground-water monitoring program must include provisions for measuring static water level elevations in each well prior to purging the well for sampling. Measurements of ground-water elevations are used for determining horizontal and vertical hydraulic gradients for estimation of flow rates and direction.

Field measurements may include the following:

- Depth to standing water from a surveyed datum on the top of the well riser (static water level)
- Total depth of well from the top of the riser (to verify condition of well)
- Thickness of immiscible layers, if present.

Measurements of the static water level and the depth to the well bottom can be made with a wetted steel tape. Electronic water level measuring devices may also be used. Accepted standard operating procedures call for the static water level to be accurately measured to within 0.01 foot (USEPA, 1992a). Water level measurements should be made at all monitoring wells and well clusters in a time frame that avoids changes that may occur as a result of barometric pressure changes, significant infiltration events, or aquifer pumping. To prevent possible cross contamination of wells, water level measurement devices must be decontaminated prior to use at each well.

The ground-water monitoring program should include provisions for detecting immiscible fluids (i.e., LNAPLs or DNAPLs). LNAPLs are relatively immiscible liquids that are less dense than water and that spread across the water table surface. DNAPLs are relatively immiscible liquids that are more dense than the ground water and tend to migrate vertically downward in aquifers. The detection of an immiscible layer may require specialized equipment and should be performed before the well is evacuated for conventional sampling. The ground-water monitoring program should specify how DNAPLs and LNAPLs will be detected. The program also should include a contingency plan describing procedures for sampling and analyzing these liquids. Guidance for detecting the presence of immiscible layers can be found in USEPA (1992a).

Well Purging

Because the water standing in a well prior to sampling may not represent in-situ ground-water quality, stagnant water should be purged from the well and filter pack prior to sampling. The QAPjP should include detailed, step-by-step procedures for purging wells, including the parameters that will be monitored during purging and the equipment that will be used for well purging.

Purging should be accomplished by removing ground water from the well at low flow rates using a pump. The use of bailers to purge monitoring wells generally should be avoided. Research has shown that the "plunger" effect created by continually raising and lowering the bailer into the well can result in continual development or overdevelopment of the well. Moreover, the velocities at which ground water enters a bailer can actually correspond to unacceptably high purging rates (Puls and Powell, 1992; Barcelona et al., 1990).

The rate at which ground water is removed from the well during purging ideally should be approximately 0.2 to 0.3 L/min or less (Puls and Powell, 1992; Puls et al., 1991; Puls and Barcelona, 1989a; Barcelona, et al., 1990). Wells should be purged at rates below those used to develop the well to prevent further development of the well, to prevent damage to the well, and to avoid disturbing accumulated corrosion or reaction products in the well (Kearl et al., 1992; Puls et al., 1990; Puls and Barcelona, 1989a; Puls and Barcelona, 1989b; Barcelona, 1985b). Wells also should be purged at or below their recovery rate so that migration of water in the formation above the well screen does not occur. A low purge rate also will reduce the possibility of stripping VOCs from the water, and will reduce the likelihood of mobilizing colloids in the subsurface that are immobile under natural flow conditions. The owner/operator should ensure that purging does not cause formation water to cascade down the sides of the well screen. At no time should a well be purged to dryness if recharge causes the formation water to cascade down the sides of the screen, as this will cause an accelerated loss of volatiles. This problem should be anticipated; water should be purged from the well at a rate that does not cause recharge water to be excessively agitated. Laboratory experiments have shown that unless cascading is prevented, up to 70 percent of the volatiles present could be lost before sampling.

To eliminate the need to dispose of large volumes of purge water, and to reduce the amount of time required for purging, wells may be purged with the pump intake just above or just within the screened interval. This procedure eliminates the need to purge the column of stagnant water located above the well screen (Barcelona et al., 1985b; Robin and Gillham, 1987; Barcelona, 1985b; Kearl et al., 1992). Purging the well at the top of the well screen should ensure that fresh water from the aquifer moves through the well screen and upward within the screened interval. Pumping rates below the recharge capability of the aquifer must be maintained if purging is performed with the pump placed at the top of the well screen, below the stagnant water column above the top of the well screen (Kearl et al., 1992). The Agency suggests that a packer be placed above the screened interval to ensure that "stagnant" casing water is not drawn into the pump. The packer should be kept inflated in the well until after ground-water samples are collected.

In certain situations, purging must be performed with the pump placed at, or immediately below, the air/water interface.

If a bailer must be used to sample the well, the well should be purged by placing the pump intake immediately below the air/water interface. This will ensure that all of the water in the casing and filter pack is purged, and it will minimize the possibility of mixing and/or sampling stagnant water when the bailer is lowered down into the well and subsequently retrieved (Keeley and Boateng, 1987). Similarly, purging should be performed at the air/water interface if sampling is not performed immediately after the well is purged without removing the pump. Pumping at the air/water interface will prevent the mixing of stagnant and fresh water when the pump used to purge the well is removed and then lowered back down into the well for the purpose of sampling.

In cases where an LNAPL has been detected in the monitoring well, special procedures should be used to purge the well. These procedures are described in USEPA (1992a).

For most wells, the Agency recommends that purging continue until measurements of turbidity, redox potential, and dissolved oxygen in in-line or downhole analyses of ground water have stabilized within approximately 10% over at least two measurements (Puls and Powell, 1992; Puls and Eychaner, 1990; Puls et al., 1990; Puls and Barcelona, 1989a; Puls and Barcelona, 1989b; USEPA, 1991; Barcelona et al., 1988b). If a well is purged to dryness or is purged such that full recovery exceeds two hours, the well should be sampled as soon as a sufficient volume of ground water has entered the well to enable the collection of the necessary ground-water samples.

All purging equipment that has been or will be in contact with ground water should be decontaminated prior to use. If the purged water or the decontamination water is contaminated (e.g., based on analytical results), the water should be stored in appropriate containers until analytical results are available, at which time proper arrangements for disposal or treatment should be made (i.e., contaminated purge water may be a hazardous waste).

Field Analyses

Several constituents or parameters that owners or operators may choose to include in a ground-water monitoring program may be physically or chemically unstable and should be tested after well purging and before the collection of samples for laboratory analysis. Examples of unstable parameters include pH, redox (oxidation-reduction) potential, dissolved oxygen, temperature, and specific conductance.

Field analyses should not be performed on samples designated for laboratory analysis. Any field monitoring equipment or field-test kits should be calibrated at the beginning of each use, according to the manufacturers' specifications and consistent with methods in SW-846 (USEPA, 1986b).

Sample Withdrawal and Collection

The equipment used to withdraw a ground-water sample from a well must be selected based on consideration of the parameters to be analyzed in the sample. To ensure the sample is representative of ground water in the formation, it is important to keep physical or chemical alterations of the sample to a minimum. USEPA (1992a) provides an overview of the issues involved in selecting ground-water sampling equipment, and a summary of the application and limitations of various sampling mechanisms. Sampling materials and equipment should be selected to preserve sample integrity. Sampling equipment should be constructed of inert material. Sample collection equipment should not alter analyte concentrations, cause loss of analytes via sorption, or cause gain of analytes via desorption, degradation, or corrosion. Sampling equipment should be designed such that Viton®, Tygon®, silicone, or neoprene components do not come into contact with the ground-water sample. These materials have been demonstrated to cause sorptive losses of contaminants (Barcelona et al., 1983; Barcelona et al., 1985b; Barcelona et al., 1988b; Barcelona et al., 1990). Barcelona (1988b) suggests that sorption of volatile organic compounds on silicone, polyethylene, and PVC tubing may result in gross errors when determining concentrations of trace organics in ground-water samples. Barcelona (1985b) discourages the use of PVC sampling equipment when sampling for organic contaminants. Fluorocarbon resin (e.g., Teflon®) or stainless steel sampling devices which can be easily disassembled for thorough decontamination are widely used. Dedicating sampling equipment to each monitoring well will help prevent cross-contamination problems that could arise from improper decontamination procedures.

Sampling equipment should cause minimal sample agitation and should be selected to reduce/eliminate sample contact with the atmosphere during sample transfer. Sampling equipment should not allow volatilization or aeration of samples to the extent that analyte concentrations are altered.

Bladder pumps are generally recognized as the best overall sampling device for both organic and inorganic constituents, although other types of pumps (e.g., low-rate submersible centrifugal pumps, helical rotor electric submersible pumps) have been found suitable in some applications. Bailers, although inexpensive and simple to use, have been found to cause volatilization of samples, mobilization of particulates in wells and imprecise results (USEPA, 1992a).

The following recommendations apply to the use and operation of ground-water sampling equipment:

- Check valves should be designed and inspected to ensure that fouling problems do not reduce delivery capabilities or result in aeration of samples.

- Sampling equipment should never be dropped into the well, as this will cause degassing of the water upon impact.

- Contents of the sampling device should be transferred to sample containers in a controlled manner that will minimize sample agitation and aeration.

- Decontaminated sampling equipment should not be allowed to come into contact with the ground or other contaminated surfaces prior to insertion into the well.

- Ground-water samples should be collected as soon as possible after the well is purged. Water that has remained in the well casing for more than about 2 hours has had the opportunity to exchange gases with the atmosphere and to interact with the well casing material (USEPA, 1991b).

- The rate at which a well is sampled should not exceed the rate at which the well was purged. Low sampling rates, approximately 0.1 L/min, are suggested. Low sampling rates will help to ensure that particulates, immobile in the subsurface under ambient conditions, are not entrained in the sample and that volatile compounds are not stripped from the sample (Puls and Barcelona, 1989b; Barcelona, et al., 1990; Puls et al., 1991; Kearl et al., 1992; USEPA, 1991b). Pumps should be operated at rates less than 0.1 L/min when collecting samples for volatile organics analysis.

- Pump lines should be cleared at a rate of 0.1 L/min or less before collecting samples for volatiles analysis so that the samples collected will not be from the period of time when the pump was operating more rapidly.

- Pumps should be operated in a continuous manner so that they do not produce samples that are aerated in the return tube or upon discharge.

- When sampling wells that contain LNAPLs, a stilling tube should be inserted in the well. Ground-water samples should be collected from the screened interval of the well below the base of the tube.

- Ground-water samples collected for analysis for organic constituents or parameters should not be filtered in the field.

Once appropriate sampling equipment has been selected and operating procedures established, samples should be collected and containerized in the order of the volatilization sensitivity of the parameter. The preferred collection order for some of the more common ground-water analytes is depicted on the flow chart shown in Figure 5-4.

The ground-water monitoring program documentation should include explicit procedures for disassembly and decontamination of sampling equipment before each use. Improperly decontaminated equipment can affect samples in several ways. For example, residual contamination from the previous well may remain on equipment, or improper decontamination may not remove all of the detergents or solvents used during decontamination. Specific guidance regarding decontamination of the sampling equipment is available (USEPA 1992a). To keep sample cross-contamination to a minimum, sampling should proceed from upgradient or background locations to downgradient locations that would contain higher concentrations of contaminants.

Sample Preservation and Handling

The procedures for preserving and handling samples are nearly as important for ensuring the integrity of the samples as the collection device itself. Detailed procedures for sample preservation must be provided in the Quality Assurance Project Plan (QAPjP) that is included in the sampling and analysis program description.

STEP	*PROCEDURE*	*ESSENTIAL ELEMENTS*
Well Inspection	Hydrologic Measurements	Water Level Measurements
Well Purging	Removal or Isolation of Stagnant Water	Representative Water Access
	Determination of Well-Purging Parameters (pH, Eh, -π, Ω)*	Verification of Representative Water Sample Access
Sample Collection** Field Determinations*		Sample Collection by Appropriate Mechanism Minimal Sample Handling
	Volatile Organics, TOX	Head-Space Free Samples
	Dissolved Gases, TOC	Head Space Free Samples
	Large Volume Samples for Organic Compound Determinations	Minimal Aeration or Depressurization
	Metal Samples Cyanides	Adequate Rinsing against Contamination
Preservation Field Blanks Standards	Assorted Sensitive Inorganic Species NO_2^-, NH_4^+, Fe(II)	
	Major Cations and Anions	
	(as needed for good QA/QC)	Minimal Air Contact, Preservation
Storage Transport		Minimal Loss of Sample Integrity Prior to Analysis

* Denotes analytical determinations which should be made in the field.
** This is a suggested order for sampling, not all parameters are required by Part 258.

Figure 5-4
Generalized Flow Diagram of Ground-Water Sampling Steps

Sample Containers

To avoid altering sample quality, the samples should be transferred from the sampling equipment directly into a prepared container. Proper sample containers for each constituent or group of constituents are identified in SW-846 (USEPA, 1986b). Samples should never be composited in a common container in the field and then split. Sample containers should be cleaned in a manner that is appropriate for the constituents to be analyzed. Cleaning procedures are provided by USEPA (1986b). Sample containers that have been cleaned according to these procedures can be procured commercially.

Most vendors will provide a certification of cleanliness.

Sample Preservation

During ground-water sampling, every attempt should be made to minimize changes in the chemistry of the samples. To assist in maintaining the natural chemistry of the samples, it is necessary to preserve the sample. The owner or operator should refer to SW-846 (USEPA, 1986b) for the specific preservation method and holding times for each constituent to be analyzed. Methods of sample preservation are relatively limited and are intended to retard chemical reactions, such as oxidation, retard, biodegradation, and to reduce the effects of sorption. Preservation methods are generally limited to pH control, refrigeration, and protection from light.

Sample Storage and Shipment

The storage and transport of ground-water samples must be performed in a manner that maintains sample quality. Samples should be cooled to 4°C as soon as possible after they are collected. These conditions should be maintained until the samples are received at the laboratory. Sample containers generally are packed in picnic coolers or special containers for shipment.

Polystyrene foam, vermiculite, and "bubble pack" are frequently used to pack sample containers to prevent breakage. Ice is placed in sealed plastic bags and added to the cooler. All related paperwork is sealed in a plastic bag and taped to the inside top of the cooler. The cooler top is then taped shut. Custody seals should be placed across the hinges and latches on the outside of the cooler.

Transportation arrangements should maintain proper storage conditions and provide for effective sample pickup and delivery to the laboratory. Sampling plans should be coordinated with the laboratory so that appropriate sample receipt, storage, analysis, and custody arrangements can be provided.

Most analyses must be performed within a specified period (holding time) from sample collection. Holding time refers to the period that begins when the sample is collected from the well and ends with its extraction or analysis. Data from samples not analyzed within the recommended holding times should be considered suspect. Some holding times for Appendix I constituents are as short as 7 days. To provide the laboratory with operational flexibility in meeting these holding times, samples usually are shipped via overnight courier. Laboratory capacity or operating hours may influence sampling schedules. Coordination with laboratory staff during planning and sampling activities is important in maintaining sample and analysis quality.

The documentation that accompanies samples during shipment to the laboratory usually includes chain-of-custody (including a listing of all sample containers), requested analyses, and full identification of the origin of samples (including contact names, phone numbers, and addresses). Copies of all documents shipped with the samples should be retained by the sampler.

Chain-of-Custody Record

To document sample possession from the time of collection, a chain-of-custody record should be filled out to accompany every sample shipment. The record should contain the following types of information:

- Sample number
- Signature of collector
- Date and time of collection
- Media sampled (e.g., ground water)
- Sample type (e.g., grab)
- Identification of sampling location/well
- Number of containers
- Parameters requested for analysis
- Signatures of persons involved in the chain of possession
- Inclusive dates of possession with time in 24-hour notation
- Internal temperature of shipping container when samples were sealed into the container for shipping
- Internal temperature of container when opened at the laboratory
- Any remarks regarding potential hazards or other information the laboratory may need.

An adequate chain-of-custody program allows for tracing the possession and handling of individual samples from the time of collection through completion of laboratory analysis. A chain-of-custody program should include:

- Sample labels to prevent misidentification of samples
- Sample custody seals to preserve the integrity of the samples from the time they are collected until they are opened in the laboratory
- Field notes to record information about each sample collected during the ground-water monitoring program
- Chain-of-custody record to document sample possession from the time of collection to analysis
- Laboratory storage and analysis records, which are maintained at the laboratory and which record pertinent information about the sample.

Sample Labels

Each sample's identification should be marked clearly in waterproof ink on the sample container. To aid in labeling, the information should be written on each container prior to filling with a sample. The labels should be sufficiently durable to remain legible even when wet and should contain the following information:

- Sample identification number
- Name and signature of the sampler
- Date and time of collection
- Sample location
- Analyses requested.

Sample Custody Seal

Sample custody seals should be placed on the shipping container and/or individual sample bottle in a manner that will break the seal if the container or sample is tampered with.

Field Logbook

To provide an account of all activities involved in sample collection, all sampling activities, measurements, and observations should be noted in a field log. The information should include visual appearance (e.g., color, turbidity, degassing, surface film), odor (type, strength), and field measurements and calibration results. Ambient conditions (temperature, humidity, wind, precipitation) and well purging and sampling activities should also be recorded as an aid in evaluating sample analysis results.

The field logbook should document the following:

- Well identification
- Well depth
- Static water level depth and measurement technique
- Presence and thickness of immiscible layers and the detection method
- Well yield (high or low) and well recovery after purging (slow, fast)
- Well purging procedure and equipment
- Purge volume and pumping rate
- Time well purged
- Collection method for immiscible layers
- Sample withdrawal procedure and equipment
- Date and time of sample collection
- Results of field analysis
- Well sampling sequence
- Types of sample bottles used and sample identification numbers
- Preservatives used
- Parameters requested for analysis
- Field observations of sampling event
- Name of collector
- Weather conditions, including air temperature

- Internal temperature of field and shipping containers.

Sample Analysis Request Sheet

A sample analysis request sheet should accompany the sample(s) to the laboratory and clearly identify which sample containers have been designated for each requested parameter and the preservation methods used. The record should include the following types of information:

- Name of person receiving the sample
- Laboratory sample number (if different from field number)
- Date of sample receipt
- Analyses to be performed (including desired analytical method)
- Information that may be useful to the laboratory (e.g., type and quantity of preservatives added, unusual conditions).

Laboratory Records

Once the sample has been received in the laboratory, the sample custodian and/or laboratory personnel should clearly document the processing steps that are applied to the sample. All sample preparation (e.g., extraction) and determinative steps should be identified in the laboratory records. Deviations from established methods or standard operating procedures (SOPs), such as the use of specific reagents (e.g., solvents, acids), temperatures, reaction times, and instrument settings, should be noted. The results of the analyses of all quality control samples should be identified for each batch of ground-water samples analyzed. The laboratory logbook should include the time, date, and name of the person who performed each processing step.

Analytical Procedures

The requirements of 40 CFR Part 258 include detection and assessment monitoring activities. Under detection monitoring, the constituents listed in 40 CFR Part 258, Appendix I are to be analyzed for. This list includes volatile organic compounds (VOCs) and selected inorganic constituents. No specific analytical methods are cited in the regulations, but there is a requirement (40 CFR §258.53(h)(5)) that any practical quantitation limit (PQL) used in subsequent statistical analysis "be the lowest concentration level that can be reliably achieved within specified limits of precision and accuracy during routine laboratory operating conditions that are available to the facility." Suggested test methods are listed in Appendix II of Part 258 for informational purposes only. Method 8240 (gas chromatography with packed column; mass spectrometry) and Method 8260 (gas chromatography with capillary column; mass spectrometry) are typical methods used for all Appendix I VOCs. The inorganic analyses can be performed using inductively coupled plasma atomic emission spectroscopy (ICP) Method 6010. These methods, as well as other methods appropriate to these analyses, are presented in *Tests Methods for Evaluating Solid Waste, Physical/Chemical Methods*, SW-846 (USEPA, 1986), and are routinely performed by numerous analytical testing laboratories. These methods typically provide PQLs in the 1 to 50 µg/L range. The ground-water monitoring plan must specify the analytical method to be used.

Evaluation and documentation of analytical performance requires that quality control samples be collected and analyzed along with the ground-water monitoring samples. Chapter One of SW-846 (Quality Assurance) describes the types of quality control samples necessary, as well as the frequency at which they must be collected and analyzed. In general, these quality control samples may include trip blanks, equipment rinsate samples, field duplicates, method blanks, matrix spikes and duplicates, and laboratory control samples.

Other mechanisms, including sample holding times, surrogate constituents, and standard additions, are also used to control and document data quality. The specification of and adherence to sample holding times minimizes the sample degradation that occurs over time. Evaluating the recovery of surrogate constituents spiked into organic samples allows the analyst and data user to monitor the efficiency of sample extraction and analysis. The method of standard additions is used to eliminate the effects of matrix interferences in inorganic analyses.

Quality Assurance/Quality Control

One of the fundamental responsibilities of the owner or operator is to establish a continuing program to ensure the reliability and validity of field and analytical laboratory data gathered as part of the overall ground-water monitoring program. The owner or operator must explicitly describe the QA/QC program that will be used in the laboratory. Most owners or operators will use commercial laboratories to conduct analyses of ground-water samples. In these cases, the owner or operator is responsible for ensuring that the laboratory of choice is exercising an appropriate QA/QC program.

The owner or operator should provide for the use of standards, laboratory blanks, duplicates, and spiked samples for calibration and identification of potential matrix interferences, especially for metal determinants. Refer to Chapter One of SW-846 for guidance. The owner or operator should use adequate statistical procedures (e.g., QC charts) to monitor and document performance and to implement an effective program to resolve testing problems (e.g., instrument maintenance, operator training). Data from QC samples (e.g., blanks, spiked samples) should be used as a measure of performance or as an indicator of potential sources of cross-contamination, but should not be used by the laboratory to alter or correct analytical data. All laboratory QC data should be submitted with the ground-water monitoring sample results.

Field Quality Assurance/Quality Control

To verify the precision of field sampling procedures, field QC samples, such as trip blanks, equipment blanks, and duplicates, should be collected. Additional volumes of sample also should be collected for laboratory QC samples.

All field QC samples should be prepared exactly as regular investigation samples with regard to sample volume, containers, and preservation. The concentrations of any contaminants found in blank samples should not be used to correct the ground-water data. The contaminant concentrations in blanks should be documented, and if the concentrations are more than an order of magnitude greater than the field sample results, the owner/operator should resample the ground water. The owner/operator should prepare the QC samples as recommended in Chapter One of SW-846 and at the frequency recommended by Chapter One of SW-846 and should analyze them for all of the required monitoring parameters. Other QA/QC practices, such as sampling equipment calibration, equipment decontamination procedures, and chain-of-custody procedures, are discussed in other sections of this chapter and should be described in the owner/operator's QAPjP.

Validation

The analytical data report provided by the laboratory will present all data measured by the laboratory but will not adjust those data for field or laboratory quality control indicators. This means that just because data have been reported, they are not necessarily an accurate representation of the quality of the ground water. For example, acetone and methylene chloride are often used in laboratories as cleaning and extraction solvents and, consequently, are often laboratory contaminants, transmitted through the ambient air into samples. Method blanks are analyzed to evaluate the extent of laboratory contamination. Constituents found as contaminants in the method blanks are "flagged" in the sample data. The sample data are not, however, adjusted for the contaminant concentration.

Other kinds of samples are analyzed to assess other data quality indicators. Trip blanks are used to assess contamination by volatile organic constituents during sample shipment and storage. Matrix spike/matrix spike duplicate sample pairs are used to evaluate analytical bias and precision. Equipment rinsate samples are used to assess the efficacy of sampling equipment decontamination procedures. The data validation process uses the results from all of these QC samples to determine if the reported analytical data accurately describe the samples. All reported data must be evaluated -- a reported value of "non-detect" is a quantitative report just like a numerical value and must be validated.

The data validation process must also consider the presence and quality of other kinds of data used to ensure data quality (e.g., calibration frequency and descriptors, matrix specific detection limits). All of the criteria for data quality are described in the quality assurance project plan (QAPjP) or sampling and analysis plan (SAP). These documents may reference criteria from some other source, (e.g., the USEPA Contract Laboratory Program). The performance criteria must be correctly specified and must be used for data validation. It is a waste of time and money to evaluate data against standards other than those used to generate them. Several documents are available to assist the reviewer in validation of data by different criteria (i.e., Chapter One of *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods,* USEPA CLP *Functional Guidelines for Evaluating Organics Analyses,* USEPA CLP *Functional Guidelines for Evaluating Pesticides/PCBs Analyses,* etc.).

In addition to specific data that describe data quality, the validator may consider other information that may have an impact on the end-use of the data, such as background concentrations of the constituent in the environment. In any event, the QAPjP or SAP also should describe the validation procedures that will be used. The result of this validation should be the classification of data as acceptable or unacceptable for the purposes of the project. In some cases, data may be further qualified, based either on insufficient data or marginal performance (i.e., qualitative uses only, estimated concentration, etc.).

Documentation

The ground-water monitoring program required by §258.50 through §258.55 relies on documentation to demonstrate compliance. The operating record of the MSWLF should include a complete description of the program as well as periodic implementation reports.

At a minimum, the following aspects of the ground-water monitoring program should be described or included in the operating record:

- The Sampling and Analysis plan that details sample parameters, sampling frequency, sample collection, preservation, and analytical methods to be used, shipping procedures, and chain-of-custody procedures;

- The Quality Assurance Project Plan (QAPjP) and Data Quality Objectives (DQOs);

- The locations of monitoring wells;

- The design, installation, development, and decommission of monitoring wells, piezometers, and other measurement, sampling, and analytical devices;

- Site hydrogeology;

- Statistical methods to be used to evaluate ground-water monitoring data and demonstrate compliance with the performance standard;

- Approved demonstration that monitoring requirements are suspended (if applicable);

- Boring logs;

- Piezometer and well construction logs for the ground-water monitoring system.

5.9 STATISTICAL ANALYSIS 40 CFR §258.53 (g)-(i)

5.9.1 Statement of Regulation

(g) The owner or operator must specify in the operating record one of the following statistical methods to be used in evaluating ground-water monitoring data for each hazardous constituent. The statistical test chosen shall be conducted separately for each hazardous constituent in each well.

(1) A parametric analysis of variance (ANOVA) followed by multiple comparisons procedures to identify statistically significant evidence of contamination. The method must include estimation and testing of the contrasts between each compliance well's mean and the background mean levels for each constituent.

(2) An analysis of variance (ANOVA) based on ranks followed by multiple comparisons procedures to identify statistically significant evidence of contamination. The method must include

estimation and testing of the contrasts between each compliance well's median and the background median levels for each constituent.

(3) A tolerance or prediction interval procedure in which an interval for each constituent is established from the distribution of the background data, and the level of each constituent in each compliance well is compared to the upper tolerance or prediction limit.

(4) A control chart approach that gives control limits for each constituent.

(5) Another statistical test method that meets the performance standards of §258.53(h). The owner or operator must place a justification for this alternative in the operating record and notify the State Director of the use of this alternative test. The justification must demonstrate that the alternative method meets the performance standards of §258.53(h).

(h) Any statistical method chosen under §258.53(g) shall comply with the following performance standards, as appropriate:

(1) The statistical method used to evaluate ground-water monitoring data shall be appropriate for the distribution of chemical parameters or hazardous constituents. If the distribution of the chemical parameters or hazardous constituents is shown by the owner or operator to be inappropriate for a normal theory test, then the data should be transformed or a distribution-free theory test should be used. If the distributions for the constituents differ, more than one statistical method may be needed.

(2) If an individual well comparison procedure is used to compare an individual compliance well constituent concentration with background constituent concentrations or a ground-water protection standard, the test shall be done at a Type I error level of no less than 0.01 for each testing period. If a multiple comparisons procedure is used, the Type I experiment wise error rate for each testing period shall be no less than 0.05; however, the Type I error of no less than 0.01 for individual well comparisons must be maintained. This performance standard does not apply to tolerance intervals, prediction intervals, or control charts.

(3) If a control chart approach is used to evaluate ground-water monitoring data, the specific type of control chart and its associated parameter values shall be protective of human health and the environment. The parameters shall be determined after considering the number of samples in the background data base, the data distribution, and the range of the concentration values for each constituent of concern.

(4) If a tolerance interval or a predictional interval is used to evaluate ground-water monitoring data, the levels of confidence and, for tolerance intervals, the percentage of the population that the interval must contain, shall be protective of human health and the environment. These parameters shall be determined after considering the number of samples in the background data base, the data distribution, and the range of the concentration values for each constituent of concern.

(5) The statistical method shall account for data below the limit of detection with one or more statistical procedures that are protective of human health and the environment. Any practical quantitation limit (PQL) that is used in the statistical method shall be the lowest concentration level that can be reliably achieved within specified limits of precision and accuracy during routine laboratory operating conditions that are available to the facility.

(6) If necessary, the statistical method shall include procedures to control or correct for seasonal and spatial variability as well as temporal correlation in the data.

(i) The owner or operator must determine whether or not there is a statistically significant increase over background values for each parameter or constituent required in the particular ground-water monitoring program that applies to the MSWLF unit, as determined under §§258.54(a) or 258.55(a) of this part.

(1) In determining whether a statistically significant increase has occurred, the owner or operator must compare the ground-water quality of each parameter or constituent at each monitoring well designated pursuant to §258.51(a)(2) to the background value of that constituent, according to the statistical procedures and performance standards specified under paragraphs (g) and (h) of this section.

(2) Within a reasonable period of time after completing sampling and analysis, the owner or operator must determine whether there has been a statistically significant increase over background at each monitoring well.

5.9.2 Applicability

The statistical analysis requirements are applicable to all existing units, new units, and lateral expansions of existing units for which ground-water monitoring is required. The use of statistical procedures to evaluate monitoring data shall be used for the duration of the monitoring program, including the post-closure care period.

The owner or operator must indicate in the operating record the statistical method that will be used in the analysis of ground-water monitoring results. The data objectives of the monitoring, in terms of the number of samples collected and the frequency of collection, must be consistent with the statistical method selected.

Several options for analysis of ground-water data are provided in the criteria. Other methods may be used if they can be shown to meet the performance standards. The approved methods include both parametric and nonparametric procedures, which differ primarily in constraints placed by the statistical distribution of the data. Control chart, tolerance interval, and prediction interval approaches also may be applied.

The owner or operator must conduct the statistical comparisons between upgradient and downgradient wells after completion of each sampling event and receipt of validated data. The statistical procedure must conform to the performance standard of a Type I error level of no less than 0.01 for inter-well comparisons. Control chart, tolerance interval, and prediction interval approaches must incorporate decision values that are protective of human health and the environment. Generally, this is meant to include a significance level of a least 0.05. Procedures to treat data below analytical method detection levels and seasonality effects must be part of the statistical analysis.

5.9.3 Technical Considerations

The MSWLF rule requires facilities to evaluate ground-water monitoring data using a statistical method provided in §258.53(g) that meets the performance standard of §258.53(h). Section 258.53(g) contains a provision allowing for the use of an alternative statistical method as long as the performance standards of §258.53(h) are met.

The requirements of §258.53(g) specify that one of five possible statistical methods be used for evaluating ground-water monitoring data. One method should be specified for each constituent. Although different methods may be selected for each constituent at new facilities, use of a method must be substantiated by demonstrating that the distribution of data obtained on that constituent is appropriate for that method (§258.53(h)). Selection of a specific method is described in *Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities - Interim Final Guidance"* (USEPA, 1989) and in *Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities - Addendum to Interim Final Guidance* (USEPA, 1992b). EPA also offers software, entitled User Documentation of the Ground-Water Information Tracking System (GRITS) with Statistical Analysis Capability, GRITSTAT Version 4.2. In addition to the statistical guidance provided by EPA, the following references may be useful for selecting other methods (Dixon and Massey, 1969; Gibbons, 1976; Aitchison and Brown, 1969; and Gilbert, 1987). The statistical methods that may be used in evaluating ground-water monitoring data include the following:

- Parametric analysis of variance (ANOVA) with multiple comparisons
- Rank-based (nonparametric) ANOVA with multiple comparisons
- Tolerance interval or prediction interval
- Control chart
- An alternative statistical method (e.g., CABF t-test or confidence intervals).

If an alternative method is used, then the State Director must be notified, and a justification for its use must be placed in the operating record.

The statistical analysis methods chosen must meet performance standards specified under §258.53(h), which include the following:

1) The method must be appropriate for the observed distribution of the data

2) Individual well comparisons to background ground-water quality or a ground-water protection standard shall be done at a Type I error level of no less than 0.01 or, if the multiple comparisons procedure is used, the experiment-wise error rate for each testing period shall be no less than 0.05

3) If a control chart is used, the type of chart and associated parameter values

shall be protective of human health and the environment

4) The level of confidence and percentage of the population contained in an interval shall be protective of human health and the environment

5) The method must account for data below the limit of detection (less than the PQL) in a manner that is protective of human health and the environment

6) The method must account for seasonal and spatial variability and temporal correlation of the data, if necessary.

These statistical analysis methods shall be used to determine whether a significant increase over background values has occurred. Monitoring data must be statistically analyzed after validated results from each sampling and analysis event are received.

The statistical performance standards provide a means to limit the possibility of making false conclusions from the monitoring data. The specified error level of 0.01 for individual well comparisons for probability of Type I error (indication of contamination when it is not present or false positive) essentially means that the analysis is predicting with 99-percent confidence that no significant increase in contaminant levels is evident when in fact no increase is present. Non-detect results must be treated in an appropriate manner or their influence on the statistical method may invalidate the statistical conclusion. Non-detect results are discussed in greater detail later in this section.

Multiple Well Comparisons

If more than two wells (background and downgradient combined) are screened in the same stratigraphic unit, then the appropriate statistical comparison method is a multiple well comparison using the ANOVA procedure. The parametric ANOVA procedure assumes that the data from each well group come from the same type (e.g., Normal) of distribution with possibly different mean concentrations. The ANOVA tests for a difference in means. If there are multiple background wells, one should consider the possibility of trying to pool these background data into one group. Such an increase in sample size often allows for more accurate statistical comparisons, primarily because better information is known about the background concentrations as a whole. Downgradient wells should not be pooled, as stated in the regulations. Ground-water monitoring data tend to follow a log normal distribution (USEPA, 1989), and usually need to be transformed prior to applying a parametric ANOVA procedure. By conducting a log transformation, ground-water monitoring data will generally be converted to a normal distribution. By applying a Shapiro-Wilk test, probability plots, or other normality tests on the residuals (errors) from the ANOVA procedure, the normality of the transformed data can be determined. In addition, data variance for each well in the comparison must be approximately equivalent; this condition can be checked using Levene's or Bartlett's test. These tests are provided in USEPA (1992b) and USEPA (1989).

If the transformed data do not conform to the normality assumption, a nonparametric ANOVA procedure may be used. The nonparametric statistical procedures do not depend as much on the mathematical properties of a specified distribution. The nonparametric equivalent to the parametric ANOVA is the Kruskal-Wallis test, which analyzes variability of the average ranks of the data instead of the measurements themselves.

If the data display seasonality (regular, periodic, and time-dependent increases or decreases in parameter values), a two-way ANOVA procedure should be used. If the seasonality can be corrected, a one-way ANOVA procedure may still be appropriate. Methods to treat seasonality are described in USEPA (1989).

ANOVA procedures attempt to determine whether different wells have significantly different average concentrations of constituents. If a difference is indicated, the ANOVA test is followed by a multiple comparisons procedure to investigate which specific wells are different among those tested. The overall experiment-wise significance level of the ANOVA must be kept to a minimum of 0.05, while the minimum significance level of each individual comparison must be set at 0.01. USEPA (1992b) provides alternative methods that can be used when the number of individual contrasts to be tested is very high.

Tolerance and Prediction Intervals

Two types of statistical intervals are often constructed from data: tolerance intervals and prediction intervals. A comprehensive discussion of these intervals is provided in USEPA 1992b. Though often confused, the interpretations and uses of these intervals are quite distinct. A tolerance interval is designed to contain a designated proportion of the population (e.g., 95 percent of all possible sample measurements). Because the interval is constructed from sample data, it also is a random interval. And because of sampling fluctuations, a tolerance interval can contain the specified proportion of the population only with a certain confidence level.

Tolerance intervals are very useful for ground-water data analysis because in many situations one wants to ensure that at most a small fraction of the compliance well sample measurements exceed a specific concentration level (chosen to be protective of human health and the environment).

Prediction intervals are constructed to contain the next sample value(s) from a population or distribution with a specified probability. That is, after sampling a background well for some time and measuring the concentration of an analyte, the data can be used to construct an interval that will contain the next analyte sample or samples (assuming the distribution has not changed). Therefore, a prediction interval will contain a future value or values with specified probability. Prediction intervals can also be constructed to contain the average of several future observations.

In summary, a tolerance interval contains a proportion of the population, and a prediction interval contains one or more future observations. Each has a probability statement or "confidence coefficient" associated with it. It should be noted that these intervals assume that the sample data used to construct the intervals are normally distributed.

Individual Well Comparisons

When only two wells (e.g., a single background and a single compliance point well) are being compared, owners or operators should not perform the parametric or nonparametric ANOVA. Instead, a parametric t-test, such as Cochran's Approximation to the Behrens-Fisher Students' t-test, or a nonparametric test should be performed. When a single compliance well group is being compared to background data and a nonparametric test is needed, the Wilcoxin Rank-Sum test should be performed. These tests are discussed in more detail in standard statistical references and in USEPA (1992b).

Intra-Well Comparisons

Intra-well comparisons, where data of one well are evaluated over time, are useful in evaluating trends in individual wells and for identifying seasonal effects in the data. The intra-well comparison methods do not compare background data to compliance data. Where some existing facilities may not have valid background data, however, intra-well comparisons may represent the only valid comparison available. In the absence of a true background well, several monitoring events may be required to determine trends and seasonal fluctuations in ground-water quality.

Control charts may be used for intra-well comparisons but are only appropriate for uncontaminated wells. If a well is intercepting a release, then it is already in an "out-of-control" state, which violates the principal assumption underlying control chart procedures. Time series analysis (i.e., plotting concentrations over time) is extremely useful for identifying trends in monitoring data. Such data may be adjusted for seasonal effects to aid in assessing the degree of change over time. Guidance for and limitations of intra-well comparison techniques are provided in USEPA (1989) and USEPA (1992b).

Treatment of Non-Detects

The treatment of data below the detection limit of the analytical method (non-detects) used depends on the number or percentage of non-detects and the statistical method employed. Guidance on how to treat non-detects is provided in USEPA (1992b).

5.10 DETECTION MONITORING PROGRAM 40 CFR §258.54

5.10.1 Statement of Regulation

(a) Detection monitoring is required at MSWLF units at all ground-water monitoring wells defined under §§258.51(a)(1) and (a)(2) of this part. At a minimum, a detection monitoring program must include the monitoring for the constituents listed in Appendix I of this part.

1) The Director of an approved State may delete any of the Appendix I monitoring parameters for a MSWLF unit if it can be shown that the removed constituents are not reasonably expected to be in or derived from the waste contained in the unit.

2) The Director of an approved State may establish an alternative list of inorganic indicator parameters for a MSWLF unit, in lieu of some or all of

the heavy metals (constituents 1-15 in Appendix I), if the alternative parameters provide a reliable indication of inorganic releases from the MSWLF unit to the ground water. In determining alternative parameters, the Director shall consider the following factors:

(i) The types, quantities, and concentrations of constituents in wastes managed at the MSWLF unit;

(ii) The mobility, stability, and persistence of waste constituents or their reaction products in the unsaturated zone beneath the MSWLF unit;

(iii) The detectability of indicator parameters, waste constituents, and reaction products in the ground water; and

(iv) The concentration or values and coefficients of variation of monitoring parameters or constituents in the background ground-water.

(b) The monitoring frequency for all constituents listed in Appendix I, or the alternative list approved in accordance with paragraph (a)(2), shall be at least semiannual during the active life of the facility (including closure) and the post-closure period. A minimum of four independent samples from each well (background and downgradient) must be collected and analyzed for the Appendix I constituents, or the alternative list approved in accordance with paragraph (a)(2), during the first semiannual sampling event. At least one sample from each well(background and downgradient) must be collected and analyzed during subsequent semiannual sampling events. The Director of an approved State may specify an appropriate alternative frequency for repeated sampling and analysis for Appendix I constituents, or the alternative list approved in accordance with paragraph (a)(2), during the active life (including closure) and the post-closure care period. The alternative frequency during the active life (including closure) shall be no less than annual. The alternative frequency shall be based on consideration of the following factors:

1) Lithology of the aquifer and unsaturated zone;

2) Hydraulic conductivity of the aquifer and unsaturated zone;

3) Ground-water flow rates;

4) Minimum distance between upgradient edge of the MSWLF unit and downgradient monitoring well screen (minimum distance of travel); and

5) Resource value of the aquifer.

(c) If the owner or operator determines, pursuant to §258.53(g) of this part, that there is a statistically significant increase over background for one or more of the constituents listed in Appendix I or the alternative list approved in accordance with paragraph (a)(2), at any monitoring well at the boundary specified under §258.51(a)(2), the owner or operator:

(1) Must, within 14 days of this finding, place a notice in the operating record indicating which constituents have shown statistically significant changes from

background levels, and notify the State Director that this notice was placed in the operating record; and

(2) Must establish an assessment monitoring program meeting the requirements of §258.55 of this part within 90 days, except as provided for in paragraph (3) below.

(3) The owner/operator may demonstrate that a source other than a MSWLF unit caused the contamination or that the statistically significant increase resulted from error in sampling, analysis, statistical evaluation, or natural variation in ground-water quality. A report documenting this demonstration must be certified by a qualified ground-water scientist or approved by the Director of an approved State and be placed in the operating record. If a successful demonstration is made and documented, the owner or operator may continue detection monitoring as specified in this section. If after 90 days, a successful demonstration is not made, the owner or operator must initiate an assessment monitoring program as required in §258.55.

5.10.2 Applicability

Except for the small landfill exemption and the no migration demonstration, detection monitoring is required at existing MSWLF units, lateral expansions of units, and new MSWLF units. Monitoring must occur at least semiannually at both background wells and downgradient well locations. The Director of an approved State may specify an alternative sampling frequency. Monitoring parameters must include all Appendix I constituents unless an alternative list has been established by the Director of an approved State.

During the first semiannual monitoring event, the owner or operator must collect at least four independent ground-water samples from each well and analyze the samples for all constituents in the Appendix I or alternative list. Each subsequent semiannual event must include, at a minimum, the collection and analysis of one sample from all wells. The monitoring requirement continues throughout the active life of the landfill and the post-closure care period.

If an owner or operator determines that a statistically significant increase over background has occurred for one or more Appendix I constituents (or constituents on an alternative list), a notice must be placed in the facility operating record (see Table 5-2). The owner or operator must notify the State Director within 14 days of the finding. Within 90 days, the owner or operator must establish an assessment monitoring program conforming to the requirements of §258.55.

If evidence exists that a statistically significant increase is due to factors unrelated to the unit, the owner or operator may make a demonstration to this effect to the Director of an approved State or place a certified demonstration in the operating record. The potential reasons for an apparent statistical increase may include:

- A contaminant source other than the landfill unit
- A natural variation in ground-water quality
- An analytical error

- A statistical error
- A sampling error.

The demonstration that one of these reasons is responsible for the statistically significant increase over background must be certified by a qualified ground-water scientist or approved by the Director of an approved State. If a successful demonstration is made and documented, the owner or operator may continue detection monitoring.

If a successful demonstration is not made within 90 days, the owner or operator must initiate an assessment monitoring program. A flow chart for a detection monitoring program in a State whose program has not been approved by EPA is provided in Figure 5-5.

5.10.3 Technical Considerations

If there is a statistically significant increase over background during detection monitoring for one or more constituents listed in Appendix I of Part 258 (or an alternative list of parameters in an approved State), the owner or operator is required to begin assessment monitoring. The requirement to conduct assessment monitoring will not change, even if the Director of an approved State allows the monitoring of geochemical parameters in lieu of some or all of the metals listed in Appendix I. If an owner or operator suspects that a statistically significant increase in a geochemical parameter is caused by natural variation in ground-water quality or a source other than a MSWLF unit, a demonstration to this effect must be documented in a report to avoid proceeding to assessment monitoring.

Independent Sampling for Background

The ground-water monitoring requirements specify that four independent samples be collected from each well to establish background during the first semiannual monitoring event. This is because almost all statistical procedures are based on the assumption that samples are independent of each other. In other words, independent samples more accurately reflect the true range of natural variability in the ground water, and statistical analyses based on independent samples are more accurate. Replicate samples, whether field replicates or lab splits, are not statistically independent measurements.

It may be necessary to gather the independent samples over a range of time sufficient to account for seasonal differences. If seasonal differences are not taken into account, the chance for false positives increases (monitoring results indicate a release, when a release has not occurred). The sampling interval chosen must ensure that sampling is being done on different volumes of ground water. To determine the appropriate interval between sample collection events that will ensure independence, the owner or operator can determine the site's effective porosity, hydraulic conductivity, and hydraulic gradient and use this information to calculate ground-water velocity (USEPA, 1989). Knowing the velocity of the ground water should enable an owner/operator to establish an interval that ensures the four samples are being collected from four different volumes of water. For additional information on establishing sampling interval, see *Statistical Analysis of Groundwater Monitoring Data at RCRA*

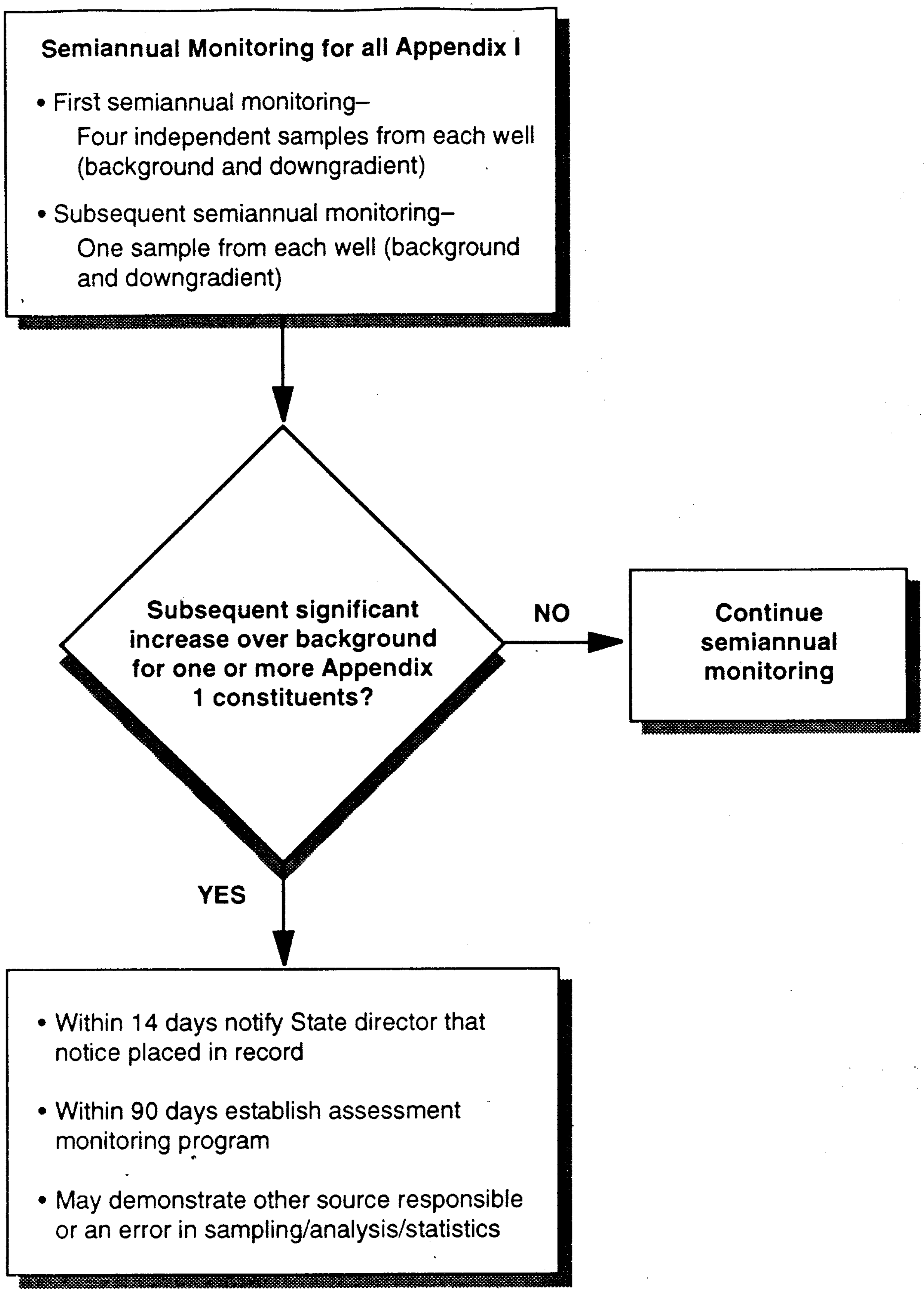


Figure 5-5. Detection Monitoring Program

Facilities - Interim Final Guidance, (USEPA, 1989).

Alternative List/Removal of Parameters

An alternative list of Appendix I constituents may be allowed by the Director of an approved State. The alternative list may use geochemical parameters, such as pH and specific conductance, in place of some or all of the metals (Parameters 1 through 15) in Appendix I. These alternative parameters must provide a reliable indication of inorganic releases from the MSWLF unit to ground water. The option of establishing an alternative list applies only to Parameters 1 through 15 of Appendix I. The list of ground-water monitoring parameters must include all of the volatile organic compounds (Appendix I, Parameters 16 through 62).

A potential problem in substituting geochemical parameters for metals on the alternative list is that many of the geochemical parameters are naturally occurring. However, these parameters have been used to indicate releases from MSWLF units. Using alternative geochemical parameters is reasonable in cases where natural background levels are not high enough to mask the detection of a release from a MSWLF unit. The decision to use alternative parameters also should consider natural spatial and temporal variability in the geochemical parameters.

The types, quantities, and concentrations of wastes managed at the MSWLF unit play an important role in determining whether removal of parameters from Appendix I is appropriate. If an owner or operator has definite knowledge of the nature of wastes accepted at the facility, then removal of constituents from Appendix I may be acceptable. Usually, a waste would have to be homogeneous to allow for this kind of determination. The owner or operator may submit a demonstration that documents the presence or absence of certain constituents in the waste. The owner or operator also would have to demonstrate that constituents proposed for deletion from Appendix I are not degradation or reaction products of constituents potentially present in the waste.

Alternative Frequency

In approved States, 40 CFR §258.54(b) allows the Director to specify an alternative frequency for ground-water monitoring. The alternative frequency is applicable during the active life, including the closure and the post-closure periods. The alternative frequency can be no less than annual.

The need to vary monitoring frequency must be evaluated on a site-specific basis. For example, for MSWLF units located in areas with low ground-water flow rates, it may be acceptable to monitor ground water less frequently. The sampling frequency chosen must be sufficient to protect human health and the environment. Depending on the ground-water flow rate and the resource value of the aquifer, less frequent monitoring may be allowable or more frequent monitoring may be necessary. An approved State may specify an alternative frequency for repeated sampling and analysis of Appendix I constituents based on the following factors:

1) Lithology of the aquifer and the unsaturated zone

2) Hydraulic conductivity of the aquifer and the unsaturated zone

3) Ground-water flow rates

4) Minimum distance between the upgradient edge of the MSWLF unit and the downgradient well screen

5) The resource value of the aquifer.

Approved States also can set alternative frequencies for monitoring during the post-closure care period based on the same factors.

Notification

The notification requirement under 40 CFR §258.54(c) requires an owner or operator to 1) place a notice in the operating record that indicates which constituents have shown statistically significant increases and 2) notify the State Director that the notice was placed in the operating record. The constituents can be from either Appendix I or from an alternative list.

Demonstrations of Other Reasons For Statistical Increase

An owner or operator is allowed 90 days to demonstrate that the statistically significant increase of a contaminant/constituent was caused by statistical, sampling, or analytical errors or by a source other than the landfill unit. The demonstration allowed in §258.54(c)(3) may include:

1) A demonstration that the increase resulted from another contaminant source

2) A comprehensive audit of sampling, laboratory, and data evaluation procedures

3) Resampling and analysis to verify the presence and concentration of the constituents for which the increase was reported.

A demonstration that the increase in constituent concentration is the result of a source other than the MSWLF unit should document that:

- An alternative source exists.
- Hydraulic connection exists between the alternative source and the well with the significant increase.
- Constituent(s) (or precursor constituents) are present at the alternative source or along the flow path from the alternative source prior to possible release from the MSWLF unit.
- The relative concentration and distribution of constituents in the zone of contamination are more strongly linked to the alternative source than to the MSWLF unit when the fate and transport characteristics of the constituents are considered.
- The concentration observed in ground water could not have resulted from the MSWLF unit given the waste constituents and concentrations in the MSWLF unit leachate and wastes, and site hydrogeologic conditions.
- The data supporting conclusions regarding the alternative source are historically consistent with hydrogeologic

conditions and findings of the monitoring program.

The demonstration must be documented, certified by a qualified ground-water scientist, and placed in the operating record of the facility.

Demonstrations of Other Sources of Error

A successful demonstration that the statistically significant change is the result of an error in sampling, analysis, or data evaluation may include the following:

- Clear indication of a transcription or calculation error
- Clear indication of a systematic error in analysis or data reduction
- Resampling, analysis, and evaluation of results
- Corrective measures to prevent the recurrence of the error and incorporation of these measures into the ground-water monitoring program.

If resampling is necessary, the sample(s) taken must be independent of the previous sample. More than one sample may be required to substantiate the contention that the original sample was not representative of the ground-water quality in the affected well(s).

5.11 ASSESSMENT MONITORING PROGRAM 40 CFR §258.55(a)-(f)

5.11.1 Statement of Regulation

(a) Assessment monitoring is required whenever a statistically significant increase over background has been detected for one or more of the constituents listed in Appendix I or in the alternate list approved in accordance with § 258.54(a)(2).

(b) Within 90 days of triggering an assessment monitoring program, and annually thereafter, the owner or operator must sample and analyze the ground water for all constituents identified in Appendix II of this part. A minimum of one sample from each downgradient well must be collected and analyzed during each sampling event. For any new constituent detected in the downgradient wells as a result of the complete Appendix II analysis, a minimum of four independent samples from each well (background and downgradient) must be collected and analyzed to establish background for the new constituents. The Director of an approved State may specify an appropriate subset of wells to be sampled and analyzed for Appendix II constituents during assessment monitoring. The Director of an approved State may delete any of the Appendix II monitoring parameters for a MSWLF unit if it can be shown that the removed constituents are not reasonably expected to be contained in or derived from the waste contained in the unit.

(c) The Director of an approved State may specify an appropriate alternate frequency for repeated sampling and analysis for the full set of Appendix II constituents required by §258.55(b) of this part, during the active life (including closure) and post-closure care of the unit considering the following factors:

(1) Lithology of the aquifer and unsaturated zone;

(2) Hydraulic conductivity of the aquifer and unsaturated zone;

(3) Ground-water flow rates;

(4) Minimum distance between upgradient edge of the MSWLF unit and downgradient monitoring well screen (minimum distance of travel);

(5) Resource value of the aquifer; and

(6) Nature (fate and transport) of any constituents detected in response to this section.

(d) After obtaining the results from the initial or subsequent sampling events required in paragraph (b) of this section, the owner or operator must:

(1) Within 14 days, place a notice in the operating record identifying the Appendix II constituents that have been detected and notify the State Director that this notice has been placed in the operating record;

(2) Within 90 days, and on at least a semiannual basis thereafter, resample all wells specified by § 258.51(a), conduct analyses for all constituents in Appendix I to this Part or in the alternative list approved in accordance with §258.54(a)(2), and for those constituents in Appendix II that are detected in response to paragraph (b) of this section, and record their concentrations in the facility operating record. At least one sample from each well (background and downgradient) must be collected and analyzed during these sampling events. The Director of an approved State may specify an alternative monitoring frequency during the active life (including closure) and the post closure period for the constituents referred to in this paragraph. The alternative frequency for Appendix I constituents or the alternate list approved in accordance with §258.54(a)(2) during the active life (including closure) shall be no less than annual. The alternative frequency shall be based on consideration of the factors specified in paragraph (c) of this section;

(3) Establish background concentrations for any constituents detected pursuant to paragraphs (b) or (d)(2) of this section; and

(4) Establish ground-water protection standards for all constituents detected pursuant to paragraph (b) or (d)(2) of this section. The ground-water protection standards shall be established in accordance with paragraphs (h) or (i) of this section.

(e) If the concentrations of all Appendix II constituents are shown to be at or below background values, using the statistical procedures in §258.53(g), for two consecutive sampling events, the owner or operator must notify the State

Director of this finding and may return to detection monitoring.

(f) If the concentrations of any Appendix II constituents are above background values, but all concentrations are below the ground-water protection standard established under paragraphs (h) or (i) of this section, using the statistical procedures in §258.53(g), the owner or operator must continue assessment monitoring in accordance with this section.

5.11.2 Applicability

Assessment monitoring is required at all existing units, lateral expansions, and new facilities whenever any of the constituents listed in Appendix I are detected at a concentration that is a statistically significant increase over background values. Figure 5-6 presents a flow chart pertaining to applicability requirements.

Within 90 days of beginning assessment monitoring, the owner or operator must resample all downgradient wells and analyze the samples for all Appendix II constituents. If any new constituents are identified in this process, four independent samples must be collected from all upgradient and downgradient wells and analyzed for those new constituents to establish background concentrations. The complete list of Appendix II constituents must be monitored in each well annually for the duration of the assessment monitoring program. In an approved State, the Director may reduce the number of Appendix II constituents to be analyzed if it can be reasonably shown that those constituents are not present in or derived from the wastes. The Director of an approved State may specify an appropriate subset of wells to be included in the assessment monitoring program. The Director of an approved State also may specify an alternative frequency for repeated sampling and analysis of Appendix II constituents. This frequency may be decreased or increased based upon consideration of the factors in §258.55(c)(1)-(6). These options for assessment monitoring programs are available only with the approval of the Director of an approved State.

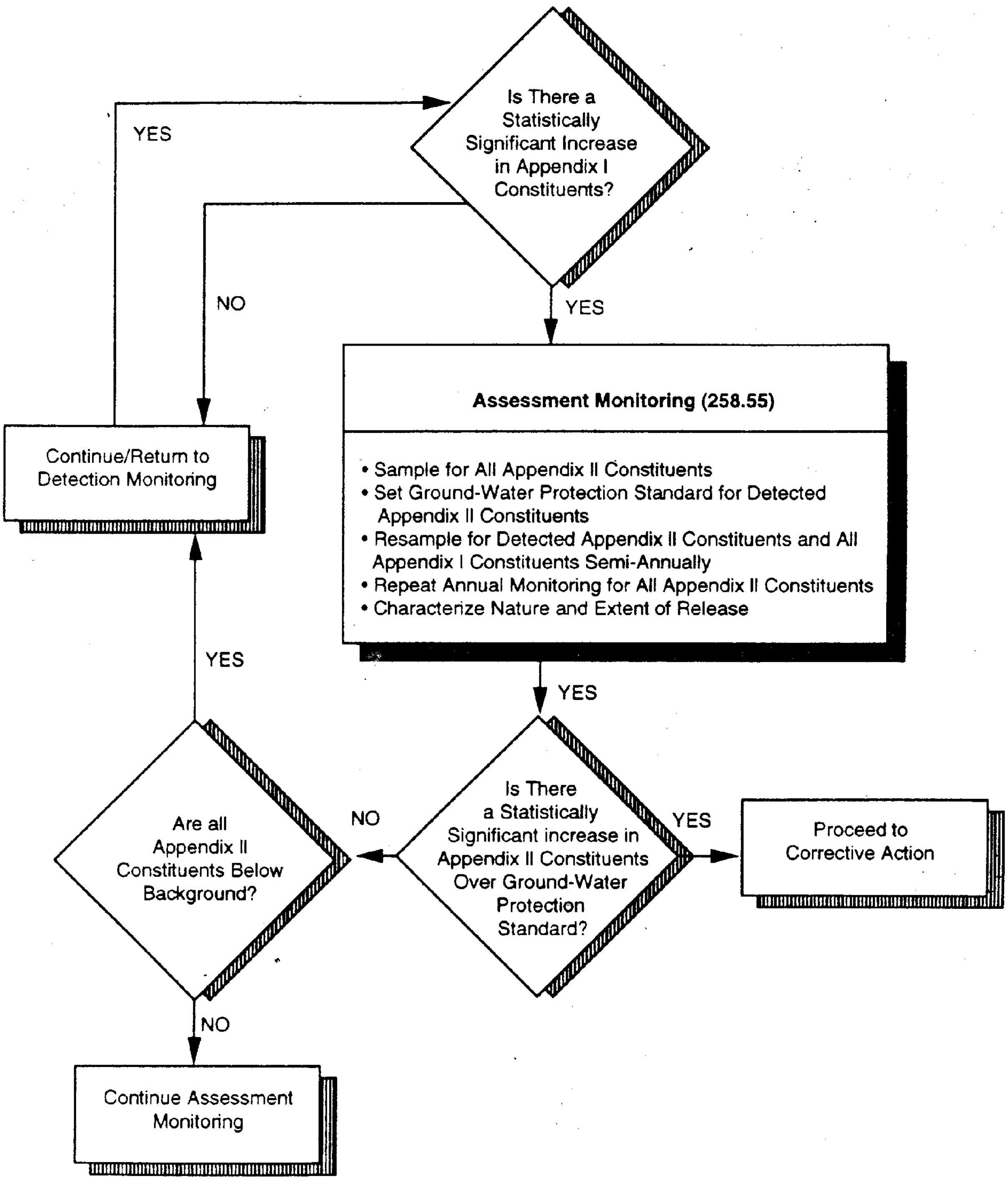
Within 14 days of receiving the results of the initial sampling for Appendix II constituents under assessment monitoring, the owner or operator must place the results in the operating record and notify the State Director that this notice has been placed in the operating record.

Within 90 days of receiving these initial results, the owner or operator must resample all wells for all Appendix I and detected Appendix II constituents. This combined list of constituents must be sampled at least semiannually thereafter, and the list must be updated annually to include any newly detected Appendix II constituents.

Within the 90-day period, the owner or operator must establish background values and ground-water protection standards (GWPSs) for all Appendix II constituents detected. The requirements for determining GWPSs are provided in §258.55(h). If the concentrations of all Appendix II constituents are at or below the background values after two independent, consecutive sampling events, the owner or operator may return to detection monitoring after notification has been made to the State Director. If, after these two

Figure 5-6

ASSESSMENT MONITORING



sampling events, any detected Appendix II constituent is statistically above background but below the GWPSs, the assessment monitoring program must be continued.

5.11.3 Technical Considerations

The purpose of assessment monitoring is to evaluate the nature and extent of contamination. The assessment monitoring program is phased. The first phase assesses the presence of additional assessment monitoring constituents (Appendix II or a revised list designated by an approved State) in all downgradient wells or in a subset of ground-water monitoring wells specified by the Director of an approved State. If concentrations of all Appendix II constituents are at or below background values using the statistical procedures in §258.53(g) for two consecutive sampling periods, then the owner or operator can return to detection monitoring.

Following notification of a statistically significant increase of any Appendix I constituent above background, the owner or operator has 90 days to develop and implement the assessment monitoring program. Implementation of the program involves sampling downgradient monitoring wells for ground water passing the relevant point of compliance for the unit (i.e., the waste management unit boundary or alternative boundary specified by the Director of an approved State). Downgradient wells are identified in §258.51(a)(2). Initiation of assessment monitoring does not stop the detection monitoring program. Section 258.55(d)(2) specifies that analyses must continue for all Appendix I constituents on at least a semiannual basis. Within the 90-day period, the owner or operator must collect at least one sample from each downgradient well and analyze the samples for the Appendix II parameters. If a downgradient well has detectable quantities of a new Appendix II constituent, four independent samples must be collected from all background and downgradient wells to establish background for the new constituent(s). The date, well locations, parameters detected, and their concentrations must be documented in the operating record of the facility, and the State Director must be notified within 14 days of the initial detection of Appendix II parameters. On a semiannual basis thereafter, both background and downgradient wells must be sampled for all Appendix II constituents.

Alternative List

In an approved State, the Director may delete Appendix II parameters that the owner or operator can demonstrate would not be anticipated at the facility. A demonstration would be based on a characterization of the wastes contained in the unit and an assessment of the leachate constituents. Additional information on the alternative list can be found in Section 5.10.3.

Alternative Frequency

The Director of an approved State may specify an alternate sampling frequency for the entire Appendix II list for both the active and post-closure periods of the facility. The decision to change the monitoring frequency must consider:

1) Lithology of the aquifer and unsaturated zone;

2) Hydraulic conductivity of the aquifer and unsaturated zone;

3) Ground-water flow rates;

4) Minimum distance of travel (between the MSWLF unit edge to downgradient monitoring wells); and

5) Nature (fate and transport) of the detected constituents.

The Director of an approved State also may allow an alternate frequency, other than semiannual, for the monitoring of Appendix I and detected Appendix II constituents.

The monitoring frequency must be sufficient to allow detection of ground-water contamination. If contamination is detected early, the volume of ground water contaminated will be smaller and the required remedial response will be less burdensome. Additional information on the alternate frequency can be found in Section 5.10.3.

In an approved State, the Director may specify a subset of wells that can be monitored for Appendix II constituents to confirm a release and track the plume of contamination during assessment monitoring. The owner or operator should work closely with the State in developing a monitoring plan that targets the specific areas of concern, if possible. This may represent a substantial cost savings, especially at large facilities for which only a very small percentage of wells showed exceedances above background. The use of a subset of wells likely will be feasible only in cases where the direction and rate of flow are relatively constant.

5.12 ASSESSMENT MONITORING PROGRAM 40 CFR §258.55(g)

5.12.1 Statement of Regulation

(g) If one or more Appendix II constituents are detected at statistically significant levels above the ground-water protection standard established under paragraphs (h) or (i) of this section in any sampling event, the owner or operator must, within 14 days of this finding, place a notice in the operating record identifying the Appendix II constituents that have exceeded the ground-water protection standard and, notify the State Director and all appropriate local government officials that the notice has been placed in the operating record. The owner or operator also:

(1) (i) Must characterize the nature and extent of the release by installing additional monitoring wells as necessary;

(ii) Must install at least one additional monitoring well at the facility boundary in the direction of contaminant migration and sample this well in accordance with §258.55(d)(2);

(iii) Must notify all persons who own the land or reside on the land that directly overlies any part of the plume of contamination if contaminants have migrated off-site if indicated by sampling of wells in accordance with §258.55(g)(i); and

(iv) Must initiate an assessment of corrective measures as required by §255.56 of this part within 90 days; or

(2) May demonstrate that a source other than a MSWLF unit caused the contamination, or that the statistically significant increase resulted from error in sampling, analysis, statistical evaluation, or natural variation in ground-water quality. A report documenting this demonstration must be certified by a qualified ground-water scientist or approved by the Director of an approved State and placed in the operating record. If a successful demonstration is made the owner or operator must continue monitoring in accordance with the assessment monitoring program pursuant to §258.55, and may return to detection monitoring if the Appendix II constituents are below background as specified in §258.55(e). Until a successful demonstration is made, the owner or operator must comply with §258.55(g) including initiating an assessment of corrective measures.

5.12.2 Applicability

This requirement applies to facilities in assessment monitoring and is applicable during the active life, closure, and post-closure care periods.

5.12.3 Technical Considerations

If an Appendix II constituent(s) exceeds a GWPS in any sampling event, the owner or operator must notify the State Director within 14 days and place a notice of these findings in the operating record of the MSWLF facility. In addition, the owner or operator must:

1) Characterize the lateral and vertical extent of the release or plume by installing and sampling an appropriate number of additional monitoring wells

2) Install at least one additional downgradient well at the facility property boundary in the direction of migration of the contaminant plume and sample that well for all Appendix II compounds initially and thereafter, in conformance with the assessment monitoring program

3) Notify all property owners whose land overlies the suspected plume, if the sampling of any property boundary well(s) indicates that contaminants have migrated offsite

4) Initiate an assessment of corrective measures, as required by §258.56, within 90 days.

In assessment monitoring, the owner or operator may demonstrate that a source other than the MSWLF unit caused the contamination or that the statistically significant increase was the result of an error in sampling, analysis, statistical evaluation, or natural variation in ground-water quality. The demonstration must be certified by a qualified ground-water scientist or approved by the Director of an approved State. Until a successful demonstration is made, the owner or operator must comply with §258.55(g) and initiate assessment of corrective measures. If the demonstration is successful, the owner or operator must return to assessment monitoring and may return to the detection program provided that all Appendix II constituents are at or below background for two consecutive sampling periods.

Release Investigation

If the GWPS is exceeded, a series of actions must be taken. These actions are described in the next several paragraphs. The owner or operator must investigate the extent of the release by installing additional monitoring wells and obtaining additional ground-water samples. The investigation should identify plume geometry, both laterally and vertically. Prior to such field activities, records of site operation and maintenance activities should be reviewed to identify possible release locations within the landfill and whether such releases are expected to be transient (e.g., one time release due to repaired liner) or long-term. Due to the presence of dissolved ionic constituents, such as iron, magnesium, calcium, sodium, potassium, chloride, sulfate, and carbonate, typically associated with MSWLF unit leachates, geophysical techniques, including resistivity and terrain conductivity, may be useful in defining the plume. Characterizing the nature of the release should include a description of the rate and direction of contaminant migration and the chemical and physical characteristics of the contaminants.

Property Boundary Monitoring Well

At least one monitoring well must be installed at the facility boundary in the direction of contaminant migration. Additional wells may be required to delineate the plume. Monitoring wells at the facility boundary should be screened to monitor all stratigraphic units that could be preferential pathways for contaminant migration in the uppermost aquifer. In some cases, this may require installation of nested wells or individual wells screened at several discrete intervals. The well installed at the facility boundary must be sampled semiannually or at an alternative frequency determined by the Director of an approved State. The initial sample must be analyzed for all Appendix II constituents.

Notification of Adjoining Residents and Property Owners

If ground-water monitoring indicates that contamination has migrated offsite, the owner or operator must notify property owners or residents whose land surface overlies any part of the contaminant release. Although the requirement does not describe the contents of the notice, it is expected that the notice could include the following items:

- Date of detected release
- Chemical composition of release
- Reference to the constituent(s), reported concentration(s), and the GWPS
- Representatives of the MSWLF facility with whom to discuss the finding, including their telephone numbers
- Plans and schedules for future activities
- Interim recommendations or remedies to protect human health and the environment.

Demonstrations of Other Sources of Error

The owner or operator may demonstrate that the source of contamination was not the MSWLF unit. This demonstration is discussed in Section 5.10.3.

Return to Detection Monitoring

A facility conducting assessment monitoring may return to detection monitoring if the concentrations of all Appendix II constituents are at or below background levels for two consecutive sampling periods using the statistical procedures in §258.53(g). The requirement that background concentrations must be maintained for two consecutive sampling events will reduce the possibility that the owner or operator will fail to detect contamination or an increase in a concentration of a hazardous constituent when one actually exists. The Director of an approved State can establish an alternative time period (§258.54(b).

5.13 ASSESSMENT MONITORING PROGRAM 40 CFR §258.55(h)-(j)

5.13.1 Statement of Regulation

(h) The owner or operator must establish a ground-water protection standard for each Appendix II constituent detected in the ground water. The ground-water protection standard shall be:

(1) For constituents for which a maximum contaminant level (MCL) has been promulgated under Section 1412 of the Safe Drinking Water Act (codified) under 40 CFR Part 141, the MCL for that constituent;

(2) For constituents for which MCLs have not been promulgated, the background concentration for the constituent established from wells in accordance with §258.51(a)(1); or

(3) For constituents for which the background level is higher than the MCL identified under subparagraph (1) above or health based levels identified under §258.55(i)(1), the background concentration.

(i) The Director of an approved State may establish an alternative ground-water protection standard for constituents for which MCLs have not been established. These ground-water protection standards shall be appropriate health based levels that satisfy the following criteria:

(1) The level is derived in a manner consistent with Agency guidelines for assessing the health risks of environmental pollutants (51 FR 33992, 34006, 34014, 34028);

(2) The level is based on scientifically valid studies conducted in accordance with the Toxic Substances Control Act Good Laboratory Practice Standards (40 CFR Part 792) or equivalent;

(3) For carcinogens, the level represents a concentration associated with an excess lifetime cancer risk level (due to continuous lifetime exposure) with the 1 x 10^{-4} to 1 x 10^{-6} range; and

(4) For systemic toxicants, the level represents a concentration to which the human population (including sensitive subgroups) could be exposed to on a daily basis that is likely to be without appreciable risk of deleterious effects during a lifetime. For purposes of this subpart, systemic toxicants include toxic chemicals that cause effects other than cancer or mutation.

(j) In establishing ground-water protection standards under paragraph (i), the Director of an approved State may consider the following:

(1) Multiple contaminants in the ground water;

(2) Exposure threats to sensitive environmental receptors; and

(3) Other site-specific exposure or potential exposure to ground water.

5.13.2 Applicability

The criteria for establishing GWPSs are applicable to all facilities conducting assessment monitoring where any Appendix II constituents have been detected. The owner or operator must establish a GWPS for each Appendix II constituent detected.

If the constituent has a promulgated maximum contaminant level (MCL), then the GWPS is the MCL. If no MCL has been published for a given Appendix II constituent, the background concentration of the constituent becomes the GWPS. In cases where the background concentration is higher than a promulgated MCL, the GWPS is set at the background level.

In approved States, the Director may establish an alternative GWPS for constituents for which MCLs have not been established. Any alternative GWPS must be health-based levels that satisfy the criteria in §258.55(i). The Director may also consider any of the criteria identified in §258.55(j). In cases where the background concentration is higher than the health-based levels, the GWPS is set at the background level.

5.13.3 Technical Considerations

For each Appendix II constituent detected, a GWPS must be established. The GWPS is to be set at either the MCL or background. Where the background concentration is higher than the MCL, then the GWPS is established at background.

Directors of approved States have the option of establishing an alternative GWPS for constituents without MCLs. This alternative GWPS must be an appropriate health-based level, based on specific criteria. These levels must:

- Be consistent with EPA health risk assessment guidelines
- Be based on scientifically valid studies
- Be within a risk range of $1x10^{-4}$ to $1x10^{-6}$ for carcinogens
- For systemic toxicants (causing effects other than cancer or mutations), be a concentration to which the human population could be exposed on a daily basis without appreciable risk of deleterious effects during a lifetime.

The health-based GWPS may be established considering the presence of more than one constituent, exposure to sensitive environmental receptors, and other site-specific exposure to ground water. Risk assessments to establish the GWPS must consider cumulative effects of multiple pathways to receptors and cumulative effects on exposure risk of multiple contaminants. Guidance and procedures for establishing a health-based risk assessment may be found in *Guidance on Remedial Actions for*

Contaminated Groundwater at Superfund Sites, (USEPA, 1988).

5.14 ASSESSMENT OF CORRECTIVE MEASURES 40 CFR §258.56

5.14.1 Statement of Regulation

(a) Within 90 days of finding that any of the constituents listed in Appendix II have been detected at a statistically significant level exceeding the ground-water protection standards defined under §258.55(h) and (i) of this part, the owner or operator must initiate an assessment of corrective measures. Such an assessment must be completed within a reasonable period of time.

(b) The owner or operator must continue to monitor in accordance with the assessment monitoring program as specified in §258.55.

(c) The assessment shall include an analysis of the effectiveness of potential corrective measures in meeting all of the requirements and objectives of the remedy as described under §258.57, addressing at least the following:

(1) The performance, reliability, ease of implementation, and potential impacts of appropriate potential remedies, including safety impacts, cross-media impacts, and control of exposure to any residual contamination;

(2) The time required to begin and complete the remedy;

(3) The costs of remedy implementation; and

(4) The institutional requirements such as State or local permit requirements or other environmental or public health requirements that may substantially affect implementation of the remedy(s).

(d) The owner or operator must discuss the results of the corrective measures assessment, prior to the selection of remedy, in a public meeting with interested and affected parties.

5.14.2 Applicability

An assessment of corrective measures must be conducted whenever any Appendix II constituents are detected at statistically significant levels exceeding the GWPS. The assessment of corrective measures must be initiated within 90 days of the finding. During the initiation of an assessment of corrective measures, assessment monitoring must be continued. The assessment of corrective measures must consider performance (including potential impacts), time, and cost aspects of the remedies. If implementation requires additional State or local permits, such requirements should be identified. Finally, the results of the corrective measures assessment must be discussed in a public meeting with interested and affected parties.

5.14.3 Technical Considerations

An assessment of corrective measures is site-specific and will vary significantly depending on the design and age of the facility, the completeness of the facility's historical records, the nature and concentration of the contaminants found in the ground water, the complexity of the site hydrogeology, and the facility's proximity to sensitive receptors. Corrective measures are generally approached from two directions: 1) identify and remediate the source of contamination and 2) identify and remediate the known contamination. Because each case will be site-specific, the owner or operator should be prepared to document that, to the best of his or her technical and financial abilities, a diligent effort has been made to complete the assessment in the shortest time practicable.

The factors listed in §258.56(c)(1) must be considered in assessing corrective measures. These general factors are discussed below in terms of source evaluation, plume delineation, ground-water assessment, and corrective measures assessment.

Source Evaluation

As part of the assessment of corrective measures, the owner or operator will need to identify the nature of the source of the release. The first step in this identification is a review of all available site information regarding facility design, wastes received, and onsite management practices. For newer facilities, this may be a relatively simple task. However, at some older facilities, detailed records of the facility's history may not be as well documented, making source definition more difficult. Design, climatological, and waste-type information should be used to evaluate the duration of the release, potential seasonal effects due to precipitation (increased infiltration and leachate generation), and possible constituent concentrations. If source evaluation is able to identify a repairable engineering condition that likely contributed to the cause of contamination (e.g., unlined leachate storage ponds, failed cover system, leaky leachate transport pipes, past conditions of contaminated storm overflow), such information should be considered as part of the assessment of corrective measures.

Existing site geology and hydrogeology information, ground-water monitoring results, and topographic and cultural information must be documented clearly and accurately. This information may include soil boring logs, test pit and monitoring well logs, geophysical data, water level elevation data, and other information collected during facility design or operation. The information should be expressed in a manner that will aid interpretation of data. Such data may include isopach maps of the thickness of the upper aquifer and important strata, isoconcentration maps of contaminants, flow nets, cross-sections, and contour maps. Additional guidance on data interpretation that may be useful in a source evaluation is presented in *RCRA Facility Investigation Guidance: Volume I - Development of an RFI Work Plan and General Considerations for RCRA Facility Investigations*, (USEPA 1989a), *RCRA Facility Investigation Guidance: Volume IV - Case Study Examples*, (USEPA 1989d), and *Practical Guide For Assessing and Remediating Contaminated Sites* (USEPA 1989e).

Plume Delineation

To effectively assess corrective measures, the lateral and vertical extent of contamination must be known. When it is determined that a GWPS is exceeded during the assessment monitoring program, it may be necessary to install additional wells to characterize the contaminant plume(s). At least one additional well must be added at the property boundary in the direction of contaminant migration to allow timely notification to potentially affected parties if contamination migrates offsite.

The following circumstances may require additional monitoring wells:

- Facilities that have not determined the horizontal and vertical extent of the contaminant plume
- Locations where the subsurface is heterogeneous or where ground-water flow patterns are difficult to establish
- Mounding associated with MSWLF units.

Because the requirements for additional monitoring are site-specific, the regulation does not specifically establish cases where additional wells are necessary or establish the number of additional wells that must be installed.

During the plume delineation process, the owner or operator is not relieved from continuing the assessment monitoring program.

The rate of plume migration and the change in contaminant concentrations with time must be monitored to allow prediction of the extent and timing of impact to sensitive receptors. The receptors may include users of both ground-water and surface water bodies where contaminated ground water may be discharged. In some cases, transfer of volatile compounds from ground water to the soil and to the air may provide an additional migration pathway. Information regarding the aquifer characteristics (e.g., hydraulic conductivity, storage coefficients, and effective porosity) should be developed for modeling contaminant transport if sufficient data are not available. Anisotropy and heterogeneity of the aquifer must be evaluated, as well as magnitude and duration of source inputs, to help explain present and predicted plume configuration.

Currently, most treatment options for ground-water contamination at MSWLF units involve pump and treat or in-situ biological technologies (bio-remediation). The cost and duration of treatment depends on the size of the plume, the pumping characteristics of the aquifer, and the chemical transport phenomena. Source control and ground-water flow control measures to reduce the rate of contaminant migration should be included in the costs of any remedial activity undertaken. Ground-water modeling of the plume may be initiated to establish the following:

- The locations and pumping rates of withdrawal and/or injection wells
- Predictions of contaminant concentrations at exposure points
- Locations of additional monitoring wells
- The effect that source control options may have on ground-water remediation
- The effects of advection and dispersion, retardation, adsorption, and other attenuation processes on the plume dimensions and contaminant concentrations.

Any modeling effort must consider that simulations of remedial response measures and contaminant transport are based on many necessary simplifying assumptions, which affect the accuracy of the model. These assumptions include boundary conditions, the degree and spatial variability of anisotropy, dispersivity, effective porosity, stratigraphy, and the algorithms used to solve contaminant transport equations. Model selection should be appropriate for the amount of data available, and the technical uncertainty of the model results must be documented by a sensitivity analysis on the input parameters. A sensitivity analysis is generally done after model calibration by varying one input parameter at a time over a realistic range and then evaluating changes in model output. For additional information on modeling, refer to the Further Information Section of Chapter 5.0 and the *RCRA Facility Investigation Guidance: Volume II - Soil, Groundwater and Subsurface Gas Releases* (USEPA, 1989b).

Ground-Water Assessment

To assess the potential effectiveness of corrective measures for ground-water contamination, the following information is needed:

- Plume definition (includes the types, concentration, and spatial distribution of the contaminants)
- The amenability of the contaminants to specific treatment and potential for contaminants to interfere with treatability
- Fate of the contaminants (whether chemical transformations have, are, or may be occurring, and the degree to which the species are sorbed to the geologic matrix)
- Stratigraphy and hydraulic properties of the aquifer
- Treatment concentration goals and objectives.

The owner or operator should consider whether immediate measures to limit further plume migration (e.g., containment options) or measures to minimize further introduction of contaminants to ground water are necessary.

The process by which a remedial action is undertaken will generally include the following activities:

- Hydrogeologic investigation, which may include additional well installations, detailed vertical and lateral sampling to characterize the plume, and core sampling to determine the degree of sorption of constituents on the geologic matrix
- Risk assessment, to determine the impact on sensitive receptors, which may include identification of the need to develop treatment goals other than GWPSs
- Literature and technical review of treatment technologies considered for further study or implementation
- Evaluation of costs of different treatment options
- Estimation of the time required for completion of remediation under the different treatment options

- Bench-scale treatability studies conducted to assess potential effectiveness of options

- Selection of technology(ies) and proposal preparation for regulatory and public review and comment

- Full-scale pilot study for verification of treatability and optimization of the selected technology

- Initiation of full-scale treatment technology with adjustments, as necessary

- Continuation of remedial action until treatment goals are achieved.

Corrective Measures Assessment

To compare different treatment options, substantial amounts of technical information must be assembled and assessed. The objective of this information-gathering task is to identify the following items for each treatment technology:

- The expected performance of individual approaches

- The time frame when individual approaches can realistically be implemented

- The technical feasibility of the remediation, including new and innovative technologies, performance, reliability and ease of implementation, safety and cross media impacts

- The anticipated time frame when remediation should be complete

- The anticipated cost of the remediation, including capital expenditures, design, ongoing engineering, and monitoring of results

- Technical and financial capability of the owner or operator to successfully complete the remediation

- Disposal requirements for treatment residuals

- Other regulatory or institutional requirements, including State and local permits, prohibitions, or environmental restrictions that may affect the implementation of the proposed remedial activity.

The performance objectives of the corrective measures should be considered in terms of source reduction, cleanup goals, and cleanup time frame. Source reduction would include measures to reduce or stop further releases and may include the repair of existing facility components (liner systems, leachate storage pond liners, piping systems, cover systems), upgrading of components (liners and cover systems), or premature closure in extreme cases. The technology proposed as a cleanup measure should be the best available technology, given the practicable capability of the owner or operator.

The technologies identified should be reliable, based on their previous performance; however, new innovative technologies are not discouraged if they can be shown, with a reasonable degree of confidence, to be reliable.

Because most treatment processes, including biorestoration, potentially produce byproducts or release contaminants to different media (e.g., air stripping of volatile compounds), the impacts of such potential releases must be evaluated. Releases to air may constitute a worker health and safety concern and must be addressed as part of the alternatives assessment process. Other cross media impacts, including transfer of contaminants from soils to ground water, surface water, or air, should be assessed and addressed in the assessment of corrective actions. Guidance for addressing air and soil transport and contamination is provided in USEPA (1989b) and USEPA (1989c).

Analyses should be conducted on treatment options to determine whether or not they are protective of human health and the environment. Environmental monitoring of exposure routes (air and water) may necessitate health monitoring for personnel involved in treatment activities if unacceptable levels of exposure are possible. On a case-by-case basis, implementation plans may require both forms of monitoring.

The development and screening of individual corrective measures requires an understanding of the physio-chemical relationships and interferences between the constituents and the sequence of treatment measures that must be implemented. Proper sequencing of treatment methods to produce a feasible remedial program must be evaluated to avoid interference between the presence of some constituents and the effective removal of the targeted compound. In addition, screening and design parameters of potential treatment options should be evaluated in the early stages of conceptual development and planning to eliminate technically unsuitable treatment methods. In general, selection of an appropriate treatment method will require the experience of a qualified professional and will necessitate a literature review of the best available treatment technologies.

Numerous case studies and published papers from scientific and engineering technical journals exist on treatability of specific compounds and groups of related compounds. Development of new technologies and refinements of technologies have been rapid. A compendium of available literature that includes treatment technologies for organic and inorganic contaminants, technology selection, and other sources of information (e.g., literature search data bases pertinent to ground-water extraction, treatment, and responses) is included in *Practical Guide for Assessing and Remediating Contaminated Sites* (USEPA, 1989e).

The general approach to remediation typically includes active restoration, plume containment, and source control as discussed below. The selection of a particular approach or combination of approaches must be based on the corrective action objectives. These general approaches are outlined in Table 5-3. It should be emphasized that the objective of a treatment program should be to restore ground water to pre-existing conditions or to levels below applicable ground-water protection standards while simultaneously restricting further releases of contaminants to ground water. Once treatment objectives are met, the chance of further contamination should be mitigated to the extent practicable.

Active Restoration

Active restoration generally includes ground-water extraction, followed by onsite or offsite wastewater treatment. Offsite wastewater treatment may include sending the contaminated water to a local publicly owned treatment works (POTW) or to a facility designed to treat the contaminants of concern. Treated ground water may be re-injected, sent to a local POTW, or discharged to a local body of surface water, depending on local, State, and Federal requirements. Typical treatment practices that may be implemented include coagulation and precipitation of metals, chemical oxidation of a number of organic compounds, air stripping to remove volatile organic compounds, and biological degradation of other organics.

The rate of contaminant removal from ground water will depend on the rate of ground-water removal, the cation exchange capacity of the soil, and partition coefficients of the constituents sorbed to the soil (USEPA, 1988). As the concentration of contaminants in the ground water is reduced, the rate at which constituents become partitioned from the soil to the aqueous phase may also be reduced. The amount of flushing of the aquifer material required to remove the contaminants to an acceptable level will generally determine the time frame required for restoration. This time frame is site-specific and may last indefinitely.

In-situ methods may be appropriate for some sites, particularly where pump and treat technologies create serious adverse effects or where it may be financially prohibitive. In-situ methods may include biological restoration requiring pH control, addition of specific micro-organisms, and/or addition of nutrients and substrate to augment and encourage degradation by indigenous microbial populations. Bioremediation requires laboratory treatability studies and pilot field studies to determine the feasibility and the reliability of full-scale treatment. It must be demonstrated that the treatment techniques will not cause degradation of a target chemical to another compound that has unacceptable health risks and that is subject to further degradation. Alternative in-situ methods may also be designed to increase the effectiveness of desorption or removal of contaminants from the aquifer matrix. Such methodologies may include steam stripping, soil flushing, vapor extraction, thermal desorption, and solvent washing, and extraction for removal of strongly sorbed organic compounds. These methods also may be used in unsaturated zones where residual contaminants may be sorbed to the geologic matrix during periodic fluctuations of the water table. Details of in-situ methods may be found in several sources: USEPA (1988); USEPA (1985); and Eckenfelder (1989).

Plume Containment

The purpose of plume containment is to limit the spread of the contaminants. Methods to contain plume movement include passive hydraulic barriers, such as grout curtains and slurry walls, and active gradient control systems involving pumping wells and french drains. The types of aquifer characteristics that favor plume containment include:

- Water naturally unsuited for human consumption
- Contaminants present in low concentration with low mobility
- Low potential for exposure to contaminants and low risk associated with exposure

- Low transmissivity and low future user demand.

Often, it may be advantageous for the owner or operator to consider implementing ground-water controls to inhibit further contamination or the spread of contamination. If ground-water pumping is considered for capturing the leading edge of the contaminant plume, the contaminated water must be managed in conformance with all applicable Federal and State requirements. Under most conditions, it is necessary to consult with the regulatory agencies prior to initiating an interim remedial action.

Source Control

Source control measures should be evaluated to limit the migration of the plume. The regulation does not limit the definition of source control to exclude any specific type of remediation. Remedies must control the source to reduce or eliminate further releases by identifying and locating the cause of the release (e.g., torn geomembrane, excessive head due to blocked leachate collection system, leaking leachate collection well or pipe). Source control measures may include the following:

- Modifying the operational procedures (e.g., banning specific wastes or lowering the head over the leachate collection system through more frequent leachate removal)

- Undertaking more extensive and effective maintenance activities (e.g., excavate waste to repair a liner failure or a clogged leachate collection system)

- Preventing additional leachate generation that may reach a liner failure (e.g., using a portable or temporary rain shelter during operations or capping landfill areas that contribute to leachate migrating from identified failure areas).

In extreme cases, excavation of deposited wastes for treatment and/or offsite disposal may be considered.

Public Participation

The owner or operator is required to hold a public meeting to discuss the results of the corrective action assessment and to identify proposed remedies. Notifications, such as contacting local public agencies, town governments, and State/Tribal governments, posting a notice in prominent local newspapers, and making radio announcements are effective. The public meeting should provide a detailed discussion of how the owner or operator has addressed the factors at §258.56(c)(1)-(4).

5.15 SELECTION OF REMEDY 40 CFR §258.57 (a)-(b)

5.15.1 Statement of Regulation

(a) Based on the results of the corrective measure assessment conducted under §258.56, the owner or operator must select a remedy that, at a minimum, meets the standards listed in paragraph (b) below. The owner or operator must notify the State Director, within 14 days of selecting a remedy, that a report describing the selected remedy has been placed in the operating record and how it meets the standards in paragraph (b) of this section.

(b) Remedies must:

(1) Be protective of human health and the environment;

(2) Attain the ground-water protection standard as specified pursuant to §§258.55(h) or (i);

(3) Control the source(s) of releases so as to reduce or eliminate, to the maximum extent practicable, further releases of Appendix II constituents into the environment that may pose a threat to human health or the environment; and

(4) Comply with standards for management of wastes as specified in §258.58(d).

5.15.2 Applicability

These provisions apply to facilities that have been required to perform corrective measures. The selection of a remedy is closely related to the assessment process and cannot be accomplished unless a sufficiently thorough evaluation of alternatives has been completed. The process of documenting the rationale for selecting a remedy requires that a report be placed in the facility operating record that clearly defines the corrective action objectives and demonstrates why the selected remedy is anticipated to meet those objectives. The State Director must be notified within 14 days of the placement of the report in the operating records of the facility. The study must identify how the remedy will be protective of human health and the environment, attain the GWPS (either background, MCLs, or, in approved States, health-based standards, if applicable), attain source control objectives, and comply with waste management standards.

5.15.3 Technical Considerations

The final method selected for implementation must satisfy the criteria in §258.57(b)(1)-(4). The report documenting the capability of the selected method to meet these four criteria should include such information as:

- Theoretical calculations
- Comparison to existing studies and results of similar treatment case histories
- Bench-scale or pilot-scale treatability test results
- Waste management practices.

The demonstration presented in the report must document the alternative option selection process.

5.16 SELECTION OF REMEDY 40 CFR §258.57 (c)

5.16.1 Statement of Regulation

(c) In selecting a remedy that meets the standards of §258.57(b), the owner or operator shall consider the following evaluation factors:

(1) The long- and short-term effectiveness and protectiveness of the potential remedy(s), along with the degree of certainty that the remedy will prove successful based on consideration of the following:

(i) Magnitude of reduction of existing risks;

(ii) Magnitude of residual risks in terms of likelihood of further releases due to waste remaining following implementation of a remedy;

(iii) The type and degree of long-term management required, including monitoring, operation, and maintenance;

(iv) Short-term risks that might be posed to the community, workers, or the environment during implementation of such a remedy, including potential threats to human health and the environment associated with excavation, transportation, and redisposal or containment;

(v) Time until full protection is achieved;

(vi) Potential for exposure of humans and environmental receptors to remaining wastes, considering the potential threat to human health and the environment associated with excavation, transportation, redisposal, or containment;

(vii) Long-term reliability of the engineering and institutional controls; and

(viii) Potential need for replacement of the remedy.

(2) The effectiveness of the remedy in controlling the source to reduce further releases based on consideration of the following factors:

(i) The extent to which containment practices will reduce further releases;

(ii) The extent to which treatment technologies may be used.

(3) The ease or difficulty of implementing a potential remedy(s) based on consideration of the following types of factors:

(i) Degree of difficulty associated with constructing the technology;

(ii) Expected operational reliability of the technologies;

(iii) Need to coordinate with and obtain necessary approvals and permits from other agencies;

(iv) Availability of necessary equipment and specialists; and

(v) Available capacity and location of needed treatment, storage, and disposal services.

(4) Practicable capability of the owner or operator, including a consideration of the technical and economic capability.

(5) The degree to which community concerns are addressed by a potential remedy(s).

5.16.2 Applicability

These provisions apply to facilities that are selecting a remedy for corrective action. The rule presents the considerations and factors that the owner or operator must evaluate when selecting the appropriate corrective measure.

5.16.3 Technical Considerations

The owner or operator must consider specific topics to satisfy the performance criteria under selection of the final corrective measure. These topics must be addressed in the report documenting the selection of a particular corrective action. The general topic areas that must be considered include the following:

- The anticipated long- and short-term effectiveness of the corrective action
- The anticipated effectiveness of source reduction efforts
- The ease or difficulty of implementing the corrective measure
- The technical and economic practicable capability of the owner or operator
- The degree to which the selected remedy will address concerns raised by the community.

Effectiveness of Corrective Action

In selecting the remedial action, the anticipated long-term and short-term effectiveness should be evaluated. Long-term effectiveness focuses on the risks remaining after corrective measures have been taken. Short-term effectiveness addresses the risks during construction and implementation of the corrective measure. Review of case studies where similar technologies have been applied provide the best measures to judge technical uncertainty, especially when relatively new technologies are applied. The long-term, post-cleanup effectiveness may be judged on the ability of the proposed remedy to mitigate further releases of contaminants to the environment, as well as on the feasibility of the proposed remedy to meet or exceed the GWPSs. The owner or operator must make a reasonable effort to estimate and quantify risks, based on exposure pathways and estimates of exposure levels and durations. These estimates include risks for both ground-water and cross-media contamination.

The source control measures that will be implemented, including excavation, transportation, re-disposal, and containment, should be evaluated with respect to potential exposure and risk to human health and the environment. The source control measures should be viewed as an integral component of the overall corrective action. Health considerations must address monitoring risks to workers and the general public and provide contingency plans should an unanticipated exposure occur. Potential exposure should consider both long- and short-term cases before, during, and after implementation of corrective actions.

The time to complete the remedial activity must be estimated, because it will have direct financial impacts on the project management needs and financial capability of the owner or operator to meet the remedial objectives. The long-term costs of the remedial alternatives and the long-term financial condition of the owner or operator should be reviewed carefully. The implementation schedule should indicate quality control measures to assess the progress of the corrective measure.

The operational reliability of the corrective measures should be considered. In addition, the institutional controls and management practices developed to assess the reliability should be identified.

Effectiveness of Source Reduction

Source control measures identified in previous sections should be discussed in terms of their expected effectiveness. If source control consists of the removal and re-disposal of wastes, the residual materials, such as contaminated soils above the water table, should be quantified and their potential to cause further contamination evaluated. Engineering controls intended to upgrade or repair deficient conditions in landfill component systems, including cover systems, should be quantified in terms of anticipated effectiveness according to current and future conditions. This assessment may indicate to what extent it is technically and financially practicable to make use of existing technologies. The decision against using a certain technology may be based on health considerations and the potential for unacceptable exposure(s) to both workers and the public.

Implementation of Remedial Action

The ease of implementing the proposed remedial action will affect the schedule and startup success of the remedial action. The following key factors need to be assessed:

- The availability of technical expertise
- Construction of equipment or technology
- The ability to properly manage and dispose of wastes generated by treatment
- The likelihood of obtaining local permits and public support for the proposed project.

Technical considerations, including pH control, ground-water extraction feasibility, or the ability to inject nutrients, may need to be considered, depending on the proposed treatment method. Potential impacts, such as potential cross-media contamination, need to be reviewed as part of the overall feasibility of the project.

The schedule of remedial activities should identify the start and end points of the following periods:

- Permitting phase
- Construction and startup period, during which initial implementation success will be evaluated, including time to correct any unexpected problems
- Time when full-scale treatment will be initiated and duration of treatment period
- Implementation and completion of source control measures, including the timeframe for solving problems associated with interim management and disposal of waste materials or treatment residuals.

Items that require long lead times should be identified early in the process and those tasks should be initiated early to ensure that implementation occurs in the shortest practicable period.

Practical Capability

The owner or operator must be technically and financially capable of implementing the chosen remedial alternative and ensuring project completion, including provisions for future changes to the remedial plan after progress is reviewed. If either technical or financial capability is inadequate for a particular alternative, then other alternatives with similar levels of protectiveness should be considered for implementation.

Community Concerns

The public meetings held during assessment of alternative measures are intended to elicit public comment and response. The owner or operator must, by means of meeting minutes and a record of written comments, identify which public concerns have been expressed and addressed by corrective measure options. In reality, the final remedy selected and implemented will be one that the State regulatory agency, the public, and the owner or operator agree to.

5.17 SELECTION OF REMEDY 40 CFR §258.57 (d)

5.17.1 Statement of Regulation

(d) The owner or operator shall specify as part of the selected remedy a schedule(s) for initiating and completing remedial activities. Such a schedule must require the initiation of remedial activities within a reasonable period of time taking into consideration the factors set forth in paragraphs (d) (1-8). The owner or operator must consider the following factors in determining the schedule of remedial activities:

(1) Extent and nature of contamination;

(2) Practical capabilities of remedial technologies in achieving compliance with ground-water protection standards established under §§258.55(g) or (h) and other objectives of the remedy;

(3) Availability of treatment or disposal capacity for wastes managed during implementation of the remedy;

(4) Desirability of utilizing technologies that are not currently available, but which may offer significant advantages over already available technologies in terms of effectiveness, reliability, safety, or ability to achieve remedial objectives;

(5) Potential risks to human health and the environment from exposure to contamination prior to completion of the remedy;

(6) Resource value of the aquifer including:

(i) Current and future uses;

(ii) Proximity and withdrawal rate of users;

(iii) Ground-water quantity and quality;

(iv) The potential damage to wildlife, crops, vegetation, and physical structures caused by exposure to waste constituent;

(v) The hydrogeologic characteristic of the facility and surrounding land;

(vi) Ground-water removal and treatment costs; and

(vii) The cost and availability of alternative water supplies.

(7) Practicable capability of the owner or operator.

(8) Other relevant factors.

5.17.2 Applicability

The requirements of §258.57(d) apply to owners or operators of all new units, existing units, and laterally expanded units at all facilities required to implement corrective actions. The requirements must be complied with prior to implementing corrective measures. The owner or operator must specify the schedule for remedial activities based on the following considerations:

- The size and nature of the contaminated area at the time the corrective measure is to be implemented
- The practicable capabilities of the remedial technology selected
- Available treatment and disposal capacity
- Potential use of alternative innovative technologies not currently available
- Potential risks to human health and the environment existing prior to completion of the remedy
- Resource value of the aquifer
- The practicable capability of the owner/operator
- Other relevant factors.

5.17.3 Technical Considerations

The time schedule for implementing and completing the remedial activity is influenced by many factors that should be considered by the owner or operator. The most critical factor is the nature and extent of the contamination, which significantly affects the ultimate treatment rate. The size of the treatment facility and the ground-water extraction and injection rates must be balanced for system optimization, capital resources, and remedial timeframe objectives. The nature of the contamination will influence the degree to which the aquifer must be flushed to remove adsorbed species. These factors, which in part define the practicable capability of the alternative (treatment efficiency, treatment rate, and replenishment of contaminants by natural processes), should be considered when selecting the remedy.

In addition, the rate at which treatment may occur may be restricted by the availability or capacity to handle treatment residues and the normal flow of wastes during remediation. Alternative residue treatment or disposal capacity must be identified as part of the implementation plan schedule.

If contaminant migration is slow due to low transport properties of the aquifer, additional time may be available to evaluate the value of emerging and promising innovative technologies. The use of such technologies is not excluded as part of the requirement to implement a remedial action as soon as practicable. Delaying implementation to increase the availability of new technologies must be evaluated in terms of achievable cleanup levels, ultimate cost, additional environmental impact, and potential for increased risk to sensitive receptors. If a new technology clearly is superior to existing options in attaining remediation objectives, it may be appropriate to delay implementation. This may require that existing risks be controlled through interim measures.

In setting the implementation schedule, the owner or operator should assess the risk to human health and the environment within the timeframe of reaching treatment objectives. If the risk is unacceptable, considering health-based assessments of exposure paths and exposure limits, the implementation time schedule must be accelerated or the selected remedy altered to provide an acceptable risk level in a timely manner.

Establishment of the schedule also may include consideration of the resource value of the aquifer, as it pertains to current and future use, proximity to users, quality and quantity of ground water, agricultural value and uses (irrigation water source or impact on adjacent agricultural lands), and the availability of alternative supplies of water of similar quantity and quality. Based on these factors, a relative assessment of the aquifer's resource value to the local community can be established. Impacts to the resource and the degree of financial or health-related distress by users should be considered. The implementation timeframe should attempt to minimize the loss of value of the resource to users. The possibility that alternative water supplies will have to be developed as part of the remedial activities may need to be considered.

Because owners or operators may not be knowledgeable in remediation activities, reliance on the owner or operator to devise the schedule for remediation may be impracticable. In these instances, use of an outside firm to coordinate remediation scheduling may be necessary. Similarly, development of a schedule for which the owner or operator cannot finance, when other options exist that do allow for owner or operator financing, should be prevented.

5.18 SELECTION OF REMEDY 40 CFR §258.57 (e)-(f)

5.18.1 Statement of Regulation

(e) The Director of an approved State may determine that remediation of a release of an Appendix II constituent from a MSWLF unit is not necessary if the owner or operator demonstrates to the satisfaction of the Director of an approved State that:

(1) The ground water is additionally contaminated by substances that have originated from a source other than a MSWLF unit and those substances are present in concentrations such that cleanup of the release from the MSWLF unit would provide no significant reduction in risk to actual or potential receptors; or

(2) The constituent(s) is present in ground water that:

(i) Is not currently or reasonably expected to be a potential source of drinking water; and

(ii) Is not hydraulically connected with waters to which the hazardous constituents are migrating or are likely to migrate in a concentration(s) that would exceed the ground-water protection standards established under §258.55(h) or (i); or

(3) Remediation of the release(s) is technically impracticable; or

(4) Remediation results in unacceptable cross-media impacts.

(f) A determination by the Director of an approved State pursuant to paragraph (e) above shall not affect the authority of the State to require the owner or operator to undertake source control measures or other measures that may be necessary to eliminate or minimize further releases to the ground water, to prevent exposure to the ground water, or to remediate the ground water to concentrations that are technically practicable and significantly reduce threats to human health or the environment.

5.18.2 Applicability

The criteria under §258.57(e) and (f) apply in approved States only. Remediation of the release of an Appendix II constituent may not be necessary if 1) a source other than the MSWLF unit is partly responsible for the ground-water contamination, 2) the resource value of the aquifer is extremely limited, 3) remediation is not technically feasible, or 4) remediation will result in unacceptable cross-media impacts. The Director may determine that while total remediation is not required, source control measures or partial remediation of ground water to concentrations that are technically practicable and significantly reduce risks is required.

5.18.3 Technical Considerations

There are four situations where an approved State may not require cleanup of hazardous constituents released to ground water from a MSWLF unit. If sufficient evidence exists to document that the ground water is contaminated by a source other than the MSWLF unit, the Director of an approved State may grant a waiver from implementing some or all of the corrective measure requirements. The owner or operator must demonstrate that cleanup of a release from its MSWLF unit would provide no significant reduction in risk to receptors due to concentrations of constituents from the other source.

A waiver from corrective measures also may be granted if the contaminated ground water is not a current or reasonably expected potential future drinking water source, and it is unlikely that the hazardous constituents would migrate to waters causing an exceedance of GWPS. The owner or operator must demonstrate that the uppermost aquifer is not hydraulically connected with a lower aquifer. The owner or operator may seek an exemption if it can be demonstrated that attenuation, advection/dispersion or other natural processes can remove the threat to interconnected aquifers. The owner or operator may seek the latter exemption if the contaminated zone is not a drinking water resource.

The Director of an approved State may waive cleanup requirements if remediation is not technically feasible. In addition, the Director may wave requirements if remediation results in unacceptable cross-media impacts. A successful demonstration that remediation is not technically feasible must document specific facts that attribute to this demonstration. Technical impracticabilities may be related to the accessibility of the ground water to treatment, as well as the treatability of the ground water using practicable treatment technologies. If the owner or operator can demonstrate that unacceptable cross-media impacts are uncontrollable under a given remedial option (e.g., movement in response to ground-water pumping or release of volatile organics to the atmosphere) and that the no action option is a less risky alternative, then the Director of an approved State may determine that remediation is not necessary.

A waiver of remedial obligation does not necessarily release the owner or operator from the responsibility of conducting source control measures or minimal ground-water remediation. The State may require that source control be implemented to the maximum extent practicable to minimize future risk of releases of contaminants to ground water or that ground water be treated to the extent technically feasible.

5.19 IMPLEMENTATION OF THE CORRECTIVE ACTION PROGRAM 40 CFR §258.58 (a)

<u>5.19.1 Statement of Regulation</u>

(a) Based on the schedule established under §258.57(d) for initiation and completion of remedial activities the owner/operator must:

(1) Establish and implement a corrective action ground-water monitoring program that:

(i) At a minimum, meets the requirements of an assessment monitoring program under §258.55;

(ii) Indicates the effectiveness of the corrective action remedy; and

(iii) Demonstrates compliance with ground-water protection standard pursuant to paragraph (e) of this section.

(2) Implement the corrective action remedy selected under §258.57; and

(3) Take any interim measures necessary to ensure the protection of human health and the environment. Interim measures should, to the greatest extent practicable, be consistent with the objectives of and contribute to the performance of any remedy that may be required pursuant to §258.57. The following factors must be considered by an owner or operator in determining whether interim measures are necessary:

(i) Time required to develop and implement a final remedy;

(ii) Actual or potential exposure of nearby populations or environmental receptors to hazardous constituents;

(iii) Actual or potential contamination of drinking water supplies or sensitive ecosystems;

(iv) Further degradation of the ground water that may occur if remedial action is not initiated expeditiously;

(v) Weather conditions that may cause hazardous constituents to migrate or be released;

(vi) Risks of fire or explosion, or potential for exposure to hazardous constituents as a result of an accident or failure of a container or handling system; and

(vii) Other situations that may pose threats to human health and the environment.

5.19.2 Applicability

These provisions apply to facilities that are required to initiate and complete corrective actions.

The owner or operator is required to continue to implement its ground water assessment monitoring program to evaluate the effectiveness of remedial actions and to demonstrate that the remedial objectives have been attained at the completion of remedial activities.

Additionally, the owner or operator must take any interim actions to protect human health and the environment. The interim measures must serve to mitigate actual threats and prevent potential threats from being realized while a long-term comprehensive response is being developed.

5.19.3 Technical Considerations

Implementation of the corrective measures encompass all activities necessary to initiate and continue remediation. The owner or operator must continue assessment monitoring to anticipate whether interim measures are necessary, and to determine whether the corrective action is meeting stated objectives.

Monitoring Activities

During the implementation period, ground-water monitoring must be conducted to demonstrate the effectiveness of the corrective action remedy. If the remedial action is not effectively curtailing further ground water degradation or the spread of the contaminant plume, replacement of the system with an alternative measure may be warranted. The improvement rate of the condition of the aquifer must be monitored and compared to the cleanup objectives. It may be necessary to install additional monitoring wells to more clearly evaluate remediation progress. Also, if it becomes apparent that the GWPS will not be achievable technically, in a realistic time-frame, the performance objectives of the corrective measure must be reviewed and amended as necessary.

Interim Measures

If unacceptable potential risks to human health and the environment exist prior to or during implementation of the corrective action, the owner or operator is required to take interim measures to protect receptors. These interim measures are typically short-term solutions to address immediate concerns and do not necessarily address long-term remediation objectives. Interim measures may include activities such as control of ground-water migration through high-volume withdrawal of ground water or response to equipment failures that occur during remediation (e.g., leaking drums). If contamination migrates offsite, interim measures may include providing an alternative water supply for human, livestock, or irrigation needs. Interim measures also pertain to source control activities that may be implemented as part of the overall corrective action. This may include activities such as excavation of the source material or in-situ treatment of the contaminated source. Interim measures should be developed with consideration given to maintaining conformity with the objectives of the final corrective action.

5.20 IMPLEMENTATION OF THE CORRECTIVE ACTION PROGRAM 40 CFR §258.58 (b)-(d)

5.20.1 Statement of Regulation

(b) An owner or operator may determine, based on information developed after implementation of the remedy has begun or other information, that compliance with requirements of §258.57(b) are not being achieved through the remedy selected. In such cases, the owner or operator must implement other methods or techniques that could practicably achieve compliance with the requirements, unless the owner or operator makes the determination under §258.58(c).

(c) If the owner or operator determines that compliance with requirements under §258.57(b) cannot be practically achieved with any currently available methods, the owner or operator must:

(1) Obtain certification of a qualified ground-water specialist or approval by the Director of an approved State that compliance with requirements under §258.57(b) cannot be practically achieved with any currently available methods;

(2) Implement alternate measures to control exposure of humans or the environment to residual contamination, as necessary to protect human health and the environment; and

(3) Implement alternate measures for control of the sources of contamination, or for removal or decontamination of equipment, units, devices, or structures that are:

(i) Technically practicable; and

(ii) Consistent with the overall objective of the remedy.

(4) Notify the State Director within 14 days that a report justifying the alternative measures prior to implementing the alternative measures has been placed in the operating record.

(d) All solid wastes that are managed pursuant to a remedy required under §258.57, or an interim measure required under §258.58(a)(3), shall be managed in a manner:

(1) That is protective of human health and the environment; and

(2) That complies with applicable RCRA requirements.

5.20.2 Applicability

The requirements of the alternative measures are applicable when it becomes apparent that the remedy selected will not achieve the GWPSs or other significant objectives of the remedial program (e.g., protection of sensitive receptors). In determining that the selected corrective action approach will not achieve desired results, the owner or operator must implement alternate corrective measures to achieve the GWPSs. If it becomes evident that the cleanup goals are not technically obtainable by existing practicable technology, the owner or operator must implement actions to control exposure of humans or the environment from residual contamination and to control the sources of contamination. Prior to implementing alternative measures, the owner or operator must notify the Director of an approved State within 14 days that a report justifying the alternative measures has been placed in the operating record.

All wastes that are managed by the MSWLF unit during corrective action, including interim and alternative measures, must be managed according to applicable RCRA requirements in a manner that is protective of human health and the environment.

5.20.3 Technical Considerations

An owner or operator is required to continue the assessment monitoring program during the remedial action. Through monitoring, the short and long term success of the remedial action can be gauged against expected progress. During the remedial action, it may be necessary to install additional ground-water monitoring wells or pumping or injection wells to adjust to conditions that vary from initial assessments of the ground-water flow system. As remediation progresses and data are compiled, it may become evident that the remediation activities will not protect human health and the environment, meet GWPSs, control sources of contamination, or comply with waste management standards. The reasons for unsatisfactory results may include:

- Refractory compounds that are not amenable to removal or destruction (detoxification)
- The presence of compounds that interfere with treatment methods identified for target compounds
- Inappropriately applied technology
- Failure of source control measures to achieve desired results
- Failure of ground-water control systems to achieve adequate containment or removal of contaminated ground water
- Residual concentrations above GWPSs that cannot be effectively reduced further because treatment efficiencies are too low
- Transformation or degradation of target compounds to different forms that are not amenable to further treatment by present or alternative technologies.

The owner or operator should compare treatment assumptions with existing conditions to determine if assumptions adequately depict site conditions. If implementation occurred as designed, the owner or operator should attempt to modify or upgrade existing remedial technology to optimize performance and to improve treatment effectiveness. If the existing technology is found to be unable to meet remediation objectives, alternative approaches must be evaluated that could meet these objectives while the present remediation is continued. During this re-evaluation period, the owner or operator may suspend treatment only if continuation of remedial activities clearly increases the threat to human health and the environment.

5.21 IMPLEMENTATION OF THE CORRECTIVE ACTION PROGRAM 40 CFR §258.58 (e)-(g)

5.21.1 Statement of Regulation

(e) Remedies selected pursuant to §258.57 shall be considered complete when:

(1) The owner or operator complies with the ground-water protection standards established under §§258.55(h) or (i) at all points within the plume of contamination that lie beyond the ground-water monitoring well system established under §258.51(a).

(2) Compliance with the ground-water protection standards established under §§258.55(h) or (i) has been achieved by demonstrating that concentrations of Appendix II constituents have not exceeded the ground-water protection standard(s) for a period of three consecutive years using the statistical procedures and performance standards in §258.53(g) and (h). The Director of an approved State may specify an alternative length of time during which the owner or operator must demonstrate that concentrations of Appendix II constituents have not exceeded the ground-water protection standard(s) taking into consideration:

(i) Extent and concentration of the release(s);

(ii) Behavior characteristics of the hazardous constituents in the ground water;

(iii) Accuracy of monitoring or modeling techniques, including any seasonal, meteorological, or other environmental variabilities that may affect the accuracy; and

(iv) Characteristics of the ground water.

(3) All actions required to complete the remedy have been satisfied.

(f) Upon completion of the remedy, the owner or operator must notify the State Director within 14 days that a certification that the remedy has been completed in compliance with the requirements of §258.58(e) has been placed in the operating record. The certification must be signed by the owner or operator and by a qualified ground-water specialist or approved by the Director of an approved State.

(g) When, upon completion of the certification, the owner or operator determines that the corrective action remedy has been completed in accordance with the requirements under paragraph (e) of this section, the owner or operator shall be released from the requirements for financial assurance for corrective action under §258.73.

§258.59 [Reserved].

5.21.2 Applicability

These criteria apply to facilities conducting corrective action. Remedies are considered complete when, after 3 consecutive years of monitoring (or an alternative length of time as identified by the Director), the results show significant statistical evidence that

Appendix II constituent concentrations are below the GWPSs. Upon completion of all remedial actions, the owner or operator must certify to such, at which point the owner or operator is released from financial assurance requirements.

5.21.3 Technical Considerations

The regulatory period of compliance is 3 consecutive years at all points within the contaminant plume that lie beyond the ground-water monitoring system unless the Director of an approved State specifies an alternative length of time. Compliance is achieved when the concentrations of Appendix II constituents do not exceed the GWPSs for a predetermined length of time. Statistical procedures in §258.53 must be used to demonstrate compliance with the GWPSs.

The preferred statistical method for comparison is to construct a 99 percent confidence interval around the mean of the last 3 years of data and compare the upper limit of the confidence interval to the GWPS. An upper limit less than the GWPS is considered significant evidence that the standard is no longer being exceeded. The confidence interval must be based on the appropriate model describing the distribution of the data.

Upon completion of the remedy, including meeting the GWPS at all points within the contaminant plume, the owner or operator must notify the State Director within fourteen days that a certification that the remedy has been completed has been placed in the operating record. The certification must be signed by the owner or operator and a qualified ground-water scientist or approved by the Director of an approved State. Upon completion of the remedial action, in accordance with §258.58(e), the owner or operator is released from the financial assurance requirements pertaining to corrective actions.

The Director of an approved State may require an alternate time period (other than 3 years) to demonstrate compliance. In determining an alternate period the Director must consider the following:

- The extent and concentration of the release(s)
- The behavior characteristics (fate and transport) of the hazardous constituents in the ground water (e.g., mobility, persistence, toxicity, etc.)
- Accuracy of monitoring or modeling techniques, including any seasonal, meteorological or other environmental variabilities that may affect accuracy
- The characteristics of the ground water (e.g., flow rate, pH, etc.).

Consideration of these factors may result in an extension or shortening of the time required to show compliance with remediation objectives.

5.22 FURTHER INFORMATION

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CHAPTER 6

SUBPART F
CLOSURE AND POST-CLOSURE

CHAPTER 6
SUBPART F

TABLE OF CONTENTS

CHAPTER 6
SUBPART F
CLOSURE AND POST-CLOSURE

6.1 INTRODUCTION

The 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 limited 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 the:

- Degree and rate of post-closure 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; and
- Environmental performance of the combined bottom liner and final cover system.

Full closure and post-closure care requirements apply to all MSWLF units that receive wastes on or after October 9, 1993. For MSWLF units that stop receiving wastes prior to October 9, 1993, only the final cover requirements of §258.60(a) apply.

*[NOTE: EPA finalized several revisions to 40 CFR Part 258 on October 1, 1993 (58 FR 51536) and issued a correction notice on October 14, 1993 (58 FR 53136). Questions regarding the final rule and requests for copies of the Federal Register notices should be made to the RCRA/Superfund Hotline at (800) 424-9346. These revisions delay the effective date for some categories of landfills. More detail on the content of the revisions is included in the introduction.

6.2 FINAL COVER DESIGN
40 CFR §258.60(a)

6.2.1 Statement of Regulation

(a) Owners or operators of all MSWLF units must install a final cover system that is designed to minimize infiltration and erosion. The final cover system must be designed and constructed to:

(1) Have permeability less than or equal to the permeability of any bottom liner system or natural subsoils present, or a permeability no greater than 1 x 10^{-5} cm/sec, whichever is less, and

(2) Minimize infiltration through the closed MSWLF unit by the use of an infiltration layer that contains a minimum of 18-inches of an earthen material, and

(3) Minimize erosion of the final cover by the use of an erosion layer that contains a minimum 6-inches of earthen material that is capable of sustaining native plant growth.

6.2.2 Applicability

These final cover requirements apply to all MSWLF units required to close in accordance with Part 258, including MSWLF units that received wastes after October 9, 1991 but stopped receiving wastes prior to October 9, 1993. Units closing during this two-year period are required to install a final cover.

The final cover system required to close a MSWLF unit, whether the unit is an existing unit, a new unit, or a lateral expansion of an existing unit, must be composed of an infiltration layer that is a minimum of 18 inches thick, overlain by an erosion layer that is a minimum of 6 inches thick.

The final cover should minimize, over the long term, liquid infiltration into the waste. The final cover must have a hydraulic conductivity less than or equal to any bottom liner system or natural subsoils present to prevent a "bathtub" effect. In no case can the final cover have a hydraulic conductivity greater than 1 x 10^{-5} cm/sec regardless of the permeability of underlying liners or natural subsoils. 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.

In approved States, an alternate cover system may be approved by the Director (see Section 6.3).

6.2.3 Technical Considerations

Design criteria for a final cover system should be selected to:

- Minimize infiltration of precipitation into the waste;
- Promote good surface drainage;
- Resist erosion;
- Control landfill gas migration and/or enhance recovery;
- Separate waste from vectors (e.g., animals and insects);
- Improve aesthetics;
- Minimize long-term maintenance;
- Protect human health and the environment; and
- Consider final use.

The first three points are directly related to the regulatory requirements. The other points typically are considered in designing cover systems for landfills.

Reduction of infiltration in a well-designed final cover system is achieved through good surface drainage and run-off with minimal erosion, transpiration of water by plants in the vegetative cover and root zone, and restriction of percolation through earthen material. The cover system should be designed to provide the desired level of long-term performance with minimal maintenance. Surface water run-off 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. In addition, the cover system should be geotechnically stable to prevent failure, such as sliding, that may occur between the erosion and infiltration layers, within these layers, or within the waste. Figure 6-1 illustrates the minimum requirements for the final cover system.

Infiltration Layer

The infiltration layer must be at least 18 inches thick and consist of earthen material that has a hydraulic conductivity (coefficient of permeability) less than or equal to the hydraulic conductivity of any bottom liner system or natural subsoils. MSWLF units with poor or non-existent bottom liners possessing hydraulic conductivities greater than 1×10^{-5} cm/sec must have an infiltration layer that meets the 1×10^{-5} cm/sec minimum requirement. Figure 6-2 presents an example of a final cover with a hydraulic conductivity less than or equal to the hydraulic conductivity of the bottom liner system.

For units that have a composite liner with a 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. A final cover system for a MSWLF unit with a FML combined with a soil liner and leachate collection system is presented in Figure 6-3a. Figure 6-3b shows a final cover system for a MSWLF unit that has both a double FML and double leachate collection system.

The earthen material used for the infiltration layer should be free of rocks, clods, debris, cobbles, rubbish, and roots that may increase the hydraulic conductivity by promoting preferential flow paths. To facilitate run-off while minimizing erosion, the surface of the compacted soil should have a minimum slope of 3 percent and a maximum slope of 5 percent after allowance for settlement. It is critical that side slopes, which are frequently greater than 5 percent, be evaluated for erosion potential.

Membrane and clay layers should be placed below the maximum depth of frost penetration to avoid freeze-thaw effects (U.S. EPA, 1989b). Freeze-thaw effects may include development of microfractures or realignment of interstitial fines, which can increase the hydraulic conductivity of clays by more than an order of magnitude (U.S. EPA, 1990). Infiltration layers may be subject to desiccation, depending on climate and soil water retention in the erosion layer. Fracturing and volumetric shrinking of the clay due to water loss may increase the hydraulic conductivity of the infiltration layer. Figure 6-4 shows the regional average depth of frost penetration; however, these values should not be used to find the maximum depth of frost penetration for a particular area of concern at a particular site. 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.

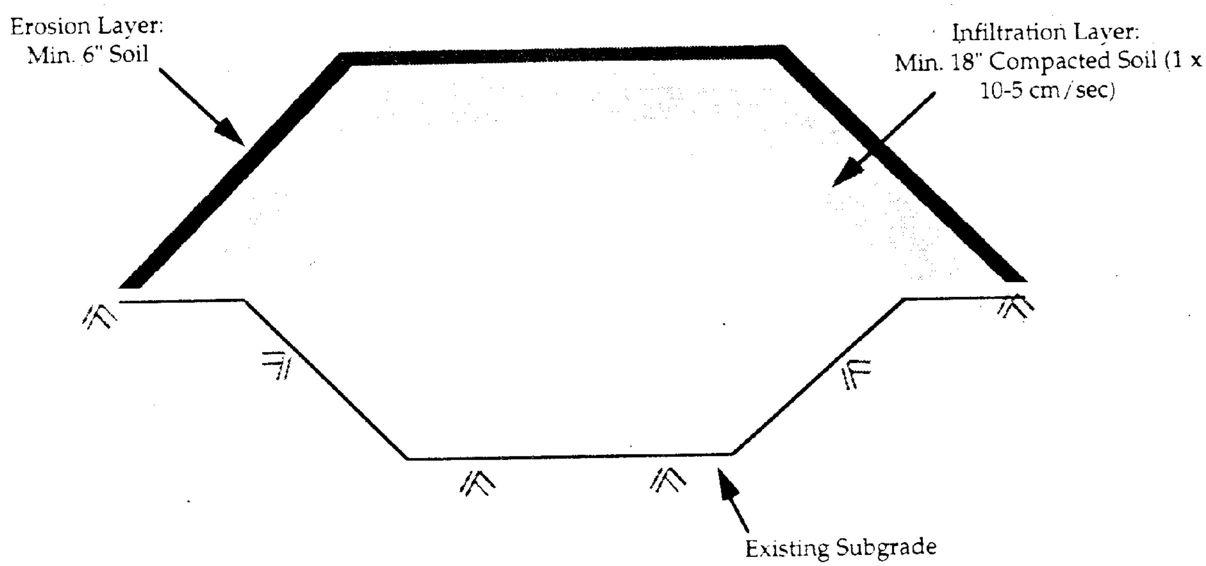


Figure 6-1
Example of Minimum Final Cover Requirements

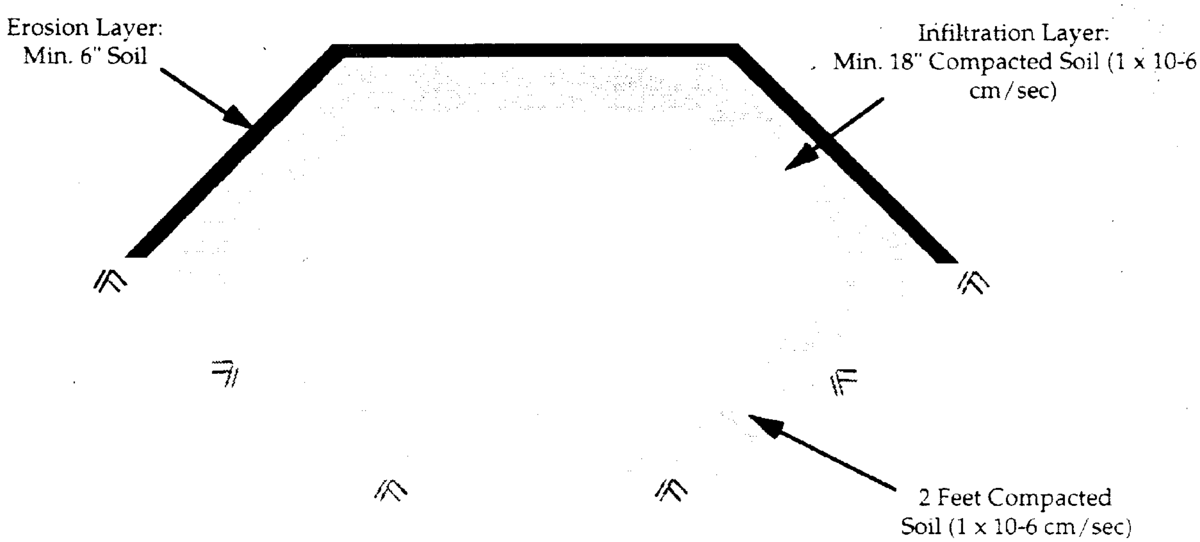


Figure 6-2
Example of Final Cover With Hydraulic Conductivity(K) ≤ K of Liner

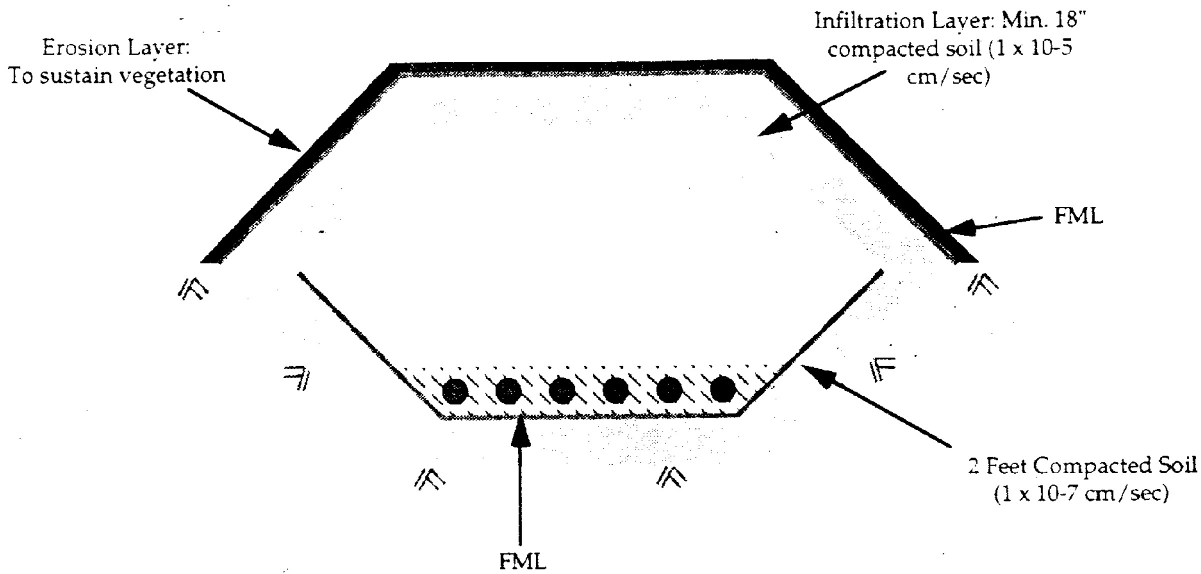


Figure 6-3a
Example of Final Cover Design for a MSWLF Unit With a FML and Leachate Collection System

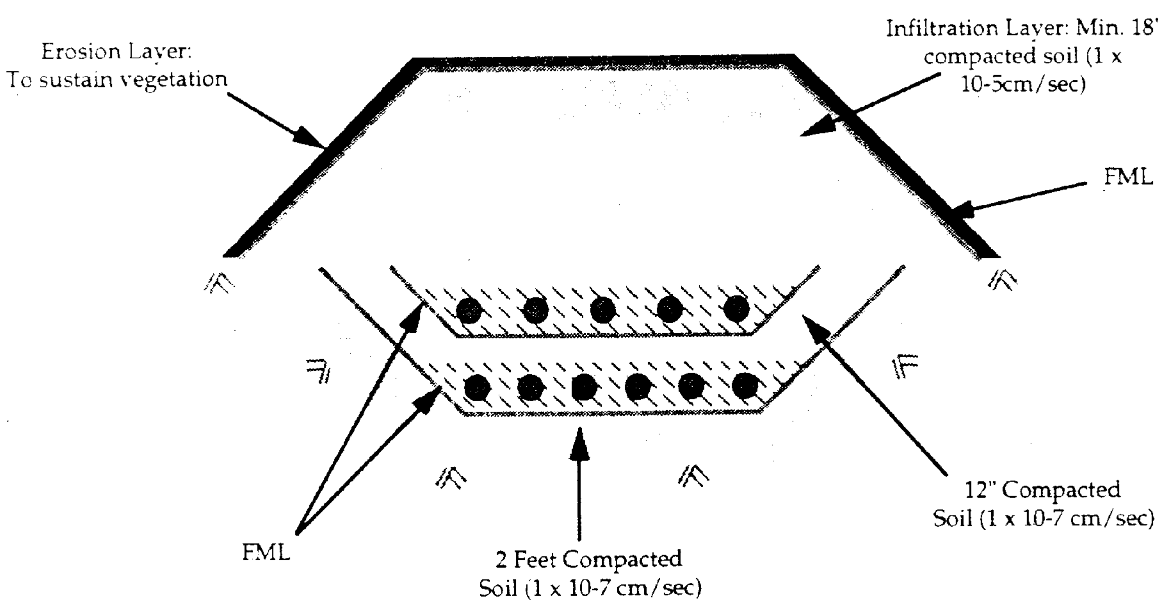
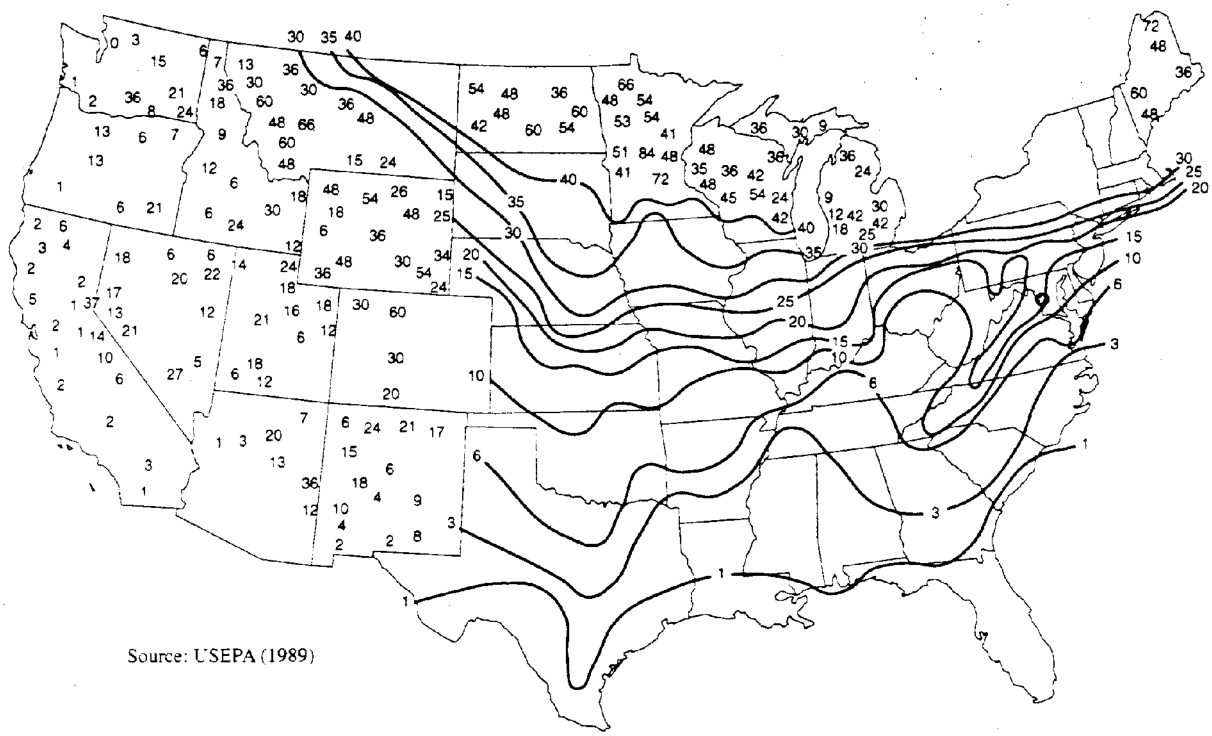


Figure 6-3b
Example of Final Cover Design for a MSWLF Unit With a Double FML and Leachate Collection System



Source: USEPA (1989)

Figure 6-4
Regional Depth of Frost Penetration in Inches

The infiltration layer is designed and constructed in a manner similar to that used for soil liners (U.S. EPA, 1988), with the following differences:

- Because the cover is generally not subject to large overburden loads, the issue of compressive stresses is less critical unless post-closure land use will entail construction of objects that exert large amounts of stress.

- The soil cover is subject to loadings from settlement of underlying materials. The extent of settlement anticipated should be evaluated and a closure and post-closure maintenance plan should be 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.

The design of a final cover is site-specific and the relative performance of cover design options may be compared and evaluated by the HELP (Hydrologic Evaluation of Landfill Performance) model. The HELP model was developed by the U.S. Army Corps of Engineers for the U.S. EPA and is widely used for evaluating expected hydraulic performance of landfill cover/liner systems (U.S. EPA, 1988).

The HELP program calculates daily, average, and peak estimates of water movement across, into, through, and out of landfills. The input parameters for the model include soil properties, precipitation and other climatological data, vegetation type, and landfill design information. Default climatologic and soil data are available but should be verified as reasonable for the site modeled. Outputs from the model include precipitation, run-off, 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. Data from the model are presented in a tabular report format and include the input parameters used and a summary of the simulation results. Results are presented in several tables of daily, monthly, and annual totals for each year specified. A summary of the outputs also is produced, including average monthly totals, average annual totals, and peak daily values for several simulation variables (U.S. EPA, 1988).

The HELP model may be used to estimate the hydraulic performance of the cover system designed for a MSWLF unit. Useful information provided by the HELP model includes surface run-off, duration and quantity of water storage within the erosion layer, and net infiltration through the cover system to evaluate whether leachate will accumulate within the landfill. For the model to be used properly, the HELP Model User's Guide and documentation should be consulted.

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).

Increased thickness and tensile strengths may be necessary to prevent failure under stresses caused by construction and waste settlement during the post-closure care period. The strength, resistance to sliding, hydraulic performance, and actual thickness of geomembranes should be carefully evaluated. The quality and performance of some textured sheets may be difficult to evaluate due to the variability of the textured surface.

Erosion Layer

The thickness of the erosion layer is influenced by depth of frost penetration and erosion potential. This layer is also used to support vegetation. The influence of frost penetration was discussed previously on page 6-3.

Erosion can adversely affect the performance of the final cover of a MSWLF unit by causing rills that require maintenance and repair. As previously stated, a healthy vegetative layer can protect the cover from erosion; conversely, severe erosion can affect the vegetative growth. Extreme erosion may lead to the exposure of the infiltration layer, initiate or contribute to sliding failures, or expose the waste. Anticipated erosion due to surface water run-off for given design criteria may be approximated using the USDA Universal Soil Loss Equation (U.S. EPA, 1989a). By evaluating erosion loss, the design may be optimized to reduce maintenance through selection of the best available soil materials or by initially adding excess soil to increase the time required before maintenance is needed. Parameters in the equation include the following:

$$X = RKLSCP$$

where
X = Soil loss (tons/acre/year)
R = Rainfall erosion index
K = Soil erodibility index
L = Slope length factor
S = Slope gradient factor
C = Crop management factor
P = Erosion control practice.

Values for the Universal Soil Loss Equation parameters may be obtained from the U. S. Soil Conservation Service (SCS) technical guidance document entitled "Predicting Rainfall Erosion Losses, Guidebook 537" (1978), available at local SCS offices located throughout the United States. State or local SCS offices can provide factors to be used in the soil loss equation that are appropriate to a given area of the country. Figure 6-5 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):

$$X' = I'K'C'L'V'$$

where
X' = Annual wind erosion
I' = Field roughness factor
K' = Soil erodibility index
C' = Climate factor
L' = Field length factor
V' = Vegetative cover factor.

A vegetative cover not only improves the appearance of the site, but it also controls erosion of the final cover; a vegetated cover may require only minimal maintenance. The vegetation component of the erosion layer should have the following

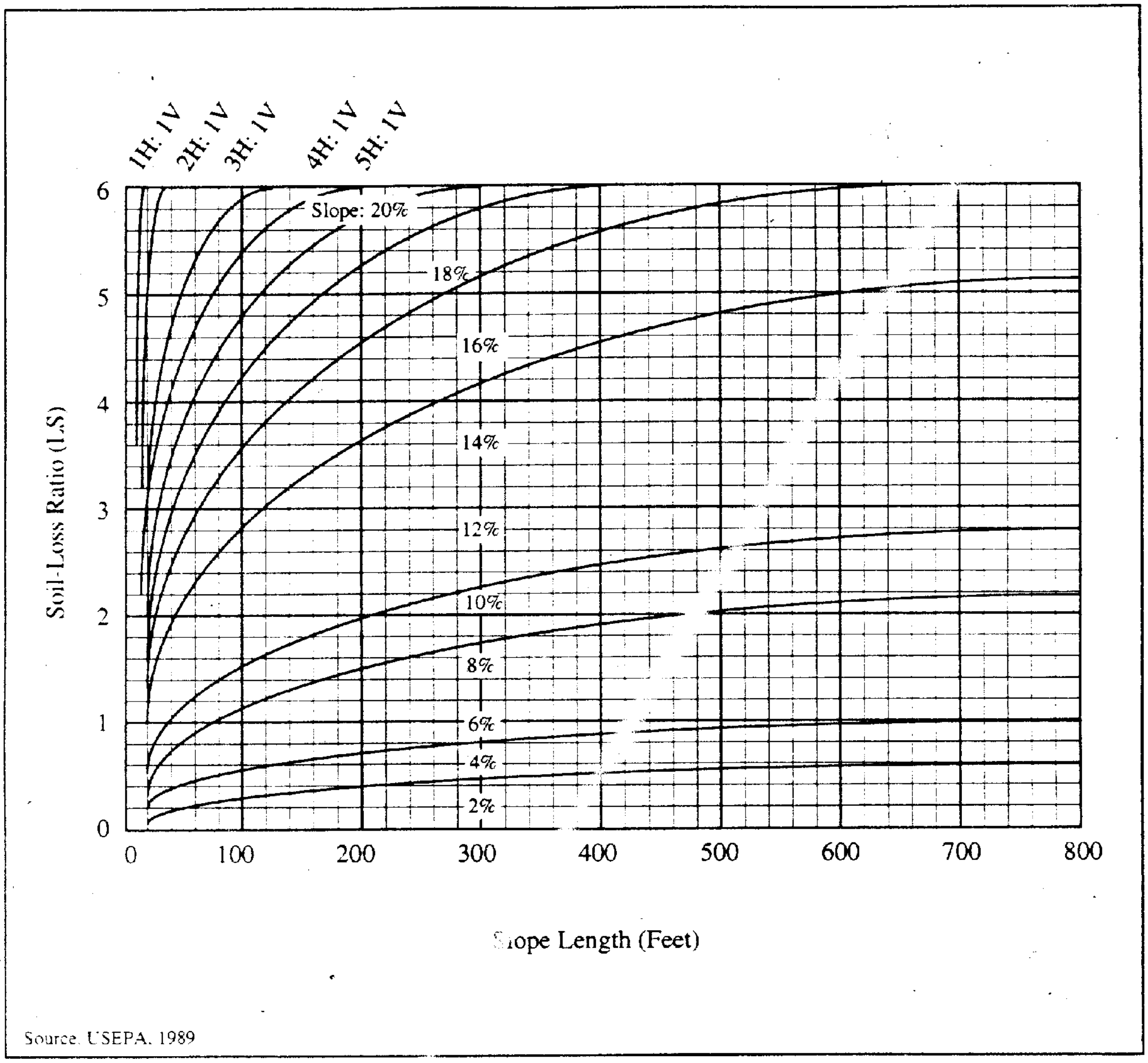


Figure 6-5
Soil Erosion Due to Slope

specifications and characteristics (U.S. EPA, 1989b):

- Locally adapted perennial plants that are resistant to drought and temperature extremes;
- Roots that will not disrupt the low-permeability layer;
- The ability to thrive in low-nutrient soil with minimum nutrient addition;
- Sufficient plant density to minimize cover soil erosion;
- The ability to survive and function with little or no maintenance (i.e., self-supportive); and
- Sufficient variety of plant species to continue to achieve these characteristics and specifications over time.

The use of deep-rooted shrubs and trees is generally inappropriate because the root systems may penetrate the infiltration layer and create preferential pathways of percolation. Plant species with fibrous or branching root systems are suited for use at landfills, and can include a large variety of grasses, herbs (i.e., legumes), and shallow-rooted plants. The suitable species in a region will vary, dependent on climate and site-specific factors such as soil type and slope gradient and aspect. The timing of seeding (spring or fall in most climates) is critical to successful germination and establishment of the vegetative cover (U.S. EPA, 1989b). Temporary winter covers may be grown from fast-growing seed stock such as winter rye.

Selection of the soil for the vegetative cover (erosion layer) should include consideration of soil type, nutrient and pH levels, climate, species of the vegetation selected, mulching, and seeding time. Loamy soils with a sufficient organic content generally are preferred. The balance of clay, silt, and sand in loamy soils provides an environment conducive to seed germination and root growth (USEPA, 1988).

The Director of an approved State can allow alternate designs to address vegetative problems (e.g., the use of pavement or other material) in areas that are not capable of sustaining plant growth.

6.3 ALTERNATIVE FINAL COVER DESIGN 40 CFR §258.60(b)

6.3.1 Statement of Regulation

(b) The Director of an approved State may approve an alternative final cover design that includes:

(1) An infiltration layer that achieves an equivalent reduction in infiltration as the infiltration layer specified in paragraphs (a)(1) and (a)(2) of this section, and

(2) An erosion layer that provides equivalent protection from wind and water erosion as the erosion layer specified in (a)(3) of this section.

6.3.2 Applicability

The Director of an approved State may approve alternative final cover systems that can achieve equivalent performance as the minimum design specified in §258.60(a). This provides an opportunity to incorporate different technologies or improvements into cover designs, and to address site-specific conditions.

6.3.3 Technical Considerations

An alternative material and/or an alternative thickness may be used for an infiltration layer as long as the infiltration layer requirements specified in §258.60(a)(1) and (a)(2) are met.

For example, an armored surface (e.g., one composed of cobble-rich soils or soils rich in weathered rock fragments) could be used as an alternative to the six-inch erosion layer. An armored surface, or hardened cap, is generally used in arid regions or on steep slopes where the establishment and maintenance of vegetation may be hindered by lack of soil or excessive run-off.

The materials used for an armored surface typically are (U.S. EPA, 1989b):

- Capable of protecting the underlying infiltration layer 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 that is approximately the same as the underlying soil (at least 2 percent slope); and
- Capable of controlling the rate of soil erosion.

The erosion layer may be made of asphalt or concrete. These materials promote run-off with negligible erosion. However, asphalt and concrete deteriorate due to thermal expansion and due to deformation caused by subsidence. Crushed rock may be spread over the landfill cover in areas where weather conditions such as wind, heavy rain, or temperature extremes commonly cause deterioration of vegetative covers (U.S. EPA, 1989b).

Other Considerations

Additional Cover System Components

To reduce the generation of post-closure leachate to the greatest extent possible, owners and operators can install a composite cover made of a geomembrane and a soil component with low hydraulic conductivity. The hydraulic properties of these components are discussed in Chapter 4 (Subpart D).

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 discussed in the following sections and are shown in Figure 6-6.

<u>Drainage Layer</u>

A permeable drainage layer, constructed of soil or geosynthetic drainage material, may be constructed between the erosion layer and the underlying infiltration layer. The drainage layer in a final cover system removes percolating water that has infiltrated through the erosion layer after surface run-off and evapotranspiration losses. By removing water in contact with the low-permeability layer, the potential for

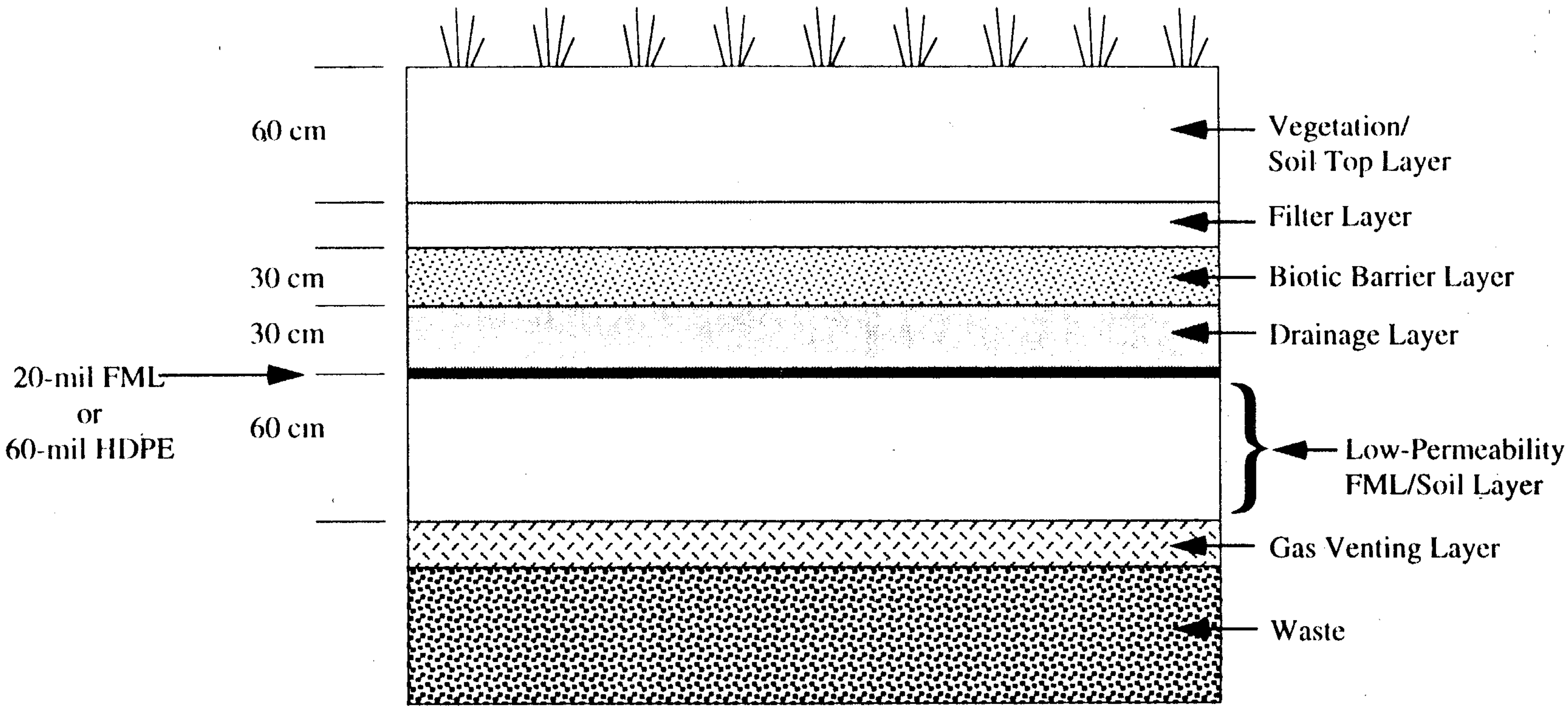


Figure 6-6
Example of an Alternative Final Cover Design

leachate generation is diminished. Caution should be taken when using a drainage layer because this layer may prematurely draw moisture from the erosion layer that is needed to sustain vegetation.

If a drainage layer is used, owners or operators should consider methods to minimize physical clogging of the drainage layer by root systems or soil particles. A filter layer, composed of either a low nutrient soil or geosynthetic material, may be placed between the drainage layer and the cover soil to help minimize clogging.

If granular drainage layer material is used, the filter layer should be at least 12 in. (30 cm) thick with a hydraulic conductivity in the range of 1 x 10^{-2} cm/sec to 1 x 10^{-3} cm/sec. The layer should be sloped at least 3 percent at the bottom of the layer. Greater thickness and/or slope may be necessary to provide sufficient drainage flow as determined by site-specific modeling (U.S. EPA, 1989b). Granular drainage material will vary from site to site depending on the type of material that is locally available and economical to use. Typically, the material should be no coarser than 3/8 inch (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 (U.S. EPA, 1989b).

Crushed stone generally is not appropriate because of the sharpness of the particles. If the available drainage material is of poor quality, it may be necessary to increase the thickness and/or slope of the drainage layer to maintain adequate drainage. The HELP model can be used as an analytical tool to evaluate the relative expected performance of alternative final cover designs.

If geosynthetic materials are used as a drainage layer, the fully saturated effective transmissivity should be the equivalent of 12 inches of soil (30 cm) with a hydraulic conductivity range of 1 x 10^{-2} cm/sec to 1 x 10^{-3} cm/sec. Transmissivity can be calculated as the hydraulic conductivity multiplied by the drainage layer thickness. A filter layer (preferably a non-woven needle punch fabric) should be placed above the geosynthetic material to minimize intrusion and clogging by roots or by soil material from the top layer.

<u>Gas Vent Layer</u>

Landfill gas collection systems serve to inhibit gas migration. The gas collection systems typically are installed directly beneath the infiltration layer. The function of a gas vent layer is to collect combustible gases (methane) and other potentially harmful gases (hydrogen sulfide) generated by micro-organisms during biological decay of organic wastes, and to divert these gases via a pipe system through the infiltration layer. A more detailed discussion concerning landfill gas, including the use of active and passive collection systems, is provided in Chapter 3 (Subpart C).

The gas vent layer is usually 12 in. (30 cm) thick and should be located between the infiltration layer and the waste layer. Materials used in construction of the gas vent layer should be medium to coarse-grained porous materials such as those used in the drainage layer. Geosynthetic materials may be substituted for granular materials in the vent layer if equivalent performance can be demonstrated. Venting to an exterior collection point can be provided by means such as horizontal pipes patterned laterally throughout the gas vent layer, which channel gases to vertical risers or lateral headers. If vertical risers are used, their number should be minimized (as they are frequently vandalized) and located at high points in the cross-section (U.S. EPA, 1989b). Condensates will form within the gas collection pipes; therefore, the design should address drainage of condensate to prevent blockage by its accumulation in low points.

The most obvious potential problem with gas collection systems is the possibility of gas vent pipe penetrations through the cover system. Settlement within the landfill may cause concentrated stresses at the penetrations, which could result in infiltration layer or pipe failure. If a geomembrane is used in the infiltration layer, pipe sleeves, adequate flexibility and slack material should be provided at these connections when appropriate. Alternatively, if an active gas control system is planned, penetrations may be carried out through the sides of the cover directly above the liner anchor trenches where effects of settlement are less pronounced. The gas collection system also may be connected to the leachate collection system, both to vent gases that may form inside the leachate collection pipes and to remove gas condensates that form within the gas collection pipes. This method generally is not preferred because if the leachate collection pipe is full, gas will not be able to move through the system. Landfill gas systems are also discussed in Chapter 3 (Subpart C).

Biotic Layer

Deep plant roots 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-inch) 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. Geosynthetic products that incorporate a time-released herbicide into the matrix or on the surface of the polymer also may be used to retard plant roots. The longevity of these products requires evaluation if the cover system is to serve for longer than 30 to 50 years (USEPA, 1991).

Settlement and Subsidence

Excessive settlement and subsidence, caused by decomposition and consolidation of the wastes, can impair the integrity of the final cover system. Specifically, settlement can contribute to:

- Ponding of surface water on the cap;
- Disruption of gas collection pipe systems;
- Fracturing of low permeability infiltration layers; and
- Failure of geomembranes.

The degree and rate of waste settlement are difficult to estimate. Good records regarding the type, quantity, and location of waste materials disposed will improve the estimate. Settlement due to consolidation may be minimized by compacting the waste during daily operation of the landfill unit or by landfilling baled waste. Organic wastes will continue to degrade and deteriorate after closure of the landfill unit.

Several models have been developed to analyze the process of differential settlement. Most models equate the layered cover to a beam or column undergoing deflection due to various loading conditions. While these models are useful to designers in understanding the qualitative relationship between the various land disposal unit characteristics and in identifying the constraining factors, accurate quantitative analytical methods have not been developed (U.S. EPA, 1988).

If the amount of total settlement can be estimated, either from an analytical approach or from empirical relationships from data collected during the operating life of the facility, the designer should attempt to estimate the potential strain imposed on the cover system components. Due to the uncertainties inherent in the settlement analysis, a biaxial strain calculation should be sufficient to estimate the stresses that may be imposed on the cover system. The amount of strain that a liner is capable of enduring may be as low as several percent; for geomembranes, it may be 5 to 12 percent (U.S. EPA, 1990). Geomembrane testing may be included as part of the design process to estimate safety factors against cover system failure.

The cover system may be designed with a greater thickness and/or slope to compensate for settlement after closure. However, even if settlement and subsidence are considered in the design of the final cover, ponding may still occur after closure and can be corrected during post-closure maintenance. The cost estimate for post-closure maintenance should include earthwork required to regrade the final cover due to total and differential settlements. Based on the estimates of total and differential settlements from the modeling methods described earlier, it may be appropriate to assume that a certain percentage of the total area needs regrading and then incorporate the costs into the overall post-closure maintenance cost estimate.

Sliding Instability

The slope angle, slope length, and overlying soil load limit the stability of component interfaces (geomembrane with soil, geotextile, and geotextile/soil). Soil water pore pressures developed along interfaces also can dramatically reduce stability. If the design slope is steeper than the effective friction angles between the material, sliding instability generally will occur. Sudden sliding has the potential to cause tears in geomembranes, which require considerable time and expense to repair. Unstable slopes may require remedial measures to improve stability as a means of offsetting potential long-term maintenance costs.

The friction angles between various media are best determined by laboratory direct shear tests that represent the design loading conditions. Methods to improve stability include using designs with flatter slopes, using textured material, constructing benches in the cover system, or reinforcing the cover soil above the membrane with geogrid or geotextile to minimize the driving force on the interface of concern. Methods for applying these design features can be found in (U.S. EPA 1989), (U.S.EPA 1991), and (Richardson and Koerner 1987).

6.4 CLOSURE PLAN
40 CFR §258.60(c)-(d)

6.4.1 Statement of Regulation

(c) The owner or operator must prepare a written closure plan that describes the steps necessary to close all MSWLF units at any point during their active life in accordance with the cover design requirements in §258.60(a) or (b), as applicable. The closure plan, at a minimum, must include the following information:

(1) A description of the final cover, designed in accordance with §258.60(a) and the methods and procedures to be used to install the cover;

(2) An estimate of the largest area of the MSWLF unit ever requiring a final cover as required under §258.60(a) at any time during the active life;

(3) An estimate of the maximum inventory of wastes ever on-site over the active life of the landfill facility; and

(4) A schedule for completing all activities necessary to satisfy the closure criteria in §258.60.

(d) The owner or operator must notify the State Director that a closure plan has been prepared and placed in the operating record no later than the effective date of this part, or by the initial receipt of waste, whichever is later.

6.4.2 Applicability

An owner or operator of any MSWLF unit that receives wastes on or after October 9, 1993, must prepare a closure plan and place the plan in the operating record. The plan must describe specific steps and activities that will be followed to close the unit at any time after it first receives waste through the time it reaches its waste disposal capacity.

The closure plan must include at least the following information:

- A description of the final cover and the methods and procedures to be used to install the cover;
- An estimate of the largest area that will have to be covered (typically this is the area that will exist when the final full capacity is attained); and
- A schedule for completing closure.

The area requiring cover should be estimated for the operating period from initial receipt of waste through closure.

The closure plan must be prepared and placed in the operating record before October 9, 1993 or by the initial receipt of waste, whichever is later. The owner or operator must notify the State Director when the plan has been completed and placed in the operating record.

6.4.3 Technical Considerations

The closure plan is a critical document that describes the steps that an owner or operator will take to ensure that all units will be closed in a manner that is protective of human health and the environment. Closure plans provide the basis for cost estimates that in turn establish the amount of financial responsibility that must be demonstrated.

The closure plan must describe all areas of the MSWLF unit that are subject to Part 258 regulations and that are not closed in accordance with §258.60. Portions of the landfill unit that have not received a final cover must be included in the estimate. The area to be covered at any point during the active life of the operating unit can be determined by examining design and planned operation procedures and by comparing the procedures with construction records, operation records, and field observations. Units are operated frequently in phases, with some phases conducted on top of previously deposited waste. If the owner or operator routinely closes landfill cells as they are filled, the plan should indicate the greatest number of cells open at one time.

The estimate must account for the maximum amount of waste on-site that may need to be disposed in the MSWLF unit over the life of the facility (this includes any waste on-site yet to be disposed). The maximum volume of waste ever on-site can be estimated from the maximum capacity of each unit and any operational procedures that may involve transfer of wastes to off-site facilities. Where insufficient design, construction, and operational records are found, areas and volumes may be estimated from topographic maps and/or aerial photographs.

Steps that may be included in the closure plan are as follows:

- Notifying State Director of intent to initiate closure §258.60(e);
- Determining the area to receive final cover;
- Developing the closure schedule;
- Preparing construction contract documents and securing a contractor;
- Hiring an independent registered professional engineer to observe closure activities and provide certification;
- Securing borrow material;
- Constructing the cover system;
- Obtaining signed certificate and placing it in operating record;
- Notifying State Director that certificate was placed in operating record; and
- Recording notation in deed to land or other similar instrument.

The closure plan should include a description of the final cover system and the methods and procedures that will be used to install the cover. The description of the methods, procedures, and processes may include design documents; construction specifications for the final cover system, including erosion control measures; quality control testing procedures for the construction materials; and quality assurance procedures for construction. A general discussion of the methods and procedures for cover installation is presented in Section 6.3.3.

6.5 CLOSURE CRITERIA 40 CFR §258.60(e)-(j)

6.5.1 Statement of Regulation

(e) Prior to beginning closure of each MSWLF unit as specified in

§258.60(f), an owner or operator must notify the State Director that a notice of the intent to close the unit has been placed in the operating record.

(f) The owner or operator must begin closure activities of each MSWLF unit no later than 30 days after the date on which the MSWLF unit receives the known final receipt of wastes or, if the MSWLF unit has remaining capacity and there is a reasonable likelihood that the MSWLF unit will receive additional wastes, no later than one year after the most recent receipt of wastes. Extensions beyond the one-year deadline for beginning closure may be granted by the Director of an approved State if the owner or operator demonstrates that the MSWLF unit has the capacity to receive additional wastes and the owner or operator has taken and will continue to take all steps necessary to prevent threats to human health and the environment from the unclosed MSWLF unit.

(g) The owner or operator of all MSWLF units must complete closure activities of each MSWLF unit in accordance with the closure plan within 180 days following the beginning of closure as specified in paragraph (f). Extensions of the closure period may be granted by the Director of an approved State if the owner or operator demonstrates that closure will, of necessity, take longer than 180 days and he has taken and will continue to take all steps to prevent threats to human health and the environment from the unclosed MSWLF unit.

(h) Following closure of each MSWLF unit, the owner or operator must notify the State Director that a certification, signed by an independent registered professional engineer or approved by Director of an approved State, verifying that closure has been completed in accordance with the closure plan, has been placed in the operating record.

(i)(1) Following closure of all MSWLF units, the owner or operator must record a notation on the deed to the landfill facility property, or some other instrument that is normally examined during title search, and notify the State Director that the notation has been recorded and a copy has been placed in the operating record.

(2) The notation on the deed must in perpetuity notify any potential purchaser of the property that:

(i) The land has been used as a landfill facility; and

(ii) Its use is restricted under §258.61(c)(3).

(j) The owner or operator may request permission from the Director of an approved State to remove the notation from the deed if all wastes are removed from the facility.

<u>6.5.2 Applicability</u>

These closure requirements are applicable to all MSWLF units that receive wastes on or after October 9, 1993. The owner or operator is required to:

- Notify the State Director of the intent to close;

- Begin closure within 30 days of the last receipt of waste (or 1 year if there is remaining capacity and it is likely that it will be used);
- Complete closure within 180 days following the beginning of closure (in approved States, the period of time to begin or complete closure may be extended by the Director);
- Obtain a certification, by an independent registered professional engineer, that closure was completed in accordance with the closure plan;
- Place the certificate in the operating record and notify the State Director; and
- Note on a deed (or some other instrument) that the land was used as a landfill and that its use is restricted. Should all wastes be removed from the unit in an approved State, the owner or operator may request permission from the Director to remove the note on the deed.

<u>6.5.3 Technical Considerations</u>

Closure activities must begin within 30 days of the last receipt of waste and must be completed within 180 days. Some MSWLF units, such as those in seasonal population areas, may have remaining capacity but will not receive the next load of waste for a lengthy period of time. These MSWLF units must receive waste within one year or they must close. Extensions to both the 1-year and the 180-day requirements may be available to owners or operators of MSWLF units in approved States. An extension may be granted if the owner or operator can demonstrate that there is remaining capacity or that additional time is needed to complete closure. These extensions could be granted to allow leachate recirculation or to allow for settlement. The owner or operator must take, and continue to take, all steps necessary to prevent threats to human health and the environment from the unclosed MSWLF unit. In general, this requirement should be established for a unit in compliance with the requirements of Part 258. The owner or operator may need to demonstrate how access to the unclosed unit will be controlled prior to closure or receipt of waste and how the various environmental control and monitoring systems (e.g., surface run-off, surface run-on, leachate collection, gas control system, and ground-water and gas monitoring) will be operated and maintained while the unit remains unclosed.

Following closure of each MSWLF unit, the owner or operator must have a certification, signed by an independent registered professional engineer, verifying closure. In approved States, the Director can approve the certification. The certificate should verify that closure was completed in accordance with the closure plan. This certification should be based on knowledge of the closure plan, observations made during closure, and documentation of closure activities provided by the owner or operator. The signed certification must be placed in the operating record and the State Director must be notified that the certification was completed and placed in the record.

After closure of all units at a MSWLF facility, the owner or operator must record a notation in the deed, or in records typically examined during a title search, that the property was used as a MSWLF unit and that its use is restricted under 40 CFR §258.61(c)(3). Section 258.61(c)(3) states:

"... Post-closure use of the property shall not disturb the integrity of the final cover, liner(s), or any other components of the containment systems or the function of the monitoring systems unless necessary to comply with the requirements of Part 258...and... The Director of an approved State may approve any other disturbance if the owner or operator demonstrates that disturbance of the final cover, liner, or other component of the containment system, including any removal of waste, will not increase the potential threat to human health or the environment."

These restrictions are described further in Section 6.7 (Post-Closure Plan) of this document.

The owner or operator may request permission from the Director of an approved State to remove the notation to a deed. The request should document that all wastes have been removed from the facility. Such documentation may include photographs, ground-water and soil testing in the area where wastes were deposited, and reports of waste removal activity.

6.6 POST-CLOSURE CARE REQUIREMENTS 40 CFR §258.61

6.6.1 Statement of Regulation

(a) Following closure of each MSWLF unit, the owner or operator must conduct post-closure care. Post-closure care must be conducted for 30 years, except as provided under paragraph (b) of this part, and consist of at least the following:

(1) Maintaining the integrity and effectiveness of any final cover, including making repairs to the cover as necessary to correct the effects of settlement, subsidence, erosion, or other events, and preventing run-on and run-off from eroding or otherwise damaging the final cover;

(2) Maintaining and operating the leachate collection system in accordance with the requirements in §258.40, if applicable. The Director of an approved State may allow the owner or operator to stop managing leachate if the owner or operator demonstrates that leachate no longer poses a threat to human health and the environment;

(3) Monitoring the ground water in accordance with the requirements of Subpart E and maintaining the ground-water monitoring system, if applicable; and

(4) Maintaining and operating the gas monitoring system in accordance with the requirements of §258.23.

(b) The length of the post-closure care period may be:

(1) Decreased by the Director of an approved State if the owner or operator demonstrates that the reduced period is sufficient to protect human health and the environment and this demonstration is approved by the Director of an approved State; or

(2) Increased by the Director of an approved State if the Director of an approved State determines that the lengthened period is necessary to protect human health and the environment.

6.6.2 Applicability

Post-closure care requirements apply to MSWLF units that stop receiving waste after October 9, 1993. They also apply to units that stop receiving waste between October 9, 1991, and October 9, 1993, and fail to complete closure within six months of the final receipt of waste.

Post-closure care requirements are focused on operating and maintaining the proper functions of four systems that prevent or monitor releases from the MSWLF unit:

- Cover system;
- Leachate collection system;
- Ground-water monitoring system; and
- Gas monitoring system.

Owners or operators must comply with these requirements for a period of 30 years following closure. In approved States, the post-closure care period may be shortened if the owner or operator demonstrates to the satisfaction of the Director that human health and the environment are protected. Conversely, the Director may determine that a period longer than 30 years is necessary. The requirement to operate and maintain the leachate collection system may be eliminated by the Director of an approved State if the owner or operator demonstrates that leachate does not pose a threat to human health and the environment.

6.6.3 Technical Considerations

When the final cover is installed, repairs and maintenance may be necessary to keep the cover in good working order. Maintenance may include inspection, testing, and cleaning of leachate collection and removal system pipes, repairs of final cover, and repairs of gas and ground-water monitoring networks.

Inspections should be made on a routine basis. A schedule should be developed to check that routine inspections are completed. Records of inspections detailing observations should be kept in a log book so that changes in any of the MSWLF units can be monitored; in addition, records should be kept detailing changes in post-closure care personnel to ensure that changing personnel will not affect post-closure care due to lack of knowledge of routine activities. The activities and frequency of inspections are subject to State review to ensure that units are monitored and maintained for as long as is necessary to protect human health and the environment.

Inspection of the final cover may be performed on the ground and through aerial photography. Inspections should be conducted at appropriate intervals and the condition of the facility should be recorded with notes, maps, and photographs. The inspector should take notice of eroded banks, patches of dead vegetation, animal burrows, subsidence, and cracks along the cover. The inspector also should note the condition of concrete structures (e.g., manholes), leachate collection and removal pipes, gas monitoring systems, and monitoring wells.

For larger facilities, annual aerial photography may be a useful way to document the extent of vegetative stress and settlement if either of these has been observed during routine inspections. It is important to coordinate the photography with the site "walkover" to verify interpretations made from aerial photographs. Aerial photography should not be used in place of a site walkover but in conjunction with the site walkover. An EPA document (U.S. EPA 1987) provides further information on using aerial photography for inspecting a landfill facility. (See the Reference section at the end of this chapter.)

Topographic surveys of the landfill unit(s) may be used to determine whether settlement has occurred. These should be repeated every few years until settlement behavior is established. If settlement plates are used, they should be permanent and protected from vandalism and accidental disturbance (U.S. EPA, 1987). Depressions caused by settlement may lead to ponding and should be filled with soil. Excessive settlement may warrant reconstructing or adding to portions of the infiltration layer. Damage caused by settlement such as tension cracks and tears in the synthetic membrane should be repaired.

Cover systems that have areas where the slope is greater than 5 percent may be susceptible to erosion. Large and small rills (crevices) may form along the cover where water has eroded the cover. This may lead to exposure of the synthetic geomembrane and, in severe cases, depending on the cover system installed, exposure of the waste. Erosion may lead to increased infiltration of surface water into the landfill. Areas showing signs of erosion should be repaired.

Certain types of vegetative cover (e.g., turf-type grasses) may require mowing at least two times a year. Mowing can aid in suppression of weed and brush growth, and can increase the vigor of certain grass species. Alternatively, certain cover types (e.g., native prairie grasses) require less frequent mowing (once every three years) and may be suitable for certain climates and facilities where a low-maintenance regime is preferable. For certain cover types, fertilization schedules may be necessary to sustain desirable vegetative growth. Fertilization schedules should be based on the cover type present. Annual or biennial fertilization may be necessary for certain grasses, while legumes and native vegetation may require little or no fertilizer once established. Insecticides may be used to eliminate insect populations that are detrimental to vegetation. Insecticides should be carefully selected and applied with consideration for potential effects on surface water quality.

Some leachate collection and removal systems have been designed to allow for inspections in an effort to ensure that they are working properly. Leachate collection and removal pipes may be flushed and pressure-cleaned on a regular schedule (e.g., annually) to reduce the accumulation of sediment and precipitation and to prevent biological fouling.

Similarly, gas collection systems should be inspected to ensure that they are working properly. Vents should be checked to ensure they are not clogged by foreign matter such as rocks. If not working properly, the gas collection systems should be flushed and pressure-cleaned.

At some landfill facilities, leachate concentrations eventually may become low enough so as not to pose a threat to human health or the environment. In an approved State, the Director may allow an owner or operator to cease managing leachate if the owner or operator can demonstrate that the leachate no longer poses a threat to human health and the environment. The demonstration should address direct exposures of leachate releases to ground water, surface water, or seeps. Indirect effects, such as accumulated leachate adversely affecting the chemical, physical, and structural containment systems that prevent leachate release, also should be addressed in the demonstration.

The threat posed by direct exposures to leachate released to ground water, to surface waters, or through seeps may be assessed using health-based criteria. These criteria and methods are available through the Integrated Risk Information System (IRIS) (a database maintained by U.S. EPA), the RCRA Facility Investigation Guidance (U.S. EPA, 1989c), the Risk Assessment Guidance for Superfund (U.S. EPA, 1989d), and certain U.S. EPA regulations, including MCLs established under the Safe Drinking Water Act and the ambient water quality criteria under the Clean Water Act. These criteria and assessment procedures are described in Chapter 5 (Subpart E) of this document. Concentrations at the points of exposure, rather than concentrations in the leachate in the collection system, may be used when assessing threats.

6.7 POST-CLOSURE PLAN 40 CFR §258.61(c)-(e)

6.7.1 Statement of Regulation

(c) The owner or operator of all MSWLF units must prepare a written post-closure plan that includes, at a minimum, the following information:

(1) A description of the monitoring and maintenance activities required in §258.61(a) for each MSWLF unit, and the frequency at which these activities will be performed;

(2) Name, address, and telephone number of the person or office to contact about the facility during the post-closure period; and

(3) A description of the planned uses of the property during the post-closure period. Post-closure use of the property shall not disturb the integrity of the final cover, liner(s), or any other components of the containment system, or the function of the monitoring systems unless necessary to comply with the requirements in Part 258. The Director of an approved State may approve any other disturbance if the owner or operator demonstrates that disturbance of the final cover, liner or other component of the containment system, including any removal of waste, will not increase the potential threat to human health or the environment.

(d) The owner or operator must notify the State Director that a post-closure plan has been prepared and placed in the operating record no later

than the effective date of this part, October 9, 1993, or by the initial receipt of waste, whichever is later.

(e) Following completion of the post-closure care period for each MSWLF unit, the owner or operator must notify the State Director that a certification, signed by an independent registered professional engineer or approved by the Director of an approved State, verifying that post-closure care has been completed in accordance with the post-closure plan, has been placed in the operating record.

6.7.2 Applicability

Owners and operators of existing units, new units, and lateral expansions of existing MSWLF units that stop receiving waste after October 9, 1993 are required to provide a post-closure plan. MSWLF units that received the final waste shipment between October 9, 1991 and October 9, 1993 but failed to complete installation of a final cover system within six months of the final receipt of waste also are required to provide a post-closure plan.

The post-closure plan describes the monitoring activities that will be conducted throughout the 30-year period. The plan also establishes:

- The schedule or frequency at which these activities are conducted;
- Name, address, and telephone number of a person to contact about the facility;
- A description of a planned use that does not disturb the final cover; and
- The procedure for verifying that post-closure care was provided in accordance with the plan.

In approved States only, the owner or operator may request the Director to approve a use that disturbs the final cover based on a demonstration that the use will not increase the potential threat to human health and the environment.

6.7.3 Technical Considerations

The State Director must be notified that a post-closure plan, describing the maintenance activities required for each MSWLF unit, has been placed in the operating record. The post-closure plan should provide a schedule for routine maintenance of the MSWLF unit systems. These systems include the final cover system, the leachate collection and removal system, and the landfill gas and ground-water monitoring systems.

The plan must include the name, address, and telephone number of the person or office to contact regarding the facility throughout the post-closure period. Additionally, the planned uses of the property during the post-closure period must be provided in the plan. These uses may not disturb the integrity of the final cover system, the liner system, and any other components of the containment or monitoring systems unless necessary to comply with the requirements of Part 258. Any other disturbances to any of the MSWLF components must be approved by the Director of an approved State. An example of an acceptable disturbance may include remedial action necessary to minimize the threat to human health and the environment.

Following completion of the post-closure care period, the State Director must be notified that an independent registered professional engineer has verified and certified that post-closure care has been completed in accordance with the post-closure plan and that this certification has been placed in the operating record. Alternatively, the Director of an approved State may approve the certification. Certification of post-closure care should be submitted for each MSWLF unit.

6.8 FURTHER INFORMATION

6.8.1 References

Giroud, J.P., Bonaparte, R., Beech, J.F., and Gross, B.A., "Design of Soil Layer -Geosynthetic Systems Overlying Voids". Journal of Geotextiles and Geomembranes, Vol. 9, No. 1, 1990, pp. 11-50.

Richardson, G.N. and R.M. Koerner, (1987). "Geosynthetic Design Guidance for Hazardous Waste Landfill Cells and Surface Impoundments"; Hazardous Waste Engineering Research Laboratory; USEPA, Office of Research and Development; Cincinnati, Ohio; Contract No. 68-07-3338.

U.S. EPA, (1987). "Design, Construction and Maintenance of Cover Systems for Hazardous Waste: An Engineering Guidance Document"; PB87-19156; EPA/600/2-87/039; U.S. Department of Commerce, National Technical Information Service; U.S. Army Engineering Waterways Experiment Station; Vicksburg, Mississippi.

U.S. EPA, (1988). "Guide to Technical Resources for the Design of Land Disposal Facilities"; EPA/625/6-88/018; U.S. EPA; Risk Reduction Engineering Laboratory and Center for Environmental Research Information; Office of Research and Development; Cincinnati, Ohio 45268.

U.S. EPA, (1989a). "Seminar Publication - Requirements for Hazardous Waste Landfill Design, Construction and Closure"; EPA/625/4-89/022; U.S. EPA; Center for Environmental Research Information; Office of Research and Development; Cincinnati, Ohio 45268.

U.S. EPA, (1989b). "Technical Guidance Document: Final Covers on Hazardous Waste Landfills and Surface Impoundments"; EPA/530-SW-89-047; U.S. EPA; Office of Solid Waste and Emergency Response; Washington, D.C. 20460.

U.S. EPA, (1989c). "Interim Final: RCRA Facility Investigation (RFI) Guidance"; EPA 530/SW-89-031; U.S. EPA; Waste Management Division; Office of Solid Waste; U.S. Environmental Protection Agency; Volumes I-IV; May 1989.

U.S. EPA, (1989d). "Interim Final: Risk Assessment Guidance For Superfund; Human Health Evaluation Manual Part A"; OS-230; U.S. EPA; Office of Solid Waste and Emergency Response; July 1989.

U.S. EPA, (1991). "Seminar Publications - Design and Construction of RCRA/CERCLA Final Covers"; EPA/625/4-91/025; U.S. EPA, Office of Research and Development; Washington, D.C. 20460.

6.8.2 Organizations

U.S. Department of Agriculture
Soil Conservation Service (SCS)
P.O. Box 2890
Washington, D.C. 20013-2890
(Physical Location: 14th St. and Independence Ave. NW.)
(202) 447-5157

Note: This is the address of the SCS headquarters. To obtain the SCS technical guidance document concerning the Universal Soil Loss Equation (entitled "Predicting Rainfall Erosion Loss, Guidebook 537," 1978), contact SCS regional offices located throughout the United States.

6.8.3 Models

Schroeder, et al., (1988). "The Hydrologic Evaluation of Landfill Performance (HELP) Model"; U.S.EPA; U.S. Army Engineer Waterways Experiment Station; Vicksburg, MS 39181-0631; October 1988.

Schroeder, P.R., A.C. Gibson, J.M. Morgan, T.M. Walski, (1984). "The Hydrologic Evaluation of Landfill Performance (HELP) Model, Volume I - Users Guide for Version I (EPA/530-SW-84-009), and Volume II - Documentation for Version I (EPA/530-SW-84-010); U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, June 1984.

6.8.4 Databases

Integrated Risk Information System (IRIS), U.S. Environmental Protection Agency, Office of Research and Development, Cincinnati, Ohio.