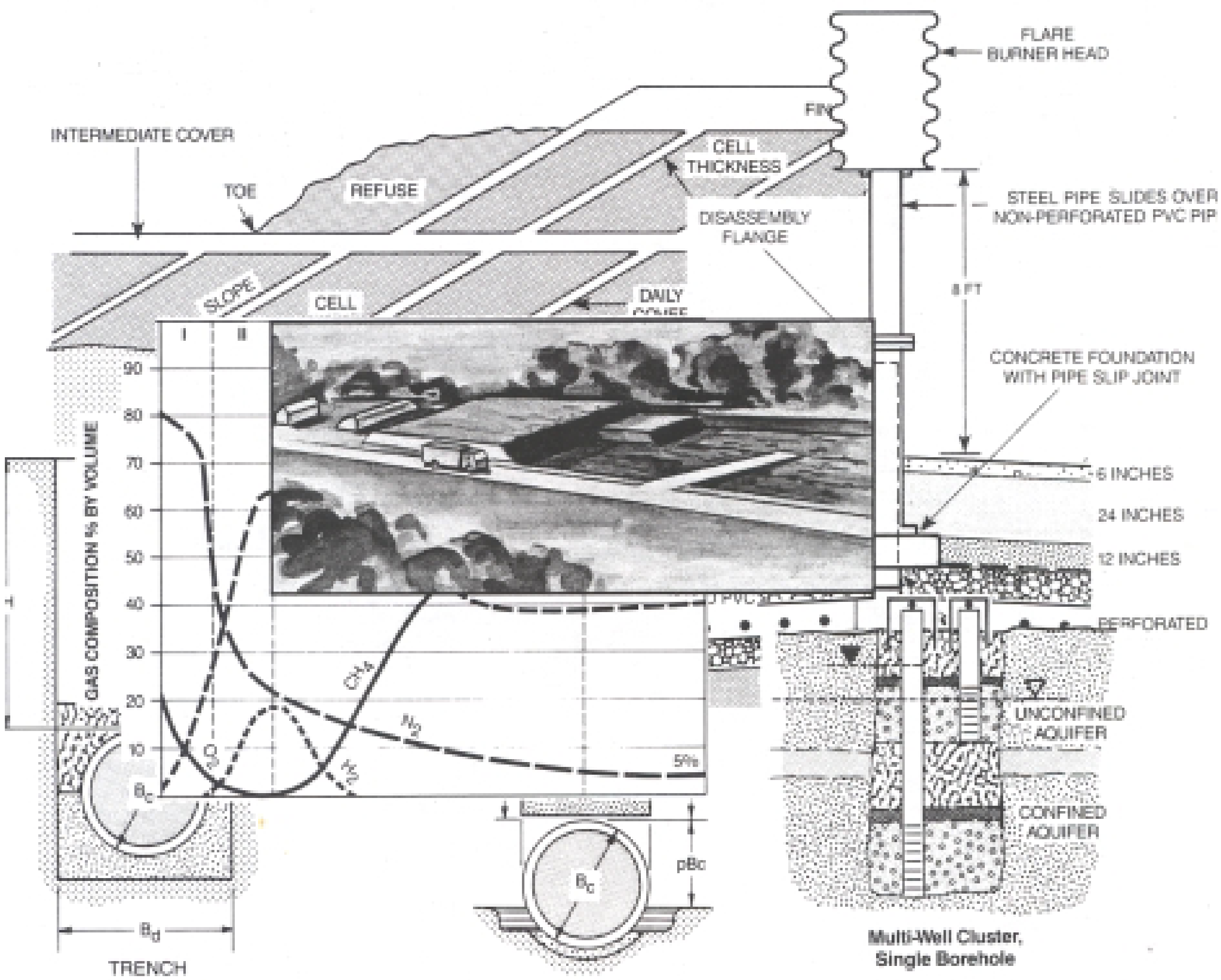
Solid Waste Landfill Design Manual

Washington State Department of Ecology



SOLID WASTE LANDFILL DESIGN MANUAL

by

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Introduction

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1.1 PURPOSE

The proper disposal of solid wastes is the responsibility of citizens, haulers, operators of solid waste facilities and public regulatory agencies. Regulatory agencies, such as the jurisdictional health department and the Department of Ecology, play an important role because they are responsible for enforcing solid waste laws, establishing regulations, and monitoring environmental conditions. The improper disposal of solid wastes can result in adverse impacts not only on the physical and aesthetic environments, but also on human health. Cost-effective technical solutions to solid waste disposal must also be socio-politically acceptable.

Among the currently available methods for solid waste disposal is burial in landfills. Landfills are major construction projects which must be properly sited, designed, constructed, operated and closed. They can be operated by public agencies and/or private industries. Landfilling of solid wastes was originally promoted as a method for both disposing of solid wastes and reclaiming unusable lands. As more scientific and operational data has been collected and evaluated, the regulatory agencies, design professionals, solid waste industry and general public have become aware of the significant short and long term impacts associated with landfills.

Landfills should no longer be promoted as land reclamation projects unless they meet strict siting, design, construction and operational criteria. The vast majority of problems associated with past and existing solid waste landfills can be traced to improperly sited and designed facilities.

This Manual was developed at the request of the Washington State Department of Ecology (Ecology) to assist in developing a comprehensive understanding of properly designed and operated solid waste landfills. This Manual is a guidance document to assist in the implementation of the Minimum Functional Standards for Solid Waste Handling (Chapter 173-304 WAC) which replaced the previous standards (Chapter 173-301 WAC) in November 1985.

1.2 SCOPE

Solid waste landfills across the state are at various stages of development. Some have been in operation for many years; others are in the process of closing or have been closed. There will always be a need for solid waste landfills, regardless of other solid waste disposal alternatives. Currently, there are new landfills being sited, planned, designed and constructed.

The Manual has been organized to reflect the various stages of the "life cycle" of solid waste landfills. The Manual is organized into the following major chapter and topics:

- Introduction (including user's guide)
- Laws, Regulations and Permits
- Landfill Siting

- Landfill Design
- Landfill Construction
- Landfill Operation
- Landfill Closure
- Environmental Monitoring
- Minimum Functional Standards Facility Requirements

Many topics related to solid waste landfills are addressed within this framework. The level of detail varies accordingly. For example, a preliminary landfill design is required during the siting process, but final engineering detail is needed for permits and the construction process. Geology, soils, and hydrogeologic investigations have a similar interaction with the landfill life cycle process. Leachate and gas management are important considerations during siting, design, operations, closure and post closure of landfills.

1.3 AUDIENCE

The primary audience for the Solid Waste Landfill Design Manual is the Department of Ecology and the jurisdictional health districts. Ecology and jurisdictional health districts are required to review permit applications A for both new and existing solid waste landfills. The jurisdictional health districts also inspect the landfills and enforce the regulations and the Manual will assist them in the performance of these responsibilities and help them understand the expectations of Ecology concerning the operation of new and existing landfills. Ecology is also required to review and monitor funding assistance grant applications for solid waste landfills and related projects.

The Manual is also valuable to landfill project developers and operators, public agencies or private industries and their consultants for understanding the expectations and requirements of the regulatory agencies. The Manual also provides methods for designing and implementing the performance and design elements of solid waste landfills. Although not specifically intended to be, the Manual can also function as a public information and educational text for the community-at-large and elected officials.

1.4 LIMITATIONS

Solid waste characteristics can vary significantly depending upon the source. The definition of solid waste includes waste generated by residential households, and industrial, demolition, and sewage sludges, among others. Although hazardous wastes may be included in the definition of solid wastes, land disposal of these wastes is not covered in this Manual. Specific state laws and regulations (i.e. RCW Chapter 70.105 and WAC Chapter 173-303) pertain to the handling and disposal of "dangerous wastes" as defined in the statute. The state regulation distinguishes wastes by degree-of -hazard, including extremely hazardous and dangerous waste. EPA defines hazardous waste in one category in their regulations. The siting, permitting, design, construction and operation of disposal facilities for dangerous wastes is clearly outlined in the regulations. They are not within the scope of this Manual, which deals with the disposal of non-hazardous, non-dangerous solid wastes. However, it should be noted that landfills are repositories for long-term disposal of unregulated and small quantity generator hazardous waste.

The non-homogeneous characteristics of solid waste throughout Washington State, along with the significant variations in soils, geohydrology, climatology, environmental constraints and public interest and involvement, makes it infeasible to develop a "cookbook" type of Solid Waste Landfill Design Manual which addresses every possible condition relating to solid waste landfills in the state of Washington. This Manual does not provide formulas for solutions to every problem involved in the siting, design, construction, operation and closure of every solid waste landfill. Rather, it provides regulatory agency staff and design professionals with a logical methodology for the review of proposed and ongoing projects. The Manual includes discussions of the preparation of siting studies, environmental compliance reports, permit applications, design reports, plans, specifications and construction documents, operation plans, closure plans, and environmental monitoring programs.

The Manual addresses solid waste issues that arise after the decision to site and develop a landfill has been made. This includes proposed, operating, and closed or abandoned landfills. This Manual does not address the preparation of solid waste management plans.

Under the laws of the State of Washington, public agencies (counties or municipalities) are required to plan for the proper disposal of solid waste. Solid waste management plans are designed to develop an understanding of the geographical planning area, solid waste generation and practices; identify and evaluate solid waste management alternatives; make recommendations; and develop an implementation program for the recommended alternatives. Guidelines for developing or updating a solid waste management plan which have been updated for 1986 can be obtained from Ecology.

1.5 USER'S GUIDE

1.5.1 Introduction

This Manual was not designed to be read from cover to cover. However, many chapters are interrelated, and the reader may find it helpful to research the topic of interest throughout the Manual. The Manual user should first identify specific needs, whether it is a landfill siting program or implementation of an environmental monitoring program for an operating landfill. Then the user should then proceed to the appropriate chapter of the Manual for- guidance in addressing the specific issues. To help the reader research a topic, the following elements have been built into the Manual:

- Table of contents for each chapter
- List of references for each chapter
- Chapter Nine: Minimum Functional Standards' Facility Requirements

Each chapter contains a detailed table of contents with a list of figures and tables. A list of references is provided for each chapter and includes each cited source in the main body of the text and in the supporting appendices.

The final chapter of the Manual summarizes the key aspects of the Minimum Functional Standards, including permits and required performance and design elements for mixed municipal solid waste landfills.

1.5.2 Manual Contents

The Manual has been organized following the "landfill life cycle" concept from siting through closure. A brief discussion of the contents of each chapter is provided in the following sections.

1.5.2.1 Laws, Regulations and Permits - Chapter Two

This chapter of the Manual reviews federal, state and local regulatory requirements associated with the siting, construction, operation and maintenance of solid waste landfills. The discussion focuses on solid waste and water quality laws. Air quality, noise, hazardous waste, SEPA requirements and other miscellaneous controls are also outlined in this chapter.

1.5.2.2 Landfill Siting - Chapter Three

There are four basic areas addressed in the siting of a solid waste landfill. These are:

1) Basic project needs, such as type of waste, capacity requirements, multi-use and jurisdictional considerations

2) Economics

3) Physical environment requirements (soils) and impacts (water resources, air, biological resources)

4) Human environment impacts (land use, zoning, community acceptance)

Siting a landfill is a lengthy, complex and costly process which must be carefully planned. The Manual provides an orderly planning process to ensure that the siting decision is cost-effective, technically correct and in compliance with procedural and legal technicalities. The siting study should be conducted in a manner providing opportunity for public involvement during the siting process. The socio-political issues are often more difficult than the technical requirements.

Public Involvement. Guidance is provided to implement a successful public involvement program. Information is included on planning public involvement strategy, selecting techniques, initiating the program and monitoring its success.

Phasing the Siting Process. The Manual provides direction on how to phase the siting process. This includes establishment of selection and "fatal flaw" criteria, identification of potential landfill sites utilizing the established criteria, and how to narrow the number of sites from the so-called "universe of sites" to a preferred site for which a Draft Environmental Impact Statement (DEIS) and Final Environmental Impact Statement (FEIS) can be prepared.

A significant amount of labor-intensive field work is associated with siting a solid waste landfill. This Manual provides guidance for the sources and use of available data in the initial stages of landfill siting.

Hydrogeologic Investigations. Discussions in Chapter 3 relating to hydrogeologic issues and investigations include:

- The development of hydrogeologic criteria to screen and rank possible sites
- Procedures for final site selection and necessary design-level, site-specific studies
- Integration of hydrogeologic studies into the overall assessment and the design and implementation of a ground water monitoring program

Key hydrogeologic factors such as precipitation and recharge rates, geology, soil permeability, location of. aquifers, ground water flow directions, potential receiving water bodies, and existing water quality are among the factors discussed. Their significance in siting and design of a landfill is presented in light of the differing geologic environments within Washington State.

1.5.2.3 Landfill Design - Chapter Four

Landfill design progresses in increasing levels of detail as a solid waste landfill project develops from siting to closure. The principal objectives for Chapter 4 are:

- To establish basic design criteria for use by implementing agencies and engineers
- To present and review specific, individual technologies for landfill development and environmental controls.

Design Criteria. The design of solid waste landfill and subsequent operations and environmental control systems are site-specific issues. As such this section covers basic and alternative design concepts. It respects the site-specific character of a landfill project, and presents criteria which are comprehensive and performance-oriented, and which comply with Minimum Functional Standards, Chapter 173-304 WAC.

Leachate Management. Of all unit processes conducted at a solid waste landfill, leachate management is one of the most critical to overall site environmental integrity. Proper leachate management is essential to avoid surface and ground water contamination and is one of the principal elements of a landfill management program that remains when the site closes. Consequently, the Manual emphasizes leachate management requirements, and provides guidance on available management options, design criteria for process design/installation and monitoring, and finally economic considerations.

Leachate management is discussed in several sections of the Landfill Design Chapter:

- Ground water management
- Prediction of leachate generation
- Leachate attenuation
- Liners
- Leachate collection and transmission system
- Leachate treatment and disposal system
- Final cover system design

Landfill Gas Management. Topics addressed include:

- Landfill gas generation and migration
- Landfill gas control system design including the prediction of gas generation potential and migration patterns, alternative control methods and strategies, selection of appropriate control system(s), and design criteria
- Landfill gas recovery system design including prediction of gas production system design, types of recovery systems, design criteria, and coordination of control/recovery system designs

1.5.2.4 Landfill Construction - Chapter Five

This chapter addresses issues related to construction management, inspection, and actual construction of solid waste landfills. This chapter applies to contracted construction services, as well as to projects undertaken with staff from local agencies.

Specialized construction activities associated with existing solid waste landfills are also addressed. Among these are:

- Bottom liners
- Leachate collection and transmission systems
- Leachate treatment and disposal
- Gas control/recovery systems

1.5.2.5 Landfill Operation - Chapter Six

Each landfill is unique due to the type of waste, size of the facility, and local environment - Therefore, it is impossible to provide a "cookbook" chapter on landfill operations. However, this Manual provides:

- Detailed job descriptions and qualifications of landfill personnel
- Guidance in the preparation of Operation Plans (specifically planning for wet weather)
- Guidance in the development of an equipment preventative maintenance program
- Record keeping and data management guidance
- Overall equipment specifications and suggested equipment requirements for different types of solid waste landfill facilities

1.5.2.6 Landfill Closure - Chapter Seven

The Manual addresses landfill closure and post-closure requirements, including:

- Corrective actions (surface water run-on, ground water infiltration, erosion control, leachate and gas management needs)
- Closure plan elements
- Post-closure plan elements
- Closure/post closure economics
- Final land use considerations

1.5.2.7 Environmental Monitoring - Chapter Eight

Environmental monitoring is required at solid waste landfills to continuously evaluate the effectiveness of environmental protection systems as they relate to water resources and gas management. The Manual provides:

- Guidance and recommendations for the establishment of surface and ground water quality sampling stations
- Protocol for collecting and transporting water quality samples
- Recommended water quality parameters
- Frequency of sampling

- Guidelines for the location and installation of gas monitoring systems
- Sampling procedures for solid waste landfill gases
- Reporting and record keeping methods
- Sampling quality assurance

1.5.2.8 Minimum Functional Standards' Facility Requirements - Chapter 9

This chapter of the Manual provides a discussion of the key sections of the Minimum Functional Standards as they relate to typical mixed municipal solid waste landfills. The discussion includes permit requirements and performance and design elements. Reference is given to appropriate sections of the Manual providing information to assist in implementing the standards.

Chapter 2

Laws, Regulations and Permits

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2.1 INTRODUCTION

The purpose of this Section is to review the controls and regulatory requirements associated with the siting, construction, operation, maintenance, and closure of solid waste landfills. Rather than list the regulations verbatim, an overview is provided with specific references to portions and sections so that the reader can easily research the regulation as necessary. A copy of the Minimum Functional Standards (MFS) has been included as Appendix A.

An attempt has been made to identify all relevant regulatory requirements and guidelines for all levels of government. The description of local requirements is generic, and specifies what local governments are authorized to regulate. The specific permitting and approval processes established by each local regulatory agency is not listed here.

This chapter is divided into two sections:

1) Federal and state laws and regulations

2) Local regulations and permits

The state and federal regulations are discussed together because they are interrelated and often redundant. The authority to administer federally initiated permitting programs is frequently delegated to the state. Aside from regulatory constraints that deal directly with solid waste, related laws concerning water quality, air quality, noise control, hazardous waste and other miscellaneous issues such as flood control and safety are covered in this Section.

These (and all) regulations are subject to review, and may be amended, changed or repealed at any time. For the most recent version of a federal regulation, one should refer to the most recent issue of the Code of Federal Regulations and the Federal Register. At the state level, the appropriate references are the Washington Administrative Code and the Washington Register. At the local level it would be most appropriate to 'consult with officials of the agency sponsoring or administering the regulations being considered.

2.2 FEDERAL AND STATE REQUIREMENTS

At the state and federal levels of government, the principal regulators of solid waste facilities are the U.S. Environmental Protection Agency (EPA) and the Washington State Department of Ecology (Ecology). Both agencies have promulgated regulations governing solid waste, water quality, air quality, dangerous waste and noise control. An overview of these provisions as they apply to solid waste landfills is provided below.

2.2.1 Federal Solid Waste Disposal Laws and Regulations

At the federal level, the Resource Conservation and Recovery Act of 1976 (RCRA), amended by the Solid Waste Disposal Act Amendments of 1980 and the Hazardous and Solid Waste Amendments of 1984 (HSWA),,is the primary source of solid waste legislation. Subtitle D deals with non-hazardous solid waste disposal and requires the development of a state comprehensive solid waste management program that outlines the authorities of local, state and regional agencies. The state program must prohibit "open dumps," and provide that all solid waste will be used for resource recovery, disposed in landfills, or otherwise disposed in an environmentally sound way. In addition, EPA is required to promulgate regulations containing guidelines for the development and implementation of state solid waste management plans and specific criteria for classification of landfills to determine if they are "open dumps".

EPA's solid waste regulations appear in 40 CFR Parts 240-257. The key provisions are Part 241 - Guidelines for the Land Disposal of Solid Waste and Part 257 - Criteria for Classification for Solid Waste Facilities and Practices. Part 241 of EPA's regulations addresses all aspects of solid waste disposal, including site selection, facility design, water and air quality considerations, gas control, vector control, aesthetics, cover material, compaction, safety considerations, recordkeeping and exclusion of specific solid wastes. Part 257 defines eight criteria used to determine when a solid waste disposal site will be considered an "open dump" for purposes of a state's solid waste management plan under RCRA. These criteria also define unacceptable impacts caused be solid waste handling activities, and set minimum standards that all landfills must satisfy. A summary of these criteria is provided below:

> Criterion No. 1 relates to floodplain protection. Although it does not prohibit The location of disposal facilities on a floodplain, it does state that they shall not restrict the flow of a 100-year flood, reduce the temporary water storage capacity of any floodplain, or result in a "washout" of solid waste materials by flood waters.
>
> Criterion No. 2 stipulates that no facility or practice may in any way harm, or adversely affect, an endangered or threatened species of plant, fish, or wildlife, or the habitat of any such species.
>
> Criterion No. 3 applies to surface water considerations and refers to provisions of the Federal Water Pollution Control Act (FWPCA). It prohibits: discharges of pollutants into navigable waters in violation of an NPDES permit; discharges of dredged or fill material in violation of the FWPCA; or nonpoint source pollution of surface waters in violation of any Section 208 plan.
>
> Criterion No. 4 concerns ground water in that no solid waste facility or practice may in any way "contaminate an underground drinking water source beyond the solid waste boundary... 11 "Underground drinking water source" is defined to include aquifers which serve as drinking' water sources, and aquifers with ground water containing "less than 10,000 mg/L total dissolved solids." "Solid waste boundary" is defined as the "outermost perimeter of the solid waste (projected in the horizontal plane) as it would exist at completion of disposal activity."
>
> Criterion No. 5 protects land used for the production of food-chain crops. Subpart (a) addresses cadmium concentrations. Subpart (b) discusses solid wastes containing concentrations of polychlorinated biphenyls(PCB's) "equal to or greater than 10 mg/g (dry weight)." Specific requirements for land disposal of such wastes are listed in the regulation.
>
> Criterion No. 6 involves disease control. Subpart (a) requires the control of on-site populations of disease carrying vectors such as rodents, flies and mosquitoes. Subpart (b) prohibits the disposal of sewage sludge or septic tank wastes not in compliance with

specified requirements. Sewage sludge must be treated by a "Process to Significantly Reduce Pathogens" (listed in Appendix II, Section A to Part 257). Limitations on public access. Septic tank waste and animal grazing are also specified. Note, however, that these provisions do not apply to "sewage sludge disposed of by a trenching or burial operation."

Criterion No. 7 addresses air quality control. Open burning of solid waste is prohibited. In addition, no disposal facility or practice may violate the requirements of a state implementation plan approved by EPA under the Federal Clean Air Act.

Criterion No. 8 addresses miscellaneous safety concerns. Subpart (a) limits concentrations of methane in structures at the facility and at the boundary of the site. Subpart (b) specifies that the disposal facility or practice shall not pose a fire hazard. Subpart (c) applies to facilities located in close proximity to airport runways and provides that no such facility such pose a bird hazard to aircraft. Subpart (d) prohibits uncontrolled public access which could expose the public to safety or health hazards at the disposal site.

The EPA, the State or private citizens can file suit, pursuant to Section 7002 of the Act, to force compliance with the Criteria. Prior to HSWA of 1984, the federal government had no authority to take legal action against parties not in compliance with the Criteria.

As a result of HSWA, the Subtitle D Criteria and the mechanisms used to enforce them have changed. EPA is required to prepare a report to Congress by November 8, 1987, determining whether the Criteria are adequate to "protect human health and the environment" from ground water contamination or whether additional authorities are needed to enforce them. Furthermore, EPA must revise the Criteria by March 31, 1988, to address facilities that receive household hazardous waste or hazardous waste from small quantity generators. At a minimum, the revisions are mandated to require ground water monitoring at the level necessary to detect contamination (in contrast to a standard minimum number of monitoring points), to establish Criteria in the acceptable location of new or existing facilities, and to provide for corrective action, as appropriate.

In addition, HSWA requires the development of a permit system by November 8, 1987, for facilities that receive small quantities of hazardous waste. This system is intended to ensure compliance with the new Criteria. The State must modify its permit program accordingly within eighteen months of the promulgation of the new revised Criteria or the authority for enforcement reverts to EPA.

The EPA also has the authority to issue RCRA Section 7003 Orders in any situation where "an imminent and substantial endangerment to health or the environment" is caused by the handling of non-hazardous or hazardous solid wastes. EPA, or an authorized State, can order any person contributing to the problem to take steps to clean it up. Contributing parties can include past or present generators, transporters, owners or operators of the site. Violation of a Section 7003 order can result in penalties of up to $5,000 per day.

2.2.2 Washington State Solid Waste Disposal Laws and Regulations

The basis for Washington State's solid waste regulatory program is the Solid Waste Management Act, RCW Chapter 70.95. This legislation, as amended by SHB 1164:

- Establishes priorities for management of solid waste
- Authorizes the adoption of minimum functional standards for solid waste handling
- Requires the development of city and/or county solid waste management plans and updates
- Provides for a permit system for solid waste disposal sites
- Assigns enforcement and regulatory responsibilities to Jurisdictional health departments
- Provides for the development of siting criteria to be used in evaluating potential sites for disposal facilities
- Mandates the formation of county solid waste advisory committees

A brief discussion of each of these provisions follows:.

The priorities for solid waste management are, in descending order: waste reduction, waste recycling, energy recovery or incineration, and landfilling.

The Minimum Function Standards were promulgated by the legislature as WAC 173-304. These standards reflect the solid waste criteria established by RCRA and amendments to RCW 70.95 as mentioned above. Responsibilities of individuals and government are prescribed in the regulation. To summarize, regulations in the standards include:

- The establishment of county solid waste advisory-committees to review and comment upon solid waste issues
- Development of solid waste management plans and their review and/or revision every five years
- Evaluation of potential sites for disposal facilities based on siting criteria listed in the regulation
- A permitting system for solid waste disposal facilities including recycling centers
- Restoration of closed or abandoned disposal sites
- Standards for solid waste storage, transportation, transfer stations, incineration and landfilling
- A permitting system for sludge utilization sites

- Responsibility for management and surveillance of woodwaste and other wastes disposal

One of the principal functions of this manual is to assist owners, operators and enforcement agencies in implementing the performance and design elements for solid waste landfills that are specified in the Minimum Functional Standards. Chapter 9 includes a discussion of the permitting requirements and the performance and design elements pertinent to mixed municipal solid waste landfills. It also provides reference to appropriate sections of the manual where detailed information on those elements may be found.

The rights and responsibilities of counties with regard to solid waste disposal are set forth in RCW Chapter 36.58. Counties are given the right to own disposal sites and establish rules of operation and maintenance. In addition, counties may designate by ordinance disposal sites for waste generated in unincorporated areas and may establish solid waste districts for providing and funding disposal facilities.

Under provisions of RCW Chapter 35.21, cities and towns may also provide solid waste disposal and establish ordinances relating **to disposal and** disposal fees.

2.2.3 Water Quality Controls

Water pollution controls are mentioned by reference in solid waste regulations for the prevention of ground and surface water contamination from solid waste activities. The primary federal legislation is the Federal Water Pollution Control Act as amended by the Federal Water Pollution Control Act Amendments of 1972 and the Clean Water Act of 1977, 33 USC 1251 et sea (FWPCA). Much of the regulatory responsibility has been delegated to the state. The state's role and authority over water quality control is discussed below with emphasis on the State Water Pollution Control Act, RCW Chapter 90.48.

The FWPCA specifies effluent limitations, water quality standards, and a permitting system for point source discharges of pollutants into navigable surface waters. The authority to administer this permitting system, referred to as the National Pollutant Discharge Elimination System (NPDES), has been delegated to Ecology in accordance with provisions of the Act. The NPDES system addresses point discharges only. Section 404 of the FWPCA provides for the permitting program for disposition of fill or dredged materials into navigable waters or in adjacent wetlands. This permit, obtained from the Corps of Engineers, would be necessary if excavations from a landfill site were to be disposed in this manner. The Section 404 permit application would require an accompanying site certification of compliance with water quality standards.

EPA authority for regulating ground water discharges comes primarily from the Federal Safe Drinking Water Act, as amended, 42 USC 300f et sea. Two main objectives of this Act are to: regulate the quality and contamination levels of public water supplies and to protect subsurface sources of drinking water by regulating underground injection wells. The regulations promulgated by this act are contained in 40 CFR Parts 241-243.

Another source of federal regulations pertaining to ground and surface water protection is found in regulations resulting from RCRA, 40 CFR Part 257.3-3 and 257.3-4. These Sections are criteria No. 3 and 4 pertaining to the classification of solid waste disposal facilities and practices (see Section 2.2.2). Criterion No. 4 states that solid waste activities shall not contaminate ground water used as a drinking water source beyond the boundary of the solid waste facility. Maximum contaminant levels used to determine compliance with this criteria are included in Appendix I of Part 257 of the regulation and are equivalent to primary drinking water standards promulgated in the Safe Drinking Water Act mentioned above.

The State Water Pollution Control Act, RCW Chapter 90.48 (WPCA), augments the FWPCA with more extensive measures to protect against the discharge of pollutants. Ecology is given considerable latitude in its regulatory authority over the discharge of pollutants into waters of the state. The state act contains provisions for permitting and approval programs which may be relevant to solid waste related activities. The water quality standards for surface waters which are consulted for these permitting and approval programs are established in WAC 173-201.

A state waste discharge permit program was established in WAC 372-24, prior to the development of provisions for the NPDES permitting system at the federal level. This original program has been superseded by WAC 173-216. The discharge permit system is relevant to solid waste facilities which discharge leachate to the waters (ground or surface) of the state, either directly, or through the public sewer systems. Issuance of the permit is based on compliance with conditions which may be stipulated by Ecology. Ecology can delegate authority to administer this program to the operator of publicly owned sewerage systems.

Ecology has been designated the State Water Pollution Control Agency for the administration of the FWPCA with respect to navigable waters in the state. Responsibilities include the administration and establishment of an NPDES permit program. This permit program is contained in WAC 173-220, and applies only to point source discharges to surface waters.

Both permit programs overlap to some degree. However, both permits are not required for every activity that is subject to one. Note also that both programs deal with point source discharges only.

Leachate treatment and control systems not covered by either of these permitting systems are subject to review and approval by Ecology (RCW 90.48.110). The procedures for this process are contained in regulations set forth in WAC 173-240. Under these regulations, leachate is included in the definition of industrial waste water. The review and approval process includes the submittal of engineering reports and final plans for a proposed facility. Specific requirements for the engineering report covering a leachate treatment system are provided in WAC 173-240-130(2)(v). In addition, a detailed operations and maintenance manual must be prepared.

The VPCA deals primarily with point source discharges. However, the right to exercise control over non-point source discharges has been established in WAC 173-201-035(s). This Section of the regulation states that non-point sources which are not in compliance with state water quality standards, and not covered by any of the permitting programs established in the VPCA, may be subject to citation or sanction by Ecology. The activities creating the discharge are exempt from citation ' if the activities are in compliance with Ecology's management practices or have received a special regulatory order. Compliance with Minimum Functional Standards may be sufficient to obtain this exemption for solid waste facilities.

Another provision of WPCA authorizes development of sewage drainage basin plans for pollution control and abatement. Minimum plan requirements include water quality considerations pertaining to "solid waste disposal runoff and seepage water," (WAC 372-68-060). Compliance with these plans is required. Currently, sewage drainage basin plans do not exist for all basins in the state. The local planning agencies should be consulted for the plan status in a specific area.

The General Sanitation regulations, WAC 248-50, are also concerned with the protection of water quality. This chapter includes the prohibition of contamination of ground water.

Cities and towns are provided with the authority (RCW Chapter 35.88) to enjoin any activity which is polluting or tending to pollute the source of their public water supplies. The source of public water supplies includes all watersheds or similar areas draining into the supplies.

2.2.4 Air Quality Controls

The Federal Air Quality Act, 42 USC 7401-7642, provides for state implementation plans for national primary and secondary ambient air quality standards, and state implementation and enforcement of standards of performance for new stationary sources of air pollutants. The State of Washington has been delegated the authority to administer the federal air quality program and issue permits.

The Washington Clean Air Act, RCW Chapter 70.94, requires the development of regulations for air pollution control. The act also creates county, or multi-county, air pollution control authorities. These authorities are responsible for enforcing the state regulations, or developing regulations at least as stringent as those established by Ecology in WAC 173-400 and WAC 173-403.

Unless the operations involve some form of open burning or controlled combustion, such as for weed abatement, solid waste landfills will not require a permit or approval from the state or local air pollution control authority. However, other provisions of the state's air quality regulations may be relevant to the construction and operation of solid waste landfills. These provisions contain standards for the emission of particulate matter, odor, fugitive dust and other air contaminants.

The procedures for enforcing the air quality regulations and for the permit/review process are outlined in WAC 173-403. A notice of construction is required before a new source of air contaminants is built or installed. The local air pollution control authority should determine whether A solid waste landfill, or the related construction activity, would be considered a new source.

2.2.5 Noise Control

The primary source of noise control legislation at the federal level is the Noise Control Act of 1972, as amended. This act delegates most of the authority to regulate noise to state and local governments. The Washington Noise Control Act of 1974, RCW Chapter 70.107, requires Ecology to set up standards establishing maximum noise levels for specific environments and noise abatement and control measures. The maximum noise levels are set forth in WAC 173-60. These levels vary depending on the classification of property and adjacent property.

Classifications of property can be determined at the local level of government with Ecology approval.

Most noise generated from temporary construction activity is exempt from these state regulations. Noise from motor vehicles off public highways is also exempt except in areas classified as Class A. Enforcement of noise control regulations is left to local government when they have adopted abatement and control measures.

2.2.6 Disposal of Dangerous or Extremely Hazardous Waste

An overview of regulations addressing the disposal of hazardous waste is provided here as a reference, primarily for the owner/operator of disposal facilities and local permitting authorities. The Manual itself does not deal with hazardous waste disposal facilities. However, a knowledge of these regulations can aid in handling suspect waste and identifying important regulatory issues which will become significant if hazardous wastes are discovered in a landfill.

It should be noted that landfills are repositories for previously unregulated quantities of hazardous waste. Such practices will be greatly curtailed as a result of the Hazardous and Solid Waste Amendments (HSWA) of 1984. The 1984 amendments require EPA to upgrade the Resource Conservation and Recovery Act (RCRA) Criteria for sanitary landfills as necessary to protect public health and the environment since landfills have received hazardous wastes from both households and small quantity generators. Congress has required these revisions because accumulation of these hazardous wastes at landfills (Subtitle D facilities) poses a health hazard. Although it is not clear how EPA will choose to regulate these facilities, Congress believes that the authority already exists for EPA to require the 12,000 to 18,000 municipal-owned sanitary landfills nationwide to comply fully with more stringent hazardous waste landfill standards. However unlikely such an action might be, ground water monitoring, leachate collection and corrective actions at such facilities seem inevitable.

In addition to revising the RCRA Criteria, HSWA requires that a permit program (or other system of prior approval) be implemented by November 8, 1987 for facilities receiving small quantities of hazardous waste. This permit process is intended to ensure that facilities comply with existing Criteria. Within 18 months of the promulgation of revised Criteria, the State of Washington must modify its permit program accordingly. Should the State fail to develop and implement an appropriate permit program by September 31, 1989, EPA is given the authority under HSWA to enforce the revised Criteria at facilities accepting hazardous waste from households and small quantity generators.

At the federal level, Subtitle C of RCRA (1980) and HSWA (1984) address the management and disposal of hazardous wastes. The statute, as amended, requires the establishment of a regulatory framework for the identification of hazardous waste characteristics, the listing of particular hazardous wastes and the careful tracking of such wastes. A set of hazardous waste regulations (40 CFR Parts 261-270) was promulgated by EPA in response to this mandate. Under RCRA, every owner and operator of a hazardous waste treatment, storage or disposal facility is required to acquire a permit from EPA or an authorized state, such as Washington state. Those facilities generating less that 220 pounds (100 kilograms) of hazardous waste or less than 2.2 pounds (1 kilogram) of acutely hazardous waste per month, however, are exempt from this requirement.

The relevant regulations for hazardous waste disposal facilities are in 40 CFR 264-Interim Standards for Owners and Operators of New Hazardous Waste Land Disposal Facilities. These regulations require that:

- Adequate records be maintained for all hazardous waste disposed at a land disposal facility
- The waste be treated and disposed of properly
- The disposal facility be located, designed and constructed to specified standards
- Contingency plans be developed to minimize unanticipated damage from treatment, storage or disposal operations

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) was enacted in 1980 and amended and reauthorized in 1986, to enable state and federal governments to respond to hazardous waste sites, both abandoned and active, which threaten public health or the environment. Until passage of CERCLA, also known as the Superfund, the federal government's authority to remedy such problems was restricted to notification, elimination of "imminent hazards," enforcement, civil and criminal action provisions of various environmental laws, and cleanup efforts under Section 311 of the Clean Water Act.

By Executive Order 12286, the President delegated responsibility for administering the Superfund to several federal agencies, and initially provided for the payment of government response costs and payment of claims from the Hazardous Substance Response Trust Fund of approximately $1.6 billion over 5 years. Upon reenactment, the Superfund Amendments and Reauthorization Act allocated over eight billion dollars for management of uncontrolled wastes. EPA is directed, as part of the National Hazardous Substance Response Plan, to establish procedures and standards for responding to releases of hazardous substances and to prepare a list of priority sites of known releases or threatened releases throughout the United States. The list of sites is known as the National Priority List (NPL). Many solid waste landfills have been identified as hazardous waste sites and included on this list. Reference to the listing of a particular site on the NPL was promulgated in the National Oil and Hazardous Substances Contingency Plan (NCP) by EPA on July 16, 1982 (47 FR 31180-31243). In addition, EPA is authorized to provide federal funds to:

- Undertake such investigations deemed appropriate to identify the existence and extent of hazardous substances which are potentially a danger to public health and the environment (Section 104(b})
- Provide for the appropriate remedial actions (Section 104[a})

These funds, will not be committed unless the state first enters into a cooperative agreement with EPA providing assurances for all future maintenance of the remedial actions, the availability of an acceptable hazardous waste disposal facility, and payment of 10 to 50 percent of the costs (Section 104[c)[3}). The Department of Ecology derives its authority from enabling legislation (RCW 43.21A), the state's Hazardous Waste Disposal Act (RCW 70.105), and regulations to implement it (WAC 173-303).

State legislation directed at hazardous waste disposal was first enacted in 1976 with the passage of the Hazardous Waste Disposal Act (Chapter 70.105 RCW). Amendments to the Act, passed in 1980, provide the Department of Ecology with additional authority as required by the Resource Conservation and Recovery Act.

The 1980 amendments to the Hazardous Waste Disposal Act authorized Ecology to regulate the storage, treatment and disposal of both extremely hazardous waste (EHW) and dangerous waste (DW). Prior to the 1980 amendments, regulations for hazardous waste were designated in Chapter 173-302 of the Washington Administrative Code (WAC). In 1982 these regulations were revised to comply with the federal requirements (RCRA) that states' hazardous waste programs adopt regulations which are "essentially equivalent" to EPA's rules.

The regulations, WAC 173-303, entitled "Dangerous Waste Regulations" replace WAC 173-302. These regulations establish standards and rules for the identification, transport, treatment, storage and disposal of dangerous and extremely hazardous wastes.. Many provisions are relevant to the solid waste management process.

"Hazardous waste" is the general term that covers both dangerous and extremely hazardous waste as defined in the state regulations (WAC 173-303):

"Dangerous wastes" means any discarded, useless, unwanted, or abandoned nonradioactive. substances, including but not limited to certain pesticides, or any residues or containers of such substances which are disposed of in such quantity or concentration as. to pose a substantial present or potential hazard to human health, wildlife, or the environment because such wastes or constituents, or combinations of such wastes:

(a) Have short-lived, toxic properties that may cause death, injury, or illness or have mutagenic, teratogenic, or carcinogenic properties; or

(b) Are corrosive, explosive, flammable, or may generate pressure through decomposition or other means.

"Extremely hazardous waste" means any dangerous waste which:

(a) Will persist in a hazardous form for several years or more at a disposal site and which in its persistent form

  (i) presents a significant environmental hazard and may be concentrated by living organisms through a food chain or may affect the genetic makeup of man or wildlife, and

  (ii) is highly toxic to man or wildlife,

(b) If disposed of at a disposal site in such quantities would present an extreme hazard to man or the environment.

2.2.7 State Environmental Policy Act

The State Environmental Policy Act of 1971 (SEPA) was developed to ensure that environmental considerations are part of the review and approval process undertaken by state and local agencies. The Act, as amended in 1984, requires that an analysis of environmental impacts be included in the decision making process.

The SEPA process begins when a permit application or a proposal is submitted to a public agency. The lead agency, usually the city or county where the proposal activity is to take place, makes a threshold determination on whether or not the activity is expected to have significant adverse environmental impacts. This decision is based on a review of an environmental checklist completed by the proponent of the activity. An environmental checklist and threshold determination would not be necessary if the lead agency and the proponent have already agreed that an environmental impact statement (EIS) is necessary. The basic format for the checklist is contained in WAC 197-11 but may vary with the county or city (lead agency) involved. The lead agency may have established additional guidelines or requirements for the SEPA process and these must be determined on a case by case basis.

The SEPA rules contain a list of categorical exemptions (activities for which no environmental documentation is required). These include some minor construction and excavation activities.

Based on the review of the environmental checklist, the lead agency issues either a determination of significance (DS) or non-significance (DNS). A determination of non-significance indicates that no further environmental documentation (i.e., an EIS) is necessary. In cases where mitigative measures are possible to reduce or eliminate environmental impacts, the lead agency may issue a mitigated DNS which stipulates measures to be implemented to mitigate the impacts.

When an EIS is required the lead agency must decide on its scope. That is, it must specify "the range of actions, alternatives, and impacts to be discussed" (WAC 197-11-793). Then the scoping process is initiated requesting public and private comment on the scope of the EIS.

The scoping process leads to the production of a draft EIS which is distributed for a 30-day public comment period. A final EIS is issued which has incorporated comments received on the draft EIS.

The agencies involved in approval of the proposed activity or policy use the EIS to make decisions regarding the proposal. However, other information or documentation may also be used in their decision process.

2.2.8 Other Controls

2.2.8.1 Proximity to Highways

According to federal statute (23 USC 136) the apportionment of federal-aid highway funds to states can be reduced if a state does not provide control over junkyards which are within 1,000 feet of and visible from an interstate highway. Junkyards are defined to include landfills.

The state statute enacted in response to the federal legislation is in RCW Chapter 47.41. This statute expands on the federal limitations noted above by prohibiting junkyards within 1,000 feet of any interstate or federal-aid primary highway with the following exceptions:

1) When not visible or screened from view

2) When located in areas zoned for industry

3) When located in unzoned industrial areas (as defined by State Department of Transportation).

2.2.8.2 Shoreline Protection

The Coastal Zone Management Act (6 USC 1451-64), passed by Congress in 1972, authorized financial assistance to states to administer and develop Shoreline protection programs. The Shoreline Management Act was passed by state legislature in 1971 to protect the shoreline of the state. The enabling statute, RCW Chapter 90.58, established a state program to manage the coastal areas, defined "shoreline of statewide significance," and set up a permit system.

Under the state's program, local governments are assigned the responsibility to administer the regulatory program and to coordinate with Ecology to insure compliance with state policy and regulations. Permits are required for developments in the area which includes: "all of the state's marine waters and their associated wetlands, including at a minimum all upland area 200 feet landward from the ordinary high water mark." Permits and review/approval procedures may be necessary in areas adjacent to the coastal areas defined above. The state master program specifically prohibits the siting of solid waste disposal sites in the shoreline. The Shoreline Management Master Program for an area, county, city or town, must be consulted for compliance with local and state regulations.

2.2.8.3 Flood Control

Two federal acts relevant to solid waste landfills are the Watershed Protection and Flood Prevention Act, 16 USC 1001 et sea., and flood control legislation codified at 33 USC et seg. At the state level, RCW Title 86 covers floodplain management and flood control. Regulations resulting from this statute are in WAC Chapter 173-142. The location of a solid waste landfill within a floodplain, flood control zone, major watershed area or above an aquifer recharge area serving a public water system should be reviewed in the context of the federal and state laws mentioned above.

2.2.8.4 Health and Safety

The design, construction and operation of a solid waste landfill must be in compliance with the Washington Department of Labor and Industry's General Safety and Health Standards, WAC Chapter 296-24.

2.2-8.5 Nuisance Control

Nuisance control is covered in, many of the regulations already discussed in this Section. General nuisance control is covered in RCW Chapter 7.48. Public nuisances are addressed in RCW Chapter 9.66. Nuisances are defined; abatement measures and offenses described.

2.3 LOCAL REGULATIONS, PERMITS AND ORDINANCES

Many of the relevant local regulations and permits have already been introduced in the section on state and federal regulations because authority is delegated to this level of government. In addition to regulations and permits, a review of applicable plans and policies that may be in effect in a given, locale is provided. Two previously discussed regulators are air pollution control authorities (see Section 2.2.4) and jurisdictional health departments (see Section 2.2.2).

2.3.1 Air Pollution Control Authorities

The air pollution control authorities issue permits and enforce air quality regulations. Siting a new landfill may require that a notice of construction be filed with this agency. The air pollution control authority would also handle complaints related to odor or dust problems emanating from a solid waste disposal site.

2.3.2 Jurisdictional Health Departments

The jurisdictional health departments are assigned the responsibility of:

1) Enforcing the state solid waste regulations (WAC 173-304) and any additional solid waste regulations the, health department may have developed

2) Issuing permits and conducting inspections

3) Monitoring solid waste activities

The permit system involves the application for a permit before a new site is established. The requirements for the permit are included in the Minimum Functional Standards, WAC 173r3O4-600. The application must be approved by both the jurisdictional health department and Ecology. Annual renewals of this permit are required, and subject to inspections by the health department and review by Ecology. A fee may be charged for initial and renewal permits.

2.3.3 Zoning Authorities

Zoning ordinances have been adopted by most counties and many incorporated areas in the state. These ordinances establish a classification system which groups areas according to permitted land uses. Solid waste landfills are usually permitted in a specific zone or zones as a conditional use. That is, the location of solid waste disposal activity in the zone is subject to review by the appropriate Zoning Board or Hearings Examiner. Conditions may be stipulated by the review board and/or in the zoning code Itself. The appropriate zoning regulations for a given area must be considered when siting or making modifications to a solid waste landfill.

2.3.4 Building and Grading Permits

Other permits which may be required by local government are related to construction and excavation activities at the solid waste landfill site.
Specifically, building permits for new construction activity and grading or excavation permits for earthmoving activities maybe required. These permits will also usually incorporate by reference the conditions or requirements of other permits, particularly conditional use permits.

2.3.5 Refuse Disposal Ordinances

Counties, cities or towns may adopt ordinances which establish rates or fees for solid waste disposal, hours of operation for disposal facilities, and rules for disposal operations. These rules can include limitations on types of wastes accepted at a disposal facility and health and safety considerations for public use of the site. These ordinances would normally be part of the county or municipal code.

2.3.6 Local or Regional Plans

There are many types of plans which may have a bearing on solid waste disposal activities. Some of these plans have been mentioned in the state and' federal regulations section because the authority and mandate to develop such plans originates at those levels of government. In particular, shoreline management master plans, regional 208 plans and comprehensive solid waste management plans can significantly impact solid waste landfill activities.

Shoreline management master plans are similar to land use plans, but primarily directed at the protection of shorelines of the state. They are adopted as state regulation and contain specific guidelines for permitted development in the regulated areas.

Regional 208 plans may be developed under provisions of the Clean Water Act of 1977. These plans contain controls and policy guidelines for the protection of ground and surface water quality from contamination by land disposal of pollutants.

Comprehensive solid waste management plans are prepared for counties, cities or multi-county areas under requirements established in the state's Solid Waste Management Act (RCW 70.95) and associated regulations (WAC 173-304). These plans provide guidelines for solid waste activities in the plan area for six-year and 20-year planning horizons. Solid waste generation is projected for these planning periods and disposal needs assessed. Recommendations for the development of solid, waste facilities, programs and policies are established. Any proposed solid waste landfill must be included in these recommendations in order to be permitted by the jurisdictional health department. In addition, operations at the facility must be in compliance with policies and programs recommended in the plan.

Other local plans that may be relevant to the siting, construction and operation of solid waste landfills are comprehensive land use plans and water and sever district plans. Comprehensive land use plans may be developed for counties, cities, communities or other regional areas. These plans establish guidelines for the future use of specific areas. The plan is implemented through the zoning regulations. Water and sever district plans contain guidelines for the development of water and sever services in an area. This plan is relevant to solid waste landfills because sever limitations are important considerations in design decisions for leachate control and treatment systems.

Chapter 3

Landfill Siting

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3.1 INTRODUCTION

Solid waste landfills affect the environment in a multitude of ways. Depending on the specific location of the landfill and the types of solid waste to be disposed, impacts will vary in magnitude. Landfill effects of greatest concern are related to ground and surface water, air, odor and traffic/transportation. Because the potential for adverse effects does exist, it is important that the owner/operator of a future landfill site make responsible decisions when considering locations for the facility. The more significant the environmental concern, the greater the costs of developing and operating a landfill. A siting study which addresses these concerns and meets the requirements of both the State Environmental Policy Act (SEPA) and Washington State solid waste management regulations is a very difficult, time-consuming and expensive process. However, such a commitment is necessary to ensure that the health, safety and welfare of the public is protected.

3.1.1 Siting Process

The decision to site a new landfill to expand landfill capacity in a county must be based on recommendations made in the appropriate jurisdictional comprehensive solid waste management plan. This plan, as required by Chapter 70.95 RCW, provides guidelines for solid waste handling and disposal activities for a twenty-year period. Whether for public or private facilities, siting plans must be consistent with the recommendations made within an adopted and approved solid waste management plan. Expansion of an existing facility is considered part of the siting process.

Once the need for expanded landfill capacity has been established, the basic characteristics of the expected waste stream are identified. The quantity and type of waste, whether mixed municipal solid waste, demolition debris, sludges or industrial wastes, influence location suitability. A determination of the "best" location for a solid waste landfill takes four factors into consideration:

<u>Legal</u>

All potential solid waste disposal sites or facilities must be analyzed and evaluated based on a set of factors as established in WAC 173-304-130. In addition, SEPA rules (WAC 197-11) imply that a **landfill proposed by a** governmental agency needs to consider alternative sites as part of the Environmental Impact Statement (EIS) preparation. I Because the requirement for an EIS is expected to apply to any proposed new landfill, the siting process is, in part, a means to this end. Strict adherence to the legal procedural steps for environmental review and project approval processes is crucial for smooth and uninterrupted progress of the siting project.

<u>Environmental</u>

State and federal regulations as well as local policy protect ground and surface water from disposal site leachate contamination. Other environmental issues of concern are: health and safety hazards associated with landfill
gas generation and migration; other air quality impacts such a dust, particulates and odor; noise potential; species of concern; and wetlands.

<u>Economic/Engineering</u>

Significant costs associated with development of a landfill include land acquisition, construction, transportation, access, special equipment or facilities, loss of alternative productive land use, and impacts on adjacent land use. Because of the variation in site characteristics, there are significant cost differentials among potential landfill sites. These cost differentials, in turn, place different burdens on the public in terms of disposal fees and/or taxes. When evaluating cost effectiveness, long-term costs, such as post-closure maintenance and leachate treatment, should be considered as well as short-term expenditures.

Sociopolitical

It is important to understand and accommodate the concerns of the affected public and government officials. Public acceptance of the project -will assist in the approval process. An understanding of the roles of elected officials in the review, approval and appeal process can also be helpful.

In addition to technical considerations, many procedural issues must be carefully addressed. There should be a legal review of the process, criteria, content of reports, documentation, and decision making process. Elected officials and various public agency staff have specific roles and responsibilities during a landfill siting process and these must be understood by all before the siting process begins. The review and definition of roles and responsibilities should be undertaken by legal staff of the public agency and/or by a consulting legal firm specializing in land use, zoning and environmental law.

The siting process discussed here was designed for any public or private solid waste landfill project. The process applies to siting analyses undertaken in-house, by a private consultant, or as a cooperative effort between the sponsoring agency and a consultant. Siting studies developed and implemented as a cooperative effort are, in general, more successful than strictly public or private efforts because expertise and knowledge are shared.

3.1.2 Methodology

The siting process involves the development of a strategy to comprehensively review potential landfill sites against established and approved criteria. This process culminates in the selection of at least two candidate sites which are then subjected to a detailed site evaluation analysis including SEPA compliance. This methodolgy may involve up to five (5) separate steps which are summarized below:

Development of Siting Criteria

This includes the identification of environmental, engineering, and sociopolitical constraints for a given area and development of weighting and ranking system to be used to apply these criteria to specific sites.

Potential Site Identification

In this step, as many potential sites as possible are chosen. Sources include existing landfill expansion possibilities, previously selected or evaluated sites, site nominations by the public, private companies or public agencies and an area-wide research effort.

Level I Criteria Site Evaluation

All potential sites are evaluated utilizing the siting criteria developed above and data for each site from published or readily available sources. Approximately six to ten sites are selected for Level II consideration.

Level II Field Investigations Site Evaluation

At this level, the remaining sites are evaluated based on the same basic criteria but at a higher level of detail. This includes more site specific published data supplemented by surveys and field investigations. Additionally, a preliminary engineering design concept should be developed to determine the engineering feasibility and economic costs of a site', and an approximate estimate of potential environmental impacts should be made based on the preliminary engineering design.

Level III Detailed Site Evaluation

At this point, two to three sites remain. Detailed evaluations and field investigations are conducted to support comprehensive preliminary design concepts. The design concepts provide the basis for comparing project impacts and costs. This step in the site selection process essentially becomes the analysis contained in the environmental impact statement. In some instances it may become obvious that one site is the best location. Resources can then be concentrated to verify this site's suitability. The beginning of the Level III Evaluation also should begin the formal scoping process to comply with SEPA rules. The identification of a preferred alternative should be accomplished within SEPA guidelines.

In addition to the engineering and environmental evaluation described above, it is recommended that a public involvement program be developed to operate concurrently with the siting process and subsequent SEPA compliance efforts. Each of these steps is discussed in detail in the following sections.

3.2 SITING CRITERIA

3.2.1 Development

Siting criteria are developed to help select the most feasible solid waste landfill site. The purpose of criteria development is twofold: protecting public health, public safety, the environment, historical and cultural resources; and minimizing development costs and impacts on land development, economic growth and aesthetics. Criteria are also established to ensure compliance with laws and regulations.

Experience at the national level with solid waste management practices has demonstrated that every solid waste landfill site has its own environmental, operational and sociopolitical requirements and constraints. Therefore, there are no standard, predetermined site selection criteria that are applicable to all solid waste landfill siting projects, with the exception of Federal Aviation Administration regulations concerning distance between runways and landfills.

Siting criteria must cover a wide range of technical and environmental issues as well as ensure compliance with regulatory requirements. The revised Minimum Functional Standards for Solid Waste Handling, WAC 173-304, provide general guidance in criteria development by listing various factors and elements that "must be analyzed and evaluated" for any proposed landfill site. The factors listed in WAC 173-304-130 include technical, environmental, and land use issues.

Other local factors pertinent to ordinances, regulations or policies are relevant as siting criteria. For example, an issue such as land ownership (public versus private) may be important in those counties having a very high proportion of land in public holdings. Another example is local zoning ordinances that may prohibit the development of landfills in certain areas.

The purpose of Sections 3.2.2 and 3.2.3 is to explain what factors should be considered, what are their impacts, and whether or not their impacts can be mitigated. Section 3.2.4 contains a criteria ranking system, providing a method for quantifying siting criteria into a workable format for evaluation of each potential site.

3.2.2 Fatal Flaws

A fatal flaw eliminates a site from any further consideration, no matter how favorable the site may be from other perspectives. The rationale for developing fatal flaw criteria may be the result of regulations, operational impracticability or local policy. The Washington State Department of Ecology (Ecology) has specified certain statewide fatal flaw criteria (WAC 173-304130), discussed below. Additional factors may be designated as fatal flaws if the siting team determines their impacts are unacceptable.

Geology

No facility may be located over a holocene fault, in a subsidence area, or on or adjacent to any geologic feature which would impair the structural integrity of the facility.

Groundwater

Three fatal flaws exist for groundwater related standards. First, no facility may be located at a site where the distance from the bottom of lowest liner to the highest seasonal groundwater table is less than ten feet, unless hydraulic control of the water table is implemented. In this case, the minimum separation distance is five feet. The second fatal flaw is the presence of a sole source aquifer. No facility may be located over such an aquifer. Finally, the active area of any landfill may be no closer than 1,000 feet to a down gradient drinking water supply well, unless the hydraulic travel time from the active area to the well is greater than 90 days.

Surface Water

A landfill's active area may not be located closer than 200 feet, measured horizontally, to a surface water body, wetland or any public land that is being used by a public water system for watershed control for municipal drinking water purposes.

Slope

No landfill may be sited on any hill whose slope is unstable.

Land Use

Landfills that receive putrescible waste and attract birds will not be permitted with 1110,000 feet any airport runway currently used by turbojet aircraft or 5,000 feet of any airport runway currently used by only piston-type aircraft" (WAC 173-304-130). The purpose of this regulation is to reduce the danger posed by birds to aircraft.

Solid waste landfills will not be permitted in areas designated by the U.S. Fish and Wildlife Service or the Department of Game as critical habitat for endangered or threatened species of plants, fish or wildlife (WAC 173-3041_30) . In addition to already designated areas, an evaluation of each site should be made in accordance with the U.S. Fish and Wildlife Service's Habitat Evaluation Procedures to determine if the site contains any critical habitats (U.S. Fish and Wildlife Service, 1980). This would typically be done during the Level II evaluation (Section 3.4.3).

No landfill's active area may be located closer than 100 feet to the facility property line for land zoned non-residential or no closer than 250 feet for land zoned residential (at the time of the county's adoption of the solid waste management plan). Also, the landfill may not be at variance with any
locally adopted land use plan, unless otherwise provided by local law or ordinance.

Finally, the active area of the landfill may not be closer than 1,000 feet to any state or national park.

Flood Plain

The Minimum Functional Standards state that landfills located in flood plains must "not restrict the flow of the base flood, reduce the temporary water storage capacity of the flood plain, or result in washout of solid waste so as to pose a hazard to human life, wildlife, land or water resources site boundaries" (WAC 173-304-460). To meet these requirements, a landfill located in a flood plain would require extraordinary protection measures. Furthermore, if a landfill did become flooded, the potential impacts to the public health and the environment could be very serious. Consequently, a site within a 100-year flood plain should be fatal flawed in all situations.

Other Fatal Flaws

Fatal flaws are not limited to criteria established by a regulatory agency. The team developing the siting criteria can make other criteria fatal flaws if they determine that the impact of a particular factor would create an unacceptable condition or situation. Common examples include sites located outside the political boundaries of the siting agency, lack of adequate soils for liner and cover materials, destruction of irreplaceable archaeological or historical resources, and a lack of adequate landfilling capacity to meet the requirements stipulated in the county's solid waste management plan.

3.2.2 Other Criteria

A variety of factors is considered when developing solid waste landfill siting criteria. The following discussion outlines a logical progression to assist a siting team in developing criteria. The team should consider the following questions:

1. What factors are significant to the local siting process?
2. What potential impacts may these factors relate to?
3. Can these potential impacts be adequately and economically mitigated?
4. How can these factors be developed into siting criteria?

In the discussion below, important factors are grouped into major categories, such as hydrogeology, land use, and landfill design. Answers to the first three questions are presented in tables that list key factors, potential impacts, and mitigation measures. Examples of how to address the fourth question are presented following the tables.

It must be emphasized that the information presented here is not meant to be a complete list of all appropriate factors. It is a list of factors that are commonly of significance in landfill siting and that are required by the WDOE to be evaluated (revised Minimum Functional Standards, WAC 173-304-130).

Likewise, the methodology for developing the siting criteria is only an example of one method that has worked in the past. The primary goal of this section is to stimulate thinking and provide guidance to the siting team so that they may develop the best siting criteria possible given the environmental, economic, social and political conditions under which they must operate.

3.2.3.2. Climate

Table 3.1. Climatic Factors.

Key Factors	Impacts	Mitigation
Precipitation	Leachate production	Cover soils and phasing of operations
	Gas production	Gas control/recovery system
	Operation problems	Operation/design modifications
	Site runoff	Drainage and erosion controls
Wind	Litter	Operations plan
	Odor	Daily cover
	Dust	Gas Control

High levels of precipitation lead to higher levels of leachate production and operational difficulties. Therefore, sites with greater amounts of precipitation should be rated lower than sites with lesser amounts of precipitation. On a county-wide basis there may or may not significant differences in precipitation levels. If differences are not significant this would not be a valuable criteria in comparing sites.

High wind velocities contribute to litter and dust problems. If sites can be located so they are protected or otherwise isolated from high winds, they would be rated higher than sites that could not. Wind direction is important in controlling odor problems. Although the wind can blow from any direction on any particular day, there are predominant wind directions that tend to follow seasonal patterns. Sites that have predominant wind flow toward population centers would be rated 'Lower than sites that do not.

3.2.3.3 Surface Features

Topography can contribute positively or negatively to the development of a solid waste landfill site. Sites hidden behind hills or in valleys have less visual impact, and would be rated higher than a site located in the middle of a level plain with no visual isolation. On the other hand, a site location in hilly country may be more difficult to access because of steep slopes and the expense of road construction in hilly terrain. The highest rated site might be one with sufficient relief to provide some visual isolation and wind protection, yet have easy access and level areas in which to operate heavy equipment.

Topography can also influence the cost of developing landfill capacity. A site that can take advantage of a natural depression or valley to be filled with refuse is preferable. This is because volume for disposing of refuse is available without having to conduct expensive excavation operations.

Table 3.2. Surface Features Factors.

Key Factors	Impacts	Mitigation
Topography	Access Operations Aesthetics Capacity	Design/operations plan Buffer (visual and acoustic)
Water bodies	Contamination	Buffer (site proximity) Surface water/leachate management plan
Roads	Disruption of use	Relocation Upgrading
Utility systems	Access Availability	Extension of services Design of on-site services

Sites located closer to surface water bodies are more likely to cause contamination problems either through direct surface runoff from the working face of the landfill or through a ground water system discharging leachate into the surface water body. Sites located away from water bodies would rate higher than sites located close to water bodies.

Roads and utility locations can have both positive and negative impacts. It is advantageous to have adequate roads passing close to the landfill to allow easy access. However, major roads passing through the property proposed for a landfill become a negative factor since the available landfill area would be reduced. The highest rating for a road might be one that passes close by the proposed site, but is well screened from it. Utilities like sewer, water, electricity and communications are needed on every landfill site. If they are not available, they must be provided for by on-site systems (i.e., wells and septic systems) or public utility systems must be extended to the site. Like roads, the ideal situation features utilities adjoining the site, but not necessarily passing through it.

3.2.3.4 Geology

Table 3.3. Geological Factors.

Key Factors	Impacts	Mitigation
Bedrock	Operations	Operations plan
Hazards	Environmental contamination Personnel danger	Buffer zones

In general, it is preferable to locate landfills in areas where there is sufficient soil overlying the bedrock. If bedrock is close to the surface, landfill operations are limited to shallow excavation methods which reduce the capacity of the landfill. Also, if it is a fractured or otherwise permeable bedrock, it increases the potential for off-site leachate migration. Normally sites with a greater soil depth over bedrock are rated higher than those with bedrock at or near the surface.

Identifying hazardous geologic areas is also important. Such areas include potentially active (earthquake producing) fault zones, active volcanic zones, landslide areas and subsidence areas. Mitigation of areas where geologic hazards exist is generally not possible, unless very large buffer zones can be established. Normally such sites are considered to have a fatal flaw.

3.2.3.5 Soils

Soils are employed in landfill construction and operation for bottom liners, final cover, daily and intermediate cover, dikes and roads. Different types of soils are required for different applications. Some applications require silt and clay type soils (bottom liner and final cover), while other applications require sand and gravel type soils (gas venting and backfill for leachate collection system). Soils suitable for road construction and topsoil are also needed. It is important to identify which soils exist on a potential site as well as off-site soil sources that will satisfy the operational demands of the landfill. not met by on-site soils.

Undisturbed soil surrounding and beneath the potential site will exert a strong influence on the potential for movement of leachate beyond the boundaries of the site. Soils with very low hydraulic conductivity (10-7 cm/sec or less) are desirable, since they severely restrict the movement of leachate away from the site.. Soils; surrounding or beneath a landfill which have significantly higher permeabilities, such as 10-5 cm/sec or above, would be considered of poorer quality.

Table 3.4. Soil Factors.

Key Factors	Impacts	Mitigation
Thickness	Ground water contamination	Secondary bottom liner
	Construction	Excavation plan
	Operations	operations plan
	on-site availability	
Physical and chemical characteristics	Leachate movement	Soils import
	Leachate attenuation	Soil amendments
	Operations usage	Artificial substitute

The presence of certain types of soil can be a positive factor in the selection of a landfill site. Generally, sites underlain by silt and clay soils are rated high because of the protection such soils provide to the ground water. Sites with sand and gravel soils require extensive engineering to provide adequate protection to the ground water and would be rated lower. However, because of the need for sand and gravel soils for some applications, a site with none of these types of soil may be rated lower than a site that has both fine-grained and coarse-grained soils on-site. The stratigraphy, or sequential order, in which the different layers of soil are laid down is also important. Sites where coarse-grained soils overlay fine-grained soils would be rated high because the coarse-grained soils can be excavated and used for roads and daily cover, while the fine-grained soils could be left in place to protect ground water.

3.2-3.6 Hydrogeology

Hydrogeology is the study of the occurrence, distribution and movement of water below the surface of the earth, and its interrelationships with geologic materials and processes (Todd, 1980 and Fetter, 1980). Information about hydrogeology is critical to site evaluation. It is the basis for analyzing the potential for leachate contamination of ground water resources. The primary concerns in this siting category are the potential for contamination of ground water beneath the landfill site, and the subsequent movement of this contaminated water to important aquifers or other valuable water resources.

Table 3.5. Hydrogeological Factors.

Key Factors	**Impacts**	**Mitigation**
Flow system	Ground water contamination	Leachate management system
Aquifer	Public health	Alternative water sources
Aquitard	Leachate movement: Operations	Ground water flow modifications

Ground water flow systems determine where leachate will flow from the site, what the flow velocity will be, whether groundwater aquifer will be adversely impacted and where the leachate will emerge again on the surface. Ground water flow systems consist of a recharge area (where water enters the system) and a discharge area (where the ground water discharges to the surface). Recharge areas are normally topographically high areas, while discharge areas are normally topographically low areas like rivers. Preferred potential sites are in areas controlled by 'Local ground water flow systems (discharge area is the nearest topographical low) where the hydraulic gradient is small and the hydraulic conductivity of the soil is low (Freeze and Cherry, 1979).

Locating a landfill within such a system would prevent leachate contamination from spreading very far from the. site in the event of a leachate management system failure.

Ground water flow systems with shallow water tables are less desirable than systems with deep water tables. Shallow water tables are more likely to become contaminated by leachate. In determining the water table depth, it is important to consider seasonal fluctuations. Water table fluctuations are caused by seasonal variations in precipitation. Typically, water tables are highest during the late winter and early spring months. In some areas of Washington where significant irrigation occurs, a reverse condition may be present in which the water table is highest in late summer..

The presence of aquifers (saturated geologic formations that yield sufficient water to pumping wells) beneath a potential site would normally lower the site rating because of the potential for aquifer contamination with leachate. Sites with aquitards (geologic formations that restrict the movement of ground water) are generally rated higher than sites without since the aquitard provides natural protection against leachate contamination.

3.2.3.7 Biological Environment

All solid waste landfill sites disrupt the biological environment. Ratings for this category are based on a matter of degree of disruption, and the uniqueness of the resource. Certain types of habitat are less abundant than others, and sites containing such habitats should be rated lower. Likewise, sites that support unique species of plants and animals would be rated lower than sites that do not. Important migration routes, such as streams used by anadromous fishes, are valuable resources and those sites located near such routes should be rated lower than those that are not.

Table 3.6. Biological Environment Factors.

Key Factors	**Impacts**	**Mitigation**
Habitat	Loss or disruption	Replacement
Unique species		Compensation
Migration routes		Buffer zones

3.2.3.8 Land Use

Land use criteria are very important because they are often perceived by the public as having the most direct impact on them. Most people recognize the need for landfills, but universally feel they should not be located "in my backyard". Therefore, land use criteria should be established to limit as much as possible the establishment of landfills in areas of high population density, economically important land uses, or areas of heavy public use.

Certain types of land use may be valued more highly than others. For example, the preservation of agricultural land is a high priority in Washington and, therefore, sites located in agricultural lands may be rated lower than sites located in commercial land use areas. Other land use areas that are normally considered less suitable for landfills include residential, local conservation, and national forest areas. The number of people impacted is also important and sites with higher surrounding population densities may be rated lower than sparsely populated rural areas.

Table 3.7. Land Use Factors.

Key Factors	Impacts	Modification
On-site property	Loss of present use	Compensation
Adjacent property	Loss of land value	Buffer zones
Number of property owners	Aesthetics	Operations modifications
	Cost of land purchase	
Existing zoning	Permitting landfill	Conditional use permit
Comprehensive plan	Future land use	Zoning modifications

The ease and expense with which the proposed area can be obtained can also be an important consideration. Areas where zoning ordinances permit landfills would be preferable to areas where conditional use permits would be required. Areas where landfills could not be permitted at all would have to be fatally flawed unless the zoning ordinances could be changed. Also, fewer property owners are preferable to many.

The final end use plans are significant in how they relate to future land use plans and growth management. Landfill sites whose end use plan can be compatible with the responsible planning agency's comprehensive plan are rated higher than sites whose end use cannot be made compatible with future plans.

3.2.3.9 Archaeological and Historical Resources

Archaeological and historical resources range from sites on the National Register to areas identified as archaeologically important to Native Americans. In some cases, it may be possible to have the resource on the landfill site, and to provide appropriate buffering or other protective measures to minimize potential impacts of the project. At the other extreme, construction of the landfill could destroy the resource if it is not feasible to remove it from the site. The potential destruction of these resources could constitute a fatal flaw.

3.2.3.10 Transportation

Table 3.8. Transportation Factors.'

Key Factors	Impacts	Mitigation
Existing roadways	Level of service reduction	Transfer station
	Access	Road & traffic improvements
	Traffic safety	Buffer zones
Existing collection network	Operations	Collection system modifications

Sites located near roads that can support the increased level of service required by a landfill operation without modification are preferable to sites that cannot. Modifications to road systems, particularly new road construction or upgrading, can be very expensive.

Although it is desirable to have sites located near adequate roads, it is undesirable to have them located so that the main access corridor to the landfill passes through residential, school, hospital or other areas where traffic safety could be a problem.

Sites located nearer the center of the waste generating area are normally rated higher than sites farther away. The closer a site is to the center,
the lower the haul costs to the landfill. These costs are very substantial over the life of the landfill, and are often one of the major cost considerations in the siting process.

3.2-3.11 Landfill Design

Landfill design encompasses site plans and improvements along with engineering systems used to manage leachate, surface water, ground water and landfill gas. The management systems are designed to mitigate impacts caused by the presence or absence of various factors, and from a criteria standpoint, are significant because of the economic cost involved. Generally, sites requiring the least amount of engineering modifications are the least expensive to develop, and are preferable to sites requiring extensive modifications.

One of the easiest criteria to-apply relates to site capacity. If a proposed site is not large enough to meet the capacity requirements it would be considered a fatal flaw and dropped from consideration.

3.2.4 Ranking Procedure

After siting criteria have been developed it is helpful to have a system whereby these criteria can form the basis for evaluating the potential sites. To accomplish this, a numerical value can be assigned to conditions that might be found for each criterion. A higher number can be given to more desirable conditions. An example of how this might be done for geology follows:

Rating	**Condition**
10	Greater than 50 feet of fine-grained unconsolidated material
8	10 to 50 feet of fine-grained unconsolidated material
6	Greater than 50 feet of coarse-grained unconsolidated material
4	10 to 50 feet of coarse-grained unconsolidated material
1	Less than 10 fee to non-rippable bedrock

This rating procedure could be established for each criterion. During the evaluation process, only those sites with the highest total rating would be selected to continue in the siting process.

A weighting system should be added to the ranking procedure to recognize the ,relative importance of different criteria. For example, hydrogeological criteria selected to protect public health and ground water quality may be considered more important than criteria selected to limit aesthetic impacts. The hydrogeological criteria rating could then be multiplied by a value chosen to reflect this increased importance. Therefore, even if both criteria received the same rating for a particular site, the multiplier would increase the total score of the hydrogeological criteria, illustrated below:

Criteria	Rating		Multiplier	Score
Hydrogeology	5	x	5	25
Aesthetics	5	x	2	10

A rating system, such as described above, cannot be applied blindly. Sound judgment and common sense are very important in reaching a final decision on the preferred site. These factors cannot be readily quantified, but are crucial to a successful landfill siting process.

In summary, the development of landfill siting criteria, including the selection of ratings and multipliers, should be approached as an interdisciplinary effort. Site selection criteria should be developed not only from applicable regulations, but should also incorporate the siting group's understanding of the project based on their technical experience, specific research conducted for the siting study, and discussions between members of the group and the regulatory agencies. The results of such a procedure are illustrated in Figures 3.1 and 3.2. The information in these figures is not meant to be used in lieu of an independent siting criteria development study, but rather to serve merely as an example.

3.3 POTENTIAL SITE IDENTIFICATION

At the beginning of the siting process, potential solid waste landfill sites include any "available" land of the approximate size as determined to be required in the siting decision. "Available" in this context means undeveloped, with the potential for sale or lease to the sponsoring agency, although it may be necessary for the public agency to obtain a site by condemnation. The identification of these available sites can be accomplished through solicited nomination and research.

A solicited nomination process involves specific requests from the sponsoring agency for site nominations by private and public entities. This process should be closely linked to the public involvement program, since informed citizens are generally good information sources.

The first consideration for site nominations should be expansion possibilities at existing disposal sites, and sites previously selected and/or evaluated in other siting studies. Nominations can be solicited by advertising in the local newspaper. This advertisement can also aid the public involvement program. An example of an advertisement used in Snohomish County is shown in Figure 3.3.

Other sources for site nominations are public agencies such as U.S. Forest Service, Washington State Department of Natural Resources, and the county property manager. Private sector sources are realtors specializing in large acreage transactions. Major property owners in the area can be determined from local public knowledge, and from information contained in the county

I. General Requirements Multiplier	
Geographical Boundaries	5
Ownership/Acquisition Potential	3
Compatibility with Resource Recovery Facility	3
Site Capacity	5
Site Parcel Assemblage	3
II. Physical Environment	
Geology	5
Soils (Above Area Wide Water Table)	5
Gas Control	2
Ground Water Table Depth/Permeability	5
Ground Water Flow Systems	3
Ground Water Hydrologic Boundaries/Beneficial Use	5
Surface Water	5
Flood Hazard	2
Topography	4
Air	1
Precipitation Zone	3
Noise, Light and Glare	2
Biological - Endangered Species	3
Biological - Fisheries	3
Biological - Terrestrial Habitat	3
III. Human Environment	
Zoning	4
Surrounding Land Use	5
Agricultural Land	3
Effect on Cultural/Historical/Archaeological Resources	2
Airport Safety	1
Direct Access	3
Access Routes	4
Population Density - Residential	3
Aesthetics	3
IV. Economic Considerations and Operational Costs	
Leachate Transport	4
Solid Waste Transport	5

Figure 3.1
Multipliers Used In
Snohomish County Siting Project

Rating	Rating Category	Multiplier
	I. General Requirements	
	Geographic Boundaries	
10	Snohomish County	x 5
0	Other	Fatal Flaw
	Ownership/Acquisition Potential	
10	Snohomish County	x 3
7	Private	x 3
6	State	x 3
5	Municipal	x 3
4	Federal	x 3
4	Tribal	x 3
	Compatibility With Resource Recovery Facility	
10	Suitable Site Within 2 Miles of Steam User	x 3
5	Suitable Site	x 3
1	Not Suitable Site	x 3
	Site Capacity	
10	1,000,000 Cubic Yards of Solid Waste	x 5
5	3,000,000 Cubic Yards to 10,000,000 Cubic Yards of Solid Waste	x 5
1	Under 3,000,000 Cubic Yards of Solid Waste	x 5
	Site Parcel Assemblage	
10	Single Owner	x 3
7	2 to 3 Owners	x 3
5	4 to 5 Owners	x 3
3	6 to 10 Owners	x 3
1	More Than 10 Owners	x 3
	II. Physical Environment	
	Geology	
10	Bedrock/Overlain by Minimum 15' Rippable Material	x 5
6	Fine Grained Sediments	x 5
4	Coarse and Fine Grained Sediments	x 5
2	Coarse Grained Sediments	x 5
0	Bedrock (Non-Rippable)/Thin Soil Cover (Less Than 5 Feet)	Fatal Flaw
	Soils (Above Area Wide Water Table)	
10	Both Fine and Coarse Grained Soils Greater than 30' Thick	x 5
7	Fine Grained Soils Greater than 30' Thick	x 5
4	Fine Grained Soils Less than 30' Thick	x 5
1	Coarse Grained Soils Less than 30' Thick	x 5
	Gas Control	
10	Soils Low Gas Movement Potential/No Structures Within 1000' (Providing Major Opportunities for Gas Collection)	x 2
5	Soils High Gas Movement Potential/No Structure Within 1000' (Providing Major Opportunities for Gas Collection)	x 2
1	Soils High Gas Movement Potential/Structures Within 1000' (Providing Major Opportunities for Gas Collection)	x 2

Rating	Rating Category	Multiplier
	Ground Water/Water Table Depth Permeability (Areawide Minimum Regional Water Table Depth)	
10	Deeper Than 60' and Low Permeability	x 5
8	30' to 60' and Low Permeability	x 5
6	Deeper Than 60' and High Permeability	x 5
4	Shallower Than 30' and Low Permeability	x 5
2	30' to 60' and High Permeability	x 5
1	Shallower Than 30' and High Permeability	x 5
	Ground Water Flow Systems	
10	Regional and Local Discharge Area	x 3
5	Regional Recharge/Local Discharge	x 3
1	Regional and Local Recharge Area	x 3
	Ground Water/Hydrologic Boundaries/Beneficial Use	
10	Low Present and Projected Future Beneficial Use With Hydrologic Boundaries	x 5
5	Present and Projected Future Beneficial Use With Hydrologic Boundaries	x 5
1	Present and Projected Future Beneficial Use Without Hydrologic Boundaries	x 5
0	RCRA Sole Source Aquifer Recharge Zone	Fatal Flaw
	Surface Water	
10	Low Present and Projected/Future Beneficial Use	x 5
5	High Present and Projected/Future Beneficial Use	x 5
0	Destruction of Significant Wetlands on or Adjoining Site	Fatal Flaw
0	Within 200' of Designated Shoreline (Shoreline Management Act)	Fatal Flaw
	Flood Hazard	
10	No Apparent Flood Hazard	x 2
1	100 to 500 Year Flood Hazard	x 2
0	100 Year Flood Plain	Fatal Flaw
	Topography	
10	Excavations Volume Ratio Good/ On-Site Access Good	x 4
5	Excavations Volume Ratio Good/ On-Site Access Poor	x 4
2	Excavations Volume Ratio Poor/ On-Site Access Good	x 4
1	Excavations Volume Ratio Poor/ On-Site Access Poor	x 4
	Air	
10	Existing Air Quality Does Not Impact Resource Recovery Plant Siting	x 1
5	Existing Air Quality Impacts Resource Recovery Plant Siting	x 1
1	Existing Air Quality Inhibits Resource Recovery Plant Siting	x 1

The Highest Rating of 10 Indicates Most Desirable. A Rating of 0 is Least Desirable and Denotes a Fatal Flaw Which Cannot Be Mitigated.

Multipliers are a Measure of the Relative Importance of a Category. A Multiplier of 5 Denotes Greater Importance and a Multiplier of 1 Denotes Least Importance

Source: Snohomish County, Department of Public Works, Solid Waste Division, *Phase I-1 Technical Report: Landfill Site Selection and Fatal Flaw Criteria*, (Everett, WA: Aug. 1982) p. 40-47.

Figure 3.2
Rating System Used in
Snohomish County Siting Project

Rating Category		Multiplier
	Precipitation Zone	
10	Under 35" Per Year	x 3
5	Between 35" and 45" Per Year	x 3
1	Over 45" Per Year	x 3
	Noise, Light and Glare	
10	Existing/Available Satisfactory Buffers	x 2
5	Limited Existing/Available Satisfactory Buffers	x 2
1	Requires All Manmade Buffers	x 2
	Biological — Fisheries	
10	No significant Impacts Anticipated on Fisheries Resources	x 3
5	Impacts Anticipated on Resident Fisheries Resources	x 3
1	High Impacts Anticipated on Anadromous/ Culture Facilities Fisheries Resource	x 3
	Biological — Terrestrial Habitat	
10	Low Habitat Value	x 3
5	High Habitat Value	x 3
1	"Critical" Habitat	x 3
0	Significant Impacts to "Critical" Habitat	Fatal Flaw
	III. Human Environment	
	Zoning	
10	Zoning Requires Conditional Use Permit	x 4
1	Would Require Rezoning and Conditional Use Permit	x 4
	Surrounding Land Use	
10	Would Have Low Impact Potential on Surrounding Land Uses — Relatively Easy to Mitigate	x 5
5	Would Have Moderate Impact Potential on Surrounding Land Uses — Can be Adequately Mitigated	x 5
1	Would Have Significant Impact on Surrounding Land Use — Difficult to Mitigate	x 5
	Agricultural Land	
10	No Significant Impact on Prime Agricultural Land	x 3
5	Potential Impacts on Nearby Prime Agricultural Land	x 3
1	Site Predominantly Consists of Prime Agricultural Land	x 3
	Effect on Cultural/Historical/Archaeological Resources	
10	No Resources on Site, Access Corridor and/or Adjoining Areas	x 2
5	No Resources on Site or Access Corridor But Low Impact on Adjoining Areas	x 2
1	Impact on Resources on Site and/or Access Corridor	x 2
0	Would Destroy Cultural/Historical/Archaeological Resources on Site and/or Access Corridor	Fatal Flaw
	Airport Safety	
10	Over 10,000' From Propeller Planes Runway or to 20,000' From Jet Planes Runway	x 1
5	5,000' to 10,000' From Propeller Planes Runway or 10,000' to 20,000' From Jet Planes Runway	x 1
0	Site Within 5,000' From Propeller Planes Runway or 10,000' From Jet Planes Runway	Fatal Flaw

Rating Category		Multiplier
	Direct Access	
10	County Arterial or State Highway Built to Applicable Standards, No Defined Safety Hazards	x 3
8	Substandard Arterial Correctable to Applicable Standards Within Existing ROW and Low Cost	x 3
4	Substandard Arterial Requiring High Cost Improvement	x 3
2	Access Only by Non-Arterial Route	x 3
1	No Road Access Within 2 Miles of Site	x 3
	Access Routes	
10	Truck Access Through Non-Residential or Very Low Density Uses	x 4
5	Truck Access Through Low-Medium Density Development	x 4
1	Access Available Only Through High Density Development	x 4
	Population Density — Residential	
10	Low	x 3
5	Medium	x 3
1	High	x 3
	Aesthetics	
10	Operations Not Easily Visible From Off-Site	x 3
5	Operations Visible From Off-Site	x 3
1	Impairment of Scenic Vistas	x 3
	IV. Economic Considerations and Operational Costs	
	Leachate Transport	
10	Satisfactory Sewers Available at Site	x 4
5	Satisfactory Sewers Available in General Area	x 4
1	No Sewers Available in Area	x 4
	Solid Waste Transport (Proximity to Centroids of Generation)	
10	Within 10 Miles	x 5
5	Between 10 and 30 Miles	x 5
1	Further Than 30 Miles	x 5

The Highest Rating of 10 Indicates Most Desirable. A Rating of 0 is Least Desirable and Denotes a Fatal Flaw Which Cannot Be Mitigated.

Multipliers are a Measure of the Relative Importance of a Category. A Multiplier of 5 Denotes Greater Importance and a Multiplier of 1 Denotes Least Importance.

Source: Snohomish County, Department of Public Works, Solid Waste Division, *Phase I-1 Technical Report: Landfill Site Selection and Fatal Flaw Criteria*, (Everett, WA: Aug. 1982) p. 40-47.

**Figure 3.2 (Continued)
Rating System Used in
Snohomish County Siting Project
(Continued)**

We Must Have a New Landfilll
Site in Snohomish County……
Even Though We Are
Aggressively Pursuing a
Waste-to.-Energy Program

If you own, or know of property
suitable for a landfill site in the
County, please let us know by:

December 31, 1985

For suggestions or more
information, please contact:

John Doe
Snohomish County Solid Waste Division
(206) 000-0000
1-800-000-0000

Figure 3.3
Example of Landfill
Solicitation Advertisement

assessor's files. These owners can be approached for site nominations as well.

The research method of identifying potential landfill sites requires an extensive geographical data base, with information on geohydrology, land use, topography, climate, demography and other related categories. This data base would then be researched for areas with characteristics amenable to development of a solid waste landfill. For this method, there must be a clearly defined set of parameters which establish the minimum characteristics of a piece of land for consideration as a potential landfill site. This data base, if available, would likely be developed at the county or state level.

3.4 POTENTIAL SITE EVALUATION

3.4.1 Introduction

The next step in the landfill process is to select the best, or most feasible, sites for solid waste landfills from the list of potential sites. The process used to achieve this goal can be expensive and time consuming. Therefore, it is necessary to use a procedure that relies on progressively more detailed evaluations.

One successful method is a three level evaluation that begins by using published information and an objective ranking procedure, and ends by conducting extensive field investigations in conjunction with the preparation of a draft Environmental Impact Statement to identify the preferred alternative site.

The following sections discuss this three-level evaluation process to identify the preferred alternative.

3.4.2 Level I Evaluation

3.4.2.1 Objective

It is assumed at this stage of the evaluation process that there are a large .number of potential sites nominated during the site identification process. The Level I evaluation objective is to reduce the number of potential sites to approximately six to ten. The number can vary considerably depending on the general suitability of the area for landfill development. The most cost effective approach to the Level I evaluation limits the level of detail of the analysis and restricts data collection efforts to available published material.

3.4.2.2 Methodology

It is important to realize that since only a limited amount of time can be spent evaluating each site, the information used should be readily available through libraries, government agencies, and other public records.

Sites should first be examined for fatal flaws and rejected if appropriate. The remaining criteria can be evaluated according to the ranking system. The six to ten sites that achieve the highest total score should represent the best potential sites for development of a landfill. These sites should be visited to determine the general accuracy of the evaluation, and to identify any conditions that might call for a revision of criteria scores.

Factors that form the basis for a Level I evaluation are listed below. These factors are provided as guidelines only. Some siting studies may not have to examine all these factors to reach a smaller number of sites. Other siting studies must expand this list to be able to reach the desired number of sites. In addition to discussing what factors to consider, the next section also discusses sources of information needed to evaluate each factor.

3.4.2.3 Major Factors to Consider

Fatal Flaws

Potential solid waste landfill sites can be plotted on base maps such as USGS topographical maps or county maps. Information on the fatal flaws listed in Table 3.9, and any other criteria designated as fatal flaws, can be collected for areas where potential landfill sites have been nominated. If any of the potential sites fall within areas that are fatally flawed, they can be rejected without further consideration. This should be the first step in the Level I evaluation since a number of sites may be rejected using only the fatal flaws.

Table 3.9. Fatal Flaw Evaluation.

Key Factors	Data Sources
Proximity to airports	USGS topographical maps[1] WSDOT, Aeronautics Division[2]
Designated critical habitats	U.S. Fish and Wildlife Service
Flood plain	U.S. Army Corps of Engineers Local planning agency
Geology	Published geologic reports
Ground water	Published hydrogeologic reports Water well logs Local water supply districts
Surface water	USGS topographic maps
Slope	Published geologic reports Local planning agency

[1]U.S. Geological Survey
[2]Washington State Department of **Transportation**

Surface Features

The physical surface features listed in Table 3.10 show up on the topographical base maps or can be obtained from other maps or aerial photographs. Although surface water bodies will most likely be mapped, the value of that resource cannot be estimated from the maps. The state agencies listed in Table 3.10 can provide information on whether a particular water body has a designated shoreline, or if it is a public water supply, or flows into one. These are not the only measures of value of a surface water resource, but at this level of evaluation they should be adequate.

Geology

Geological analysis during a Level I evaluation should be limited to information published by the USGS, WDNR, and WDOE, and should concentrate on identifying hazardous areas and depth to bedrock. Geologic hazards and shallow depth to bedrock are often considered fatal flaws. The USGS, VDNR and WDOE publish surficial geologic maps and geologic reports for selected areas. The agencies also have technical staff who are familiar with particular areas and available data, and may be contacted to assist in developing a data base. Local planning agencies may be aware of technical studies conducted in a site vicinity that would provide valuable information.

Table 3.10. Surface Features Evaluation.

Key Factors	Data Sources
Topography	USGS topographical maps
Surface water bodies	Aerial photographs from planning agencies
Roads	Road mans
Utilities	WSDNR[1]
	WSDSHS[2]
	County/city public works or planning departments

[1]Washington State Department of Natural Resources
[2]Washington State Department of Social and Health Services

Soils

Generalized soil information is available from the U.S. Department of Agriculture Soil Conservation Service (SCS). A soil survey should be available for each county. These surveys contain soil maps on which the boundaries of the potential sites can be overlaid to determine the types of soil on the site. The soil survey also contains information on the grain size, permeability and other physical and chemical characteristics of the soil. In addition, estimates of the depth of the water table in each soil type are made. The SCS has interpreted this information and provides a table in the soil survey which rates individual soil types for their suitability in solid waste landfills. Table 3.11 is extracted from one of the soil surveys and presented as an example.

Table 3.11. Example of Table from SCS Soil Survey.

Soil name and map symbol	Trench landfill	Area landfill	Daily cover for landfill
47 Pastik	Severe: wetness	Moderate: wetness	Fair: too clayey, wetness

Source: Debose and Klungland, (1983)

In addition to the soil surveys, the staff at local Soil and Water Conservation Districts usually provide valuable assistance, and may have more site specific information than what is available in the soil survey. Also, geologic reports and maps often contain estimates of soil depth and classification. These publications, available from the U.S. Geological Survey and the Washington Department of Natural Resources, should be used in conjunction with the SCS soil maps.

Hydrogeology

Table 3.12. Hydrogeological Evaluation.

Key Factors	Data Sources
Depth to water table	USGS
Aquifers	VDOE
Aquitards	WSDSHS
Flow system	WDNR, Division of Geology and Earth Resources
	Local health department

The location and position of major aquifers, and the flow systems that they are part of, can be determined from publications available from the agencies listed in Table 3.12. Heavily used aquifers will generally have more information available on them. In addition to locating the major aquifers, it may be possible to determine if they are protected by any confining layers of low hydraulic conductivity. Such layers may be either bedrock layers like slate, or soil layers like clay and silt.

Besides major regional aquifers, it is important to locate local aquifers in the area. Information on aquifers of this type may be nearly non-existent, except for that which can be supplied by local users. At this stage of the evaluation process, an easy way to determine local aquifers of importance is to contact local municipalities to ascertain their water source. In rural areas, a reasonable assumption is that domestic water supplies come from ground water sources.

Information collected can be plotted on base maps for the potential sites. This display can then be used in determining the hydrogeological rating of each site.

Biological Environment

Site habitat criteria can be initially evaluated from topographical maps on a very broad basis. Distinctions can be made between wetlands, forest and meadows, for example. Aerial photographs may be available from local planning agencies and these can provide greater detail for habitat determination. Available color infrared aerial photography is particularly useful for identification of vegetation patterns and bodies of water.

Table 3.13. Biological Environment Evaluation.

Key Factors	Data Sources
Habitat	U.S. Fish and Wildlife Service
Unique species	Washington State Department of Game (WSDOG)
Migration routes	Washington State Department of Fisheries(WSDOF)
	USGS topographical maps
Aerial photographs	

To determine if there are important fisheries resources in the area, the Washington State Department of Fisheries (WSDOF) should be contacted. it maintains a file of stream catalogs *containing information* on fisheries resources for individual streams.

The Washington State Natural Heritage Program should be contacted to determine the presence or absence of biological species of concern.

Land Use

A large number of sites can be eliminated without an extensive amount of research by evaluating land use criteria. Local planning agencies at the county or municipal level have existing land use maps for their areas of responsibility. These same agencies also have land use plans for future development. Such plans are useful for evaluating future trends in the area, and the compatibility of a landfill with those plans.

Zoning restrictions may prohibit the development of a landfill in a particular area. Even if the zoning ordinances do not prohibit a landfill, they may require that special conditional use permits be obtained from the appropriate jurisdictional agency. Again, planning agencies are the best source of information.

The county assessor's office can provide information on property owners at a particular site, and an estimated value of the property.

Archaeological and Historical Resources

In general, information on archaeological and historical resources must be obtained from government publications like the National Register of Historical Places, or lists maintained by the State Historic Preservation Office (SHPO). In Washington, the SHPO is the Office of Archaeology and Historic Preservation. Much of SHPO's archaeological site information is confidential and should not be released to the general public. Counties may have a historic preservation planner who can provide additional information.

Transportation

Table 3.14. Transportation Evaluation.

Key Factors	Data Sources
Existing roadways	Road maps
Existing solid waste collection network	WSDOT
	Local highway departments
	Local solid waste jurisdictional agency

Potential landfill sites can be plotted on county road maps. Major access routes can then be determined easily, including reasonable alternatives. Highway departments can provide information on load ratings of roads and traffic volumes.

Local solid waste agencies should be able to provide information on the waste generation area, including its centroid. This information can also be plotted on the county map to determine the distance from the various sites to the waste generation area centroid.

Landfill Design

At this level of evaluation, site capacity is one simple, but very important consideration in landfill design. Prior to initiating the siting effort, a determination should have been made on what landfill capacity 'is required. In this initial evaluation, those sites not meeting the size requirement can be rejected. This would be considered a fatal flaw.

Summary

A large number of professionals in various fields will be involved in the evaluation process. They will be researching and studying the sites in their particular area of expertise. Their efforts should first be directed toward analyzing sites for fatal flaws. Sites with fatal flaws should be discovered as soon as possible to prevent needless research efforts. After sites with fatal flaws have been determined, the remaining sites must receive a rating for each criteria. The rating assigned to each site for a particular criteria should be determined by professionals with experience in that field. Thus, hydrogeologists will rate sites on criteria pertaining to ground water, while biologists will rate sites on biological criteria. This will be done for all criteria. Total scores for each site can then be determined according to the system described in Section 3.2.4. The six to ten sites with the highest total score are' carried forward into Level II analysis. Prior to making the final decision, the chosen sites should be surveyed from the ground and the air to ensure that the evaluation was reasonably accurate, and that no conditions exist that might require revision of the criteria scores.

3.4.3 Level II Evaluation

3.4.3.1.<u>0biective</u>

Approximately six to ten potential solid waste landfill sites should be examined at this level. This represents an optimum number that can be examined at the level of detail required without incurring unreasonable costs and time delays. The objective is to reduce the number of potential sites to approximately two or three. This will be achieved through a more in-depth analysis and expanded data collection effort.

3.4.3.2 <u>Methodology</u>

The Level II data collection effort is enhanced significantly and the degree of analysis is increased. Information collected is more extensive and more site specific. Of particular importance is field work by -professionals in specialized areas like hydrogeology, biology, landfill design and transportation engineering. Previously examined factors are often evaluated in greater depth.

During the Level II evaluation the process requires more subjectivity. Differences between sites become more subtle and less subject to simple numerical rating. Professionals in various disciplines conduct their investigations of the remaining sites and evaluate them. They can then rate each site according to their experience and judgment. A site area feasibility matrix can be prepared to plot the ratings for all the appropriate categories, as below:

The selection of the best sites normally involves trade-offs between different categories. Trade-offs can be discussed with respect to the relative benefits and constraints associated with each site. A consensus should be reached among the team members on which sites represent the best potential for development as a landfill.

Information collected in the Level I evaluation is still valid and should also be used in the Level II evaluation. However, in the discussion below, only factors or methods not introduced before will be discussed.

3.4-3.3 **Major Factors to Consider**

Surface Features

Surface features evaluated from maps in the Level I evaluation can now be confirmed by visiting the remaining sites. Site surveys can confirm features on the maps, note changes or discrepancies, and highlight particular factors perceived to have the most significance on landfill development. Personnel conducting field surveys should be particularly alert to features not otherwise noted, but that could have a significant impact. As an example, consider the visual screening of a potential site. It is difficult to determine from maps how adequately a site might be concealed from residences, other buildings and roads, During site surveys this can be directly evaluated by persons in the field.

Table 3.15. Sample Site Area Feasibility Matrix.

Category	Site A	Site B	Site C[1]
Soils: protecting ground water	H	L	M
Soils: operational use	M	M	H
Aquatic biological resources	H	L	L
Land use	L	M	M
Transportation	M	H	H
Engineering	H	M	L

[1]H = high feasibility, M = moderate feasibility with appropriate mitigation, L = low feasibility.

Another valuable observation method is aerial reconnaissance of the sites. Observation from the air often provides a more complete picture of how the potential site relates to the surrounding area than what can be obtained from ground surveys. In addition to reconnaissance flights over the sites, professional aerial photographs should be taken of each site. Both black and white photographs and color infrared photographs are valuable. These photos, in combination with earlier reconnaissance flights, are very useful in planning effective ground field work. Also, detailed topographical maps can be produced from the photographs which can be used in preliminary engineering design work.

Geology, Soils and Hydrogeology

The principal objective in this category is to confirm earlier estimates, or modify them based on new information. One of the best methods to achieve this is by reviewing water well logs that are on the potential sites or in close proximity to them. The WDOE maintains files of water well logs. The logs are the well driller's estimate of the types of soil and bedrock that w I ere encountered during the drilling. The classifications used in these logs are usually fairly general. The well logs also have information on saturated soil conditions and the static level of water in the casing after the well was completed. Information from the well logs can be plotted as geological cross-sections through the potential sites. The cross-sections show the stratigraphy of the soil, location of aquifers and aquitards, the water table, and estimated flow directions of the ground water. Such cross-sections facilitate comparisons between different sites.

Field surveys by geologists and soil scientists are also useful to confirm earlier estimates. Geophysical surveys allow, under certain conditions, the evaluation of soil, bedrock and ground water conditions without direct sampling. Electrical resistivity and seismic surveys are the most common. Soil samples can be collected by hand operated boring samplers to a depth of about six feet, or from backhoe excavations to a depth of about ten feet. Experienced geologists can make classifications in the field. Soils are normally classified according to the Unified Soil Classification System (USCS). The Environmental Protection Agency (EPA) has developed a chart to estimate the suitability of all the USCS classifications for various landfill applications (Luitton, Regan and Jones, 1979).

Table 3.16. Geological, Soils and Hydrogeological Evaluation.

Key Factors	Data Sources
Depth to ground water	WDOE water well logs
Flow system characteristics	Field surveys
Depth of soil	Geophysical surveys
Soil classification	Jurisdictional health agency
Bedrock classification	
Aquifers	

A significant part of the field work is the completion of a beneficial use survey. The objective of this survey is to locate all the users of the ground water resource within a given radius of the boundaries of the potential sites. The Ecology water well logs and water rights files, and information from jurisdictional health departments, are useful for this purpose.

Biological Environment

Field surveys can provide site specific information about important biologic conditions. The habitat of the site and the surrounding area can be examined for its ability to support both single species and species diversity of plants, wildlife and fishes. Of particular importance is the identification of unique or endangered species that inhabit the site or surrounding area that may be impacted by the development of a landfill. The identification of anadromous fish streams used for migration and breeding is also important.

Land Use

Most land use information is available from documents collected during the Level I analysis. However, field surveys can provide insight into impacts on nearby residences, recreational land uses, and agricultural land uses. Such information can be used to refine initial ratings of potential sites on land use issues.

Transportation

Access to the site, which was initially estimated from maps, can be more accurately assessed by visiting the potential sites. Impacts on residences or other buildings along the main corridor route can be estimated. Other potential access routes can be explored.

Several agencies can be of assistance in this analysis. They include the WSDOT, the Utilities and Transportation Commission, and local transportation or highway departments.

Landfill Design

At this point landfill design considerations must go beyond simple matters of area alone. There are two major divisions of design effort at this stage: site development and mitigation measures.

Site development includes estimates of boundaries for active fill area and buffer zones, excavation requirements in the active fill area, and final contours for the completed landfill. Various site improvements are required. The cost of developing these improvements may differ significantly between potential sites. Such improvements may include access roads onto the site, and extending required utilities to the site.

Mitigation measures can vary widely among sites. Prior to determining which mitigation measures may be necessary, an understanding of potential impacts on ground water, land use, and other factors is required. Mitigation will include management of leachate, landfill gas, surface water, or ground water. It may also include plans to visually isolate the site, or special provisions to control blowing litter.

The preliminary design concept should be laid out on an appropriate topographical base map. The base maps are usually prepared from aerial photographs of the sites. The concept plan should include the boundaries of the site, the boundaries of the active fill area, special operational facilities, access roads, maintenance and operational buildings, and other important features.

It should be emphasized that the Level II design is preliminary and does not include detailed plans or specifications. It does require that decisions be made on the various mitigation measures based on their effectiveness and cost, and how the site will be developed. Such decisions will be helpful in selecting the best sites from those originally considered at the beginning of the Level II evaluation.

Summary

As the various professionals gather information on the factors in their area of expertise, they will be rating the sites based on their training and experience. Thus, a transportation engineer may be rating a site as highly feasible, while a hydrogeologist may be rating the same site as, having a low feasibility. The process of selecting two or three sites from the original six to ten will involve the ranking of each site in each category by the professional with expertise in that category. These evaluations can be displayed in matrix form as show in Table 3.15. Deciding which sites represent the best potential for development as a landfill must be accomplished through discussions among the professionals involved.

3.4.4 Level III Evaluation

3.4.4.1 Introduction

The Level III evaluation process is conducted in conjunction with the State Environmental Policy Act (SEPA) requirements. The Level III analysis studies will be incorporated into a draft Environmental Impact Statement (DEIS). The DEIS will identify a preferred alternative from two to three sites considered.

3.4.4.2 SEPA Compliance

The State Environmental Policy Act (SEPA) Rules in Chapter 197-11 WAC were established to ensure that environmental considerations are part of the review and approval process undertaken by state and local agencies. The SEPA review process applies to all siting projects, public or private. Each siting project is subject to various governmental permitting and approval processes. However, there are some differences in the exact application of SEPA rules for public versus private siting procedures. Also, SEPA review procedures have been, or are in the process of being, adopted by the counties in the state. Each county may have some requirements that others do not. Each county's adopted rules should be consulted for the procedures that apply to a given project. It is important that these procedures be followed precisely so that legal restraints are not placed on the project.

This review process should begin "when the principal features of proposal and its environmental impacts can be reasonable identified" (WAC 197-11-055). For a landfill siting project, this point would be at the termination of the Level II evaluation, when two or three potential sites remain in the evaluation process. It is assumed that all landfill siting projects are likely to have potentially significant, adverse impacts on the environment and, hence, would require preparation of an EIS. If this requirement has been agreed upon by the lead agency (usually the county) and the sponsoring agency, then a determination of significance (DS) and scoping notice (WAC 197-11-980) is issued and the formal SEPA process begins.

Prior to preparation of an EIS, scoping must take place. Scoping consists of narrowing the "... scope of every EIS to the probable significant adverse impacts and reasonable alternatives, including mitigation measures" (WAC 197-11-408). The scoping process involves inviting comment from local, state and federal agencies, affected tribes and the public. The techniques which may be used to solicit these comments are outlined in the SEPA rules and include letters, meetings, public notices, workshops and other methods (some of these are discussed in Section 3.6 of this chapter). The lead agency utilizes these comments to determine the scope of the EIS, the range of reasonable alternatives and probable significant adverse environmental impacts to be covered.

A draft EIS (DEIS) is prepared according to the scope as decided by the lead agency. The DEIS may begin during the scoping process. The style, size, format, and contents of the EIS are specified in the SEPA rules. In particular, the requirements for consideration of alternatives are contained in Section (5), and the requirements for consideration of the affected environment, significant impacts, and mitigation measures are contained in Section (6) of Chapter 197-11-440 WAC of the SEPA rules.

Section (5) defines "reasonable alternatives", and describes how these alternatives should be analyzed and compared. It also delineates special considerations for private projects under certain conditions. Specifically, the alternatives section of the EIS must:

- Describe the reasonable alternatives and mitigation measures that are part of the proposal
- Analyze each alternative and present a comparison of the impacts associated with each one
- Discuss the implications of implementation of the proposal at a later date

The subsection of the SEPA Rules dealing with private projects and their treatment of alternatives in an EIS is discussed in Section 3.5 of this document.

Section (6) of WAC 197-11-440 lists the requirements for the section of the EIS which must address the existing environment, significant impacts of the proposal and alternatives, and the mitigation measures. Basically, these requirements include:

- Descriptions of the environment affected by the proposal and alternatives
- Discussion of the impacts affecting the beneficial uses of the environment
- Summary of the significant adverse impacts that cannot or will not mitigated
- Summary of zoning regulations, land use and other plans as they apply to the proposal and alternatives
- Analysis of significant impacts on both the natural and man-made environment

The draft EIS is circulated to the public by the lead agency for comments, which are then responded to by the lead agency. These responses could result in changes in the analysis or alternatives. All substantive comments, responses and modifications to the DEIS are included in the final BIS (FEIS). After the HIS has been released, there is a seven-day waiting period before public agencies can approve or deny a proposal.

Most of the requirements for the EIS are contained in the Level III Evaluation of potential sites. In fact, it is the SEPA process itself which should determine the preferred alternative. The impact assessment and selection of a preferred alternative are a result of evaluation of project alternatives and existing environmental conditions.

3.4.4.3 Methodology

The landfill siting factors considered in the Level III evaluation are similar to those considered in the Level I and II evaluations. Chapter 19711-444 WAC is a list of elements of the environment that must be addressed in the EIS. Some of these elements may be combined to "simplify the EIS format, reduce paperwork and duplication, improve readability, and focus on the significant issues" (WAC 197-11-444). If the Level I and Level II evaluations have been conducted properly, there should be no difficulty in addressing many of the required elements of the environment. Those elements for which insufficient data or analysis exists will be the subject of further studies during the Level III evaluation. For the preparation of the EIS, data must be site specific and in sufficient detail to allow a reviewer the opportunity to thoroughly evaluate the proposal.

The method of evaluation should parallel the Level II evaluation which involves professionals in various disciplines evaluating each site with respect to their area of expertise. The evaluations can be summarized in a site feasibility matrix (see Table 3.15) and a consensus reached on the preferred alternative based on discussions among the siting team.

Normally, the Level III evaluation does not include factors beyond those considered in the Level I and Level II evaluation, with the exception of unique factors that may be brought up during the scoping process. What does change significantly during the Level III evaluation is the method of collecting certain types of environmental data and the level of professional analysis applied to each evaluation category. Section 3.4.4.4 discusses methods employed during the Level III evaluation that have not been addressed before.

3.4.4.4 New Analysis Methods

Boring, Piezometers and Monitoring Wells

On-site borings and the installation of piezometers and monitoring wells will provide site specific information on soil and bedrock stratigraphy and classification, water table depth and type, and ground water flow direction and velocity. Drilling should occur at points selected to maximize the value of the information collected. The number and depth of the explorations will depend on site variability, size, and the quantity of previously collected data. Soil samples can be collected at selected depths.

Test pits can also be excavated by using a backhoe. This exploration method typically exposes soils to a depth of approximately ten feet. Soil logs can be prepared and soil samples collected at selected depths.

The installation of piezometers and monitoring wells can provide a permanent means of measuring the hydraulic head in the well. Proper interpretation of this data will indicate the depth of the water table and the direction and velocity of ground water movement. Ground water samples can be collected from monitoring wells for laboratory analysis of water quality.

In situ hydraulic conductivity tests can be conducted using piezometers. Bail or slug tests will provide estimates of hydraulic conductivity of the undisturbed deep soils or bedrock (Freeze and Cherry, 1979).

The additional information collected from these exploratory methods can be used to update the geologic cross-sections previously prepared. These cross-sections should now represent a fairly accurate description of the subsurface conditions at each of the remaining sites. They can now be applied in refining the feasibility estimates of each site in such areas as ground water protection and movement.

Soil Analysis

Soil analysis is an area where much additional information will be obtained from laboratory tests on samples taken from borings and. test pits. soil samples can undergo a wide variety of tests, the most significant of which are listed in Table 3.17. The results of these tests will determine the soil's suitability for various landfill operations and its ability to protect the ground water.

Surface Water and Ground Water

Surface water and ground water samples should be analyzed to establish background water quality levels. This information is very important for evaluating potential impacts of the landfill on the future water quality in the area. See Chapter 8 for a more complete discussion of water quality monitoring.

Table 3.17. Soil Tests.

Atterberg limits	Grain size distribution
Porosity	Hydraulic conductivity
Moisture content	Moisture retention curve
Shear strength	Compaction curve
Cation exchange capacity	pH

Summary

The Level III data collection methods are generally more expensive than other methods. Therefore, these methods are not employed until the field of potential sites has been reduced to two or three. They are a very important part of the Level III analysis because they provide site specific information that can be obtained in no other way. Of equal importance in the preparation of the EIS and selection of the preferred alternative, however, are other elements of the environment are not addressed by the analysis described. Such elements include land use, transportation, public services and landfill design. These elements have been addressed in the Level I and II evaluations, and should have an extensive data base upon which to conduct more detailed analysis. Thus, each professional person on the siting team will continue to analyze and evaluate the remaining sites in their area of expertise, even though additional data collection efforts may not be necessary. These more detailed analyses will be used to further evaluate the sites and rate them according to their feasibility in a particular category or element of the environment. As in the Level II evaluation, the final decision on which of the two or three remaining sites is the preferred alternative should be reached by a consensus evolving from group discussions among the siting team.

3.5 THE PRIVATE SECTOR AND THE SITING PROCESS

In addition to mixed municipal solid waste (MMSW), waste streams considered suitable for landfilling in the State of Washington include industrial, demolition and woodwaste materials. Traditionally, these wastes have been primarily the responsibility of the private sector, both in terms of collection and disposal. It is estimated that the quantities of these waste streams statewide are less than total MMSW volumes. However, the number of disposal sites permitted for these waste streams appears to be greater than the number of sites permitted to accept putrescible wastes. In addition, comprehensive solid waste management plans and updates completed since 1980 generally recommend that, demolition, woodwaste and industrial waste streams continue to be the responsibility of the private sector. This indicates continued involvement by the. private sector in landfill development and siting.

The siting of a privately owned and operated landfill should by design be similar to the concepts developed in previous sections. However, there are important differences which must be recognized in terms of the limitations and requirements placed upon private industry in fully executing all elements of the siting process.

A significant limiting factor is the potential inability of private industry to acquire land at "fair market value". Without eminent domain capabilities, private industry must limit site selection efforts to geographical areas with favorable property acquisition. This restriction may exclude potentially viable landfill sites.

A second factor affecting privately organized siting efforts relates to current regulatory requirements, specifically SEPA regulations. Any 11privatell action, including solid waste landfill proposals, must consider alternatives to the proposed action. However, the extent of the alternatives evaluated need not necessarily include alternative sites to be procedurally correct. In Section (5)(d) of WAC 197-11-440, private projects, under certain conditions, are not required to evaluate alternative sites in the EIS:

> When a proposal is for a private project on a specific site, the lead agency shall be required to evaluate only the no action alternative 'plus other reasonable alternatives for achieving the proposal's objective on the same site. This subsection shall not apply when the proposal includes a rezone, unless the rezone is for a use allowed in an existing comprehensive plan that was adopted after review under SEPA. Further, alternative sites may be evaluated if other locations for the type of proposed use have not been included or considered in existing planning or zoning documents.

As implied by these rules, and under the conditions stipulated in this subsection, private projects may begin the formal SEPA process at the time they select a preferred site for the project. Alternative sites would not be required for consideration in the EIS preparation. The siting process of a private solid waste landfill may be affected by narrowing the focus of the EIS to investigating alternative development strategies on a single site only. However, local SEPA review procedures may differ for private projects, and these should be consulted. In fact, the SEPA rules (WAC 197-11-055) state this:

> "In general, agencies should adopt procedures for environmental review and for preparation of EIS's on private proposals at the conceptual stage rather than the final detailed design stage-"

The term "agencies" in this rule refers to the county agencies responsible for developing local SEPA procedures.

Clearly, the previously developed siting programs will provide the best opportunity to site and permit a solid waste landfill and should be utilized by any siting team (public or private) as a guide to develop their specific siting strategies. Private industry applicants may be required to tailor their siting efforts to effectively accommodate market forces, legal limitations and regulatory requirements.

3.6 PUBLIC INVOLVEMENT

Public involvement in the siting process, required by law, can foster a more thorough review of the project and gain political and public acceptance of the outcome. It also allows collection of valuable information to assist in evaluating alternatives and mitigation options. When a community learns of a siting project too late, or has little opportunity to influence decisions, the experience may create negative feelings and hostile actions. To achieve positive and meaningful participation by the public, the sponsor of the project must be willing to provide timely and accurate information well in advance of decision deadlines. Planners must be willing and prepared to listen carefully to community views, and provide early and convenient. opportunities for public comment.

Public involvement is viewed as a "process" that enables people affected by decisions to have an influence. The public may become involved even without a formal public participation process if decisions being considered have widespread community impact. Effective public involvement involves meaningful, positive and systematic interaction between affected citizens and/or their representatives, and the technical specialists and planners. The goal is to create a workable and-publicly supported plan. It should also serve as an educational experience for all concerned parties and as a way to build mutual trust and confidence among the planners, technical specialists and the public.

In this section, the following topics will be discussed:

- Why public involvement is needed
- Success factors for public involvement
- How to develop and implement a public involvement plan for a siting project

The text of this section is directed to the agencies, public or private, sponsoring the siting process. It is important that a public involvement program be planned when siting either public or private landfills.

3.6.1 Why Public Involvement is Needed

Public involvement is not a public relations "sales job". The goal is not to sell a predetermined solution to the citizenry, nor to provide the appearance of participation while the real decisions are made behind closed doors. Public involvement is a two-way communication process between planners and citizens. This process must not only meet legal requirements, but also address basic political and practical concerns. To be effective, it should not be based simply on the "letter of the law" but should also be within the "spirit of public participation" as part of the democratic process. This means that planners may have to adjust some of their attitudes about the public and the roles citizens play in this process.

There are specific state and federal legal requirements to involve the public. Both the State Environmental Policy Act (SEPA), and the Federal Resource Conservation and Recovery Act (RCRA) require certain types of public involvement, particularly public notification of pending actions, public meetings and public hearings. These laws mandate that public involvement will take place. They do not, however, guarantee the quality of public involvement. That is the job of the project team. How public involvement occurs may be a critical factor in a project's success or failure.

On April 4, 1984, new SEPA guidelines went into effect. They specify how and when to provide public notice (WAC 197-11-510); when to hold public hearings and meetings (WAC 197-11-535); and how to handle comments from other agencies and the public (WAC 197-11-545 and WAC 197-11-550). They do not, however, describe the tools for conducting or implementing each of the items.

Siting a landfill is a "political" issue from the very beginning. Politicians know that landfills are unpopular yet necessary. Many opinions, concerns and disagreements among the various interest groups are likely.

Often there are different impacts upon different publics. As a result, benefits and costs may not appear to be fair. The rural neighbor who fears odors and truck noise from the landfill may not perceive the process to be as fair as does the urban citizen several miles away who only wants the trash removed weekly at a reasonable cost.

A public involvement process has several goals:

- Giving a formal voice to taxpayers, ratepayers and other affected
- parties
- Discussing community values and trade-offs
- Identifying and resolving issues of concern
- Bringing out new viewpoints and alternatives

The extent to which taxpayer and ratepayer groups are included or encouraged to participate in a siting decision will be reflected in the design of the public involvement plan. If the plan is open and conducive to a mutual education process, then affected publics will more likely perceive the process to be fair. For example, a reasonable method for informing the public according to WAC 197-11-510 might include posting the property and publishing a notice in the local newspaper. Without adequate notice to special interest groups, however, taxpayers and ratepayers either become discouraged or angry at the perception of having been excluded. It may be necessary to go beyond the minimum legal requirements to achieve meaningful participation.

Openly discussing community values and trade-offs is another important aspect of the decision process. Communities must understand the potential costs and benefits of a landfill site. Costs may range from a change in how the community views itself to increased street traffic and odors. Benefits may include employment opportunities and an increased tax base for the local community. The degree to which common ground can be found among the divergent viewpoints will determine the success or failure of the project. There are not likely to be any "right" or "wrong" viewpoints. The goal will be to build all of these viewpoints into a working consensus to meet the various needs.

Once a well-organized and open process is developed, each interest group will have equal access to the decision-making process. Credibility then develops for the project as well as for the agency.

Open two-way communication reduces the chances for surprises and lowers the potential for hostility from a public that has not been kept informed, or not encouraged to be involved. It brings out new viewpoints and alternatives, and it results in a more open discussion of issues, differences and concerns. Moreover, it provides the means by which issues can be resolved.

When a public involvement plan is truly working, citizens help make project team members more aware of community values, concerns, goals and attitudes. At the same time, citizens learn factual information and public policy dilemmas which better enable them to appreciate choices, and more effectively contribute to solutions. All parties learn from each other and are more able to build a sense of ownership in the final product.

3.6.2 Success Factors for Public Involvement

An effective public participation plan should result in changes in the siting project and the planning process. This means that a variety of viewpoints have been considered and incorporated into the site selection process.

First, the plan must be timely and integrated into the decision making process.' Public involvement events must reflect key points in the siting study process. For example, when technical reports are available, the public should be informed. The document should be easy to read and provide a key contact person for any questions.

The basis for achieving an effective program rests with how it is initially presented. The plan must be clear and understandable to everyone. Dates for specific events must be listed and their purpose clearly defined. According to SEPA rules, public notice must be reasonable. For each landfill siting project, the situation is likely to reflect the particular needs of the affected community. Using a "standard" method of informing people, such as a media article, may not be sufficient. The notification process should be adapted to fit the community in which it is to be implemented.

Second, public participation must be seriously considered in order to offer opportunities for contribution. Nothing deflates or infuriates the public faster than the belief that no matter what they do or say the outcome will not change. The public must know that their concerns are heard and addressed. Many times, technical experts may want to disregard an angry homeowner's testimony as being "too emotional". However, it is these emotions that get groups motivated to stop projects.

Involve as many diverse groups as possible, both proponents and opponents of the siting process. All sides of an issue must be represented in the process for it to be perceived as fair. Of course, there is always the possibility of two divergent groups squaring off and strongly disagreeing during a public meeting. Better to have the open forum than to be charged with favoritism after the process has been completed. Every effort must be made to adequately inform the public 'so it can choose whether or not to participate in the process in the first place.

Public participation must be thoroughly planned, for no detail is too small to consider. Each aspect of the plan must be researched and tailored to the specific situation. Although communities may share some similarities, there' is not a "canned" program which will work in every case.

A key ingredient must be information dissemination. The public will require timely and accurate information regarding the project. A variety of methods for supplying information are discussed later in this section. Information, however, must not be confused with involvement. The public needs information to constructively participate in the decision-making process.

Finally, the plan must provide for different levels of involvement over time. People will be more interested in reviewing the alternative sites than technical materials. They will tend to show more interest as the impacts are defined and as the process moves closer to a preferred alternative.

3.6.3 How to Develop and Implement a Public Involvement Plan

The development of a public involvement program for a specific siting project should begin with steps to identify key publics, interests and issues. Once this task is completed, a public involvement strategy can be developed using appropriate techniques selected for implementation. Making the program work involves some key considerations and an understanding -of resources and limitations. While the program is being implemented, the situation must be constantly monitored to encourage and utilize feedback received in the process. These key elements of the public involvement planning and implementation process are discussed in the following order:

- Required Steps to Initiate a Public Involvement Plan
- Planning the Public Involvement Strategy
- Selecting the Techniques
- Implementation

- Monitoring and Evaluation

3.6.3.1 Steps Required to Initiate a Public Involvement Plan

First, assess the situation. Before developing a public involvement plan, the community issues and overall situation must be evaluated. This process is called issues assessment, and provides the foundation of a good plan. There are three basic steps in assessing issues:

- Identify affected publics and their interests

- Review the public involvement history of the area, particularly related to solid waste issues

- Identify and analyze issues

Identify the Public. Defining "the public" is likely to be the most difficult problem, yet is crucial to formulate an effective public involvement plan. Generally, the people who believe that the siting decision will significantly affect them are the key public. Some of "the public" may step forward and announce themselves as they learn of the project. Others will be identified by the project team, while still others may be referred by a third, party during the issues assessment or survey. Some groups or individuals may show a great deal of interest in the beginning of the process while others may become involved later in the process.

The interest groups can generally be separated into seven categories:

1. Ratepayers and taxpayers
2. Elected and appointed officials
3. Customers and users, including major waste generators
4. Neighbors, or property owners, in and around sites under consideration
5. Interest groups
6. Governmental organizations and agencies
7. Disposal facility operators and refuse haulers

This list provides a starting point for identifying the publics. Talking to co-workers and other agency personnel who may have had similar projects in the community will also be helpful. Find out as much as possible about community politics, leaders, and potential problems. Use available directories and lists to further identify publics. Review tax assessment records to determine names and addresses of property owners near the proposed sites. These lists will be valuable as the project develops and more people become interested. Each individual or group's interest should also be noted. This will provide the basis for step three, the issues assessment.

Review the History. Once these target publics have been identified, analyze the situation historically. A review will provide insights into the community and its values, and will help to assess the types and level of involvement to expect. News clippings are always a good source of history, as are existing plans, documents, correspondence files and other literature, such as solid waste management plans and environmental impact statements.

Assess the Issues. Upon completion of the first two steps, design the issues assessment. This process will clarify problems and concerns that are likely to come up during the siting process. It will also identify any key publics which have not yet come to light. There are several ways to accomplish this task, one of which is to design questions that relate to the interests identified in step one. The objective will be to determine what issues will be important, as well as the level of interest in the issues.

Conduct the interviews either in person or by telephone, or use a combination of both, depending on the budget. Based on experience, a minimum of 15 to 20 people should be interviewed. After completing several interviews, issues will begin to emerge. Begin to categorize and prioritize the issues according to the number of times mentioned in the interview process. During each interview, ask about any other people or groups that should be interviewed or included in the process. This will encourage a "snowball" effect and broaden the affected publics list.

Once the interviews are completed, analyze the results to determine the ramifications for the project. An important influence on program design will be the amount of *interest in the project. Interest is usually related to controversy. Public opposition may be minimal, so small, informal public involvement techniques such as coffee klatches and small-group meetings might be appropriate. If interest is high, other methods should be considered, such as mailings and public meetings. Also, use techniques that encourage communication rather than conflict.

Another technique for identifying issues is the mail survey. However, depending on the extent of the mailing list, mail surveys can be more expensive. In addition, the percentage of returns is much lower than with a telephone interview. Respondents to a mail survey are self-selected, which may bias the results. However, in some instances, it may be an appropriate method of determining issues.

3.6.3.2 Planning the Strategy

One study on public participation noted that "the tendency of planning staffs to view public participation as a necessary evil and to 'wing it' continues to 'be one of the major causes for public participation failures." In other words, careful planning and strategizing are important for the public involvement program to work. There are a number of strategies and techniques available. The following describes how to plan the overall public involvement strategy.

There are four areas critical to this planning effort:

- Setting goals and objectives
- Determining level of intensity and involvement
- Timing
- Defining roles

Setting goals and objectives.. As with any other task, decide what must be accomplished. This means knowing with whom, when, and finally, how it will be done.

Describe the stages and timeframe of the process. A graph of the timeline listing milestones may be all that is necessary. Know the legal requirements, and identify both the human and financial resources.
Look at each stage of the decision-making process to determine what public involvement objectives would work at each stage. Perhaps the first step would be information gathering. For example, what does the public think about a solid waste landfill in Littletown, U.S.A?

By looking at overall goals, determine which issues and publics are to be involved. Determine what information the public must get if they are to be informed participants. Also define what will be needed from them to make decisions. Next, determine what the planning team needs to learn from the public and identify any unique conditions to be considered.

Special circumstances might be revealed in the past history of the solid waste management issue or community, or the credibility of the agency, or the level of interest in the issue. The techniques chosen to attain the goal must reflect these and other special considerations.

Level of intensity and involvement. In developing the strategy, decide how much interest will be generated by the siting project. Perhaps the sites being considered are in a sparsely populated farming community. There may be little concern about odor and truck traffic, but a lot of concern about water contamination. The issues assessment will define what issues will generate the most concern. It will also delineate the level of involvement to expect from the various publics. Remember that the more controversy an issue generates, the more active the public will be. Gear planning efforts to the amount of controversy anticipated.

Timing. Be sure the public involvement plan is coordinated with the release of technical reports. Look at the milestones in the project and what products will be available. Make sure to disseminate sufficient information for the public to sink its teeth into before scheduling a public meeting. If there isn't enough information, there's a risk of either giving the impression of hiding something or losing the public's interest at the outset. Give the public enough time to review materials, and make sure summaries are not filled with jargon. Also look at the calendar--do not overload schedules during summer months, holidays, right before national elections or during late December.

Defining roles. Be sure that each member of the team knows what is expected and when. Determine who will manage the public involvement process and make sure everyone knows "where the buck stops." The key public involvement person, whether full-time or part-time, will need to play several different roles during the decision-making process. These include: facilitator, researcher, educator, and writer.

The start-up phase of the siting project will require the key facilitator to meet with community members. This role, requiring good interpersonal communications skills, will continue throughout the life of the project. During the issues assessment and data collection phase, the job will be that of an investigator or researcher. The next phase involves community information and education, requiring good public speaking and meeting leadership skills. Finally, the role will be that of a writer communicating with the public and the media.

3.6.3.3 Selecting The Techniques

A variety of tools are available to get the public involvement program up and running, and to keep it running. The following categories and brief discussions offer a sampling of the techniques available:

- Media relations
- Information techniques
- Consultation techniques

Media Relations. Media relations involve several different areas, including guidelines for press relations, press releases, press conferences and briefings, media events, and press inquiries. Each is briefly described below.

Guidelines for working with the mass media are important since the media represent important audiences and partners for public involvement programs. In some cases, the media may stimulate interest but they may not provide sufficient depth of information to do more than alarm the public. To inform the media, use fact sheets, public meetings, newsletters and other informal pieces. Here are some basic guidelines for maintaining good media relations:

- Make sure the information is newsworthy. News is something people have not heard before that could affect their lives. Newsworthy reports involve real people and real events, not abstractions or preaching.
- Get to know the reporters who will be covering the activities. Deal with them personally throughout the entire process.
- Always have a fact sheet, press release or other handout available when contacting the media.
- Learn and always meet the deadlines for both print and electronic media.
- Don't send trivial or relatively unimportant news to the media; they will learn to ignore releases.
- Never quarrel with a reporter when the project has not been fairly represented; rather, try a follow-up story or editorial.
- If you're not prepared, call the reporter back in ten minutes. Think through your answers carefully.

Press releases are brief informational tools that help you get a message to the public. Releases offer information and announce findings, events and decisions. A good press release clearly demonstrates the five W's: who, what, where, when and why. Use press releases at key points in the study to inform the public, as well as to encourage its involvement.

Press conferences and briefings are useful ways of getting the press interested and involved in the story. However, press conferences should be held only when there is a major story, or a "name" figure who will be the spokesperson. They usually consist of a short statement presented by the spokesperson, followed by a questions and answer session. If material to be presented could just as easily be handled by a press release, then use the press release, the media contact of choice.

Media events are pre-arranged and scheduled activities to encourage coverage of the story. Events can range from special site tours to a "name" person walking through a landfill. These must be used sparingly as the media representatives will resent wasting their time at "non-events".

Press inquiries should be handled by one person to avoid contradictory or confusing messages. Carefully define how questions will be addressed.

<u>Information Techniques.</u> Use techniques to get the information out to the public. They may include some of the following methods.

Brochures are useful tools to explain the background and mandate of the program, and the role of the public in the planning process. They can also identify the program goals. Brochures should be easy to read and answer most of the commonly asked questions.

Fact sheets are useful for inexpensively presenting a great deal of information to the public. They provide in-depth analysis of issues,. and contain details and background which can be easily updated.

Newsletters provide a regular and timely flow of information to the key publics.

Public meetings are gatherings sponsored by the agency which are open to everyone and held to inform or involve the public. Effective meetings have specific goals to accomplish which can be measured.

<u>Consultation Techniques.</u> Consultation techniques are used to focus on exchanging information about the proposed alternatives and to assure that final recommendations are publicly acceptable. They are both organized and informal. The following are the primary consultation mechanisms.

Workshops and open houses are informal gatherings of small groups of people to discuss a specific issue. The public is encouraged to talk on a one-on-one basis with planners and technical specialists.

Public hearings are more formal, allowing the public to go "on record" with their comments. Little or no question and answer interchange occurs during a public hearing; rather, the meeting is intended to gather-comments from those involved or affected.

Telephone surveys provide an information gathering tool for planners and a means by which the public can offer opinions, concerns and comments about a proposed project.

Mail surveys or questionnaires offer the public a written form of communication about an issue or project.

Focus groups are designed to complement telephone or in-person surveys. A focus group uses a small group of randomly selected people to identify and discuss a specific topic.

Advisory committees provide a community perspective to the planning process. They should represent a wide variety of interests to provide new ideas and potential sources of information. They are helpful in resolving controversial projects and evaluating complicated issues. The advisory committee also serves as a valuable communication link between the planning team and the community. Its role and membership must be considered carefully to achieve an effective process with maximum credibility.
Selecting the appropriate technique or series of techniques for the situation involves knowing:

- Available resources
- Community history and any special circumstances
- Who the public is
- What the public needs to know
- What needs to be accomplished with the public
- What the decision-making process is

Both common sense and legal requirements will determine the best techniques.

3.6.3.4 Implementation

This stage of the public involvement program is where the plan begins to work. Key considerations discussed in this section include:

- Roles and responsibilities
- Organization and management
- Budget
- Practical suggestions for implementation

Roles and Responsibilities. The role of the sponsoring agency is to make the public involvement plan work effectively and efficiently. The agency is responsible not only for managing the process, but also for ensuring that:

- Public comments help shape the final decision, and make their influence is clearly demonstrated

- Brochures, newsletters and presentations are easy to understand and avoid technical jargon

- All potentially affected or interested publics have been invited to participate

- Credibility of the process, the planning team, and the agency are maintained

Organization and Management. The organization and management of the public involvement plan will reflect the general attitude of the agency toward decision-making. In most large agencies, decisions are made unilaterally be someone higher up the ladder. Encourage decision-makers to meet with the interested individuals and groups from time to time to create a climate of open communication.

Other agencies may be involved in the public involvement process through legal requirements or agreements. These agencies should be considered as separate publics. Determination must be made, however, as to the level of interest in the subject. For example, if the Washington Department of Ecology is working with a county government to site a landfill near a game refuge, it is likely that the State Game Department or other similar agency would be interested and want to be involved. All likely agencies should be considered for their level of interest and involvement, as well as the political ramifications of that involvement.

Budgets. Budgets are critical to public involvement programs since they help determine the types of techniques to be employed, as well as the extent to which the project encourages participation. Estimating the costs for various public involvement techniques is easier if a detailed plan has been developed. It may be necessary to use "best guesstimates" until the level of controversy, and hence, the level of involvement has been determined.

Staff time is, of course, the major cost item for a public involvement program. Adequate management time and clerical support are as important as the staff implementing the activities. Possible staff activities include:

- Overall management of the public involvement program

- Review of program and evaluation of each activity

- Planning, budgeting and coordinating all activities

- Writing, reviewing and approving written materials

- Staff support for the advisory group or other appropriate committees

- Media coordination and contacts

- Preparation of responses to telephone calls and letters

- Maintenance of a mailing list and production and mailing of materials

- issues assessment interviews

Cost variables related to direct expenses include:

- The amount of work that can be done in-house
- The complexity of the products (for example, a slide show is more expensive if a taped narration is required)
- The number of each item relates to size of audience)
- The ability to use standard graphics and formats
- The availability of inexpensive/no-cost meeting facilities and equipment

Additional direct cost factors will become evident as the plan is defined.

Practical Suggestions. Practically speaking, the plan should be designed to fit the budget, suit the audience and meet the regulatory requirements. Close communication between all team members will encourage the evolution of a suitable plan with flexibility to accommodate unforeseen events, new issues and new key publics. Perhaps the most practical suggestion for implementing a 'plan is for team members to be committed to the process of public involvement. In addition, the team must be prepared. Know what the team wants for the program, what the different groups of citizens want, and how the groups are going to work together.

3.6.3.5 Monitoring and Evaluation

"Taking the pulse" of a public involvement program is the job of all participants. However, the sponsoring agency will ultimately be responsible for the program and, therefore, must develop a way to monitor it. Feedback should be encouraged from all participants throughout the program to help in this process. The public involvement techniques, the amount and type of response to the techniques, as well as the formal and informal public feedback should be assessed regularly, and the program adjusted or modified accordingly. For example, an evaluation form at the end of a workshop should ask participants what they liked about the workshop, what they disliked, what they thought could be improved, and so forth. The questions should relate not only to the information presented at the workshop but also to the facilitators and the physical surroundings. This feedback should allow planners to assess how the public feels about the event as well as about the overall process. The public may indicate that the project manager is not credible. Adjustments must then be made if the project is to succeed and the agency maintain credibility.

Several methods for monitoring and tracking a project over time may be particularly useful in small communities where a landfill directly affects a large proportion of the population. one effective tool is reviewing newspaper articles and editorials as the plan progresses. In addition, file cards can be maintained on the various issues and key publics to track changes. Finally, a follow-up issues assessment to determine how issues and perceptions changed over time may be appropriate.

Stay in touch with all the various publics and remind team members that if the project is to succeed it depends on developing a dialogue between the project staff and the community.

What to do if things go wrong. Sometimes, no matter how carefully a plan is designed, problems will emerge. Perhaps a citizen was offended by a remark at a public meeting and decided to sabotage the rest of the public involvement plan. Or maybe a citizen's group forms that was not identified in the issues assessment, and actively opposes the landfill. There are methods for correcting just about any situation. The main consideration, however, must be to listen carefully to the other offended parties and take care not to pre-judge a situation. Maintaining open lines of communication is always crucial when things go wrong.

Resolving a problem includes looking at:

- Who the affected participants are
- What the specific issues are
- Where the event(s) occurred or is occurring
- When the event(s) occurred
- How the situation might be handled

Weigh all the options and determine which ones would be most suitable to resolve the public involvement problem. , Perhaps a series of small group meetings would meet the needs of a newly formed organization that felt left out of the decision-making process. Or perhaps keeping that new group well informed during the remaining steps of the project would be adequate. The process of resolving a problem is always a learning situation. Hopefully, each lesson will have to be learned only once.

In the final analysis, a public involvement program should be assessed at the end of the project to determine if each goal was met, and to indicate how the public made a difference in the planning process. The evaluation should also determine what the most successful techniques were, what actions could have been improved, and suggest actions for the future.

3.7 SUMMARY

This chapter has outlined a process to determine the "best" location for a solid waste landfill. After the decision is made to acquire landfill capacity, and the waste stream characteristics are known, the siting process begins. The first step is to develop siting criteria which will be used to evaluate potential sites. Second, a set of potential sites is identified. Site evaluation involves three levels of analysis which successively reduce the number of potential sites utilizing the siting criteria developed in the first step. Public involvement is an ongoing and integral part of the entire siting process. The requirements of the State Environmental Policy Act (SEPA) Rules (WAC 197-11) area also incorporated into the process. The preferred alternative for a solid waste landfill site is identified in the environmental impact statement.

Special considerations are warranted for private companies or individuals sponsoring the siting of a solid waste landfill. Limiting factors imposed upon them are their potential inability to acquire property at "fair market value", and SEPA regulations applicable to privately sponsored projects.

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Chapter 4

Landfill Design

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4.1 INTRODUCTION

4. 1.1 Purpose

Chapter 4, Landfill Design, presents both general and detailed discussions of all aspects associated with the design of a solid waste landfill. Its principal purpose is to provide the reader with an understanding of the landfill design process and to describe the application of available and reliable technologies for the design of solid waste landfills. The information provided in this chapter should provide the reader, whether landfill operator, designer or regulator, with a comprehensive understanding of the requirements, procedures and methodologies for designing a solid waste landfill that will be in compliance with the design elements mandated by the Minimum Functional Standards, WAC 173-304.

This chapter will also provide valuable information to readers outside the technical community, including policy makers and the general public. It will provide readers with a better understanding of solid waste landfills and therefore encourage more informed participation in the issues surrounding solid waste landfills.

4.1.2 Scope

This chapter is intended to present information and technologies that are applicable to the design of solid waste landfills. It is not intended to cover each design process or technology exhaustively, nor is it intended to be applied as a "cookbook" when approaching a solid waste landfill design problem.

The development of a solid waste landfill is a complex undertaking requiring the application of a wide spectrum of technical disciplines. Recognizing this concept, Chapter 4 presents design programs involving a full range of engineering and environmental science applications.

Chapter 4 is divided into two main parts. Part A, which includes Sections 4.2 through 4.9, provides more general information that provides a general overview of the physical characteristics of solid waste landfills and some of the common problems associated with them. Typical waste stream characteristics and operational alternatives are presented. Basic background information is provided on such issues as leachate, landfill gas and surface water management. Also, general design procedure is discussed to illustrate the overall process that occurs in the design of a solid waste landfill.

Part B, which includes Sections 4.10 through 4.16, provides much more detailed, technical information and is generally not intended for the casual reader. Specific design procedures are discussed and much technical information is cited. There are major sections on:

- Water balance analysis
- Surface water management systems

- Bottom liners
- Leachate collection and transmission systems
- Leachate treatment and disposal systems
- Landfill gas management systems
- Final cover systems

Certain technologies associated with landfill design are extremely complex. To develop detailed design procedures specific to these issues would in some cases require a more significant effort than is available for the entire chapter. In addition, the benefit of such detail would be useful to only a small fraction of the intended audience. In these cases, the reader will be provided with a technology overview, important design decisions and a reference list of applicable design aids for further assistance.

Additional auxiliary information which is important to the design process has been included in the seven appendices included at the end of this chapter. Much of this information is of a reference nature and is presented in tabular form or summarized directly from the cited sources. This information is considered helpful to the reader and, therefore, has been included in the manual.

4.1.3 Relationship to Other Chapters

The design chapter is by no means a stand-alone document and should be used interactively with all of the manual chapters. Successful landfill management, from siting through post-closure, is a continuing process requiring a commitment of up to twenty years or more. The design process is basic to this life cycle theme and Chapter 4 relies heavily on input from the Siting Chapter and provides direct application to the remaining manual chapters covering construction, operations, closure and environmental monitoring. Conversely, the specific applications of construction, operations and closure will refer back to the design chapter to provide the manual user with a ready reference to problem identification, criteria development and implementation.

PART A

4.2 GEORYDROLOGIC AND GROTECHNICAL ASSESSMENTS

Geohydrologic and geotechnical assessments provide much of the fundamental data needed to prepare the permit application and develop the landfill design. These assessments are also required by the Minimum Functional Standards. The specific requirements and "level of effort" of geohydrologic and geotechnical.work will depend on site conditions and landfill type (mixed municipal, inert and demolition, special purpose waste or woodwaste.) These assessments also provide data required to permit and design surface impoundments and waste piles that may be associated with landfills.

Site and soil characteristics to be considered are related to both geotechnical engineering and geohydrology. Although the two disciplines overlap, geotechnical engineering is generally concerned with the engineering properties of site soils associated with excavation, compaction, settlement, stability, trafficability, and odor control. Geohydrology addresses issues related to leachate generation, migration and control, and potential contamination of ground water and surface water. The geohydrologic properties of a site form the basis for design of an environmental monitoring system as required by WAC 173-304-490.

As discussed in Chapter 3, any new or expanded landfills need to meet the siting criteria of WAC 173-304-130. During the site selection process, a number of site visits have likely been made and a significant amount of background data has been collected. Topographic and geologic maps, and geologic cross sections have been prepared. Site features such as surface water bodies, springs, and existing water supplies have been located and a general appraisal of site conditions has been made. These preliminary data are usually sufficient for assessing site feasibility and environmental risk, and developing a conceptual landfill design.

Actual design of a landfill generally requires more detailed data on site conditions. Typically, design studies will be more extensive compared with work completed during the site selection process. Data collected during site selection should be used in developing an appropriate design phase study.

No simple, general rule of thumb is available to define the appropriate level of effort or cost of geohydrologic and geotechnical assessments for a specific site. The regulations define the general type of data and information required, while the site conditions will dictate the work program necessary to characterize the site for permitting and design purposes. The level of effort should be balanced against the consequences of a poor appraisal of environmental risk and costly site redesign should surprises be encountered during construction or operation. Delays in the permit process caused by insufficient information should also be considered.

The work program required to produce a specific geohydrological and geotechnical report typically proceeds through several phases:

- Field explorations assess soil, geologic and ground water conditions beneath the site. These explorations can include field reconnaissance geophysical surveys, drilling of soil borings and the installation of monitoring wells.

- Laboratory testing of soil samples is completed to assess soil engineering properties.

- Field and/or laboratory testing is completed for hydraulic conductivity and measurement of monitoring well water levels are made to assess ground water flow directions.

- Ground water (and surface water) samples are obtained for chemical analysis to provide data on background water quality conditions and/or to assess whether an existing landfill has adversely affected water quality.

- Data is compiled and analyzed to characterize the site soil, geologic and geohydrologic conditions.

- The need for the collection of additional data is assessed and a work program is developed and implemented.

A wide variety of field exploration and testing methods is available to assess the conditions beneath a potential/existing landfill site. Some of the more common methods are briefly discussed in Appendix A. The following sections present -some of the more important concepts in analyzing geohydrological and geotechnical data for landfill projects.

4.2.1 Soil Properties

4.2.1.1 Representative Samples

During field explorations, soil samples can be collected by a variety of methods. How well a sample represents actual conditions depends on the soil type and variability, method of collection, and care used in collection. . In some cases, a large amount of judgment may be required to make a proper assessment. This assessment may not only be based on the sample collected but also on observations made during collection, such as drill action or Standard Penetration Test (ASTM Test Method D1586).

When interpreting or reviewing soil data, the soil collection method and/or test method should be considered. Some collection methods (such as those using a thin walled Shelby tube sampler) provide relatively undisturbed soil samples, while others, such as sampling using the conventional air rotary drilling technique, typically provide only soil cuttings. Interpretation of a soil sequence is more difficult based on soil cuttings compared with samples obtained using a split spoon sampler or tube sampler.

The natural variability of soil units can also affect how well a particular soil sample or test represents the general soil conditions. The greater variability in soil conditions, the greater the number of soil explorations or tests that may be required to properly characterize a site. The number of explorations and tests needs to be balanced against the natural variation in soil properties, the costs to evaluate these properties and acceptable levels of uncertainty.

4.2.1.2 Soil Classification

Two general methods of soil classification are currently used in landfill design and construction (U.S. EPA, 1984; U.S. EPA, 1979). These include the U.S. Department of Agriculture (USDA) Classification System and the Unified Soil Classification System (USCS) (ASTM 2487). The USDA system, used by soil scientists and agronomists, is based principally on texture (grain size distribution). The USCS system is generally used in assessing the engineering properties of soils and is based on grain size and plasticity characteristics (Atterberg limits).

Summaries of the USCS and the USDA systems are presented in Figures 4.1 and 4.2. The division in soil type based on grain size are different for the two systems and in classifying soils the system being used should be identified. Typical soil description will include soil type, relative density, moisture content, and color.

4.2.1.3 Grain Size Distributions

Grain size distribution refers to the particle size distribution of a soil sample. This distribution provides a meaning for classifying a soil sample as either clay, silt, sand, gravel or cobbles (or silty sand, sandy gravel, etc.)

Procedures for conducting grain size analyses are contained in ASTM D422 and D1140. For soils with particle sizes greater than the No. 200 sieve (0.08 mm particle size), mechanical shaking through sieves is typically used. For particle sizes that pass through the No. 200 sieve, the hydrometer method is typically used. Several-examples of grain size distributions are presented in Figure 4.3. The curves were prepared using both mechanical shaking and hydrometer analysis.

4.2.1.4 Atterberg Limits

Atterberg limits (liquid limit, plastic limit and plasticity index) are standardized engineering indices of the mechanical properties or consistency of fine grained soils. They are a measure of the plasticity of the soil fraction finer than the U.S. No. 40 sieve (0.4 mm particle size). Important states of consistency from a geotechnical standpoint are shown in Figure 4.3. Procedures for assessing the more important Atterberg limits are contained in ASTM D4318 and D427. As noted in Figure 4.1, the liquid limit and the plasticity index are used in the laboratory classifications of soil using the Unified Soil Classification System.

MAJOR DIVISIONS			GROUP SYMBOLS	TYPICAL NAMES	LABORATORY CLASSIFICATION CRITERIA		
COARSE-GRAINED SOILS (MORE THAN HALF OF MATERIAL IS LARGER THAN NO. 200 SIEVE SIZE) 0.08 mm	GRAVELS (MORE THAN HALF OF COARSE FRACTION IS LARGER THAN NO. 4 SIEVE SIZE)	CLEAN GRAVELS (LITTLE OR NO FINES)	GW	WELL- GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES	DETERMINE PERCENTAGES OF SAND AND GRAVEL FROM GRAIN-SIZE CURVE. DEPENDING ON PERCENTAGE OF FINES (FRACTION SMALLER THAN NO. 200 SIEVE SIZE), COARSE-GRAINED SOILS ARE CLASSIFIED AS FOLLOWS: LESS THAN 5 PER CENT ..... GW, GP, SW, SP; MORE THAN 12 PER CENT ..... GM, GC, SM, SC; 5 TO 12 PER CENT ..... BORDERLINE CASES REQUIRING DUAL SYMBOLS**	$C_U = \frac{D_{60}}{D_{10}}$ greater than 4; $C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 & 3	
			GP	POORLY GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES		NOT MEETING ALL GRADATION REQUIREMENTS FOR GW	
		GRAVELS WITH FINES (APPRECIABLE AMOUNT OF FINES)	GM* d / u	SILTY GRAVELS, GRAVEL-SAND-SILT MIXTURES		ATTERBURG LIMITS BELOW "A" LINE OR P.I. LESS THAN 4	ABOVE "A" LINE WITH P.I. BETWEEN 4 AND 7 ARE *BORDERLINE* CASES REQUIRING USE OF DUAL SYMBOLS
			GC	CLAYEY GRAVELS, GRAVEL-SAND-CLAY MIXTURES		ATTERBURG LIMITS ABOVE "A" LINE WITH P.I. GREATER THAN 7	
	SANDS (MORE THAN HALF OF COURSE FRACTION IS SMALLER THAN NO. 4 SIEVE SIZE)	CLEAN SANDS (LITTLE OR NO FINES)	SW	WELL-GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES		$C_U = \frac{D_{60}}{D_{10}}$ greater than 6; $C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 & 3	
			SP	POORLY GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES		NOT MEETING ALL GRADATION REQUIREMENTS FOR SW	
		SANDS WITH FINES (APPRECIABLE AMOUNT OF FINES)	SM* d / u	SILTY SANDS, SAND-SILT MIXTURES		ATTERBURG LIMITS BELOW "A" LINE OR P.I. LESS THAN 4	LIMITS PLOTTING IN HATCHED ZONE WITH P.I. BETWEEN 4 AND 7 ARE *BORDERLINE* CASES REQUIRING USE OF DUAL SYMBOLS
			SC	CLAYEY SANDS, SAND-CLAY MIXTURES		ATTERBURG LIMITS ABOVE "A" LINE WITH P.I. GREATER THAN 7	
FINE-GRAINED SOILS (MORE THAN HALF OF MATERIAL IS SMALLER THAN NO. 200 SIEVE) 0.08 mm	SILTS AND CLAYS (LIQUID LIMIT LESS THAN 50)		ML	INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS, OR CLAYEY SILTS WITH SLIGHT PLASTICITY	Plasticity Chart (see below)		
			CL	INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS			
			OL	ORGANIC SILTS AND ORGANIC SILTY CLAYS OF LOW PLASTICITY			
	SILTS AND CLAYS (LIQUID LIMIT GREATER THAN 50)		MH	INORGANIC SILTS, MICOCEOUS OR DIATOMACEOUS FINE SANDY OR SILTY SOILS, ELESTIC SILTS			
			CH	INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS			
			OH	ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS			
	HIGHLY ORGANIC SOILS		P_t	PEAT AND OTHER HIGHLY ORGANIC SOILS			

Plasticity Chart

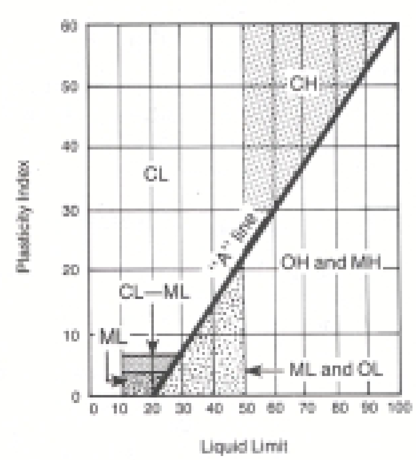

Figure 4.1
Unified Soil Classification System

*DIVISION OF GM AND SM GROUPS INTO SUBDIVISION OF d and u ARE FOR ROADS AND AIRFIELDS ONLY. SUBDIVISION IS BASED ON ATTERBURG LIMITS; SUFFIX d USED WHEN L.L. IS 28 OR LESS AND THE P.I. IS 6 OR LESS THE SUFFIX u USED WHEN L.L. IS GREATER THAN 28.

**BORDERLINE CLASSIFICATIONS, USED FOR SOILS POSSESSING CHARACTERISTICS OF TWO GROUPS ARE DESIGNATED BY COMBINATIONS OF GROUP SYMBOLS. FOR EXAMPLE GW-GC, WELL GRADED GRAVEL-SAND MIXTURE WITH CLAY BINDER.

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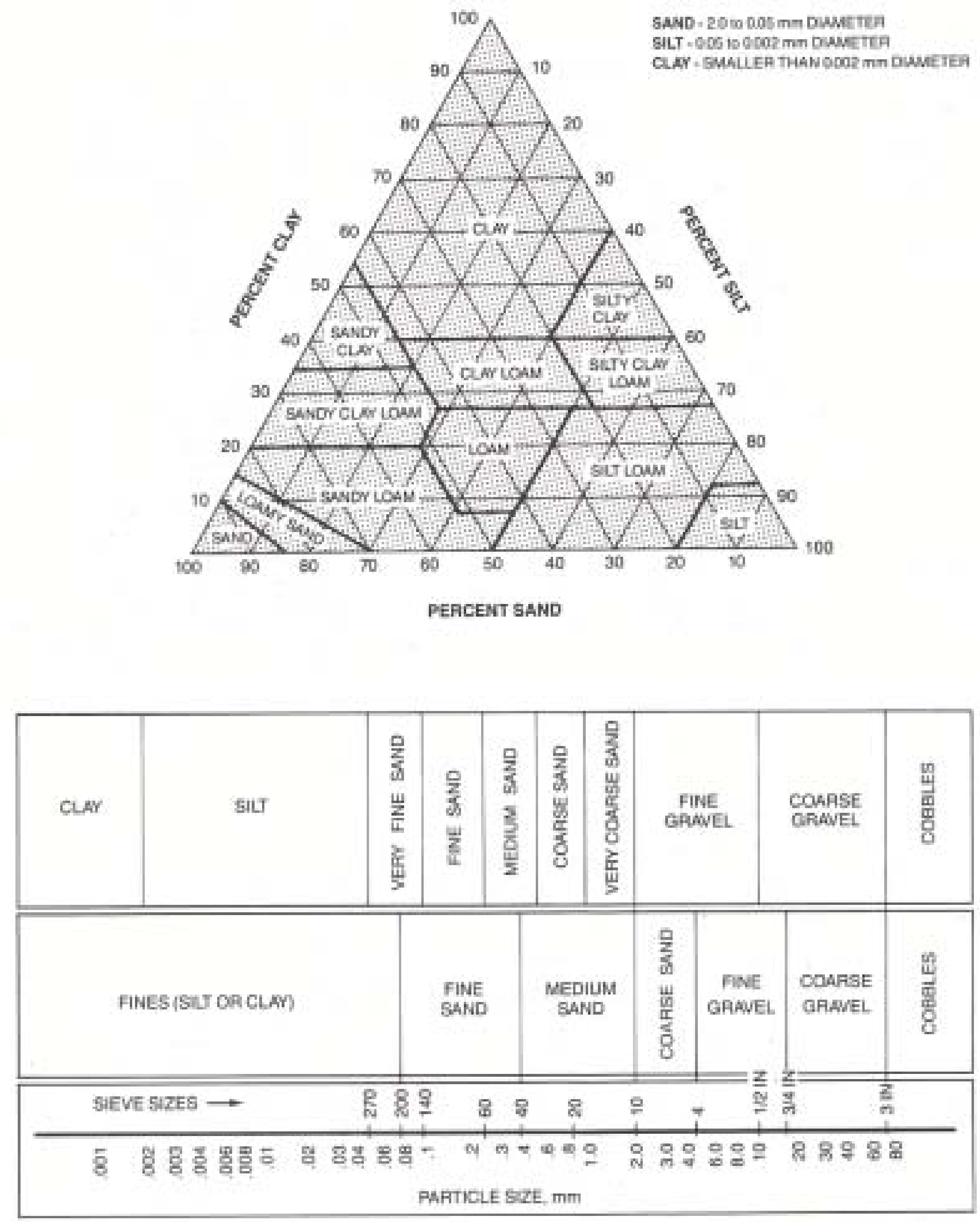
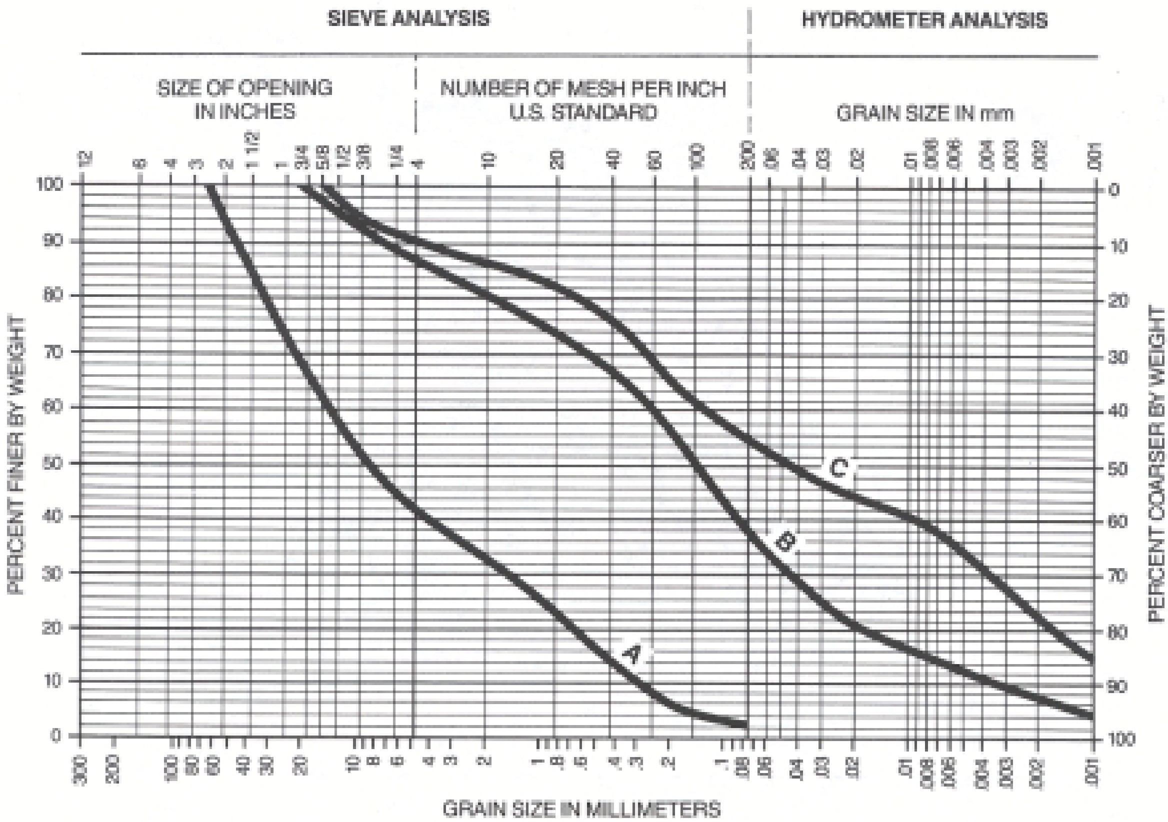
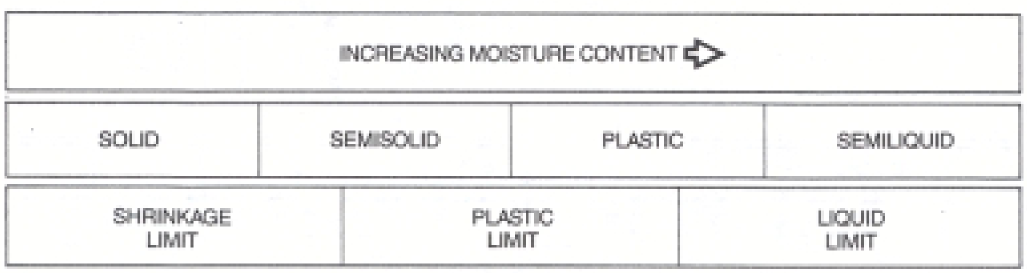


Figure 4.2
U.S.D.A. Textured Classification Chart and Comparison of Particle Size for U.S.D.A. and Unified Soil Classification Systems



A Very Sandy Gravel (Tacoma, WA)
B Gravelly Very Silty Sand (Lake Stevens, WA)
C Slightly Gravelly, Clayey, Very Sandy Silt (King County, WA)

1. Grain Size Analyses



2. Atterberg Limits

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Figure 4.3
Grain Size Analyses and States of Consistency of Soil (Atterberg Limits)

4.2.1.5 Water Content

In engineering applications, water content (ASTM D2216 test method) is expressed as a percentage change in weight between the natural and the oven-dried soil (weight of water to weight of oven-dried soil). Water content is important in assessing soil handling characteristics (such as compaction), especially of fine-grained soils. Water content is also important in assessing the degree to which fill soils may be compacted in the field to a specified degree.

In geohydrologic applications, where the movement of water or leachate through soil is being assessed, water content is often expressed as a percentage of total volume. Volumetric water content is important in assessing the degree of saturation of a soil and will affect unsaturated hydraulic conductivities.

4.2.1.6 Field Capacity, Wilting Point, and Moisture Retention

These soil properties describe soil conditions in the unsaturated state (i.e., soil pores are not totally filled with water). Monitoring of the unsaturated or vadose zone is discussed in Chapter 8. Field capacity and wilting point are concepts that were developed in agriculture.

Field Capacity (water holding capacity) is the volumetric water content retained in soil after drainage by gravity has apparently ceased. The remaining soil water is "held" by capillary forces. Agronomists use the soil suction pressure of 0.33 atmospheres or a three-day drainage period as a somewhat arbitrary standard (U.S. EPA, 1979; Freeze, 1979). In fact, water will flow under the influence of gravity via unsaturated flow, at much higher suction pressures or longer periods of time (Dunne and Leopold, 1978). Field capacity is not a valid concept for indicating truly no-flow conditions.

Wilting Point is the lower limit of plant use of capillary water. By definition, this point is 15 atmospheres of soil suction (U.S. EPA, 1979).
Field capacities and wilting points for USDA soils are presented in Figure 4.4.

Moisture retention also refers to the ability of soil to retain water under unsaturated conditions. It is generally expressed as a curve relating soil moisture suction versus volumetric water content. Typical curves for different soil types are shown on Figure 4.5 (U.S. EPA, 1984).

Field capacity and wilting point are typically not tested as part of a landfill project. However, field capacity is related to the water holding capacity factor discussed in Section 4.10 in estimating a site water balance. Moisture retention curves are also not typically prepared for landfill projects, but they can be useful in estimating unsaturated hydraulic conductivities as shown on Figure 4.5.

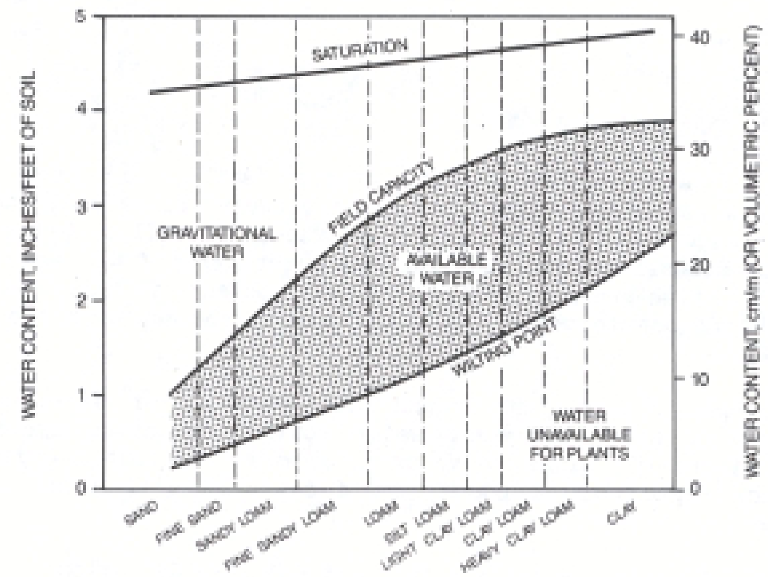


Figure 4.4
Field Capacity and Wilting points of U.S.D.A. Soils

Adapted From: U.S. EPA, 1979

4.2.1.7 Comaction

Soil compaction is a major consideration in designing landfills, especially for selection of soil materials to be used as bottom liners or as final cover. On specific projects, soil compaction may also be required to provide structural support for buildings and other structures.

Moisture-density relationships are established in the laboratory to assess the compaction characteristics of soil. Soils have unique laboratory moisture-density relationships that define a maximum compacted density value and a corresponding optimum moisture content.

The Standard Proctor (ASTM D698 Test Method) or Modified Proctor (ASTM D1557 Test Method) tests are used to define the relationship between density and water content. The compaction tests compact a soil sample in lifts within a mold using a specified number of blows of a standard hammer weight per lift to compact the soil.

In some cases, the relatively soft nature of soils and refuse providing the base for a compacted soil layer may require that the standard laboratory test be modified to represent densities that can practically be obtained in the field. The standardized tests may represent conditions not practically obtained. Tests using lower amounts of compactive energy, i.e., fewer blows, fewer lifts and/or smaller hammers, may be more appropriate. These tests

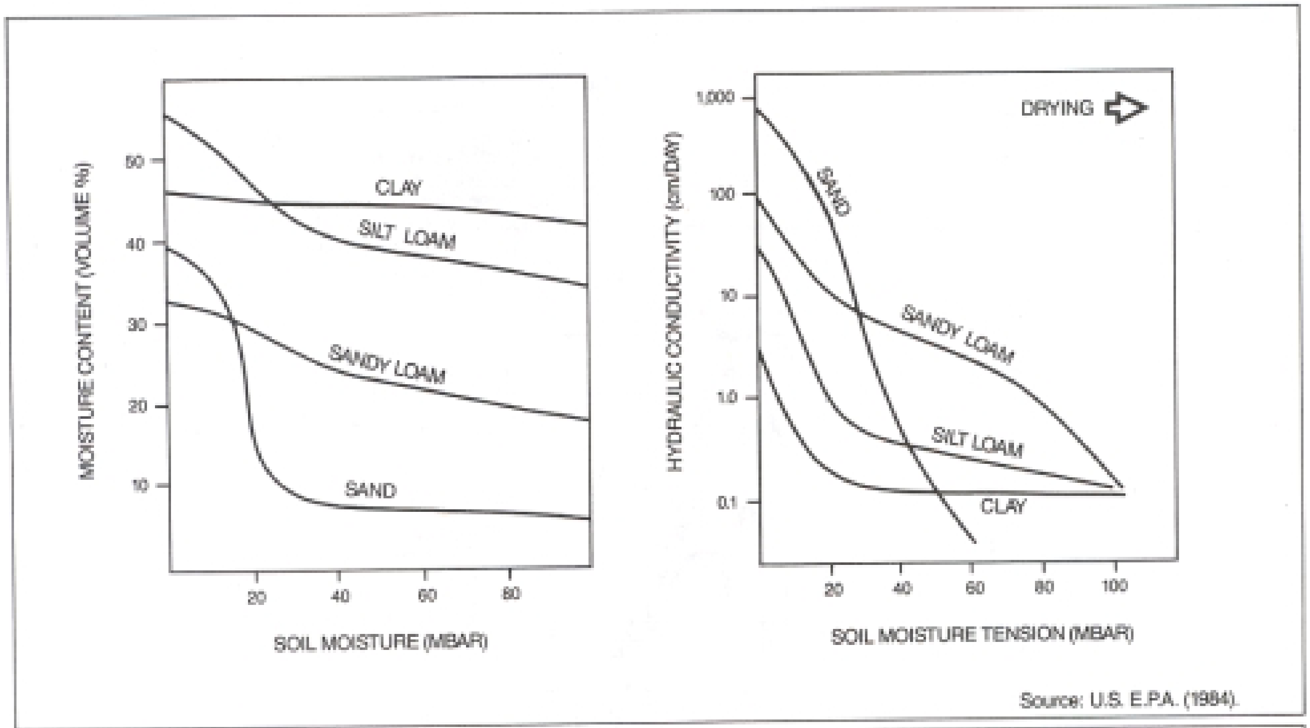


Figure 4.5
Moisture Retention and Hydraulic Conductivity for Various Soil Types

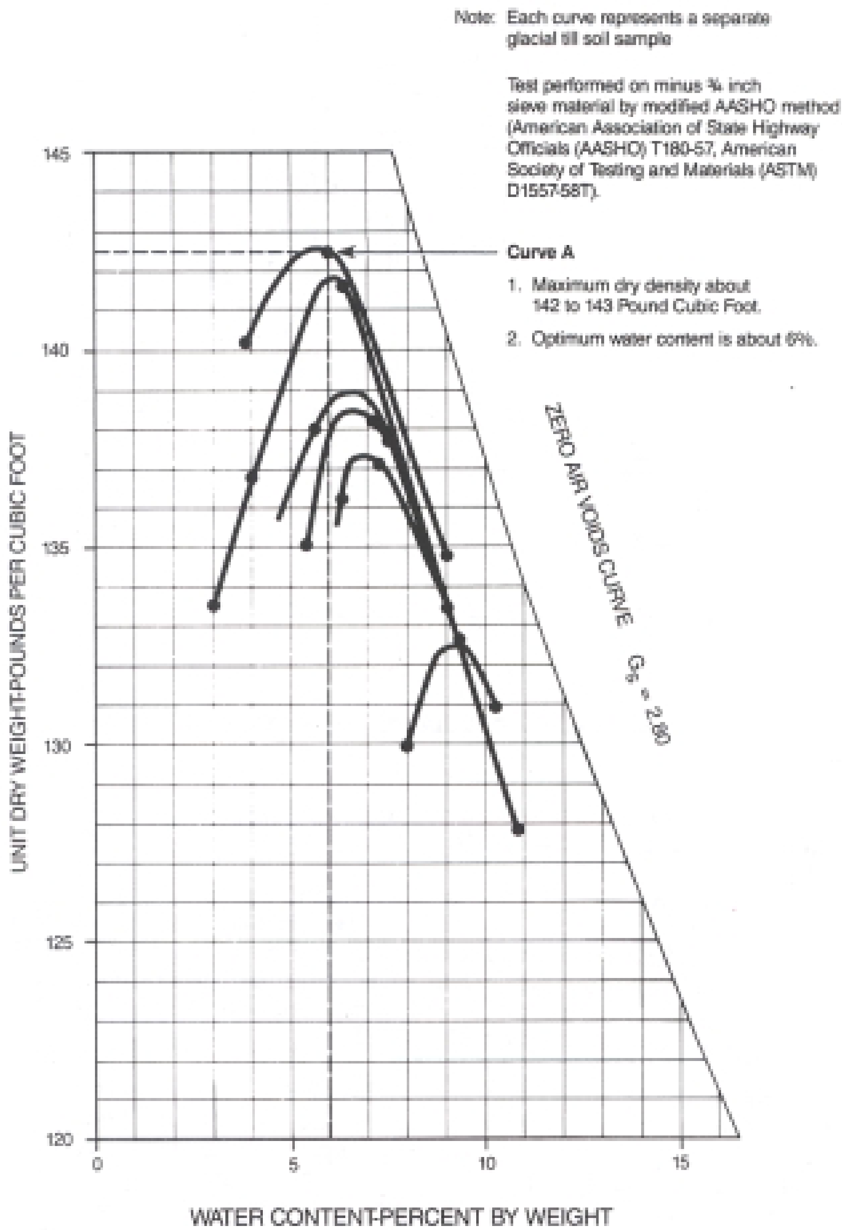
tend to result in lower maximum densities and higher optimum water contents. See Section 5.8 for additional information.

In landfill projects, soil is often compacted to reduce the hydraulic conductivity of liner or cover soils. In assessing soil-density/hydraulic conductivity relationships, the expected field conditions should be taken into account. In place or field soil densities can be determined using a variety of methods such as the sand cone density method (ASTM D1556 Test Method) or nuclear densiometer (ASTM D2992).

Laboratory moisture-density test results are presented in the form of a compaction curve on a plot of dry densities weight of oven-dried soil per unit volume of soil versus the corresponding water content (Figure 4.6). The water content at the peak is the optimum dry density. Design specifications normally state the desired compaction in terms of the percentage of the laboratory maximum density and the method to be used to obtain the results. An example of such a specification would be that a soil sample is to be compacted to 95 percent of its maximum dry density.

4.2.1.8 Hydraulic Conductivity

Hydraulic conductivity affects how water or leachate moves through soil and is one of the more important soil properties when designing a landfill soil liner and cover system. The following discussions provide a brief overview



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Adapted From: Olmsted, 1969

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Figure 4.6
Typical Compaction Curves for Glacial Till

of this soil property. More detailed information is contained in publications by Cedergren (1977), Freeze and Cherry (1979) and U.S. EPA (1984).

Hydraulic conductivity values can represent both saturated and unsaturated conditions. Saturated conditions are far easier to evaluate than unsaturated conditions. In saturated flow, all soil pores are filled with water and hydraulic conductivity is not affected by varying water contents. However, for unsaturated flow, soil pores are only partially filled with water. As water content decreases, fewer pores transmit water, capillary forces become stronger and the ability to transmit water decreases. The unsaturated hydraulic conductivity decreases by decreasing water content and increasing soil tension (see Figure 4.5).

Hydraulic conductivity can be defined by Equation 4-1 (after Darcy's Law):

$$K = \frac{Q}{i(A)} \qquad (4\text{-}1)$$

where:

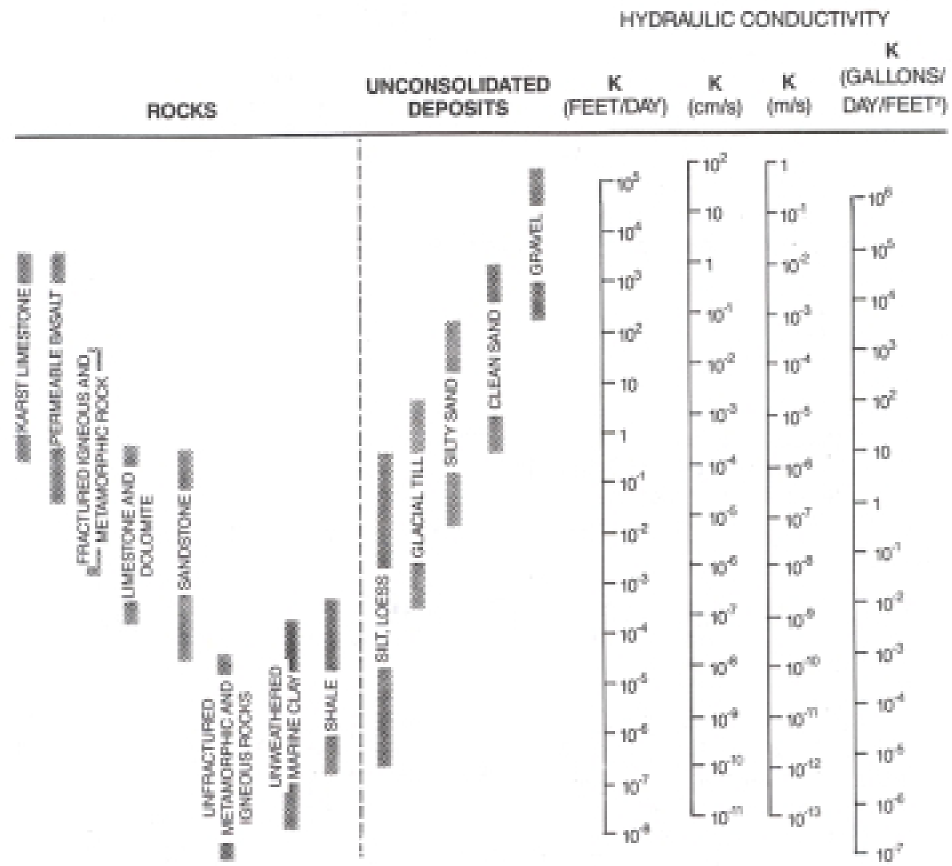
K = Hydraulic conductivity (length/time)
Q = Rate of flow (volume/time)
i = Hydraulic gradient (length/length)
A = Cross sectional area (length squared)

These K values may be reported using several sets of units including (but not limited to): centimeters per second (cm/sec), feet per day (ft/day), gallons per day per square foot (gpd/ft2

The saturated hydraulic conductivity of natural materials can vary by over 13 orders of magnitude. Typically, fine-grained soils have lower saturated hydraulic conductivity compared with coarse-grained soils. Representative values for natural materials are presented in Figure 4.7.

As shown in Figure 4.7, grain size has a significant effect on hydraulic conductivity. Soil density can also affect hydraulic conductivity values. Typically, the denser the soil, the lower the hydraulic conductivity. Density effects can cause a given soil to vary in hydraulic conductivity by one to three orders of magnitude (Cedergen, 1977). As a rule, the narrower the range in particle size, the less the hydraulic conductivity is affected by density.

Soil structure should also be considered in assessing soil hydraulic conductivity. Soil structure refers to the arrangement of soil particles by either sorting or stratification, or by orientation of particles and the clustering or broad dispersion of fines. Soils deposited in water are typically horizontally stratified and often display a higher horizontal hydraulic conductivity compared with vertical hydraulic conductivity. However, wind blown sands and silts are often more conductive in the vertical direction compared with the horizontal direction. For fine textured soils, horizontal



Adapted From: Freeze and Cherry, 1979

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Figure 4.7
Range of Values of Hydraulic Conductivity

hydraulic conductivity may be 0.9 to 40 times the vertical conductivity (U.S. EPA, 1984). Soil disturbance by root growth, organic matter decay and other causes can also Affect soil structure and hydraulic conductivity.

Soil structure can be an especially important factor when compacting finegrained soils. Compaction under dry conditions may develop a different soil structure compared to compaction under wetter conditions. A study made on glacial till/gravel mixes for the core of the Mud Mountain Dam (Cary, et al., 1943) illustrates this point. A mixture of 20 percent till and 80 percent gravel had hydraulic conductivities of around 5 x 10-4 cm/sec at a water content of 14 percent, but only 5 x 10-7 cm/sec at 16 percent. This represents a change of over 1000 times with a variation-in water content of only 2 percent (Cedergren, 1977).

Unsaturated hydraulic conductivity is affected by several of the factors affecting saturated conductivity and, in addition, water content or soil tension (negative pressure). Unsaturated hydraulic conductivities at high soil tensions (very low water contents) can be surprising. Figure 4.5 shows that clays at moderate soil tensions (60 MBar) can have higher unsaturated hydraulic conductivities than sands. A saturated sand with a hydraulic conductivity 100 times that of a saturated clay may have 10 to 100 times lower unsaturated hydraulic conductivity under dry conditions. A detailed discussion of unsaturated hydraulic conductivity can be found in Freeze and Cherry (1979).

Field methods for evaluating saturated hydraulic conductivity are discussed in Appendix A (Field Exploration and Testing Methods). A variety of laboratory methods is also available to determine saturated hydraulic conductivity. The various methods are discussed in Cedergren (1977) and U.S. EPA (1984).

Unsaturated hydraulic conductivity can also be measured in the field or laboratory. In many cases, values for similar materials published in the literature are used. Unsaturated hydraulic conductivity testing is more difficult than testing for saturated hydraulic conductivity. Methods for testing unsaturated soils are presented in U.S. EPA (1984).

In-situ (field) testing is generally more reliable than laboratory testing for hydraulic conductivity, depending on soil conditions, especially variations in soil type and structure. Laboratory tests generally require more sample disturbance than field testing. This disturbance can alter the soil significantly and may not be representative of field conditions. Extreme care should be exercised in conducting laboratory tests for hydraulic conductivity. Field conditions should be adequately represented. In-situ density and structure must be recreated or undisturbed samples (often impossible to obtain) must be used.

4.2.1.9 Cation Exchange Capacity (CEC) and PH

Soil cation exchange capacity (CEC) and pH affect the chemical attenuation characteristics of soil. The long-term ability of soils to attenuate contaminants in leachate is often unknown, but a comparison of soil conditions between sites can often be made to select favorable sites, Typically, soils that offer low to moderate hydraulic conductivity, high clay content, high CEC, and relatively high pH (>6.0) are preferred over coarse-grained soils with high hydraulic conductivity and low CEC values. Typical values of CEC for soils are presented in Table 4.1.

Table 4.1. Typical Ranges of Cation Exchange Capacity for Various Soils.

Soil Type	Range meq[1]/loog
Sandy soils	1 - 10
Silt loams	12 - 20
Clay and organic rich	>20

[1]meq = milliequivalents

Source: U.S. EPA,.(1977b)

4.2.2 Monitoring Wells and Piezometers

Boreholes completed during the geohydrologic/geotechnical assessments are commonly converted into piezometers or *monitoring wells*. These wells are used to assess ground water flow directions, conduct in-situ hydraulic conductivity tests and obtain water samples. Piezometers and *monitoring* wells consist of a screen or slotted section of casing (to allow ground water to enter freely) attached to a casing which extends upward to land surface. A piezometer is of small diameter (usually less than 2 inches), short-screened (usually under 5 feet), sealed installation designed principally for obtaining hydraulic head measurements from discrete depth zones. A monitoring well is designed to provide hydraulic head measurements and access for ground water sampling over a larger depth interval (5 to 10 feet). Since piezometers are essentially specialized monitoring wells*,* the following discussion pertains to both monitoring wells and piezometers.,

4.2.2.1 Relationship to *Environmental Monitoring Program*

Although piezometers and *monitoring wells* are commonly installed during preliminary investigations at proposed landfill sites, these installations can be part of a long-term environmental *monitoring system*. Early data collected from monitoring wells and piezometers aid in defining geohydrologic systems and establishing baseline *conditions at* the site. Once a landfill has started operation, ground water monitoring wells are used to determine compliance with the performance standards of VAC 173-304-460(2). The environmental monitoring aspects of piezometers and monitoring wells discussed in Chapter 8 includes such topics as *monitoring well* design and *installation, ground* water sampling, and interpretation of monitoring results.

4.2.2.2 Well Locations and Number

The total number of monitoring wells at a landfill depends on the same factors discussed in the previous section pertaining to the extent of exploration. Locations of future monitoring wells should be considered in the planning stages of the subsurface exploration program for the site.

The number of wells required is very site dependent. If the ground water flow system is relatively simple (hydraulic gradients are small and flow occurs in one direction), three wells can provide a general indication of flow (Todd, 1980). However, under most conditions, more than three wells should be installed because ground water flow paths are often more complex than the relatively simple conditions than can be evaluated with three wells. The Minimum Functional Standards require at least one background and three compliance monitoring wells.

After initial subsurface results have been analyzed, it may be necessary to revise the number and locations of monitoring wells to provide a complete picture of the geohydrologic conditions beneath the site. For example, if two aquifers separated by a clay layer are discovered beneath the site, it may be necessary to install multiple wells (clusters) at selected locations, to allow measurement of hydraulic head and collection of ground water samples from both units. The number and locations of monitoring wells at a landfill site must be sufficient to define the ground water conditions and at the same time satisfy legal requirements regarding ground water monitoring.

4.2.3 Data Interpretation

Data collected during the geohydrological/geotechnical assessments must be interpreted for inclusion into a final report for the study. Background data compiled during the initial site selection process (Chapter 3) should be evaluated with the field investigation data to prepare a complete analysis. For site soil conditions that can be quantified (such as soil hydraulic conductivity and ground water flow directions), geostatistical techniques have been developed which can provide insight into how well the data represent the site conditions. In some cases, these techniques can be used to determine the number of samples or tests that are required to achieve a certain level of statistical certainty. However, in most cases, the adequacy of data to represent site conditions will be based on the professional judgment of the site evaluation/design team.

The following portions of this section describe the broad components of the data interpretation process.

4.2.3.1 Geology

Components of geology include: topography, soil types, and underlying "parent" geologic materials. Although the term "soil" is often used in a general sense to describe unconsolidated geologic materials, soils are defined as materials that have formed at the earth's surface as a result of organic and inorganic processes. The underlying geologic strata from which the soils were formed are called parent materials. In some areas, soils are not present as a result of erosion, man-induced activities, or absence of soil-forming conditions. Soil scientists from the U.S. Soil Conservation Service have described and mapped soil series over many areas of the state, and these maps are commonly compiled during the site selection process (Chapter 3).

Near-surface geology can be interpreted by evaluating air photos, regional topographic maps, published soil maps, test boring and test pit logs, and field reconnaissance of outcrops and exposures. Air photo interpretation can be an extremely useful tool in the evaluation of earth features over wide areas and subsequent correlation of regional data with site specific geologic information. Earth features which can be evaluated by means of air photo interpretation include: landforms, rock types, surface drainage patterns, geologic structure (beds, fractures, faults) and erosional features (Leuder, 1959).

Once the near-surface geology of a site has been established by a thorough interpretation of geologic data, site specific maps can be prepared which show topographic contours, soil series, and sub-soil geologic units. Examples of site topographic, soils, and geologic maps are shown in Figure 4.8.

4.2.3.2 Subsurface Geology

Subsurface geology is interpreted by evaluating data from subsurface explorations (Appendix A). Geologic logs of the subsurface are used in conjunction with published geologic maps, air photos, and field records of outcrops to define subsurface conditions over the site area. Geologic strata encountered at a particular site can often be correlated with rock formations which have been identified and named in the literature. Establishing the subsurface conditions at a proposed landfill site is a prerequisite to evaluation of geotechnical constraints, the ground water flow system, and site design.

Many techniques are available for representing subsurface conditions. Perhaps the most basic and useful method of illustration is the geologic cross section. A geologic cross section is a two-dimensional representation of earth materials as a vertical "slice" through the earth. Test borings, ideally situated in a straight line, are selected as control points for the cross section. The top surface of a geologic cross section most often represents land surface, and the various strata penetrated by the control borings are illustrated at the appropriate depths on the section. if sufficient control exists, the strata can be correlated from borehole to borehole and allow delineation of geological formations over the length of the section. An example of a geologic cross section is shown in Figure 4.9. Other methods of illustrating and interpreting subsurface geology include: geologic maps, structural contour maps, isopach (thickness) maps, fence diagrams, and solid models (Haun and LeRoy, 1972).

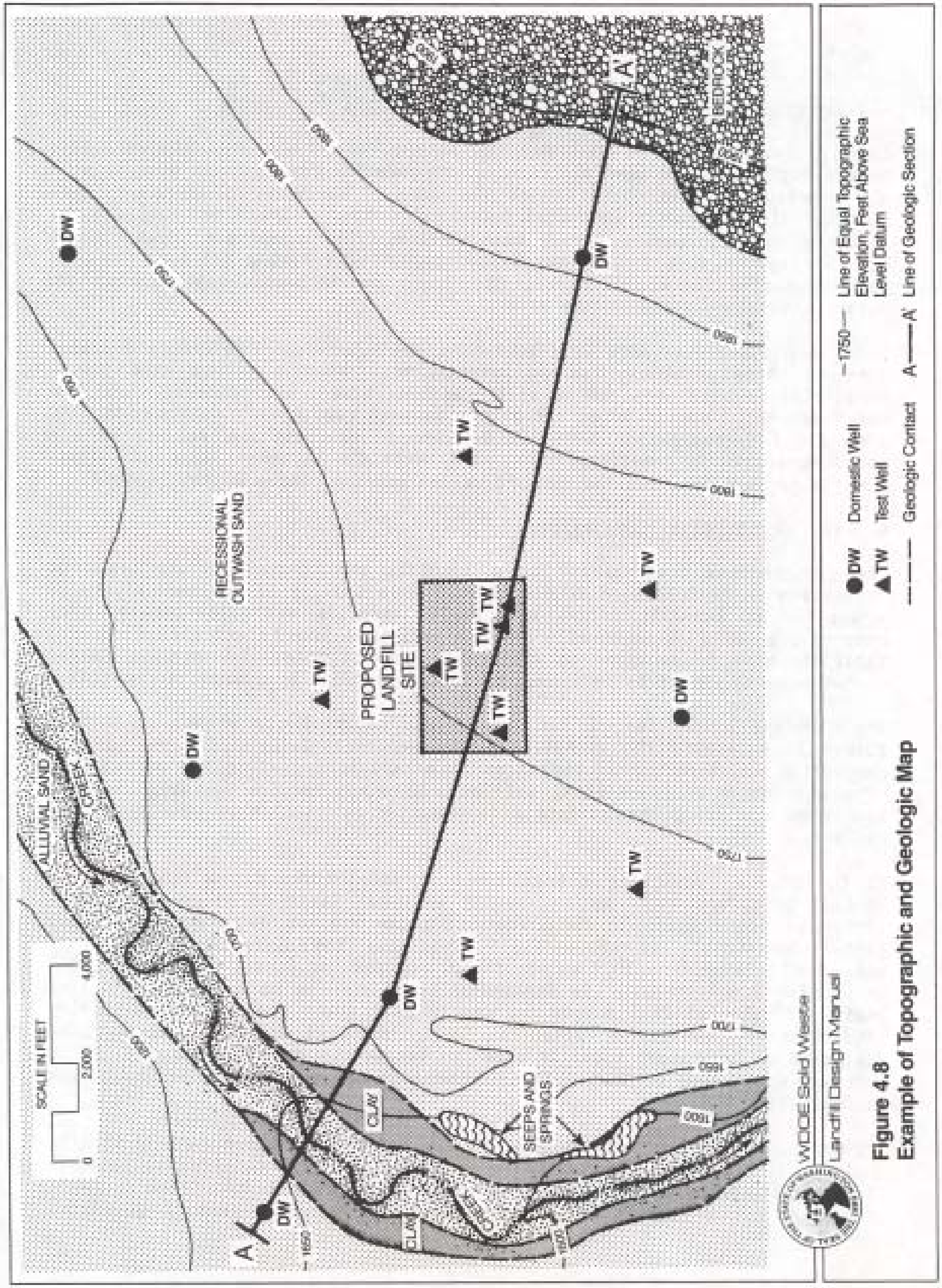

Figure 4.8
Example of Topographic and Geologic Map

4.2.3.3 Volumes of On-site Earth Materials

One important aspect of defining the nature and extent of earth materials underlying a proposed landfill site is the possible use of these materials in the construction and operation of the site. The potential uses of these materials include daily and final cover (of refuse), liners, drainage, fill, building construction, and road construction. The subsurface investigation of the proposed site should provide sufficient test boring and soil property data to define the areal extent, thickness, and physical properties of the earth materials underlying the site.

After the subsurface materials have been characterized, the future disposition of these materials can be established. Materials that have future beneficial on-site uses can be distinguished between materials that must be excavated and disposed on or off-site. Isopach (thickness) maps constructed from field investigation data can be used to estimate the volumes of the earth materials in question. The earth materials thickness maps can subsequently be used to guide the excavation and grading phases of the project.

4.2.3.4 Geotechnical Constraints

The geotechnical constraints for a landfill site depend on the types of facilities to be installed at the site. The stability of man-made slopes is a concern at landfill sites, especially landfills and impoundments where extensive grading is required. Berms around impoundments and side slopes of landfills must be designed to withstand loads of materials retained behind the structures and to be resistant to surface erosion by stormwater runoff.

The physical properties of earth materials underlying a proposed landfill site will determine the workability of these materials, i.e., the ease of excavation and handling at the site. Limitations regarding the workability of a particular earth material unit at a site may require revising the site layout or modifying the materials in question to facilitate development of the site.

In the case of designing a soil liner or final cover for a landfill, the general procedure would be to specify an upper limit of hydraulic conductivity at least equal to requirements in the Minimum Functional Standards (WAC-73-3047460(c)) or 460(e)(i)). Typically the hydraulic conductivity values will range from 10-6 cm/sec to 10- cm/sec for liners and 10^{-5} to 10^{-6} cm/sec for final covers. An assessment would then be made as to the suitability of selected fill borrow sources to meet these hydraulic conductivity requirements. Samples of potential borrow material would be obtained and subjected to laboratory tests in order to assess the requisite density. This material would then be subjected to laboratory tests to assess its hydraulic conductivity.

Typically, it is necessary to place natural soils with large amounts of fine grained (silt and clay) particles to achieve low values of hydraulic conductivity. Higher percentages of fines makes the soil more sensitive to small changes in water content. As the percentage of fine-grained particles increases, adequate compaction becomes much more difficult to achieve under the wet weather conditions typical in parts of Washington.

The behavior of earth materials under various loading conditions is critical in the design of landfills. Potential impacts of settlement on liners and leachate collection systems must be evaluated, in addition to the standard foundation analyses. Potential impacts of the often large consolidation settlements of the waste material need to be evaluated in terms of deformation and integrity of final cover systems.

4.2.3.5 Ground water Flow System

A subsurface investigation of a proposed landfill site should provide sufficient data to allow evaluation of the ground water flow system. Interpretation of near-surface and subsurface geologic data and definition of the site geologic setting, as described in previous sections of this chapter, are the first steps necessary in defining the ground water flow system. Geologic maps and cross sections compiled during the interpretation of field data and published geohydrologic reports provide the basis for site specific evaluation of the geohydrologic setting.

Ground water level data provide the most basic information for interpreting the ground water flow system. Water levels from monitoring wells (constructed in test borings) can be plotted on geologic cross sections to illustrate relative elevations of the water table or piezometric surface, the depth to water below land surface, direction of ground water flow and saturated thicknesses of waterbearing formations. A cross section *containing* ground water level data is shown in Figure 4.9.

Water level (water table and potentiometric) contour maps can be constructed by plotting water levels from the same aquifer (or other appropriate water-bearing zones) on a map adjacent to the respective well locations and using these data points to draw contours of equal ground water elevation. Water supply wells and surface water measuring stations can often be used as additional control points in constructing water level contour maps. Ground water flow directions can also be measured from water level contour maps. Flow is generally at right angles to contours in an isotropic system (an assumption that is often used). An example of a water level contour map is illustrated in Figure 4.10.

Additional maps which can be compiled to aid in interpretation of the geohydrologic system at landfill sites include: aquifer thickness maps, depth to water maps, and ground water geochemical contour maps. Aquifer thickness maps are useful in evaluating the areal extent of vaterbearing formations. Depth to water maps are most often used to delineate areas which do not allow sufficient separation between the water table and land surface for construction of a landfill (see siting discussion in Chapter 3). Ground water chemical contour maps show *concentrations of* selected chemical constituents in ground water and are useful in delineating plumes of ground water contamination. *Presentation and* interpretation of ground water quality data are discussed in Chapter 8 of this manual.

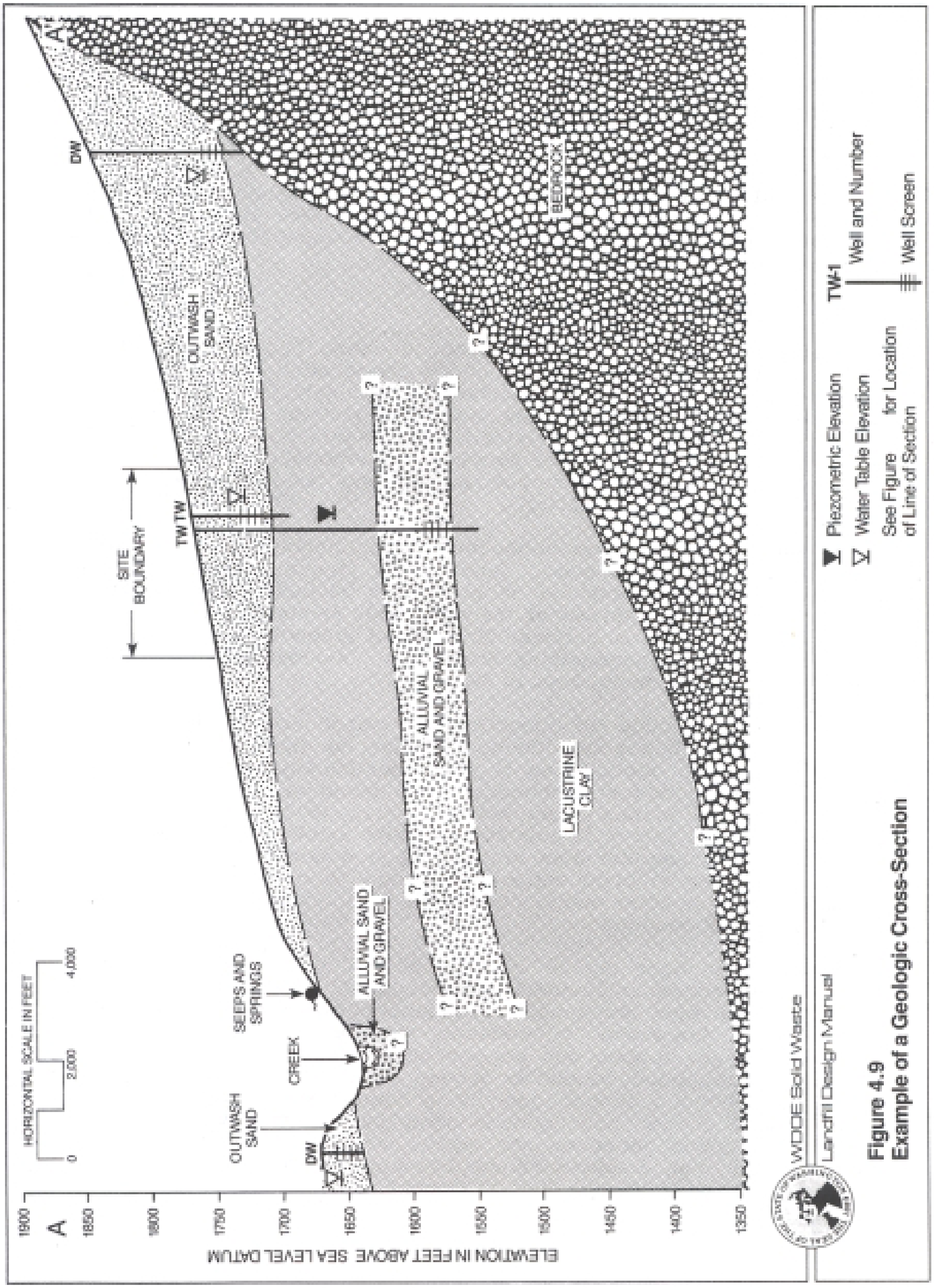

Figure 4.9
Example of a Geologic Cross-Section

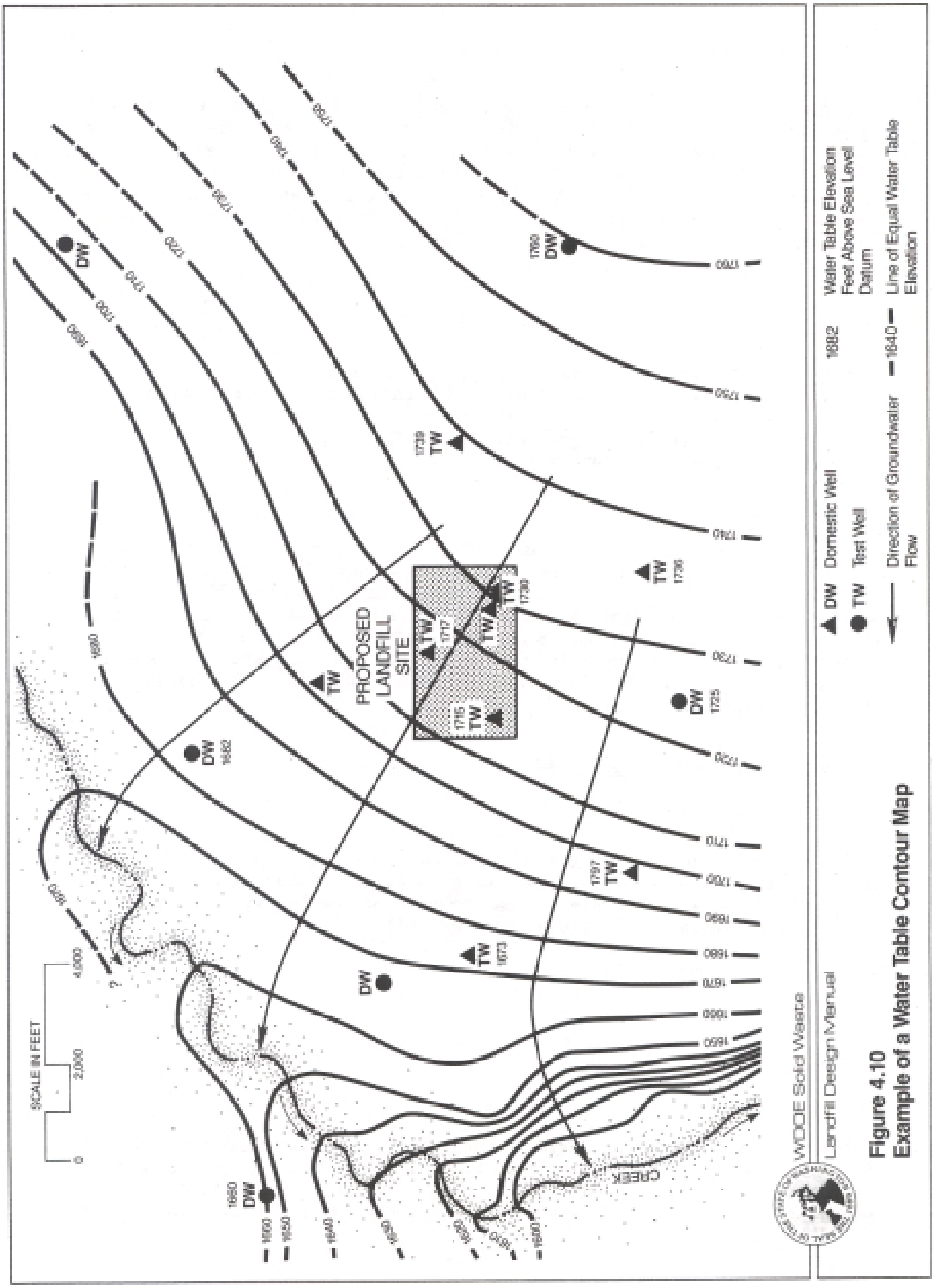

Figure 4.10
Example of a Water Table Contour Map

Ground water gradients (horizontal and vertical) can be calculated from water level contour maps and geologic cross sections by measuring the drop in ground water level elevation over a fixed distance. The ground water gradient, hydraulic conductivity and porosity of the aquifer material can then be used to calculate the ground water discharge (see Equation 4-1). Ground water velocity can be calculated in accordance with the following expression of Darcy's Law (Freeze and Cherry, 1979):

$$V = \frac{K(I)}{n} \qquad (4\text{-}2)$$

where:
V = Ground water velocity (length/time)
K = Hydraulic conductivity (horizontal or vertical, as appropriate), (length/time)
I = Ground water gradient (length/length)
n = Porosity (percent)

4.2.3.6 Reporting

Data and analyses completed as part of designing a new facility or expanding an existing facility will be presented to support the permitting and design efforts. Typically, at least two types of reports will be prepared: geohydrological assessment report and a geotechnical design report. Section 600 of the Minimum Functional Standards (WAC 173-304) outlines the required information to be included in the geohydrological assessment. Additional data and analyses will likely be included based on the judgment of the landfill design team.

4.3 WASTE STREAM CATEGORIZATION

4.3.1 Background

Solid waste is defined in the Minimum Functional Standards and includes a detailed list of waste types. For purposes of this manual however, landfilling of solid wastes in Washington can be categorized by five generalized nondangerous, non-hazardous waste streams as follows:

- Mixed Municipal
- Demolition and Inert
- Wood
- Industrial

Statewide, each of these waste streams has currently operating, dedicated disposal sites, as well as a more larger number of sites receiving various combinations of all of the above. In addition, each category may have special waste types which may require modified techniques. Consequently, design criteria developed for a solid waste landfill must accommodate both the variability of the delivered wastes and operating requirements tailored to a specific waste category. It is important to emphasize the understanding required for these individual categories prior to proceeding with specific landfill design.

4.3.2 Mixed Municipal Solid Waste

Landfills categorized as mixed municipal solid wastes (MMSW) sites receive predominantly household and commercial refuse. A typical make-up of this waste stream is presented in Table 4.2.

This waste stream is typically delivered to the landfill by commercial collection and/or transfer vehicles. Where public access to the site is allowed, residential self-hauled MMSW may also be received. When delivered loose, this waste stream has a density of approximately 200 to 300 pounds per cubic yard (lbs/cy). In compacted form, densities from 400 to 600 pounds per cubic yard are common. As presented later in this chapter, normal in-place landfill densities ranging from 1000 to 1300 pounds per cubic yard are common.

Special fractions of this waste stream which may affect the design of a MMSW landfill are primarily related to bulky wastes such as appliances and tires. These items, if present in sufficient quantity, may dictate certain design modifications to improve operations. Factors to consider include waste separation prior to landfilling for potential recovery, and segregation to provide for separate burial.

Table.4.2. Typical Waste Composition of Mixed Municipal Solid Waste (MMSW)

Component	% By Weight Composition
Paper	44
Metals	9
Food Waste	12
Yard Waste	11
Wood	4
Textiles, Leather, Plastics, Rubber	7
Glass	9
Other Material	4
Total	100

Source: U.S. EPA (1976)

4.3.3 Demolition and Inert Wastes

This category includes construction demolition materials, land clearing wastes, and wastes defined as inert. This particular waste stream is significantly affected by economic activity and generation rates and volumes are widely variable. This variability greatly affects the operational and financial elements of planning and designing dedicated facilities. To be operated successfully, a landfill relies on waste stream consistency. Demolition waste sites rank far below comparable MMSW sites in this category.

Special fractions of this waste stream which impact design decisions again reflect the bulky nature of products. Stumps, large timbers and other miscellaneous construction debris can greatly affect capacity calculations due to their relatively low density and compaction problems. These types of wastes can also cause significant damage to landfill liners and leachate collection systems, if installed.

By comparison, demolition and inert landfills rank below MMSW sites in terms of leachate and gas production. Depending upon the organic content of delivered materials, these by-products of decomposition can be significantly below normal generation rates. Due to their lower organic content, demolition and inert landfills generally undergo less settlement and can support a wider variety of final land uses. Performance and design requirements for these types of landfills are specified in WAC 173-304-461.

4.3.4 Wood 'Wastes

Wood waste landfills are composed of by-products of the forest industry, with chips, sawdust, slash and sorting yard waste the traditional constituents. Like demolition material, wood waste generation is tied directly to economic factors. In many areas of Washington, this results in the co-disposal of these wastes into MMSV or demolition landfills for economic reasons.

The organic content of a dedicated woodwaste landfill may be lower than, a MMSW site; however, leachate and gas production may be significant. Leachate constituents may also be different from normal MMSW strengths requiring process modifications for leachate treatment and disposal. The nature of woodwaste leachate and its effect on the environment is discussed in detail by Schermer and Phipps (1976).

Design factors affecting a woodwaste landfill are generally simpler than for a MMSW site because of the homogenous, relatively non-putrescible nature of the material, ease of compaction, and reduced litter and vector potential. However, potential environmental impacts associated with surface and ground water contamination are potentially significant and should be given equal consideration in the design of the landfill's protective mechanisms. Design requirements for wood waste facilities are listed under WAC 173-304-462.

4.3.5 Industrial Wastes

This is a broad category of waste streams generally tied to the manufacturing sector. It should be noted that the manufacturing community in Washington State also contributes to the previously discussed MMSW segment. The term industrial waste focuses on industrial process residual streams that use landfilling as a final disposal technique. Industrial wastes do not include dangerous wastes as defined by Chapter 70.105 RCW and Chapter 173-303 VAC. Common constituents include, but are not limited to, the following:

- Boiler ash (bottom and fly)
- Food processing wastes
- Fish processing wastes
- Foundry wastes
- Mining wastes

Waste categories requiring special handing procedures include:

- Sludges (semi-solid and liquid)
- Asbestos wastes (may be a dangerous waste)
- Dredge spoils
- Problem wastes
- Some dangerous wastes as permitted by WAC 173-303

Because of the variability of these wastes, this manual cannot provide comprehensive design criteria for each particular waste at a dedicated landfill. Rather, general design considerations are presented and specific reference sources may be obtained from the U.S. EPA. Co-disposal of certain industrial wastes with MMSV refuse is currently being practiced at a number of sites in both eastern and western Washington. Specific waste streams utilizing this technique include:

- Wastewater treatment plant sludges
- Agricultural processing wastes

In addition, there is a limited amount of bottom and fly ash and asbestos co-disposal occurring at a small number of facilities. General safety procedures applicable to co-disposal of wastes are included in Chapter 6 of this manual. Co-disposal of sludges with MMSW takes advantage of the bulking quality of the MMSW to absorb free water; however, there are disadvantages and some jurisdictional health departments may prohibit the practice.

- Odors may increase somewhat depending upon the stability of the sludge.

- Leachate may be generated sooner (if not already existing) or leachate quantities may increase (if already existing).

- Operational problems may develop including equipment slippage or stoppage, or sludge tracked around the site by equipment and haul vehicles.

If sufficient data is available, dewatering procedures may be employed to avoid the operational difficulties of a semi-solid material. Additionally, sludge may be stored or treated in surface impoundments according to WAC 173304-430.

Another option mixes sludge with on-site soils, which is applied as an interim or final cover over completed portions of the site. In MMSW sites with low quality soils, the sludge is considered a soil amendment and can materially enhance the ability of cover soils to support vegetation.

Land application of the sludges is a third alternative for disposal. Land application methods, regulations, design criteria, operation and maintenance are contained in ' Criteria for Sewage Works Design (WDOE, 1985) and will not be discussed in this manual.

Agricultural processing wastes, including aquaculture wastes, can similarly affect a MMSW site. Odor problems and leachate generation are the more significant issues affecting design and operation elements.

Problem and dangerous wastes meeting the requirements for disposal in a solid waste landfill must be handled with attention to operator safety. Ideally, material should be sealed in bags or other containers prior to delivery to the landfill and should be covered immediately after disposal. Regulatory agencies may require further operational procedures when handling these materials.

4.4, OPERATIONAL ALTERNATIVES

Prior to discussion of detailed design elements, it is valuable to point out various types of landfill operations applicable to Washington. These alternatives are discussed below, along with schematic layouts depicting operating techniques. Recent environmental controls over solid waste landfill development have had a marked effect. on options available to site operators. Traditional goals of onsite soil balance and effective topographic use are still important in determining the optimum landfill configuration; however, leachate collection systems and bottom liner requirements have somewhat limited operational options.

4.4.1 Area Fill

As the name implies, an area fill includes a fairly large working face for waste disposal. Refuse is off-loaded either on undisturbed ground or on a prepared, tipping pad where it is pushed onto the working face in lifts from 16-30 inches in thickness and then compacted. Each layer is compacted as the filling progresses over the course of the day or until the thickness of the compacted wastes reaches a height of 6 to 15 feet. At that time, and at the end of each day's operation, a 6 to 12-inch layer of cover material is placed over the completed fill. Cover material may be excavated from adjacent higher points of land, imported from borrow pit areas, or from previously constructed stockpiles. The area method of landfilling is illustrated in Figure 4.11.

The width and length of the fill or working face depends upon several factors:

- Daily quantity (tons/day)
- Traffic volumes (vehicles/day)
- Landfill equipment

Accommodating refuse vehicles in a timely manner may be one of the more important considerations in the determination of the working face width. The length of the fill is dependent upon daily volumes and the ability of the landfill compaction equipment to cost effectively "push" the refuse. The working face slope (tipping pad to top of fill) is generally maintained at 3:1 or less. Modern landfill compaction equipment, while operating excellently on moderate grades, is less effective on steeper slopes.

A completed * fill, including the cover material, is called a cell. Subsequent filling operations proceed from these previously completed cells. Successive cells are placed adjacent to one another until the first lift, covering the platform area called for in the operating plan, has been completed. Successive lifts are placed on top of one another until the final grade is reached, at which point a final cover is provided. Additional compaction of the lower lifts (20 to 40 percent) can be achieved by routing traffic over completed cells. For inclement weather, a backup fill area next to an all-weather road is sometimes necessary. Daily cell construction, covering and cover material are further discussed in Chapter 6 of this manual.

Applications:

- Moderate and rolling topographic conditions, where cover material sources are readily available
- Large volume MMWS or demolition sites with high traffic volumes
- High in-place densities possible (greater than 1200 lb/cy)

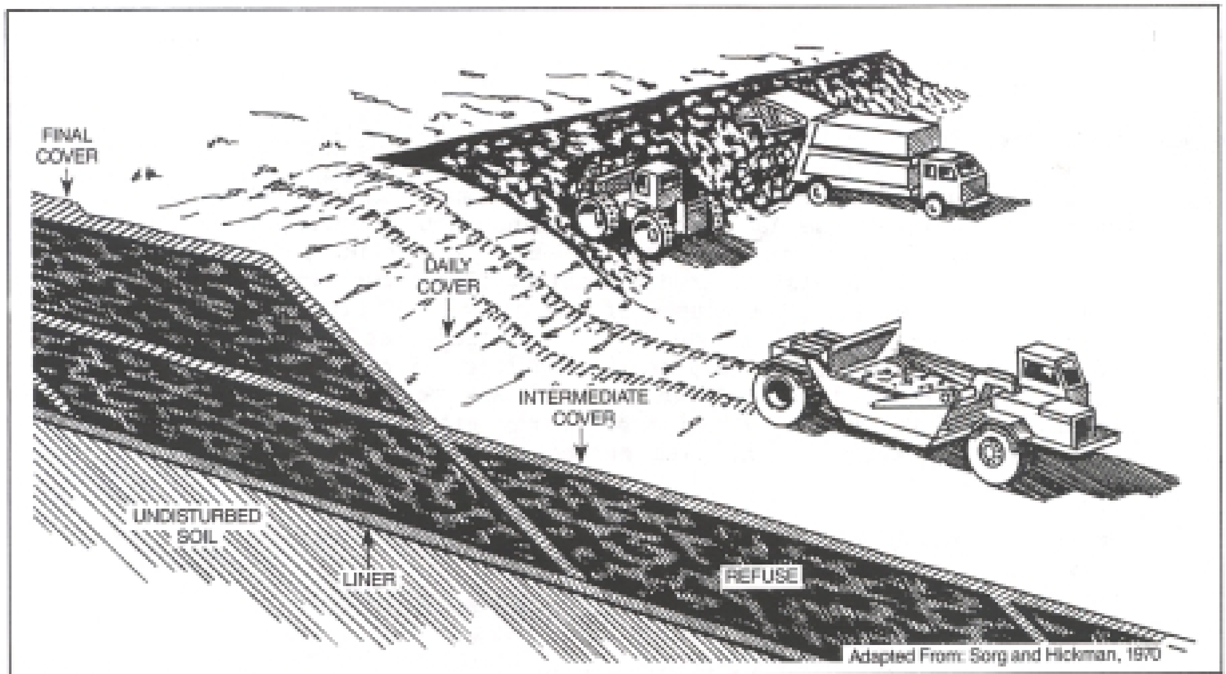

Figure 4.11
Area Method

Limitations:

- Larger overall area/volume ratio results in higher leachate production and higher capital costs
- Higher daily cover requirements
- Cover material may have to be imported
- Higher litter problems

4.4.2 Trench Fill

In the trench method of landfilling, waste is spread and compacted in an excavated trench. To begin operation, the first part of the trench is excavated to the desired depth and the soils are stockpiled. Wastes are placed in one end of the trench and compacted until the desired height is reached. The daily cover material is obtained from stockpiled soil, continuing the trench or borrowed from adjacent trenches. The trench fill method is illustrated in Figure 4.12.

The size of individual trenches is generally governed by topography, constructability and refuse volume. A recommended trench width is generally 100 feet wide or less to provide a manageable trench and orderly construction of cells. Typically, operators prefer to develop a new trench with high

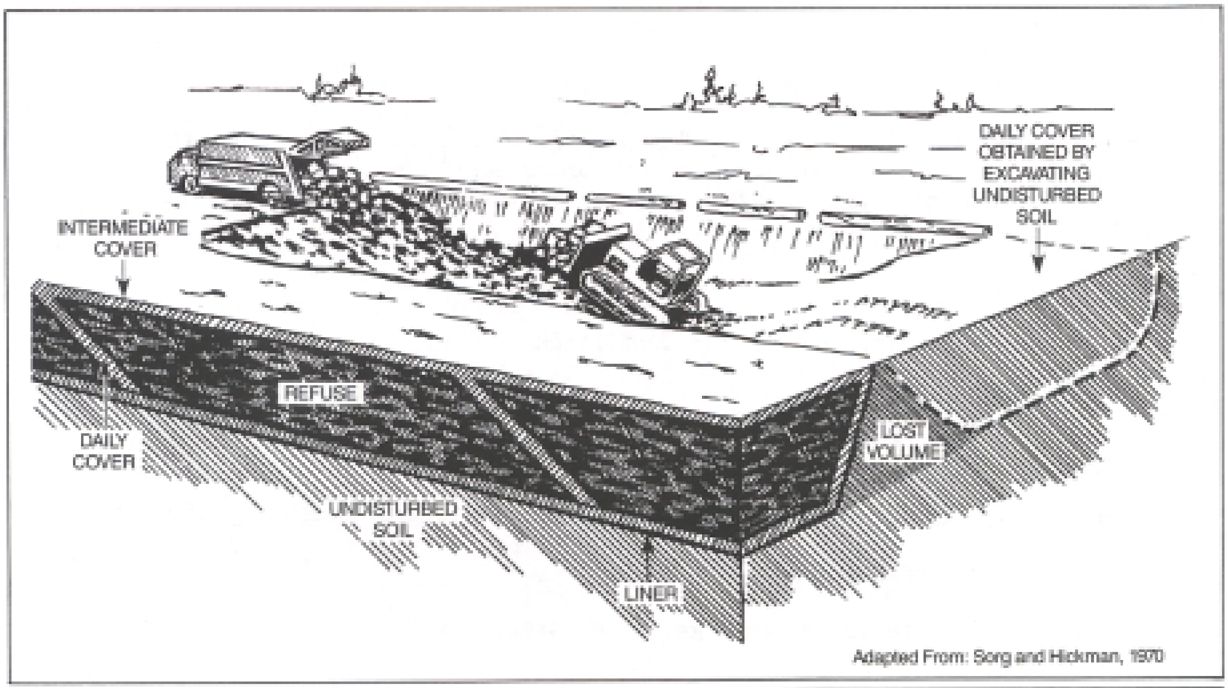

Figure 4.12
Trench Method of Landfilling

production excavation equipment, such as scrapers, rather than normal landfill equipment and will endeavor to maximize trench volume per unit construction cost. In wetter climates, trench sizes may be governed by limited dry weather construction conditions and must be sized to last at least one year. Trench depths depend upon soil types and excavation equipment. Using conventional scrapers or track dozers in glacial till, economical and safe trench depths may exceed 20 feet. In less cohesive soils, this depth may be reduced to 10-15 feet because of the increased possibility of bank failure for non-cohesive soils in slopes of significant height. Additionally, cohesionless soils that cannot maintain a minimum 3 horizontal to'l vertical slope are unsuitable for the trench method of fill.

As one trench is filled to completion, a subsequent trench is **excavated** adjacent to it. Because the two trenches are independent, there is a loss of landfill volume between the trenches. This loss of volume increases as trench side slopes decrease to allow for non-cohesive soils or as trench depth increases. It is desirable to minimize this lost volume; however, side slopes should not exceed a safe stable slope as recommended by the geotechnical evaluation. A maximum 2 horizontal to 1 vertical slope is recommended for the side slope. Landfill cell depth may vary from 5 feet or less to 30 feet or more depending on site constraints. Operationally, landfill cells of 8 to 12 feet provide for most effective operation and efficiency of daily cells. It is possible that a series of lifts could be placed within a trench, depending on the operators requirements. The trench method allows better control of litter than the area fill method. Litter is contained somewhat in the trench, and especially well in a narrow trench (100 feet wide or less). Also, the trench method may offer some cost savings over the area method, since material excavated from the trenches will be used as daily cover, eliminating imported cover costs.

Applications:

- Small volume, low traffic facilities
- Moderate topography
- Areas with a low ground water table
- Lower area/volume ratio results in less gas and leachate production
- Below grade landfill
- Specialized wastes (sludge, woodwastes, demolition)

Limitations:

- Lower efficiency of land use (ton/acre)
- Difficult to cost effectively implement leachate management systems (liner and collection system)

4.4.3 Modified Area Fill

The modified area method is probably more ty pical of current landfilling practices in Washington for medium to large facilities (>200 tons/day) than either the area or trench method. The system is flexible and can resemble either of the previously described techniques with very little alteration of the operating plan. In fact, many facilities begin early operations resembling a trench landfill altered by the modified area method, later changing to an area method to complete the landfill.

The modified area method of landfilling develops a fairly large working face similar to the area method. Depending on ground water levels and the required operation size, one or a number of cells may be excavated prior to operation and the material stockpiled for use as daily cover. This tends to create a more cost effective landfill than the area method. Once deposited on the tipping pad, waste is pushed to a working face which is actually constructed on an incline. Waste is compacted in an "uphill" fashion and the lift is expanded laterally in proportion to the daily quantities delivered.

Applications:

- Moderate and rolling topographic conditions
- Large volume MMSW or high traffic demolition sites
- Moderate in place densities possible, 1,000 lb/cy to 1,200 lb/cy

- Areas with a low ground water table
- Generally constructed as a below grade landfill

Limitations:

- Larger overall area/volume ratio results in higher leachate/gas production and higher capital costs

4.4.4 Prepared Refuse

Shredding and baling are two techniques involving preparation of refuse prior to landfilling which are applicable to Washington. Both have been employed at sites in Washington in an attempt to reduce landfill operations expense, to increase in place density (thereby prolonging site life), and to reduce environmental impacts. The techniques have had mixed success in meeting the objectives. Future applications should be carefully evaluated on the basis of cost effectiveness versus benefits to the landfill operation.

4.4.4.1 Shredding

Shredded waste has been reduced to particles less than 2 to 6 inches by mechanical processes such as cutting, tearing, ripping and impact shattering. The most common method is hammermilling, an impact shattering process. Shredded waste disposal is similar to the methods discussed above for unprocessed wastes, with the following advantages:

- Operation of the landfill is simplified when the waste is shredded. Successful operations have shown that very little daily cover may be necessary to prevent vectors because compaction is highly efficient. Blowing paper and debris is reduced since large pieces that may catch the wind are eliminated by the shredder. Spreading and compaction can be accomplished in significantly less time. Traffic routing and other operations during foul weather are also simplified.
- Because the shredded waste can be compressed to a greater density than unprocessed waste, by about 25 percent, the life of the landfill may be increased proportionately with the same compaction effort.
- Decomposition will proceed faster in a shredded waste landfill. This may be an advantage, particularly if methane gas or other by-products are to be recovered from the landfill, or to meet an ultimate land use plan for the site.

Disadvantages for shredding operations include:

- Initial cost of equipment and ongoing cost of operation and maintenance.
- Leachate may be of higher strength due to more rapid decomposition and potentially longer retention times.

- Higher methane production may be a disadvantage if not collected and recovered.

4.4.4.2 Baling

Waste is baled by compression into large, rectangular blocks with densities up to 1,700 lb/cy. The advantages are similar to the advantages for shredded waste:

- Improved aesthetics over unprocessed waste

- Cover costs are reduced because the bales create fairly uniform surfaces, thus minimizing the volume of cover material required. The bales can be manuevered with a front end loader of forklift, thus the only compaction equipment required is for the daily cover. Hauling costs can also be reduced if the waste is processed at transfer stations or more central locations..

- •The life of the landfill is prolonged due to the greater density achieved with baled wastes compared to unprocessed wastes.

Disadvantages to baling waste are also similar to those for,shredded waste:

- Cost of equipment, operation and maintenance

- Increased strength of leachate and higher methane production due to higher waste density.

Additional elements important to all landfill operating and processing options, including system economics are discussed in Chapter 6, Landfill Operations.

4.4.5 Delivery Modes

A -sometimes overlooked, yet very important factor in the design of a landfill, is the method by which wastes will be delivered to and deposited at the site'. Sizing of a facility generally relates to a quantity or volume figure represented as either tons per day (TPD) or cubic yards per day (CY/D). These are important in determining overall landfill volume requirements, however, they do not provide the designer with sufficient information concerning working face requirements and the number and type of vehicles utilizing the site per day. Three major types of waste delivery at MMSW sites are discussed below.

4.4.5.1 Commercial Haulers Only

This category refers to a site which restricts usage to commercial collection and transfer vehicles only. Commercial collection trucks have capacities ranging from 12 to 30 cubic yards and, with on-board compaction equipment, can deliver wastes with densities ranging from 400 - 800 pounds per cubic yard. Unloading of wastes from these vehicles is by gravity tipping or push ram. Unloading speeds vary with truck design but are generally fairly swift (2 to 5 minutes). Both unloading techniques generally require the truck to move ahead approximately one full truck length to complete the operation. For longer vehicles this may mean a tipping pad with a minimum length of 50 feet. Truck spacing between commercial vehicles at the working face should be at least 15 to 20 feet.

Other types of commercial vehicles include drop box or container units and transfer trailers. Capacities can range from 20 to 130 cubic yards depending upon t railer/ container length and height and whether or not wastes are compacted. Unloading can be by gravity tipping or push ram. In either case, the unloading length is generally one full container length as the vehicle moves ahead to facilitate refuse removal. Unloading times are again fairly swift, ranging from 4 to 8 minutes. Tipping pads established for large transfer station trailers should allow for 20 foot spacing between trucks and be 100 feet long.

Depending upon the site specific layout, appropriate turn-around space should be designed to accommodate the largest commercial vehicles. The normal traffic pattern for vehicle ingress and egress to the working face requires the truck operator to maneuver the vehicle to a common staging area and then back the truck in a rear turning movement to place the rear of the vehicle against the working face or unloading area.

4.4.5.2 Commercial and Private Vehicles

This type of MMSW site is similar to -a commercial vehicle only facility except that private vehicles would also be allowed to access the working face. Private vehicle capacities range from one 32 gallon garbage can (less than 0.2 cy) up to 5 cy for light commercial vehicles. Working face space allocations for these landfill users should range from 10 to 15 feet per vehicle depending upon site layout.

Unloading techniques are as variable as the capacities. Generally, these private vehicles require only a small distance between the rear of the vehicle and the designated unloading area. If a tipping pad is designed for commercial vehicles, it will be adequate for private passenger cars and light trucks. Unloading times range from 5 to 20 minutes.

At sites accepting both commercial and private vehicles, the working face/tipping pad should be designed to segregate the private vehicles from commercial users. Driver safety, working face operation and convenience are cited as the principle reasons for this recommendation.

4.4.5.3 Special Waste Delivery

MMSW sites commonly accept one or more waste streams categorized as special, including tires, appliances, sludges or specialized industrial wastes. Vehicle types may be identical to the commercial units described above, and if so, no additional design criteria need be applied in terms of working face allocation or ingress/egress.

Differing vehicle types, especially those with lengthy unloading periods, will require special consideration. Generally, the waste type and unloading mechanism will dictate criteria.

The landfill designer/operator should be aware that special waste haulers may require modification to the tipping pad and working face design to successfully operate at the site.

4.5 SITE DESIGN

4.5.1 General Design Procedure

An engineering plan or design report for a solid waste landfill site should be prepared in which the requirements for site improvements are assessed and appropriate designs are prepared. Chapter 173-304 WAC (MFS) provides the regulations and requirements for all solid waste landfills in Washington State and will provide the basis for site design. An orderly procedure should be established to facilitate design and reduce the possibility of overlooked site and design details.

4.5.1.1 Establish Goals and Objectives

Overall goals can be established for landfills, although the degree of implementation will vary with individual sites. For instance, a common goal will be to control gas and leachate to avoid environmental degradation. However, how the goals are achieved may differ from one situation to another. For example, at one landfill the objective may be to accelerate waste decomposition to produce a stable fill, allowing early abandonment of the leachate collection system and reducing the need to treat the leachate. The situation at another landfill may require the inhibition of leachate formation to minimize the need for treatment and disposal.

Additional goals may include maximizing the use of the land when the site is completed, minimizing costs, and completing the site as quickly as possible. To ensure proper design, the identification of goals and objectives should be based upon input from the site operator, potential landfill users, regulatory authorities, and residents near the site. Typical goals include:

- Meet all applicable regulations and provide plans suitable for meeting permit requirements
- Protect the physical environment (ground water, surface water, air quality)
- Minimize operation nuisances (litter, dust, noise, fires)
- Minimize dumping time for site user
- Ensure worker and user safety
- Maximize use of land when site is completed

- Maintain aesthetic site
- Provide for orderly closure and post-closure period
- Minimize costs (initial, operation, total)

4.5.1.2 Design Basis

The next step in the design of solid waste landfills is the collection of the background information and data needed for developing the design. Data previously collected during site selection will be incorporated into the site design, but changing conditions and the need for greater detail will require reevaluation of available data and accumulation of additional data.

Data collected at this stage may suggest a modification to earlier observations. For example, a site that appeared to have adequate onsite material for use as the bottom liner may need an admixed system or flexible membrane liner because the soil is more permeable, or less material is available, than previously indicated. Typical data requirements include (O'Leary, 1983):

- Environmental Regulations
  - Federal RCRA standards
  - Performance and design requirements of the Minimum Functional Standards WAC 173-304 (see Chapter 9)
  - Local county or municipality standards
  - Plan submittals procedures
  - Required permitsand procedures for application and approval
- Waste Characteristics
  - Waste sources
  - Waste loadings--daily, monthly or yearly variations
  - Waste quantities in cubic yards and tonnage
  - Waste type and variations in composition
  - Leachate generation potential
  - Gas generation potential
  - Unique physical features
- Physical Site Characteristics
  - Topographic map of site and immediate area
  - Surrounding land use patterns and zoning
  - Property line survey
  - Existence of easements or rights-of-way
  - Location of utilities
  - Location of buildings, roads, other structures
  - Vegetation cover on the proposed site
  - Existing drainage patterns on and off-site
- Geotechnical Data
  - Depth and type of topsoil and subsoils
  - Physical characteristics of subsoils such as grain size, permeability, compaction, and Atterberg limits.

Location of rock outcroppings
Regional geology
Hydrogeological setting
Ground water depth, flow direction and quality

- Hydrological Data
  Surface water runoff rates and patterns
  Drainage basins
  On-site ponds, streams, and intermittent drainages
  Flood plain designations

- Climatologic Conditions
  Temperatures
  Precipitation
  Evapotranspiration
  Wind velocities and direction

- Transportation Systems
  Access roads
  Potential site entrances
  Traffic patterns and counts
  Anticipated arrival times of waste loads
  Existing roads on-site
  Facilities for private citizens

- Site Operation
  Site operator
  Equipment limitations
  Management systems to be employed
  Desirable operating hours

- Final Use
  Natural or architectural landforms
  Existing and anticipated final drainage patterns
  Necessary settlement allowances
  Existing vegetation to be saved
  Requirements for property line grade transitions
  Potential uses of landfill facilities (well, power, buildings, etc.) for final use.

4.5.1.3 Development of Alternative Designs

A number of factors must be considered when evaluating design alternatives. For example, when considering leachate control and ground water protection, the following may be examined:

- Unprocessed wastes versus baling or shredding of wastes
- Clay versus artificial liner
- On-site leachate treatment versus treatment at municipal plant

- Accelerated versus retarded leaching
- Slopes of 2 percent versus 10 percent slopes

Often a procedure of trial and adjustment is necessary to find the combination of alternatives best for each specific site. Alternative designs should also consider method of disposal, source and use of cover material, entrance location and design, road design and routing, cell sequencing, cell size and location, gas control techniques, landscaping, utilities and facilities, litter control, drainage control, and final site use.

The final product of this step is a written description of the alternatives, drawings showing the major features of each alternative, and a cost estimate for each alternative. The descriptions, drawings, and cost proposals should be in a form that is readily understood by the persons who will be evaluating the various concepts and will be included in the preliminary engineering report discussed in the following section.

.Each of the alternatives is evaluated with respect to the goals and objectives. Trade-offs will be necessary. For instance, one alternative may be the best in terms of leachate control, but have some disadvantages for gas control or final site use. Ranking of goals and objectives helps to define the alternative which satisfies the most important goals.

After obviously infeasible systems are discarded, an evaluation technique such as assigning a numerical value to each criterion and a numerical weight to the extent that a particular alternative satisfies the criterion is sometimes employed. This evaluation method provides for inclusion of many criteria in the evaluation process.

Selection of the best design should include input from individuals or groups who will be directly or indirectly affected by the landfill. Public involvement, as described in the landfill siting chapter, as well as the involvement of site operators, solid waste disposal authority, public and commercial refuse hauler, and regulators at all levels should be a part of the design selection process.

The'final product of the landfill design phase is a preliminary engineering report which is submitted to the regulatory agencies for review. This report describes the design criteria and presents all performance and design elements for the selected alternative. Although preparation of this report adds another step in the design process, it allows for reconciliation of review agency questions before the detailed plans are prepared.

4.5.1.4 Detailed Design

The fifth step in landfill design is the preparation of construction plans and specifications and detailed operations, closure and post-closure plans. The final product includes complete instructions for maintaining the landfill over its operating life, as well as the twenty to thirty year post-closure period.

The detailed design of the landfill will generally consist of the following:

1 Plans and specifications for all facilities in the proposed active areas, access roads, stormwater controls, fencing, buildings, sanitary facilities, monitoring, and all other site improvements required for the landfill.

2. A series of drawings delineating the landfill at various stages of completion.

3. A narrative description of operating procedures (operating plan).

4. An analysis of equipment and manpower requirements.

5. An estimate of capital and annual operating costs.

6. A final land use plan for the completed landfill.

4.5.2 Basic Data Requirements

4.5.2.1 Regulatory Requirements

The applicable laws, regulations and permits that relate to landfill design are included in Chapter 2 of this manual. Federal, state, and in some areas, local governmental standards will apply. Chapter 9 of this manual discusses the specific Washington State design and permit requirements contained in the Minimum Functional Standards.

4.5.2.2 Solid Waste Quantities and Characteristics

It is necessary to know the type and quantity of wastes which will be handled. The waste type or types will affect the handling techniques, while the waste quantities will be the determining factor in site lifetime, daily operating procedures, and cover requirements. The waste type most commonly encountered is generated by residential and commercial sources and consists of a mixture of paper, wood, metal, glass, food wastes, yard trimmings, plastic, and rubber. Other materials, such as auto bodies, refrigerators, and demolition debris, can also be expected unless specifically excluded. Solid waste may be delivered in baled form or shredded prior to disposal on land. The physical condition of the waste, whether processed or unprocessed, will influence the methods and equipment used in filling operations.

4.5.2.3 Physical Site Characteristics

A base topographic map delineating existing site topography prepared to a convenient scale may be available. Existing topography should be shown using contour intervals of 5 feet or less, depending on site topography. A topographic map published by the U.S. Geological Survey is useful as a base map to show the location of roads, rivers and lakes, buildings, railroad tracks, highways, some utilities, gravel pits, and other features. The topographical contours also show the shape of the land surface.

If available maps are inadequate or outdated, the site should be resurveyed or recent maps should be obtained. Aerial photographs are particularly useful for the landfill base map. The map should include the entire site and encompass surrounding areas that may be affected by site operations. The' property line, buildings, buffer areas, vegetation, wells, watercourses, rock outcroppings, roads, utilities, and other pertinent details should be delineated on the base map.

4.5.2.4 Geotechnical and Hydrological Data

Geotechnical and hydrological data are both important areas of concern in landfill design and should be included in the basic data requirements. Each is discussed in detail in Section 4.2 of this manual.

4.5.2.5 Climatological Data

Weather conditions are important considerations in the design of landfills. Surface water control is directly dependent on precipitation, infiltration and evaporation. Leachate control will also be directly influenced by precipitation, along with evaporation and transpiration. Site access may be affected by wet or freezing weather conditions. Where freezing is severe, landfill cover material should be stockpiled when excavation is impractical. Wind patterns should be considered in the establishment of windbreaks to control blowing debris. Climatological data can usually be obtained from the National Weather Service or from local weather observers. It is particularly important that recent, accurate precipitation data representative of the landfill site be obtained since the design of surface water and leachate management facilities is so dependent on this information.

4.5.2.6 Waste Transport System

The transportation system over which wastes are carried to the landfill is a major consideration in site selection and design of the landfill. Potential site entrance points and the type of roads needed on-site must be identified. A high volume site should have permanent roads built to the disposal area, while a low volume site may satisfactorily employ temporary roads.

Control of traffic at the site is an important concern, specifically, how the on-site roads route trucks to the working face. Commercial and municipal collectors will want to minimize waiting times at the site. Procedures for private citizens wanting to dump wastes must also be considered.

Many landfill operators find that allowing private citizens at the disposal face interferes with site operation and can lead to unsafe conditions. Separate facilities for private citizens, such as on-site transfer stations, can provide citizens with disposal service and eliminate interference with commercial haulers.

4.5.2.7 Operational Procedures

One purpose of careful landfill design is to maximize operational effectiveness of the site. Operational procedures should be incorporated into the site design to ensure compatible procedures. Necessary background information includes identifying who will operate the site, possible operating procedures, current equipment availability, and the performance limitations of the equipment.

Management facilities which must be identified include:

- Scales to weigh incoming loads of refuse
- , Methods for determining the volume of the site which has been filled
- Records on machinery use, maintenance, and fuel consumption
- Accounts of landfill costs and revenues
- Data on waste quantities, cover soil location and use
- Safety records

Generally, phased or modular development is employed, whereby the landfill is constructed in segments and the excavation from the phase under development is used for cover material in the active phase. Building the landfill in phases allows the completed sections to be used for other purposes, or, if necessary, the landfill can be closed after the completion of any phase. This also limits the area exposed at any one time.

4.5.2.8 Final Site Use

The final use of the landfill should be considered when the site is being designed, in order to provide for the best use of the property. Site closure is an important and expensive part of the site use; even relatively small sites can cost hundreds of thousand dollars to close properly. Good planning at the earliest possible point in site design will minimize costs and maximize the usefulness of the site after closure, including the need to do monitoring and maintenance for a number of years after closure.

Options for final use should be identified. Final use should be compatible with nearby land use as well as the limitations of the landfill to support structures. Consideration should also be given to compatibility with existing landforms and land use, settlement allowances, and drainage patterns.

4.5.3 Capacity Requirements and Site Life Estimates

4.5.3.1 Solid Waste Generation

Generally, the quantity of solid waste that is to be disposed of in the landfill will have been identified in the Solid Waste Management Plan or some other planning document prepared by the solid waste disposal authority. If no information is available, the quantity must be estimated.

Solid waste generation rates vary widely, depending on many factors such as climate, locale, season, collection frequency, population characteristics, extent of recycling, etc. Both volume and weight are used to measure solid waste quantities. However, volume as a measure of quantity can be misleading. To avoid confusion, solid waste quantities should be expressed in terms of weight, then converted to volume by a more accurate in-place refuse conversion.

Methods commonly used to assess the generation of solid wastes are:

1. Load-count analysis
2. Weight-volume a nalysis
3. Materials-balance analysis.

Load-count analysis determines the quantity of solid waste collected over a period of time from a given location. Weight-volume analysis provides information on the density of solid waste collected from a given location. But only a materials -balance analysis will determine the generation and movement of solid wastes for each generation source. Because of the high cost and effort involved, the materials-balance method should be used only in special situations. Typical solid waste generation rates are listed in Table 4.3 and may be used if actual generation rates for the subject area are not available.

Table 4.3. Typical Solid Waste Generation Rates.

	Rate, lb/capita/day	
Source	Range	Typical
Municipal (1)	2.0 - 5.0	3.5
Industrial	1.0 - 3.5	1.9
Demolition	0.1 - 0.8	0.6
Other municipal (2)	0.1 - 0.6	0.4
Agricultural (3)	unknown	
Special wastes (3)	unknown	

Source: Tchobanoglous, et al., (1977)
(1) Includes residential And commercial
(2) Excludes water, waste water and industrial treatment plant wastes which must be estimated separately for each location
(3) Must be estimated separately for each location

4.5.3.2 Solid Waste Densities

Reported densities of solid waste vary widely because there is little or no uniformity in the way the densities are reported. Often, no distinction has been made between uncompacted or compacted densities. Typical densities of municipal solid wastes are listed in Table 4.4. These values can be used where specific information is not available.

Table 4.4. Typical Densities of Municipal Solid Waste.

Source	Density, (lb/cy) Range	Typical
Residential (uncompacted)		
Mixed refuse(l)	225 - 500	350
Rubbish(l)	150 - 300	220
Garden trimmings	100 - 250	175
Ashes	1,100 - 2,000	1,400
Residential (compacted)		
In compactor vehicle	300 - 750	500
In landfill (normally compact	600 - 850	750
In landfill (well compacted)(2)	800 - 1,400	1,100
Residential (after processing)		
Baled	1,000 - 1,800	1,200(3)
Shredded, uncompacted	200 - 450	360(3)
Shredded, compacted	1,100 - 1,800	1,300(3)
Commercial-industrial (uncompacted).		
Food waste (wet)	800 - 1,600	900
Combustible rubbish	80 - 300	200
Noncombustible rubbish	300 - 600	500
Commercial-industrial		
In landfill (well compacted)(2)	1,000 - 2,500	1,600
Combination refuse		
In landfill (well compacted)(2)	1,200 - 1,800	1,400

Source: Tchobanoglous, et al., (1977)

(1) Does not include ashes.
(2) Using special landfill compactor equipment, two foot maximum lift thickness, and four to five compactor passes per lift.
(3) Low pressure compaction, less than 100 lbs/sq. in-.

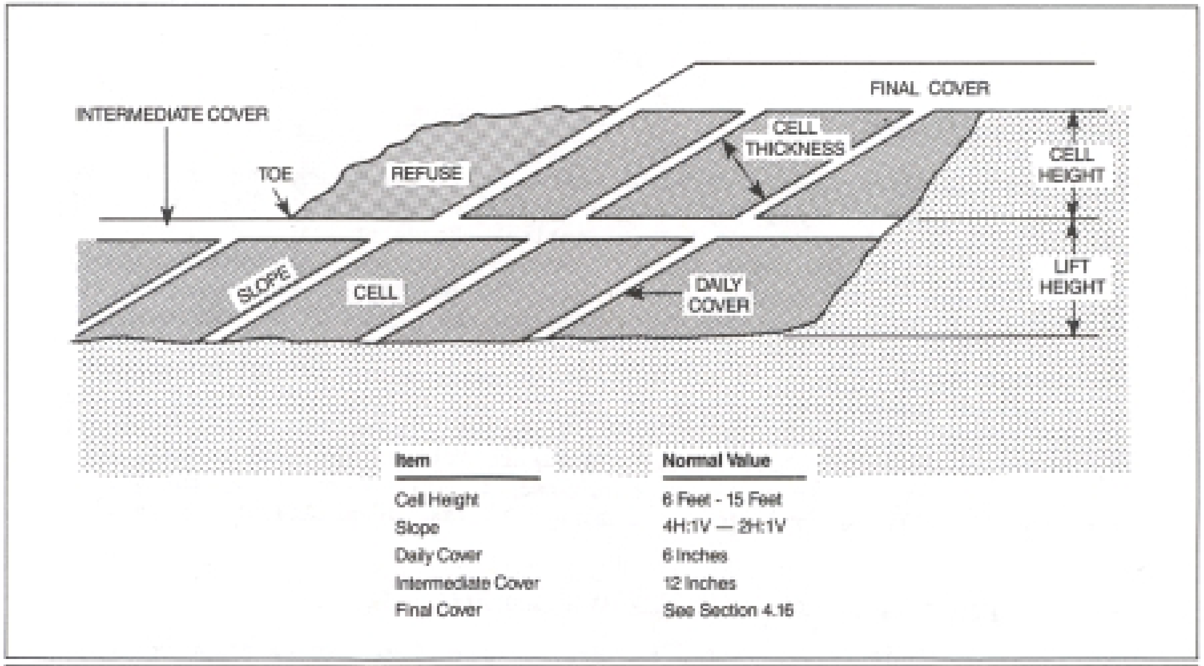

Figure 4.13
Typical Landfill Cell Construction

4.5.3.3 Cell Construction and Cover Material

Landfilling should be accomplished using a series of cells and lifts as illustrated in Figure 4.13, regardless of the operational method of landfilling used (i.e., area method, trench method, etc.). The cell height should be determined on the basis of the area required to adequately dispose of the daily refuse volume while minimizing the cover material volume and active area exposed to precipitation.

Cover material volume requirements depend on the surface area of waste to be covered and the thickness of soil needed to perform particular functions. As might be expected, cell configuration can greatly affect the volume of cover material needed. The surface area to be covered should be kept minimal. In general, the cell should be about square, with sides sloped as steeply as practical operation will permit.

Cover volume generally runs about 15 to 30 percent of the compacted refuse volume depending on factors such as the cell height, cell configuration and thickness of cover. For design purposes, if specific information is not available, a value of 25 percent (1 cubic yard of cover for every 4 cubic yards of compacted waste) is often used (Tchobanoglous et al., 1977; ASCE, 1976; Noble, 1976; Brunner and Keller, 1972; APWA, 1970). This value includes daily and intermediate cover material requirements.

4.5.3.4 Settlement

Settlement normally occurs at solid waste landfills and during the active life of the landfill may add to the available capacity. The extent of settlement depends on the initial compaction, characteristics of the waste, degree of decomposition and effects of consolidation when leachate and gases are formed out of the compacted material. The height of the compacted fill will also influence the initial compaction and the degree of consolidation.

The degree of settlement to be expected in solid waste landfills resulting from initial compaction is shown in Figure 4.14. About 90 percent of the ultimate settlement occurs within the first five years (Tchobanoglous, et al., 1977; and APWA, 1970). Data from Figure 4.14 can be used to determine landfill capacity requirements and estimated site life when the operations of the landfill will be conducted in a -manner to take advantage of any settlement.

4.5.3.5 Determination of Landfill Volume and Site Life

The required landfill volume for the desired site life can be computed based on the quantity of solid waste to be generated over the design period, the in-place compacted density to be achieved, the volume of cover material to be used during the life of the landfill, and any allowance for expected settlement.

If it is assumed that all cover material comes from on-site, then it is possible to estimate the total life of the site by first *determining the* amount of solid waste that can be adequately covered by the volume of cover material available on the site. This quantity can then be compared to the estimated solid waste generation rates to approximate site life in years. Imported cover material would extend the site life, subject to other constraints on landfill volume, although cover material availability is commonly a major constraint.

4.5.4 Soil and Geosynthetic Materials Requirements

Early in the landfill design process, the quantity of different types of soil materials needed for construction of the various landfill design elements should be determined so that maximum use can be made of on-site soils. Several types of soils will generally be needed:

- Low permeability, fine-grained soils for the bottom liner and cover cap
- High permeability sand and gravel for the drainage layers and gas venting system
- Suitable soil for daily and intermediate cover
- Topsoil for the final cover

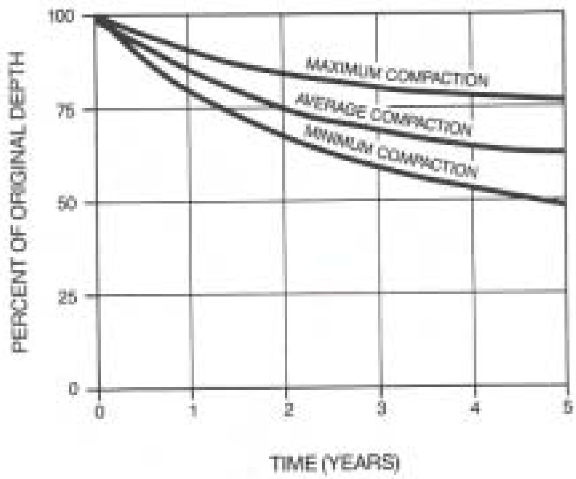

Figure 4.14
Surface Settlement of Compacted Landfill

Adapted From: Tchobanoglous, Theisen and Eliassen, 1977

Once volume and area requirements of the landfill have been estimated, the quantities of the various types of soil materials needed for construction can be determined. Few sites will have adequate quantities of all the types. of required soils and the import of certain soils or the use of geosynthetics may be necessary. A brief discussion of the requirements for the various soil materials used in landfill *construction follows*.

4.5.4.1 Bottom Liner

Requirements for bottom liners constructed of natural. soils or amended natural soils, as well as alternate bottom liners, are discussed in Section 4.12. Natural soil liners are clay soils with extremely low permeability, generally containing 50 percent or more fines. Some silty soils containing fewer fines may be suitable for use in admixtures.

4.5.4.2 Leachate Collection Laver

Requirements for soil materials used in the leachate collection system are discussed in Section 4.13. Materials are required for the gravel bedding and drainage envelope around the collection pipes, as well as the drainage layer between the pipes. Material for the envelope around the pipe will likely need processing and may have to be imported.

4.5-4.3 Daily and Intermediate Cover

A method to estimate the total amount of cover material needed for construction and operation of a landfill based on the volume of solid waste is presented in Section 4.5-3. A better method, however, is to estimate the daily and intermediate cover material requirements based on the proposed fill operation. Final cover material requirements are estimated separately as discussed below. By preparing a filling plan and operation sequence that estimates the cell configuration and number of lifts, the required quantity of daily and intermediate cover material can be determined. Daily cover should be 6 Inches thick, while intermediate cover should be 12 inches thick.

Materials suitable for daily and intermediate cover should meet several criteria. After being placed in the landfill, the material should be fairly permeable so that leachate can percolate through to the collection system without being forced horizontally to the sides of the landfill forming seeps. Also, the material should be permeable enough to allow passage of landfill gas to the gas venting system. Material for c ' over use in wet weather should be free draining enough to minimize handling problems. A suitable cover material should fall within the following guidelines: percent fines below 30 percent and minimum permeability of 1x10-4 cm/sec.

A wide variety of soils may be suitable for use as daily and intermediate cover, but a sandy soil can best meet the above criteria. Soils that have too great a fines content may still be usable if they are supplemented with a sandy soil to provide adequate permeability for gas venting and good trafficability. For wet weather cover, sandy soils could be imported if they are not available on the site.

4.5-4.4 Final Cover

Material requirements and methods to determine the required thickness for the various components in the landfill final cover are discussed in Section 4.16. Typical requirements include:

- Low permeable soil for the barrier layer
- High permeable soil for the drainage layer, if specified
- Loamy topsoil for establishing vegetative growth

4.5.4.5 Miscellaneous Soil Requirements

Besides the soil requirements necessary for construction and operation of the actual landfill, soil requirements for other facilities constructed in conjunction with the landfill should be considered. Typical facilities that may require soil materials are surface water control facilities such as dikes and detention basins, ground water control facilities such as impermeable barriers, leachate treatment facilities such as lagoons, and site improvements such as roads and berms.

4.5.4.6 Geosynthetics

Geosynthetics are man-made products that can substitute for soils in some applications. Typical geosynthetics used at solid waste landfills include:

- Flexible membrane liners used as low permeable layers in the bottom liner or final cover
- Drainage net used for leachate collection or as a drainage layer in the final cover
- Filter fabrics used to protect collection systems from clogging by fine soil particles
- Plastic grids used for reinforcement of slopes or road base foundationsupport
- Plastic mesh used for erosion control on steep slopes and in ditches

4.5.5 Design Methodology

Once the basic data has been obtained, the required volume estimated and the requirements for the various soil or geosynthetic materials determined, the actual design of the landfill can begin. There is no single standard approach to landfill design; each site should be considered on its merits. Generally, the procedure involves locating the landfill within the confines of the site, determining the base and top elevations, and then doing a soi 1 materials balance to determine if the materials to be excavated for construction are adequate or excessive for the various requirements. A series of trials and adjustments will be necessary to optimize the design.

4.5.5.1 Location

By examining topographic, geotechnical, and hydrogeological data, as well as MFS Locational Standards and other information obtained with the basic data requirements, a location for the landfill within the site area can be selected. Landfills can usually be adapted to various types of terrain, but certain topographical features are better suited than others. Landfills can be constructed in swales and ravines or on side hills with minimum excavation and the finished landfill can be designed to blend in with the surrounding topography. Landfills on flat terrain generally require more excavation, at least initially, and it may be difficult to blend the completed landfill into surrounding topography.

4.5.5.2 Base Elevation

Establishing the base elevation of a landfill is one of the most important aspects of the design process. This elevation should be established on the basis of the minimum 10-foot allowable separation between the bottom of the lowest landfill liner and the top of the underlying ground water aquifer as required in WAC 173-304-130. This minimum 10-foot separation may be reduced to 5 feet only if a ground water hydraulic gradient control system is installed. Geotechnical data, as discussed in Section 4.2, should provide information on the soils underlying the landfill and the location of the ground water aquifer.

With the required separation and ground water levels determined, the base elevation can be set. Once the base elevation is set, the top elevation can be determined based on the required volume and the area available for the landfill.

4.5.5.3 Materials Balance

Once the top and bottom elevations are known, the quantities of the various types of materials to be excavated for any proposed bottom elevation and landfill configuration are balanced against the previously determined soil material requirements for landfill construction and operation. The most economical landfill design excavates no more soil materials than necessary for construction and operation of the landfill. However, other considerations, such as the ability for leachate to flow by gravity from the landfill to a treatment facility, may be an overriding factor.

The soil materials balance is a procedure of trial and adjustment. Because importation of material may be very costly, it is generally better to have a slight excess of material, rather than a shortage. Soil material requirements that cannot be met by the on-site materials excavated for construction of the landfill must be imported to the site. In some cases, a source may be close enough to the landfill site that a borrow operation can be set up and operated in conjunction with the normal landfill operation, even though the borrow pit will not be used as part of the landfill.

When the final landfill base elevation has been selected and the landfill configuration determined, a bottom grading plan and final grading plan should be prepared. Because the landfill is normally constructed in phases, intermediate grading plans for each of the phases should also be prepared. These plans should show the proposed grade contours for the base, top and each of the various phases of landfill development.

4.5.6 Site Development Plan

Once the final landfill base elevation and configuration are determined, the remaining steps in the design process focus on the site development and related facilities necessary for the landfill operation.

A solid waste landfill is like a long-term construction project. Most aspects of conventional construction activity are undertaken, including clearing, earthwork, road construction, building design and erection, drainage control, and installation of utilities. In addition, special attention must be given to the design of features unique to the landfill operation. These include provisions for odor, gas, and leachate control, subsidence and differential settlement control, construction of temporary facilities, phased construction of solid waste cells, final grading of the site following cessation of filling activity, and landscaping. All of these considerations should be a part of the site development plan.

4.5.6.1 Roads

Various specifications and manuals are available from the Washington State Department of Transportation and other sources for reference in the design and construction of all-weather access roads. An all-weather access road should be provided from the public road to the site. This road, designed to safely accommodate the anticipated volume of vehicular traffic, should consist of two lanes of sufficient width and strength to carry the delivery vehicles. The grade of the access road should be maintained at 8 percent or less and its intersection with the existing public road should be carefully designed to reflect traffic volumes and safety requirements. Roads should be laid out to eliminate crossing of traffic and consequent tie-ups. Waiting space should be provided near the scales and parking areas should be provided for employee vehicles and landfill equipment.

The access road generally terminates at the scale or other delivery control facility. Temporary roads utilized for transporting wastes from this point to the unloading area may be constructed of on-site soil with a topping of suitable material, such as gravel, crushed aggregate, cinders, broken concrete, or demolition wastes. Lime, portland cement, or asphalt may be used as binders to maintain stability and control dust. Plans should include provisions to keepthe access road and adjacent public roads free of mud and litter.

4.5.6.2 Drainage

Appropriate permanent and temporary drainage facilities must be provided to control surface runoff at the site. Surface waters must be diverted away from the areas to be filled with solid wastes. Methods to determine the quantity of surface runoff and various types of control facilities are discussed in Section 4.8 and 4.11. Methods to control ground water are discussed in Section 4.9.

4.5-6.3 Leachate and Gas

The Minimum Functional Standards include design elements for leachate and landfill gas management. The final design will be dependent upon specific site conditions such as climate, surrounding land use and proximity of treatment facilities. Leachate generation can be largely prevented by preventing contact between water and waste materials by diverting surface waters away from the fill, preventing infiltration of precipitation into the fill by properly covering refuse, maintaining adequate drainage during operation and properly compacting and grading the final cover when filling activities are completed. Methods to predict leachate generation are discussed in Section 4.10. Bottom liners and leachate collection systems are discussed in Sections 4.12 and 4.13, respectively. The treatment and disposal of leachate is discussed in Section 4.14.

Gas migration is a potentially dangerous problem at existing, unlined solid waste landfills. Suitable gas control facilities must be provided to prevent off-site migration of methane. Methods to control landfill gas are discussed in Section 4.15. New, lined landfills should not experience the same problems with subsurface methane migration because the liner will contain the methane gas.

4.5-6.4 Monitoring

Surface and ground waters are required to be monitored. Air quality should also be monitored, particularly in regard to emissions from gas burning flares. Monitoring for subsurface methane migration is required at unlined landfills to ensure methane is not moving beyond the facility boundary in excess of state standards. At new, lined landfills, methane monitoring may be employed to ensure the integrity of the liner. Monitoring- devices and methods are discussed in Chapter 8. These facilities should be included in the site plan development.

4.5.6.5 Overburden and Material Storage

A stockpile area should be provided for storage of material excavated during construction of a landfill and for the various materials that may need to be imported to the site for operation. The stockpile area should be large enough to store the excess material that is excavated during construction of the landfill, prior to its use as cover during filling operations. In addition, adequate area should be provided to store a supply of any imported materials such as winter cover material. All-weather access to the stockpile area should be provided. Drainage facilities and provisions to control erosion should be provided in conjunction with the stockpile area.

4.5-6.6 Special Wastes

Landfills that receive special wastes that must be handled differently from ordinary solid wastes should include a designated area and facilities as necessary to handle and dispose of these wastes. Special wastes that should be given consideration for separate handling and disposal areas are discussed in Sections 4.3 and 4.4.

4.5.6.7 Fencing and Signs

Fending controls or limits access to the landfill site. Woven and chain link fencing is commonly used for these purposes. A gate is required at the site entrance and should be locked when the site is unattended or otherwise closed to users. The entrance should be attractively designed and landscaped. A sign prominently located should identify the landfill site, the hours of operation, fees, and any restrictions on users or materials acceptable for delivery.

4.5.6.8 Buffer Zone

The site development plan must include a zone around the perimeter of the landfill site to buffer adjacent property, to limit access by unauthorized. persons and prevent litter, dust and noise from escaping the site. The working area of the landfill should be visually separated from adjacent property by natural vegetation or by the use of plantings and berms which also reduce the problems of litter, noise and dust. Minimum width of the buffer zone, as specified in VAC 173-304-130, is 100 feet except in areas zoned for residential, where the buffer must be at least 250 feet wide.

4.5.6.9 Buildings

A building should be provided for office space and employee facilities at most landfills. Very small sites may not require these facilities. Equipment used at the site should be provided with a shelter. A single building or shed may be used both for equipment maintenance and storage, as well as for the office purposes. Appropriate sanitary facilities must be provided for landfill employees and users of the site. Portable chemical toilets can be used for this purpose. At larger sites, employees should be provided with shower and lunchroom facilities. Generally, the design of such facilities will depend upon the size and planned duration of landfill use.

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

4.5.6.10 Utilities

Solid waste landfills should be provided with power, water, and telephone. Power is required for maintenance of on-site operating equipment and for lighting. An electric generator may be installed rather than extending power lines to the site. Water in sufficient quantities and under adequate pressure is needed in the event of a fire, for machine maintenance, and for dust control. Portable water should be made available for site personnel. A telephone or radio should be provided for communications. Communications are particularly important in the event of an accident or a fire at the landfill.

4.5.6.11 Scale

Recording the weights of solid waste delivered to a site not only regulates and controls the landfill operation, as well as the solid waste collection system that serves it, but can also provide an equitable basis for the assessment. The scale type and size will depend on the size of the landfill operation and the vehicles using the facility. A portable scale and periodic weight surveys may suffice for a small site, while a very elaborate system employing load cells and printed output may be justified at a large landfill. Electronic scales cost more than the simple beam scale, but their speed and accuracy may justify their use. The scale should be capable of weighing the largest (weight and wheel base) delivery vehicle that will use the landfill on a routine basis. The platform should be long enough to simultaneously weigh all axles.

4.5.6.12 Truck Wash Facilities

Vehicles hauling solid waste to the landfill working area often must drive over dusty or muddy roads and previously spread solid waste. In order to prevent mud and debris from dropping from the vehicles when they return to the public roads, consideration should be given to truck wash facilities at the landfill site to routinely clean the trucks. These facilities can also be used to clean the landfill equipment. The need for wash facilities should be considered on a case-by-case basis, but generally the more vehicles entering and leaving the site, the greater the need for wash facilities.

4.5.6.13 Public Access and Transfer Station

Public access to the working area of the landfill can create conflicts with landfill equipment and large hauling vehicles which could create unsafe conditions. When these conditions could exist, consideration should be given to providing a drop-box container or transfer station near the entrance of the landfill. This will allow for wastes delivered by individual persons to be deposited properly, while keeping traffic away from the working area.

4.5.6.14 Recycling Facilities

While scavenging, or the uncontrolled removal of materials from the landfill, is prohibited by law, salvage or recycle operations are required by WAC 173304-460, unless an equivalent method of encouraging the public to recycle is provided. Containers should be provided for recycled materials and a designated area should be included in the site development plan. Access to the recycling area should be controlled by fencing to prevent unauthorized removal of salvaged materials.

4.6 LRACHATE MANAGEMENT

4.6.1 Generation

4.6.1.1 Precipitation

Leachate is defined in the Minimum Functional Standards as:

> "water or other liquid that has been contaminated by dissolved or suspended materials due to contact with solid waste or gases therefrom."

Typically, the largest source of water that contributes to the generation of leachate is precipitation. During a precipitation event, some of the water runs off the surface and some is evaporated. The remaining fraction infiltrates the ground surface and enters the soil. Some of this water will be held in storage by the soil and some-will be evapotranspirated by the plants whose roots penetrate the soil and withdraw the moisture. That water which is not held in storage and not evapotranspirated will percolate down into the buried solid waste. Once in contact with solid waste, the percolating water becomes contaminated and is termed leachate. Methods for estimating the volume of leachate generated from precipitation are presented in Section 4.10.

Management of leachate generated from precipitation is directed toward increasing runoff, evapotranspiration and soil moisture storage capacity.

This is achieved through proper design of the final cover system. The design of a final cover is discussed in Section 4.16.

4.6.1.2 Surface Water Run-on

Vater originating off-site but flowing into the solid waste will generate leachate. The Minimum Functional Standards do not permit surface water run-on into solid waste landfills. Facilities must therefore be provided to divert run-on away from the solid waste. This subject is more fully discussed in Sections 4.8 and 4.11.

4.6-1.3 Ground Water Inflow

Ground water that comes into contact with solid waste will also generate leachate. The Minimum Functional Standards require a minimum separation of ten feet between the seasonally high ground water table and the buried solid waste. This requirement will prevent ground water contact with solid waste and the subsequent generation of leachate from this source.

Existing landfills permitted prior to enactment of the new Minimum Functional Standards may not have met this standard. Therefore, solid waste in some landfills may be in contact with ground water and generating leachate. Possible corrective actions for this situation are described in Section 7.6.

4.6.2 Attenuation

Attenuation is the reduction in concentration of chemical constituents in leachate for some fixed time or distance traveled (Fuller and Korte, 1976). Attenuation occurs through various physical, chemical and biological processes, some of which are listed in Table 4.5.

Leachate attenuation is of little significance in the design of new or expanded solid waste landfill in non-arid regions since the Minimum Functional Standards require a bottom liner and leachate collection system for these facilities. However, for existing unlined landfills or new landfills in arid regions, an understanding of leachate attenuation is necessary to assess the potential for leachate contamination of ground water.

Filtration of leachate through the soil profile entraps settleable and suspended solids much like sand filters in conventional water treatment plants (Crump and Malotky, 1978). Dissolved constituents are not removed unless they are adsorbed to the surface of particles that can be entrapped. Very fine particles could move through the soil pore spaces without being entrapped.

Molecular diffusion and hydrodynamic dispersion in the ground water flow system facilitates dilution of leachate constituents by mixing with uncontaminated ground water. Molecular diffusion is the movement of solutes across a concentration gradient from an area of higher concentration to an area of lower concentration. This is a very slow process and it is significant only in a ground water flow system with a very slow flow velocity. Hydrodynamic dispersion is caused by velocity gradients in the pores, different cross-sectional area of the pores and different lengths and branching of the pores (Freeze and Cherry, 1979). In addition to these microscopic processes, macroscopic dispersive processes caused by heterogeneities in the geologic environment promote mechanical mixing (Gilham and Cherry, 1982). Neither molecular diffusion nor hydrodynamic dispersion remove any constituents from solution; they merely reduce the observed concentration by dilution with uncontaminated water.

Table 4.5. Attenuation Processes.

Physical	Chemical	Biological
filtration	precipitation	degradation of organics
molecular diffusion	ion exchange	nitrification and denitrification
hydrodynamic dispersion	adsorption	oxidation or reduction of inorganic compounds
	oxidation	modification of organic compounds
	reduction	production of carbonic and organic acids
		depletion of oxygen supply

Chemical reactions remove or modify some constituents of landfill leachate. Removal may be permanent or temporary, depending on a wide variety of conditions. Precipitation is the phase change of a dissolved constituent to a solid phase when the solubility of the constituent is exceeded. Each chemical constituent has its own solubility constant. The solubility is also influenced by temperature, ph, pressure and common ion effects **(Snoeyink and** Jenkins, 1980). Of these, pH is one of the most important (Crump and Malotky, 1978). Changes in environmental conditions therefore affect precipitation reactions, such as a reduction in pH increasing the solubility of metal precipitates. Thus, a constituent that is precipitated at one time may dissolve into solution in response to environmental changes.

Ion exchange and adsorption are recognized as the most important chemical attenuation mechanisms (Crump and Malotky, 1978; U.S. EPA, 1977b). Ion exchange reactions substitute one ion for another on the surface of a substrate molecule. In leachate, heavy metals and other cations are exchanged for calcium, magnesium and sodium (U.S. EPA, 1977b). Adsorption does not depend on an ion exchange reaction. Adsorption phenomena are controlled by chemical and electrical forces, orientation energy, London-van der Waals force, hydrogen bonding and surface tension (Stumm and Morgan, 1981). Factors important in adsorption reactions include pH, soil clay content and the presence of hydrous oxides (Fuller and Korte, 1976).

Oxidation and reduction reactions influence the oxidation state of various leachate constituents and subsequently affect their participation in precipitation/dissolution, ion exchange, complexation and adsorption reactions. The oxidation state of reactants is controlled by pH, pE and biological activity (Stumm and Morgan, 1981). Oxidation and reduction reactions do not remove reactants from solution, but they do affect whether or not a reactant will be removed by other mechanisms.

Biological reactions are very important in determining the degree of attenuation that leachate constituents undergo. As shown in Table 4.5, biological activity affects both organic and inorganic compounds. Organic compounds can be consumed as an energy source or transformed into other compounds that, in turn, influence other chemical and biological reactions. Consumption of oxygen and production of carbonic and organic acids influence the subsurface environment and subsequently the reactions that take place there. Changing environmental conditions also affect the development of microbial species which, in turn, affects the biological reactions taking place. A common example is the depletion of oxygen by aerobic decomposition, which leads to the development of anaerobic decomposition and methanogenic bacteria populations.

The leachate attenuation process is extremely complex and has an enormous variety of interrelated factors. Limitations of current theoretical models and the complexity of the system have prevented the development of a reliable predictive model for leachate attenuation (Crump and Malotky, 1978). However, based on previous research some general conclusions can be made. In comparing work by Fuller and Korte (1976) and Griffin and Shimp (1976), Roulier (1977) notes the following order of mobility for non-metallic constituents and iron:

$$Cl > Na > COD > Mg > NH4 > K > Si > Fe$$

Metallic constituents were ranked into mobility categories as follows:

High mobility - Hg, Cr(VI), Se (IV) and Ni
Intermediate mobility - Cd, As(III), As(V), V, Be and Zn
Low mobility - Cu, Pb and Cr(III)

With the exception of Ni, these results compare favorably with conclusions reached by Crump and Malotky (1978). They developed a synthetic lyotropic series of attenuation potential for Minnesota soils that indicated an order of mobility as follows:

$$N0_3=Cr(VI)>SO_4=Se>F=Hg>phenols=oil=COD=CN>NH_4>B=As>Ni=Cd>Zn=Mn=Fe=Cu>Cr(III)>Pb=Ba>P=Ag$$

It was also noted during these studies that the clay content of the soil, the presence of iron and manganese oxides, and the pH of the ground water solution were the most significant environmental variables affecting the attenuation of leachate constituents.

Even if ideal environmental conditions exist for the attenuation of leachate contaminants, it is unwise to assume that all contaminants escaping from the landfill will be attenuated. From the mobility series presented above, it can be concluded that some toxic leachate contaminants will still be highly mobile in the subsurface environment. Such contaminants include mercury, nitrate, hexavalent chromium, selenium, flouride and some organics.

It is likely that these contaminants are present in solid waste landfill leachates. In a study of five mixed municipal solid waste landfills, James (1977) found several toxic trace metals to exceed U.S. EPA drinking water standards. They included lead, selenium and mercury. Cadmium and chromium were found to vary widely in concentration from site to site.

A wide variety of organics can exist in landfill leachate. Dunlap, et al., (1976) found over 40 undesirable organic compounds in a study of landfill leachate. It was concluded these compounds were leaching from finished products common to household refuse since the landfill had no history of industrial waste disposal. In another study of municipal solid waste landfills, Sabel and Clark (1983) found several priority pollutants to be ubiquitous to landfill leachate. These *contaminants were* found to be mobile in both sand and clay soils. They included:

toluene	methylene chloride
trichlorethylene	dichloroethane
ethylbenzene	benzene
dichloroethylene	

Reliance on attenuation to protect ground water quality is not recommended because of the ability of a wide variety of landfill contaminants to migrate through the subsurface environment and the inability to accurately model or predict such migration. The determination of the pollution potential of an unlined solid waste landfill must be based on climatic and hydrogeological conditions, as well as on any leachate collection and treatment systems included in the corrective action plans.

4.6.3 Collection

The Minimum Functional Standards require all solid waste landfills regulated under WAC 173-304-460, with the exception of those using the arid liner design, to install a leachate collection system sized according to water balance calculations or other accepted methods. The collection system ensures that no more than two feet of leachate develops at the topographical low point of the active area. The two feet are measured from the top of the bottom liner.

A leachate collection system is installed directly over the bottom liner and typically consists of a layer of very permeable sand or gravel. Within this layer, is a network of perforated pipes into which the leachate flows. After entering one of the perforated pipes, the leachate flows into the transmission pipe for further transfer to the leachate treatment and disposal system.

Recently, the use of synthetic drainage materials has been applied to the design of leachate collection systems. These materials have the advantage of high flow capacity, alleviating the need for perforated pipes. However, their long term performance has not been documented and it may be prudent to include. perforated. pipes within a collection system using these materials until a reliable performance record has been established.

4.6.4 Treatment

Treatment or pre-treatment of MMSW leachate is required prior to disposal. Biological, chemical, and physical unit processes, alone or in combination, have all been successfully used for treatment of leachate. However, prior to the design of any treatment system, the chemical and physical characteristics of the leachate must be determined. Additionally, variations in leachate characteristics over time should be predicted to ensure that treatment systems are effective in treating the leachate throughout the life of the landfill. Site specific parameters such as leachate generation rate, treatment area size, and potential disposal methods must also be considered in selecting and designing a leachate treatment system. Finally, the selection of a treatment system must be based upon compatibility with other elements of the landfill design, including leachate collection, transmission, and disposal systems.

4.6.5 Disposal

Leachate disposal is one of the most environmentally sensitive issues facing the landfill operator. A leachate disposal system consists of an effluent disposal arrangement which discharges treated leachate to the environment
without endangering public health and safety. Three disposal methods have seen varying degrees of use throughout the country:

- Discharge to a publicly owned treatment works (POTW) is practiced extensively in this country and provides an efficient and effective means of treatment, if the leachate is compatible with POTW unit processes.

- Land application of pre-treated leachate is a very site specific disposal method. Used successfully in other parts of the country, it should be considered for landfills in this state that have the required land area, climate, and soil characteristics.

- Discharge to surface waters following full treatment is often a prohibitively expensive method of treatment and disposal. However, some circumstances may make discharge to surface waters a cost effective method of disposal.

Site specific parameters such as potential land application area size, distance to the nearest acceptable PON, and size and classification of nearby surface waters must also be considered in selecting and designing a leachate disposal system. Finally, the selection of a disposal system must be based upon compatibility with other elements of the landfill design, including leachate collection, transmission, and treatment systems.

4.7 LAMDFILL GAS MANAGEMENT

Placement of solid waste under the anaerobic conditions of modern solid waste landfills has virtually eliminated many of the nuisances and health hazards associated with open dumps. However, the method has, at the same time, introduced a new environmental problem, methane gas generation and migration.

Gas production within a landfill, and subsequent gas migration, may stress vegetation growing on or near the landfill, create an odor nuisance, or result in a potential threat to public safety. Therefore, gas management is a necessary consideration in the design of all landfills. containing organic wastes.

Methane is a colorless, odorless and lighter- than-air gas which can readily concentrate to explosive levels in enclosed areas. It is flammable at concentrations from 5 to 15% by volume in air at atmospheric pressure and normal temperature. Several cases of landfill methane gas explosions have been reported (Stone, 1978).

A significant environmental effect of landfill gas migration is damage to vegetation on the landfill site or adjacent property. Landfill gas production and migration can affect plants in several ways, including:

- Oxygen depletion in the root zone
- Elevated soil temperatures
- Toxic effects of methane gas on plant physiology

Odor problems are an environmental nuisance associated with landfill gas production. Although methane and carbon dioxide, the principal components of landfill gas, are odorless, other constituents of landfill gas, including hydrogen sulfide, mercaptans, and volatile organic gases produced as the result of decomposition, give the gas an offensive odor.

An effective gas management program, preferably initiated at the landfill design level, can do much to alleviate these potential landfill **gas hazards** and nuisances and to ensure protection of the environment.

4.7.1 Methane Generation

Methane gas production is a common and unavoidable microbiological phenomenon which occurs following the landfilling of organic solid wastes. Typically, the rate of generation is roughly 0.04 cubic feet of methane gas per pound of refuse per year (Schumacher, 1983). However, this rate is highly variable, depending upon the solid waste characteristics and environmental conditions within the landfill. Landfill methane production is also time dependent, with four characteristic phases as shown in Figure 4.15.

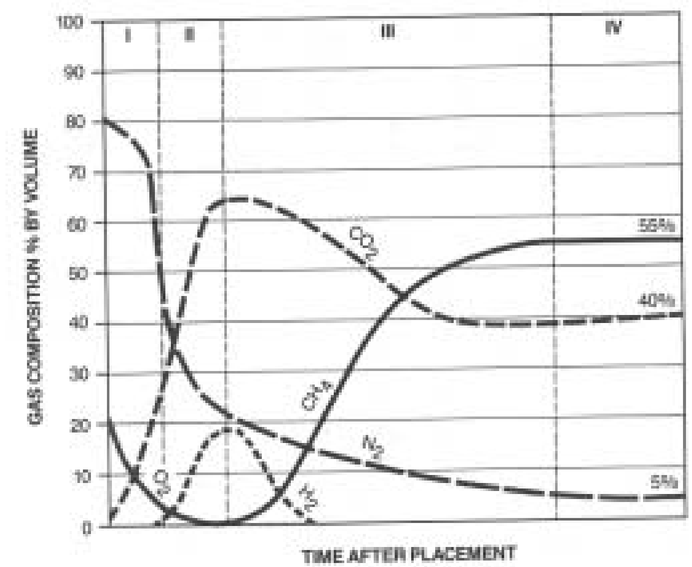

Figure 4.15
Evolution of Typical Landfill Gas Composition

I = Aerobic
II = Anaerobic, Non-Methanogenic
III = Anaerobic, Methanogenic, Unsteady
IV = Anaerobic, Methanogenic, Steady

When initially placed, air trapped in the solid waste provides an aerobic environment. Aerobic microorganisms quickly consume the oxygen, producing carbon dioxide, water, residual organics, and heat (Ham, et al., 1979). As the landfill becomes anaerobic, a second phase begins, dominated by anaerobic acid-forming bacteria. The anaerobic microorganisms hydrolyze and ferment complex organics (primarily carbohydrates, proteins, and lipids) to form fatty acids, alcohols, carbon dioxide, ammonia, and hydrogen. The organisms involved are anaerobic and facultative anaerobic fermenting bacteria such as Bacillus, Clostridium, and Enterobacteria. Carbon dioxide production peaks, while hydrogen production begins (Schumacher, 1983). Peaks of as much as 90% carbon dioxide by volume have been reported to occur 11 to 40 days after solid waste placement (Boyle, 1977). The characteristic phases of anaerobic decomposition of landfill refuse are illustrated in Figure 4.16.

When the refuse is totally depleted of oxygen, a third phase begins in which methane-forming bacteria become dominant. Methanogenic bacteria are obligate anaerobes, meaning that any oxygen will destroy their activity. Actually,, two complex microbiological processes take place during methane generation:

1. Organic acids and alcohols produced as discussed above are converted into acetate, hydrogen, and carbon dioxide.

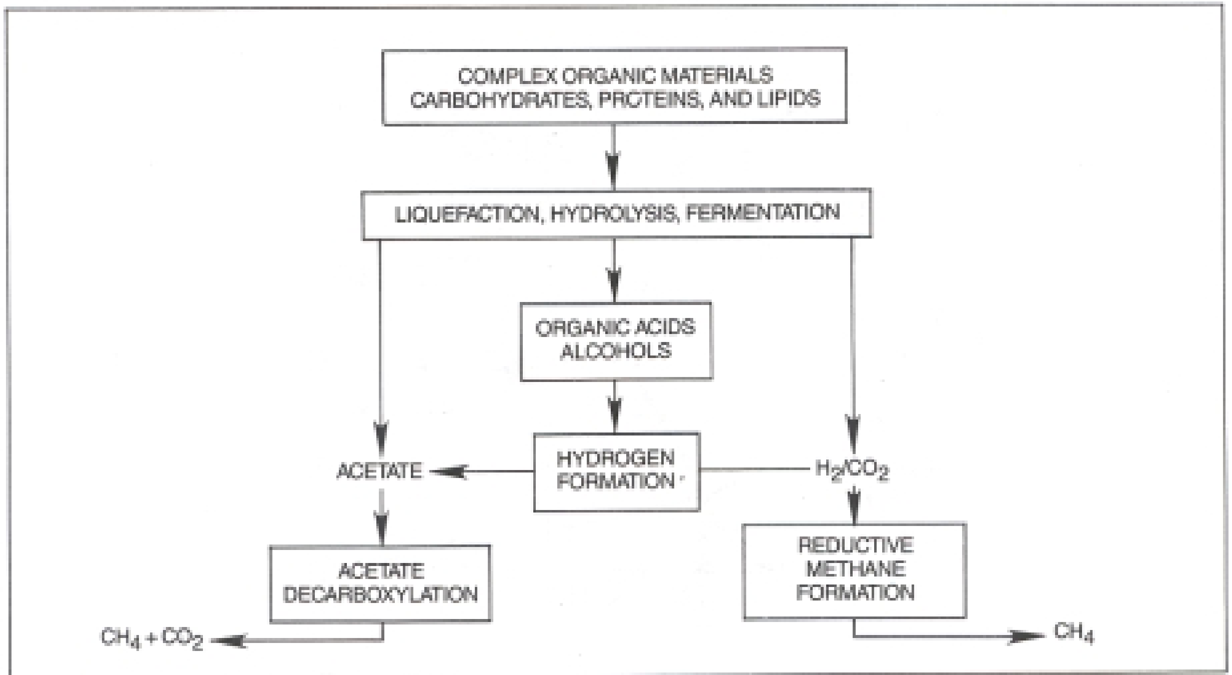

Figure 4.16
Multi-Step Methanogenesis in Anaerobic Digestion

Adapted From: Zehnder, 1978

2. Two types of methanogenic bacteria produce methane from the products of process 1: a) methanogens that reduce carbon dioxide to methane (hydrogen as the reducing agent), and b) methanogens that decarboxylate acetate to methane and carbon dioxide.

The fraction by volume of methane increases, with a concurrent decrease in carbon dioxide and hydrogen. This third phase has been oM;erved to occur between 180 and 500 days after solid waste placement (Boyle, 1977).

The fourth phase of landfill gas generation occurs one to two years after refuse placement. In this final phase, gas production and composition approach steady-state conditions, with methane ranging from 50% to 70% and carbon dioxide from 30% to 50%.

In order to design an effective gas control system, it is necessary to have some idea of the amount of gas likely to be generated at the landfill, and the probable paths along which it will migrate from the landfill. A prediction can be developed by a thorough evaluation of the following elements:

- Site size
- Average depth of fill
- Refuse composition

- Refuse disposal rates
- Quantity of in-place refuse
- Topographic surveys
- Hydrogeologic information

Preliminary estimates of both quantity of refuse in place and moisture conditions within the landfill can be a valuable tool in the initial design process (Figure 4.17). As discussed previously, the typical landfill, with a moisture content of approximately 25 percent and only limited added moisture after refuse placement, will produce approximately 0.04 cubic feet of methane per pound of mixed municipal solid waste per year. Drier landfills may have lower gas yields; those with added moisture may have higher yields. While the moisture is required for microbiological growth, it also aids in mixing and homogenizing the nutrients available in the wastes.

The moisture content of refuse may change over time for a number of reasons, including:

- Surface water infiltration
- Ground water inflow
- Release of water as a result of refuse decomposition
- Seasonal variation in solid waste moisture content
- Managed addition of liquids (e.g., leachate recirculation)

These moisture additions must be accounted for, since the gas production rate at the landfill is highly dependent on refuse moisture content. Wide variations in the rate of gas production can even exist among landfills of the same size.

4.7.2 Methane Migration

Limiting methane gas migration to below dangerous levels should be the goal of any gas control system. The Minimum Functional Standards require methane concentrations less than the lower explosive limits (5% by volume) at the landfill property boundary or beyond, and less than 100 parts per million methane by volume in off-site structures. Therefore, measures must be taken upon closure of an existing, unlined landfill to reduce methane migration to acceptable levels. As stated previously, new, lined landfills should not experience the same potential for methane migration since the gas will be contained within the liner. However, a system for the extraction of methane and its subsequent use or disposal must be provided.

Methane moves by way of diffusive (concentration gradient) and convective (pressure gradient) mechanisms. Diffusive flow of gas is in the direction of decreasing concentration. Diffusion within a landfill may occur by ordinary

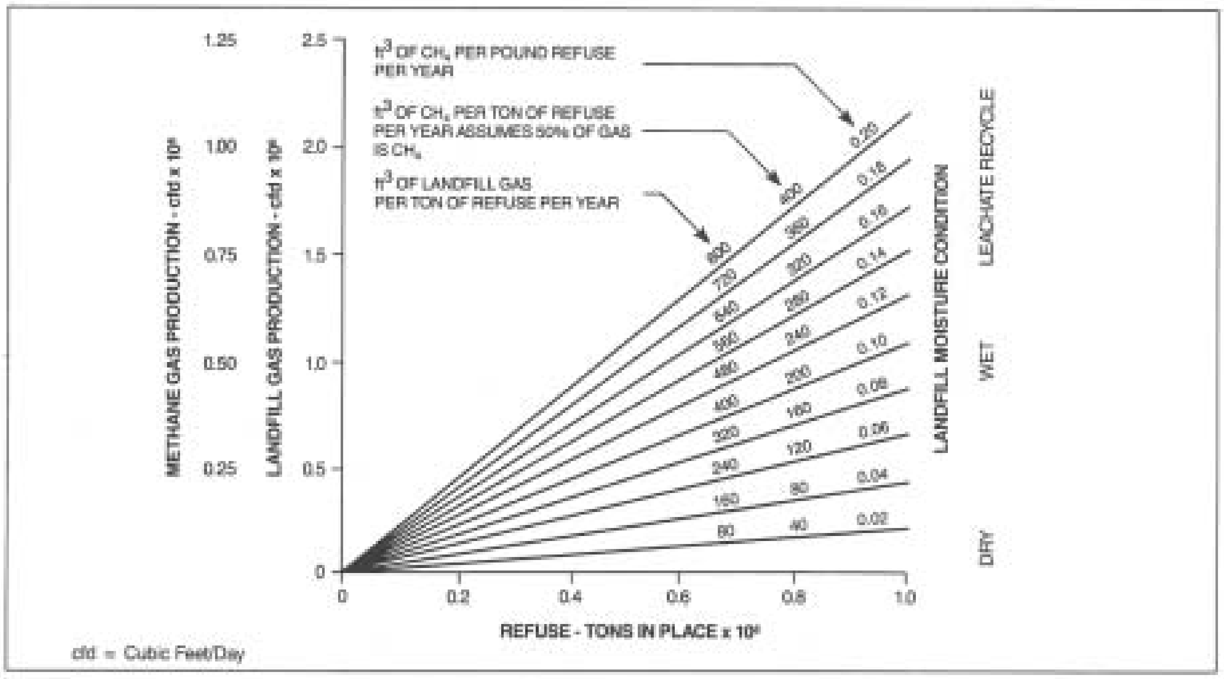

Figure 4.17
Gas Production Rates for Landfills of Various Sizes and Moisture Conditions

diffusion, Knudsen diffusion, and surface migration (Schumacher, 1983). While diffusion can be an important element in lateral migration of methane, its effect is minimal where naturally occurring pressures are high within the landfill, or an induced exhaust system is used to increase the landfill pressure gradient (Moore, 1979, Schumacher, 1983).

In systems in which a natural or induced pressure gradient occurs, convective mechanisms will be the primary means of gas flow (Schumacher, 1983). Therefore, the method of removing methane from a landfill is by producing a pressure/concentration sink to which the gas will flow. Darcy's law has been used to characterize the flow of gas through the refuse (Findikakis and Leckie, 1979).

Gas movement will occur in sand, silt, or even clay soils if there are continuous voids. However, since the rate of movement decreases as pore size decreases, gas movement is facilitated in highly porous sand or gravel and inhibited in dense clay soils.

Without a gas collection system, the gas produced within a landfill must escape the refuse either by vertical venting or lateral migration. Being lighter than air, methane tends to rise. Therefore, much of the gas produced within a landfill will typically exist through the permeable cover soil. However, if this vertical pathway is sealed by ice, frost, rain-saturated cover soil, pavement, or an impermeable cover cap, there will be a greater tendency toward lateral migration. Such lateral migration may ultimately result in significant hazard, particularly if buildings or other structures have been developed on or adjacent to the landfill.

Mathematical models are available as an aid in predicting both gas production and gas movement. However, because methane gas production and migration in landfills is dependent on so many uncontrolled factors, using a combination of methods is advisable. Before final design of any gas control system, monitoring probes should be installed at strategic locations near the landfill boundary and between the landfill and any nearby structures to test for the presence of methane gas and to permit sampling of the air in the ground to determine its composition.

4.7.3 Methane Migration Control and Collection

Methods for controlling the migration of landfill gas may include one or a combination of the following:

- Placement of impermeable liner materials at or just beyond the refuse boundary to block the flow of gas
- Selective placement of granular materials at or just beyond the refuse boundary for gas venting and/or collection
- Evacuation and venting of gas from the landfill interior
- Excavation and venting of gas from the perimeter area beyond the landfill

Illustrations showing the common locations of these landfill gas control systems are presented in Figure 4.18.

Effective impermeable liner materials are synthetic membranes, clay, concrete and asphalt. Natural soil barriers such as clay may serve as highly efficient barriers to gas migration, provided the soil is kept nearly saturated. When dry, even clay soil is an ineffective barrier, since it then provides a continuous void system through which methane gas can migrate. In order to prevent drying, an additional soil cover should be placed over the clay barrier to provide adequate moisture retention in the clay. Barriers to control lateral flow of gas are best placed during landfill construction. The bottom and side liners required by the Minimum Functional Standards will effectively limit subsurface, lateral methane migration. Landfill using the arid design (no liner required) should evaluate the potential for methane migration.

Perimeter vent systems include gravel trenches, rubble vent stacks, and gravel filled vent wells, or a combination of these. Venting may be accomplished by either passive or active (mechanically induced exhaust) systems, with selection depending on site conditions.

Passive systems rely on highly permeable material (such as sand or gravel) placed in the path of the gas f low. Since the permeable material offers a path more conducive to convective gas flow than the surrounding soil or

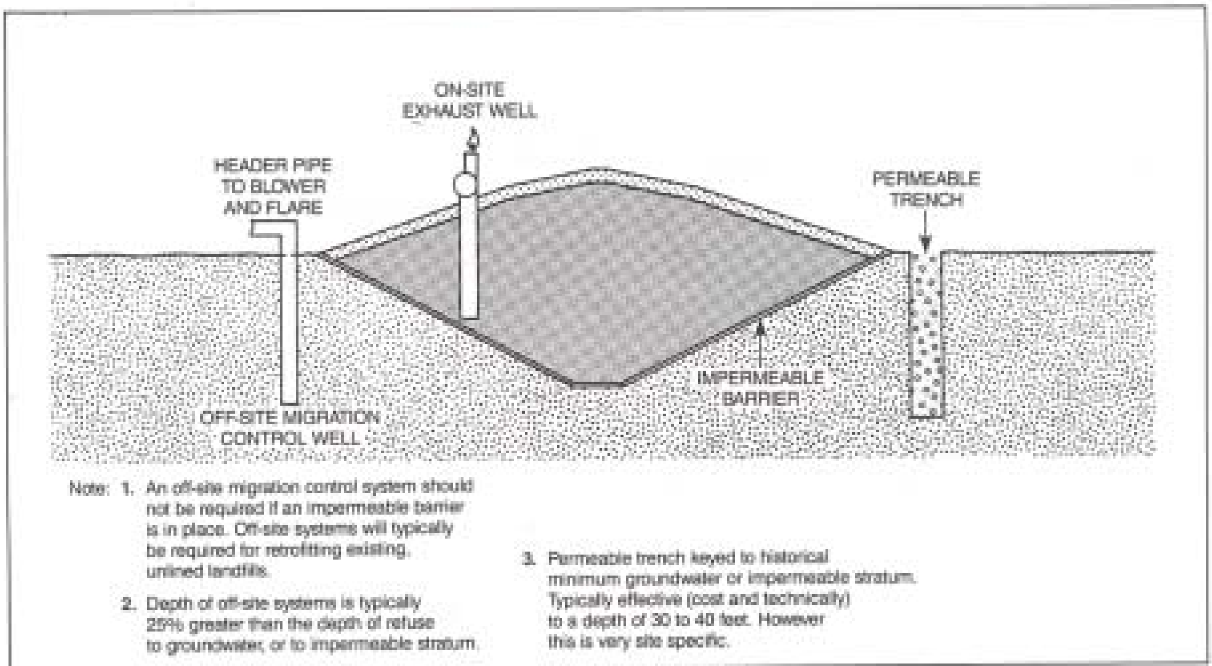

Figure 4.18
Common Locations for
Gas Control Systems

refuse, some gas is diverted to a point of controlled release. Some gas flow will occur beyond the permeable area as a result of diffusion; consequently, any investigation of gas migration potential should assess the extent to which diffusion will move the gas beyond the vent.

Vent/barrier trenches (Figure 4.19), which employ impermeable membrane barriers in conjunction with gravel-filled trenches, are common and effective passive control measures, provided there is an underlying impermeable soil stratum or water table into which they can be keyed. If the trench does not key into one of these, gas can migrate beneath the barrier.

In **situations where passive control of gas migration would be inadequate or** too costly to install, active systems have proven very effective. Typically, such active systems incorporate perforated pipe in vertical gravel-filled wells similar to those used in gas recovery systems (Figure 4.20), or in horizontal perforated pipe in gravel filled trenches. The wells are spaced at intervals along the perimeter margin of the landfill, either within the edge of the fill or outside of, it in the surrounding native soils (Figure 4.21). The wells or trenches are connected by header pipes to an exhaust blower which creates a vacuum. Since the gas flow in the volume of soil or refuse influenced by each well or trench is toward the well or trench, migration is effectively controlled, provided the zone of influence of adjoining wells overlaps.

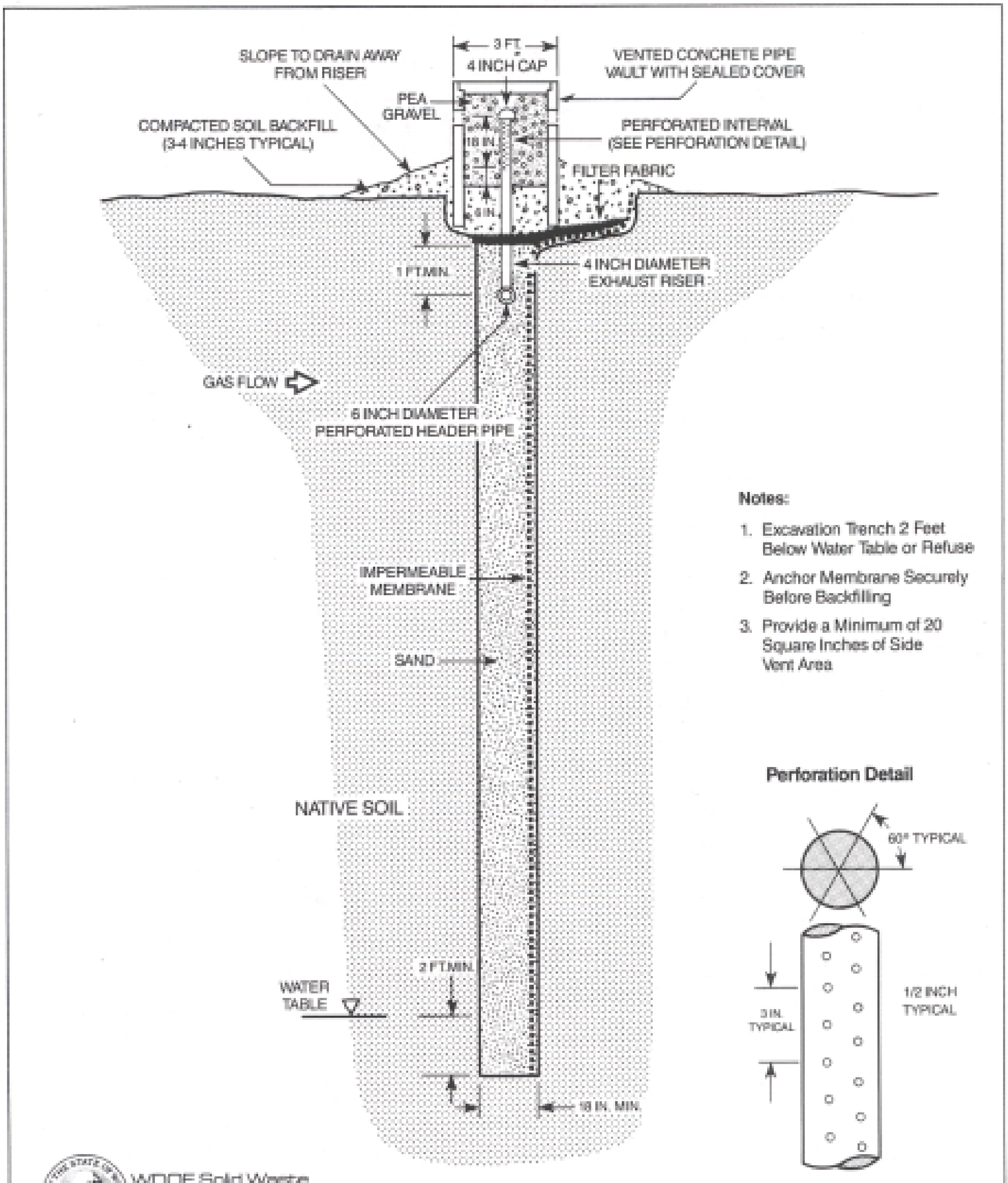

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Figure 4.19
Typical Cross-section of Vent/Barrier Trench

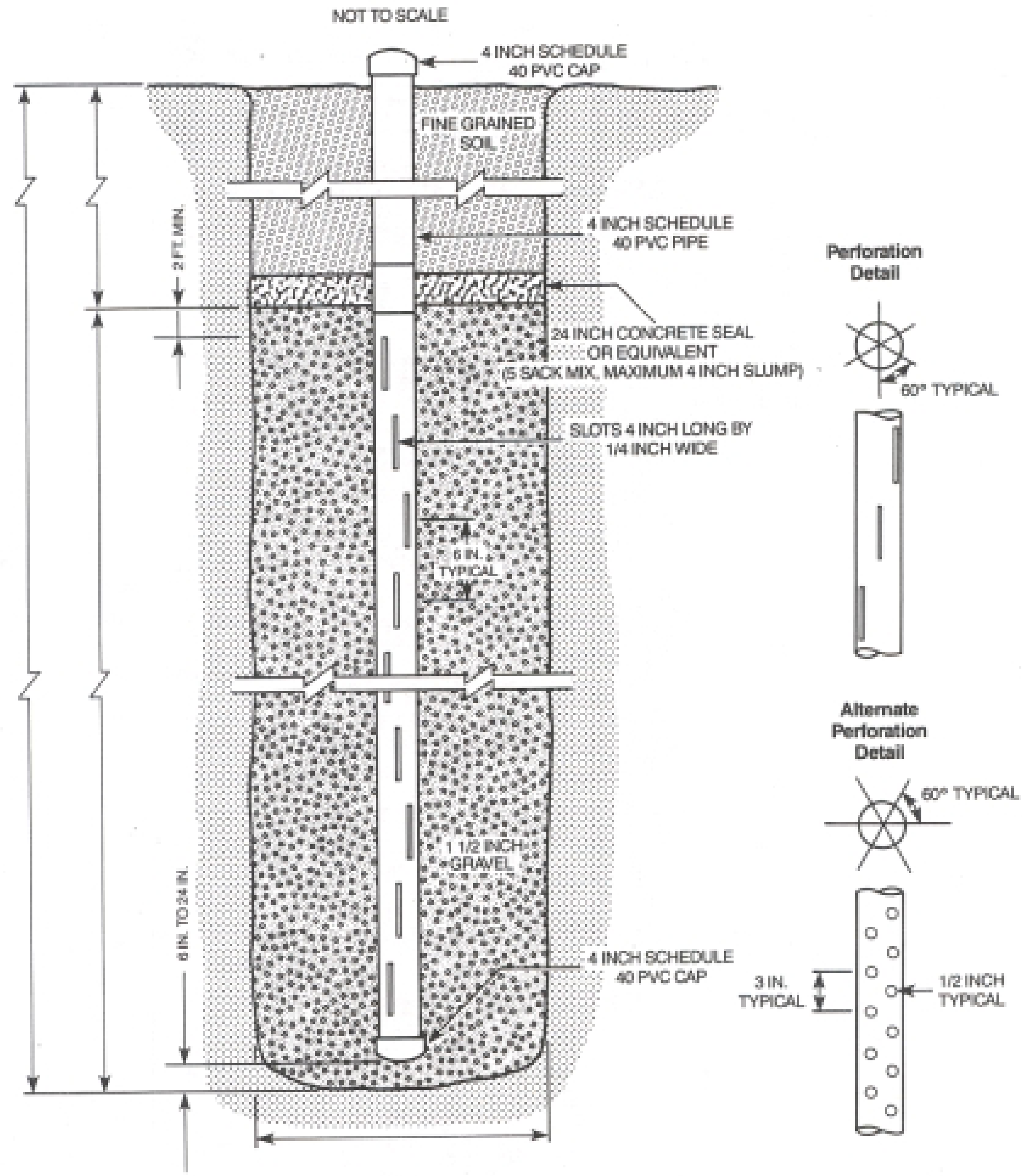

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Figure 4.20
Typical Well Configuration

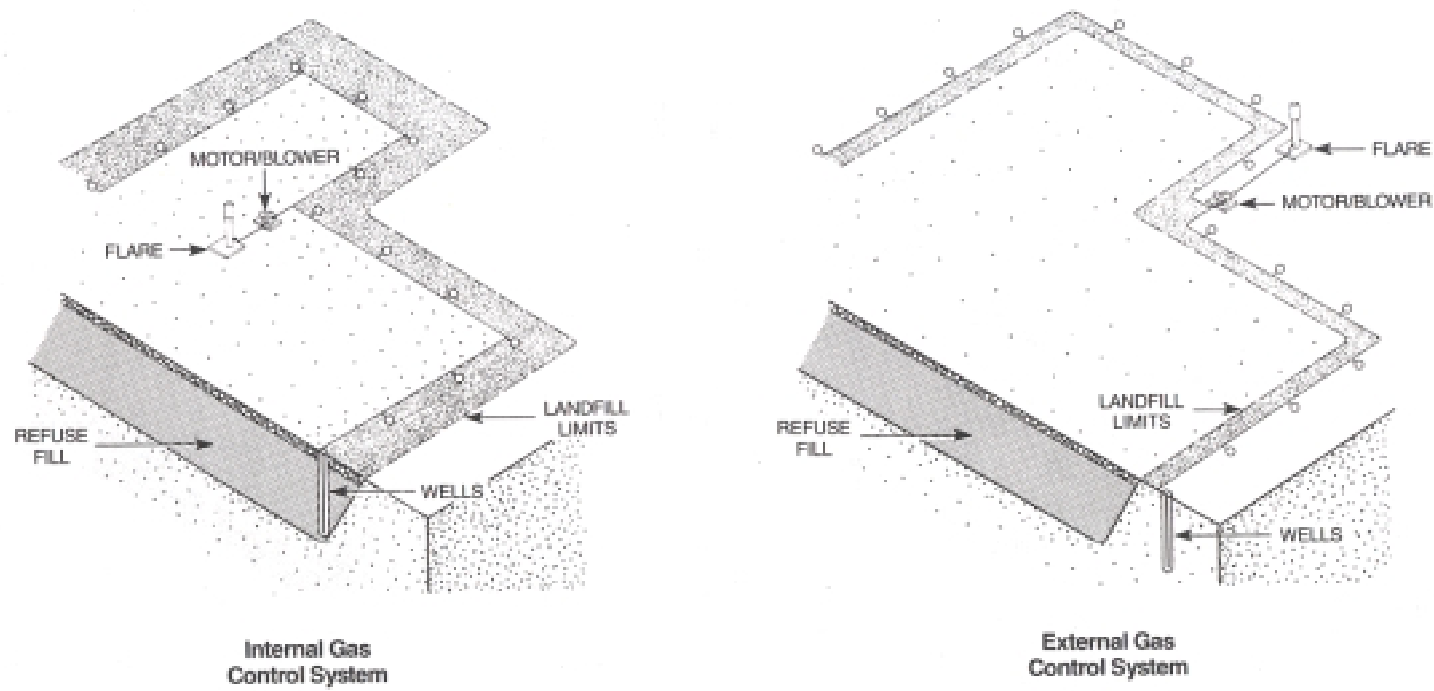

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Figure 4.21
Alternative Gas Control System Locations

4.7.4 Landfill Gas Recovery

4.7.4.1 Predicting Gas Production Over Time

Assessing a landfill's potential as a methane gas producer is essential for landfill gas recovery projects. The reliability of predictive methods will influence potential gas users and investors and, to a large extent, determine the viability of such projects. There are several methods of predicting landfill gas production: site evaluation, mathematical modeling and field testing. However, since methane gas production in landfills is influenced by many uncontrollable factors, using a combination of methods is recommended.

Site Evaluation. A preliminary prediction of landfill gas production and yield can be developed through an evaluation of the landfill site. However, the reliability of this method is highly dependent on the availability of recorded data on site size, average depth of fill, refuse composition, disposal rate, quantity of in-place refuse, and ultimate site capacity. Quantity of refuse in place and moisture conditions should be estimated. To arrive at a reliable estimate of gas production at a given landfill site, all available data, based on experience and comparison with similar landfills, must be properly interpreted.

Mathematical Modeling. Efficient utilization of landfill gas requires knowledge of both current yield and long-term production rates. Although considerable research has been devoted to the development of predictive methods, they remain approximate, since the factors influencing methane production in a landfill are still not clearly understood. Nevertheless, models which predict gas production and flow characteristics under various conditions can be highly informative. Based on a landfill unit weight, one can theoretically predict the amount of gas produced by considering refuse composition and making certain assumptions as to what portion of the refuse mass is biodegradable. Based on this theoretical approach, researchers have estimated the maximum methane yield to range from a low of 1.5 cubic feet per pound of wet refuse to a high of 4.3 cubic feet per pound. These values serve as maximum boundaries for methane production, since they are based on the assumption that favorable environmental conditions exist for bacterial growth. The high values assume complete conversion of the organic fraction of the refuse. The lower values assume certain limiting conditions.

Gas yields refer to the total amount of gas that can be produced by a unit weight of refuse. Equally important, is the rate of gas production, which is the summation of the gas production of all the individual unit masses of refuse in different stages of gas production. Various models of gas production rates have been developed based on theoretical considerations involving bacterial growth kinetics under fixed substrate levels. The models are somewhat different for each landfill, depending upon site and refuse conditions.

Field Testing. While a general idea of a landfill's potential as a methane producer can be formed by evaluating a site's physical characteristics and operational history, and by using mathematical models to estimate gas production over time, extraction testing is the best means of reliably assessing the present gas yield. Field testing provides definitive point-in-time gas production information that serves as a means of verifying preliminary estimates of current yield, thereby lending credence to estimates of future production potential.

As a general rule, greater reliability in gas production estimates can be achieved for tests of longer duration than for those of shorter duration. Short-term extraction testing, which typically ranges from several hours to several days per extraction rate per well, is a means of obtaining a first look at pressure and gas composition as they relate to the extraction rate employed. The results of short-term testing give an indication of the extent of air intrusion and the influence of a selected withdrawal rate on the refuse mass in close proximity to the extraction wells. In addition, determining the vacuum required to achieve a given flow rate permits more rational selection of well spacing, blower capacity and well flow rates.

Preliminary estimates of gas production and recovery rates can be made on the basis of short-term testing. However, the results of short-term testing may not accurately reflect the sustainable gas production rate, since up to 50 percent of landfill volume can be comprised of void space within which landfill gas may be stored. Short-term testing is analogous to withdrawing a small volume of gas from a large reservoir. However, in evaluating the results of short-term testing, it is often difficult to differentiate the gas produced during extraction from that already stored in the voids at the beginning of testing.

Long-term testing, which proceeds long enough to permit extraction of at least one void volume of gas, simulates conditions expected from a full recovery project. The time required to permit reasonable estimation of the sustainable recovery rate depends on the landfill void volume (a function of moisture content, density and characteristics of the refuse), the gas extraction rate, the potential recovery rate, and the fraction of the total refuse mass from which gas is being withdrawn.

To accurately estimate the sustainable recovery rate, it is necessary to determine the maximum rate at which gas can be extracted without significant air intrusion or deterioration of gas quality. Tests of shorter duration and/or at lower extraction rates can be used to establish a lower limit on the sustainable recovery rate. However, these tests do not permit estimation of the actual recovery rate.

In summary, several methods are available to estimate landfill gas production. It is clear, however, that these methods are interrelated and should be correlated to provide the most reliable estimate possible. Information gained in site evaluations can provide needed input to mathematical models and, to a large extent, forms the basis for initiating and structuring a field test program. Field testing, while providing a reliable point-in-time estimate' of sustainable gas yield, falls short of providing a means of predicting gas production over time. Mathematical models and site evaluations, while having this capability cannot be reliable without the substantiation and verification of a field test program.

4.7.5 Non-Recovery Methane Disposal

The Minimum Functional Standards require that methane not purified for sale or otherwise utilized for its energy value be fl red. Flaring is more effective with an active extraction system since th flow rate through the flare can be controlled. In a passive extraction s stem, the flow rate is controlled by processes within the landfill and climate changes. High barometric pressure can create a pressure gradient that will cause air to flow in through the flares. This extinguishes the f are. When the pressure gradient reverses, methane and other components of landfill gas will exit through the flare without being burned until it is relit. It is for this reason that automatic flare ignitions are sometimes used on landfill flares in a passive system.

4.7.6 Air Pollution Control

Typical components of landfill gas may include methane, carbon dioxide, and a variety of organic compounds resulting from the decomposition of refuse and volatilization of materials (e.g., spent solvents) deposited in the landfill. Current standards do not allow landfill operators to violate any ambient air quality standard at the property boundary or emission standard from any emission of landfill gases, combustion or any other mission associated with a landfill. Additionally, local health and air quality jurisdictions have emission and ambient air standards with which landfills must comply. In order to meet these requirements, most landfills vi 1 require some means of landfill gas control. The primary objective of these controls should be the protection of public health and safety and prevention of environmental degradation. A properly operating landfill gas collection and disposal system should be able to meet air quality standards.

4.8 SURFACE WATER MANAGEMENT

4.8.1 Runoff

Surface water runoff is the residual of precipitation after all other losses have been satisfied (Novotny and Chesters, 1981). Typical losses include interception on vegetation, depression storage and pending evaporation, and infiltration. Runoff will initially flow directly overland as a sheet flow, but will eventually be concentrated into channel low within ditches and drainage ways.

When runoff occurs from a solid waste landfill it haE the potential to create two major types of problems. They are:

- Erosion of soil covers, exposed slopes, drainagevays or other unprotected areas
- Transport of contaminants to receiving water bodies that may degrade the water quality

The Minimum Functional Standards, as well as many local jurisdictional agencies, require surface water runoff to be managed to mitigate the above problems. Management takes several forms, including the following:

- Temporary erosion and siltation controls for intermittently exposed areas

- Terracing, soil reinforcement, mulching and hydroseeding for erosion control of areas receiving final cover

- Lining or armoring of ditches to provide erosion protection at design storm velocity

- Detention basins for reducing peak flows

- Siltation basins for removing sediments from the water prior to discharge into a receiving body

- Diverting runoff from uncovered solid waste into the leachate treatment and disposal system

Management facilities are designed to control a pre-determined amount of precipitation during a given period of time, based on its probability of occurrence. Such a precipitation event is termed a design storm and is based on historical records of precipitation events. The Minimum Functional Standards require that surface water management facilities for runoff control be designed to handle the 25 year - 24 hour storm. Local ordinances may require management of more severe storm events, such as the 50 year - 24 hour storm. The amount represented by the design storm will vary with location. For example, the following precipitation amounts represent the 25 year - 24 hour storm for the localities indicated (SCS, 1982a, 1982b):

Aberdeen, Grays Harbor County ....5.5 inches
Seattle, King County ....3.5 inches
Yakima, Yakima County ....1.8 inches
Spokane, Spokane County ....2.2 inches

4.8.2 Run-on

Run-on surface water originates in an identical manner to runoff. It is distinguished from runoff because it originates from off-site sources and flows onto the site property. Whereas all sites will generate runoff, not all sites will be subject to run-on. Unless the surrounding topography is such that water will flow onto the site, run-on will not be a problem. However, if the site is located, wholly or in part, within a well defined intermittent or permanent drainage way, then management facilities will be required.

The potential problems that uncontrolled run-on may create at a solid waste landfill are not unlike those described for runoff. However, because run-on will most likely be reaching the site in a concentrated channel flow, its potential for causing erosion damage or degradation of receiving water quality is more immediate and severe.

Management of run-on usually involves diversion of the incoming flows around the site. Diversion is typically achieved through construction of berms, dikes and ditches. The Minimum Functional Standards require the design of facilities to prevent run-on from the maximum flow of a 25 year storm. Since no storm period is specified, it may be necessary to investigate 25 year storms of different durations to find the maximum flow. For example, a 25 year - 12 hour storm may produce a higher peak flow than a 25 year - 24 hour storm. As always, local ordinances should also be reviewed to ensure compliance with mandated standards.

Consideration should also be given to the impacts of failure of the management facilities. If failure could cause major economic damage or severe degradation of water quality, it may be prudent to design the facilities for the 50 or 100 year storm.

4.8.3 Water Quality

Surface water originating from the completed portions of the solid waste landfill site (runoff) will eventually reach a receiving water body. Runoff originating from completed areas of the landfill is typically assumed to be uncontaminated since it has not been in contact with the buried solid waste. However, although it may not be contaminated with constituents from the solid waste, it may be contaminated depending upon the receiving water body's water quality standards. For example, if erosion control is poor, there may sufficient fine-grained sediments in the runoff to exceed the turbidity standard of the receiving water. Also, some amount of fertilizers used for hydroseeding will be carried in the surface runoff. If excess amounts of fertilizer are used or hydroseeding is done at wrong times of the year, the runoff may exceed standards for nitrates or phosphates. Standards for all the state's surface water bodies are included in WAC 173-201 and these regulations should be reviewed to ensure the discharges from the facility will be in compliance.

4.9 GROUND WATER MANAGEMENT

The objective of ground water management is to prevent the movement of uncontaminated ground water into refuse. This differs from leachate management where the objective is to prevent the movement of leachate into uncontaminated ground water. Successful ground water management reduces the amount of leachate generated and improves operating conditions within the fill area.

The Minimum Functional Standards require that a minimum separation be maintained between the bottom of the lowest liner and the seasonal high ground water level in the uppermost aquifer beneath the landfill. The specified separation is 10 feet, or 5 feet if a hydraulic gradient control system (or equivalent) has been installed.

Ground water management measures may be required at existing landfills as part of a corrective action program. They may also be implemented at new landfill locations where the ground water table is within ten feet of the elevation of the bottom of the lowest liner as part of a hydraulic gradient control system.

The need for ground water management is determined by analyzing hydrologic and geologic data. Typically, ground water management facilities are employed to control the lateral movement of shallow ground water into the disposal area. The sources of such movement include shallow water tables, perched water table conditions and seasonal changes in ground water levels and flow patterns. Perched water tables are especially common in Washington where stratified layers of permeable and impermeable soils are present.

4.9.1 Impermeable Barriers

One passive method of ground water control excludes and/or diverts ground water away from the waste disposal area through construction of low permeable barriers. Possible measures include slurry trenches, grout curtains, sheet pilings, and synthetic membranes. The first three measures provide methods for installing low permeable barriers without the difficulty of maintaining an open trench. Synthetic membrane placement is effective only when a relatively shallow barrier is needed. The application of such a barrier depends on site characteristics and plan requirements. For these barriers to be effective, they are normally keyed into low permeability subsurface layers. In some situations this is not necessary. If the barrier is sunk into the water table far enough, it may. reduce the hydraulic head of the ground water and cause it to flow at a greater depth beneath the disposal site (U.S. EPA, 1982). This method must be analyzed carefully to ensure it will achieve the desired results. It is applicable only where geologic conditions are favorable.

4.9.2 Trenches and Drainage Pipes

Buried drain pipe, which has been used for many years in agriculture to control shallow ground water problems, is also effective in controlling shallow ground water problems at landfills. Location of-trenches and drain pipe, backfilled with highly permeable material, upgradient of the disposal area will induce flow into the drain pipe. If undisturbed soils are highly permeable, a combination of trench and drain pipe with low permeable liners is effective. To prevent clogging of the drain pipe with soil fines, a properly graded backfill or filter fabric is necessary (see Appendix B).

4.9.3 Pumping

Control of ground water by pumping requires that wells be installed near the disposal area. Pumping of the wells creates a cone of depression that will lower ground water levels and prevent its movement into the disposal area. Water removed. by pumping is diverted into the surface drainage system. Pumping can be an effective management technique in most cases. However, it adds significantly to the operational costs of the landfill.

PART B

4.10 WATER BALANCE ANALYSIS

Leachate can be generated from water entering refuse from the following sources:

- Surface water run-on
- Ground water inflow
- Decomposition water
- Infiltration of precipitation

Leachate volumes from surface water run-on and ground water inflow can be predicted by analyzing hydrological and hydrogeological data. Typically, these situations are avoided by careful site selection or by controlling the conditions with various management systems as discussed in Sections 4.9 and 4.11. Water is also generated within the landfill from the biological and chemical decomposition of the waste. However, this is a minor fraction compared to the other three sources.

The purpose of this section is to address the methods for predicting leachate generation caused by the infiltration of precipitation. A variety of mathematical models is available to predict leachate generation from precipitation, from simple "desk top" versions to complex computer models. The models discussed in this section include the following:

- 1975 EPA water balance method
- Modified 1975 EPA water balance method
- HELP model
- Rainfall simulator model
- Other models applicable to solid waste landfills

4.10.1 Application

The design and performance evaluation of several landfill elements depends upon developing a water balance for the landfill. In order to properly size and design the leachate collection, transmission, and treatment systems, estimates of maximum monthly, minimum average daily, maximum average daily, and peak daily flows are often required. The water balance aids in predicting these flow rates, and can be used throughout the life of the landfill, with appropriate modifications, to determine treatment modifications which may be required.

Additionally, the water balance is useful in determining the efficiency of various final cover systems. This allows the landfill operator to determine the cost effectiveness of more efficient cover systems in view of leachate treatment costs. For an existing landfill without a bottom liner, a water balance can determine the overall efficiency of a final cover in reducing leachate generation and thus ground water contamination. In this instance, the peak flows are not of concern because leachate is not being collected; however, the total amount of leachate generated is of concern.

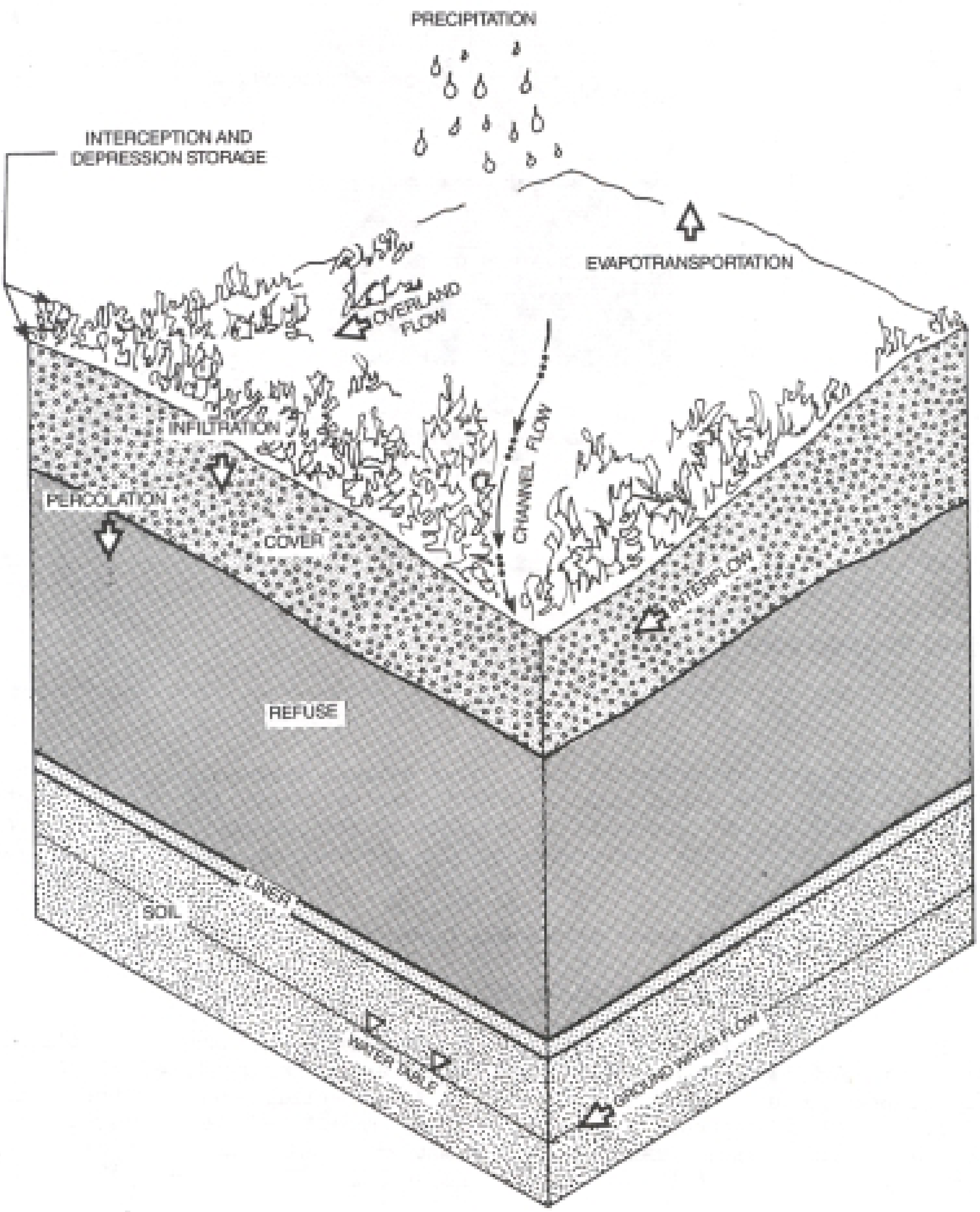
4.10.2 Background

Predicting the amount of leachate to be generated from precipitation at a solid waste landfill assumes that a fraction of the water will infiltrate through the soil surface and percolate into the refuse. To predict the amount of leachate generated requires simulation of the various hydrological processes that influence the transfer of precipitation into the subsurface environment. These processes, illustrated in Figure 4.22, include the following:

- Evapotranspiration
- Interception
- Depression storage
- Overland flow
- Channel flow
- Infiltration
- Interflow
- Percolation

It is important to realize that model results are subject to large uncertainties. These may be errors in the model itself, caused by omitting important processes from the simulation or representing nonlinear functions as linear ones. Errors also occur in measuring data used for input values to the model, which can be magnified in the simulation process.

Models are also limited in the output they can provide based upon their structure. For example, some models use monthly average climatological data and can therefore provide only monthly average leachate generation values (1975 EPA method). More sophisticated models can use daily climatological information and provide not only average values, but also daily peak flow estimates (HELP model).



Adapted From: Parametrix, Inc., 1984

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Figure 4.22
Hydrologic Processes Important in Leachate Generation Predictions

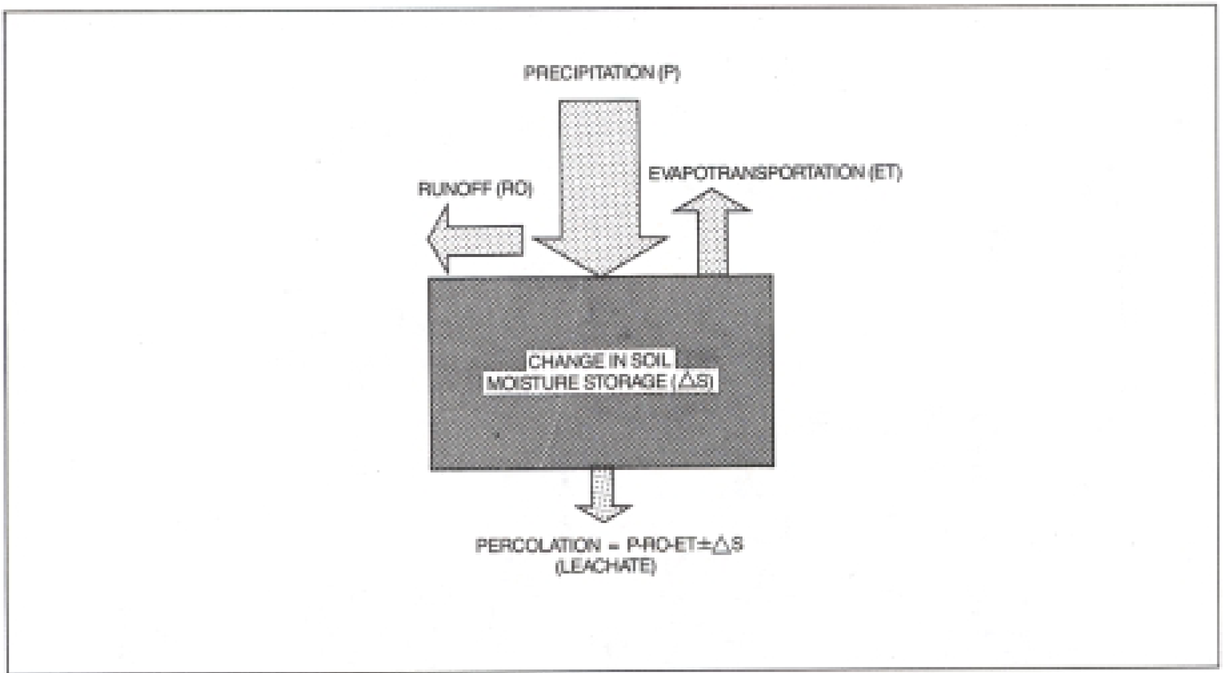


Figure 4.23
Landfill Water Balance

Figure 4.23 Landfill Water Balance

Most leachate generation models use a water balance appro ach. As illustrated in Figure 4.23, the water balance method involves computing the difference between precipitation and runoff, evapotranspiration and change in soil moisture storage. This difference equals percolation, which becomes leachate.

4.10.3 Modeling Closed Areas with Final Cover

4.10.3.1 1975 EPA Water Balance Method

The'1975 EPA water balance method is a popular method for predicting leachate generation and is described in the basic reference by Fenn, et al. (1975). This simple accounting procedure, adapted from earlier work by Thornthvaite and Mather (1957), predicts average monthly amounts of percolation. This technique lends itself well to microcomputer ad4p_tation using commercial spreadsheet software (i.e., VisicalcTM, Lotus 1-2-3TM, or SymphonyTM

To use this model the following data are needed:

- Monthly precipitation data
- Mean monthly temperatures
- Latitude

- Tables from Thornthwaite and Mather (1957)
- Field capacity of soil
- Runoff coefficient

Detailed instructions for using the model are contained in the basic references (Fenn, et al., 1975; Thornthwaite and Mather, 1957) and a report by Kmet (1982) and will not be repeated here.

There are significant limitations with this model. The use of runoff f coefficients on large (>10 acres), non-urban areas such as landfill sites creates large uncertainties in the results. Using runoff coefficients larger than those recommended in Fenn, et al. (1975) should be avoided. The recommended procedure uses the range of values provided for a particular slope and soil type. The result will be a range of leachate generation rates more likely to bracket the actual rate.

The method is also sensitive to the selection of soil field capacity values. Estimates are available in the references sited above, from county soil surveys published by the Soil Conservation Service and Table 4.15 in Section 4.16. A range of likely values should be chosen to provide a best and worst case.

This method does not provide peak flow estimates so its use in final design of leachate collection and treatment systems is limited. To use this method for preliminary sizing of collection and treatment systems, conservative parameters should be used because of the limitations associated with the model. Minimum runoff coefficients and field capacity values should be used. The maximum monthly recorded precipitations should be used for the month when the soil is most likely to be at field capacity, typically at the end of the wet season. However, this method will not yield the most efficient collection and treatment systems and is most applicable to preliminary site evaluations.

4.10.3.2 <u>Modified 1975 EPA Water Balance Method</u>

To improve the accuracy of the 1975 EPA method for estimating leachate generation at solid waste landfills, a more appropriate runoff prediction model can be used As discussed in Section 4.11, the Soil Conservation Service curve number (CN) method is better adapted to conditions at solid waste landfills. However, the CN method is a model developed to predict runoff from individual 24 hour precipitation events. Using average monthly rainfall amounts with this model overestimates surface runoff and underestimates leachate generation. Average monthly precipitation can be adapted to the CN method by breaking it down into average precipitation events occurring during a particular month based on historical precipitation records. This information is available from a publication on Washington climate by the Cooperative Extension Service, College of Agriculture, Washington State University, Pullman, Washington, in tables entitled "Average Number of Days with Precipitation." The runoff from each of the average precipitation events is predicted using the CN method. The total monthly runoff is then determined by summing the runoff predictions from the individual, average precipitation events. This method requires more calculations than the 1975 EPA method, but it also can be adapted to microcomputer spreadsheet software, and therefore, calculation time is irrelevant.

Next, the Thornthwaite and Mather method is used for estimating evapotranspiration in the same manner as for the 1975 EPA method. Actual evapotranspiration is then calculated based upon the amount of infiltration and the moisture content of the soil. That portion of precipitation that does not runoff or is not evapotranspirated is assumed to percolate through the topsoil.

As with its predecessor, this method has limitations also. The process of averaging precipitation events is a source of error which increases the uncertainty of the results. It is also subject to the same limitations, imposed by its sensitivity to soil field capacity, as the 1975 EPA method. Peak flow estimates are not provided by this method either and therefore it is limited in its applicability to some aspects of final design. This method is most applicable to site evaluations and preliminary designs.

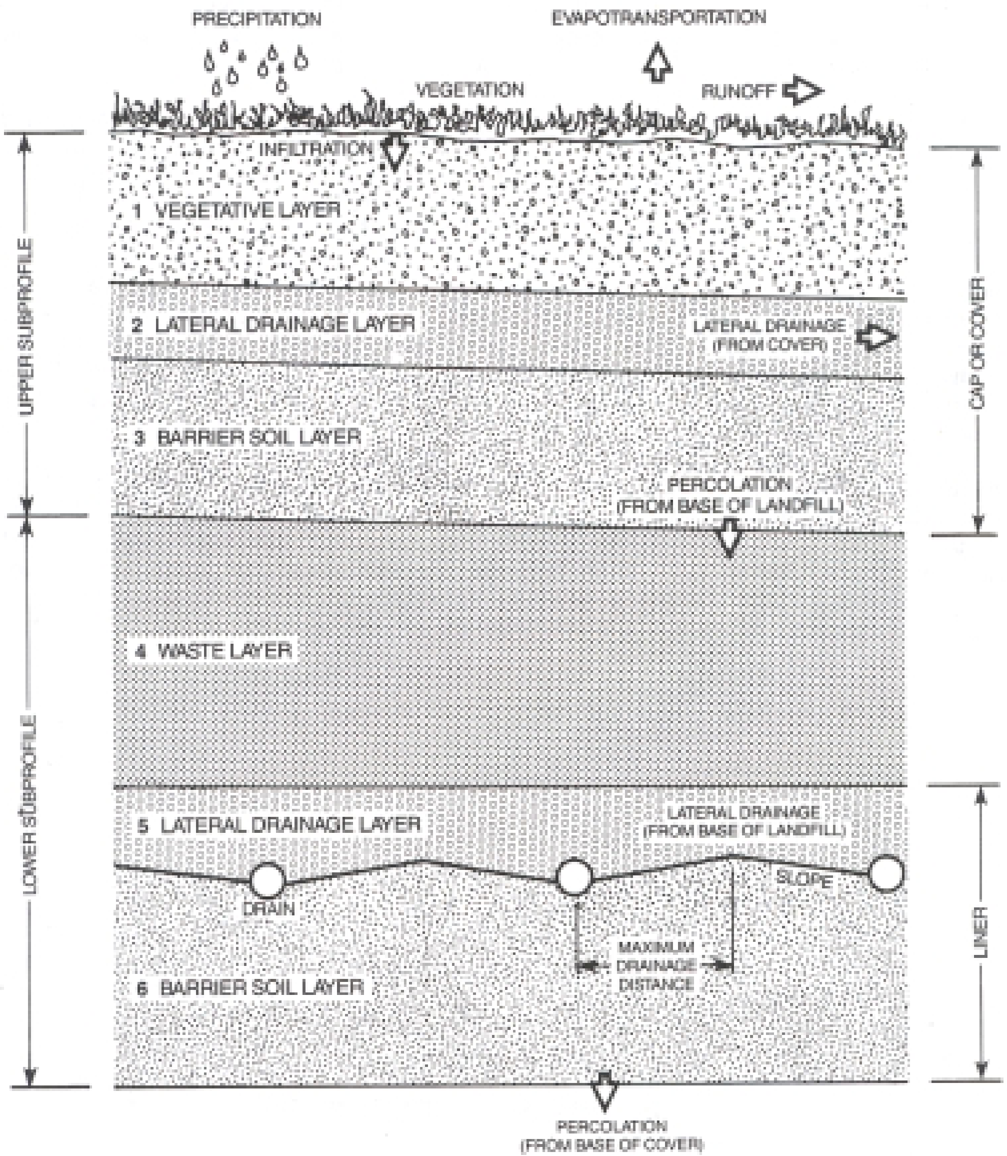
4.10.3.3 HELP Model

The Hydrological Evaluation of Landfill Performance (HELP) model is another computer model developed to assist landfill designers and regulators in evaluating cover systems, bottom liners and leachate collection systems (Schroeder, et al., 1983b). Figure 4.24 illustrates the profile of a typical lined landfill and processes that are simulated by the HELP model. Access to the HELP model computer- program is available through the National Computer Center in Research Triangle Park, North Carolina. Specific instructions for accessing the program are contained in the basic reference (Schroeder, et al., 1983a). The model has also been made available to run on personal computers. The program disks are available from the U.S. Army Corps of Engineers' Waterway Experiment Station at Vicksburg, Mississippi.

Different input data types are required than the previously discussed models and include:

- Climatologic
- Vegetative cover type
- Soil characteristics
- Landfill design data

Default data is available for climate and soil. In Washington, default climatologic data is available for Seattle, Yakima and Pullman. The program user may specify either of these cities and the program will refer to an historical record of daily precipitation data and other factors for the requested city. Unfortunately, unless the landfill being evaluated is in close proximity to one of these cities, the user must manually enter the required data. Detailed procedures for accomplishing this are provided in



Adapted From: Schroeder et al., 1984, p.5

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Figure 4.24
Waste Landfilll Profile Modeled by HELP

the user's manual (Schroeder, et al., 1983a). Site specific climatologic data may be obtained from the publications of the National Weather Service. Although manual entry of climatologic data is time consuming and tedious, failure to use local data could cause the model to make erroneous predictions that could have major ramifications when the design is operational.

Default soil characteristics data are also provided for fifteen standard soil types. Selection of an appropriate default type is made by comparing the characteristics of on-site soils to the fifteen standard types and selecting the closest match. Soil data can also be entered manually if the default types are not adequate, and should be if the information is available.

Vegetative cover data are an estimate of the quality of the grass cover. Subjective evaluations of excellent, good, fair and poor cover are available. Along with this choice, the model user must specify the evaporative zone depth. This is usually the expected depth of the plant roots and typical values for different quality vegetative covers are provided in the user's manual.

The design data are specified by the model user and include the various materials used in the bottom liner and final cover, as well as the physical layout of the landfill. Default data are not available and the information must be entered manually. This information includes the number and types of layers making up the landfill profile (see Figure 4.24), layer thicknesses, slopes, drainage distance between leachate collection pipes and landfill area.

The output of the HELP model is composed of several parts, including:

- Daily volumes
- Monthly totals
- Monthly averages
- Annual totals
- Annual averages
- The amount of leachate collected
- The amount that percolates through the bottom of the landfill

The HELP model has two main uses. During the conceptual planning and evaluation stage, the model can be used to evaluate a large number of different designs for both the bottom liner and leachate collection system and the final cover system. For example, a cover system with a drainage layer (see Section 4.16) can be compared to the cover required by the Minimum Functional Standards to evaluate the predicted differences in leachate generation. In this type of analysis, the absolute numbers are not as important as the trends indicated by the results.

once the basic design is determined, the HELP model can be used to specify design details such as:

- Required permeabilities for barrier and drainage layers
- Layer thicknesses
- Bottom liner slopes
- Leachate collection pipe spacing

This type of analysis requires more accurate predictions since construction plans and specifications will be prepared based on the results. It is here that the caution flag must be raised. No model, including HELP, can provide predictably accurate results without calibration and verification. Calibration is the comparison of model output to measured output and the subsequent adjustment of various parameters within the model (soil characteristics, climatic indices, evaporative zone depth, etc.) such that the two outputs are as similar as possible. Verification describes the comparison of model and measured output after calibration, using a different set of input data. If calibration is successful, the model output will be within accept ' able limits of the measured output. The problem faced in modeling landfills is that the measured data (percolation, runoff, evapotranspiration, etc.) are not available and therefore calibration and verification are not possible. Thus, the model results contain an unknown amount of uncertainty.

In an ongoing study sponsored by the U.S. EPA (Peters, et al., 1986), the uncalibrated HELP results underpredicted leachate production for two cover systems by 54% and 36%. The model was then calibrated to the measured data and then verified against another period for which measured data was available. The results underpredicted leachate production by only 12% and 23%. In another study, Gee (1983) used the HELP model to simulate leachate production from lysimeters filled with refuse and found the error in total leachate production over three years was a 12% overestimate. However, the mean monthly absolute error was 75% of the actual average monthly leachate production. This indicates that for long-term predictions, the model is reasonably accurate. However, for the short-term predictions, considerable error is.possible.

The limitations imposed by the lack of data for calibration and verification can be partially overcome by observing the following guidelines:

- Use site specific climatic data, especially daily precipitation values. In some cases, it may be necessary to average the precipitation from several surrounding gage stations using Thiesson, isohyetal or other averaging methods (Linsley, et al., 1982).
- Analyze soil borrow sources for the parameters required by the model and input the results manually rather than using default soil data.

- • Conduct a sensitivity analysis to determine those parameters that have a major impact on the results. Vary these parameters'over a reasonable range to establish an output range that defines probable minimum and maximum values.

- • Frere, et al., (1982) states that 11 ... perhaps the most important need in model use is knowledge of errors and sources of uncertainty." This means that the model user must be fully knowledgeable in the model algorithms, limits of the available data and experienced in model application. Modeling should be done by qualified personnel only if the results are to be meaningful and costly mistakes avoided.

The HELP model is the most powerful and readily available model for evaluating landfill leachate management alternatives and developing design criteria. It is well documented and is the subject of ongoing research to improve its usefulness. In most cases, it should be the model of choice.

4.10.3.4 Rainfall Simulator Model

An empirical equation model specific to solid waste landfills has been developed by Gee (1981 and 1983). This model predicts percolation based upon an exponential relationship between the amount of rainfall, the initial moisture content of the soil, the dry density of the soil, and slope. Coefficients in the equation are determined from statistical analysis of data collected using a rainfall simulator and laboratory scale lysimeter.

Application of this model would require construction of a rainfall simulator and lysimeter, as well as conducting controlled laboratory experiments on soil samples to be used at the landfill. Data from these experiments must be analyzed using a computerized statistical analysis program to determine the value of the coefficients in the basic equation. Applying the basic equation with calibrated constraints to lysimeters filled with refuse, Gee (1983) found the mean monthly error to be 63% of the actual average monthly leachate production.

4.10.3.5 Other Models

Some of the more sophisticated hydrological models could also be applicable to directly predicting the amount of leachate generation. These models attempt to simulate the important hydrological processes by physically based equations versus simple empirical relationships. An example of these types of models is the Hydrological Simulation Program- -FORTRAN (Johanson, et al., 1980). Output from this model could be directly applied to leachate generation predictions without going through tabular calculations as in the 1975 EPA water balance method. Such models have the capability of providing more accurate simulations if there is adequate data for calibration and verification. However, because of the higher cost and time to develop these models, they are seldom employed in leachate prediction studies. Also, they are designed for surface hydrological studies and therefore do not provide estimates of the efficiency of bottom liners and leachate collection systems as the HELP model does.

Another concept suggested for predicting leachate generation is the extrapolation of data collected at other landfills. There are many potential pitfalls in following this procedure. Currently, there is little existing data in Washington relating precipitation and leachate generation. The Cathcart Sanitary Landfill in Snohomish County is the only landfill in the state that has a long-term record of data on precipitation and leachate generation. Although providing very useful information, using such a small data base to extrapolate results directly to other landfills is not advisable. Another problem arises in the differences between two sites. Data collected from one site are particular to it and are a function of the various factors specific to that site. Unless the important factors and conditions are identical, or at least very similar between the sites, it is unlikely that similar effects will be observed.

4.10.4 Modeling Active Areas without Final Cover

In the early life of a landfill, the refuse is not at field capacity - Field capacity is the moisture content of the refuse after gravity drainage is complete (Linsley, et al. 1982). The initial moisture content of refuse placed in the landfill is usually below its field capacity. Therefore, as precipitation infiltrates into the landfill, the moisture is absorbed by the refuse until moisture content reaches field capacity. After the refuse has reached field capacity, any additional water cannot be adsorbed and therefore it flows through the refuse and is discharged as leachate.

To account for the moisture holding capacity of the solid waste, it is necessary to know the initial moisture content of the refuse and what its moisture content is at field capacity. These values will vary according to the type of refuse, the time of year in which the refuse is collected, the size and condition of the refuse, and the density of the refuse in the ,landfill. An initial moisture content of 2 inches of water per foot of refuse and a field capacity of 3.6 inches per foot are reasonable values (Burns and Karpinski, 1980).

It should be noted that prior to actually reaching field capacity, there will likely be measureable leachate production (Kmet 1982). This has been experienced at landfills in Washington where liners and leachate collection systems have been installed. Channelization within the refuse allows water to flow through the refuse ' without being absorbed. Different pockets of refuse may also reach field capacity at different times. It can be safely assumed that operating landfills will generate leachate immediately, although probably in smaller quantities until the field capacity of the solid waste is reached. When the entire landfill reaches field capacity, leachate generation will increase to levels approximating those predicted using the models discussed in this section.

A potentially overlooked factor in predicting flows from active landfill areas are those areas that are lined and have a leachate collection system installed, yet have not received solid waste. Unless the design of the collection system allows for diversion of water collected from this area, it will flow into the leachate treatment system. Since the precipitation is falling directly on the collection layer and there is no runoff, very little evaporation and no absorptive material, the entire precipitation event will be rapidly transported to the leachate treatment system. Unless planned for, the volume and rate of this flow may overwhelm the treatment system. A careful analysis of the amount of exposed liner/collection area during periods of high precipitation should be undertaken to avoid unmanageable flows.

One model for predicting active area leachate generation makes use of the evapotranspiration equation developed by Thornthwaite (1957). The remainder of the model consists of a water balance, as discussed previously, which includes the moisture storage capacity of the solid waste. For example, the incoming solid waste may be assumed to have an initial moisture content of 2 inches per foot and a field capacity of 3.6 inches per foot, allowing for 1.6 inches per foot of additional moisture adsorption. It is assumed that any unused moisture capacity for a given month carries forward to the next month and is spread over the entire site. This simplification does not allow for saturated areas, but there is no way of accurately defining these areas. Vertical channelization through the solid waste is assumed as a given percentage of the precipitation. Because the precipitation which percolates through the vertical channels is not absorbed by the solid waste, this moisture holding capacity remains. Therefore, over the life of the site, about the same amount of moisture will be adsorbed regardless of the extent of vertical channelization.

A sensitivity analysis should be conducted to determine the effect of solid waste moisture storage, moisture storage short-circuiting, and evaporation on predicted leachate volumes.

The HELP model also can be used to predict leachate generation from an active area. No studies have yet been done to evaluate the accuracy of the HELP model predictions for the active area.

Table 4.6. Water Balance Model Selection Matrix.

Design Phase	Required Output	Applicable Model
Site selection	annual volume	1975 EPA method, modified 1975 EPA method
Conceptual design/ design criteria	annual volume	HELP, modified 1975 EPA method
Plans and specifications	annual volume maximum monthly flow maximum daily flow	HELP, rainfall simulator

4.10.5 Model Selection

During the life of a landfill there are various phases where leachate generation estimates are necessary. The level of accuracy and effort required in making these estimates will vary depending upon the purpose. Table 4.6 provides assistance in selecting the appropriate prediction model. The recommendations are for those models most appropriate to the situation based upon the level of effort it takes to apply them and the accuracy of their output. Other models may be used but they do not provide the level of accuracy to achieve the most efficient design, or they may require more effort than is appropriate for the situation.

4.111 SURFACE WATER MANAGEMENT SYSTEM DESIGN

4.11.1 Design Procedure

Designing a surface water management system to meet the goals previously established in Section 4.8 requires an extensive understanding of hydrology and hydraulics, as well as the application of these design principles to a solid waste disposal site. This section is not intended to be a tutorial for storm drainage design, but rather outlines specific techniques applicable to Washington landfill sites, documents available reference guides and design manuals, and presents key issues related to performance, reliability and costs.

A recommended design methodology for surface water systems is offered below and should be used in conjunction with the discussion of site design in Section 4.5.

- Define drainage basin boundary
- Identify major water courses and physical characteristics
- Identify potentially sensitive features (wetlands, fish migratory streams, etc.)
- Define site grading plan, including phased development Identify potential collection and diversion requirements
- Use minimum design storm as required in the Minimum Functional Standards, or local ordinance if more stringent, for specific facility sizing
- Develop design storm hydrographs and peak flow velocities
- Select and size applicable alternative facilities such as ditches, culverts and detention basins to handle the design flows
- Evaluate the alternatives for the most efficient and cost effective facilities to provide proper storm water handling
- Identify permanent and temporary erosion control plans
- Identify permanent and temporary siltation control plans

The design procedure and methodology for storm water management presented generally parallels the Washington State Department of Transportation (WDOT) Highway Hydraulic Manual (1972). The designer may also use texts and references relating to hydrology, hydraulics, and storm water management.

4.11.2 Selecting the Design Storm

The design of surface water control systems involves determination of peak runoff flow rates and velocities using accepted hydrologic analysis techniques and then sizing the appropriate conveyance facility (pipes, ditch, culvert, etc.) to pass this design flow safely. Important to this analysis is the selection of the appropriate data to be utilized in the design phase.

Precipitation information useful for the design of surface water management facilities is available from the Soil Conservation Service (1982a and 1975). This reference provides isohyetal maps displaying lines of equal precipitation for a specific duration and frequency. Another set of intensity, duration and frequency curves for many locations in Washington State are contained in Appendix 1 of the WDOT Manual (1972).

The selection of a design storm (also referred to as rainfall recurrence frequency) for solid 'waste landfill facilities can be based upon the following:

- Regulatory agency requirement
- Designer judgment

Design storm criteria are specified in the Minimum Functional Standards and discussed in Section 4.8. If local regulations specify storm frequencies for design applications, they must be applied as required. In cases where the design will impact Washington State highways, criteria established in the WDOT Manual must be applied.

In addition to regulatory criteria, designer judgment is also important. Temporary facilities are commonly employed in the fill area due to its changing configuration during the life of the landfill. These facilities may include ditches, culverts and dikes. Storm frequencies selected for these facilities may need to be no greater than the 10-year storm. Still other facilities may require a life much longer than the active life of the landfill. For example, facilities that divert, reroute or otherwise control natural drainage away from the fill area are required to remain effective long after the landfill is closed. Their failure could lead to catastrophic washout of the fill area. Such facilities should be designed to accommodate more severe storms, such as the 100-year storm or the maximum storm of record.
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4.11.3 Evaluating the Design Storm

The accurate prediction of surface runoff from the solid waste disposal site and from the surrounding area onto the site is important because of its effect on subsequent surface water management designs. Unfortunately, the simulation of the rainfall-runoff process is very complex and no model exists that can supply consistently accurate results. Nevertheless, a wide variety of models exist for simulating surface runoff and some of them are commonly used by the engineering profession to yield satisfactory results for storm water management. The most commonly used models are addressed in the following discussion.

4.11.3.1 Rational Method

The rational method has been employed for many years by engineers in urban storm water facilities design. The method works best for small areas with large percentages of impervious surfaces. Applications to areas greater than 10 acres are not recommended (Linsley and Franzini, 1972). The rational formula is recognized as a poor choice in rural areas (Linsley, et al., 1982). Because solid waste landfills are commonly greater than 10 acres in size and located in rural areas, the rational formula is not recommended as an appropriate runoff prediction method for larger areas. However, it may have applications to smaller areas and minor facilities.

4.11.3.2 Soil Conservation Service Curve Number (CN) Method

The Soil Conservation Service (SCS) CN method was developed from analyzing extensive rainfall-runoff data from rural watersheds. It allows prediction of surface runoff from unmonitored watersheds and is incorporated in the leachate prediction model (HELP) sponsored by the U.S. EPA. Derivation of the CN Method is presented in SCS (1972), Schroeder, et al. , (1983a) and McCuen (1982).

The basic CN method requires the following types of input data:

- Soil hydraulic group
- Land use cover conditions
- Antecedent moisture condition
- Type storm distribution

The CN method recognizes four soil hydrologic groups determined from soil characteristics, county soil surveys or minimum infiltration rates. Cover conditions are described for a number of land uses. Selection of an appropriate land use depends upon the evaluation of the site and the judgment of the designer. With these two variables, a CN is selected from a table and then adjusted according to the antecedent moisture condition. Three antecedent moisture conditions have been developed by the SCS for dry, average and wet conditions.

Two storm type distributions (Types IA and II) exist in Washington. Their area of influence is shown in Figure 4.25. It is important to select the correct storm type distribution because different tables and figures are used

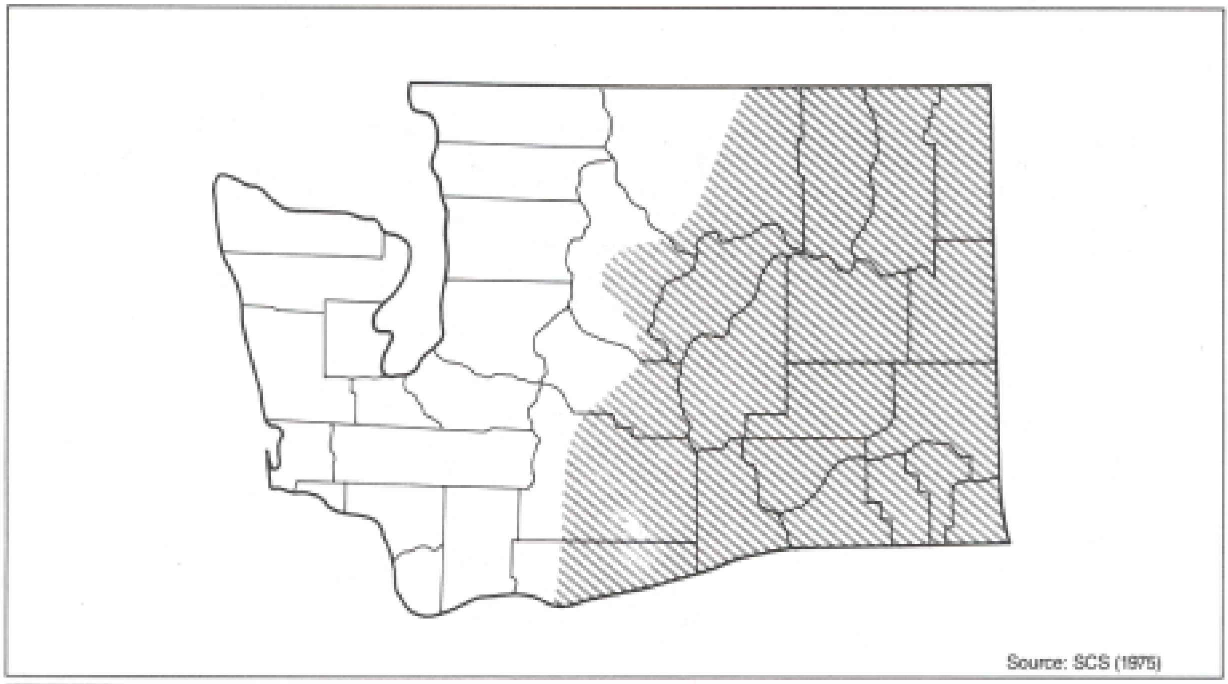

Figure 4.25
SCS Storm Distribution Regions

for the selection of the CN, the design rainfall amount, and the prediction of peak runoff rates based on the storm type.

TR-20. The CN method is used in several different forms to predict peak flow rates. The most comprehensive is the computer program documented in Technical Release Number 20 (SCS, 1982c). This program can be purchased through several suppliers and will run on a personal computer. Input data requirements include:

- Drainage area
- Runoff curve number
- Time of concentration
- Antecedent moisture condition
- Rainfall depth
- Hydrograph time increment
- Length of reach

- Reach cross section data

- Structure elevation and stage-discharge relationship

A variety of output is provided, but the most significant are hydrographs, peak flows and total runoff volumes.

The model can be set up to simulate highly complex drainage basins with numerous sub-watersheds. The model allows the designer to investigate a large number of stormwater management systems to determine the most cost effective combination. When coupled with on screen editors, macro programs and spreadsheet programs, the entire surface water management system can be designed.

A note of caution again. As discussed in Section 4.10, without calibration and verification, the results of any model, including TR-20, are subject to an unknown amount of uncertainty. The limitations must be fully understood by the model user to prevent inadequate or over-sized surface water management facilities.

TR-55. There are other ways to use the CN Method and they are described in Technical Release No. 55 (SCS, i975), and includes the Western Washington Supplement (SCS, 1982). TR-55 includes the following methodologies:

- Tabular
- Chart
- Graphical

All of these methods require manual calculations and have limitations when compared to TR-20. The tabular method was developed to provide similar output to TR-20. However, for even a moderately complex watershed, the calculations become very tedious and time consuming. Also, the tabular method was developed by making numerous runs on TR-20 using a CN of 75. If the tabular method is applied to cases having different conditions, the resultant hydrographs are likely to be different than if TR-20 had been used (McCuen, 1982). However, if the purpose is to determine the change in hydrographs before and after development, the results are relatively insensitive to the assumption of a CN of 75 (McCuen, 1982).

The chart method was developed to estimate the effect of development on peak flows. The method accounts for a number of factors that may influence peak flows. The method is only appropriate to single water sheds and does not provide a runoff hydrograph. The combined effect of several sub-water sheds cannot be simulated.

The graphical method is a very quick and simple procedure to predict a peak flow. It should be used only for watersheds of uniform land use and soil type and where valley routing is not required (McCuen, 1982). As with the chart method, no hydrograph output is provided.

4.11-3.3 U.S. Geological Survey Method

The United States Geological Survey (USGS) has prepared and published a method for estimating magnitude and frequency of floods on Washington streams. Detailed by Cummans, et al. (1975), the method uses annual peak flow data from stream gaging stations on unregulated streams having 10 years or more of records to determine a log Pearson Type III frequency curve for each station. Flood magnitudes having recurrence intervals of 2, 5, 10, 25 and 50 and 100 years were then related to physical and climatic indices of the drainage basins by multiple regression analysis. These regression relations are useful for estimating flood frequencies of specific recurrence intervals at ungaged or short record sites.

Regression equations are defined for western and eastern parts of the state. The state is further divided into 12 regions in which the annual floods exhibit similar characteristics and for which regression constants are tabulated**.** In western Washington, peak flows are related most significantly to drainage area size and mean annual precipitation. In eastern Washington, they relate most significantly to drainage area size, mean annual precipitation and percentage of forest cover.

Certain limitations apply to this method of predicting flood magnitudes for different recurrence intervals. . Natural flow stream data was used for determination of relationships and the equations should not be applied where artificial conditions affect the areas hydrology or hydraulics. The relationships can be used with most confidence in humid areas and in areas with numerous gaging stations, and with least confidence in arid areas and where limited or no stream flow data are available. Standard errors of estimates range f rom 25 to 129 percent. Because of these limitations, the CN method should be used in lieu of the USGS method.

4.11.3.4 Other Methods

A wide variety of other methods is available for simulating rainfall-runoff relationships. Most of them involve computer simulation programs that attempt to model the physical processes influencing the runoff process more accurately. This usually makes them prohibitively time-consuming and costly. Simpler models exist that have been used in hydrologic designs, such as the unit hydrograph method. The application of other models must be evaluated on a case-by-case basis.

Many hydrologic software programs are now available for personal computers. The designer must be aware of the algorithms the software uses in its calculations. Many of these software packages use the rational method, which as discussed previously, has limitations in application to most solid waste landfill sites.

Some models have the advantage of a sediment transport and/or other pollutant prediction capability. This capability is advantageous in predicting water quality effects downstream of landfill sites. A discussion of this aspect of storm water management is contained elsewhere (Morck, 1984).

4.11.4 Collection, Conveyance and Diversion

4.11.4.1 Culverts

Both temporary and permanent culverts are needed at landfill sites to convey storm water under road crossings. Designing the culvert involves:

- Determining peak flow
- Analyzing hydraulic performance
- Selecting material and type of structure
- Determining construction and placement requirements
- Estimating cost

A culvert limits flow by inlet or outlet control. The culvert is sized by calculating both inlet and outlet conditions according to standard engineering procedures and then using the most restrictive condition to select the pipe size. The VDOT Hydraulic Manual (1972) provides procedures for sizing culverts.

A variety of materials is available for constructing culverts. Selection is based on size and flow conditions, availability, on-site construction capability and cost. Concrete and corrugated metal pipe are often used. The metal pipe may be aluminum or steel with protective coatings and possibly interior paving to improve flow conditions. Other materials to consider are plastic pipe, asbestos cement and vitrified clay. For larger structures, reinforced concrete and corrugated plate pipe arches are available options.

Inlet and outlet channel conditions may require special design attention. A precast or cast-in-place headwall may be needed to avoid erosion on the inlet. For outlet velocities less than 5 feet per second, native channel material may be adequate. With velocities between 5 and 10 feet per second, special placement of gravel and rock should be considered. Above 10 feet per second velocities, larger rock and special energy dissipators may be required to'avoid destructive erosion.

A useful reference for drainage structure design, material and construction specifications is WDOT/APWA (1984).

4.11.4.2 Ditches and Open Channels

Ditches and open channels generally provide the most economical means of collecting and conveying storm water. The layout of these drainage elements depends on the landfill operation plan. The ditches and channels may be permanent or temporary installations to conform to the site operations. Design considerations include:

- Capacity requirements

- Roughness coefficient
- Size and shape
- Alignment and grade
- Permissible velocities and channel protection
- Maintenance

Larger ditches and open channels are sized to carry the design flow. The hydraulic design is dependent on the required flow capacity, available slope, channel size and shape, and the surface roughness. The most prevalent relationship used for these factors is Manning's equation. Solution of this equation for depth of flow requires trial solutions Several aids are available for rapid solutions (King and Brater, 1954; WDOT, 1972; King County, 1979).

Ditch and channel bank protection must be considered in the design. Two methods of designing stable channels are tractive force and permissible velocity. The tractive force method is described by Chow (1959). An abbreviated description and applicable charts are included in WDOT (1972). The permissible velocity method is also described by Chow (1959).

Possibilities to consider for erosion protection include seeding the channel with grass, soil stabilizing plastic mats, rock riprap, ruble masonry riprap, sack riprap, broken slab riprap, wire mesh gabions and concrete lining. Additional information for designing grassed channels is discussed by Chow (1959) and Goldman, et al. (1986). Design details for riprap are shown in WDOT (1972).

4.11.4.3 <u>Storm Sewers</u>

A solid waste disposal site plan may require underground conveyance of storm water, whether a single reach of pipe or a more complex system. At a landfill site, the system would not be as complex as for urban areas. Installing storm severs can be costly and should be utilized only where ditches and open channels are not acceptable.

Design considerations for a storm sever include:,

- Developing general system layout
- Obtaining topographic information and/or route surveys
- Computing peak flow rates
- Selecting sewer materials and/or alternate materials
- Pipe sizing
- Appurtenances required

- Soil conditions for proper installation
- Discharge location and control
- Construction and placement requirements
- Estimating costs of designed system and any alternatives

The general storm sever system layout is developed in conjunction with the site plan. The requirements for underground storm conveyances will be dictated by this planning process.

Topographic maps can be used to establish alignment and the vertical profile. Often, a route survey will be necessary to prepare the detailed design.
Storm sever materials available include:

- Plain concrete
- Reinforced concrete
- Asbestos cement concrete
- Corrugated metal pipe, both steel and aluminum, with a variety of lining and coating treatments
- Structural plate pipe
- Fiberglass reinforced pipe
- Concrete cylinder pipe
- PVC plastic pipe
- •Polyethylene plastic pipe
- Corrugated polyethylene plastic pipe
- Vitrified clay
- Ductile iron

Selection of pipe material will be based on performance for structural loading, infiltration, deterioration, hydraulic capacity, availability, ease of construction and cost. Material specifications and performance characteristics are available from manufacturers and suppliers. Material and installation specifications for concrete pipe, corrugated metal pipe and asbestos cement pipe are included elsewhere.

Structural loadings on storm severs can include gravity earth loads and superimposed dead and live loads. The theory for gravity earth loads was initially developed by Marston. For a more thorough description of this theory and application of Marston's method, refer to the discussion in ASCE and WPCF (1982).

A discussion of refuse and earth loads on underground conduits is provided in Appendix C. These discussions cover trench, embankment and superimposed load conditions. Bedding materials and factors are also included.

Sizing the storm sever depends on the required flow capacity, the slope of the sever and the nature and configuration of the pipe material selected. The most commonly used formula to size storm severs is the empirical expression, Manning's equation.

Appurtenances incorporated into a storm water system may include drain inlets, catch basins, manholes, siphons, flap or backwater gates, headwalls, energy dissipators and outlet controls. Vhere storm severs are provided on roadways, a maximum inlet spacing of 300 feet is a usual criteria. Catch basins and manholes are spaced at junction points, grade changes and at 400 to 500 foot intervals to allow cleaning. Catch basins generally provide a sump area to retain silt, whereas manholes allow access and convey water through the structure in a smooth channel. Flap or backwater gates are needed in special instances of rising stream stage or rising tidal areas. Energy dissipators are required at the outlet of steep slopes to prevent stream bed damage. Outlet controls are usually required with detention facilities as discussed in a following subsection. Many local jurisdictional agencies have specific design standards which must be adhered to.

Soil conditions for proper placement of storm severs are required for supporting the pipeline. Vhere native conditions are not adequate, special design must be implemented. This may mean replacing unsuitable material with firm unyielding foundation gravel. More extreme measures such as pile support are occasionally used.

Construction material and installation requirements must be specified for facility construction. The specifications provided by VDOT/APWA (1984) are an excellent basis for specifications.

4.11.4.4 Dikes and Embankments

The locational standards included within the Minimum Functional Standards permit the location of new or expanded landfills within the 100-year floodplain. If such a location is chosen, it may be necessary to construct dikes or embankments to prevent a washout of solid waste that could pose a hazard to human life, wildlife, land or water resources. Dikes and embankments may also be constructed as part of a diversion system for surface water run-on or as part of detention or siltation basins.

No matter what the purpose, design considerations are similar. They include:

- Maximum elevation of water to be contained
- Soil materials available for construction

- Protection of side slo pes against erosion

- Slope stability

The maximum water elevation to be contained depends on the rainfall frequency chosen. The design storm is used to model surface runoff according to Section 4.8. Surface runoff is then routed along the channel to determine the maximum stage to be reached. Various hydrologic and hydraulic routing methods are available (Linsley et al., 1982).

Available soil materials are tested to determine their compatibility and strength. Appropriate tests include the standard Proctor compaction test and a variety of methods for determining the shear strength of the soil. These tests are discussed in Cummings and Hart (1959) and other standard soil mechanics texts. A variety of soils can be used in embankment construction, although those that can be compacted to higher densities are preferred. Soils that retain more than 66 percent of the No. 4 standard sieve size should not be used, and any rock larger than six inches should be removed from the fill (Krynine and Judd, 1957). Field compaction densities should be 95 percent of the maximum standard Proctor dry density. The U.S. Army Corps of Engineers also provides safety standards for flood plain design.

It is necessary to protect the faces of the slope from flowing water. This face can be protected by riprap underlain by graded gravel. The graded gravel is necessary to prevent the wash-out of fines from the embankment and the settling of the riprap into the embankment. Soil admixtures like soil cement and various asphaltic mixtures are also useful in preventing erosion. Establishing vegetation, sometimes in combination with slope stabilizing geosynthetics, can also be an effective erosion control method. Similar methods can be applied to the opposite face of the embankment or dike.

Slope stability must be analyzed to prevent failure of the embankment or dike. Stability can be increased by reducing the degree of slope, achieving good compaction in the field and by using soil additives or geosynthetics to improve the strength of the soil. Slope stability design requires detailed analysis. A review of analysis procedures is provided in ASCE (1969).

4.11.5 Detention and Retention Basins

Detention and retention basins are storage areas to control the release of surface runoff. Detention basins are temporary storage facilities whose purpose is the- controlled release of water below a specified peak flow. Detention basins do not reduce the volume of surface runoff. Retention basins are permanent holding facilities that not only reduce the peak flow rate, but also the total volume of surface runoff. Retention basins may either retain all runoff or allow a fraction of the total to be released.

Detention or retention basins may be required upstream of a landfill site to control the run-on around the site or downstream of the site to control runoff from the site. The latter case is more common because site modifications generally lead to increases in both the peak,flow and total volume of runoff from the area.

Design of detention and retention basins is based on the following criteria:

- Pre-development peak flows
- Prediction of surface runoff hydrograph
- Routing of surface runoff along reaches
- Stage-discharge relationship of basin
- Stage-storage relationship of basin
- Impact of storage and infiltration

Typically, the desired objective is to maintain the peak flow below a specified value. Sometimes volume reduction is required also. The first objective is satisfied by a detention basin, the second by a retention basin.

Surface runoff can be predicted using methods discussed previously in this section. Runoff predictions must be made for both preconstruction and postconstruction conditions.

Routing of surface runoff to the basin is an essential step. A variety of hydrologic and hydraulic routing methods is available (Linsley et al. 1982). The TR-20 program includes reach routing. The result of this step is an inflow hydrograph to the basin.

The stage-discharge relationship is controlled by the type of outlet control. Outlet controls include orifices, sluice gates and weirs. The use of weirs does not permit complete draining of the basin -unless other facilities are provided. For each type of outlet control, a stage-discharge curve is prepared, and the size and type of outlet is selected based upon the maximum stage and flow rate desired.

Initial storage volume estimates are made using standard reservoir routing techniques and comparing inflow 'hydrographs to the specified outlet hydrograph (Rutter and Engstrom, 1964; Lindsley, et al. 1982; URS, 1977). The basin configuration is determined using the required volume and maximum stage desired. The stage-storage relationship is then computed directly for regular-shaped volumes or from topographic contour area relationships for irregular-shaped volumes. Using the inflow hydrograph, the stage-discharge curve and the stage-storage curve, the flow can be routed through the basin to yield an outflow hydrograph. The TR-20 program includes basin routing.
This hydrograph can be compared to the specified requirements to ensure the design is adequate.

The above procedure can be used for both detention and retention basins. Volume requirements for detention basins should be increased by 30% to allow for residual storage. Retention basins must be designed to allow for the long-term storage of runoff. If no runoff is permitted from the basin, outflow is estimated from evaporation and infiltration rates. If.infiltration is significant, careful consideration must be given to its potential effect on the ground water table and quality in the vicinity of the landfill.

4.11.6 Erosion Control

Any surface water management plan must be concerned with potential erosion problems. The problems are particularly prevalent around construction activities or other areas where disturbed soil is exposed to precipitation and runoff. Solid waste landfills are in this category. The potential for erosion can be estimated using the Universal Soil Loss Equation (USLE). Use of this equation is described in Appendix D.

A large number of erosion control practices are available depending upon the application. Some measures are for permanent control such as riprapping channels or protecting final grades with vegetation. Other measures are employed to control temporary situations subject to erosion such as mulching temporary grades. Specific examples of erosion control measures are discussed in Section 7.6.

4.11.7 Water Quality Control

Discharge of surface water runoff, originating in whole or in part, from the landfill site, must not cause receiving water body quality standards to be exceeded, as discussed in Section 4.8. Assuming that the runoff has not been in contact with buried solid waste, the most likely pollutant to cause water quality problems is suspended sediments. The source of this pollutant is erosion from soil slopes, ditches, embankments and other surface water management elements where water can erode and carry soil particles. Management of this pollutant can occur at its source, or at a point between the source and the receiving water body. Management at the source is achieved through erosion control practices, which are discussed in Section 7.6. Management after the source is typically achieved through the design and construction of siltation basins.

Siltation basins are designed to remove a predetermined percentage of soil particles of a given size using classical sedimentation theory developed for waste water treatment. Typically, Stoke's Law is used to calculate the settling velocity of the particle size of interest. Using this velocity and the flow rate of the runoff, the surface area of the siltation basin can be calculated (Weber, 1972).

The size determined by the calculations described above assume ideal plugflow through the basin. To approach ideal conditions in the field, it is necessary to include certain elements or criteria in the siltation basin design. These include (Weber, 1972):

- Length to width ratio between 5:1 and 3:1
- Uniform distribution of influent across inlet; desirable head loss across inlet is from 0.02 to 0.04 feet

- Effluent weir loadings less than 15,000 gallons per foot of weir length per day

Even if the above criteria are met, the efficiency of the siltation basin will not be as high as predicted. This results from the relatively small detention time found in most siltation basins under peak flow conditions. The short detention time and accompanying high flow velocity create turbulent flow conditions which are not accounted for in classical sedimentation design. Predicted siltation basin efficiencies can be adjusted by multiplying the unadjusted design settling velocity by 9.0 to achieve the adjusted design settling velocity (NVPDC, 1979). The adjusted design settling velocity can then be compared to particle settling velocities to determine the minimum size particle that will exhibit 100% removal in the basin. The efficiency of the basin in removing particles with a settling velocity less than the adjusted design settling velocity can be calculated using a settling-velocity analysis curve as described in Weber (1972) and other standard wastewater treatment tests.

If the above factors are included in the analysis, the typical siltation basin under peak flow conditions from the 25 year - 24 hour storm will be found to be efficient in removing particle sizes from course to medium sand, less efficient in removing fine sand, and generally of low efficiency in removing silts and clays. Since the efficiency of the siltation basin is sensitive to the rate of flow through it, a more accurate estimate of the efficiency of the basin under average conditions could be achieved by evaluating smaller design storms, such as the 2 year - 24 hour storm.

The lower efficiency of the siltation basin under higher peak flows also illustrates the importance of frequent basin cleaning. Previously-settled sediments may be resuspended and carried out of the basin during high peak flows, negating the efficiency of the basin during previous low flow storms. Monthly cleaning may be necessary during seasons of high precipitation. ~

Removal of other pollutants will also occur in the siltation basin since many pollutants will adsorb to sediment particles. When the sediment particle is removed, the other pollutants adsorbed to it are also removed. Typical pollutants removed in this manner include:

- BOD
- Phosphorus
- Nitrogen
- Heavy metals

Removal efficiencies can be estimated by methods described in NVPDC (1979). If the outlet from the basin uses an infiltration system, removal efficiencies will be higher since a greater fraction of the suspended solids will be removed and also some dissolved pollutants may be removed from solution as they move through the infiltration system.

4.12 LINERS

4.12.1 General Descriptions and Types

Solid waste landfill liners are designed to prevent the movement of potentially harmful pollutants beyond the boundaries of the landfill. Liners achieve this objective by either or both of the following mechanisms (Hermann and Tuttle, 1981):

- Impede leachate flow by having a very low permeability
- Attenuate specific pollutants by adsorption, ion exchange, complexation and other reactions

Solid waste landfill liners are required under WAC 173-304-460, Landfilling Standards. Applicable facilities must install liners per Subpart (3). Two liner designs are presented in the regulations, and in addition to allow an equivalent and arid design.

4.12.1.1 Standard Design

The standard design consists of a minimum four-foot thick layer of recompacted clay or other material with a permeability of no more than 1X10-7 cm/sec. The finished liner must be sloped no less than two percent. This design may not be feasible for many sites due to the quantity of material required and the expense of obtaining the material off-site, if not readily available on-site.

4.12.1.2 Alternative Design

The alternative design consists of two liners. The upper liner must be at least 50 mils thickness and be made of synthetic material. The lower liner must be a minimum two-foot thickness of recompacted clay or other material and have a permeability of no more than $1x10^{-6}$ cm/sec. The finished liner must be sloped no less than two percent.

The alternative design is frequently the more desirable liner system. The reduced impermeability and thickness requirements for the soil liner increase its feasibility in areas with little or no available silt or clay materials. The added cost of the synthetic liner is often outweighed by cost reductions in soil materials.

4.12,1.3 Equivalent Design

The equivalent design may utilize alternative methods, operating practices and locational characteristics to minimize migration of leachate into the ground water. However, the designer must show equivalence to the preceding designs to obtain a variance from the Washington State Department of Ecology.

Equivalent design liners may consist of systems such as double liners, or very deep natural deposits of materials with higher permeability than the standard design. These examples are meant to illustrate possible equivalent designs. Their inclusion here does not guarantee acceptance by Ecology.

4.12.1.4 Arid Design

Liners are not required in arid areas receiving less than 12 inches of rainfall annually. However, moisture in the vadose zone must be monitored and any evidence of leachate that violates WAC 173-304-460(2) may prompt Ecology to require corrective action, close the landfill or require installation of liners in further expansion areas.

Small landfills (total capacity 200,000 cubic yards or less), whether in arid areas or not, will be evaluated for liner requirements on a case-by-case basis.

4.12.2 Design Procedure

The design procedure for landfill liners consists of the selection of one of the previously described liner designs, a grading concept or plan and resolution of design details. Liner details may include liner penetrations, anchoring considerations and possible underlying,gas venting layers.

The selection of a liner material is based on a variety of factors. The principle factors are listed below (U.S. EPA, 1983):

- Type of waste and composition
- Required operating life of the landfill
- Required life of the liner after closure of the landfill
- Soils on or n nearby site, including subsoil
- Hydrology and hydrogeology
- Significant environmental factors
- Acceptable leakage of leachate
- Permeability of available clay soil if any
- Review of material which appear to be potentially compatible
- Compatibility tests of specific materials with sample of the waste to be contained
- Costs of candidate materials and installation
- Reliability of materials, seams and joints and documented experience in the technology

A variety of liner materials are available for use in landfills and include the following:

- Remolded natural soil
- Admixed materials (asphaltic compositions and treated soil)
- Synthetic liners
- Soil sealants
- Chemical absorptive materials

Remolded soils used for liners have significant clay fractions. If the natural soil is unsatisfactory, it can be improved by the addition of various materials such as bentonite. Asphaltic concrete and sealants have been used, but are not recommended for Washington landfills. An alternative to natural soils is synthetic liners composed of various polymeric compounds which must be used with a layer of low permeable soil. Each of these categories will be considered in the following sections.

The liner selection process should generate an appropriate liner design that will meet state and local requirements, as well as satisfy basic design objectives of feasibility, cost effectiveness and long-term integrity against leakage. In the next stage, grading and details must be addressed. These details are most effectively designed in conjunction with the leachate collection system. Methods for developing an effective liner and collection system are discussed in Section 4.13 and in Appendix E of this manual.

4.12.3 Natural Soil

4.12.3.1 General

The use of natural soil as a liner for solid waste landfills is a common practice. Recommended soil classifications (USCS) include CH, CL and MH. These soils have a low permeability and a high adsorption capacity for certain contaminants. These soils may exist uniformly over the entire site and with grading, remolding and recompaction the standard liner design can be achieved. Other on-site soils may not be suitable in their natural state, or may be concentrated in one area of the landfill requiring excavation and placement. With additional remolding and compaction, these soils may be made satisfactory. When on-site soils do not meet minimum design criteria, suitable off-site soils can be imported, remolded and compacted to form a flow impeding layer.

4.12.3.2 Availability

Soil for a solid waste landfill liner is potentially available from two sources, on-site and imported. On-site soils are preferable for two reasons. First, they are more economical because additional property is not needed for the source material and transportation costs are greatly reduced. Second, use of on-site excavated soils eliminates the need to find alternative uses for the soil or areas to dispose of the excess. If on-site soils of suitable characteristics are unavailable, then a borrow source off-site must be located. Proximity to the landfill site is an important factor to reduce transportation costs.

Estimates of required soil volumes are based on the thickness of the liner and the area of the active fill. It is important to include side liners in this calculation as well. For every acre of active fill area, 1,613 cubic yards of compacted soil is required to achieve a liner thickness of one foot. Available soil volume is calculated from geologic information collected as discussed in Section 4.2. Normally, geologic information is plotted on vertical cross-sections through the area of interest. Volume is calculated based on the indicated thickness of the formation and an estimate of its areal extent. In areas where there is significant heterogeneity of the soils, an adequate number of borings or other information is required to lend confidence to the volume estimates. This can be determined by an experienced geologist.

Consideration must be given to the volume differences between loose and compacted soils. Table 4.7 provides approximate conversions between in-place volume and loose and compacted volume. Failure to account for loss of volume by compaction for clay soils could result in underestimating required in-place volumes by over 10 percent. For a thirty-acre landfill with a two-foot thick compacted liner, the in-place volume requirements could be underestimated by over 10,600 cubic yards.

4.12.3.3 Required Physical Characteristics

The important physical characteristics required for soil liners can be determined from grain-size distribution, Atterberg limits and permeability measurements. Grain-size distribution curves indicate the uniformity of soil particle size and the percentage of fines. Fines are defined as soil particles less than 0.074 mm in diameter (U.S. Standard Sieve No. 200)

Table 4.7 Volumes of Loose and Compacted Soil from One Cubic Yard of In-place Soil

	No. of yards	
Type of Material	Loose	Compacted
Sandy-clayey loam	1.25	0.90
Clay	1.43	0.90
Sand	1.11	0.95

Source: D. P. Krynine and W. R. Judd (1957)

(Roberts, 1984). Atterberg limits are essential factors in evaluating the behavior of clay type soils used as liner materials. Permeability is obviously an important consideration in the evaluation of the soil material because of its direct effect on the ability of the soil liner to contain the leachate. The maximum allowable value specified by the Minimum Functional Standards is 10-7 cm/sec for the standard design and 10-6 cm/sec for the alternative design. Recommended values for these tests are listed in Table 4.8.

Table 4.8 Recommended Soil Physical Characteristics.

Percent Fines	>50%
Liquid Limit	35-60
Plasticity Index versus Liquid Limit	above A-line
Permeability (maximum allowable)	
standard design	1×10^{-7} cm/sec
alternative design	1 x 10-6 cm/sec

4.12.3.4 Required Chemical Characteristics

Chemical characteristics of the soil, in particular the clay fraction, are important in determining how the soil will behave hydromechanically and how effective it will be in attenuating pollutants in leachate (U.S. EPA, 1983) (See Section '4.6). The chemistry of clays varies with the type of clay mineral that makes up the clay. The three major clay minerals are kaolinite, illite and montmorillonite. The size and chemical composition of these mineral particles and their structural configuration influence their. cation exchange capacity (CEC). Montmorillonite has the largest CEC and kaolinite the smallest.

It is preferable to select a soil with a higher CEC because of its greater attenuative capacity. Table 4.9 provides typical CEC's for clays and other soil types. However, no soil can provide 100 percent attenuation of all contaminants. Therefore, selection of soil based on its CEC is of secondary important compared to its physical and engineering properties.

4.12.3.5 Required Engineering Characteristics

Engineering characteristics refer to the ability to manipulate the soil to achieve the desired results. This is measured by the Standard Proctor compaction test and permeability tests. The Standard Proctor compaction test is preferred over the Modified Proctor test because it-more closely matches actual field compaction densities (Schaefer, 1978). Permeability measurements should be conducted at densities and moisture contents that can be achieved in the field. It is extremely important to match laboratory and field conditions as much as possible to avoid large errors in predicted soil permeabilities.

Table 4.9 Typical CEC's of Soil Materials.

Soil Component	CEC (me/100a)
Organic matter	200
Clay	
Montmorillonite	80-100
Illite	15-40
Kaolinite	3-15
Silt	<1
Sand	<<1

Source: Brady (1974)

The Standard Proctor compaction test identifies a maximum dry density and an optimum soil moisture content for a given compactive effort. For fine-grained soils, the permeability can be decreased one to three orders of magnitude by compacting soil at a moisture content wet-of-optimum (Roberts, 1984) (refer to Section 5.4). Therefore, it is desirable to design the compaction operation in the field for as high a moisture content as possible. However, at moisture contents over optimum there are operational limitations that restrict the use of heavy rollers. Compaction must be achieved by increasing the number of passes over the soil with lighter equipment (U.S. EPA, 1983). When compacting wet-of-optimum, it is more important to achieve the highest density possible. A small decrease in density, on the order of one percent, may result in an increase in permeability of one order of magnitude (U.S. EPA, 1983). A maximum permeability of 10-7 cm/sec at 90 percent of maximum dry density and no drier than 2 percent of optimum moisture content would typically be minimum acceptable criteria for the standard liner design. Although it is possible to achieve higher compactions and moisture contents in the field, the quality control required is very strict. Table 4.10 presents field compaction information to achieve 95 percent of the standard maximum density on a solid base at an assumed optimum moisture content.

The stability of soil liners on side slopes is an important consideration. The placement of a compacted soil liner over undisturbed soil produces a stratified structure that is subject to translational slides. Undisturbed homogeneous soils are subject to rotational slides (Krynine and Judd, 1957).

Table 4.10 Field Compaction Requirements to Achieve 95 Percent Standard Maximum Density on a Solid Base

Equipment	Compacted Lift Thickness (in)	Number of Passes
Sheepsfoot rollers	6	4-8
Rubber-tired rollers	10	6-12
Crawler tractors	10-12	6-8

Source: Lutton, et al. (1979)

Slides are caused by the weight of the slope material and superimposed loads and by excess moisture which reduces the shear strength of the soil (Krynine and Judd, 1957). Determining the probability of slope failure requires analysis of the loads on the slope, the strength of the soil, and the hydrology at the site. In most cases, satisfactory slope performance is achieved when the slope does not exceed 4:1 (25 percent) (Lutton et al., 1979). If steeper slopes are proposed or other conditions exist that contribute to slope failure, a stability analysis must be performed according to accepted engineering methods. Final slope design should include a factor of safety of 1.4-1.5 (U.S. EPA, 1983).

Other criteria for soil liner design, such as slope to collection pipes and the permeability ratio between the liner and the drainage layer are developed using Wong's method or the HELP model. These methods are discussed in Appendix E.

4.12.3.6 Soil Liner Failure Mechanisms

The failure of the soil liner due to deterioration by landfill leachate is possible (Hermann and Tuttle, 1981). Failure can be caused by volume changes in the soil and dissolution of the clay minerals and piping (i.e., internal erosion along localized channels) (U.S. EPA, 1983). However, field and laboratory investigations of soil liners does not provide consistent evidence of soil liner failure. In fact, several investigators have found soil liners to perform satisfactorily (Wigh, 1984; EMCON, 1983a; EMCON, 1983b). Other investigators concluded soil liners are satisfactory, based on laboratory tests where soil was exposed to typical solid waste leachate (Hermann and Tuttle, 1981) and to an acidic leachate (Schaefer, 1978). Therefore, unless it is anticipated that the waste stream will contain some materials that will produce an unusually aggressive leachate, it is not necessary to perform permeability tests using a synthetic leachate. If there is uncertainty as to the effects of a particular leachate on the liner, a separate permeability test using this leachate should be performed to ascertain the impacts.

4.12.4 Admixed Materials

Admixed liner materials include hydraulic asphalt concrete, soil cement, and soil asphalt (U.S. EPA, 1983). These materials have been used successfully for water impoundments, but their application as solid waste landfill liners is limited. Bentonite clay mixtures have been used as a landfill liner with greater success, although the mixing and placing process is costly.

4.12.4.1 Bentonite-Soil Liners

Bentonite is a clay soil composed primarily of the clay mineral montmorillonite (U.S. EPA, 1983). There are two types of bentonite. They are sodium bentonite and calcium bentonite. Sodium bentonite is the preferred variety because of its high swelling capacity in water (U.S. EPA, 1983). It is available commercially as a dry powder or granular material that can be readily mixed into soil.

Bentonite-soil layers typically applied in lifts 4-6 inches thick. Bentonite may be applied to the soil in the field with an agricultural spreader and be mixed in place with a disc tiller. Bentonite may also be mixed with the base soil in a pug mill and then placed in the landfill as an admixture. Both mixing and placement techniques and their respective advantages are discussed in Section 5.4 of this manual.

The amount of bentonite applied to the soil will depend on the characteristics of the native soil. Recommended standards for the native soil are as follows (Edil and Didier, 1981):

- Percent fines greater than 30%
- Plasticity index of the fraction passing the No. 4 standard sieve greater than 15

Typical application rates for solid waste landfills range from 1.25 to 5 pounds per square foot.

Bentonite-soil liners are subject to the same failure mechanisms as clay soil liners. Sodium bentonite is particularly vulnerable to ion exchange reactions with leachate which increases its permeability. Some commercial additives have been developed to reduce this impact.

4.12.4.2 Asphaltic Compounds

Asphaltic liners include hydraulic asphalt concrete (HAQ and soil asphalt. HAC is a controlled hot mixture of asphalt and a high quality mineral aggregate that is compacted into a dense layer. Permeabilities less than 10-7 cm/sec are achieved with this method.

Soil asphalt is a mixture' of liquid asphalt and an aggregate of poorer quality than HAC. Typically on-site soils are used. The preferred soil type is a silty, gravelly soil with 10-25 percent silty fines (U.S. EPA, 1983).

Permeabilities vary with the composition of the soil and the compaction achieved.

Haxo, et al. (1982) conducted tests of asphaltic liners with municipal solid waste (MSW) leachate. Liner materials were analyzed after exposure for 56 months. The liner properties changed significantly during this period. Changes noted were lost strength and elongations. Longer exposure would continue to cause changes in the liner properties that could have adverse impacts on the ability of the liner to function as a barrier layer. Based on these results, the use of asphaltic liners in solid waste landfills is not recommended.

4.12.4.3 Soil Cement Liners

Soil cement is a mixture of Portland cement, water and in-place soils (U.S. EPA, 1983). The permeability of this lining material also varies with the composition of the in-place soils. Fine-grained soils yield lower permeabilities. Permeabilities of 10-6 cm/sec are possible (Stewart, 1978).

Soil cement was also included in the study by Haxo, et al. (1982). It retained its low permeability and high strength. However, soil cement will develop cracks over large areas like the base of solid waste landfill (Haxo, et al., 1982; U.S. EPA, 1983). This aspect of soil cement liners makes them unsuitable as liners for solid waste landfills.

4.12.5 Flexible Membrane Liners

4.12.5.1 General

Flexible membrane liners offer a viable alternative to clay soil for the lining of solid waste disposal sites. In some locations where clay soils are not available, flexible membrane liners used according to WAC 173-304-460(3) are the only alternative. In other situations, these liners may be the preferred alternative based on a cost effectiveness.

The National Sanitation Foundation has published a recent set of standards for flexible membrane liners - Standard Number 54. This document includes standard material properties, testing procedures and considerations for material selection.

4.12.5.2 Types

Flexible membrane liners are composed of plastic developed from several types of polymers and a wide variety of additives to impart special properties to the liner. The major types of flexible membrane liners are listed below (Forseth and Kmet, 1983):

- Butyl rubber
- Chlorinated polyethylene (CPE)
- Chlorosulfonated polyethylene (CSPE)

- Elasticized polyolefin (ELPO)
- Ethylene-propylene rubber (EPDM)
- Neoprene
- Polyethylene-low density (LDPH)
- Polyethylene-high density (HDPE)
- Polyvinyl chloride (PVC)

4.12.5.3 Selection

Major factors to consider in membrane selection include the following (Forseth and Kmet, 1983):

- Weathering resistance
- Soil compatibility
- Resistance to biological attack
- Physical suitability
- Compatibility with waste

Weathering of membrane liners occurs during construction. The liner is subject to ultraviolet light and potential temperature extremes which can cause liner degradation. Selected liner materials must resist these effects or be covered by a soil layer.

The following soil constituents may degrade membrane liners (Fors'eth and Kmet, 1983):

- Oxides of metals
- Chloride compounds
- Sulfur compounds
- Organic compounds
- Acidic soil pH
- Man-made compounds like petroleum products

If on-site soils contain these compounds at abnormal levels or are very acidic ($pH<5$) they should be removed or covered. Membranes resistant to these effects could also be used.

Biological resistance is important in landfill application. The principal degradation will likely result from microbial attack. Other biologic problems may include insects, rodents and plants whose activities may rupture the membrane.

The physical properties a membrane liner must have include the following (Forseth and Kmet, 1983):

- Adequate tensile strength
- Tear, puncture and creep resistance
- Adequate thickness
- Adequate elongation properties
- High seam strength
- Low permeability
- Base of field seaming

Determining what is adequate for these properties is difficult since no data exists that correlates standard test data to stresses that a liner will undergo during and after construction of a solid. waste landfill (Forseth and Kmet, 1983).

Low permeability is not a problem in membrane selection. For all practical purposes a membrane liner can be considered impermeable. A suggested value is 10-1f cm/sec (Forseth and Kmet, 1983). The principal concern with membrane liners is whether they can maintain their low permeabilities for the life of the landfill. Permeabilities can increase because of membrane rupture or degradation.

The required minimum thicknesses for membrane liners is 50 mils. Thicker membranes are stronger and more resistant to chemical degradation, but also more costly. Decisions to use liners thicker than the required minimum would be made on a site specific, case-by-case basis.

Strength may be increased in thinner membranes by adding a reinforcing scrim. However, because of minimum thickness requirements, a reinforced material of less than 50 mils would be unacceptable for a landfill liner.

Seam strength is very important since it is often the weak link for the liner. Selection of a liner must include consideration of field seaming techniques. Manufacturers will recommend techniques for joining membrane sheets. These techniques must be evaluated to ensure they are compatible with expected conditions in the field. Common problems include temperature restrictions and the presence of dust and dirt in the field. Table 4.11 includes information on the seaming quality of various materials.

Table 4.11 General Properties of Membrane Liners.

Name	Availability/Seams	Advantages	Disadvantages	MSW Leachate Test Results	Miscellaneous
Butyl Rubber	- Vulcanized elastomer - Available in unsupported & supported forms in thickness of 20-120 mils - Seamed with 2 part adhesive	- Good resistance to UV, ozone and overall weather'g - Good high and low temp. performance - Good resistance to swelling in water	- Low strength characteristic - Poor resistance to hydrocarbons - Seaming difficult	1 sample had 25% weight increase 30 mil experienced swelling & seam failure Rejected as not compatible	- Utilized extensively in canal and reservoir lining
CPE	- Thermoplastic - Available in unsupported & supported forms in thicknesses of 20-40 mils - Seamed with solvents	- Good resistance to UV, ozone and overall weathering - Good low temp. performance - Easily seamed - Good strength characteristics	- Poor resistance to many chemicals, acids and oils - Tendency to delaminate - Seam reliability a problem - Contains platicizers	3 samples had 25-28% weight increase Not tested	- Utilized often as an additive to improve weatherability and low temp. - Relatively new polymer
CSPE	- Usually unvulcanized - Available in supported & unsupported forms in (but usually supported) thicknesses of 30 & 45 mils - Seamed with solvents or heat	- Good resistance to UV, ozone and overall weathering - Good low temp. performance - Good chemical resistance including acids & oils - Easily seamed - Resistant to bacteria	- Low strength characteristic - Blocking can be a problem - Becomes more difficult to seam with time	- 3 samples had 19-32% weight 19-32% weight increase with poor seam performance on some samples - Not tested	- 2nd most widely used membrane type

Table 4.11 (Continued)

Name	Availability/Seams	Advantages	Disadvantages	Test Results	Miscellaneous
LDPE	- Thermoplastic - Available unsupported & supported forms in 15-100 mil thicknesses - Heat seamed	- Good chemical resistance - Good strength characteristics - Good low temp. performance	- Poor Resistance to UV, ozone & overall weather ability - Poor puncture resistance - Pinhole can be a problem with single ply sheets - Difficult to seam	- 1 sample had 3% weight increase - 15 mil un-specified P.E. had poor resistance & seam failure. Rejected. 20 mil unspecified P.E. had good resistance but seam failure. Rejected. 100 mil HDPE had essentially no change.	- Cheaper grades are available but are much poorer material with short life expectancy
PVC	- Thermoplastic - Available unsupported or supported form (usually supported) in 10-60 mil thickness - Seamed with heat, solvents or adhesive	- Low cost - Excellent work-ability - High strength characteristics - Easy to seam	- Poor resistance to UV, ozone & overall weather-ability - Poor low & high temp. performance - Certain plasti-cizers subject to microbial attack - Susceptible to sulfide attack - High plasticizer content	- 8 samples had 4-24% weight increase - 40 mil Nitrile PVC had major changes. Rejected 40 mil Fromacene had small effects. 60 il Trocal PVC had essentially no effect	- Used for canal linings for many years - Most widely used type of membrane

Source: Forseth and Kmet (1983)

Table 4.11 (Continued)

Name	Availability/Seams	Advantages	Disadvantages	Test Results	Miscellaneous
ELPO	- Thermoplastic - Available unsupported form only from 20-30 mils - Seamed with heat	- Good resistance to UV, ozone and overall weathering - Good low temp. performance - Acid resistant - Resistant to microbes	- Low strength characteristics - Poor high temp. resistance - Difficult to repair - Susceptible to oils	- Sample had 8% weight increase - Minimal material changes but seams failed Rejected as not compatible	- Relatively new material - Newly introduced XR-5 claims to have overcome many disadvantages
EPDM	- Usually used in vulcanized form but can be unvulcanized - Available unsupported & supported forms in 20-120 mil thicknesses - Unvulcanized forms heat seamed; vulcanized forms seamed with adhesives	- Good resistance to UV, ozone and overall weathering - High strength characteristics - Good low temp. performance - Low water absorbance	- Poor resistance to some oils and hydrocarbons & solvents - Adhesive seams are poor - Blocking can be a problem	- 5 samples had 8-24% weight increase - 40 mil has 22% low in strength considerable selling and softening Rejected as not compatible	
Neoprene	- Vulcanized - Available unsupported and supported forms in 20-125 mil thicknesses - Seamed with adhesives	- Good resistance to UV, ozone and overall weathering - Good resistance to oils and petroleum products	- High cost - Difficult to seam	- 5 samples had 3-88% weight increase - Not tested	- Developed to contain petroleum wastes

The compatibility of membrane materials with solid waste landfill leachate is still being investigated. Such tests to be representative must necessarily be long-term. Some results have been obtained from both laboratory and field studies. These tests indicate that liners are effective in containing solid waste landfill leachate. However, the materials do exhibit physical property changes and there are some organic materials that can permeate through membrane liners.

Table 4.11 provides a general summary of membrane liner properties, their compatibility with municipal solid waste leachate and some advantages and disadvantages as a liner.

4.12.5.4 Sub-grade Requirements

For the alternative liner design, the soil liner upon which the membrane liner is placed must meet the requirements for thickness and permeability of the lower liner described in WAC 173-304-460(3). In addition, the soil liner surface must be carefully prepared to prevent excess stresses against the liner. Criteria for the alternative design soil liner are as follows:

- Minimum two feet thick
- •Maximum permeability jX10-6 cm/sec
- Largest soil particles no greater than 0.75 inch
- Upper 6 inches is fine-finished to soil particles no greater than 0.25 inch with smooth rounded surfaces
- Compaction to 90 percent of maximum Standard Proctor dry density at no drier than 2% of optimum moisture content
- Maximum side slopes 3H to 1V (33%)
- Minimum slope to perimeter of 2 percent to allow gas venting
- Soil treated with herbicide to prevent vegetative growth

Refer to Section 5.4 for additional construction practices concerning synthetic membrane subgrade soil liner installation.

4.12.5.5 Collection Layer Requirements

The purpose of this layer is to protect the liner from mechanical damage, weathering and other environmental damage. This function is combined with the necessity to provide a drainage layer for the collection of leachate. the recommended requirements of this layer are as follows:

1. Maximum particle size 0.25 inch with smooth rounded surfaces
2. Minimum thickness of 2 feet

The importance of using rounded materials for the collection layer is significant. Angular materials may puncture the membrane liner and should be avoided. Other requirements for drainage layers are discussed more fully in Section 4.13.

4.12.6 Soil Sealants and Sprayed on Materials

Soil sealants are chemicals or latexes mixed with or applied to the native soil to decrease its permeability. The sealing effect is typically confined to the top few centimeters of the soil (U.S. EPA, 1983).

Sprayed-on materials include asphaltic compounds and rubber and plastic latexes. These materials are sprayed on the soil surface in a liquid form where they solidify into a low permeable layer. Historically these materials have been used in lining canals, reservoirs and ponds (U.S. EPA, 1983).

Little information exists on the use of these materials for lining solid waste landfills. There are obvious concerns associated with them. Soil sealants only are effective in the top few centimeters of the soil and likely do not provide the degree of protection desired in a landfill liner. Asphaltic compounds used in sprayed-on materials will experience the same type of physical property changes as in asphaltic liners. Given these deficiencies and the lack of supportive evidence, the use of these materials as liners for solid waste landfills is not recommended.

4.12.7 Chemical Absorptive Materials

Recent research into the use of chemical absorptive liners for lining landfills has been conducted (U.S. EPA, 1983). Various compounds are used to adsorb pollutants from leachate. This is not a liner in the usual sense of the word. Leachate is allowed to pass through, but contaminants are removed by chemical reactions with the lining material. Complete and permanent removal of all contaminants has not yet been achieved. Therefore, the use of these materials in lieu of more traditional liners is not recommended at this time.

4.13- LEACHATE COLLECTION AND TRANSMISSION SYSTEMS

4.13.1 Description

4.13.1.1 Collection System

New or Expanded Landfills. A leachate collection system, required by the Minimum Functional Standards, must be designed to ensure that leachate accumulating at the topographical low point of an active area does not exceed a depth of two feet.*

A leachate collection system is essentially a highly permeable layer that overlies the bottom liner and directs the flow of leachate percolating into it from overhead toward an outlet from the landfill. A typical leachate collection system consists of the following:

- A layer of highly permeable aggregate material, either sand or gravel (drainage layer)
- A network of perforated pipes laid within the aggregate layer (collection pipes)
- Filter layers of aggregate or geotextile fabric where needed to prevent piping and clogging

Plastic drainage nets available from a number of manufacturers can also be used in combination with the aggregate layer or perforated pipes to improve flow capacity, provide redundancy or increase system efficiency. Figure 4.26 illustrates the basic elements of a leachate collection system.

Existing. Unlined Landfills. Existing, unlined landfills do not have an installed leachate collection system as described above. To install such a system would require excavation and removal of the solid waste, an unrealistic option. If leachate collection is required at such a site as part of a corrective action program, it typically takes the form of a perimeter collection system. One possible example of such a system is illustrated in Figure 4.27.

4.13.1.2 Transmission System

Leachate collected in the collection system is drained away from the landfill by the leachate transmission system, which consists of non-perforated pipes. Pumps are usually required, although occasionally topographic features may allow leachate transport without pumping from the collection pipes to an onor off-site treatment and disposal facility or to a holding basin for further transfer to trucks which deliver the leachate to an off-site treatment and disposal facility.

4.13.2 Design Procedure

4.13.2.1 New or Expanded Landfill

The' controlling criteria for design in the Minimum Functional Standards is the maximum allowable leachate depth of two feet **at the topographical low** point of the landfill. The design variables affecting the depth of leachate in the collection system are:

- Hydraulic conductivity of the bottom liner
- Thickness of the bottom liner
- Rate of leachate percolation into the drainage layer
- Porosity of the aggregate in the drainage layer
- Hydraulic conductivity of the drainage layer

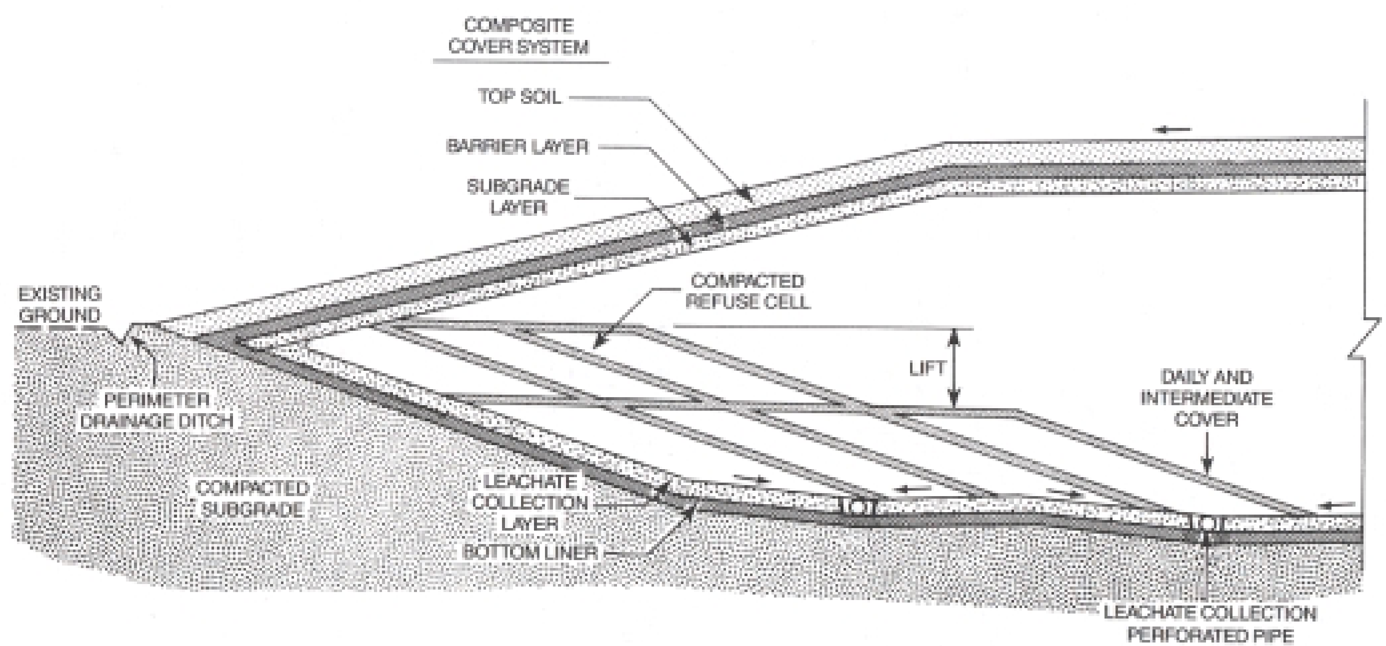

Figure 4.26
Typical Landfill Cross-Section and Leachate Collection System

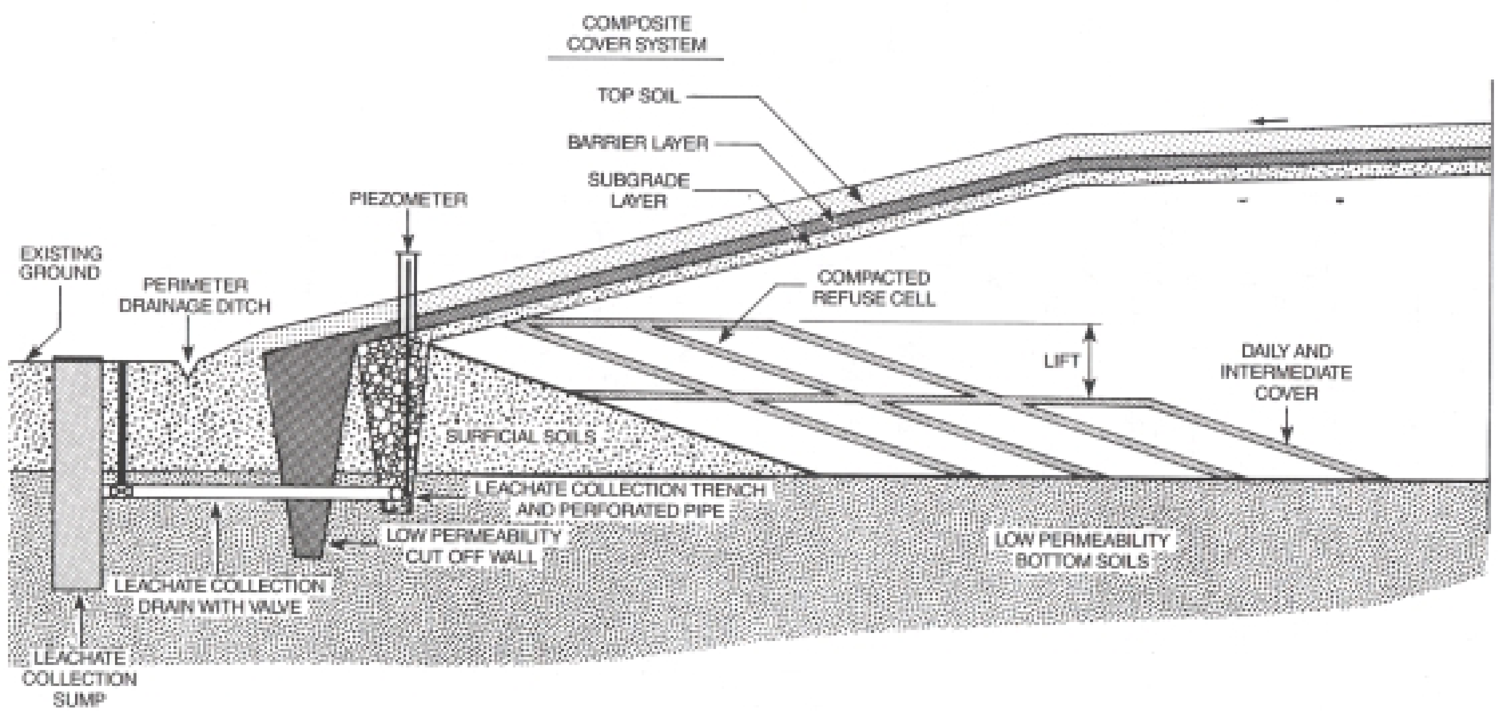

Figure 4.27
Typical Landfill Cross-Section and Perimeter Leachate Collection System

- Slope of the bottom grades
- Flow distance to a perforated pipe or other high capacity flow structure

Minimum standards for the hydraulic conductivity and thickness of the bottom liner are included in the Minimum Functional Standards and discussed in Section 4.1 2. Adherence to those standards will ensure that the bottom liner will not impair the overall efficiency of the leachate collection system.

The rate of leachate percolation into the collection layer can be estimated from the water balance methods discussed in Section 4.10. It is necessary to design for the maximum estimated inflow rate since this has a direct effect on the depth of leachate in the collection system. The maximum inflow rate usually originates from areas made ready for waste disposal and the active working face since no final or intermediate cover is in place.

The porosity of the collection layer also has a direct effect on the depth of leachate. The greater the porosity of the aggregate in the collection layer, the greater amount of leachate can be added before the two foot limit is reached. Porosity is typically a secondary characteristic of **the aggregate** that is not specified by the designer. Hydraulic conductivity is normally the controlling characteristic, and the porosity is generally accepted as long as the hydraulic conductivity specification is met. Nonetheless, the porosity value must be estimated to allow for its effect on leachate depth and the remaining parameters adjusted to achieve the desired leachate collection system performance.

The remaining parameters can be varied to develop the optimum leachate collection system design. One method for evaluating the influence of each of these parameters is discussed in Appendix E. The HELP model (see Section 4.10) can also be used to design the leachate collection system, and may be the preferred procedure since its use in the water balance analysis is usually necessary. The importance and function of each of these parameters are discussed in detail in the remainder of this section.

Once basic criteria have been established using the method described in Appendix E, the HELP model, or other accepted procedures, the following steps should be followed:

1. Locate the collection pipes to flow by gravity to the leachate removal points and space in accordance with results of the analysis.

2. Size the pipes to carry the maximum predicted leachate flows.

3. Select pipe material compatible with the anticipated leachate properties.

4. Select the pipe wall thickness, size and arrangement of perforations, and bedding characteristics required for the hydraulic and structural loadings.

5. Estimate costs of alternative systems to arrive at a reliable design for the least cost.

How well the collection system functions will not be determined until modifications to the design are prohibitively expensive. For this reason, it is important that the collection system be designed in accordance with accepted engineering practice and that appropriate factors of safety be incorporated in the design.

4.13.2.2 Existing, Unlined Landfill

The design procedures for existing, unlined landfills will vary from site to site, since a system of this type is very site specific. The collection system may involve a perimeter trench and collection pipe, extraction wells drilled within the landfill or any of a number of other alternatives.

4.13.3 Bottom Grading Plan

The bottom grading plan is important to the design of leachate collection because it determines the slopes toward the collection pipes. The minimum slope required by the Minimum Functional Standards is two percent. Based upon the results of the design procedure described in Appendix E, the HELP model, or other procedure, the designer may specify even greater slopes, although five percent appears to be a reasonable maximum for excavated grades. Natural topography may allow greater slopes than five percent without excessive excavation.

The perforated pipe system layout also must be coordinated with the bottom grading plan. The layout should take advantage of existing topography and be as simple as conditions allow.

4.13.4 Drainage Layer

4.13.4.1 Hydraulic Conductivity

The hydraulic conductivity of the drainage layer is perhaps its most important property. The overall efficiency of the leachate collection system is very sensitive to this parameter. Model results indicate a rapid decrease in efficiency as the hydraulic conductivity drops below 10-2 cm/sec. This does not mean the system will not function, but rather that collection pipes must be placed closer together to prevent the build up of leachate to a depth in excess of two feet.

The ideal hydraulic conductivity rang I e appears to be between 10-2 to 10-1 cm/sec. A very clean (typically less than 1% soil fines) aggregate is required to achieve this high conductivity. Hydraulic conductivity greater than 10-1 cm/sec is very difficult to achieve with aggregate unless extensive processing is involved.

Another way to achieve very high conductivity is to use plastic drainage nets available from a number of manufacturers. These materials have been shown to have a hydraulic conductivity in the range of 10 cm/sec. Williams, et al. (1984) and Giroud and Bonaparte (1984) provide details on the use of drainage nets. Such materials can be used in combination with aggregate to create an efficient and redundant leachate collection system. Note, a filter fabric suitable for use with the drainage net, must be placed between the drainage net and the aggregate to prevent the aggregate particles from obstructing the flow paths of the drainage net.

4.13.4.2 Gradation

The gradation of an aggregate drainage layer is important because of the effect it has on the potential for migration of soil particles from the drainage layer into the gravels surrounding the collection pipe. This could ultimately lead to clogging of the collection system. Typically, filter fabrics are used between the two aggregates to prevent the clogging of one by the other. Appendix B provides a methodology for evaluating the need for and specifying an appropriate filter fabric based upon the gradation, density and permeability of the drainage layer.

4.13.4.3 Thickness

The drainage layer actually has two functions: to provide a flow path for leachate to reach the collection pipes and to protect the bottom liner from damage caused by heavy equipment and the first lift of solid waste.

The thickness of the drainage layer required to pass the predicted volume of 9
leachate need be no greater than two feet, since this is the maximum allowable leachate depth specified by the Minimum Functional Standards. A thinner layer may be adequate depending upon the specifications for other parameters affecting the efficiency of the leachate collection system (see Appendix E).

The thickness required to protect the bottom liner depends upon the type of liner installed. An alternate bottom liner design using a thin flexible membrane liner as the primary containment layer is more susceptible to destructive physical damage than a standard bottom liner design using four feet of recompacted soil. The minimum thickness required over a flexible membrane liner will vary with operational practices, but eighteen inches should be considered a practical minimum, with two feet being more desirable. If no special precautions for disposal of the first solid waste lift are included in the operations plan, a minimum practical thickness of three feet should be considered. The minimum thickness over a standard design bottom liner should be controlled by the hydraulic performance requirements.

4.13.4.4 Suitable Materials

Aggregate material used, in the drainage layer must be a sand or gravel material to meet the permeability requirements as discussed in Subsection 4.13.4.1. The percentage of fines will have to be very low and typically the aggregate will be poorly graded (uniform particle size).

For protection of the bottom liner, granular materials should be sand and gravel, free of all vegetation, roots and construction debris. For placement on a flexible membrane bottom liner, the drainage layer should consist of 1/4 inch maximum rounded stone (Forseth and Kmet, 1983); however, base stability and trafficability should be considered when using material of this size. On a clay liner, the drainage layer could have a larger maximum particle size and be angular or crushed stone.

If plastic drainage nets are used, the material should be compatible with the leachate to be contacted. For example, high density polyethylene plastic drainage nets would normally be an acceptable material. The drainage nets should also be shown to maintain their high permeability, even under loads imposed by the overlying solid waste. Drainage net manufacturers can usually provide this information. Tests by independent laboratories can also be done.

4.13.5 Collection Pipes

4.13.5.1 Location and Spacing

Whenever possible, leachate collection pipes should be located so that they are drained by gravity to outside the landfill area. Usually, it is not desirable to locate leachate collection sumps or pump stations within the landfill area because of conflicts with landfill operations. A typical collection system with a central collection line and lateral collectors branching at regular intervals is illustrated in Figure 4.28.

The spacing of the perforated collection pipes affects the depth of leachate that accumulates in the drainage layer. One methodology for determining the appropriate spacing is contained in Appendix E. The HELP model can also be used to specify collection pipe spacing. Typical flow distances to collection pipes range from 50 to 400 feet, although values outside of this range are possible depending on the specifications for other key parameters, such as drainage layer hydraulic conductivity and bottom grade slope.

4.13.5.2 Flow Capacity

Leachate collection pipes are imbedded within aggregate material. Flow is assumed to occur under saturated conditions, in which case Darcy's Law is applicable. By Darcy's Law, the rate of flow per linear foot of collection pipe is limited by the hydraulic conductivity of the drainage layer, the hydraulic gradient (bottom slope) and the depth of leachate in the drainage layer. It can be shown using conservative assumptions that a six inch diameter collection pipe is large enough to pass the maximum flow from typical lengths of collection pipe. Minimum collection pipe diameter is more dependent on the ability to clean the pipe with standard pipe cleaning equipment. Eight inch diameter pipe is a better size for easy, efficient cleaning.

If a collection pipe is serving as a common header for a number of in flowing pipes, its size should be based on the maximum potential inflow from the combined inlet pipes. This may require a larger sized pipe than the typical

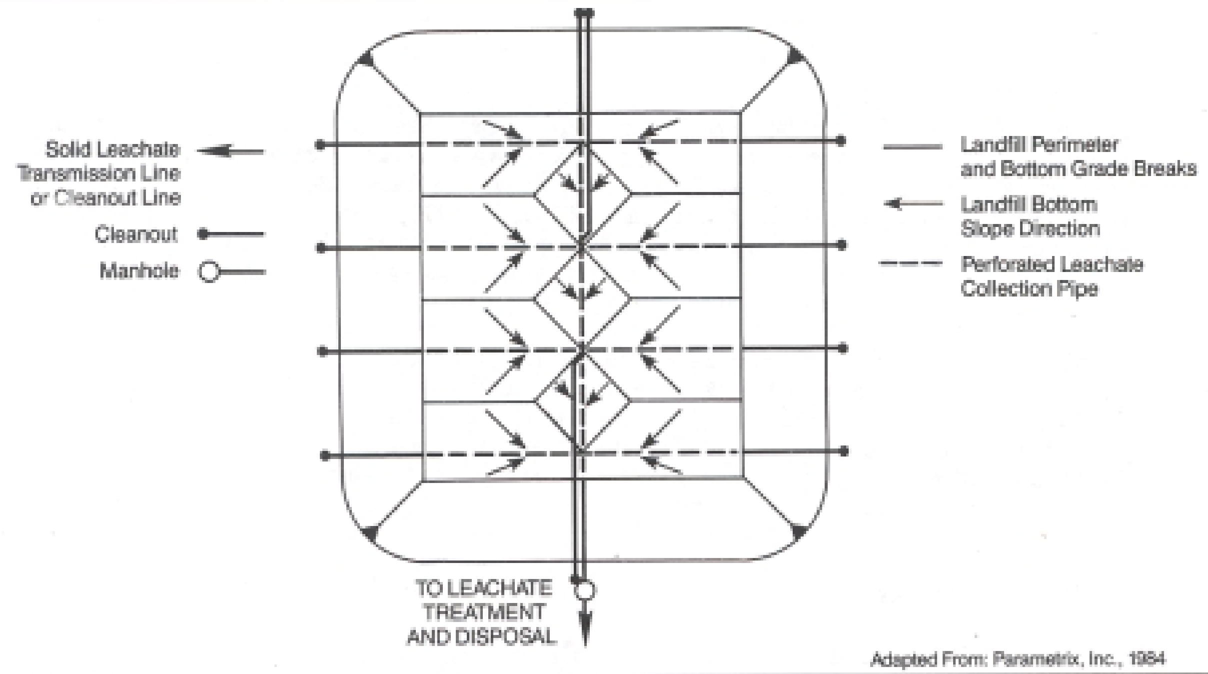

Figure 4.28
Typical Leachate Collection System Layout

six to eight inches. Manning's Formula or other acceptable methods may be used to determine the pipe diameter required.

4.13.5.3 Materials

Pipe that may be suitable for leachate collection systems is manufactured to meet nationally recognized product specifications. Some materials are more appropriate than others for use in a leachate collection system and the various types of pipe should be evaluated carefully. Various factors to consider are:

- Intended use (type of leachate)
- Flow requirements
- Scour or abrasion conditions
- Corrosion conditions
- Product characteristics
- Physical properties

- Installation requirements
- Handling requirements
- Cost effectiveness

No single pipe product will provide optimum capability in every characteristic for all leachate collection system design conditions. Specific application requirements should be evaluated prior to selecting pipe materials.

Pipe materials for leachate collection applications fall within the two commonly accepted classifications of rigid pipe and flexible pipe. Rigid pipe materials derive a substantial part of their basic earth load carrying capacity from the structural strength inherent in the rigid pipe wall, while flexible pipe materials derive load carrying capacity from the interaction of the flexible pipe and the embedment soils. Appendix C includes additional information on pipe load design.

4.13.5.4 Design Details

The function of leachate collection pipes is similar to conventional sanitary and storm sewers. For the most part, the design details of sanitary or storm sewers shown in WDOE (1985) are applicable to the design of leachate collection pipes. Design details of particular concern for leachate collection lines are discussed below.

Minimum Size. Leachate collection lines generally should be at least six inches in diameter, but preferably eight inches. In certain cases, four inch diameter lines may be acceptable if the overall performance of the leachate collection system will not be affected by failure of the four inch lines. For instance, four inch lines may be added to the leachate collection system during the initial operations to dewater specific areas, such as the area where the side-slope intersects the bottom of the landfill.

Alignment. Leachate collection lines should be designed with straight alignment between junctions. However, curved lines are acceptable and should be used where the physical shape of the landfill makes it more efficient to do so. Curved sections are preferable to bends in leachate collection lines. The installation of rigid pipe on a curve is accomplished by deflecting the pipe joint from the normal straight position. The installation of flexible pipe on a curve is accomplished by controlled longitudinal bending of the pipe and deflection of the pipe joint. The manufacturer of the pipe should be consulted on the maximum permissible joint deflection and the minimum radius of bending of the pipe. With this information, the radius of curvature can be determined using procedures discussed in ASCE and WPCF (1982). If bends are required, they should not be greater than 22 degrees to allow free passage of cleanout equipment (Bass, 1984).

Joints. Because leachate collection pipes are perforated to allow entrance of leachate, it is not necessary to provide leak-proof joints. Joints in leachate collection pipes should be compatible with the particular pipe product used. While the joint does not need to be leak-proof, it should be adequate for structural stability of the pipe and should prevent any horizontal or vertical movement that would affect the pipe's performance.

Manholes and Cleanouts. Access should be provided to all parts of the leachate collection system to facilitate inspection and maintenance. This includes the placement of manholes and cleanouts so that maintenance equipment can reach any section of the pipe. All leachate collection systems should be provided with manholes or cleanouts at the end of each line. Because of possible conflicts with the filling operations, it may not be practical to extend manholes or cleanouts vertically within the landfill area. In these cases, cleanouts should be used and extended laterally along the bottom to the perimeter of the landfill and then up the side slope to the ground surface. See Figure 4.28.

Junctions. It is desirable to make Junctions in leachate collection systems in ordinary manholes with the branch line curved into the main channel. Often, however, leachate collection systems will have a main line through the central part of the landfill with additional lines branching from it towards the outer perimeter of the landfill. Because of difficulties these would impose on the filling operations, it is not always feasible to provide manholes at the Junctions in the leachate collection system. In these instances, Junctions should be made with tee or wye fittings in the leachate collection pipes. Cleanouts should be provided so that maintenance equipment can reach each section of the pipe between Junctions. This concept is illustrated in Figure 4.28.

4.13.6 Collection Trench Design

4.13.6.1 Geometry

The collection trench is an important component of the leachate collection system because it is where the drainage layer and perforated collection pipes interface. Improper design of the collection trench can thwart the operation of the entire system. A typical design is illustrated in Figure 4.29.

The cross-section geometry of the collection trench affects the amount of load carried by the perforated pipe and the ease with which the trench can be constructed. Constructibility should be the first consideration in the preliminary design. Simple cross-sections such as shallow 'IV,' trenches are easily constructed during excavation of the bottom grade. This initial design must then be evaluated with the collection pipe load bearing capacity and expected loads, using a methodology such as presented in Appendix C, to determine if the system is structurally sound. If not, the collection trench geometry must be modified or a stronger collection pipe selected. Pipe costs versus trench construction costs must be compared to determine the most cost effective design.

4.13.6.2 Protection Against Piping

'Piping is the removal of fine particles from an aggregate matrix by the movement of water through the matrix. The fine particles can accumulate and

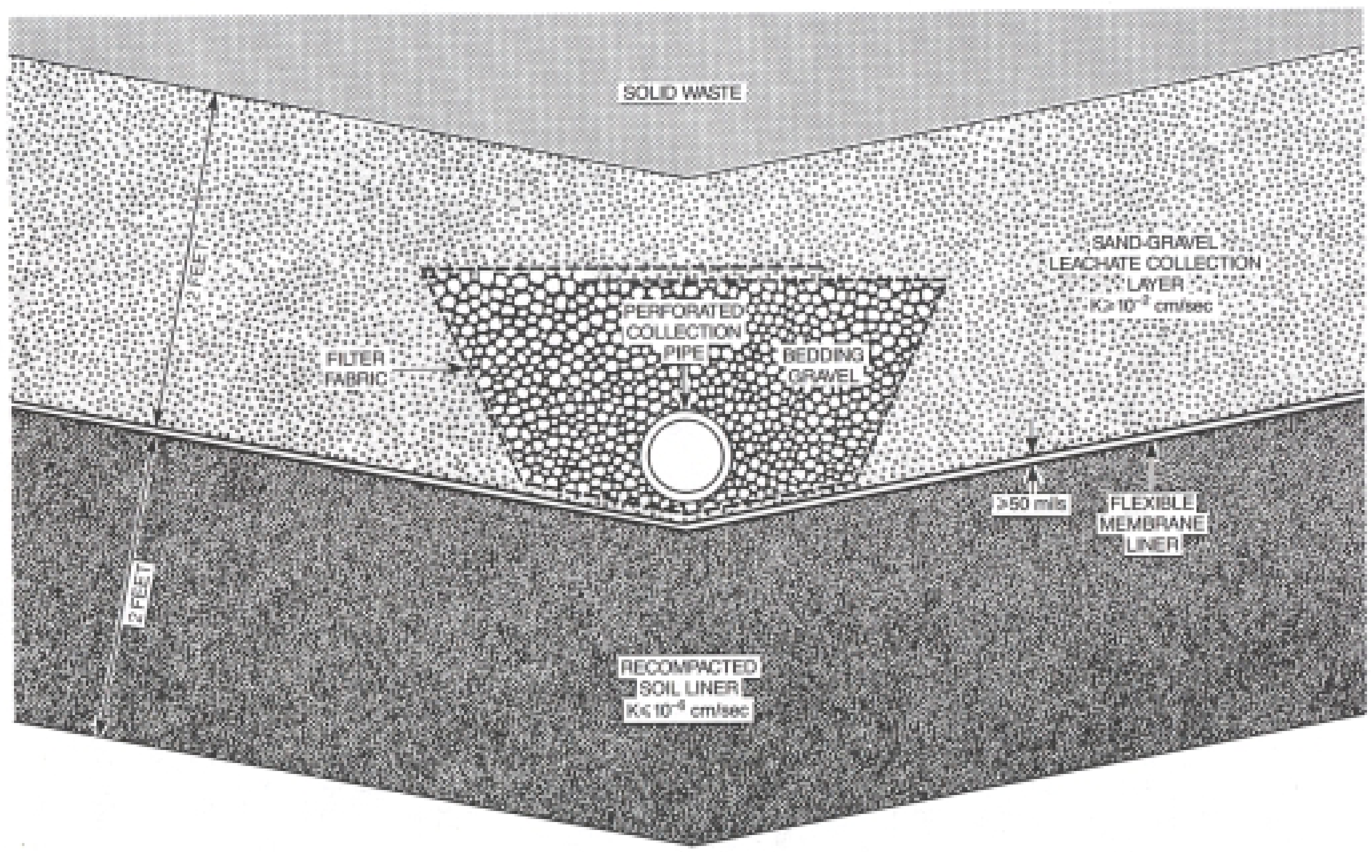

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Figure 4.29
Typical Leachate Collection
Pipe Cross Section

eventually clog collection pipe bedding material or the pipe itself - Piping can be prevented by the use of an aggregate or geotextile filter layer.

The need for a filter layer can be evaluated by comparing the gradation curves of the drainage layer and collection pipe bedding aggregates using the procedures presented in Appendix B. If a filter layer is needed, it can be either aggregate or a geotextile. An aggregate filter layer must both prevent piping within the drainage layer, as well as not being subject to piping itself. A geotextile filter layer must prevent piping in the drainage layer and at the same time not be subject to clogging. Appendix B provides details on design of both aggregate and geotextile filter layers.

Aggregate filter layers are more difficult to construct because careful placement is required. If processing of the aggregate is required, the material costs may also be high. Geotextiles are easy to install and costs may be comparable to aggregate material.

4.13-6.3 Flow Redundancy

One characteristic of good collection trench design is redundant flow capacity, meaning at least two separate systems can pass the leachate flow. Typically, the projected maximum leachate flow rate is equaled by the product of the cross-sectional area of the collection trench, the slope of the pipe trench, and the hydraulic conductivity of the pipe bedding aggregate. This provides redundant flow capacity to the collection pipe.

Another method of providing additional flow redundancy in~ the collection trench is by including the previously discussed plastic drainage net material. Two or three layers of this product along the bottom of the trench will typically provide sufficient capacity to pass the required volumes.

4.13.6.4 Materials

Typical materials used in the collection trench include aggregate for pipe bedding and filter layers, geotextiles and plastic drainage net. Pipe bedding aggregate must meet the same basic requirements as the drainage layer aggregate, although often it is more processed (graded and washed). Aggregate for filter layers must meet required gradation criteria as discussed in Appendix B.

Geotextiles used as filter layers are commonly called filter fabrics. They are available from a number of manufacturers in either woven or non-woven synthetic fabrics. The key properties of filter fabrics are:

- Retention ability
- Permeability
- Clogging Resistance

Methods for determining appropriate values for these properties are described in Appendix B.

If plastic drainage net is used in the collection trench, it should be the same material requirements as that described for the drainage layer.

4.13.7 Transmission Pipes

While the purpose of a leachate transmission system is to remove the collected leachate from the landfill, it functions in much the same manner as a sanitary sever system. Therefore, design criteria for sanitary severs, such as those in WDOE (1985), are applicable to leachate transmission lines and should be used in their design.

When designing leachate transmission systems, special consideration should be given to the characteristics of the particular leachate being handled. The pipe material should be selected for compatibility with the leachate. Materials suitable for leachate transmission pipes are the same as those for leachate collection systems.

4.13.8 Pump Stations

Pump stations and force mains in leachate transmission systems should be designed in accordance with design criteria for sewage pump stations such as those in WDOE (1985).

Materials for pump components, piping, valves and fittings that come into contact with leachate should be selected for compatibility with the particular leachate being handled. Materials described for leachate collection systems may be suitable for use in the piping systems in leachate pump stations. Consideration should be given to the use of special materials or coatings for the wetted internal parts of pumps, valves and appurtenances.

4.14 LEACHATE TREATMENT AND DISPOSAL SYSTEM

4.14.1 Description

A leachate treatment and disposal, system consists of properly designed and integrated treatment processes, and an effluent disposal arrangement to discharge treated leachate to the environment without endangering public health and safety. In general, the treatment and. disposal system must be designed and operated to function continuously through the operation, scheduled closure and post-closure life of the landfill. For this reason, selection of a leachate treatment and effluent disposal process is not a simple task, especially in view of the fact that there is limited past experience in the area of leachate treatment, and the quality and quantity of the leachate will vary with phased development and age of the landfill.

Additionally, it is important to note that certain solid waste components placed in a landfill could generate a dangerous waste leachate. The handling, treatment, and disposal of leachate which is found to be a dangerous waste is beyond the scope of this design manual. However, the type of leachate generated must be determined; and, if the leachate is a dangerous waste, the handling, treatment, and disposal of the leachate must meet the requirements of Chapter 173-303 WAC, Dangerous Waste Regulations.

Although this section. deals only with leachate treatment and disposal, leachate control also consists of the following major elements which must be thoroughly examined any time leachate generation and treatment is considered.

- Means for minimizing leachate generation, such as proper soil cover, proper grading, operation phasing and diversion of surface water runoff and groundwater. See Sections 4.5, 4.9, 4.11 and 4.16.

- Means for leachate interception and collection, such as synthetic or natural liners, porous media above the liner, collection grids, piping and pumping for conveying leachate to a treatment and disposal system. See Sections 4.12 and 4.13.

4.14.2 Design Procedure

The purpose of a leachate treatment and disposal system is to treat the raw leachate to levels acceptable for its discharge to the environment. The design of a leachate treatment and disposal system involves the following steps:

1. Define the raw leachate characteristics, i.e., quality and quantity.

2. Define the acceptable treated effluent disposal alternatives and their respective treatment level requirements.

3. Select a treatment plant process or processes which will achieve the leachate treatment level requirements for each acceptable disposal alternative.

4. Estimate the cost of each alternative treatment and disposal technique.

5., Select the best alternative treatment and disposal system with regard to cost, reliability, flexibility and any other appropriate considerations.

This information should be developed in a systematic order and should be documented in a report in sufficient detail to permit regulatory review and approval of the system prior to preparation of final construction plans and specifications, and implementation of the leachate treatment and disposal project.

4.14.3 Design Criteria

4.14-3.1 Treatment Reguirements

The degree of leachate treatment required depends on the disposal method selected. Leachate may require either extensive treatment or only minimal treatment prior to discharge. Typically, treatment requirements are defined by the disposal method as discussed below:

1. Discharge to Receiving Surface Waters:
   Subject to effluent limitations as defined in a National Pollutant Discharge Elimination System (NPDES) permit for a point discharge. Application for a permit should be completed and submitted to the regulatory authority (Ecology).

2. Discharge to Publicly-Owned Treatment Works:
   Subject to any pretreatment and/or industrial waste connection requirements established by the authority operating the treatment works. Pretreatment standards are established by local ordinance with Ecology as the state permitting authority.

3. Land Application:
   Subject to treatment requirements established by regulatory authority including Ecology, Washington Department of Social and Health Services (WDSHS), and County Health Department.

4. No Discharge (Evaporation Ponds):
   Subject to design, operation and maintenance requirements defined by Ecology for sewage treatment works (WDOE, 1985). Refer also to the discussion in this section on leachate recirculation.

4.14.3.2 Design Period

Leachate treatment and disposal systems should generally be designed to provide adequate treatment for the estimated volume of leachate generated during the life of the site and 30 years thereafter, using appropriate methods of predicting leachate generation (See section 4.10) and allowing for the phased development of the landfill. All systems should be designed so that they can be readily modified to provide additional unit treatment process operations in the event of a change in leachate quality or quantity.

4.14.3.3 Design Loadings

Leachate composition and strength varies widely from landfill to landfill and within a given landfill. This variation depends upon several factors, including: the nature of the waste, the age of the fill, and thus the degree of solid waste stabilization, the amount of precipitation infiltration, and the degree of compaction, moisture content of the waste, and whether any lined but unfilled areas are contributing to the system. Additionally, the mixed soil porosity, permeability and absorption characteristics will also affect leachate quality.

Because of the wide site to site variability, a treatment system must be designed on a case-by-case basis after completion of an extensive monitoring program on an existing leachate source.

Monitoring and testing of leachate, however, necessitates establishing strict sampling procedures and testing schedules for leachate analysis. Certain specific leachate characteristics have been shown to change considerably with time during sample storage (Chian and DeWalle, 1976).

However, in the event that an existing leachate source is not available for monitoring, representative data on the characteristics of leachate have been reported. Table 4.12 indicates the normal range of concentration values for various constituents in leachate and typical values which are intended to be used only as a guide. The composition of leachate from different sources as measured by different researchers is reported by Chian and DeWalle (1977).

Table 4.12. Composition of Leachate from Typical MMSW Landfills.

BOD_5 (5-day biochemical oxygen demand)	2,000-30,000	10,000
TOC (total organic carbon)	1,500-20,000	6,000
COD (chemical oxygen demand)	3,000-45,000	18,000
Total Suspended Solids	200- 1,000	500
Organic Nitrogen	10- 600	200
Ammonia Nitrogen	10- 800	200
Nitrite	5- 40	25
Total Phosphorus	1- 70	30
Ortho Phosphorus	1- 50	20
Alkalinity as $CaC0_3$	1,000-10,000	3,000
PH	5.3- 8.5	6
Total Hardness as CaC03	300-10,000	3,500
Calcium	200- 3,000	1,000
Magnesium	50- 150	250
Potassium	200- 2,000	300
Sodium	200- 2,000	500
Chloride	100- 3,000	500
Sulfate	100- 1,500	300
Total Iron	50- 600	60
Arsenic	ND- 40	
Barium	ND- 9.0	
Cadmium	ND- 116	
Lead	ND-6.6	
Mercury	ND- 0.16	
Selenium	ND- 0.45	
Silver	ND- 0.24	

Probably the most significant factor affecting leachate quality is the age of the landfill. Chian and DeWalle (1977) have reported the change in organic matter in leachate as related to landfill age. Additionally, Robinson and Maris (1985) reported dramatic decreases in most leachate constituents, with the notable exception of ammonia and chloride, both of which remained quite high. The parameters found to be most useful in relating to the organic matter was the ratio of chemical oxygen demand to total organic carbon (COD/TOC). The change in this ratio with the age of the landfill is shown in Figure 4.30. Similar figures for the ratio of BOD/COD, Volatile Solids/Fixed Solids and pH are also shown in Figure 4.30. These figures will aid the design engineer in the characterization of leachate from a landfill with respect to the age of the landfill.

The quantity of leachate generated from a landfill operation is determined using methods discussed in Section 4.10.

4.14.3.4 Leachate Recirculation

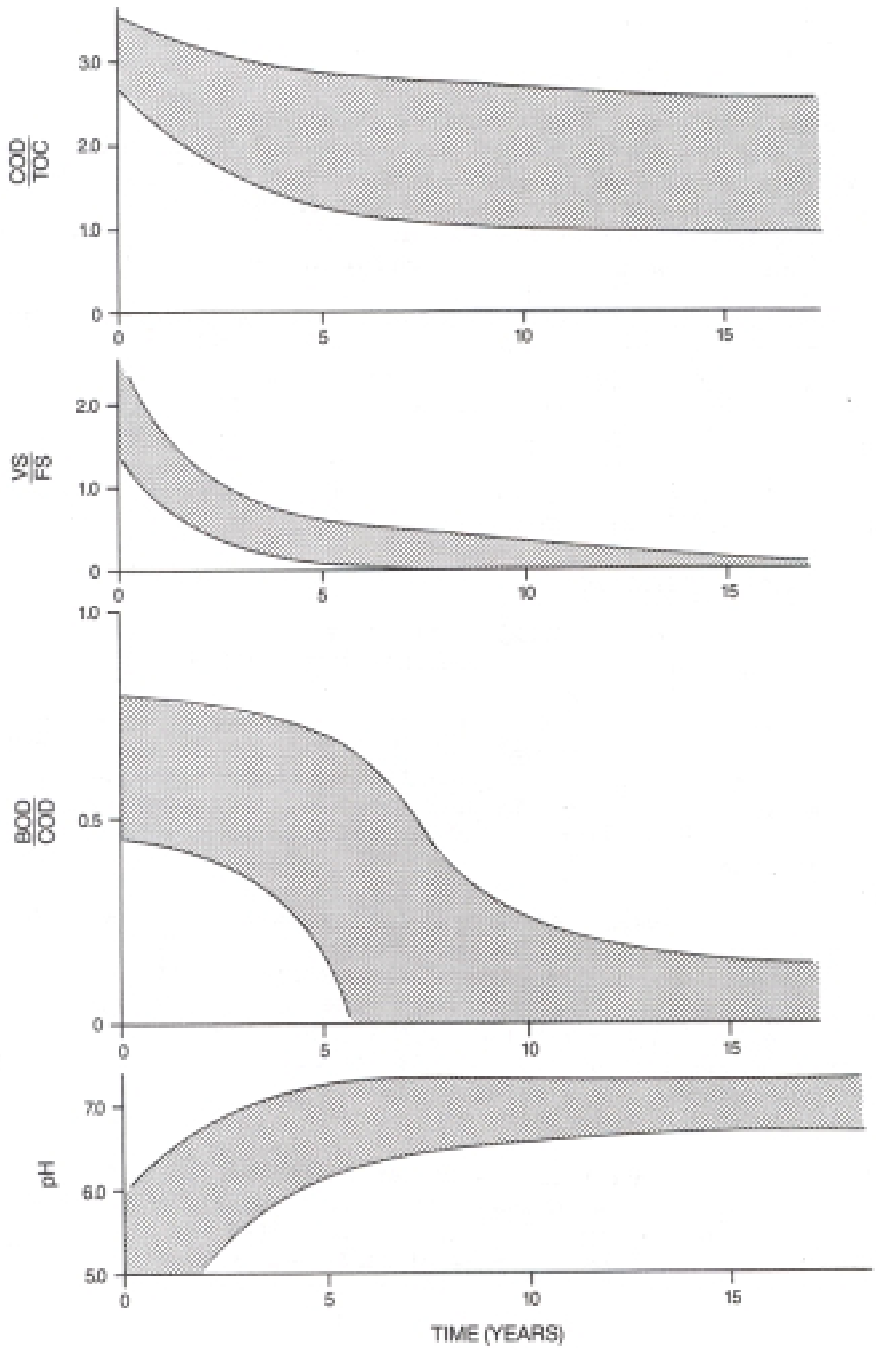
Leachate recirculation is a disposal technique whereby landfill leachate is recirculated through the deposited refuse with ultimate treatment and disposal of the collected leachate only after solid waste stabilization. Leachate recirculation in a landfill results in more rapid stabilization of the organic fraction of the deposited refuse because of the accelerated growth of an anaerobic biological population (Robinson and Maris, 1985). During the leachate recirculation landfill process, the moisture content of the solid waste is increased from 25-30 to 65-70 percent so that anaerobic microbial activity can be maximized.

The basic differences between the construction and operation of a conventional solid waste landfill and a leachate recirculation landfill are the collection, recirculation, and treatment of leachate and the monitoring of certain process parameters. The basic requirements for a leachate recirculation landfill operation are similar to those for a conventional landfill operation with the exception of the leachate recirculation system utilized in the recirculation process. This system includes a pumping station, a holding lagoon, and a distribution network.

There are only two by-products from a properly operated leachate recirculation landfill: recirculated leachate and gases emitted during anaerobic digestion. Also, by applying leachate recirculation to a landfill to increase the rate of stabilization, several additional effects may result:

- Increased rate and quantity of methane produced
- Increased rate of settlement in the landfill
- Returned the landfill to productive land use more quickly

Ultimately, a portion of the recirculated leachate must be disposed of outside of the landfill. Those disposal techniques could be the same as discussed for other types of leachate treatment.



WDOE Solid Waste

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Figure 4.30
Changes in Leachate Characteristics With Landfill Age

Range of Values Typically Observed

4.14.4 Treatment Process Selection

4.14.4.1 Methodology

The methodology for designing leachate treatment systems cannot be specified in a standard step-by-step procedures. Site specific variables require an innovative and flexible approach to the design problem. Guidance is provided in the following discussion adapted from Chian and DeWalle (1977).

If possible, selection of a process to treat leachate should 'be based upon treatability studies (laboratory or pilot scale) using the actual leachate. This is recommended for several reasons:

1. Published leachate treatment performance data are rare. In the absence of treatability studies, inferences must be drawn from laboratory experimental studies, and industrial and municipal water and wastewater treatment experience.

2. Lacking previous experience and/or treatability data, there is no guarantee that high levels'of treatment can be achieved.

3. It is likely that a combination of several unit processes will be needed to deal with the leachate. Arriving at the optimum system is unlikely without treatability studies.

4. The complex leachate may not behave like other wastewaters, thus affecting design and operating criteria (e.g., chemical dosage requirements), and invalidating extrapolations from other experiences. Leachate composition also varies with age of the landfill.

5. Capital investment, and especially operation and maintenance costs, are likely to be greater per unit volume treated than for municipal or industrial wastewater. However, costs will be difficult to estimate without treatment experience. Investment in a costly, unproven system that may not meet the required treatment objectives is imprudent.

In spite of these considerations, at new landfill sites or existing sites where leachate has not appeared or its quality is expected to change greatly, treatability studies may not be possible. Thus, a more theoretical approach (at least to conceptual design of a treatment system) with greater dependency on published data must be taken.

A general methodology which can be used for selection of a leachate treatment process in shown in Figure 4.31. This methodology revolves around the question of existence of a leachate. The left side of the flow chart applies to cases where a leachate exists and can reasonably be used in treatability studies. The right side addresses the case where leachate treatability studies cannot be conducted.

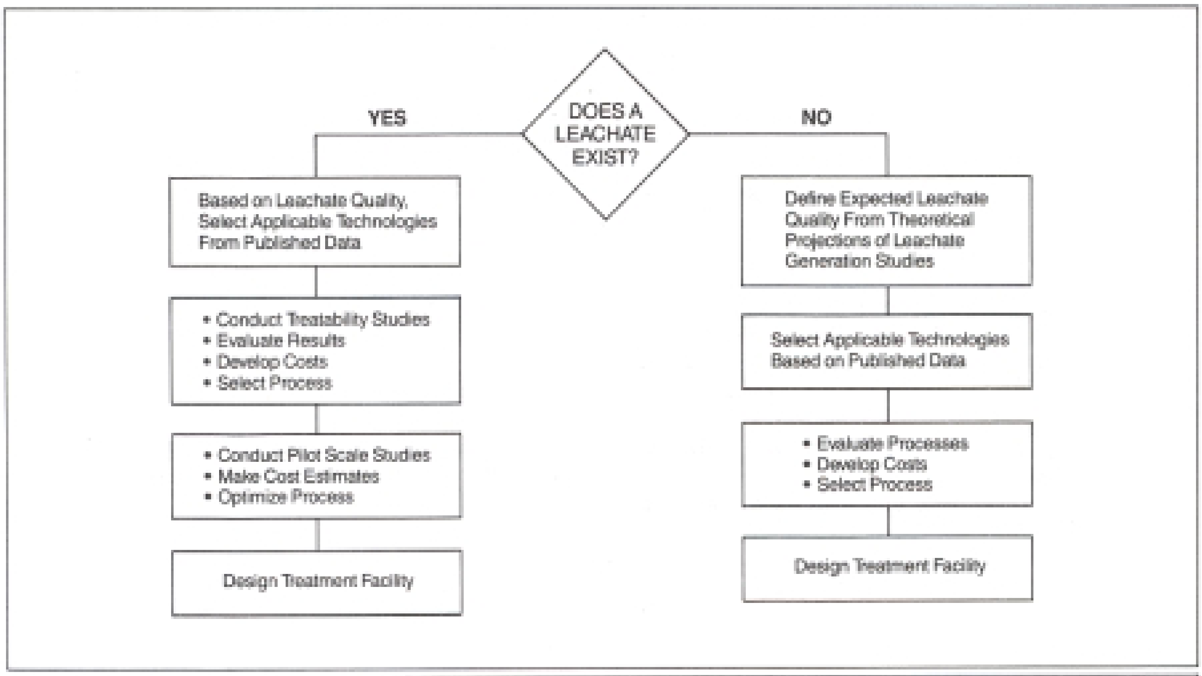

Figure 4.31
Methodology to Select Leachate Treatment Process

Adapted From: Shuckrow et al., 1982

Aside from the availability of leachate for use in treatability studies, several key questions must be answered as part of the leachate treatment technology selection process. Among these are:

1. What are the treated effluent discharge options and the corresponding performance or discharge limitations?
2. What is the leachate flow rate; how will it vary with time (diurnal, seasonal, operational phases, long-term)?
3. Are there any other aqueous wastes generated at the site and should they be combined with the leachate for treatment?
4. How will the leachate quality or quantity change (could be a function of disposal site operation) and does the leachate treatment process need to be able to respond to such changes and in what time frame?
5. How much land is available for the leachate treatment facility and are there any special constraints to construction?
6. How will leachate treatment residues be managed?
7. What is required to support the leachate treatment operation, e.g., analytical testing, operations personnel?

8. Will any spilled liquid materials get into the leachate treatment system?

9. What skills and resources will be needed for post-closure operation?

The leachate treatment system selection process must address all these issues.

Disposal Site With Existing Leachate. Where a leachate exists, a three-tiered selection methodology process is shown in Figure 4.31 to identify processes that have been reported to be capable of treating the types of constituents present in the leachate. The objective should be to focus subsequent efforts on the most promising process.

At the second level, these processes should be studies at laboratory scale individually and, if necessary, in combinations. Experimental studies will further screen out unsuccessful processes, identify viable combinations, enable development of "first cut" design criteria, identify by-products of concern, and facilitate cost projections. Depending upon the results of this step and the reliability of laboratory scale data, a pilot scale program may be warranted to develop detailed design information. The possibility of designing the pilot scale system to serve as the first stage of the full scale system should be given consideration.

The-time required and costs associated with conduct of this three-tiered program will depend upon the number of processes examined, the ease with which the leachate can be treated, and the intensity of the effort. Physical and chemical processes generally can be studied in less time than biological processes because of acclimation or stabilization requirements usually associated with the latter process type. Other considerations in designing and conducting treatability studies include:

- Obtaining representative leachate samples
- Quantities of leachate required
- Methods for collecting, handling, and transporting leachate to avoid or minimize changes which would introduce experimental error or endanger personnel
- Use of batch and continuous flow treatment processes
- Parameters used to monitor process performance because of both the considerable costs which could be incurred by analytical testing and the need for rapid data turn-around to enable timely judgments
    - Disposal of wastes (liquids, residues, gaseous emissions) generated in the treatability studies

Disposal Site Without Existing Leachate. If a leachate does not exist or if its composition is expected to change greatly, the first major step is to determine what the leachate composition is expected to be. Because disposal site design and permit acquisition requires knowledge of what wastes will be handled at the site, incoming waste composition data probably will be available. However, it will still be necessary to project which waste constituents may appear in the leachate and at what concentrations. Moreover, because treatment process selection probably will be based on a worst case rather than average or optimum condition, a projection of the worst condition must be made based upon anticipated leachate composition and quantity.

Once leachate characteristics are projected, promising technologies should be identified on the basis of published data (similar to the first step on the left side of Figure 4.31). Detailed "desk top" analysis then can be conducted to evaluate and select the process. These analyses could be aided by companies marketing pertinent technologies, if unpublished in-house experiences are provided to supplement available data.

In cases where treatment process selection is based on the "desk-top" approach, consideration should be given to contingency plans for leachate treatment and disposal in the event that the original design does not perform as required. The feasibility of adopting an interim measure, such as leachate storage and/or recycling until the design can be confirmed by actual treatability studies should also be considered.

4.14-4.2 Treatment Process Staging

Treatment process staging is necessary because leachate composition changes with time. The following discussion is adopted from Chian and DeWalle (1977).

During the life of a landfill operation and even after closure, the flow and composition of leachate from the site are likely to change. These changes will occur because of:

- Changes in wastes being disposed at the site
- On-going physical, chemical, and biological reactions within the disposal site
- Ultimate sealing of the site at the time of closure which further reduces entry of extraneous water

Thus, the leachate treatment facility must be capable of responding to these changes. This can be done either by preparing an initial design which includes processes capable of responding to 'all envisioned changes or by staging. Staging involves a design which facilitates adding or deleting new treatment processes or changing capacity of existing processes as future conditions warrant.

From both technical and economic perspectives, staging warrants detailed consideration during both disposal and leachate treatment facility selection. A major advantage of staging would be optimum utilization of the technologies judged to be most applicable to the leachates produced at different phases in the life of the landfill site. A major disadvantage, however, is the need to anticipate when a change will occur and to respond as necessary. In some cases, it may not be sufficient to recognize that a change has occurred and then modify the leachate treatment process after the fact.

An evaluation of the need to modify the leachate treatment process could be triggered by either:

- The results from routine monitoring of leachate characteristics and leachate treatment process performance

- The decision to accept a different waste at the landfill

If a change is needed in unit processes, process size, or operational procedures, this can be determined based upon the expected magnitude and duration of change in the leachate.

In the case of a new landfill operation where a leachate has not yet been generated and treatability studies cannot be conducted using actual leachate samples, the initial leachate treatment facility will have to be designed from leachate quantity and composition projections made on the basis of types of wastes to be handled, and site construction and operational procedures. However, because performance of the leachate treatment system can, at best, only be estimated on the. basis of available data, the system should be designed and constructed in such a way that processes can be added or deleted as necessary to respond to leachate characteristics and to meet performance requirements.

One aspect of staging which should be considered for new facilities is interim storage and/or leachate recycle to the landfill. The feasibility of these approaches will be highly site specific and in most cases can only be considered as interim. However, if some combination of storage and recycle is, feasible early in the life of the landfill operation, this approach may provide sufficient time to conduct treatability studies with the actual leachate. Consequently, treatment process selection could be accomplished on a firmer basis. Use of this approach, however, must be evaluated on a case-by-case basis.

The use of mobile or temporary treatment facilities early in the life of a disposal site prior to construction of a permanent facility also could be considered.

4.14.4.3 General Process Selection Criteria

The objective of this section is to provide general information on the technologies which have potential application to leachate treatment. The section is organized to first present information on which unit treatment processes would be most applicable to specific leachates. This and other information is documented in a summary of various treatment processesp including major design and performance criteria, environmental impacts, technology status and reliability.

Generally, there are only about eight unit treatment processes applicable to leachate treatment:

Biological Treatment	Chemical Precipitation
Aerobic	Ion Exchange
Anaerobic	Reverse Osmosis
Carbon Absorption	Stripping
Chemical Oxidation	Wet Oxidation

Based upon existing research and studies, these eight unit processes are identified by the most applicable process based on leachate composite in a matrix shown in Table 4.13.

Based on these findings, it is anticipated that leachate generated from young landfills can be readily degraded by biological means. Leachate from older landfills is more amenable to physical-chemical treatment processes. Leachate collected from recently installed landfills is amenable to both aerobic and anaerobic biological treatment. None of the studies indicated the need to remove heavy metals prior to biological treatment.

Activated carbon treatment of raw leachate generally gives better removal of organic material than chemical precipitation. Despite low COD removals, chemical precipitation was found to be very effective in removing carbonate and iron from leachate. However, relatively large dosages of lime are required.

The use of oxidants was less effective than activated carbon in removing organic matter from stabilized leachate. Reverse osmosis membrane treatment was found to be most effective in removal of COD. However, severe membrane fouling was experienced with raw leachate. -Biological pre-treatment prior to membrane processes is recommended.

The use of physical-chemical treatment processes on landfill leachate does not produce the degree of organic removal that can be accomplished with biological processes. However, good results are apparent with old landfill leachate.

Several other figures and tables are useful as general guides to select treatment processes for specific leachate composition. Figure 4.32 provides envelopes for the percentage of COD removal expected versus BOD/COD and COD/TOC ratios. These serve only to indicate general trends of COD removal that would occur. Follow-up laboratory experiments using existing leachate are recommended to ascertain the selection of each of the specific treatment processes.

Appendix F presents an overview of various unit treatment processes which have applicability for leachate treatment. Each unit process is summarized with regards to its applicability, major design considerations, environmental

Table 4.13 Proposed relationship between COD/TOC, BOD, COD, absolute COD, and age of fill.

Character of Leachate				Effectiveness of Various Treatment Processes							
COD/ TOC	BOD/ COD	Age of Fill	COD (mg/L)	Biological Treatment	Carbon Adsorption	Chemical Oxidation $Ca(ClO)_2$	Chemical Precip. (mass lime)	Wet Oxidation	Ion Exchange Resins	Reverse Osmosis	Stripping
>2.8	>0.5	Young > 5 yr	>10,000	Good	Poor	Poor	Poor	Poor	Poor	Fair	Good
2.0–2.8	0.1–0.5	Medium 5–10 yr	500–10,000	Fair	Fair	Fair	Fair	Fair	Fair	Good	Fair
<2.0	<0.1	Old > 10 yr	<500	Poor	Good	Fair	Poor	Fair	Fair	Good	Poor

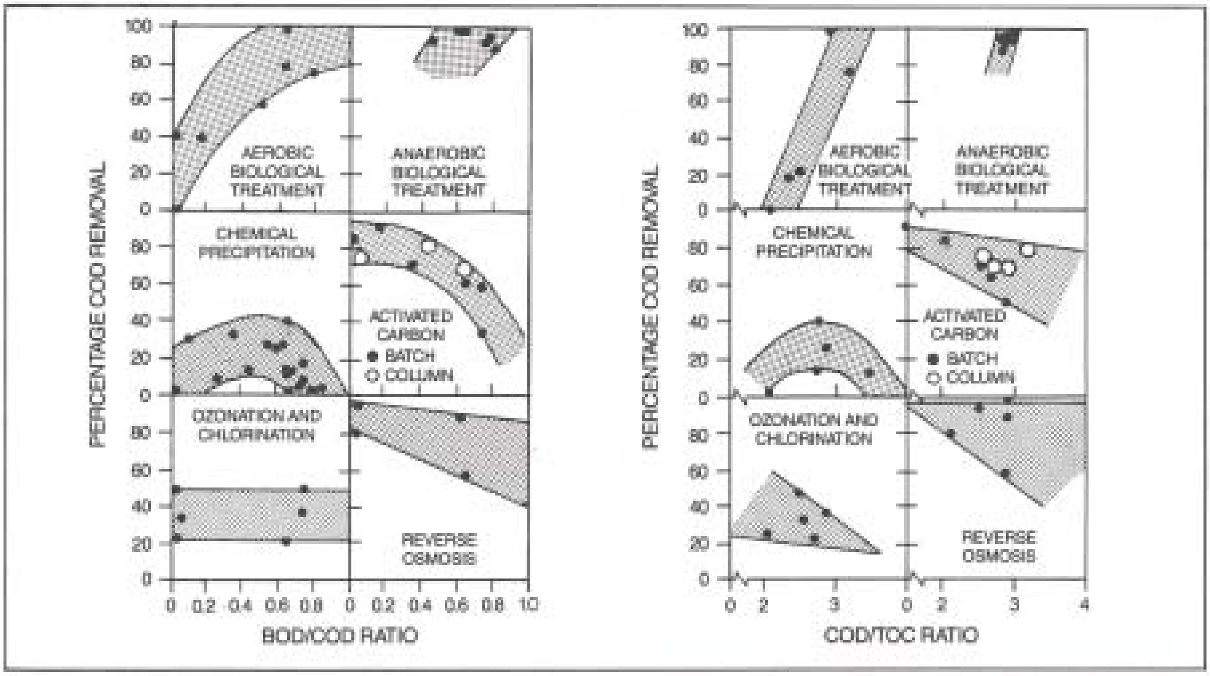

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Figure 4.32
COD Removal by Various Treatment Processes

Adapted From: Shuckrow et al., 1982

effects, technology status and reliability. A comparison of cost for various unit treatment processes applicable to leachate treatment is presented in Table 4.14.

4.14.5 Specific Process Design Criteria

Specific process design criteria for various unit processes to treat leachate have been reported 'in a small number of studies. This information, although very limited, is useful in detailed design of a treatment system and is summarized below.

4.14.5.1 Activated Sludge

The effect of leachate additions to the operation of an activated sludge sewage treatment plant has been studied in several investigations. Two investigations in particular seem to be of interest and are reported here. Boyle and Ham (1974) found that leachate with COD of 10,000 mg/L could be added to domestic sewage in an extended aeration activated sludge facility at a level of at least 5% by volume without seriously impairing the effluent quality. However, DeWalle and Chian (1977) noted significantly reduced treatment facility efficiency with only 4% by volume of leachate added. They further attributed this reduced treatment level to a phosphorous deficiency where the BOD5:P ratio in the influent varied from 130:1 to 255:1. They also noted that the activated sludge unit is preferably operated at low food to micro organism (F/M) ratios (0.3 day-1) when receiving leachate additions.

Table 4.14. Cost Comparison for Unit Processes for Leachate Treatment.

	Capital Cost	$0_{\&M}1$	Relative Energy Use
Activated sludge (with clarifier)	High	Low	Moderate
Ammonia stripping (no recovery)	Low/	High Moderate	High
Anaerobic/facultative lagoons	High	Low	Low
Biological seeding (used with conventional or pure oxygen-activated sludge)	High	Low to Moderate	Moderate to High
Carbon absorption (no regeneration)	Moderate	to High	ModerateLow
Chlorination	Low	Low	High
Equalization	Low	Low	High
Ion exchange	Generally high but very vari-	Moderate to high, variable	Low
Liquid ion exchange	Generally high but very variable	Moderate to high, variable	Low
Precipitation/floc/sedimentation	Low	Moderate	Low
Pure oxygen-activated sludge (including clarifier)	Moderate/ High	Moderate	Moderate
Rotating biological disc (including clarifier)	Moderate/ High	Moderate	Moderate
Trickling filter	Moderate	Low	Low
Wet air oxidation	High	High	High

Source: EPA, (1978); DeRenzo, (1978); EPA, (1979).

[1]See legend on next page.

Table 4.14. Cost Comparison for Unit Processes for Leachate Treatment (Cont.)

Legend Explaining Relative Cost Comparisons

(Based on 1978-1979 costs)

Capital Costs

	Low:	<$ 75,000 for 0.1 mgd; <$100,000 for 0.3 mgd
	Moderate:	$ 75,000 - $110,000 for 0.1 mgd; $100,000 - $200,000 for 0.3 mgd
	High:	>$110,000 for 0.1 mgd; >$200,000 for 0.3 mgd

O&M Costs

	Low:	<$ 7,500 for 0.1 mgd; <$ 1,300 for 0.3 mgd
	Moderate:	$ 7,500 to $20,000 for 0.1 mgd; $ 1,300 to $25,000 for 0.3,mgd
	High:	>$20,000 for 0.1 mgd; >$25,000 for 0.3 mgd

Energy

	Low:	< 7% of O&M
	Moderate:	7-15% of O&M
	High:	>15% of O&M

DeWalle and Chian (1977) noted that if leachate is treated in an activated sludge treatment plant, the sludge settling characteristics show that the addition of 0.5X leachate resulted in a decreased settling rate of the sludge interface. However, increasing the leachate addition (up to 3%) at the same loading (0.3 day-1) did not further deteriorate the settling characteristics. As would be expected, the impairment of the sludge settling was even more noticeable at the higher sludge loading, e.g., 0.6 day-1. The presence of a high concentration of iron in the leachate, with the resulting low soluble phosphate concentration, may have contributed to the impaired sludge settling upon leachate addition. Therefore, the addition of even a small amount of leachate to the activated sludge process could tend to impair the sludge settling in the secondary clarifier of an existing plant and additional clarifier capacity or chemical addition may be required. However, the advantage of leachate additions is the resulting low levels of phosphate in the effluent of the treatment facility, i.e., on the order of a fraction of 1 mg/L.

Stegmann (1982) reported that activated sludge can successfully treat leachate alone if organic loadings into the plant are kept below 10.0 lbs BOD/1000 ft3-day. Partial treatment (about 70 percent degradation) can also be achieved if loadings are kept below 31.0 lbs BOD/1000 ft3-day. Stegmann assumed a BOD/COD ratio greater than 0.4, with no phosphorus additions required. Stegmann also reported that high sludge age (30 days) with hydraulic retention times of 7-14 days are required for successful operation of an activated sludge plant treating leachate.

Stegmann also noted that instead of one large activated sludge tank to treat leachate alone, several small tanks are desirable with settling tanks behind each tank so that the number of tanks on line can be varied as the leachate quality or quantity varies. Based on his findings, the following problems have to be faced when activated sludge plants are operated to treat leachate.

- Low temperature caused by long retention times
- High foam production rates
- Precipitation of iron and carbonates that may cause clogging
- High sludge production rates

These problems can be solved when, for example, a large bubble diffused air aeration system is constructed, where the sludge is collected in a settling tank and where the foam is destroyed by a spray system with large diameter nozzles. In addition, it should be mentioned that this assumes sufficient phosphorous and nitrogen available for microorganisms.

4.14.5.2 Aerated Lagoon

The aerated lagoon is probably the most widely used unit process for the treatment or pre-treatment of MMSW landfill leachate. Its advantages of low capital and O&M costs, as well as relative ease of operation make it ideal for many leachate treatment applications.

Design Parameters, Several studies have investigated the use of aerated lagoons for treatment of solid waste leachate. Several treatment and operations parameters have been studies as to their impact on BOD5/COD removal efficiency, including:

- Addition of nutrients to the leachate to make-up deficiencies which occur in most solid waste leachate.
- Variation of leachate temperature to determine effect on reaction kinetics.

- Investigation of acute effects of heavy metals on microorganisms and bioaccumulation.

These parameters have the potential to greatly affect the removal efficiency of aerobic lagoon systems.

Nutrient Addition. Most researchers have found that the addition of nutrients greatly improves the efficiency of BOD5 and **COD removal (Robinson and Maris, 1983; Robinson** et al., 1982; Cook and Foree, 1974). The stoichiometric balance of BOD5: nitrogen: phosphorous (BOD:N:P) is usually given as 100:5:1 (Benefield and Randall, 1980). However, Robinson and Maris (1983) recommended a BOD:N ratio of no greater than 100:3.6 and preferably lower because of high residual ammonia concentrations at lower ratios. DeWalle and Chian (1977) recommended a COD:P ratio of 300:1 which also is much higher than would be expected by stoichiometry. Nelson and Storhaug (1985) recommended the use of a COD:N:P ratio of 580:12:1 for treatment of leachate in a Norwegian cold weather study. Because the ammonia concentration tends to be very high in some leachate, nitrogen addition is not always required, in fact several researchers recommend against its addition (Nelson and Storhaug, 1985; DeWalle and Chian, 1977). Ammonia and nitrite-nitrate nitrogen are often the limiting components for disposal of leachate by either discharge to surface waters or land application. When the solids retention time (SRT) of the lagoon system is kept at 20 days or less, nitrification of ammonia to nitrate does not occur (Robinson and Maris, 1985). Additionally, with a BOD5:N ratio of less than 100:3:6, a complete conversion of ammonia to organic nitrogen has been observed (Robinson and Maris, 1983). Phosphorous is characteristically low in most leachate and almost all literature sources recommend its addition. The determination of nutrient addition requirements must be periodically reviewed as part of a continued leachate analysis program.

Temperature Variations. The efficiency of treatment systems is highly dependent on leachate and ambient air temperature. Design equations for aerated lagoons take process temperatures into consideration in determining lagoon size and solids retention time (SRT). If the aerated lagoon at a site is a non- solids -recycle system, the SRT would be equal to the hydraulic retention time for the lagoon. All researchers found adequate treatment was possible for temperatures down to 50 centigrade, although longer treatment periods were required.

Heavy Metal Removal. Several researchers have investigated the effects of heavy metals on aerated lagoon systems. Acute effects of heavy metals and heavy metal bioaccumulation in system biomass generally did not lower biological treatment system efficiency (Zapf-Gilje and Mavinic, 1981). Reaction rates were already low because of the complex biological constituents present in the leachate. Therefore, heavy metals may have had a small effect which was not manifest in the reaction rates. Aerobic biological treatment systems tended to be quite efficient in removing heavy metals from influent leachate. Removal efficiencies were generally as follows: Iron, manganese, zinc (99%) > chromium (97%) > cadmium, calcium (93%) > aluminum (91%) > lead (85%) > nickel (56%) > magnesium (51%) >> potassium (17%), (Robinson and Maris, 1983; Zapf-Gilje and Mavinic, 1981). Generally, with the use of a final polishing pond, metal concentrations were within discharge limits.

Aerated Lagoon Desian. Aerated lagoon systems provide simple and reliable leachate treatment. Aerated lagoons are complete-mix aeration basins providing retention times of from 20 to 115 days at design flow. A 20 day SRT is the minimum recommended for proper lagoon operation (Uloth and Mavinic, 1977). Based on first-order kinetics for a complete-mix reactor as presented in the Criteria for Sewage Works Design (WDOE, 1985), the performance of the aeration basin can be estimated from the following:

$$\frac{S}{S_o} = \frac{1}{\quad + 2.3K_T t} \qquad (4\text{-}30$$

Where: t = retention time, days
K_T = reaction coefficient, day^{-1}
S = effluent BOD_5, mg/L
S_o = effluent BOD_5, mg/L

Based on figures from other landfills in the area and literature sources (Uloth and Mavinic, 1977), a reaction coefficient of 0.33 at 200 C could be used. The reaction coeffient can be adjusted for temperature using the following equation:

$$K_T = K(I.047).^{(T-20)}$$

Where: KT = reaction coefficient at temperature T
$K = 0.33$ at 20^0 C
T = temperature, ^{0}C

For example, using the first-order kinetic equation and assuming an influent BOD5 of 5,500 mg/L, *KT* at 5.9^0 C, and a 25 day SRT, the BOD5 removal efficiency would be estimated at about 91Z for a complete mix system. Typically, nutrient addition, particularly phosphorous, would be required to achieve this level 'of efficiency. A COD:N:P ratio of 580:12:1 has been recommended for initial nutrient addition (Nelson and Storhaug, 1985). The nutrient application rate should be integrated with a regular -leachate testing program. As per Ecology criteria (WDOE, 1985), two basins would be desirable at a site in case repairs are required. Each basin should be capable of holding the entire basin volume required and should be designed to allow either series or parallel operation.

The use of polishing ponds enhances solids settling and metals removal (ZapfGilje and Mavinic, 1981). A polishing pond, if required, would typically have a minimum retention time of 7 days (Benefield and Randall, 1980). The pond should have provisions for removal of settled solids and aeration, as the organic load of the settled solids could exert an excessive oxygen demand on the pond. Essentially, a second aeration/storage basin may serve as a polishing pond.

4.14-5.3 Anaerobic Filter

DeValle and Chian (1977) studied the effectiveness of the anaerobic filter in treating leachate. Based on their findings, up to 97 percent COD was removed from leachate using an anaerobic filter with loadings at 38 lbs COD/1000 ft3_ day. Up to 89 percent of COD was removed in the form of methane gas leaving the system, whereas the remainder of COD was present in the form of inorganic carbon in the solution. Only a small amount of COD was removed as biomass accumulated in the anaerobic filter. The low yield of biomass, i.e., approximately 0.012 gram biomass produced per gram of COD removed, allowed the filter to be operated without nutrient addition. In fact, due to the low yield of biomass, the COD:P and COD:N ratios in the feed could be maintained at 4360:1 and 39:1, respectively, without impairment of their filter operation. Any P requirement was sufficiently met by the addition of the anaerobic digester sludge added to the unit initially for seeding.

DeWalle and Chian (1977) also reported that in view of the lower installation and operation costs of the anaerobic filter as compared with those of the aerated lagoon, it is obvious that the anaerobic filter is a preferred biological process for treating high strength leachate. In addition, the absence of any nutrient additions, the extremely low yield of biological solids and the production of useful energy, i.e., methane gas, strongly supports the use of the anaerobic filter for leachate treatment.

4.14.6 Plant Construction Details

Specific construction details for leachate treatment and disposal systems should be in conformance to, the criteria set forth in Ecology's Criteria of Sewage Works Design (WDOE, 1985).

4.14.7 Specialized Leachates

The discussions preceding this section deal primarily with leachate generated by mixed municipal solid waste landfill operations. other types of solid waste landfill operations will generate varying leachate composition, requiring specialized leachate testing programs to determine.treatability.

Wood, waste landfill operations generate leachate with high COD (8,000-8,500 mg/L) and tannin levels (2,200-2,500 mg/L) (Schermer and Phipps, 1976).

Coal ash disposal sites result in leachate high in metals ranging from arsenic (32 mg/L) and zinc (9 mg/L) to chromium, copper and lead (3-4 mg/L) (Tripodi and Cheremisinoff, 1980). Also, high chloride (90 mg/L) and sulfate (342 mg/L) levels are reported (Tripodi and Cheremisinoff, 1980).

Pulp and paper mill sludge landfills generate leachates varying in COD (4,000-9,000 mg/L), BOD (2,660-6,614 mg/L) and total solids (5,000-11,800 mg/L). The total hardness (3,200-6,800 mg/L CaC03) and alkalinity (4,1008,700 mg/L) are also very high (U.S. EPA, 1976).

Each of these leachates requires specialized treatment studies in order to select applicable treatment processes and potential process design criteria.

Utilization of either general or specific leachate treatment process criteria from this section is not recommended.

4.15 LANDFILL GAS MANAGEMENT SYSTEM DESIGN

4.15.1 Introduction

A number of gas control options are available to the landfill designer. The Minimum Functional Standards require the landfill gas to be collected and purified for sale, otherwise used for its energy value or flared. However, choice of the most suitable method can only be determined after careful analysis of the following factors:

- Site conditions (including depth of fill, distance to groundwater, or low permeable soil stratum, soil types, and moisture conditions)
- Adjacent land uses (e.g., open space, or residential/commercial development)
- Other considerations, such as the cost of installation, operation and maintenance requirements, and the energy value of landfill gas collected

4.15.2 Landfill Gas Migration Control

4.15.2.1 Passive System Design

For many shallow landfills (i.e., those for which perimeter barriers can be readily constructed), use of passive control systems may be the control method of first choice. Passive systems have the advantage of lower operating and maintenance costs. Because there are no mechanical components, there are no expenses for power or replacement. However, passive systems for migration control are very dependent on site geologic conditions (i.e., low ground water table or near surface, low permeable formation) to be feasible.

Figures 4.33 and 4.34 show examples of a perimeter trench with a barrier, and an on-site gas collection trench, respectively. In order for a passive system to be effective in removing landfill gas, a natural pressure gradient must be present within the landfill. The highly permeable gas trenches used in passive systems act as a pressure sink (lower relative pressure), with landfill gas flowing toward the trenches. This means that convective mechanisms will be the primary method of gas flow (Schumacher, 1983). Darcy's equation has been used to describe convective flow of gas in several landfill gas models. An example of the use of Darcy's equation in calculat ing gas collection line spacing is presented in Appendix G. It is important to note that Darcy's equation applies only to laminar flow, not to turbulent flow (Schumacher, 1983). However, in most ' systems it has been shown that gas flow is laminar, especially in a passive system without an induced pressure gradient.

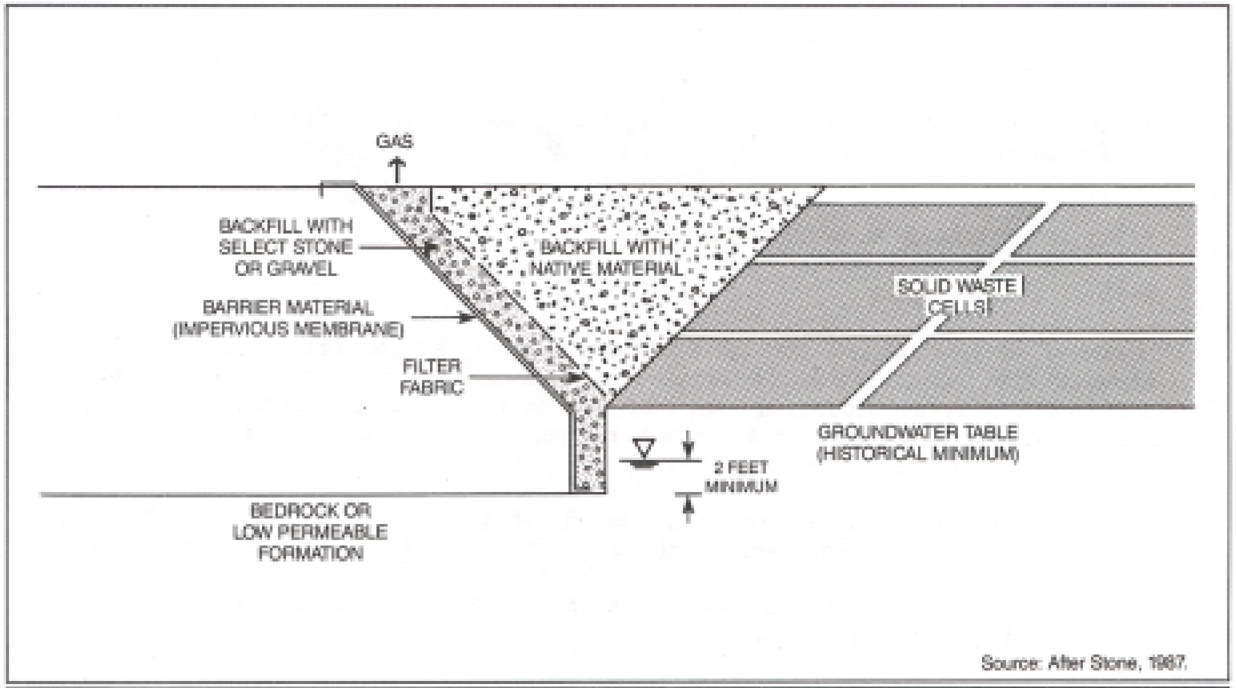


Figure 4.33
Perimeter Trench With Barrier and Highly Permeable Gravel Backfill

System Components and Equipment. The components and equipment needed for landfill gas control systems depend upon the type of system selected. For a passive control system, a backhoe or other suitable equipment will be required to perform the necessary trenching. A permeable material such as clean gravel or rock is needed for most passive control systems. If gravel or rock is used, only 10% of the aggregate by weight should be below one-half inch in diameter. Barriers and vent/barrier trenches require synthetic membranes or clay soils. The collection gas is usually flared and a typical flare design is shown in Figure 4.35.

4.15.2.2 Active System Design

Active systems provide positive control of landfill gas migration and greater flexibility; however, the greater complexity of such systems and the higher operation and maintenance costs may constitute a disadvantage in some applications. Economic considerations must, in all cases, be balanced against the effectiveness of the system in meeting the control goal.

Full control of gas migration may require the installation of an active system. For example, an active system may be preferred in deep landfills, where extensive and costly trenching would be required to effect passive control, or at landfills bounded by residential developments. An active system would also be required should a passive system fail to achieve the desired degree of control. A typical active gas extraction well is illustrated in Figure 4.36.

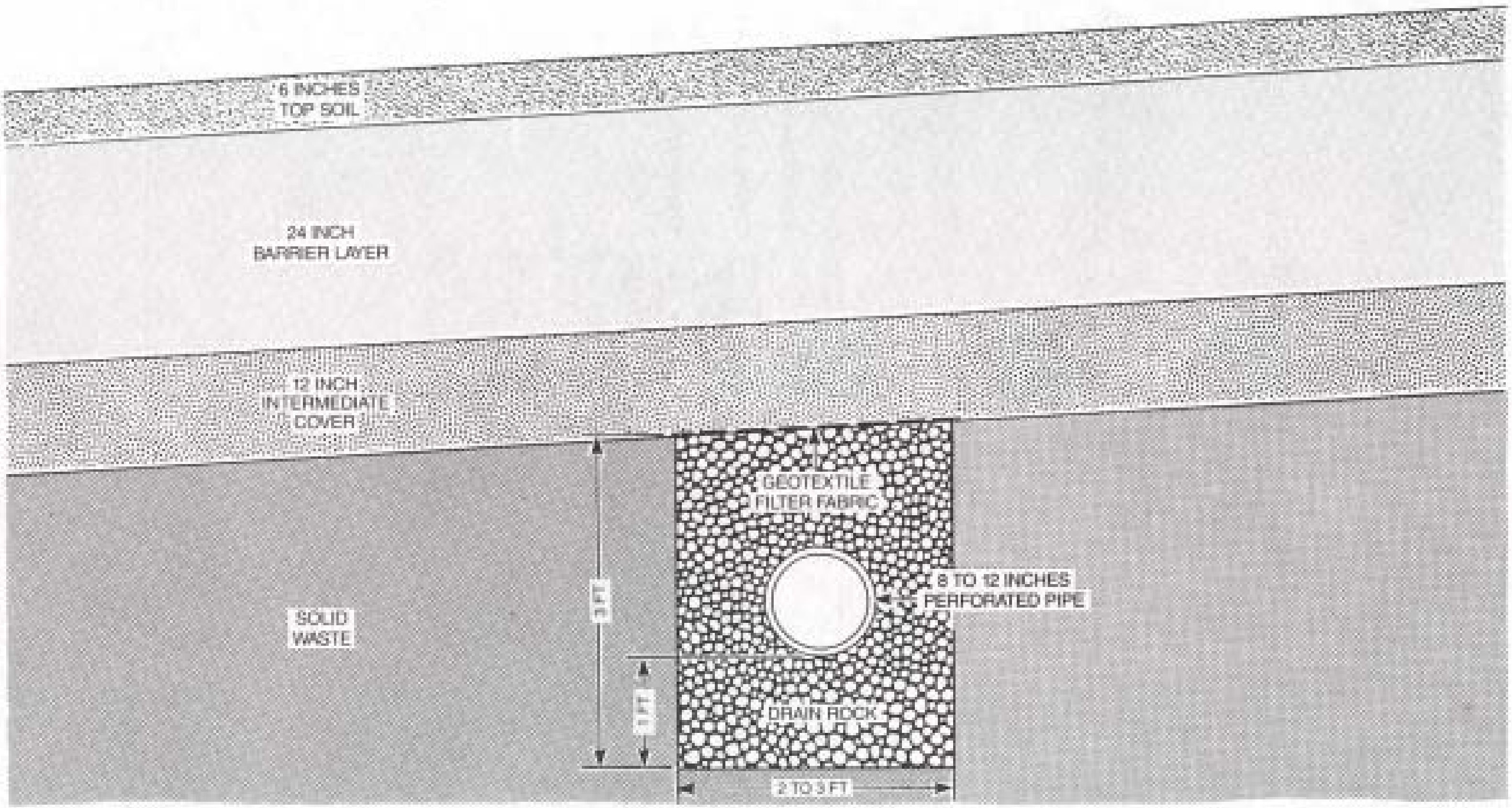
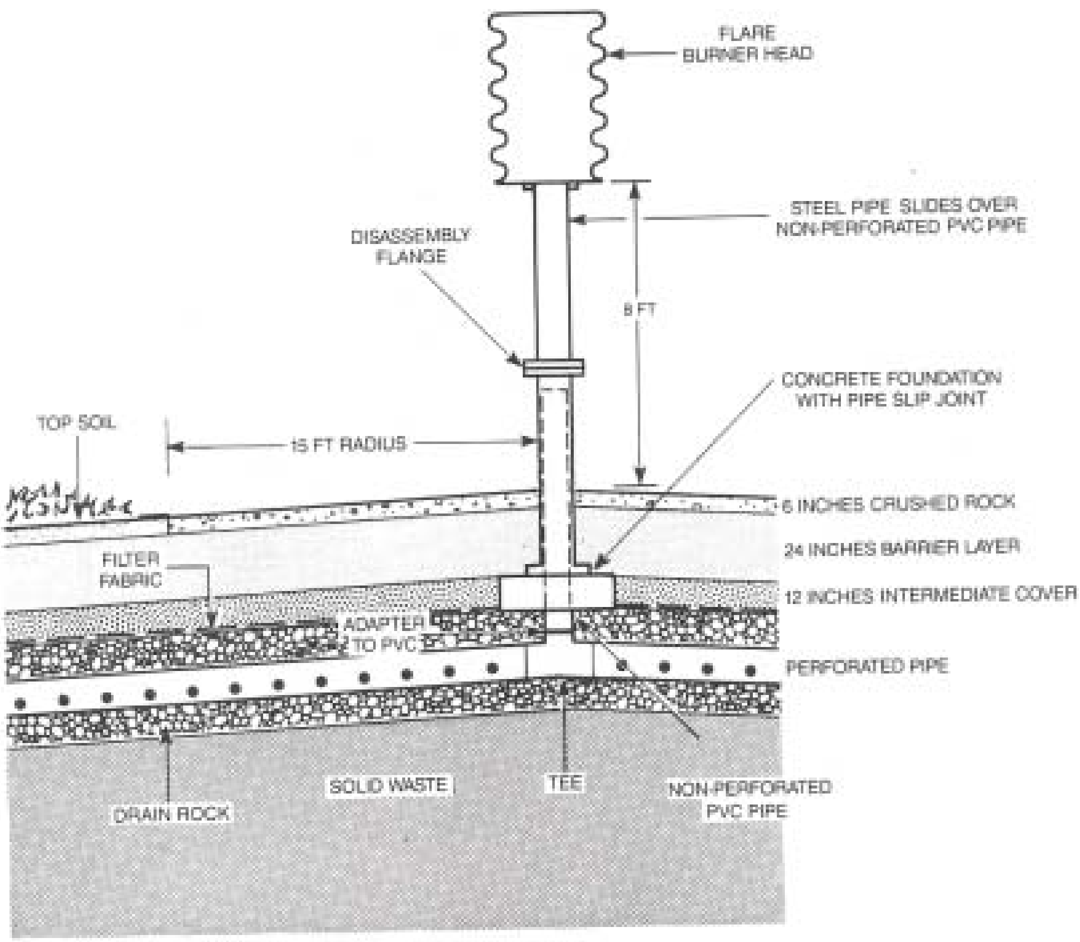


Figure 4.34
Cross-Section of Gas
Collection Trench With Final Cover



Source: Snohomish County

Figure 4.35
Gas Flare Detail With Horizontal Collection Trench

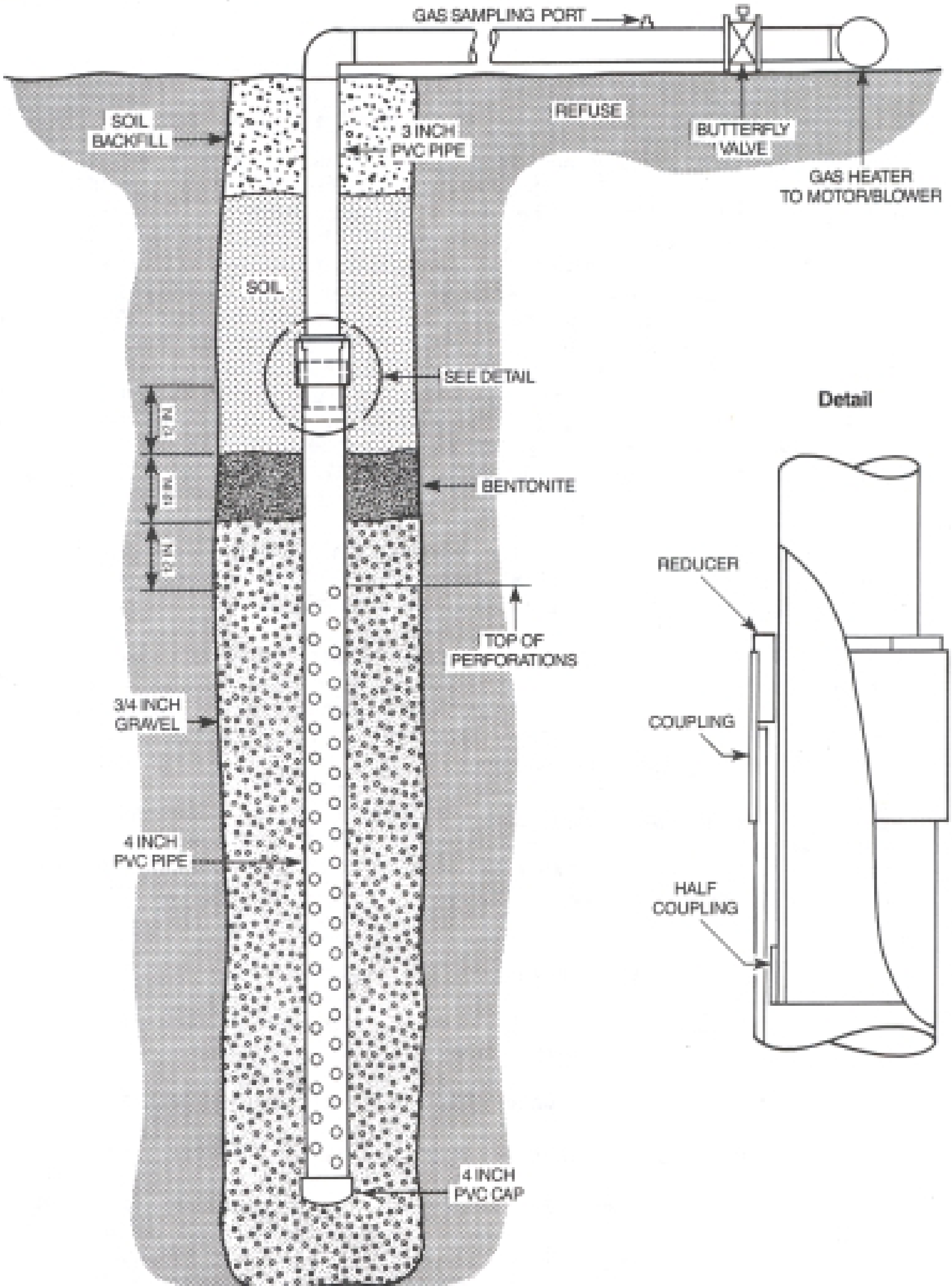


Figure 4.36
Typical Single Completion Extraction Well

Guidance for the spacing and placement of gas extraction wells is primarily rule-of-thumb. Generally, the radius of influence of a gas extraction well is approximately 150% of the depth of the refuse. For example, if the landfill is 100 feet deep at a given point, the radius of influence of a well at that point would be 150 feet. In other words, the extraction wells could be spaced 300 ft apart (the radii of influence are additive). The depth to which gas extraction wells are drilled once again depends upon the depth of the refuse. Generally, the depth of the well is about 80% of the depth of the refuse. If the depth of the refuse cannot be accurately determined, it is possible that the drilling operation may go deeper than refuse. If this occurs, a bentonite seal should be placed in the bottom of the well up to 3 feet above the bottom of the refuse. If the material under the refuse is very permeable, it may be advisable to fill further up with low permeable soil.

Horizontal trenches are usually placed with alternating lifts of refuse, spaced horizontally 100 to 150 feet apart. They are not put into service until after the next lift of refuse has been placed.

The header design for the gas extraction system must be capable of maintaining the vacuum required for extraction of gas and be properly sized to carry adequate gas volumes. other design elements which must . be taken into consideration are header slope, condensate trap placement and insulation, especially at the trap connections.

System Components and Equipment. Equipment required for an active control system depends upon whether a horizontal trench system or vertical extraction wells are utilized. A backhoe is necessary in the case of the former; while a drill. rig would be employed in the latter. Components of an active control system include:

- The horizontal or vertical collector
- The lateral and header pipe network necessary to convey the gas to a central collection point
- The motor blower which provides the vacuum to extract the gas
- Any necessary flare for disposal of the landfill gas

Design of the gas flare must consider the temperature of combustion and residence time of gas in the flare. The destruction of odorous and potentially toxic components of the gas stream is very dependent upon these parameters. In many instances, monitoring of the flare emissions will be required to ensure complete destruction of these components is occurring.

Gravel backfill, pipe casings (typically 3 to 6 inches, Schedule 40 PVC) and an impermeable material to ensure an adequate seal, are also needed for construction of collection wells and trenches. Schedule 40 PVC pipe, properly sized, is also commonly used for the system laterals, headers, and f it tings.

4.15.2.3 Hybrid System Design

Hybrid systems may be installed to enable passive systems to be easily converted to active systems, should active control become necessary at some future time. Hybrid systems (see Figure 4.37) usually consist of a vent/barrier trench incorporating a horizontal perforated pipe with one or more vertical risers. Operated as a passive system, the trench will intercept migrating gas and route it to the flare for combustion. When additional control is needed, the vertical risers may be connected to a motor blower. The gas within the area influenced by the system will then be withdrawn by vacuum. The active components of such hybrid systems need only be activated when gas production or migration increases to a point at which the passive system can no longer maintain control. In this way, the higher costs of operating an active system can be avoided until the need for active control has been determined.

4.15.2.4 Design Criteria

Design criteria for landfill gas migration control systems include:

- Protection of public health and safety
- Flexibility
- Phased construction and expansion potential

Public Health and Safety Considerations. The major consideration in designing a landfill gas control system is to ensure that the system will effectively control methane migration and thereby protect public health and safety. The system must be capable of maintaining methane gas concentrations below the lower explosive limit (LEL) of 5% at the landfill boundary and below 100 parts per million by volume in any building off-site. The effectiveness of a landfill control system can only be determined with certainty by a regular program of monitoring (See Section 8.5). However, predicting gas production and probable migration paths and examining site conditions will enable the designer to select appropriate initial control methods**.** If an active control system is chosen, the designer should include a means of adjusting the system to respond to changing gas production rates. It is important to be able to maintain gas withdrawal rates adequate to control migration, yet not so high as to draw excess oxygen into the system. Introducing too much oxygen into the fill may increase the potential for subsurface fires. If a passive system is selected, the design should incorporate a means of expanding or modifying the system (including switching to an active system) to easily and effectively control any increase in gas production and/or migration.

Unburned gas must be transported in a manner not subject to accidental ignition. After transport to a central point, the gas should be burned in a high temperature flare. The height of the flare should be such that it does

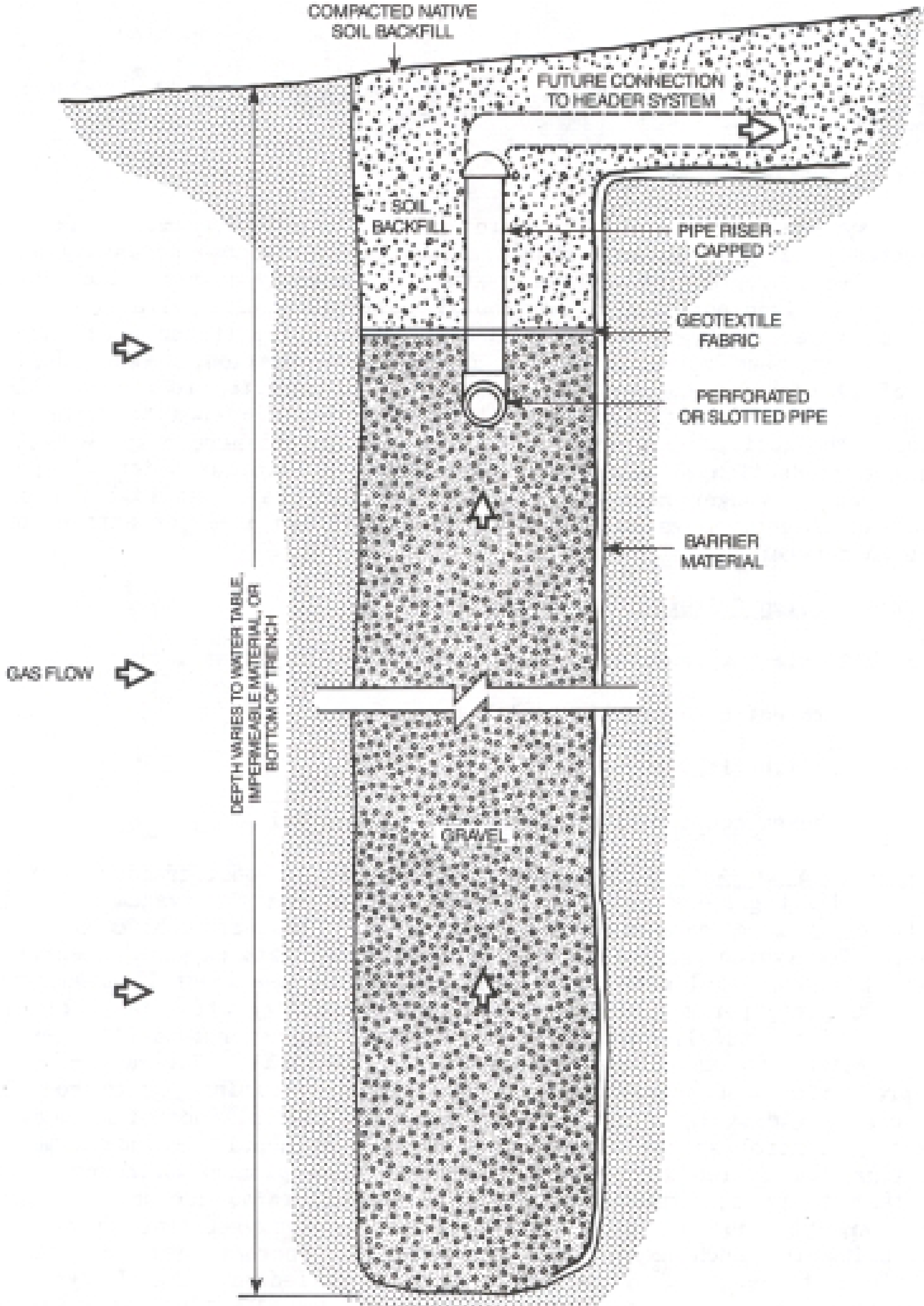


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Figure 4.37
Hybrid System Combination Vent/Barrier Trench

not ignite combustible material in the vicinity, but not so high as to be aesthetically unpleasing. Within a 30 to 50 foot area around the flare, a noncombustible ground cover (i.e., crushed rock or gravel) should be maintained. A locked enclosure should also be provided to prevent unauthorized entry to the flare area.

Special care must be taken in the design of the flare to prevent backflash. Flame arresters must also be incorporated into the system at the inlet of the flare to prevent accidental ignition in the discharge piping system. An automatic ignition system should also be provided for centralized flaring systems. For systems which do not have centralized flaring, which would include most passive systems, an automatic ignition system should be considered for each flare to prevent the off-site transport of landfill gas. This system will require frequent inspection to ensure that batteries, lines, and electro-static units are in working *condition.*

System design and the materials specified for use should reflect careful consideration of site conditions to ensure the integrity of the collection system. In colder climates, for example, it may be necessary to place all collection headers below the frost line, or use insulated pipe, to prevent freezing. A subsurface collection system might also be necessary to facilitate uninterrupted operation of a landfill or future development of the site. Piping and synthetic membranes should be chemically compatible with the likely components of landfill gas (see Section 4.15.4). Design of landfill gas control systems should also incorporate adequate means of protecting the system from vandalism and accidental damage to the system components**.** A means of isolating portions of the system, such as using valves, should also be incorporated into the design to provide protection to workmen during system repair.

<u>System Flexibility.</u> The ability of a gas migration control system to be adapted to changing gas production and migration patterns is an important design consideration. Such flexibility is especially important if future development is planned on or near the landfill site, or if gas production rates are likely to fluctuate widely on a seasonal or other basis.

Active control systems tend to provide more flexibility. Flow rates at individual wells, as well as for the system as a whole, can easily be adjusted by means of control valves. It is also possible to increase the capacity of the system at any time by adding new wells or by increasing the capacity of the motor blower.

If other considerations dictate installation of a passive control system, a hybrid system may be considered. As mentioned previously, such a system permits active control to be initiated should passive control prove inadequate. The chief advantage of a hybrid system is that it permits the higher operational costs of active gas control to be deferred until such time as active control is actually required. Return to passive control is also possible at any time by deactivating the system. However, if increased gas production or migration is likely to occur in the near future or to continue for an extended period of time, installation of an active system may be more cost effective because of the high cost of installing a hybrid system.

Phased Construction and Expansion Potential. The potential for the landfill gas control system to be expanded or constructed in phases may be an important design consideration. Increased gas production may require that the system be expanded to ensure adequate control of gas migration. It may also be necessary to initiate control of landfill gas prior to completion of the landfill, or to construct the system as the landfill is developed in order to minimize installation costs or control odors on an interim basis. If so, the designer must incorporate into the design plans provisions for expansion of the system. Interference with normal landfill operations must be minimized and due consideration should be given to protecting components of the system from damage.

Should gas recovery be considered a likely future option at the landfill, provisions must be made for coordinating the control and recovery system to ensure that the goals of either system are not jeopardized.

4.15.2.5 Operation and Maintenance

Any control system, no matter how effective when initially installed, is subject to component malfunctions, deterioration and mismanagement. There is no assurance that the system will continue to perform effectively unless properly evaluated, managed, and maintained. To ensure proper operation and maintenance of the control system, a comprehensive operation and maintenance manual should be readily available to the site operator and all responsible personnel.

Included in the operation and maintenance manual should be the following items:

- A general description of the safety precautions to be observed in a landfill gas environment
- A description of the control system, accompanied by as-built drawings and documents
- Procedures for starting up and shutting down the system
- System monitoring procedures, including detailed instructions on the use and calibration of monitoring instruments (see Section 8.5)
- System adjustment
- Routine inspection and maintenance of the system
- Reporting procedures and emergency contacts

All personnel responsible for system operation and maintenance should be thoroughly trained in the operation and maintenance of the control system, and in the proper use of necessary equipment and instrumentation. These personnel should understand the hazardous nature of landfill gas and its principal characteristics. Additionally, they should be taught' to recognize conditions and activities that could decrease the effectiveness of the system.

4.15.3 Landfill Gas Recovery

In theory, a number of alternative systems are available for recovery of the methane gas produced in landfills. These include blankets, mounds, trenches,and vertical wells. All such systems make use of permeable material to create a corridor facilitating the passage and collection of landfill gas. Of the recovery systems on-line in the United States to date, most make use of vertical collectors, with use of horizontal collectors as a promising technique, especially in larger landfills.

4.15.3.1 Vertical Extraction Well System Design

The typical gas recovery system employs vertical exhaust wells consisting of perforated pipe casing that is placed in holes drilled in the refuse. The well is backfilled with a permeable material, such as gravel, and sealed to prevent inflow of air, which is toxic to methane producing bacteria. Diameters of extraction well boreholes usually range from 12 to 36 inches. A vacuum is applied to each well casing, creating a pressure gradient within the vicinity of the extraction well. The gas flows to the extraction well, predominantly by convective flow, enters the well casing, and is conveyed to a lateral pipe system. Each well head is normally equipped with a butterfly, gate or ball valve for flow rate control to permit flexibility in system operation. The gas withdrawn from individual extraction wells is collected at a central point by means of a pipe network referred to as the gas collection header. A motor blower unit or compressor is usually the source of the applied vacuum, as well as the central point to which the gas is collected.

The depth of extraction wells commonly range from 50 to 100% of the refuse depth. While drilling to the bottom of the refuse is preferred at shallow landfills, this is sometimes . impractical and costly at very deep landfills. High leachate and/or groundwater levels might also limit the depth of the well. The lover portion of each well casing is usually perforated or slotted. The extent of the perforation depends on refuse depth and cover conditions. In a shallow landfill with excellent cover, for example, the eating might be perforated along most of its length. However, in a shallow landfill with poor gas containment, the perforation might be confined to the lower quarter of the casing length.

Recently, the use of double-completion wells has become increasingly popular. A double-completion well essentially allows a single borehole to be used for two extraction well casingi. The design consists of the first casing extending to the bottom section of the well with the bottom 50% of the casing perforated; the hole is backfilled with gravel to a point just above the perforations and sealed with about 2 ft of bentonite. The second casing is placed above this seal with the casing perforated to within about 25 ft of the ground surface; the hole is backfilled with gravel to just above the second casings perforations and sealed with about 2 ft of bentonite. Typically, a higher vacuum is placed on the lover casing to draw the maximum amount of gas, while a reduced vacuum is placed on the upper casing to reduce air intrusion through the landfill cover. A typical cross-section of a double-completion we'll is presented in Figure 4.38.

4.15.3.2 Horizontal Trench System Desian

Shallow trenches with backfill of permeable material are sometimes used for the collection of landfill gas in place of, or in combination with vertical wells. A perforated pipe is laid horizontally in each trench and connected to a vertical riser or extended to the edge of the landfill. Individual trenches can then be interconnected by a network of header pipes similar to that used in the vertical well system. Alternatively, header piping placed horizontally in the trenches could be used directly to interconnect the trenches.

The primary advantage of using a horizontal trench system for gas recovery is the ability to install the system as the landfill is constructed. Most vertical well systems. can only be installed after large portions of the landfill have been completed. Installation of trenches as filling progresses minimizes the cost of installation and provides the lease disturbance to normal landfill operations. Shallow trenches are also advantageous where leachate or groundwater levels are close to the ground surface or where the refuse thickness is insufficient for installation of vertical wells. Because of the shallow depth it is especially important that an effective seal is maintained above the trench network to preclude air intrusion.

A blanket collection system is a continuous layer of permeable material that may be placed at various locations in a landfill, including:

- Between the refuse and the final cover (the cover soil must be relatively impervious to gas flow and the permeable material must be protected from soil infiltration from above)

- Covering a side wall

- At intermediate levels in the landfill

However, unless the permeable material is readily available, a blanket collection system will generally not provide the most cost effective gas collection system.

As an alternative to horizontal trenches or blanket collection systems, unsupported or supported mounds of permeable material can be deposited on the refuse lifts to provide pathways for the movement of landfill gas. These mounds should be at least 2 feet thick in order that settlement does not interrupt the flow of gas. The placement of the mounds in a grid network would alleviate some of the concerns about settlement, since alternative gas flow pathways would be available. An unsupported mound is one that has no side support and is usually placed away from the landfill sides. A supported mound is one that is supported by a sideslope or refuse slope. Additional information concerning the design of horizontal collectors can be found in Schumacher (1983).

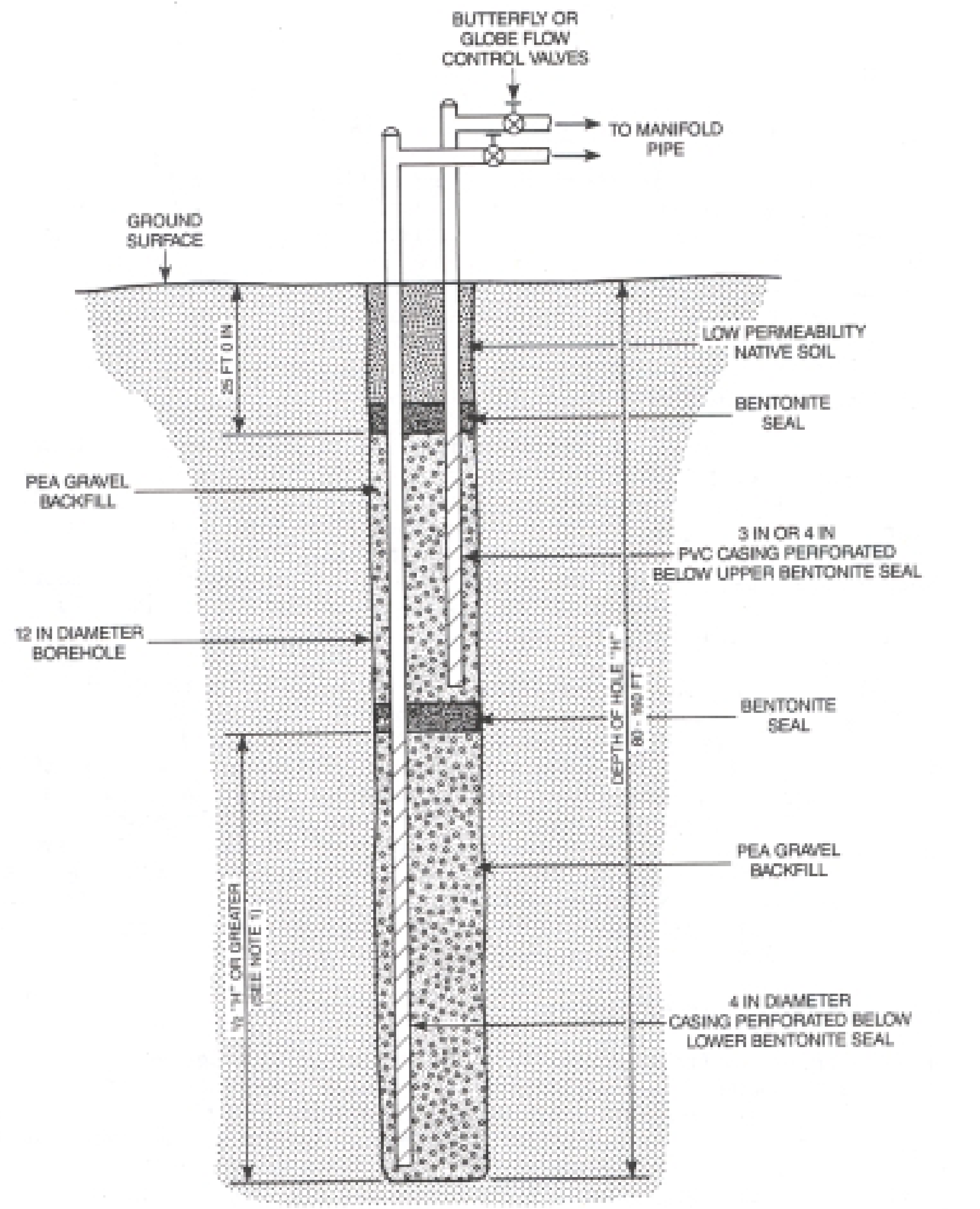

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Figure 4.38
Gas Migration Control Well
(Double Completion Detail)

4.15.3.3 Combination System Design

Recovery systems may be operated in conjunction with a control system where landfill gas migration control or control of odors is necessary. Occasionally, existing control wells can be modified to operate as recovery wells. However, it must be realized that there is a basic incompatibility between wells designed for migration and odor control and those designed for recovery. Control wells often admit large quantities of air, which is toxic to me thane- producing bacteria. Not only does this reduce potential recovery rates, but it also contributes to a gas of lower quality, requiring costly upgrading to achieve acceptable Btu values.

If a control system and a recovery system are to operate simultaneously, each system should be provided with its own collection header. High-quality gas from the specially designed (or modified) recovery wells will then be transmitted to the processing facility and from there to the end user; airrich gas from the control system will be collected and flared or put to such on-site uses as fueling the motor blower. Independent but coordinated control/ recovery systems would be preferred at landfills with a previously constructed perimeter control system.

Properly designed and constructed, the vertical extraction wells used in landfill gas recovery systems can also control the lateral migration of gas in many cases. The best way to optimize both control and recovery within a combination system is to design and operate a recovery system that minimizes air intrusion into the fill while preventing migration of gas from the landfill. This goal can best be met by placing closely spaced extraction wells operated at low extraction rates near the landfill perimeter to intercept migrating gas; this could also be achieved with high extraction/vacuum double-completion wells just outside the landfill perimeter. In the landfill interior, wells can be more widely spaced and higher extraction rates employed to optimize recovery of available gas.

4.15.3.4 Header System Design

The header or manifold system is designed to connect the motor blower with the, vertical extraction wells, thus it conveys the landfill gas, under an induced negative pressure, to the gas processing facilities. The primary elements of concern in design of the header system are header pipe size, slope, and placement of condensate traps. The engineer must size the pipes to allow for gas flow volume and velocity, and friction factors. The minimum slopes for placement of header pipes are:

- 1% when condensate and gas flow are in the same direction
- 3% when condensate and gas flow are in the opposite direction

Consideration should be given to increasing these slopes when the header pipe is over refuse that may settle unevenly, and/or if the header is to be buried and future adjustments to grade would be difficult. In general, header pipe slopes should meet these criteria and match existing grades, if possible, to allow the use of cost effective construction techniques.

Condensate traps are required as a means of removing condensate from header pipes. As a general rule, condensate traps should be placed at all low points in the header system and no more than 800 feet apart for long lengths of header pipe. The Engineer should keep condensate traps to a minimum in the design of the header system, since they require additional maintenance and represent a weak point in the header system.

4.15.3.5 Gas Purification System Design

Once collected, the gas may be treated to remove water, carbon dioxide, particulate matter, and trace gases from the methane. These constituents are removed to increase the energy and thus the economic value of the gas. Some of the methods by which these constituents are removed include:

- Water: absorption, adsorption, and condensation techniques are used for dehydrating the gas
- Carbon dioxide: absorption into a liquid, adsorption onto a solid, membrane separation, cryogenic separation, or. chemical conversion are methods used to remove carbon dioxide from the gas
- Trace gases: adsorption on solids, such as silica, alumina, activated carbon, or silicates is usually performed to remove trace gases and particulates; potentially harmful constituents which are removed by these measures are usually destroyed in the adsorbent regeneration process

All of these removal measures can be combined into one system, or only those elements which are deemed necessary can be used. Several proprietary licensed systems are available for the purification of landfill gas, and many of these are reviewed in Schumacher (1983). After gas processing, the pressure of the gas may be increased and the temperature lowered, if required, for transmission. Sale and use requirements determine the extent to which the gas is processed.

4.15.3.6 Design Criteria,

The principal design criteria for a landfill gas recovery system are:

- The minimum acceptable gas quality
- The system design capacity

The quality of gas required will depend upon its intended end use. Each landfill gas recovery project may have unique requirements based upon agreements between the seller and the user of the gas. These requirements must be taken into consideration when designing the recovery system. If the recovered gas is to be used for direct burning in space heaters or boilers or for generation of electricity, for example, the presence of trace gases is not a significant problem. In such applications, removal of particulate matter and moisture may be all that is required. Simple knock-out pots, condensate drains, and/or scrubbers would be incorporated into the main collection network. On the other hand, if the landfill gas is to be injected into a natural gas pipeline, considerable processing may be necessary, including second-stage compression, dehydration and carbon dioxide removal.

System design capacity is based on a number -of considerations, including projected ultimate gas yield and gas production rates over time, the estimated percentage of the gas than can actually be recovered, and the intended user. Specific design criteria for an extraction system (including well depths, collection intervals, inter-well spacing, and setback distances from the perimeter) are in turn determined from site configuration, background information and the results of landfill gas monitoring.

The principal components of a landfill gas recovery system are the extraction wells (or trenches) themselves and the header pipe network used to convey the captured gas to a central collection point.

4.15.4 General Landfill Gas System Material Requirements

The use of plastic piping materials should be limited to relatively moderate temperatures and pressures; otherwise, metal materials should be substituted. However, attention should be given to the greater corrodibility of metal piping.

At room temperature, PVC piping and tubing, available in sizes greater than 12 inches, are resistant to salts, alcohol, gasoline, ammonium hydroxide, and sulfuric, nitric, and hydrochloric acids. They may be damaged by ketones, aromatics, and some chlorinated hydrocarbons. PVC is resistant to temperatures ranging from minus 40OF to 150 to 2200F, depending upon the type of PVC. PVC should be handled at temperatures above 400F, although once in place. it is functional down to the lower temperature range shown above. In field applications, the recommended maximum temperature is 1400F.

Polyethylene (PE) pipe and tubing, available in sizes up to 42 inches in diameter, exhibit chemical resistance similar to that of PVC. However, mechanical properties of PE are generally poor, particularly above 1200F, and the pipe must be fully supported. The maximum recommended service temperature is 2500F.

Fiberglass reinforced pipe (FRP), available in sizes ranging from 2 to 12 inches in diameter and 20 to 40 ft long, is noted for its thermal and dimensional stability, chemical resistance, strength, durability, good electrical properties, and resistance to heat. The fiberglass reinforcement increases the strength of epoxy resins many times over that of plastic at room temperature, does not lose strength with increasing temperature, and effectively reinforces the resin to a temperature of 3000F. However, FRP is relatively expensive in comparison to the other types of pipe.

Synthetic membranes used in gas control applications should similarly be demonstrated to be compatible with the landfill environment and with the landfill gas they are to contain. Synthetic liners most commonly used in landfill applications include polyolefin, chlorosulfonated polyethylene (Hypalon), chlorinated polyethylene (CPE), polyvinyl chloride (PVC), and high density polyethylene (HDPE). These membranes are relatively low in cost, effectively contain landfill gas, and resist attack by chemicals likely to be present in the landfill. The minimum thickness recommended for synthetic membranes used for gas containment is 30 mils.

As an alternative to synthetic membranes, admixed materials and natural clay soils may also be used to contain landfill gas. The thickness required of such admixes, however, makes then susceptible to cracking under differential settlement. Natural clay soils, or soils mixed with bentonite, may also be used for containment of landfill gas, provided a. regular program of maintenance is established to guard against cracks caused by settlement, shrinkage due to drying, and damage from construction activity. The practical minimum thickness for natural soil liners is 2 feet.

4.16 FINAL COVER

4.16.1 Description

4.16.1.1 General

The final cover on a solid waste landfill:

- Prevents landfill gases from escaping at other than desired locations
- Reduces infiltration of precipitation into the refuse
- Resists wind and water erosion
- Accommodates settlement
- Is visually pleasing

Although climatic and environmental considerations may cause some of these functions to be more important than others, the cover design must take each function into account. However, no one material can adequately provide all the functions demanded of a final cover. Therefore, the concept of a multi-layered final cover system has evolved, which allows the designer to select and integrate various soils and artificial materials into the final cover system. The following sections discuss the purposes and material requirements for the following six types of layers:

- Subgrade layer
- Graded filter layer or filter fabric
- Barrier layer

- Drainage layer
- Graded filter layer or filter fabric
- Top soil layer

The configuration of these layers is illustrated in Figure 4.39.

4.16.1.2 Subgrade

The subgrade layer, located immediately above the solid waste, provides the foundation upon which the remaining layers of the final cover are placed. The subgrade layer is most often placed as an intermediate cover material prior to final closure and covering. However, depending on the climatic and environmental conditions and design of the final cover and gas control system, the subgrade layer may be required to perform other functions such as allowing free movement of landfill gases or collection of leachate seeps on steeper. slopes. The subgrade layer should be designed with the following requirements in mind.

- Thickness must be adequate to cover uneven solid waste surface
- Permeability to water and/or landfill gas must be adequate to achieve design objectives of the leachate management and/or gas management plan

To achieve adequate coverage of the refuse with this layer, the minimum thickness must be determined. Lutton (1982) suggests using the following equation to determine the minimum thickness for covering an irregular refuse surface.

$$T \geq 2R$$

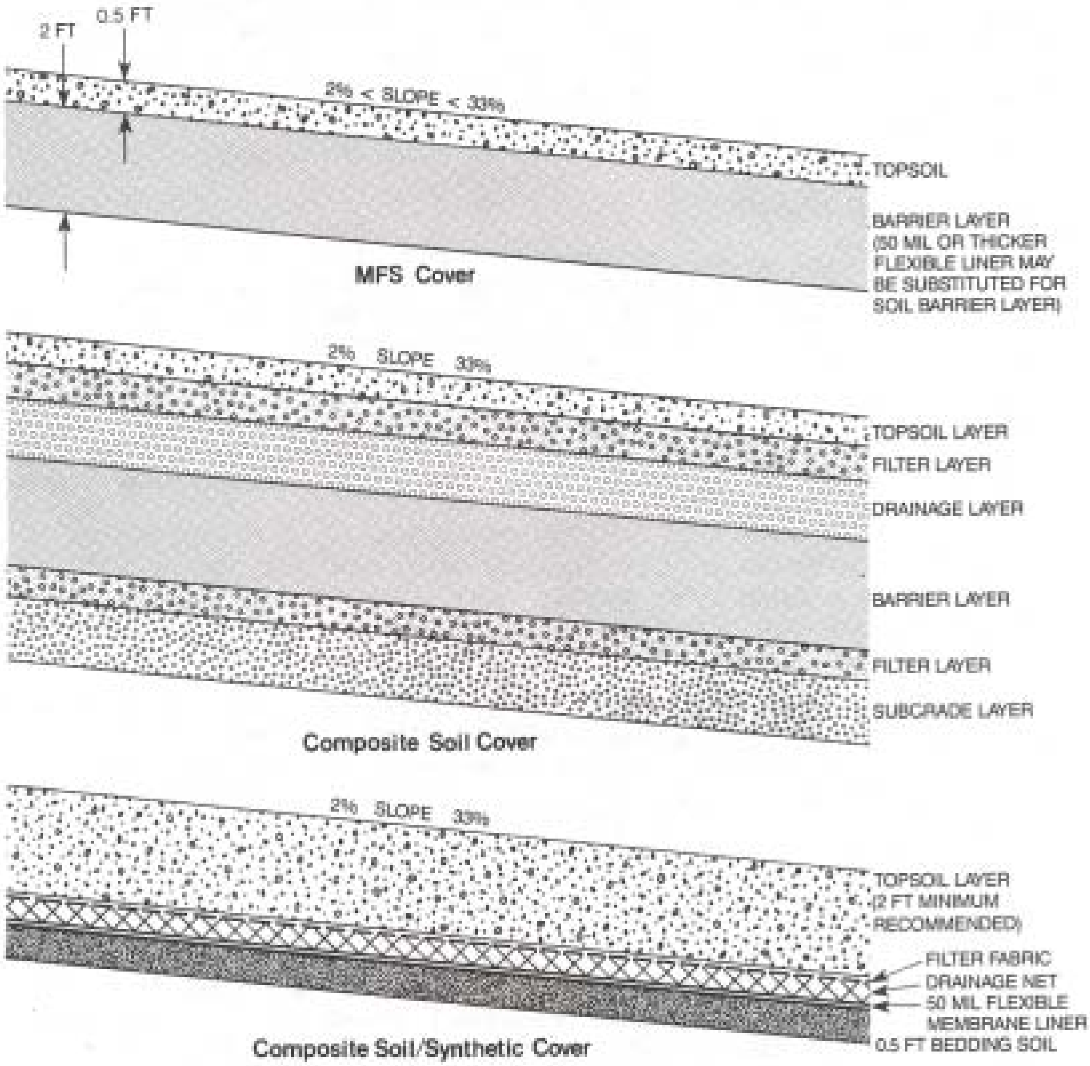
where: T = cover thickness
R = vertical distance from high point to low point of irregularities on surface of the refuse

The' area over which the variable "R11 is measured ranges from 20 x 20 feet, where intermediate sized spreading equipment is used, to 50 x 50 feet, where large sized spreading equipment is used.

If the subgrade is to also serve as a collection layer for either leachate of landfill gas, then it must meet the hydraulic conductivity requirements specified in the design. A typical minimum hydraulic conductivity would be 10-2 cm/sec, although greater or lesser permeabilities could be specified.

4.16.1.3 Filter Layer

The function of the filter layers shown in Figure 4.39 is to prevent particles of the fine-grained barrier or topsoil layer from being washed into the coarse-grained subgrade of drainage layer. Filter layers prevent the clogging of pore spaces, maintaining the permeability of coarse-grained soil



Note: WAC 173-304 Requires Only the Barrier and Topsoil Layers.

Figure 4.39
Typical Layer Types in a Final Cover System

layers. The gradation of the filter aggregate is specified such that the pore spaces of the filter layer in contact with the erodible barrier or topsoil layers are small enough to prevent particles from being washed in or through them (Cedergren, 1977). Filter layers may consist of aggregate materials or synthetic geotextile fabrics, generally termed filter fabrics. Methods for designing and specifying either aggregate or geotextile filter layers are discussed in Appendix B.

4.16.1.4 Barrier Layer

The barrier layer serves two purposes. First, it significantly reduces the amount of precipitation infiltrating into the refuse, minimizing the amount of leachate generated. Second, it also prevents the escape of landfill gases through the cover except at controlled ventilation points.

The principal material characteristics required for barrier layer soils are low permeability and high moisture retention. The Minimum Functional Standards require a maximum permeability of 10-6 cm/sec for non-arid regions and 10-5 cm/sec for arid regions of the state. The minimum thickness required is two feet.

Natural soils, although most commonly used, are not the only materials available for a final cover barrier layer. Two other material applications include the addition of soil additives to an otherwise unsatisfactory natural soil and the use of flexible membrane liners.

To reduce the permeability of a proposed barrier layer, it is common to add bentonite. Bentonite is a commercially available clay that, when mixed with a base soil, can substantially reduce permeability. The advantage of using bentonite over natural clay is ease of handling; it is shipped in a dry, granular condition, and a small quantity is sufficient for a good seal. Soil tests will determine the appropriate amount of bentonite to be added to achieve the desired permeability. Normally the application rate is the range of 1.5 - 10.0 lb/ft?. Bentonite amendment of natural soils is discussed in greater detail in Sections 4.12 and 5.4.

The use of flexible membrane liners as a barrier layer in the final cover is also allowed under the Minimum Functional Standards. The same types of flexible membrane liners discussed in Section 4.12 would be suitable. There are no degrading effects caused by contaminants since the layer is not in contact with leachate. The minimum thickness required by the Minim Functional Standards is 50 mils.

4.16.1.5 Drainage Layer

The drainage layer improves the efficiency of the system by reducing rainfall percolation into the refuse. It provides a preferential path for lateral movement of infiltrated water beyond the boundary of the landfill prior to percolation through the barrier layer. It functions much like the collection layer in the leachate collection system (see Section 4.13).

The material used for the drainage layer must have a high permeability typically no less than 10^{-2} cm/sec and preferably in the range of 10^{-1} cm/sec. Such a material will likely be coarse-grained with very little (<1%) fines. The required thickness of the drainage layer can be evaluated using the methodology.described in Appendix E or the HELP model (see Section 4.10). It typically ranges from 1.5 - 2.0 feet.

A filter layer between the topsoil and the drainage layer will most likely be required because of the coarse-grained nature of the drainage layer and the fine-grained nature of the topsoil. Design of the filter layer is described in Appendix B.

4.16-1.6 Topsoil

The Minimum Functional Standards require at least six inches of topsoil be placed over the landfill. The purpose of the topsoil is to support vegetative growth, thereby providing wind and water erosion protection and preserving the integrity of the underlying layers.

If the topsoil is to support vegetative growth, it must have the appropriate texture and moisture holding capacity. Good topsoil is termed loam and consists of a well-balanced mixture of sand, silt and clay particles, as well as high organic content. Type A or B topsoil, as described in Division 9 of WDOT/APWA (1984), provide good guides to specifying suitable topsoil material.

Although the Minimum Functional Standards require only six inches of topsoil, greater depths may be specified. Two feet of topsoil would be optimum for support of grasses and ground covers (Gilham, et al., 1983). A thicker topsoil layer will better support vegetation and can reduce leachate generation from precipitation by increasing soil moisture storage capacity and evapotranspiration.

4.16.2 Design Procedure

4.16.2.1 Determining the Reguired Efficiency

Lined and unlined landfills have very different requirements for final ' cover. Lined landfills collect, treat and dispose of leachate in a manner that does not endanger the receiving water body. Thus, the efficiency of the final cover is important only in determining how much leachate has to be treated. However, for unlined landfills, the final cover may be the only element preventing the degradation of receiving water quality by reducing the amount of leachate generated. Therefore, the efficiency of a final cover for an unlined landfill will have to be high enough to prevent the violation of ground water performance standards.

Lined Landfill. The lined landfill does not depend on the final cover for protection of ground water quality. The selection of a final cover design in this case is usually based upon the results of in economic analysis comparing the costs and efficiencies of various designs (standard, alternate or others).

The efficiency of the various designs is calculated by water balance methods described in Section 4. 10. The results of these calculations are then used to size the leachate treatment facilities and to determine treatment and disposal costs. Total present value costs are then determined for the following:

- Final cover capital costs
- Final cover annual operations and maintenance costs
- Leachate treatment and disposal facility capital costs
- Leachate treatment and disposal facility annual operations and maintenance costs

The present value of each alternative is then compared and the most economical alternative is chosen.

<u>Unlined Landfill.</u> The controlling factor for an unlined landfill will be the ability to meet ground water compliance standards as promulgated in the Minimum Functional Standards. In this case, use of the standard final cover design (see Figure 4.39) may not reduce the volume of leachate generated to an amount that will prevent ground water performance standards from being exceeded. To design a satisfactory final cover, the following steps may be taken:

1. Calculate the leakage through the standard cover design using the water balance techniques discussed in Section 4.10.

2. Calculate the concentration of constituents at the point of compliance using appropriate ground water solute transport modeling techniques.

3. If predicted concentrations are less than performance standards, the standard cover should be adequate. An appropriate safety factor should be used due to uncertainties associated with modeling (doubling leachate volumes or concentrations is suggested unless site specific data is available to allow calibration and verification of the models used).

4. If predicted concentrations, including an appropriate safety factor, are greater than performance standards, the designer should evaluate other final cover designs including the alternate design or a design including a drainage layer and/or a lower permeable barrier layer.

5. If two or more final cover designs are found to meet the ground water performance standard criteria, then cost estimates can be prepared and the most economical design selected.

As with any application of mathematical models, the level of accuracy of the predictions is increased through the use of more complex models and more site specific data. However, the cost of modeling escalates rapidly as more complex models are used and more data is required. Extensive modeling efforts should only be undertaken when the results can be economically justified. For example, a $100,000 modeling study may be justified if the results could potentially save $1,000,000 in capital construction costs of the cover.

4.16.2.2 Use of Runoff

Runoff is a major component of the hydrologic cycle that reduces the amount of precipitation infiltrating into the waste. As discussed in Section 4.8, runoff can be considered excess precipitation after all other demands have been met. These demands include:

- Interception
- Depression storage and ponding
- Evaporation from the surface
- Infiltration

Interception and evaporation from the surface are variables over which the designer has little control. Depression storage and ponding are limited by specifying a minimum slope of 2%, although slopes of 5% are often used to allow for differential settlement. Infiltration is the major contributor to leachate generation. Therefore, the reduction of infiltration, with the consequent increase in runoff, should be an objective in the design of the final cover.

Infiltration is the movement of water through the soil surface into the soil matrix (Linsley, et al., 1982). The rate at which water enters the soil from surface storage is a function of the permeability of the soils and subsoils, soil moisture, vegetative cover, temperature and possible other parameters (Novotny and Chesters, 1981). of these functions, the designer has control Over permeability. The effectiveness of permeability in significantly increasing runoff is dependent upon climate, as discussed in the following paragraphs.

Non-Arid Region. The Minimum Functional Standards require a permeability no greater than 10-6 cm/sec for the soil barrier layer. Infiltration may be reduced, and runoff increased, if the permeability were decreased further toward the range of 10-7 to 10-8 cm/sec. Such permeabilities can be achieved with some natural soils with high clay content. More often, it is necessary to amend a natural soil with sodium bentonite to reach very low permeabilities (see Section 4.12).

The use of a flexible membrane liner as a barrier layer will essentially eliminate percolation into the solid waste and will decrease infiltration and increase runoff. The cost effectiveness of either of these options should be investigated prior to implementation. This can be done using the models discussed in Section 4.10. Often times, it becomes very costly to achieve only a small decrease in leachate production.

Arid Region. The Minimum Functional Standards require a permeability of no greater than 10-5 cm/sec for the soil barrier layer. However, because of low average precipitation in an arid climate, infiltration may not be a limiting factor. Thus, although the permeability of the barrier layer could be decreased below 10-5 cm/sec, the effect may not be significant in decreasing infiltration and increasing runoff.

Slope. The Minimum Functional Standards require that the final cover have a slope between 2 and 33 percent. A common misconception is that steeper slopes will increase the volume of runoff. It can be shown that within reasonable limits, slope has little effect on the volume of runoff. However, it does have a significant effect on the rate of runoff and the shape of the runoff hydrograph. Decisions concerning final cover slopes should be made based on surface water managements needs, erosion control and access for construction equipment.

4.16.2.3 Use of Evar)otransr)iration

Evapotranspiration is the removal of water from the soil matrix through evaporation and plant transpiration. Water removed by evapotranspiration is unavailable to percolate into the solid waste to become leachate. Also, removal of water from the soil matrix creates more moisture storage capacity for the next infiltration event. Water stored in the soil is not available for leachate generation.

Although evaporation occurs from the soil surface and within the top few inches, the majority of water leaves the soil through transpiration from plants. To maximize evapotranspiration the following steps are recommended:

- Topsoil should be a loam-type material with high organic content
- Preferred depth to a barrier layer is at least 24 inches to allow for full plant root development
- Seed completed areas as soon as conditions permit

Loam soil with a high organic content provides the best medium for good vegetative growth. This type of soil allows development of a dense root system and has excellent moisture storage capacity. A depth of 24 inches allows roots to develop to their maximum potential depth and remove water from well below the soil surface.

Evapotranspiration is a seasonally varying phenomena and in evaluating its effect on reducing leachate generation, it is important to note that monthly potential evapotranspiration is lowest when typical Washington climatic conditions are wettest (November - February). Methods to evaluate evapotranspiration on a monthly basis are described in Section 4.10.

The Minimum Functional Standards require only six inches of topsoil and they do not specify the quality of that topsoil. Experience has shown that vegetation can be established using these criteria. The recommendations presented above are based on accepted horticultural practices and may not be cost effective in reducing leachate generation.

4.16.2.4 Use of Soil Moisture Storage

Soil moisture storage is a term used to describe the volume of water that can be held in a given amount of soil. The effective soil moisture storage volume is commonly determined by calculating the difference between field capacity (moisture content of soil after gravity drainage is complete) and the wilting point (moisture content when plants cannot extract water from the soil) of the soil (Linsley, et al., 1982). Typical moisture values are given in Table 4.15.

Table 4.15. Typical Moisture Values for Various Soil Types.

	Percent Dry Weight of Soil			Specific Weight (lb/cf)
Soil Type	Field Capacity	Wilting Point	Available Water	dry
Sand	5	2	3	95
Sandy loam	12	5	7	90
Loam	19	10	9	85
Silt Loam	22	13	9	80
Clay Loam	24	15	9	80
Clay	36	20	16	75
Peat	140	75	65	25

Source: Linsley, et al. (1982)

Soil moisture storage and evapotranspiration are considered complementary when designing a final cover system. Without evapotranspiration, soil moisture is of little importance since if the water is not removed, it will eventually percolate into the solid waste. The removal mechanism is evapotranspiration. However, to take full advantage of evapotranspiration, an adequate available water capacity must exist.

The available moisture capacity is a function of the depth and quality of the soil. Effective depth is determined by the depth of the root zone. As discussed in the previous section, two feet for the root zone is a reasonable design criteria. Topsoil quality is also very important. As can be seen from Table 4.15, equal depths of topsoil can easily vary in their available moisture capacity by as much as 200%. Loam (approximately equal parts of sand, silt and clay) provides the best combination of soil texture and available moisture capacity. The available moisture capacity for peat illustrates the value of amending topsoil with organic matter to improve its available moisture capacity. It can be shown using the values in Table 4.15

that amending loam with 20% by volume of organic material increases the available moisture capacity of a six inch deep layer from 0.7 inch to 1.0 inch, or an increase of 33%. Amendment with organic material also improves the texture of the soil for better vegetative growth.

The use of soil moisture storage and evapotranspiration to reduce leachate generation appears to be particularly valuable in arid regions. Increasing soil depth and available water capacity has significant impacts on the water balance because it causes actual evapotranspiration to approach the high potential evapotranspiration rates typical for this climate.

Amendment with organic material has been shown to be an effective method for increasing the available moisture capacity of the soil. The organic material need not be horticultural peat moss, which would be prohibitively expensive, but could include a number of materials including yard waste compost or sewage treatment plant sludge.

4.16.2.5 Use of Interflow

Interflow is that portion of water infiltrating the soil surface and moving laterally due to the lower permeability of the underlying subsoils (Novotny and Chesters, 1981). A final cover system can be designed to enhance and take advantage of this phenomena.

Water that has infiltrated the soil will either be evapotranspirated, percolate through the barrier layer, be temporarily held in storage, or move as interflow laterally beyond the boundary of the barrier layer. The interflow component can be enhanced through proper design of an intermediate, lateral drainage layer between the topsoil and the barrier layer. The basic requirements of this layer include a permeability significantly greater than the barrier layer (preferably greater by at least four orders of magnitude) and adequate thickness to pass the flow. Various design alternatives can be investigated using either the HELP model (Section 4.10) or Wong's Method (Appendix E). Recent field studies have verified the effectiveness of a drainage layer; measured volumes showed that the interflow component diverted approximately ten times as much water from leachate production as did surface runoff (Peters, et al., 1986).

Unsaturated flow conditions within the topsoil, drainage and barrier layer of the final cover may cause moisture movement in unexpected ways. Specifically, if the pore size of the drainage layer is significantly larger than the overlying topsoil, moisture movement into the drainage layer may be impeded for reasons discussed in Section 8.3. Specification of the drainage layer material should recognize this fact and ensure a gradual transition of soil pore size. Field pilot studies may be appropriate to ensure the design will perform as expected.

4.16.3 Design Alternatives

4.16.3.1 Standard Design

The Minimum Functional Standards specify a standard design for a solid waste landfill final cover in non-arid regions of the state. This design includes a two foot thick barrier layer with a maximum permeability of 10-6 cm/sec and six inch thick layer of topsoil (Figure 4.39). See Section 4.12 for a more detailed discussion of low permeable soil liners.

4.16.3.2 Alternative Design

As an alternative to a soil barrier layer, the Minimum Functional Standards allow the use of a flexible membrane liner at least 50 mils thick. The polymeric material is not specified and therefore a number of types are available including:

- Polyvinyl Chloride (PVC)
- Chorosulfonated Polyethylene (Hypalon)
- High Density Polyethylene (HDPE)

It should be noted that many liner materials are not readily available in sheets at least 50 mils thick. The notable exception is HDPE, which is readily available in a 60 mil thick sheet. If other materials are desired, either special arrangements would have to be made with the manufacturer or a variance allowing a thinner liner would have to be approved by the jurisdictional health department and Ecology. Additional information on flexible membrane liners is provided in Section 4.12.

4.16.3.3 Arid Design

The arid design is the same as the standard design, except the maximum allowed permeability for the barrier layer is increased to 10- cm/sec. This design is permitted only in areas where the average annual precipitation is less than 12 inches.

4.16.3.4 Other Designs

The designs specified in the Minimum Functional Standards represent minimum standards only. Other designs that meet or exceed the specifications of the Minimum Functional Standards may be appropriate in some situations. Modified designs may be evaluated using the water balance methods described in Section 4.10.

Modifications may include, but are not limited to, the following:

- Inclusion of an intermediate drainage layer
- Decreasing the permeability of the barrier layer

- Increasing the thickness of the barrier layer
- Increasing the thickness of the topsoil layer
- Specifying the quality and texture of the topsoil layer
- Amending the topsoil with organic matter

4.16.4 Establishing Vegetative Cover

The importance of establishing a good vegetative cover has been discussed previously. The solid waste landfill environment imposes some abnormal stresses on vegetation, most significantly, the shallow depth of topsoil, high density compacted layers near the surface, poor quality topsoil and the presence of methane and other gases in the root zone. Some of these stresses can be eliminated or reduced by proper design. To mitigate the effects of these stresses, more tolerant plant species can be selected and special consideration can be given to the landscaping effort.

Vegetating solid waste landfills successfully requires careful planning. The following steps are recommended (Gilham, et al., 1983):

1. Select an end-land use
2. Determine depth of cover
3. Establish an erosion control program
4. Determine soil nutrient status
5. Determine soil bulk density
6. Amend soil cover
7. Select landfill tolerant species
8. Plant grass and ground covers

Selection of an end-land use will determine the type of landscaping program required. Common uses are open spaces and parks.

The depth of cover is important to the survival of plants. It is necessary to allow for adequate *root development and moisture holding capacity. Recommended depths for grasses is two feet, although six inches is the required minimum.

Soil tests should be taken for pH, nutrients, organic matter content and bulk density. Soils can be amended with fertilizers, lime and organic matter to make up deficiencies. Compacted soil should be scarified and amended with organic matter.

During the life of the landfill, a test plot should be planted with appropriate local species. The results of this study can be used to select the most successful species for seeding of the final cover as the landfill is completed. If such information is not available, typical roadside erosion control seed mixtures have proven to be successful.

Hydroseeding is the most common method of seeding. Fertilizer can be applied at the same time as the seed. Mulch and tacking compound should be spread over the seed to hold it in place until germination. Mulch also reduces near surface soil moisture loss and helps to establish healthy vegetation growth. In addition, the mulch and tacking compound provide temporary erosion control until the vegetation becomes established.

Timing of hydroseeding operations is also critical to their success. Best results are achieved in the spring or fall. Local businesses experienced in hydroseeding will be able to recommend optimum times for hydroseeding.

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APPENDIX 4A

FIELD EXPLORATION AND TESTING METHODS

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APPENDIX 4A

FIELD EXPLORATION AND TESTING METHODS

A wide variety of field exploration methods is available to assess the conditions beneath a potential landfill site. These include relatively inexpensive field reconnaissance and mapping methods to more costly drilling and sampling methods. Some of the more common methods are discussed below.

4A.1 FIELD RECONNAISSANCE AND MAPPING

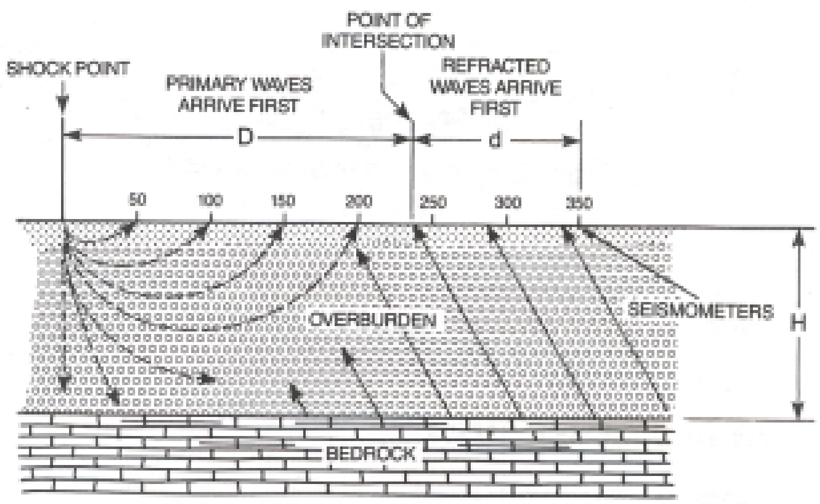
These studies consists of visually observing site conditions and plotting significant site features on base maps. A major purpose of the field reconnaissance is to determine the accessibility of the site for drilling and testing equipment. Factors critical to site access include: road conditions, location of structures and utilities, soil conditions and drainage, vegetation density, and site topography. The site reconnaissance provides an opportunity to field check and update preliminary site data, and to establish current site conditions prior to planning a subsurface testing program.

In addition to establishing current site conditions, the field reconnaissance can be expanded to include mapping of key site features. For example, rock outcrops and soil exposures in road cuts can be examined and plotted in a site base map, and evaluated in conjunction with regional geological reports to provide a geologic map of the site. Sources of existing geologic information include the Soil Conservation Service, United States Geological Survey, and Washington State Water Supply Bulletins. Specific detailed mapping efforts (soil series, vegetation, topography, etc.) commonly require a number of separate site surveys. Obvious geologic hazards can also be identified during the reconnaissance.

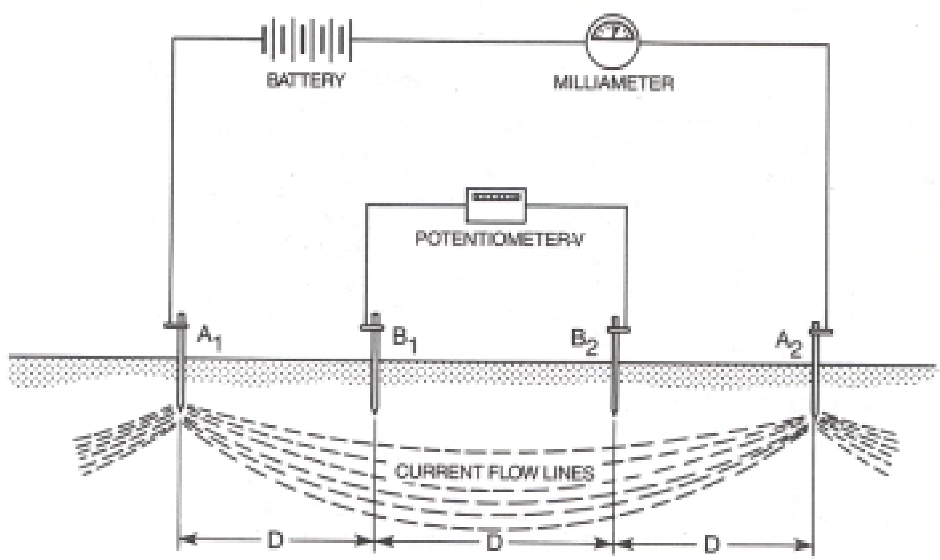
4A.2 SURFACE GEOPHYSICS

Surface geophysical methods provide an indirect means of evaluating subsurface conditions without drilling. The methods are generally less costly than drilling, but they can have limitations in providing reliable data, depending on specific site conditions. Seismic and electrical methods are most commonly used. They can be used to assist in developing a drilling program, especially during early phases where drilling rig access may be poor.

Seismic Surveys involve using the mechanics of energy wave travel through the subsurface to determine depths, general types and the thickness of subsurface strata. Seismic refraction, shown in Figure 4A.1 is the method most applicable to landfill site investigations, and is usually employed to determine the depth to bedrock or very dense strata (such as glacial till) beneath overlying, less dense unconsolidated geologic deposits. The seismic refraction method consists of an energy source (hammer and steel plate, weight drop, or explosive charge) that directs an energy wave into the earth,



Seismic Refraction Method



Electrical Earth Resistivity Method

WDOE Solid Waste

Adapted From: Acker, 1974

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Figure 4A.1
Schematic Diagrams Showing Seismic Refraction and Electrical Earth Resistivity Methods

and receiving units (geophones) which detect the returning energy wave at various distances from the source. More detailed discussions of seismic methods are found in geophysical texts (see Zohdy, et al., 1974).

The success of a.seismic survey depends, to a great extent, on the subsurface conditions beneath the site being investigated. In areas where the contact between subsurface layers is irregular or the strata do not exhibit sufficiently different seismic velocities, seismic results are difficult to interpret. Seismic data must be correlated with borehole information to be useful in extended geologic information over broad areas.

Electrical Earth Resistivity Surveys probe subsurface conditions by measuring the resistance of an electrical current through the earth. A typical electrical earth resistivity system (the Wenner electrode configuration) is shown in Figure 4A.1. *The resistance (reciprocal of electrical conductance) of earth materials depends on the mineralogy of solid earth materials and the chemical composition of fluids in the pores between the solid particles. An electrical earth resistivity system directs electricity into the ground via current electrodes and measures the return current with potential electrodes utilizing a variety of electrode arrays.

Electrical earth resistivity at landfill sites can be used in two ways:

- To define subsurface strata
- To detect and monitor plumes of contaminated ground water

Analytical techniques involving comparison of graphical data plots with theoretical type curves can be utilized to determine depths And thicknesses of geologic strata (Zohdy, et al., 1974).

As is the case with all surficial geophysical methods, the success of electrical earth resistivity depends on subsurface conditions beneath the site. Shallow, conductive (low resistance) conditions, such as clay layers, the water table, or buried metal objects can "short circuit" an electrical earth resistivity system and render interpretation of results difficult. As with seismic data, electrical earth resistivity data must be correlated with borehole information to be useful in extending geological information over broad areas.

Additional surface geophysical methods which can potentially provide subsurface information at landfill facilities include magnetic surveys, gravity surveys, and ground penetrating radar surveys. Magnetic and gravity surveys generally have been applied to evaluate regional geologic settings. A typical application for ground penetrating radar is locating the presence of buried materials. A brief description of these methods is included below.

Magnetic surveys detect the strength of the earth's magnetic field, which is affected by subsurface bodies of rock and buried metallic objects (Zohdy, et al., 1974). This technique can define the bedrock surface for geological interpretation, and detect buried objects such as metal drums.

Gravity surveys detect the strength of the earth's gravity field, which is affected by contrasts in density between subsurface materials of various types (Zohdy, et al., 1974). This type of survey is a valuable tool in investigating regional features such as depth to bedrock, old erosional features on bedrock, and buried intrusive (volcanic rock) bodies.

Ground penetrating radar is a geophysical technique directing very high frequency electrical impulses into the ground and detecting the return signals with an antenna. The source and receiving unit are pulled over the ground or floated on a raft, and large areas can be covered in a short time.

4A.3 TEST PIT

Test pit excavations are a method of directly observing near surface strata. Such pits, commonly excavated with a backhoe, are large enough for easy and safe access to the pit walls. Disturbed soil or rock samples may be easily obtained but the technique is limited by soil conditions and the capability of the backhoe (typically 8 to 12 feet). Loose soils or soils beneath the water table tend to cave in. It is usually not economical to conduct a full exploratory program by means of test pits; however, direct test pit inspections of an extremely variable subsurface formation may furnish a more valid impression of its nature than can be obtained from many borings (Peck, et al., 1974).

4A.4 TEST BORINGS

Test borings consist of individual boreholes dug into the earth by hand auguring or by drilling rigs which advance the hole and transport the resulting cuttings to land surface. Completed boreholes are commonly converted into test wells; those which are not should be' properly sealed by backfilling with appropriate materials. A variety of drilling methods has been developed for installation of boreholes, the most common of which are discussed below. Detailed discussions of drilling methods have been completed by various authors (Acker, 1974; Johnson, 1966; Campbell and Lehr, 1973). Detailed comparison of the relative advantages and disadvantages of each method are discussed by Fenn, et al. (1975) and Scalf, et al. (1981).

Hollow-Stem Auzer Method advances the borehole by means of a rotating auger which carries the drill cuttings to land surface via the screw action of the auger flighting. The hollow stem (interior) of the auger allows core samples to be taken through and ahead of the auger into undisturbed natural materials. Soil sampling is typically conducted using a barrel type sampler. These types of samplers consist of a steel barrel driven into the soil to be sampled. The sampler is extracted from the boring and the sample is opened by either splitting the barrel lengthwise (split spoon) or by pushing the sample from the barrel (Shelby tube).

During sampling, the relative densities of each material can be assessed by conducting the Standard Penetration Test (American Society Testing and Materials (ASTM) D1586 Test Method). This procedure drives a standard split spoon sampler into soil using a standard technique. The number of blows required to drive the sampler a specified distance is termed the Standard

Penetration Resistance. This resistance or blow count, provides a measure of the relative density of granular soils and consistency of cohesive soils.

Small diameter monitoring wells can also be installed through the hollow stem. The augers would be removed during well completion. Hollow stem auger drilling is illustrated in Figure 4A.2.

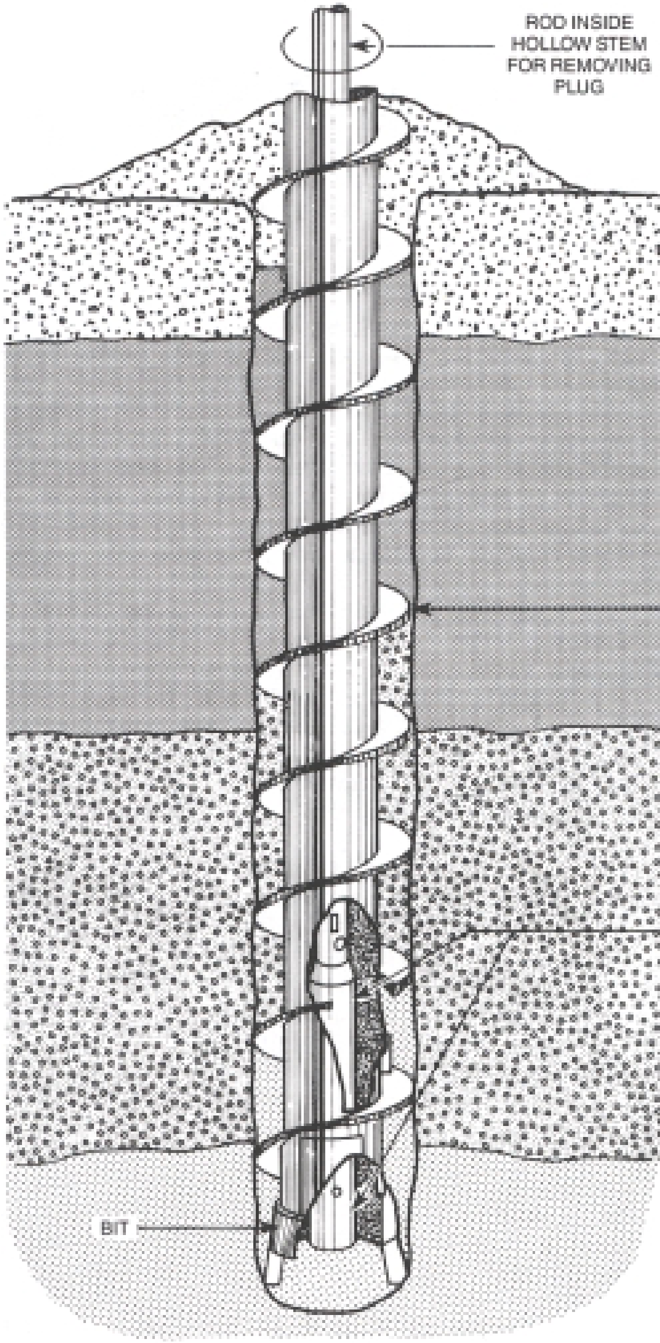
The hollow stem auger is best suited for drilling in unconsolidated materials to depths of approximately 100 to 150 feet. Auger drilling rigs are small and portable, can be mounted fairly easily on tracked vehicles, and are relatively inexpensive to operate. In addition, drilling fluids are not normally used, minimizing contaminated problems. Drilling depth limitations of the hollow stem auger method are a result of increased friction with depth and heaving of sand into the hollow stem during core sampling under shallow water table conditions. Hollow stem auger machines can be limited where hard earth materials such as rock formations or unconsolidated formations containing coarse gravels or boulders are present4

Air Rotary drilling machines use air as a drilling fluid to carry cuttings out of the boreholes. The hole, shown in Figure 4A.3, is advanced by rotating drilling rods with a bit at the end of the drills stem. As the bit cuts the hole, air circulating down the rods through the bit carries the cuttings up the borehole to land surface. This continuous flow of cuttings constitutes the geologic samples of the formations penetrated. Additional data regarding the nature of the earth materials can be obtained by noting the relative penetration rate of the drilling system.

Air rotary drilling is particularly well suited for hard rock formations or where boulders are present, and provides the most' rapid penetration rates in these situations. If only air is used (foam additives are available to aid in cutting removal), contamination during drilling is minimized. The air rotary return circulation also allows observation of relative ground water production of the hole as it is drilled (water is lifted to the surface if encountered). Open hole air rotary drilling is not applied to soft, unconsolidated formations which are prone to borehole collapse, although casing hammer attachments, which drive casing during drilling, can solve this problem.

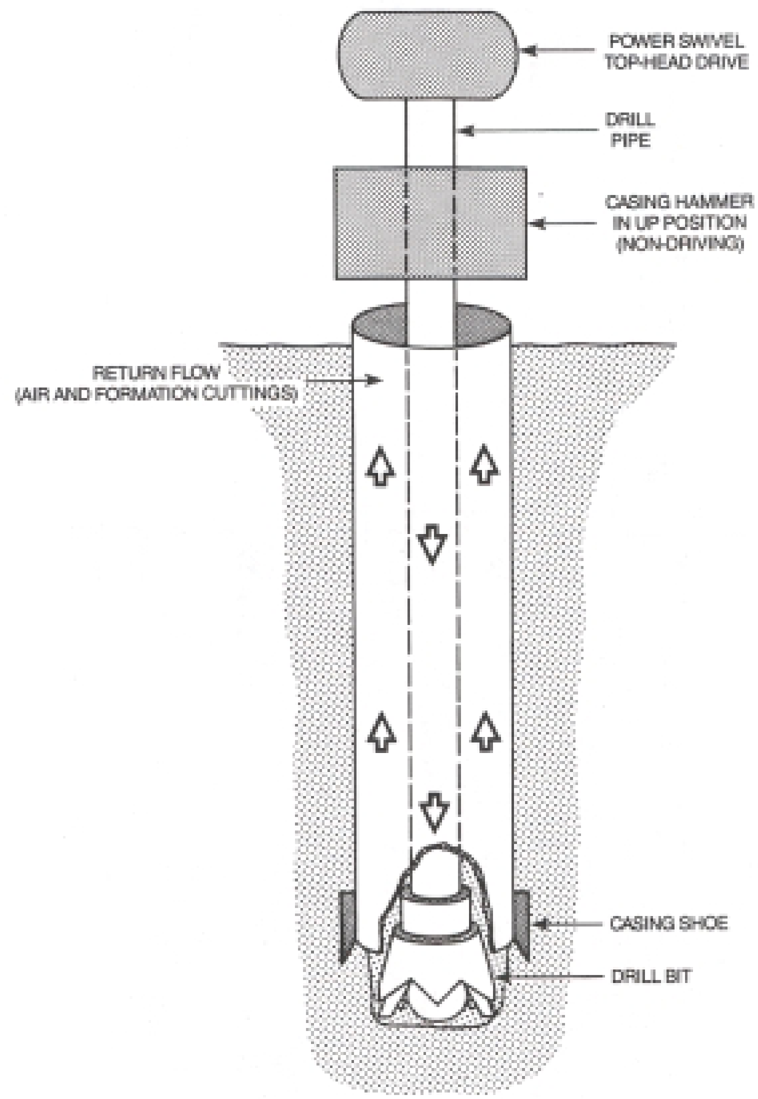
Air rotary rigs are expensive to operate, since both the rotary drive and air compressor must be powered. Barrel type samples may also be used with the technique but sampling may be costly since the drilling rods need to be removed prior to sampling.

Mud Rotary Method, as shown in Figure 4A.4, uses a liquid drilling fluid (mud) to transport drill cuttings to land surface and at the same time to keep the borehole open. Drilling mud is commonly composed of bentonite, a clay mineral, although many natural and man-made additives have been developed to perform specific downhole functions. The drilling mud is circulated down the rotating drill rods through the bit and carries cuttings generated by the bit into a pit at land surface. The cuttings are the geologic samples of the formations penetrated and can be collected in the mud discharge with a strainer. The drilling mud keeps the borehole open by means



Adapted From: Scalf et al., 1981

Figure 4A.2
Hollow-Stem Auger Drilling System



Adapted From: Scalf, et al., 1981

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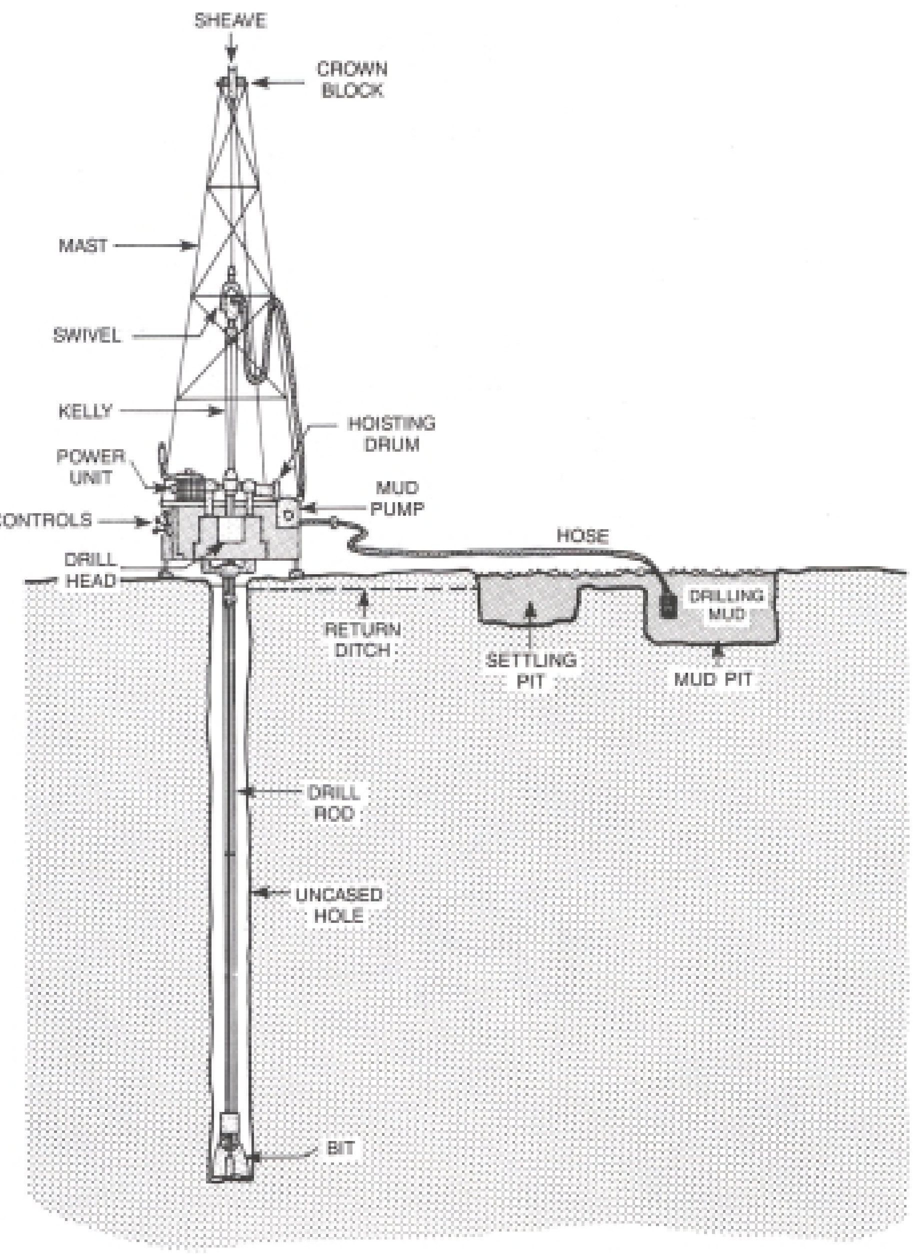
Figure 4A.3
Air Rotary Drilling System With Casing Hammer



Adapted From: Davis and DeWiest, 1966

Figure 4A.4
Mud Rotary Drilling System

of the hydraulic pressure of its weight, while at the same time mud loss is prevented by the formation of a mud cake on the borehole walls.

The mud rotary method is capable of drilling in all formations to great depths. Casing, not required during drilling, can be set and cemented after the borehole has been completed. Mud rotary rigs are fairly inexpensive to operate and can be adapted to obtain core samples in the mud borehole. The primary disadvantage of the mud. rotary method is the drilling fluid, which can infiltrate and potentially contaminate vaterbearing formations. Moreover, the fluid must be thoroughly purged from all wells installed by this method. Some drilling compounds can also cause the drilling mud to be designated as a dangerous waste under Washington State law (WAC 173-303). Drilling fluids can also cause problems if the wells are to be used for water quality sampling. Subsurface hydrologic information is limited with the mud rotary method, unless the borehole can be cleaned and a temporary well installed.

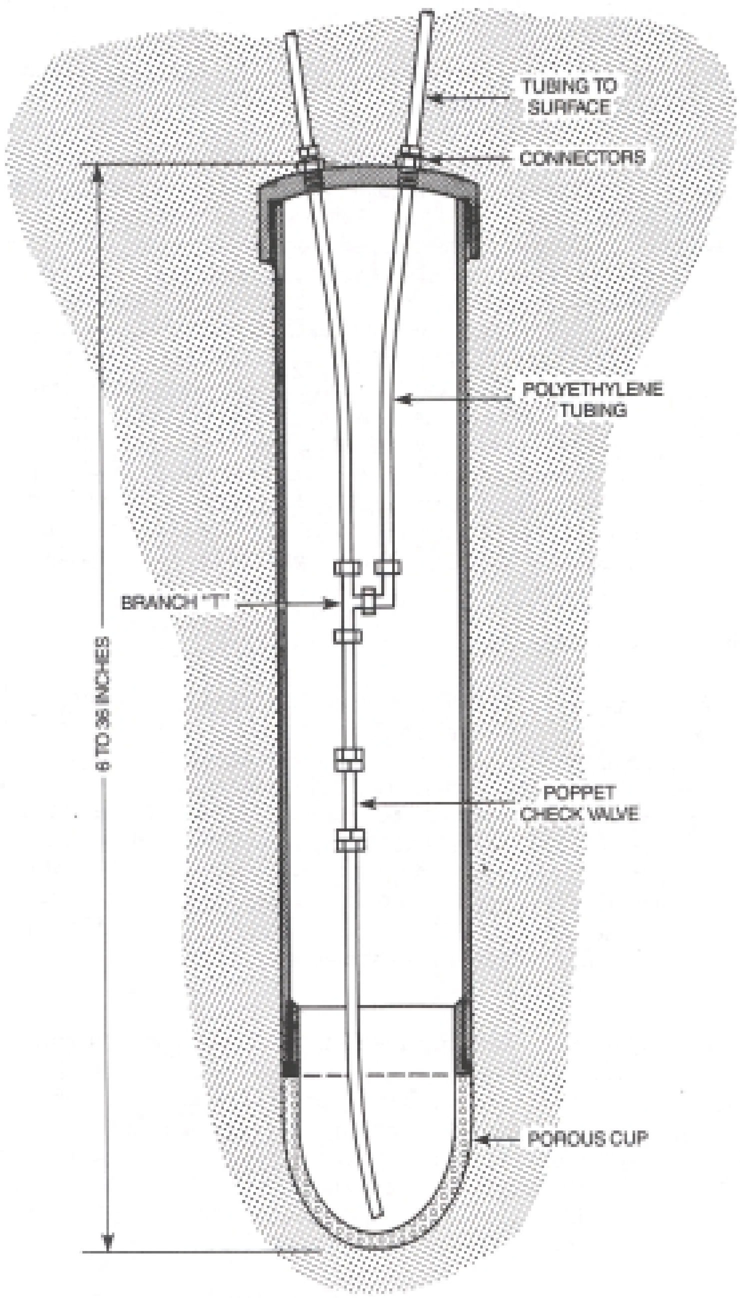
Cable Tool Method (Churn-drill), illustrated in Figure 4A.5, consists of a heavy chisel type drill bit that is alternately raised and lowered by a cable and walking beam. Cuttings created by the bit penetration are periodically removed from the hole with a bailer. Water must be added in dry holes to suspend drill cuttings in a slurry, which then can be bailed out of the hole. These cuttings constitute the geologic samples of the formations penetrated. Barrel type samples may be used to obtain relatively undisturbed samples. Casing is driven behind the hole to keep the hole open.

The cable tool system can operate in all formations, but drilling is extremely slow in hard strata. Since the hole is progressively cased with depth, earth materials samples and water samples can be collected from discrete intervals during drilling. Casing driven during drilling must be pulled back during well installation to expose the vaterbearing formation. Cable tool drilling is relatively inexpensive, but the drilling can require significant amounts of time in dense materials.

Other drilling methods potentially useful in landfill site investigations include hand augers, bucket augers, wash borings, and well points. Hand augers are useful in obtaining soil samples from shallow depths (5 feet or less). Bucket augers advance large diameter (greater than one foot) holes by directly excavating an open hole with a large rotating bucket. Wash borings are small diameter (1.5 to 2.5 inch) boreholes advanced by water-jetting with a small chisel bit. Well points are small diameter perforated pipes which are driven into waterbearing formations with a hammer and/or water-jet mechanisms. These specialized drilling methods can be applied to site investigations under certain conditions, but are not as common as the drilling methods discussed in the previous sections.

4A.5 BOREHOLE GEOPHYSICS

Geological information from test borings can be supplemented by geophysical logging methods. Probes attached to specialized detectors can be lowered into a borehole to yield data which can be interpreted to determine mineralogy, geometry, resistivity, bulk density, porosity, permeability



Adapted From: Fenn et al., 1977

Figure 4A.6
Modified Pressure-Vacuum Lysimeter Installation

(hydraulic conductivity), and moisture content. Some of these methods work only in specific borehole conditions.

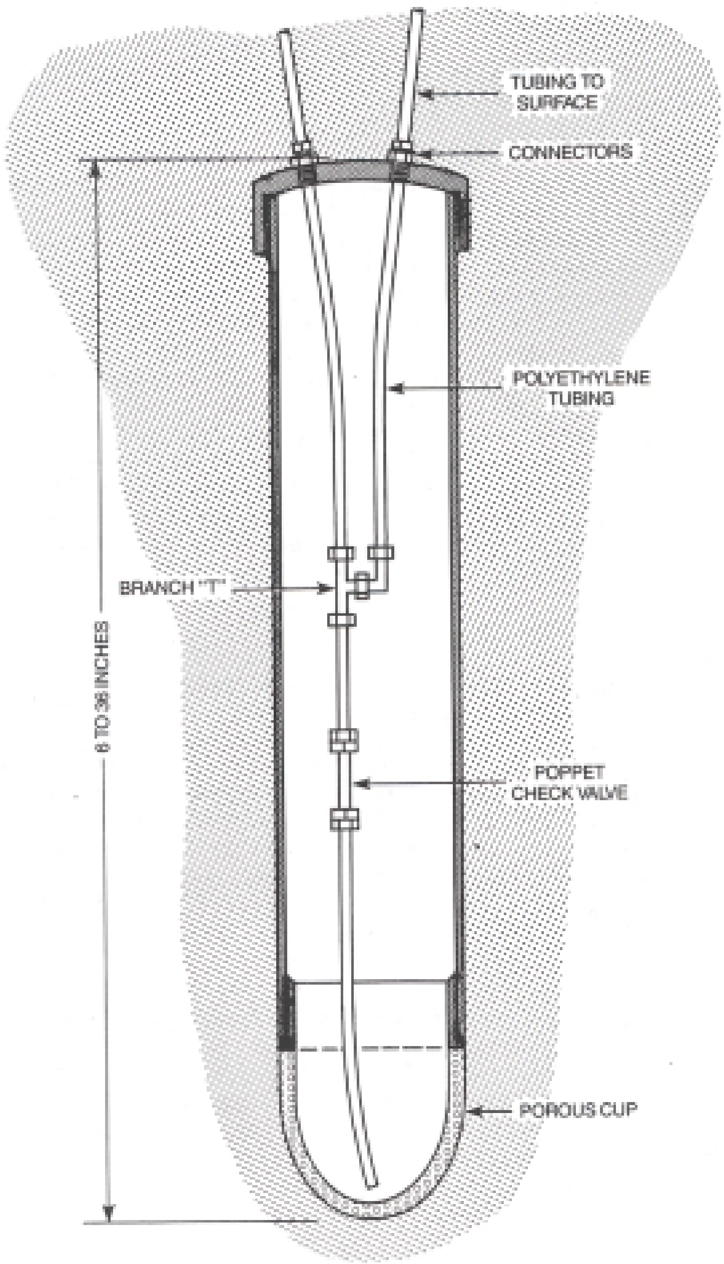
The most common borehole logs include: spontaneous potential, normal resistivity, natural gamma, gamma-gamma, caliper, temperature, and fluid conductivity (Scalf, et al., 1981). Spontaneous potential logs record the natural electrical potential developed between the borehole fluid and formation, and they are used mainly for geologic correlation of non-porous versus porous rocks. Normal resistivity logs measure the apparent resistivity of a volume of formation and help determine the types of geologic material (i.e., sands, clays, gravels, etc.). Natural gamma logs record the amount of background gamma radiation while gamma-gamma logg measure the radiation returned from a source in a probe after the radiation has penetrated the formations. Both types of gamma logs are used in identifying the lithology and the gamma-gamma log can measure both density and porosity. Caliper logs measure borehole diameter; temperature logs provide a continuous record of fluid temperature; and fluid conductivity logs measure the conductance of the borehole fluid. These logs help to identify rock types in conjunction with other data.

4A.6 TENSIOMETERS/PRESSURE VACUUM LYSIMEMS

Tensiometers and lysimeters are devices used to collect geohydrologic data in the vadose zone which lies above the water table (vadose zone monitoring is further discussed in Chapter 8). Tensiometers allow measurement of hydraulic head, in this case "negative pressure," in the vadose zone. A tensiometer consists of a porous cup attached to an air-tight, water-tilled tube. The porous cup is inserted into the soil at a specified depth where water from the tube passes through the cup into the soil until equilibrium is reached. The vacuum measured at the top of the air-tight tube is a measurement of the pressure head in the soil, which is a tension (negative) head in the unsaturated zone. Details of tensiometers are discussed in Freeze and Cherry (1979).

Pressure vacuum lysimeters are predominantly used to collect water samples from the vadose zone, although they can also collect samples if the zone becomes saturated. This device consists of a porous cup, sample accumulation chamber, and two sampling tubes leading to land surface (Figure 4A.6). A vacuum is applied to induce soil moisture to flow into the cup, the vacuum is released, and pressure is applied into the cup to force the accumulated water to land surface. Specific aspects of pressure vacuum lysimeter installation and operation are described by Fenn, et al. (1975).

Infiltrometer Tests measure the saturated hydraulic conductivity of near surface soils in the field. The double ring (cylinder) infiltrometer, commonly used to conduct such tests, is illustrated in Figure 4A.7. The inner ring is driven about 6 inches into the soil, and the outer ring is driven about 2 inches into the soil (U.S. EPA, 1977a). The "buffer zone" provided by the outer ring is designed to minimize the lateral flow in the soil, such that the measured flow is totally vertical. After the soil in



Adapted From: Fenn et al., 1977

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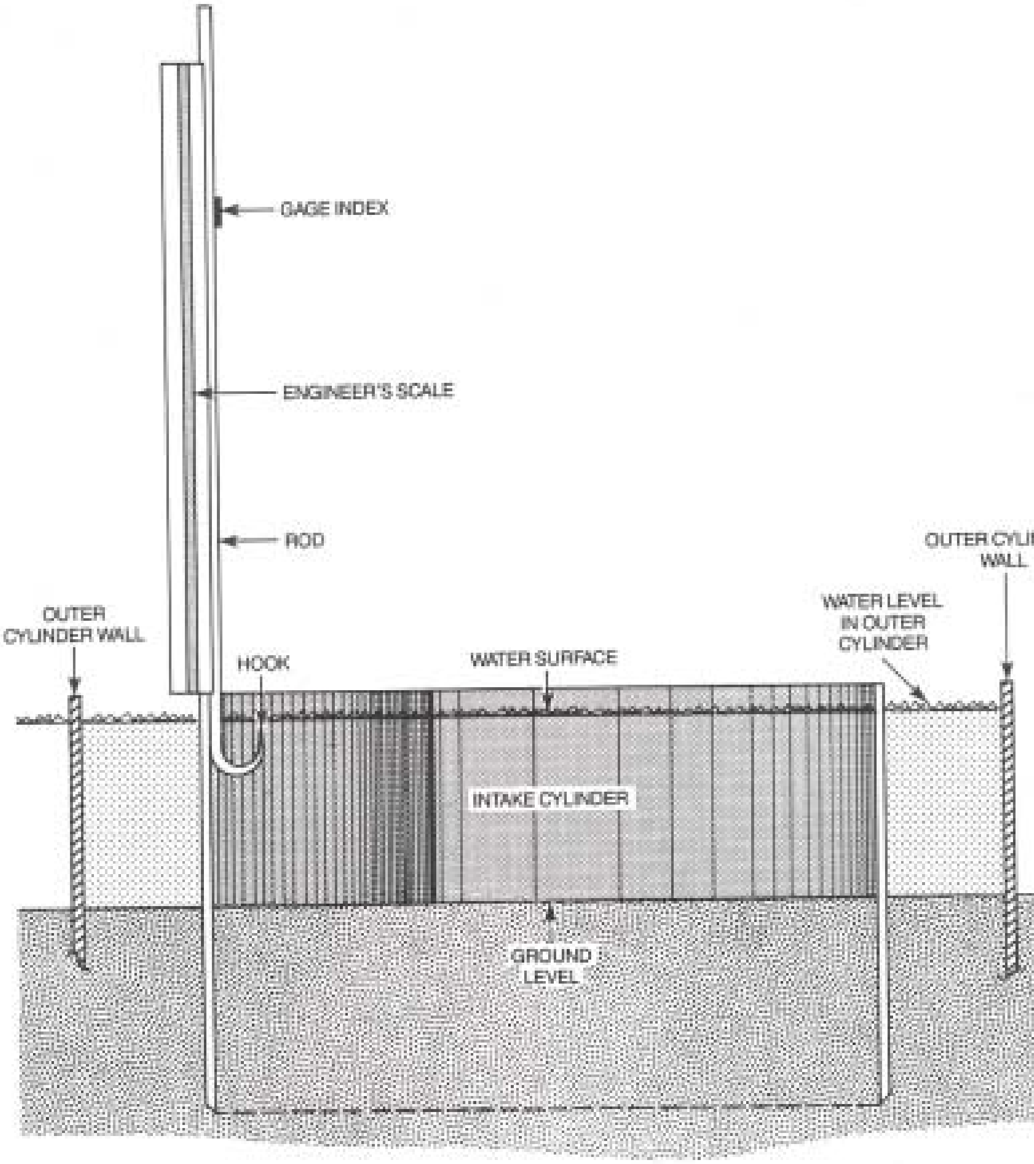
Figure 4A.6
Modified Pressure-Vacuum Lysimeter Installation



Adapted From: U.S. EPA, 1977

Figure 4A.7
Double-Cylinder Infiltrometer

both rings has been saturated long enough, the drop in water level in the inner ring is measured, while keeping the water in the outer just above the soil surface. The major factors in obtaining meaningful results in this test are homogeneity of the soil allowing the infiltration rate to reach steady state conditions and obtaining measurements while the water is "Just ponded" inside each ring.

4A. 7 HYDRAULIC REA (WATRR UKVEL) MEASUREMMS

Before representative hydraulic head measurements or groundwater samples can be obtained, monitoring wells must be properly completed and developed to assure adequate hydraulic connection between the well and surrounding waterbearing formation. Hydraulic head measurements can be made with a number of devices, the more common of which are chalked tapes, electric sounders, steel tapes with poppers, and automatic water level recorders (U.S. Department of the Interior, 1977).

Hydraulic head measurements can be made using a steel tape graduated to the nearest 0.01 foot. The end of the tape is chalked and lowered into the well. Upon hearing the weight break the water surface, the tape is held even with a labeled measuring point on the well (usually at the top lip of the well casing). The tape is pulled out of the well and the length of chalk washed off the submerged line is subtracted from the number at which the tape is held, the difference being the depth to water. Depths to water determined in this manner can be accurately measured to the nearest 0.01 foot. The chalked tape method is difficult to employ in the rain and in pumping wells in which water surging into the well bore washes the chalk off the tape.

A steel tape can also be equipped with a "popper", a metal cylinder I to 2.5 inches in diameter and 2 to 3 inches long with a concave undersurface. The popper is raised a few inches and then dropped to hit the water surface with a distinct "pop". By holding the tape relative to the measuring point on the well casing, the depths to the water surface can be measured. Popper measurements can easily be determined in the nearest 0.1 feet.

Electric Sounders

Electric sounders consist of a two-wire conductor cable marked at regular intervals and a probe which provides a small space between the conductors. When immersed in water, the circuit is completed across the probe, and the resulting current is indicated on a meter, buzzer or light. The electric sounder is lowered until the circuit is completed; the cable is hold at the labeled measuring point on the well; and the depth to water is determined by measuring from the held point with a graduated tape to the nearest footage mark on the cable. Electric sounders can measure water levels to 0.05 feet when measuring clean water, but contaminated water and/or flowing oil can foul the probe and prevent proper measurements.

Automatic Water Level Recorders are also in use. One type (Stevens recorder) consists of a float arrangement which is connected to a drum recorder. However, in many applications, mechanical recorders such as this are being replaced by systems which use pressure transducers connected to microprocessors. These latter systems provide greater flexibility than the mechanical systems.

4A.8 HYDRAULIC CONDUCTIVITY TBSTING

Slug and Bail Tests measure hydraulic conductivity in single piezometers and small diameter monitoring wells. These tests are conducted by causing an instantaneous change in the water level of a monitoring well through either sudden introduction (slug test) or removal (bail test) of water and measuring the rate of water level rise or fall within the well. The same effect can be created by displacing water by introducing or removing a solid cylinder of known volume.

Changes in water levels with time often occur very quickly in slug or bail tests, a phenomena which requires quick methods of measuring water levels such as electric sounders or pressure transducers. It is important to record early time data from slug and bail tests, as these data indicate whether the test is valid or not. Details on conducting and evaluating slug and bail tests can be found in Hvorslev (1951), Cedergren (1977) and Freeze and Cherry (1979). The tests are relatively easy to conduct but only measure the hydraulic conductivity in the immediate vicinity of the well. In addition, the wells or piezometers must be properly constructed and the geologic and construction details be documented in order to have meaningful results. Results of these tests indicate hydraulic conductivity to one significant figure, at best.

Pumping Tests are used to determine aquifer characteristics (hydraulic conductivity, transmissivity, storage coefficient) over areas greater than single well bores. A pumping well stresses the aquifer system by withdrawing ground water at a controlled rate. Water level drawdown responses to this pumping are measured in the pumping well and adjacent observations wells located at predetermined distances from the pumping well.

Water level data collected in pumping and observation wells during a controlled pumping test can be evaluated by a number of analytical methods. A discussion of basic ground water hydrology and pumping test analysis contained in Johnson (1966), Walton (1970) and Lohman (1979). Results of pumping tests can be used to determine aquifer properties. A major disadvantage of pumping tests is that, they are costly and can' be timeconsuming to conduct.

APPENDIX 4B

CRITERIA FOR AGGREGATE AND GBOTEXTILE, FILTERS

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APPENDIX 4B

CRITERIA FOR AGGREGATE AND GROT EXT ILE FILTERS

4B. 1 PURPOSE OF FILTRATION

There are several elements in the design of a solid waste landfill where percolating water is removed from aggregate materials (i.e., leachate collection system, final cover systemt etc.). Often the movement of water is across an interface between two aggregates of different gradation. For example, the movement of leachate from the leachate collection layer into the gravels surrounding the leachate collection pipe. In this situation, there is a potential for piping to occur.

Piping is the internal erosion of an aggregate caused by the movement: of water through it. In the landfill environment, this creates a problem 'when the eroded material is transported into a drainage system and subsequently clogs it. Piping can occur when some of the coursest particles of the erodible aggregate are smaller than the passageways of the drainage aggregate it is in direct contact with (Cedergren, 1977). For example, if a f inegrained sand of a leachate collection layer is in direct contact with a course-grained gravel surrounding a collection pipe, the sand particles may be carried into the gravel by the leachate flowing from the collection layer to the collection pipe. Eventually, the sand may clog the gravel and seriously impair the operation of the leachate collection system. Because of the inaccessibility for repair of the leachate collection system once solid waste has been placed in the landfill, it is imperative that this situation be prevented. That is the purpose of a filter layer.

To evaluate the potential for migration of particles from a finer aggragate into a courser (filter) aggregate, Equation (4B-1) is recommended (Cedergrent 1977; Lutton, 1982):

$$\frac{D15 \text{ (Filter Aggregate)}}{D85 \text{ (Finer Aggregate)}} < 4 \text{ to } 5 \qquad (4B\text{-}1)$$

where: D15 = grain size for which 15 percent by weight is finer
D85 = grain size for which 85 percent by weight is finer

As an example, Figure 4B.1 presents a series of gradation curves. Curve 4 is a fine-grained aggregate and Curve 1 is a course-grained aggregate. Dj!~ for Curve 1 is 2.Omm. D85 for Curve 4 is 0.2mm. Using equation 4B-1, the result is greater than 5. Therefore, it' is determined th ' at a filter layer is necessary to keep particles from the Curve 4 aggregate from migrating into and potentially clogging the Curve 1 aggregate.

$$\frac{D15}{D85} = \frac{2}{0.2s} = 10$$

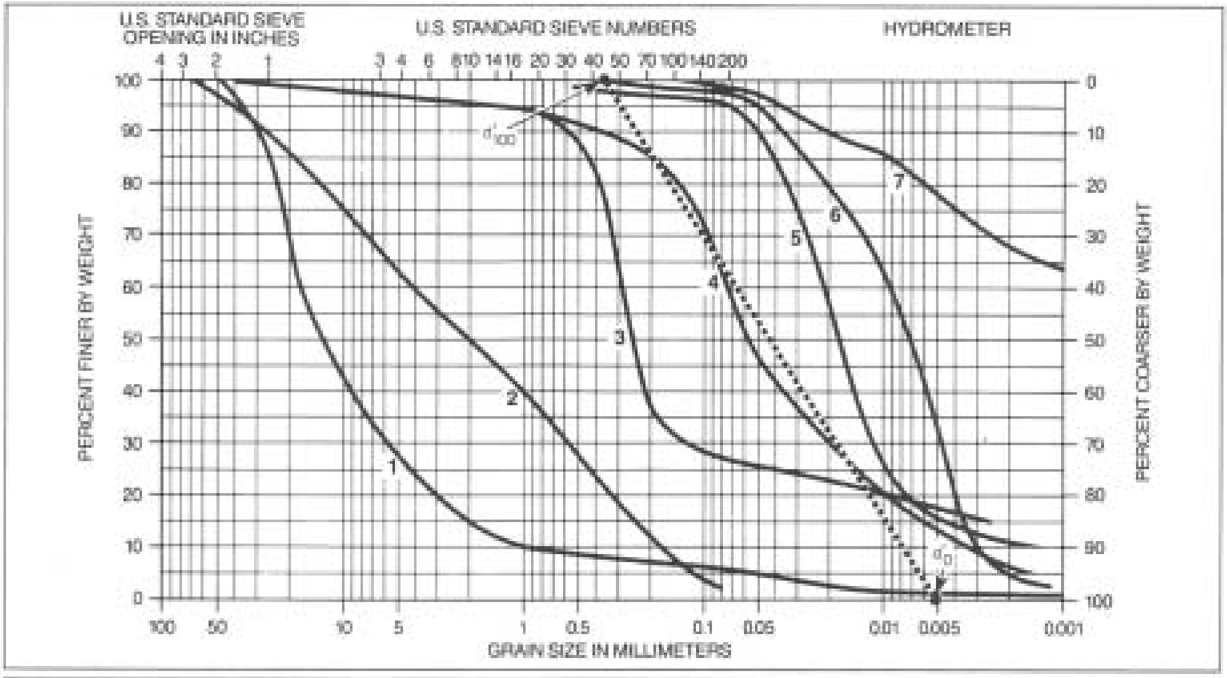


Figure 4B.1
Gradation Curves of Some Sanitary Landfill Cover Soils

A filter layer is designed such that its passageways are smaller than a percentage of the particles of the adjacent erodible aggregate (the retention criterion), but not so small as to impede the flow of water (the permeability criterion). These two contradictory criteria form the basis for the specification of a filter layer.

4B.2 AGGREGATE FILTERS

The original work for specifying design criteria for aggregate filters was done, by Terzagi in 1922, and since then has been investigated by several authors (Giroud, 1982). The criteria that have been established include Equation 4B-1 (the retention criterion) and Equation 0-2 (the permeability criterion).

D15 (Filter Aggregate)
--- > 4 to 5 (0-2)
D15 (Finer Aggregate)

Returning to the previous example, the aggregate represented by Curve 2 in Figure 4B.1 can be investigated as a suitable filter layer between the aggregates represented by Curves 1 and 4. The criteria of Equations 4B-1 and 4B-2 must be satisfied comparing Curve 2 as the filter aggregate against Curve 4 as the finer aggregate, and also by comparing Curve 1 as the filter aggregate against Curve 2 as the finer aggregate.

First, checking the retention criterion (Equation 4B-1). D15 for Curve 2 is 0.25mm, D85 for Curve 4 is 0.2mm, D15 for Curve 1 is 2.Omm, and D85 for Curve 2 is 20mm. Therefore:

$$\frac{D15}{D85} = \frac{0.25}{0.2} = 1.25 < 4 \text{ to } 5$$

and:

$$\frac{2.0}{20} = 0.1 < 4 \text{ to } 5$$

The retention criterion is met. Second, the permeability criterion is checked using Equation 4B-2. D15 for Curve 2 is 0.25mm, D15 for Curve 4 is 0.006mm, and D15 of Curve 1 is 2.Omm. Therefore:

$$\frac{D15}{D15} = \frac{0.25}{0.006} = 41.6 > 4 \text{ to } 5$$

and:

$$\frac{2.0}{0.25} = 8.0 > 4 \text{ to } 5$$

The permeability criteria is also met and therefore the aggregate represented by Curve 2 would be a satisfactory filter layer between the aggregates represented by Curves 1 and 4.

4B.3 GEOTEXTILE FILTER CRITERIA

Geotextile filter fabrics must also meet the retention and permeability ctriteria. However, the criteria are evaluated differently and are presented by Giroud (1982). The permeability criterion is defined by Equation 411-3 (Giroud, 1982).

$$K_{geotextile} > 0.1\ Ksoil \qquad (0\text{-}3)$$

Equation 4B-3 says that as long as the hydraulic conductivity (K) of the geotextile is at least one-tenth the hydraulic conductivity of the soil, the permeability criterion is met.

The retention criterion, as defined by Giroud (1982), is dependent upon the following factors:

$^{0}95$ Apparent opening size of the geotextile fabric (provided in manufacturer's specifications)

$^{D}50$ Grain size for which 50 percent by weight is finer

C' u = Linear coefficient of uniformity of the soil
ID = Density index of the soil

The linear coefficient (C'_u) is determined by drawing a straight line as close as possible to the central portion of the gradation curve and then solving Equation 4B-4 (Giroud, 1982).

$$c'u = \sqrt{\frac{D'100}{D'0}} \qquad \text{(4B-4)}$$

where D'100 and D'O are the particle diameters at the points of intersection of the straight line drawn through the central portion of the gradation curve with the 100% and 0% percent finer by weight lines (see Figure 4B.1).

The relative density index is defined by Giroud (1982) as:

$$I_D = \frac{e_{max} - e}{e_{max} \quad e_{min}} \qquad \text{(4B-5)}$$

where: e_{max} void ratio of the soil in its loosest state

e_{min} void ratio of the soil in its densest state

e = void ratio of the soil in-place

Void ratios of the soil can be measured in the laboratory using routine procedures.

The retention criterion for geotextile filter fabrics is presented in Table 4B.1.

As an example, again consider the need for a filter between the aggregates represented by Curves 2 and 4. Since Curve 4 is the finer grained material, the retention and permeability criteria for the geotextile must be evaluated against it.

From the straight line drawn through the central portion Curve 4, it can be seen from Figure 4B.1 that D1100=0.38mm and D'0=0.005mm. Theref ore, by
Equation 4B-4:

$$C'u = \sqrt{\frac{0.38}{0.005}} = 8.7$$

From curve 4, D50 = 0.42mm. Assuming the relative density (ID) is 50%, the maximum apparent opening size (095) can be determined using the appropriate relationship from Table 4B.1.

$$095 < \frac{13.5(0.042)}{8.7} = 0\text{-}065\text{mm}$$

Table 4B.1. Retention Criterion for Geotextile Filter Fabrics.

Relative Density Index	Linear Coefficient of Uniformity of the Soil $1 < C'_u < 3$	$C'_u > 3$
Loose: ID < 35%	$095 < C'_u D50$	$095 < \frac{9}{C'u} D50$
Medium Dense: 35% < ID < 65%	$095 < 1.5C'_U D50$	$095 < \frac{13.5}{C'u} D50$
Dense: ID > 65%	$095 < 2C'_U D50$	$095 < \frac{18}{C'u} D50$

SOURCE: Giroud (1982)

The permeability criterion could be verified by comparing the hydraulic conductivities of the geotextile (often provided by the manufacturer) and the soil (as measured in the lab) and ensuring that Equation 4B-3 is satisfied.

4B. 4 VERIFICATION

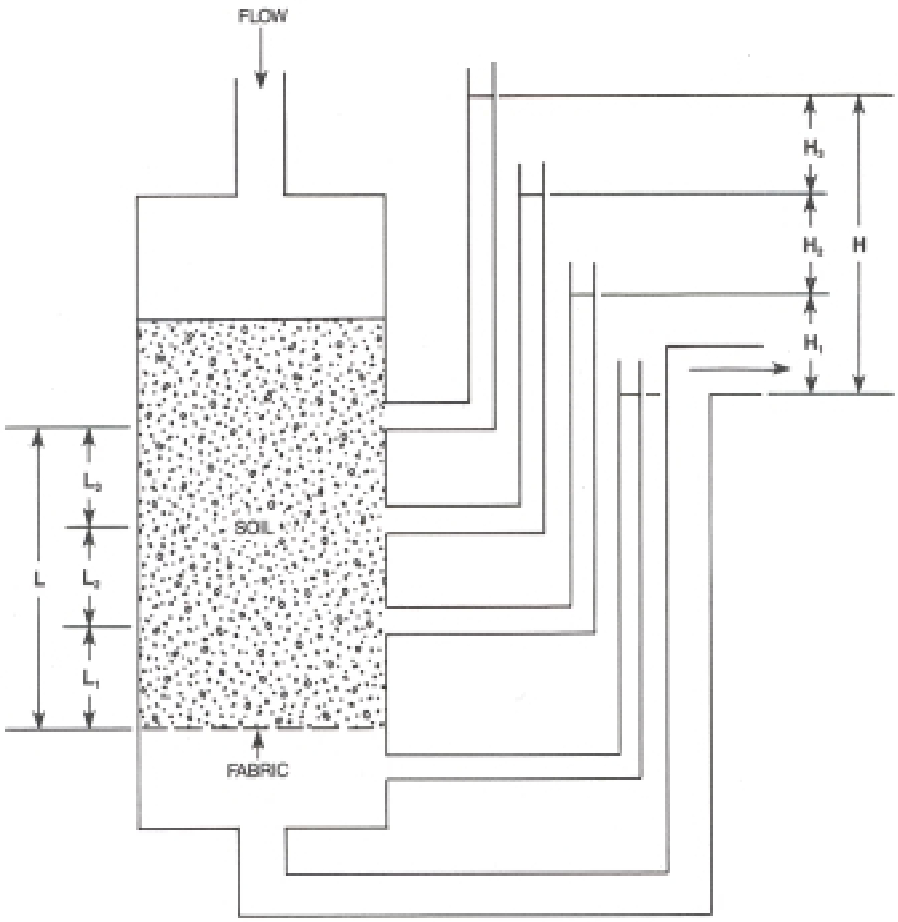
Because of the importance of the long term reliability of- filter fabrics and drainage features in a solid waste landfill, it would be prudent to test a proposed drain and filter fabric specification in the lab, prior to construction in the field. The U.S. Army Corps of Engineer's Gradient Ratio Test provides a means for such testing (Mirafi, Inc., 1983). The test apparatus is a downward flow, constant head permeameter set up as shown in Figure 4B.2. The piezometers are read after 24 hours and the Gradient Ratio (GR) is calculated as shown on Figure 4B.2. The results are interpreted as follows (Mirafi, Inc., 1983):

GR < 1: Piping of adjacent soil through the geotextile

GR = 1: The geotextile offers no inhibition to flow and soil permeability controls the soil-geotextile system behavior

GR > 1: Geotextile clogging

GR > 3: Severe geotextile clogging (unacceptable)



$L_1 = L_2 = L_3 = 1.0$ INCH

$$\text{GRADIENT RATIO} = \frac{i_1}{i_{2+3}} = \frac{\dfrac{H_1}{L_1}}{\dfrac{(H_2 + H_3)}{(L_2 + L_3)}}$$

Source: Mirafi, Inc. (1983).

Figure 4B.2
Illustration of Procedure for Computing U.S. Army Engineer Gradient Ratio

APPENDIX 4C

COLLECTION PIPE MATERIALS AND STRUCTURAL REQUIRENENTS

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COLLECTION PIPE MATERIALS AND STRUCTURAL REQUIREMENTS

4C.1 COLLECTION PIPE MATERIALS

Pipe that may be suitable for leachate collection systems is manufactured -to meet nationally recognized product specifications. Some materials are moire appropriate than others for use in a leachate collection system and the various types of pipe should be evaluated carefully. Various factors -to consider are:

- Intended use (type of leachate)
- Flow requirements
- Scour or abrasion conditions
- Corrosion conditions
- Product characteristics
- Physical properties
- Installation requirements
- Handling requirements
- Cost effectiveness

No single pipe product will provide optimum capability in every characteristic for all leachate collection system design conditions. Specific application requirements should be evaluated prior to selecting pipe materials.

Pipe materials for leachate collection applications fall within the two commonly accepted classifications of rigid pipe and flexible pipe. Rigid pipe materials derive a substantial part of their basic earth load carrying capacity from the structural strength inherent in the rigid pipe wall, while flexible pipe materials derive load carrying capacity from the interaction of the flexible pipe and the embedment soils. Products commonly available within these two classes are:

1. Rigid Pipe
   a. Asbestos-cement pipe (ACP)
   b. Cast iron pipe (CIP)
   C. Concrete pipe (CP)
   d. Vitrified clay pipe (VCP)

2. Flexible Pipe
   a. Ductile iron pipe (DIP)
   b. Steel pipe (SP)
   c. Thermoplastic pipe
      - Acrylonitrile-butadiene-styrene (ABS)
      - ABS composite
      - Polyethylene (PE)
      - Polyvinyl chlorine (PVC) d. Thermoset plastic pipe
      - Reinforced plastic mortar (RPM)

- Reinforced thermosetting resin (RTR)

Within the rigid pipe classification, the suitability of cast iron arid concrete pipe for leachate collection systems is limited by the difficulty of incorporating perforations in the pipe walls and their susceptibility to corrosion by acidic leachates. The use of asbestos-cement pipe is limited by its low beam strength. It is also susceptible to attack by acidic leachates. Vitrified clay pipe can be perforated and is highly resistant to chemical corrosion, but its relatively low beam strength limits the fill height that can be placed over it. For these reasons, rigid pipes have very limited use potential in leachate collection systems.

As a group, flexible pipes offer good potential for use in leachate collection systems. Within the flexible pipe group, however, only certain products are suitable. Ductile iron and steel pipe have little application for leachate collection systems primarily because of their susceptibility to attack by acidic leachates. Also, although ductile iron pipe has high load bearing capacity, incorporating perforations in the pipe walls is difficult. Thermoplastic and thermoset plastic pipe are more suitable products for leachate collection systems.

Thermoplastic materials are characterized by their ability to be repeatedly softened by heating and hardened by cooling through a temperature range characteristic for each plastic. Materials suitable for use in leachate collection systems include ABS pipe, ABS composite pipe, PE pipe, and PVC pipe. All of these materials are subject to attack by certain organic chemicals, so compatibility with the leachate must be considered in this selection. ABS is generally not as resistant to acids as PVC and neither of these two materials has good resistance to concentrated ketones and esters. Pipes manufactured from any of these materials are subject to excessive deflection when improperly bedded and haunched, so proper design and construction are important. With the exception of PVC pipe, these pipes are also subject to environmental stress cracking. Thermoplastic pipe product design should be based on long-term data.

Thermoset plastic materials, cured by heat or other means, are substantially infusible and insoluble. The two categories of thermoset plastic materials suitable for leachate collection systems include RPM pipe and RTR pipe. RPM pipe is manufactured containing reinforcements, such as fiberglass, arid aggregates, such as sand, embedded in or surrounded by cured thermosetting resin. RTR pipe is manufactured using a number of methods including centrifugal casting, pressure laminating, and filament winding. In general, the product contains fibrous reinforcement materials, such as fiberglass, embedded in or surrounded by cured thermosetting resin. Pipes manufactured from both of these materials are subject to strain corrosion in some environments, attack by certain organic chemicals, and excessive deflection when improperly bedded and haunched. Therefore, leachate compatibility arid proper design and construction are important when thermoset plastic pipe is used in leachate collection systems.

4C.1.1 Pipe Perforations

By nature of their intended use, leachate collection lines must be perforated. The size and spacing of the openings sho ld be determined based on hydraulic considerations. The effects of the perforations should be considered in the structural design of the leachate collection pipes.

4C.1.1.1 <u>Size and Spacing</u>

A leachate collection line, to function correctly, must be capable of accepting all the leachate flowing to it through the gravel drainage layer. After the pipe is sized to handle the flow, the size and spacing of the perforations should be selected. The rate of flow into the leachate collection pipes through the perforations is dependent on several factors, including the hydraulic conductivity of the gravel material around the pipe and the head loss due to convergence of flow to the perforations in the pipe.

W.T. Moody, as cited in U.S * Department of the Interior (1978) determined the theoretical relationship among the above factors and concluded that increasing the hydraulic conductivity of the gravel envelope around the pipe was a more effective method for increasing the rate~of flow into the pipe than increasing the size of the openings. Therefore, the selection of the size and spacing of the perforations should be based on: consideration of standard perforated pipe commonly available from manufacturer; bedding and backfill requirements for the particular installation; and effects on pipe strength. For a given rate of leachate inflow and a perforated pipe, the minimum required hydraulic conductivity of the gravel envelope around the pipe can be determined using a procedure similar to that presented in U.S. Department of the Interior (1978).

4C.1.1.2 <u>Effects on Load Capacity</u>

The various design procedures for rigid and flexible pipes and the various pipe performance limits are based on solid wall pipe. Pacey, et al., as cited in Dietzler (1984) has suggested that the effect of perforations could be compensated by arbitrarily increasing the earth load on the pipe. Data presented in Dietzler (1984) indicated the inclusion of typical perforations in'the lover quarters of 6-inch ABS and PVC pipe has little influence on pipe stiffness and deflection versus load performance. Others have stated there are indications that perforations will reduce the effective length of pipe available to carry loads and resist deflection suggest taking the effect of perforations into account by increasing the load in proportion to the reduction in the effective length. This later method appears to be an adequately conservative approach. If Lp equals the cumulative length of the perforations per unit length of the pipe, L, then thelactual load on the pipe should be increased as follows:

$$\text{Design Load} = \text{Actual Load} \times \frac{L}{L-Lp} \qquad (4C\text{-}1)$$

Methods to determine the actual load are discussed in the following sections.

4C.2 STRUCTURAL REQUIREMENTS

Leachate collection systems installed underneath a landfill must be designed to withstand the anticipated height and weight of refuse to be placed over them. It is not uncommon to find heights in excess of 100 feet. Appropriately, leachate collection systems must be designed for vertical pressure acting at the base of the landfill, considering the height of the landfill and the weighted average density of the refuse, daily cover, final cover system, and any superimposed loads during the life of the landfill. Perimeter collection systems that generally lie outside the landfill should be designed for the earth loads acting on them along with any superimposed loads.

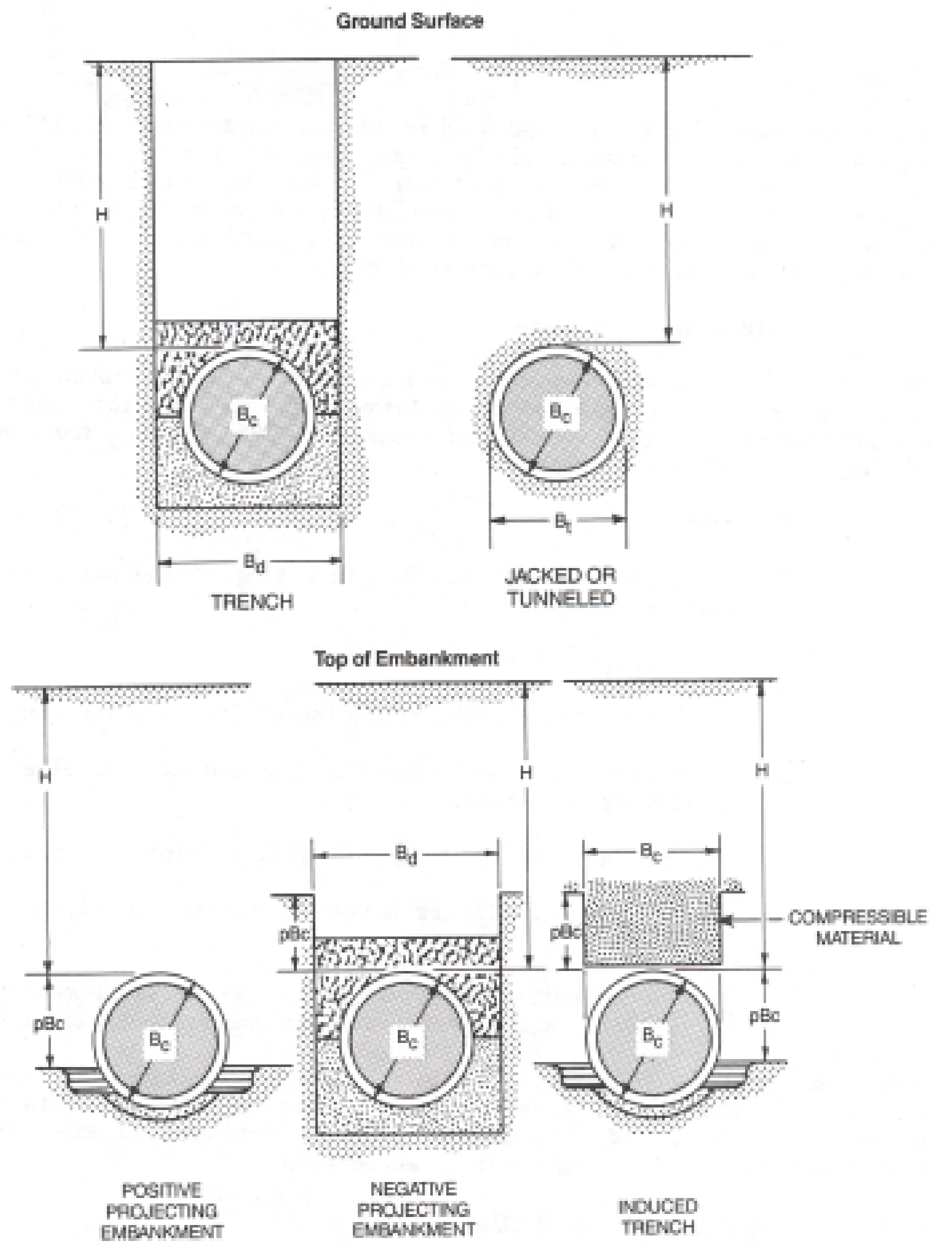
The supporting strength of a leachate collection pipe is a function of installation conditions as well as the strength of the pipe itself. Structural analysis and design of the collection system are problems of soilstructure interaction. This section presents general procedures for determining the structural requirements of the pipes in a leachate collection system. Detailed discussions concerning structural design of pipelines may be found in ASCE and WPCF (1982). The design procedure for the selection of pipe strength consists of the following:

- Determination of loading condition
- Determination of refuse and earth loads
- Determination of superimposed loads
- Selection of bedding and determination of bedding factor
- Application of factor of safety
- Selection of pipe strength

4C.2.1 Loading Conditions

The load transmitted to a pipe is largely dependent on the type of installation. The common types of installation conditions are shown in Figure 4C.1 and include trench, positive projecting embankment, negative projecting embankment, and induced trench. Jacked or tunneled is also an installation condition, but has little application for leachate collection systems. The difficulty in controlling the placement of the embankment material greatly limits the potential use of the induced trench condition for leachate collection systems.

Trench installation* conditions are defined as those in which the pipe is installed in a relatively narrow trench cut in undisturbed ground and covered with backfill to the original ground surface. Embankment conditions are defined as those in which the pipe is covered above the original ground surface or in which a trench in undisturbed soil is so wide that wall friction does not affect the load on the pipe. The embankment classification is further subdivided into positive projecting and negative projecting classification. Pipe is positive projecting when its top is above the adjacent original ground surface. Negative projecting pipe is installed with its top below the adjacent original ground surface in a trench that is narrow with respect to the pipe and depth of cover.



Adapted From: American Concrete Pipe Association, 1980

Figure 4C.1
Installation Conditions

Both the trench condition and either of the embankment conditions may be appropriate in the design of leachate collection systems. A perimeter collection system may be designed for either the trench condition or the negative projecting embankment condition, depending on trench width. Leachate collection systems underneath the landfill would generally be designed for one of the embankment conditions.

4C.2.2 Refuse and Earth Loads

The methods for determining the vertical load on buried conduits caused by soil forces were developed by Marston for all of the most commonly encountered construction conditions (ASCE and WPCF, 1982). The general form of the Marston equation is:

$$W = CWB2 \qquad (4C\text{-}2)$$

where: W = Vertical load per unit length acting on the pipe because of gravity soil loads

v = Unit weight of the soil

B = Trench or pipe width, depending on installation conditions

C = Dimensionless coefficient that measures the effects of the following variables:

- The ratio of the height of fill to width of trench or pipe
- The shearing forces between interior and adjacent soil prisms
- The direction and amount of relative settlement between interior and adjacent soil prisms for embankment conditions

While the general form of the Marston equation includes all the factors necessary to analyze all types of installation conditions, it is convenient to write a specialized form of the equation for each of the installation conditions described in the previous subsection.

4C.2.2.1 Loads for Trench Conditions

In the trench condition, the load on the pipe is caused by both the waste fill and the trench backfill (U.S. EPA, 1983). These two components of the total vertical pressure on the pipe are computed separately and then added to obtain the total vertical pressure acting on the top of the pipe.

The waste fill is assumed to develop a uniform surcharge pressure, Of, at the base of the fill. The magnitude of Qf is given by the expression:

$$Q_f = (w_f)(H_f) \qquad (4C\text{-}3)$$

where: Q_f = Vertical pressure at the base of the waste fill (lbs/sq ft)

w_f = Weighted average density of the waste fill including refuse, intermediate cover, and final cover system (lbs/cu ft)

H_f = Height of waste fill including cover (ft)

The weighted average density of the waste fill, w_f is computed as follows:

$$w_f = \frac{(w_r)(H_r) + (w_i)(T) + (w_c)(T_c)}{H_f} \qquad (4C\text{-}4)$$

where: w_r = Average in-place wet density of the refuse (lbs/cu ft)

H_r = Height of refuse excluding cover layers (ft)

w_i = Wet density of intermediate cover (lbs/cu ft)

T_i = Total thickness of intermediate cover layers (ft)

w_c = Wet density of the final cover system (lbs/cu ft)

T_c = Thickness of the final cover system (ft)

$H_f = H_r + T_i + T_c$

The value of the vertical pressure at the top of the pipe due to the waste fill, Pvf (in lbs/sq ft), is determined from the following:

$$Pvf = ({}^{Q}f)({}^{C}us) \qquad (4C\text{-}5)$$

where: Cus = Dimensionless load coefficient that is a function of the ratio of the depth of the trench, H (measured from the original ground surface to the top of the pipe) to the trench width, B_d, and of the friction between the backfill and the sides of the trench.

The load coefficient, C_{us}, may be calculated from the following equation or obtained from Figure 4C.2:

$$^{C}us = e^{-2KU'(H/Bd)} \qquad (4C\text{-}6)$$

where: e = Base of natural logarithms

K = Rankine's ratio of lateral pressure to vertical pressure

u'= Coefficient of friction between backfill material and the sides of the trench

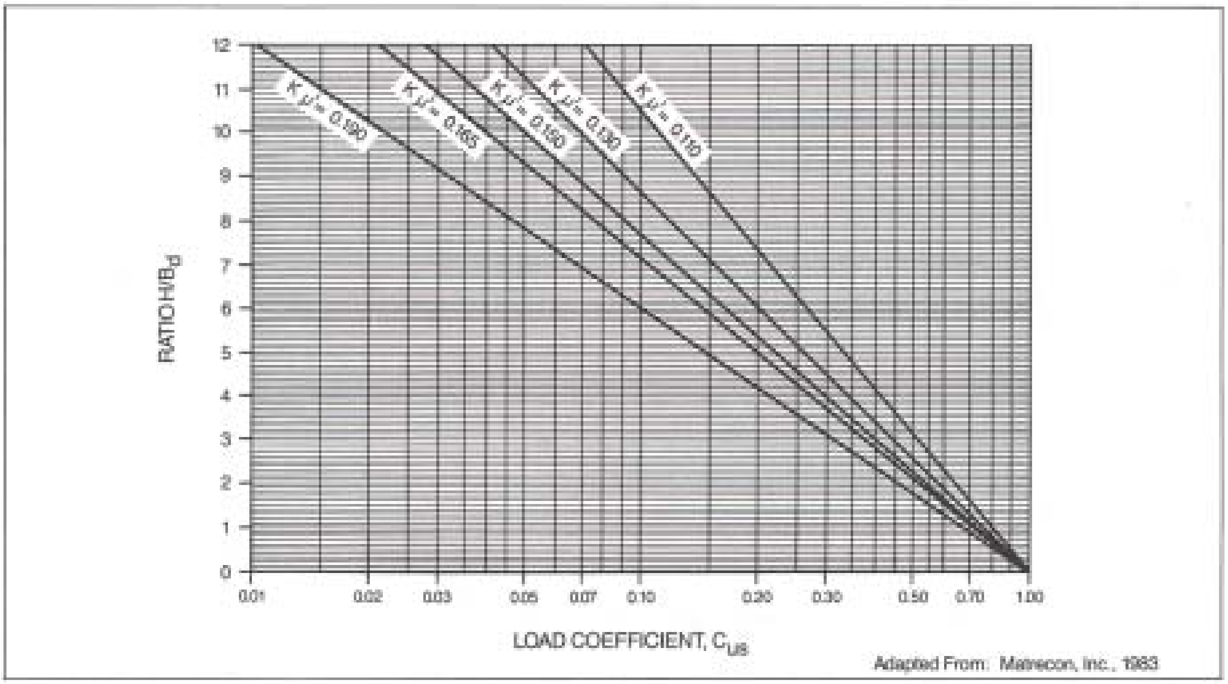


Figure 4C.2
Trench Condition—Values of Load Coefficient C_{us} (Trench Uniform Surcharge)

H = Depth of trench from original ground surface to top of pipe (f t)

B_d = Width of trench at top of pipe (ft)

The product of Ku' is characteristic for a given combination of backfills in natural, undisturbed soil. Maximum values of Kul for typical soils are listed in Table 4C.1.

Table 4C.1. Maximum Value of Kul for Typical Backfill Soils

Type of Soil	Maximum Value of Ku'
Granular Materials Without Cohesion	0.19
Sand and Gravel	0.165
Saturated Topsoil	0.150
Clay	0.130
Saturated Clay	0.110

Source: U.S. EPA (1983)

The value of the vertical pressure at the top of the pipe due to the trench backfill is determined from the following equation developed by Marston (see U.S. EPA, 1983):

$$Pvt = (Bd)(w)(Cd) \qquad (4C\text{-}7)$$

where:

Pvt = Value of the vertical pressure at. the top of the pipe (lbs/sq ft)

W = Unit weight of trench backfill (lbs/cu ft)

C_d = Dimensionless load coefficient which is a function of the ratio of the depth of the trench, H, to the trench width, B_d, and of the friction between the backfill and the sides of the trench

The load coefficient, C_d, may be computed from the following equation or obtained from Figure 4C.3:

$$C_d = \frac{1\text{-}e\text{-}2Ku'(H/B_d)}{2Ku'} \qquad (4C\text{-}8)$$

in which the terms are as previously defined.

The total vertical pressure at the top of the pipe, Pv, is equal to:

$$Pv = P_{vf} + P_{vt} \qquad (4C\text{-}9)$$

$$P_v = (Q_f)(C_{us})+(B)(w)(C_d) \qquad (4C\text{-}10)$$

Based on Marston's formula, the load on a rigid pipe in the trench condition would be:

$$we = P_v B_d \qquad (4C\text{-}11)$$

or:

$$w_c = (B_d)(Q_f)(C_{us}) + (B_d)^2 (w)(C_d) \qquad (4C\text{-}12)$$

where: w_c = Force per unit length of pipe (lb/ft)

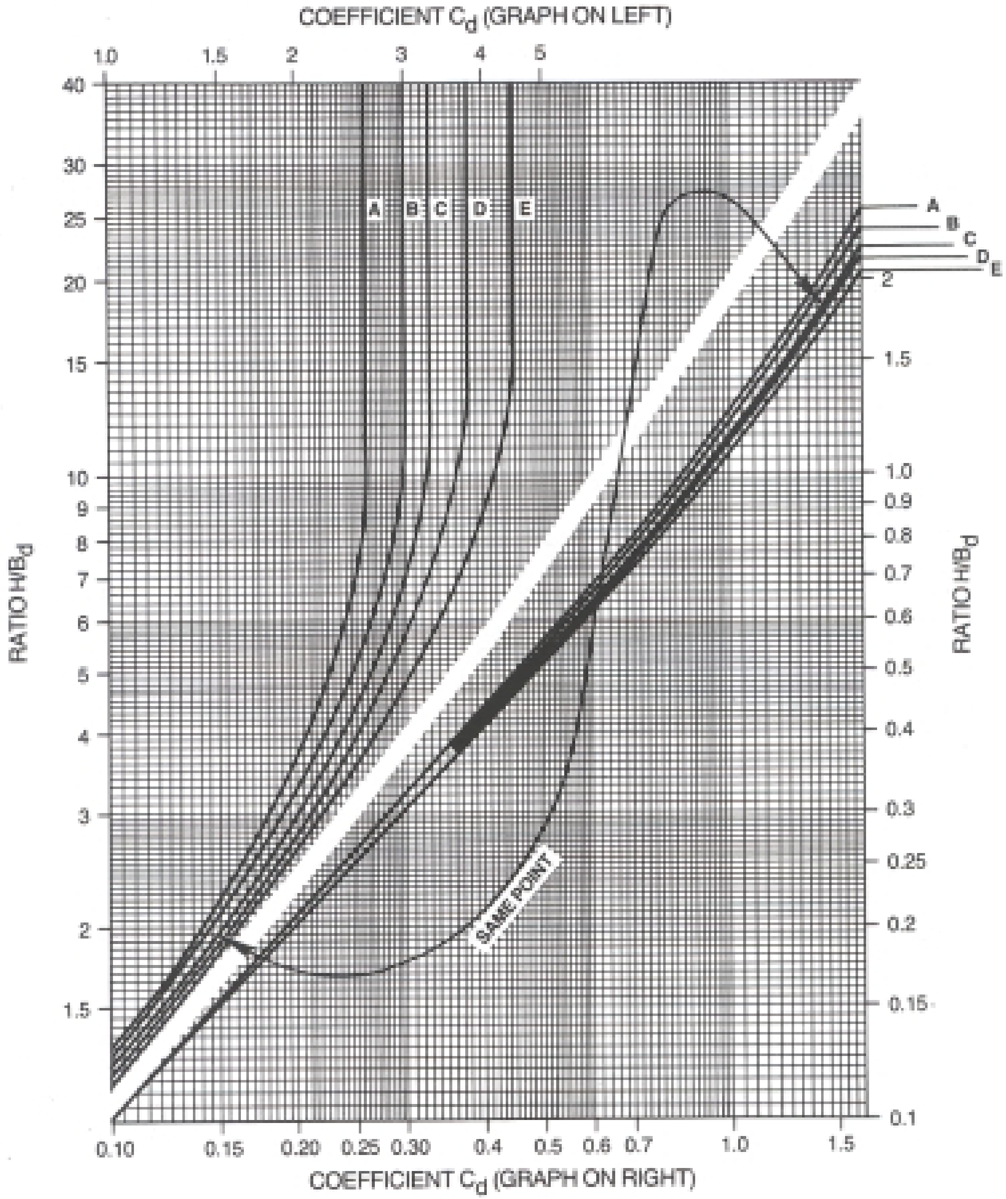
For flexible pipe in the trench condition, the load as given by Marston's formula would be:

$$w_c = P_v B_c \qquad (4C\text{-}13)$$

or:

$$w_c = (B)(Q_f)(C_{us}) + (B_d)(w)(C_d)(B_c) \qquad (4C\text{-}14)$$

where: B_c = Outside diameter of pipe (ft)



A-C_d for $K\mu'$ = 0.19, for Granular Materials Without Cohesion

B-C_d for $K\mu'$ = 0.165 Maximum for Sand and Gravel

C-C_d for $K\mu'$ = 0.150 Maximum for Saturated Top Soil

D-C_d for $K\mu'$ = 0.130 Maximum Ordinary for Clay

E-C_d for $K\mu'$ = 0.110 Maximum for Saturated Clay

Adapted From: Matrecon, Inc., 1983

Figure 4C.3
Trench Condition—Values of Load Coefficient C_d (Backfill)

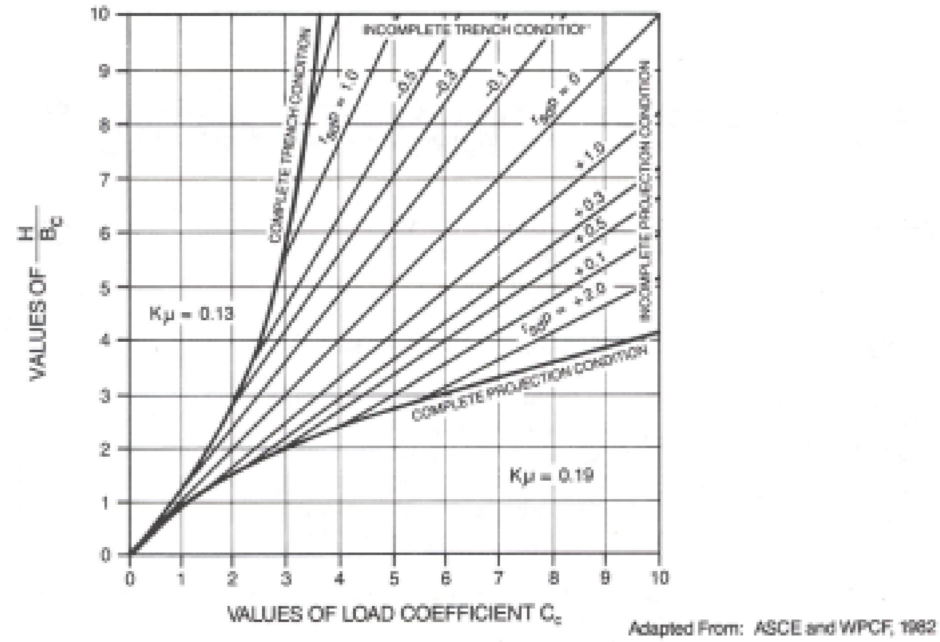


Figure 4C.4
Diagram for Load Coefficient C_c for Positive Projecting Pipes

This formula is applicable to flexible pipes only if the backfill material at the sides of the pipe is compacted so that it will deform under vertical load less than the pipe itself will deform. In this condition, the side fills between the sides of the pipe and the sides of the trench may be expected to carry their proportional share of the total load. If this condition does not exist, then the loads are determined as described below for the embankment conditions.

4C.2.2.2 Loads for Positive Protecting Embankment Conditions

Marston's formula for the fill load on a pipe in the positive projecting embankment condition is:

$$W_c = C_c^{w}fB_c^{2} \qquad (4C\text{-}15)$$

where: W_c = Load on the pipe (lbs/ft)

w_f = Weighted average density of the waste fill (lbs/cu ft)

B_c = Outside width of pipe (ft)

C_c = Load coefficient

A complete discussion of this load coefficient may be found in the Concrete Pipe Design Manual developed by the American Concrete Pipe Association (1980)' and Gravity Sanitary Sever Design and Construction published by the ASCE and WPCF (1982). Values of Cc may be obtained from Figure 4C.4.

Table 4C.2. Recommended Design Values of rsd (Positive , Projecting Embankment Conditions).

Type of Pipe	Soil Conditions	Settlement Ratio, r_{sd}
Rigid	Rock or unyielding foundation	+1.0
Rigid	Ordinary foundation	+0.5 to +0.8
Rigid	Yielding foundation	0 to +0.5
Rigid	Negative projecting installation	-0.3 to -0.5
Flexible	Poorly compacted side fills	-0.4 to 0
Flexible	Well compacted side fills	0

Source: ASCB and WPCF, 1982, p. 178

The fill load on a pipe installed in a positive projecting embankment condition is influenced by the product of the settlement ratio (r_{sd}) and the projecting ratio (p'). The settlement ratio is the relationship between the pipe deflection and the relative settlement between the prism of fill directly above the pipe and the adjacent material. Design values of the settlement ratio is the vertical distance the pipe projects above the original ground divided by the outside vertical height of the pipe, and can be determined when the size and elevation of pipe has been established.

In the last three cases shown in Table 4C.2, the settlement ratio may be conservatively assumed to be zero which results in designing for the weight of the prism of material directly above the pipe. In such cases, C_c is equal to H/B_c and Marston's formula for the prism load becomes:

$$W_c = (H)(w_f)(B_c) \qquad (4C\text{-}16)$$

where: W_c = Load on pipe (lbs/ft)

H = Height of the fill above the pipe (ft)

w_f = Weighted average density of the waste fill, including gravel backfill above the pipe, refuse, intermediate cover, and final cover system (lbs/cu ft)

B_c = Outside diameter of the pipe (ft)

The load on the pipe is also influenced by the coefficient of internal friction of the embankment material. ASCE and WPCF (1982) recommends the following values of the product Ku for use in Figure 4C.4.

For a positive settlement ratio: Ku = 0.19
For a negative settlement ratio: Ku = 0.13

4C.2.2.3 Loads for Negative Projecting Embankment and Induced Trench Conditions

The formula for the fill load on a negative projecting pipe is:

$$W_c = C_n^{wB} d^2 \qquad (4C\text{-}17)$$

where: W_c = Load on the pipe (lbs/ft)

w = Density of fill above pipe (lbs/cu ft)

B_d = Width of trench (ft)

C_n = Load coefficient

In the case of induced trench pipe, B_c is substituted for B_d in the preceding equation. B_c is the outside diameter of the sever pipe which is assumed to be the width of the trench.

A complete discussion of the load coefficient, C_n, may be found in American Concrete Pipe Association (1980) and ASCE and WPCE (1982). Values of C_n may be obtained from Figure 4C.5.

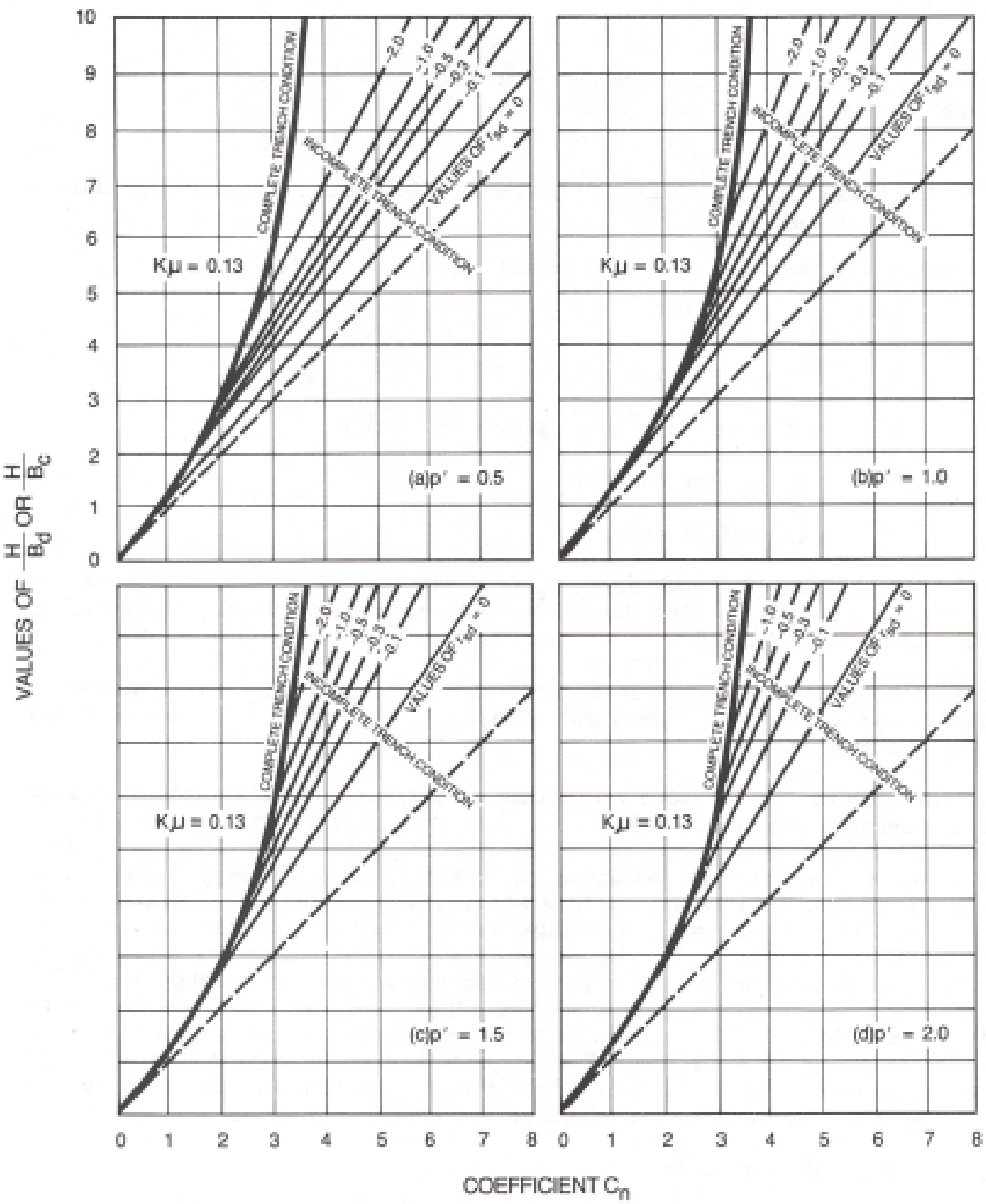
As in the case of the positive projecting embankment condition, the fill load is influenced by the product of the settlement ratio (r_{sd}) and the projection ratio (p'). The settlement ratio for the negative projecting embankment condition is the quotient obtained by taking the difference between the settlement of the firm ground surface and the settlement of the plane in the trench backfill which was originally level with the ground surface and dividing this difference by the compression of the column of material in trench. Values for the negative projecting settlement ratio range from -0.1 for P' = 0.5' to -1.0 for P' = 2.0' for rigid pipe (American Concrete Pipe Association, 1980, p. 162). Induced trench settlement ratios range from -0.3 to 05 (ASCE and WPCF, 1982). The projection ratio for this condition, p' is equal to the vertical distance from the firm ground surface down to the top of the pipe, divided by the width of the trench, B_d.

4C.2.3 Superimposed Loads

Leachate collection pipes in a landfill may be subjected to two types of superimposed loads: concentrated loads and distributed loads. Loads of pipes caused by these loadings can be determined by application of the Boussinesq equations (ASCE and WPCF, 1982).

4C.2.3.1 Concentrated Loads

The formula for load caused by a superimposed concentrated load, such as a



Adapted From: ASCE and WPCF, 1982

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Landfill Design Manual

Figure 4C.5
Diagrams for Load Coefficient C_n for Negative Projecting and Induced Trench Pipes

wheel load during construction, is given the following form (ASCE and WPCF, 1982):

$$W_{sc} = \frac{PF}{C_S L} \qquad (4C\text{-}18)$$

where: W_{sc} = Load on pipe (lbs/ft)

P = Concentrated load (lbs)

F = Impact factor

L = Effective length of pipe (ft)

C_s = Load coefficient

The load coefficient, C_s, is a function of $B_c/2H$ and $L/2H$, in which B_c is the outside diameter of the pipe and H is the height of fill from the top of the pipe to the ground surface. Table 4C.3 lists values of the load coefficients for concentrated and distributed superimposed loads centered over the pipe.

The effective length, L, is the length over which the average load caused by surface wheels produces nearly the same stress in the pipe wall as does the actual load which varies in intensity from point to point. ASCE and WPCF (1982) recommends using an effective length equal to 3 feet for pipes greater than 3 feet long and using the actual length of pipes shorter than 3 feet.

The impact factor, F, reflects the influence of dynamic loads caused by traffic at ground surface. The impact factors recommended by AASHTO are listed in Table 4C.4 (American Concrete Pipe Association, 1980).

Various equipment loads that may occur during construction are listed in Table 4C.5.

Loads on pipes resulting from concentrated loads during construction may be greater than the loads caused by the refuse placed in the landfill. It is important that both construction loads and long-term loads be considered in determining the maximum load expected on pipes.

4C.2.3.2 Distributed Loads

Superimposed loads distributed over an area of considerable extent such as a truck load during construction may be determined from the following equation (ASCE and WPCF, 1982):

$$W_{sd} = CspFBc \qquad (4C\text{-}19)$$

where: W_{sd} = Load on pipe (lbs/ft)

p = Intensity of distributed load (lbs/sq ft)

F = Impact factor

Table 4C.3. Values of Load Coefficients, C_s, for Concentrated and Distributed Superimposed Loads Vertically Centered over Sewer Pipe.

$\frac{D}{2H}$ or $\frac{B_C}{2H}$	$\frac{M}{2H}$ or $\frac{L}{2H}$													
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.5	2.0	5.0
0.1	0.019	0.037	0.053	0.065	0.079	0.089	0.097	0.103	0.108	0.112	0.117	0.121	0.124	0.128
0.2	0.037	0.072	0.103	0.131	0.155	0.174	0.189	0.202	0.211	0.219	0.229	0.238	0.244	0.248
0.3	0.053	0.103	0.149	0.190	0.224	0.252	0.274	0.292	0.306	0.318	0.333	0.345	0.355	0.360
0.4	0.067	0.131	0.190	0.241	0.284	0.320	0.349	0.373	0.391	0.405	0.425	0.440	0.454	0.460
0.5	0.079	0.155	0.224	0.284	0.336	0.379	0.414	0.441	0.463	0.481	0.505	0.525	0.540	0.548
0.6	0.089	0.174	0.252	0.320	0.379	0.428	0.467	0.499	0.524	0.544	0.572	0.596	0.613	0.624
0.7	0.097	0.189	0.274	0.349	0.414	0.467	0.511	0.546	0.584	0.597	0.628	0.650	0.674	0.688
0.8	0.103	0.202	0.292	0.373	0.441	0.499	0.546	0.584	0.615	0.639	0.674	0.703	0.725	0.740
0.9	0.108	0.211	0.306	0.391	0.463	0.524	0.574	0.615	0.647	0.673	0.711	0.742	0.766	0.784
1.0	0.112	0.219	0.318	0.405	0.481	0.544	0.597	0.639	0.673	0.701	0.740	0.774	0.800	0.816
1.2	0.117	0.229	0.333	0.425	0.505	0.572	0.628	0.674	0.711	0.740	0.783	0.820	0.849	0.868
1.5	0.121	0.238	0.345	0.440	0.525	0.596	0.650	0.703	0.742	0.774	0.820	0.861	0.894	0.916
2.0	0.124	0.244	0.355	0.454	0.540	0.613	0.674	0.725	0.766	0.800	0.849	0.894	0.930	0.956

Bc = Outside diameter of pipe (ft)

Cs = Load coefficient

Table 4C.4 Superimposed Concentrated Load Impact Factors, F.

Height of Cover	Impact Factor
0 - 1.0 ft.	1.3
1.1 - 2.0 ft.	1.2
2.1 - 2.9 ft.	1.1
3.0 ft. and greater	1.0

Table 4C.5 Equipment Loads

Equipment	Operating Weight (lbs)	Ground Contact	Track or Wheel Load (lbs)
Caterpillar D-6	32,850	181101 9.011	16,425 Track Load
Caterpillar D-8	81,950	2211x 1016.5	40,975 Track Load
Scrapers, loaded 21/31 cu yd capacity (631 D)	168,410	Wheel load	45,470 Drive Wheel Load
Compactor Caterpillar 825-C	71,429	81 Width Coverage	35,715 Roller Load

Adapted From: Caterpillar Performance Handbook, 1984

The load coefficient, Cs, is a function of D/2H and M/2H, in which H is the height from the top of the pipe to the ground surface and D and M are the width and length, respectively, or the area over which the distributed load acts. Table 4C.3 lists the values of the load coefficients for loads centered over the pipe. A method for determining the loads on the pipe from offset uniform loads may be found in ASCE and WPCF, 1982. A typical offset uniform. load would be the waste fill placed inside and adjacent to a perimeter leachate collection system.

4C.2.4 Design Safety Factor

The factor of safety for a pipe is defined as the ratio of the maximum performance limit to the design or service performance limit. The selection of a suitable safety factor is an essential part of the structural design of leachate collection pipes. The factor of safety should be related either to an allowable working stress or to a pre-established ultimate failure condition. Factors of safety compensate for poor construction practice or for inadequate inspection. Properly established design performance values and adequate factors of safety must be realized in installation and operation to provide reasonable assurance of long-term leachate collection system performance.

The relationship between safety factors and design performance values is similar for rigid and flexible pipes. However, there are differences in the design requirements for each type of pipe and these affect the form of the safety factor associated with each.

4C.2.4.1 Rigid Pipe

Design performance limits for rigid pipes are expressed in terms of strength under load. Testing is generally used to determine the service strength for rigid pipe. Strengths of rigid pipe are measured in terms of 1) the ultimate three-edge bearing strength, and 2) the ultimate and 0.01-inch crack, three-edge bearing strengths for reinforced concrete pipe. A safety factor of 1.0 should be applied to the specified minimum ultimate three-edge bearing strength to determine the working strength for other rigid pipes (ASCE and WPCF, 1982). Common practice is to use a factor of safety of 1.25 for the ultimate load of reinforced concrete pipe, and up to 1.50 for vitrified clay.

4C.2.4.2 Flexible Pipe

Design performance limits for flexible pipes are most commonly expressed in terms of deflection. The design limit varies with different pipe materials and the pipe manufacturing process. Flexible pipes must be able to deflect without experiencing cracking, liner failure, or other distress; and they should be designed with a reasonable factor of safety.

Manufacturers should be consulted on the value of the deflection limits for various types of flexible pipes. The PVC pipe manufacturers suggest limiting the deflection of buried PVC pipe to 7-1/2 percent. This strain is one-fourth the minimum strain level at which cracking and reverse curvature reportedly occurs when subjecting PVC pipe to testing in accordance with ASTSM D 2412. To maintain this same factor of safety (FS-4.0) with ABS pipe, the allowable strain for ABS pipe should be limited to 5-1/2 percent. The high safety factor of 4.0 is intended to compensate for the long-term effects of creep of the plastic. Dietzler (1984) suggests that deflections of ABS and PVC pipe should be limited to one-third the deflection at which reverse curvature of splitting occurs in ASTM D 2412, including a deflection lag factor.

4C.3 RIGID PIPE DESIGN

For reasons previously indicatedt rigid pipes have limited use potential in leachate collection systems. In situations where they are used, their structural design should follow the recognized procedures for the various rigid pipe products available. The design of rigid pipe systems relates to the product's performance limit, expressed in terms of strength of the installed pipe. When determining field strength of rigid pipes, it is convenient to classify the *installation conditions* as either trench or embankment. For each of these conditions, bedding classes and corresponding bedding factors have been developed for use in determining and the required pipe strength.

4C-3-1 Classes of Bedding and Bedding Factors

4C.3-1.1 Trench Beddings

Four general classes of bedding for installation of rigid pipes in a trench condition are illustrated in Figure 4C.6. The bedding factor for each of the classes of pipe bedding are also listed in Figure 4C.6. Because leachate collection pipes are normally installed with granular material *surrounding* the pipe, the appropriate bedding class is usually Class B with a bedding factor of 1.9.

4C.3.1.2 Embankment Beddings

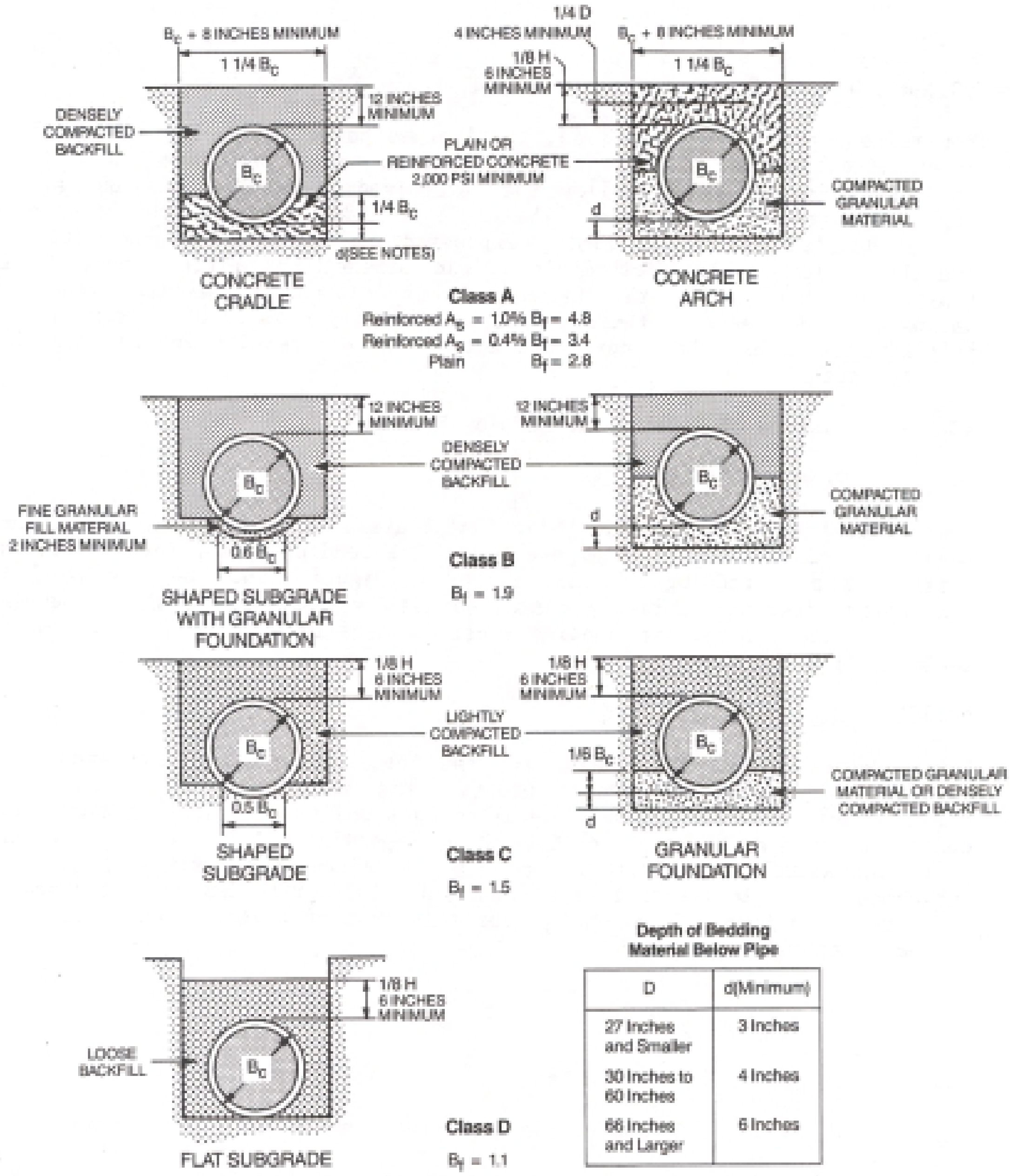
Four general classes of bedding for the installation of rigid pipes in a positive projecting embankment condition are illustrated in Figure 4C.7. Most leachate collection lines installed in a positive projecting embankment condition would have Class B or C bedding, depending on the projection ratio, p, of the actual installation. For pipe installed in a positive projecting embankment condition, active lateral pressure is exerted against the sides of the pipe. The bedding factor, Lf, for this type of installation is computed by the equation:

$$Lf \quad \frac{A}{N-xq} \qquad (4C\text{-}20)$$

where:

where:	A	Pipe shape factor
	N	A parameter that is a function of the bedding class
	x	A parameter dependent on the area over which lateral pressure effectively acts
	q	Ratio of total lateral pressure to total vertical load on the pipe

For circular pipe, A has a value of 1.431. Values of N for various classes of bedding are given in Table 4C.6. Values of x are listed in Table 4C.7.



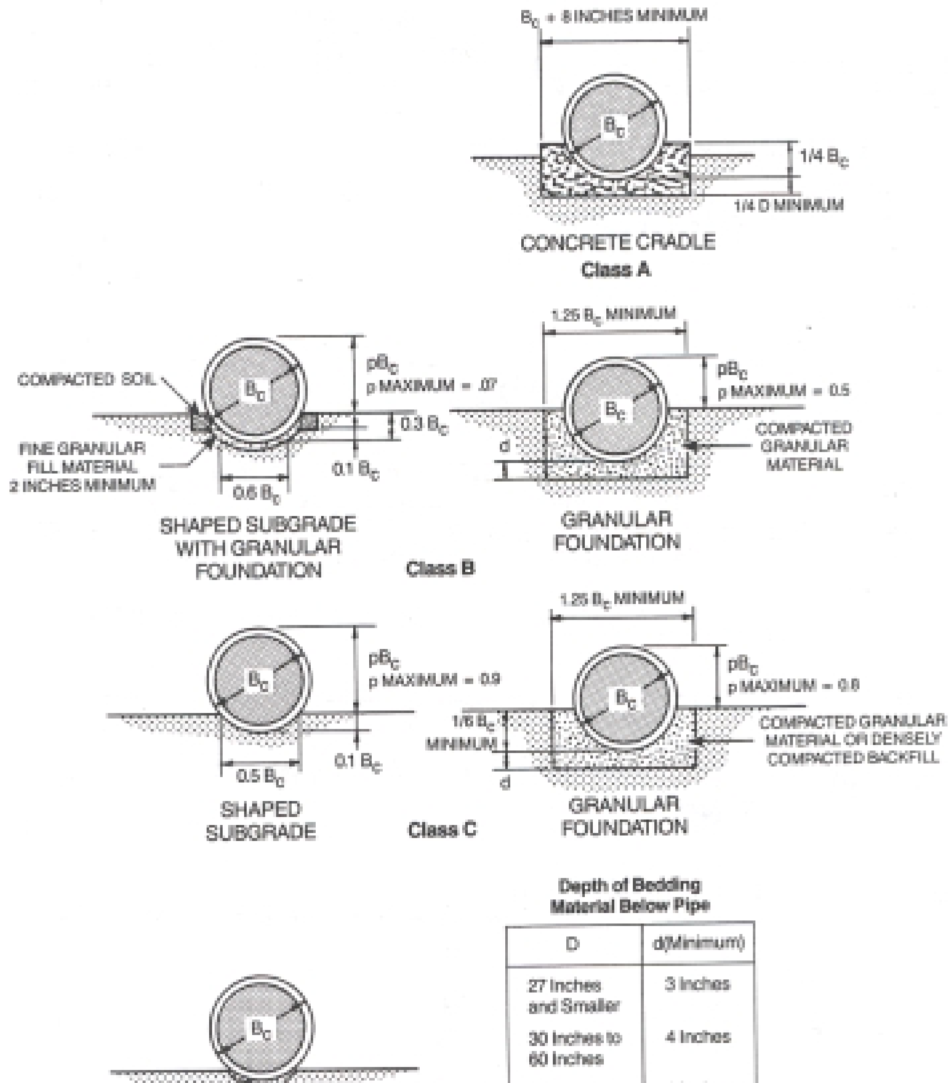
Depth of Bedding Material Below Pipe

D	d(Minimum)
27 Inches and Smaller	3 Inches
30 Inches to 60 Inches	4 Inches
66 Inches and Larger	6 Inches

Adapted From: American Concrete Pipe Association, 1980

Figure 4C.6
Trench Beddings:
Circular Pipe

B_c = Outside Diameter
H = Backfill Cover Above Top of Pipe
d = Depth of Bedding Material Below Pipe
D = Inside Diameter
A_s = Area of Transverse Steel in the Cradle of Arch Expressed as a Percentage of Area of Concrete at Invert or Crown



Depth of Bedding Material Below Pipe

D	d(Minimum)
27 Inches and Smaller	3 Inches
30 Inches to 60 Inches	4 Inches
66 Inches and Larger	6 Inches

Adapted From: American Concrete Pipe Association, 1980

Figure 4C.7
Positive Projecting Embankment Beddings: Circular Pipe

B_c = Outside Diameter
H = Backfill Cover Above Top of Pipe
D = Inside Diameter
d = Depth of Bedding Material Below Pipe

Table 4C.6 Values of N for Circular Pipe

Class of Bedding		N
A	(reinforced cradle)	0.421 to 0.505
Aa	(unreinforced cradle)	0.505 to 0.636
B		0.707
C		0.840
D		1.310

Adapted from: ASCE and WPCF (1982)

The projection ratio, m, in Table 4C.7 refers to the fraction of the vertical pipe diameter over which lateral pressure is effective. For pressure acting on the top half of the pipe above the horizontal diameter, m equals 0.5. Values for q may be estimated by the formula:

$$q \quad \frac{mk}{C_c}\left[\frac{H}{B_c} + \frac{m}{2}\right] \qquad (4C\text{-}21)$$

where: k Ratio of unit lateral pressure to unit vertical pressure (Rankine's ratio)

A value of k equal to 0.33 usually be sufficiently accurate. Values of C_c may be found in Figure 4C.4.

Table 4C.7 Values of x for Circular Pipe

Fraction of Pipe Subjected to Lateral Pressure, m	Class A Bedding	Other Than Class A Bedding
0	0.150	0
0.3	0.743	0.217
0.5	0.856	0.423
0.7	0.811	0.594
0.9	0.678	0.655
1.0	0.638	0.638

Adapted from: ASCE and WPCF (1982)

The classes of bedding for rigid pipes installed in a negative projecting embankment condition are the same as those for the trench condition. The trench condition bedding factors listed in Figure 4C.6 should be used for negative projecting embankment installations. For leachate collection lines, this would generally be Class B bedding and a bedding factor of 1.9.

4C.3.2 Selection of Pipe Strength

The design strength of rigid pipes is commonly related to a three-edge bearing strength measured at the manufacturing plant in accordance with recognized national testing standards. For pipes installed under specified conditions of bedding and backfilling, the required three-edge bearing strength for a given class of bedding and design load can be determined from the following:

$$\text{Required Three Edge Bearing Strength (lb/ft)} = \frac{\text{Design Load (lb/ft)} \times \text{Factor of Safety}}{\text{Bedding Factor}}$$

The strength of reinforced concrete pipe at either the 0.01-inch crack or ultimate load divided by the internal diameter of the pipe is defined as the D-load strength. The D-load concept provides strength classification of pipe independent of pipe diameter. The required three-edge -bearing strength of reinforced concrete pipe expressed as D-load is determined by the following equation:

$$\text{D-Load (lbs)} = \frac{\text{Design Load (lbs/ft)} \times \text{Safety Factor}}{\text{Bedding Factor} \times \text{Diameter (ft)}}$$

The above equations are applicable to rigid pipes installed in both trench conditions and embankment conditions. After determining the design load, the selection of the pipe strength involves applying the appropriate safety factor and bedding factor for the installation conditions in either of the above equations.

4C.4 FT BLE PIPE DESIGN

4C.4.1 General Approach

Flexible pipes derive the majority of their load supporting ability from the passive resistance of the soil in side fills as the pipe deflects under load. Because of this resistance, it is important ' to examine the interaction between the bedding or fill material and the pipe, rather than simply studying pipe characteristics. The extent to which flexible pipe deflects as installed is most commonly used as a basis for design since it reflects this interaction. The approximate long-term deflection of flexible pipe in place can be calculated using the Modified Iowa Formula developed by Spangler and Watkins (ASCE and WPCF, 1982):

$$Y = \frac{D_l K_b W_c r^3}{EI + 0.061\, E' r^3} \qquad (4C\text{-}22)$$

where: Y = Vertical deflection (inches), assumed to approximately equal horizontal deflection

D_l	=	Deflection lag factor
K_b	=	Bedding constant
W_c	=	Load (lbs/inch)
r	=	Mean radius of pipe (inches)
E	=	Modulus of tensile elasticity (lbs/sq in)
I	=	Moment of inertia per length (in0n)
E'	=	Modulus of soil reaction (lbs/sq in)

The above equation can be rewritten to express pipe deflection as a decimal fraction of the pipe outside diameter, Bc, and relate it to the vertical stress on the pipe, Pv, as follows:

$$\frac{W_C}{B_c} = P_v = \frac{Y(EI + 0.061\ E'n^3)}{B_c(D_l K_b r^3)} \qquad (4C\text{-}23)$$

Pipe manufacturers may establish limits for pipe deflection or vertical stress on the pipe (P_v). Maximum vertical stress is often referred to as critical buckling pressure.

The deflection lag factor, D^1, compensates ' for time consolidation of the bedding, which may permit flexible pipes to continue to deform after installation. Long-term deflection will be greater with low degrees of compaction of the bedding in the side fills compared to higher degrees of compaction. Values recommended for this factor range from 1.25 to 1.50 (ASCE and WPCF, 1982), although values over 2.5 have been recorded in dry soil. A deflection lag factor of 2.0 may be realistic for design of leachate collection pipes if weathering and/or softening of the bedding material is likely to occur over the life of the landfill or if the bedding material is rounded or may be placed with minimal compaction (Dietzler, 1984).

Values for the bedding constant, Kb, are listed in Table 4C.8. Spangler's data suggested a Kb value of 0.10 for pipe embedded in native soil with no bedding and a Kb value of 0.083 for pipe embedded in gravel up to the spring line. The installation of leachate collection pipes is more closely represented by the latter case, and a Kb value of 0.083 should therefore be used in lieu of actual field data.

Table 4C.8. Values of Bedding Constant, Kb-

Bedding Angle (Degrees)	K_b
0	0.110
30	0.108
45	0.105
60	0.102
90	0.096
120	0.090
180	0.083

Source: ASCE and WPCF (1982)

Values for the soil reaction modulus, El, range from 0 to 3,000, depending on the soil type of the bedding material and relative degree of compaction (ASCE and WPCF, 1982). The use of a high value for El is not realistic for leachate collection pipes in many localites (Dietzler, 1984). In a situation where a rounded river gravel will be used for the bedding material and a high degree of compaction may be unobtainable in the bedding around the leachate collection pipe, aa realistic value for E, of 400 may be appropriate (Dietzler, 1984).

The first term in the denominator (EI) of the Modified Iowa Formula is the stiffness factor and reflects the influence of the inherent stiffness of the pipe on deflection. The second term, 0.061 Eld, reflects the influence of the passive pressure on the side of the pipe. With flexible pipes, the second term is normally predominant.

After the allowable strain level in the pipe has been determined, the design procedure for flexible pipes is to perform a trial and adjustment analysis to find a class of pipe that will result in deflections less than the established limit. There are slight variations in the procedure for the various types of flexible pipe.

4C.4.2 Selection of Plastic Pipe

The standard test to determine pipe stiffness or the load deflection characteristic of plastic pipe is the parallel-plate loading test conducted in accordance with ASTM D 2412. The test determines the pipe stiffness, PS, at a prescribed deflection, Y, which for convenience in testing is arbitrarily set at 5 percent. The pipe stiffness is defined as the value obtained by dividing the load per unit length, F, by the resulting deflection at the prescribed percentage deflection:

$$PS = \frac{F}{Y} \qquad (4C\text{-}.24)$$

The stiffness factor, SF, in the Modified Iowa Formula is related to the pipe stiffness by the following expression:

$$SF = EI = 0.149r3(PS) \qquad (4C\text{-}25)$$

in which the terms are as previously defined.

For circular plastic pipes, the approximate deflection based on pipe stiffness can be determined by using the following simplified version of the Modified Iowa Formula:

$$Y = \frac{D_1 K_b W_c}{0.149(PS) + 0.061\,E'} \qquad (4C\text{-}26)$$

The pipe stiffness for the various plastic pipe materials and diameters of pipe may be obtained from the manufacturer or may be determined by tests performed in accordance with ASTM D 2412.

4C.4.3 Selection of Other Flexible Pipes

Flexible pipes of material other than plastic, such as ductile iron and corrugated metal, have little potential for general use in leachate collection systems for reasons previously discussed. However, if they are found suitable for a specific installation, their structural design should follow recognized procedures for the particular flexible pipe being considered. Procedures for designing ductile iron and corrugated metal pipes are described in ASCE and WPCF (1982). Manufacturers of the specific products should also be consulted.

4C.4.4 Bedding Material

Bedding provides a: contact between a pipe and the foundation on which it rests. The total load that a pipe will support depends on the width of the contact area and the quality of the contact between the pipe and the bedding material. The influence of the bedding on the supporting strength of the pipe is a factor that must be considered in the design of a leachate collection pipe. This section discusses bedding material considerations. More detailed requirements are given in previous sections of this Appendix.

An important consideration in selecting a material for bedding is positive contact between the bed and the pipe. A well-graded crush stone or a well-graded gravel are suitable bedding materials based on supporting strength considerations, and both are more suitable than a uniformly graded pea gravel (ASCE and WPCF, 1982). Larger particle sizes give greater stability; however, the maximum size and shape of the bedding material should be related to the pipe material and the recommendations of the manufacturer. For small pipes, the maximum size of the bedding material should be limited to about 10 percent of the pipe diameter and, in general, well-graded crush stone or gravel ranging in size from 3/4 inch to the No. 4 sieve will provide the most satisfactory pipe bedding (ASCE and WPCF, 1982).

In addition to providing support, bedding for leachate collection pipes must allow unrestricted flow of leachate through the bedding into the perforated leachate collection pipes. The bedding material must also be resistant to attack from the leachate. Redundancy in the design of leachate collection systems is important to minimize the effects of failures when they occur. One of the primary ways to provide redundancy is to design the bedding to meet drainage requirements through the gravel layer alone if flow through the pipe is restricted (Bass, 1984).

A well-graded material with 100 percent passing the 1-1/2 inch clear, square screen openings and not more than 5 percent passing the No. 50 U.S. Standard Series sieve is recommended for drainage purposes (U.S. Department of the Interior, 1978). To determine whether the material is well-graded, the coefficient of uniformity which describes the slope of the gradation curve must be greater than 4 for gravels and greater than 6 for sands. In addition, the coefficient of curvature that describes the shape of the curve must be between 1 and 3 for both gravels and sands. These coefficients are defined as follows:

$$\text{Coefficient of uniformity, } C_u = \frac{D60}{D_{10}} \qquad (4C\text{-}27)$$

and

$$\text{Coefficient of curvature, } C_c = \frac{(D30)_2}{(D_{10})(D_{60})} \qquad (4C\text{-}28)$$

where: D_{10}, D_{30}, and D — Diameter of particles in millimeters passing the 10, 30, and 60 percent points, respectively, on the base material gradation curve.

Based on the above criteria for supporting strength and drainage, a bedding material for leachate collection pipes should be well-graded gravel with the following properties:

Gradation:	100% passing 1-1/2" sieve 5% maximum passing No. 50 sieve
C_u:	4.0 or greater
C_c:	1.0 to 3.0

The actual bedding material should be selected within these limits after consideration of the pipe material, availability of bedding material, and its resistance to leachate attack.

APPENDIX 4D
SOIL LOSS EQUATIONS

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APPENDIX 4D

SOIL LOSS EQUATIONS

4D.1 THE UNIVERSAL SOIL LOSS EQUATION (USLE)

Estimates of soil erosion by precipitation and runoff and evaluation of grading alternatives including angle of slope and length of slope (controlled by terracing) can be made using the Universal Soil Loss Equation (USLE), presented in (Lutton, et al., 1979):

$$A = RKLSCP \qquad (4D\text{-}1)$$

where:
A = average soil loss in tons per acre
R = rainfall and runoff erosivity index
K = soil erodibility factor
LS = slope-length factor
C = cover/management factor
P = erosion control practice factor

The erosivity index, R, varies with individual storms, but annual averages are available. Figure 4D.1 provides annual averages of "R11 for Washington.

The soil erodibility factor, K is a factor that can be influenced by design specifications. It is a function of the grain size distribution, organic matter content, structure and permeability of the soil (Lutton, et al., 1979). Normally, however, other factors control the specification of the topsoil other than "KII, and the designer must mitigate erosion through other means. Initial estimates for "KII can be made from Table 4D.1, while more accurate determinations can be made using the nomograph in Figure 4D.2.

The values shown in Table 4D.1 are estimated averages of broad ranges of specific-soil values. When a texture is near the borderline of two texture classes, use the average of the two K values.

The slope-length factor (LS) can be influenced by varying the steepness and length of slopes on a final cover. The "LS" factor can be estimated from Figure 4D.3. If irregular slopes exist over the surface of the landfill, use the average slope over the length. If the average slope is used in determining the 'ILS" factor and the actual slope is convex, erosion will be underestimated. If the actual slope is concave, erosion will be overestimated (Novotny and Chesters, 1981). Of the factors in the USLE, the designer has greatest control and flexibility with the "LS" factor

The cover/management factor, C, is important and can be influenced by the designer. This factor considers the impact of vegetation against soil erosion. Specification of a good topsoil and seed mix will enhance vegetative growth. Table 4D.2 illustrates the sizeable effect of vegetation on reducing soil erosion.

The erosion control practice factor, P, is normally not a significant factor in estimating landfill erosion control. The recommended value for "P" for a rough, irregular surface with equipment tracks in all directions is 0.90 (Novotny and Chesters, 1981).

Table 4D.1. Approximate Values of Factor K for U.S.D.A. Textural Classes.

	Organic Matter Content		
	<0.5%	2%	4%
Texture Class	K	K	K
Sand	0.05	0.03	0.02
Fine sand	.16	.14	.10
Very fine sand	.42	.36	.28
Loamy sand	.12	.10	.08
Loamy fine sand	.24	.20	.16
Loamy very fine sand	.44	.38	.30
Sandy loam	.27	.24	.19
Fine sandy loam	.35	.30	.24
Very fine sandy loam	.47	.41	.33
Loam	.38	.34	.29
Silt loam	.48	.42	.33
Silt	.60	.52	.42
Sandy clay loam	.27	.25	.21
Clay loam	.28	.25	.21
Silty clay loam	.37	.32	.26
Sandy clay	.14	.13	.12
Silty clay	.25	.23	.19
Clay		0.13-0.29	

Source: Lutton, et al. (1979)

The significance of the USLE is not the absolute number that the equation will provide, but rather the comparison of predicted erosion values for various design options. The use of the USLE allows objective evaluation of the erosion potential of various cover designs and selection of the one that is most effective. For comparative purposes, natural erosion rates are estimated to be around 0.18 tons per acre per year, while sediment yields from developing urban areas have been reported -as high as 225 tons per acre per year (Novotny and Chesters, 1981).

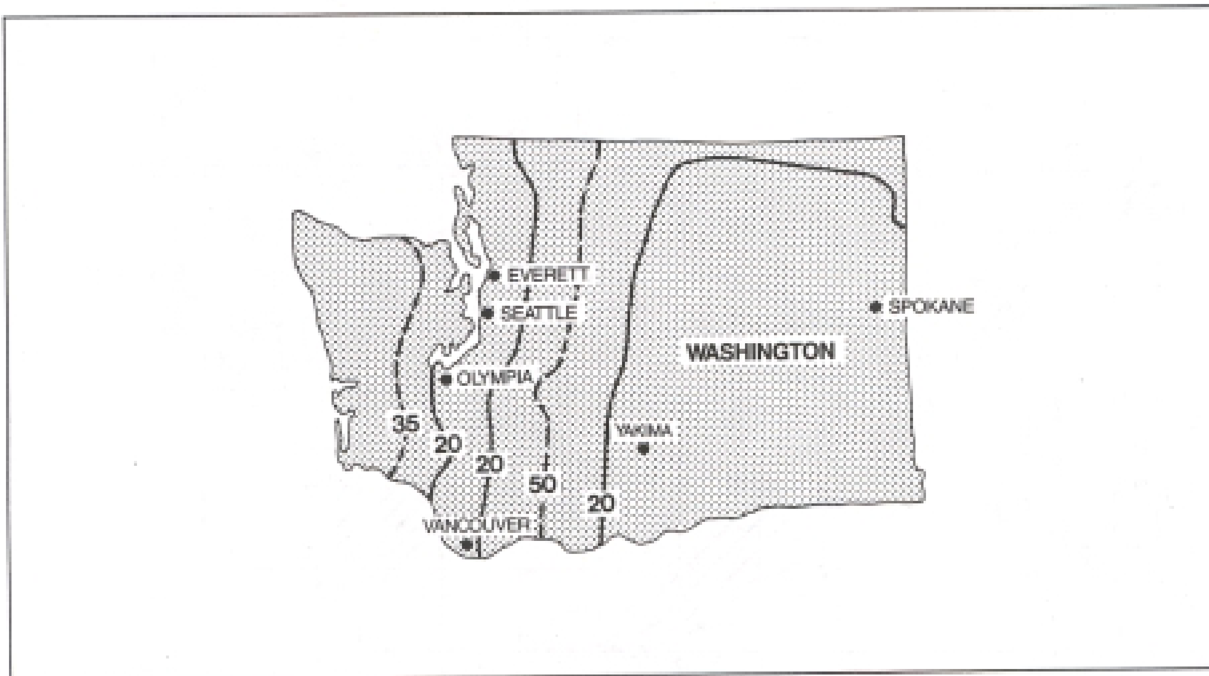


Figure 4D.1
Average Annual Values of Rainfall-Erosivity Factor R

Adapted From: Lutton, et. al., 1979

Table 4D.2. Values of C for Idle Land

	C
Ground cover 95-100%	
As grass	0-0E
As weeds	0.01
Ground cover 80%	
As grass	0.01
As weeds	0.04
Ground cover 60%	
As grass	0.04
As weeds	0.09
No ground cover	1.00

Source: Novotny and Chesters, (1981)

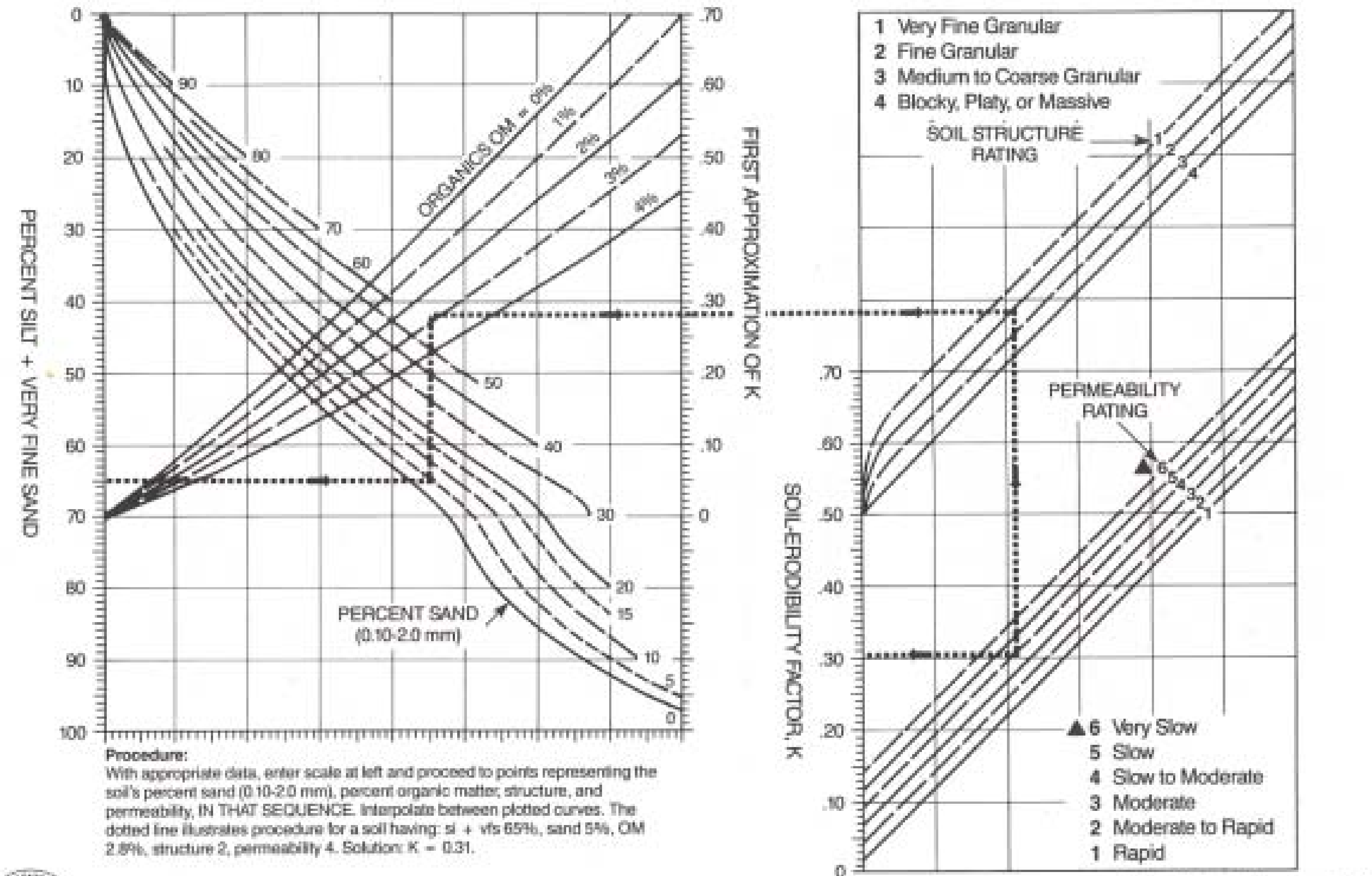
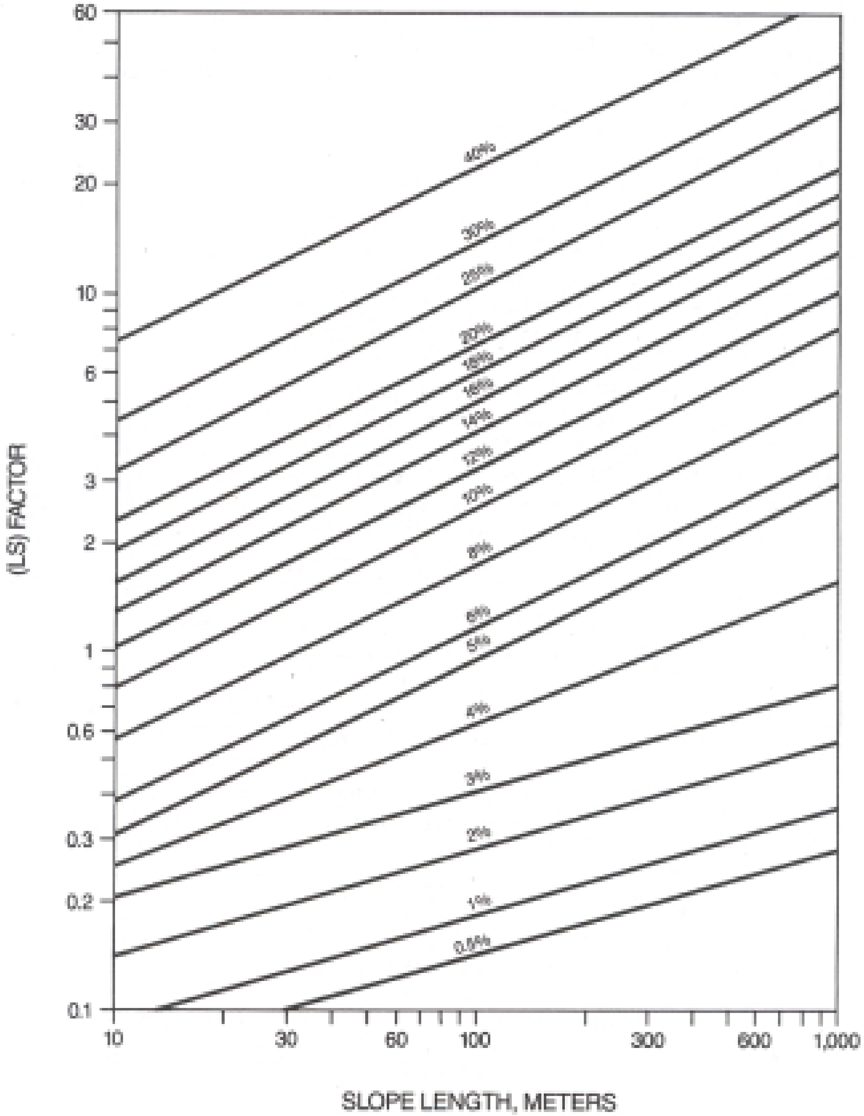


Figure 4D.2
Nomograph for Determining Soil Erodibility Factor K



WDOE Solid Waste

Adapted From: Novotny and Chesters, 1981

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Figure 4D.3
Length-Slope Factor (LS) for Different Slopes

4D.2 VIM EROSION ROUATION (WEE)

Wind erosion can be another significant problem, particularly in dry climate and open areas. Equation (0-2) is the wind erosion equation (WEE), another empirical relationship that is used to estimate the annual loss of soil due to wind erosion (Lutton, et al. 1979).

$$A = f(K,C,L,T,V) \qquad (4D\text{-}2)$$

where: K = soil erodibility
T = soil ridge roughness factor
C = climatic factor
L = field length along prevailing wind direction
V = equivalent quantity of vegetative cover ,

Because the factors in the WEE are interrelated, its solution is not a simple product of the above factors. Lutton, et al. (1979) provides various graphs and nomograms for solving the WEE and the reader is referred to this reference for specific applications. However, Figure 4D.4 is provided to illustrate the effect of two important factors in controlling wind erosion, soil grain size and vegetative cover. Figure 4D.4 shows the effect of the fraction of soil particles smaller than 0.84 mm (U.S. Standard Sieve No. 20) on the erodibility of the soil. There is a rapid increase in soil erodibility as the percentage of soil particles less than 0.84 mm increases. In the USCS, soil particles of 0.84 mm diameter are considered medium sands.

Figure 4D.4 also illustrates the importance of vegetative cover in reducing the amount of wind erosion.. For example, if A4 in Figure 4D.4 equals 10 and the equivalent vegetative cover is 0.0 lb/acre, the annual erosion would be 10 tons/acre. Establishing an equivalent vegetative cover of 3000 lb/acre would reduce the erosion to 1.8 tons/acre, a decrease of 82 percent.

In addition to wind and water erosion protection, the top cover also prevents the barrier layer from drying out. Since the barrier layer is normally a clay or silt material, such drying out would lead to cracking and subsequent increases in the permeability of the layer. There are two ways to increase the moisture holding capacity of the top layer: 1) increase the thickness of the top layer; or 2) add other materials to the soil to increase its moisture holding capacity. The addition of fine-grained soils like silts and clays or organic material like straw, increase the moisture holding capacity of a course-grained soil. The availability of soil moisture protects the barrier layer and ensures -,that the vegetative cover will have sufficient water to survive without irrigation.

A water balance study will determine if the soil moisture capacity, is adequate. If the results of this study show soil moisture reaching zero, then modifications must be made to increase the moisture holding capacity.

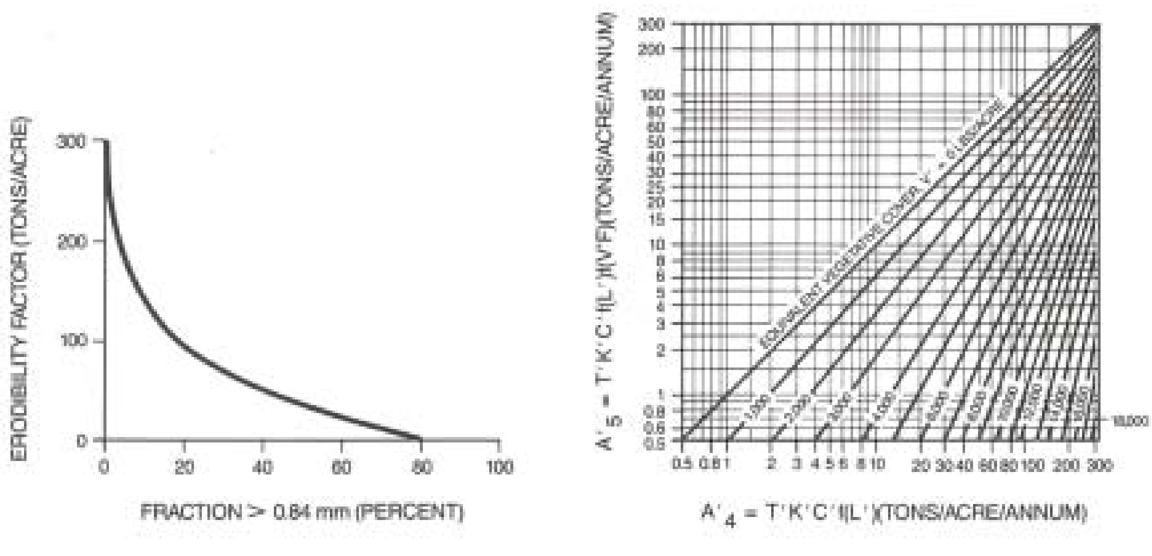

Figure 4D.4
Wind Erosion Graphs

Adapted From: Lutton, et. al., 1979

APPENDIX 4E

WONG'S METHOD FOR LEACHATE COLLECTION SYSTEM DESIGN

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APPENDIX 4E

WONG'S METHOD FOR LEACHATE COLLECTION SYSTEM DESIGN

4E.1 BACKGROUND

The performance evaluation of a leachate collection system in a lined landfill is technically feasible after the installation is in place and operational. However, from a practical point of view, modification of the system after construction, including refuse placement, is considered unacceptable. A preferable method would be to be able to rationally evaluate a collection system/liner design to predict the amount of liquid collected, the depth to which the liquid would rise over a liner, and the amount of leakage through the liner prior to construction.

Only recently have acceptable methods for evaluating the effectiveness of various landfill leachate collection systems been developed. One was published originally by Wong (1977). His method has been modified and updated recently by the EPA (Moore, 1983). The technical and mathematical approaches presented in the reference are complex; however, linearized versions of these complex mathematical equations are provided, as well as simplified boundary conditions. The net result is a rational approach, using essentially conventional algebraic techniques, which allows a greater number of users, both regulator and designer, to use a valuable tool.

The other method discussed in this manual is the HELP model (Section 4.10). This computer model provides performance evaluation information by predicting leakage through the liner and lateral flow through the drainage layer. It allows an analysis of a wide variety of design alternatives. A comprehensive and detailed user's manual is provided by Schroeder, et al. (1983) and the reader is referred there for more information.

4E.2 WONG'S METHOD

Wong (1977) derived a set of equations for evaluating the ef f iciency of leachate collection systems based on Darcy's Law of flow through a porous media. This method formed the basis for an evaluation procedure approved by the U.S. EPA (Moore, 1983). A modification to the method for predicting initial head was suggested by Kmet, et al. (1981).

Using Wong's method, the following factors can be evaluated to determine their affect on the collection system efficiency and the maximum depth of leachate over the liner:

- The impingement rate on the bottom liner (p)
- The bottom slope (a)
- The liner thickness (d)
- The spacing between the collection pipes (L)
- The hydraulic conductivity ratio between the liner (ks2) and the
- drainage layer (k_{s1})

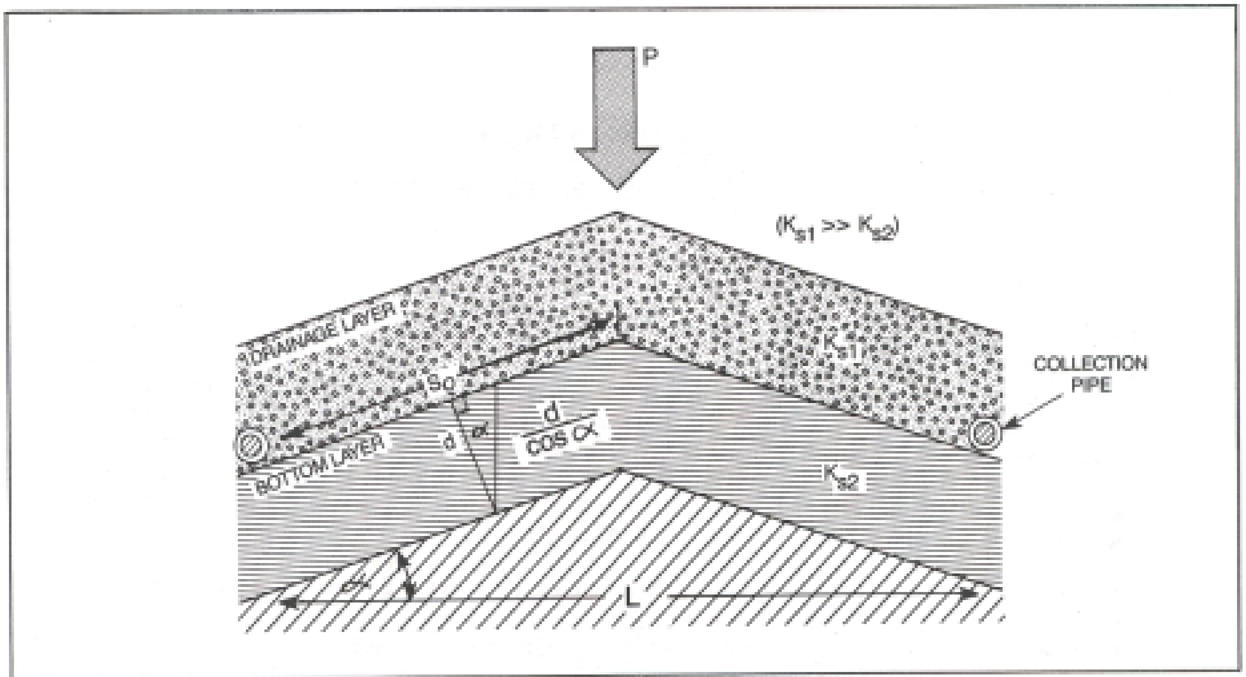


Figure 4E.1
Factors in Collection System Evaluation

These variables are illustrated in Figure 4E.1.

Additional parameters of interest are as follows:

- Porosity of the collection layer aggregate (n)
- Depth of leachate at time t=O (HO)
- Depth of leachate at time t (Ht)
- Length of saturated volume at time t=O (SO)
- Length of saturated volume at time t (St)
- Time to drain horizontally through the drainage layer (tj)
- Time to percolate through the barrier layer (t2)
- Volume in the drainage layer at time t=O (VO),
- Volume collected by the drain pipes at time t (Vc)
- Volume percolated through the liner at time t (Vp)
- Volume remaining in the drainage layer at time t (Vr)

The basic equations for St, Ht, tj and t2 were derived by Wong (1977) and are repeated in Moore (1983) and, with some modifications, by Kmet, et al. (1981).

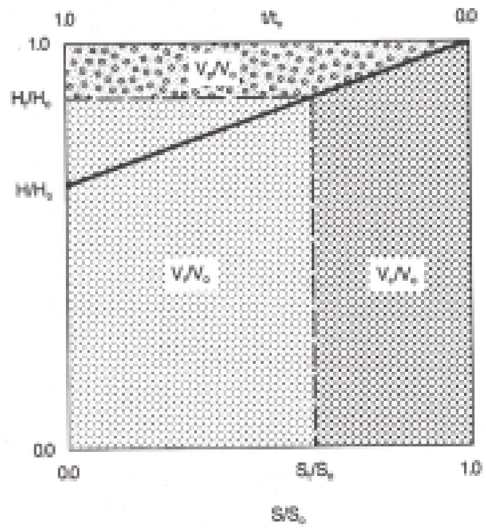


Figure 4E.2
Diagram for Computing Efficiency of Liner/Drain Systems

Figure 4E.2 is derived from the collection efficiency diagram presented by Wong (1977). It illustrates the derivation of the following equations:

$V_c/V_o = [(H_t/H_o)+1]/2*(t/t_l)$ for $H_t > 0$ (4E-1)

$V_p/V_o = [(S_t/S_o)+1]/2*[1-(H_t/H_o)]$ for $H_t > 0$ (4E-2)

$V_r/V_o = (H_t/H_o)*(S_t/S_o)$ (4E-3)

where:

V_c/V_o percent of infiltrated precipitation that is diverted off the site via the collection pipes at time t

V_p/V_o percent of infiltrated precipitation that percolates through the liner at time t

V_r/V_o percent of infiltrated precipitation that remains in the drainage layer at time t

The above equations can be rewritten by multiplying both sides by V_o. The equations would then provide estimates for the volumes of leachate collected in the pipes, percolated through the liner and remaining in the drainage layer.

These equations can be used in conjunction with some of the water balance models discussed in Section 4.10 to evaluate design options for the leachate collection system. Starting at the beginning of the water year (normally October), the estimated monthly percolation through the cover is assumed to impinge on the liner and rise to an initial depth of Ho. Instantaneously, the leachate begins to percolate through the bottom liner and flow horizontally toward the collection pipe. At the end of the month, that leachate which did not reach the collection pipes and did not percolate into the bottom liner (this would be volume V_r) can be assumed to be redistributed uniformly over the entire flow distance (S_o). In addition, the next month's estimated percolation is assumed to impinge on the, liner and together they are summed to create a new H_o. This process can be repeated throughout the twelve months of the year to include one full climatic cycle.

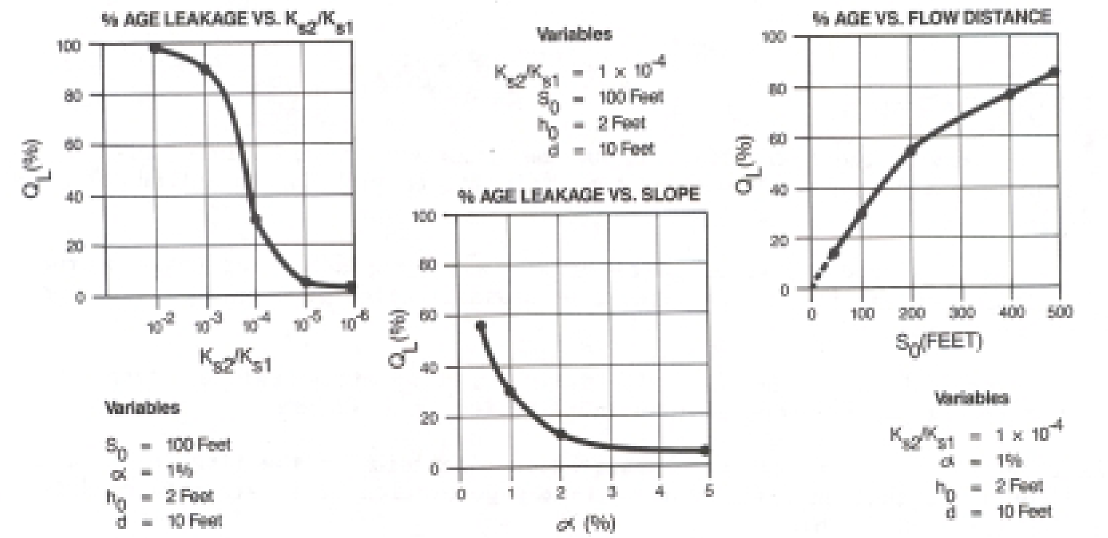
The value of this analysis is that the key leachate collection system design criteria (hydraulic conductivity of the drainage layer, slope of the bottom, and distance between collection pipes) can be evaluated to find the optimum combination that prevents the maximum leachate depth during any month from exceeding the two foot standard mandated by the Minimum Functional Standards. Once this is achieved, the model will provide estimates of the efficiency of the system and annual volumes of leachate collected in the pipes and lost through the bottom liner.

This procedure can easily be programmed on microcomputers and some of the more powerful hand-held calculators. The designer can quickly investigate a large number of design options and select the most cost effective one. The method can also be applied to the final cover system.

Kmet, et al. (1981) investigated the effects of the variables in Wong's method on the efficiency of the collection system. Figure 4E.3 illustrates the effect of three of the most significant factors in the design: the ratio of hydraulic conductivities between the barrier layer and the drainage layer, the slope of the liner, and the flow distance of the leachate.

Figure 4E.3 shows the dramatic effect of the hydraulic conductivity ratio on the efficiency of the system. An order of magnitude change from 10-3 to 10-4 can improve the efficiency of the design by approximately 60 percent. Figure 4E.3 also demonstrates the importance of liner slope on the collection system efficiency. There is rapid improvement in system efficiency until the slope reaches about 2 percent. Leachate flow distance also has an effect. Unlike hydraulic conductivity ratio and slope, there is no obvious inflection point indicating an optimum value.

In summary, Kmet et al., (1981) recommended a series of design parameters for collection systems. These included both optimal values and lower efficiency limits. An optimal value is one where further modifications would not yield significant reductions in leakage. Lower efficiency design limits represent values for which an increase or decrease would allow significantly more leakage. The values are reproduced in Table 4E.1. It should be stressed that these are for general guidance only and each landfill site should be evaluated individually to determine the optimum design using site specific conditions.



Adapted From: Kmet, et. al., 1981

Figure 4E.3
Effects of Design Parameters on Leakage

Table 4E.1. Recommended Optimal and Lower Efficiency Limit Design Parameters

Parameter	Optimal Value	Lower Efficiency Limit
k_{s2}/k_{sl}	1×10^{-4}	5×10^{-4}
∝	4 to 6 feet	2 feet
	5 percent	2 percent
S_o	50 feet[1]	150 feet

SOURCE: Kmet, et al. (1981)

[1] No apparent optimal value for this parameter exists. Fifty feet has been chosen because a lesser flow distance is not considered practical in the field.

4E - 3 LIMITATIONS

Like any model, there are limitations and uncertainties associated with the use of this procedure. There are two basic faults with Wong's Method (Wong, 1977).

- • First, the model assumes there is an instantaneous head of water on the liner and the instant it appears it begins to flow through the liner and the drainage layer.

- • Second, it also assumes the water is completely removed from the drainage layer before another infiltration event occurs.

Kmet, et al. (1981) presented a qualitative discussion of the first condition and concluded that on a relative basis the generation of a saturated head is an instantaneous event.

The second condition is not met however. All the water is not removed (a portion, Vr, remains) before another infiltration event occurs. The remaining water is assumed to be redistributed over the entire length of the drainage layer prior to the next infiltration event. This is not what is actually happening in the real system and is an obvious flaw in the model.

Nonetheless, the model is believed to be a reasonable approximation of conditions in the field. It can be set up using commercially available computer spreadsheet software and can be run with data that is readily available. When carefully applied and interpreted, the model can provide the designer a means of evaluating a wide variety of design variables.

APPENDIX 4F
SUMMARY OF LEACHATE TREATMENT PROCESS METHODS

Appendix F Summary of leachate treatment process units

Treatment Method	Feed Stream Requirements and Limitations	Major Design and Performance Criteria	Environmental Impact	Technology Status	Reliability
Biological activated sludge	Can handle BODS of 10,000 ppm Requires low level of suspended solids - usually $\leq$ 1% Oil and grease should be less than 50 mg/l Effective for readily degradable organics or organics to which it can be acclimated Sensitive to heavy metals	Detention time Organic Load Food to microorganism ratio Aeration	Generate excess sludge containing refractory organics that have been sorbed	Highly developed; widely used	Process reliability ability is very good in absence of shock loads (sudden peaks or valleys in loading concen-trations)

Appendix F Summary of leachate treatment process units (Continued)

Treatment Method	Feed Stream Requirements and Limitations	Major Design and Performance Criteria	Environmental Impact	Technology Status	Reliability
Rotating biological disc	Suitable for treatment of readily degradable organics; can handle higher organic loads than trickling filter but lower than activated sludge Better suited to treatment of suspended or colloidal organics than soluble As with other biological processes, sensitive to oil and grease and metals	Detention time Hydraulic load Organic load Temperature Number of stages and trains	Generates sludge containing refractory organics and sorbed metals; may cause odors	Process is relatively new, not widely used but gaining in popularity	Moderate in the absence of high organic loads and temperature > 55^0F

Appendix F (Continued) Summary of leachate treatment process units

Treatment Method	Feed Stream Requirements and Limitations	Major Design and Performance Criteria	Environmental Impact	Technology Status	Reliability
Trickling filter	Can handle only very low organic loads as compared with activated sludge Better suited to treating suspended and colloidal organics rather than soluble ones As with other biological processes, sensitive to metals and oil and grease	Media type Hydraulic load Organic load Bed depth Temperature Recirculation	Generates sludge that contains refractory organics and sorbed metals;	Widely used as roughing filter for industrial wastes	Fair for secondary treatment; moderate as a roughing filter

Appendix F (Continued) Summary of leachate treatment process units

Treatment Method	Feed Stream Requirements and Limitations	Major Design and Performance Criteria	Environmental Impact	Technology Status	Reliability
Anaerobic, aerated facultative lagoons	Requires very low suspended solids ($\leq$ 0.1%) Requires low strength organic wastes Sensitive to heavy metals and oil and grease	Detention time Depth Organic load	May__ create odors; may release volatile and HS and methane if anaerobic; must be lined to prevent seepage into ground-water	Well demonstrated for stabilization of organics but not widely used	High if proper pH is maintained and organic strength is low; very sensitive to shock loads since there is not sludge recycle
Biological seeding	Sensitive to heavy metals, oil and grease Can degrade a wide range of organics depending upon acclimation of the culture Sensitive t same limitations as activated sludge with regard to metals, suspended solids and oil grease	Same as air-activated sludge or pure oxygen depending upon how the bacteria is used	Generates a sludge lower in refractory organics than conventional biological treatment but sludge still contains sorbed metals	Use of acclimated bacteria is wide-spread but use of commercially available cultures is not	Can increase reliability of conventional biologic treatment; in crease stability; decrease susceptibility to shock loads

Appendix F (Continued) Summary of leachate treatment process units

Treatment Method	Feed Stream Requirements and Limitations	Major Design and Performance Criteria	Environmental Impact	Technology Status	Reliability
Pure oxygen-activated sludge	Requires suspended solid levels of about 1% or less Can handle higher organic loads than conventional activated sludge and is more tolerant of shock loads Sensitive to heavy metals and oil and grease	Detention time Organic load Food to microorganism ratio Oxygen requirements	Generates sludge containing refractory organics and sorbed metals	Relatively new technology but demonstrated for some industrial waste waters	Reliability is not fully established; complex operations and requires high level of maintenance

Appendix F (Continued) Summary of leachate treatment process units

Treatment Method	Feed Stream Requirements and Limitations	Major Design and Performance Criteria	Environmental Impact	Technology Status	Reliability
Ammonia stripping	Relatively insensitive to concentration changes Requires pH of 10.8 to 11.5 Not operable at freezing temperatures	Hydraulic load pH Air flow Tower packing and depth	May result in air pollution by NH_3 or volatile organics; not a problem if recovery is implemented	Fully demonstrated but not	High if proper pH is maintained
Wet air oxidation	Solution of any organics can be oxidized if temperature and pressure are high enough Range of organics treated is about 5-150 g/l	Temperature Residence time Waste COD	Process is very clean and generates no air pollution	Relatively new process and not fully demonstrated	Process reliability has not been adequately tested; process is complex and requires use of controls

Appendix F (Continued) Summary of leachate treatment process units

Treatment Method	Feed Stream Requirements and Limitations	Major Design and Performance Criteria	Environmental Impact	Technology Status	Reliability
Precipitation/flocculation/sedimentation	No concentration limit Sensitive to hydraulic and waste load fluctuations pH-dependent	Hydraulic load Concentrations of suspended solids and precipitable soluble species pH; alkalinity Settling rate Removal requirements for subsequent treatment processes	Generates large amounts of sludge, some of which is difficult to dewater	Highly developed widely used	Moderate; effluent quality may vary considerably; would require frequent use of jar test to determine appropriate concentrations of flocculants and precipitants
Liquid ion exchange	Volume of extractants required place a practical upper limit of about 10 g/l Sensitive to oxidants, surfactants, and suspended solids Suitable for treatment of anions, cations, metal oxyanions, and weak acids	Waste type and load Hydraulic load Mode of operation Regeneration requirements	Generates a highly concentrated regeneration solution; also clean stream may contain low con- of organic phase that should be removed	Fairly well developed but rarely used especially for dilute waste streams	

Appendix F Summary of leachate treatment process units (Continued)

Treatment Method	Feed Stream Requirements and Limitations	Major Design and Performance Criteria	Environmental Impact	Technology Status	Reliability
Ion exchange	Because of regeneration requirements, concentration should be less than 2,500 ppm (expressed as calcium carbonate) or 0.05 equiv/l; may accept up to 4,000 ppm	Waste type and load	Generates a highly concentrated regeneration solution	Fully developed but not widely used	Moderate for fixed bed; and fair for continuous systems requires a high degree of monitoring and inspection
		Hydraulic load			
		Mode of operation			
	Suitable for treatment of all soluble metal cations or anions, anionic halides, cyanides, nitrates, and some acids	Regeneration requirements			
		Resin absorption capacity			
	Sensitive to suspended matter, oxidants and some organics, especially aromatics				

Appendix F (Continued) **Summary of leachate treatment process units**

Treatment Method	Feed Stream Requirements and Limitations	Major Design and Performance Criteria	Environmental Impact	Technology Status	Reliability
Carbon Absorption	More amenable to treatment of certain classes of organics Treat organics to an upper limit of about 10,000 ppm TOC Oil and grease should be less than 10 ppm Suspended solids should be less than 50 ppm Where organics are being removed, concentrations of less than 500 ppm are advisable	Organic load Hydraulic load Contact time Regeneration and backwash requirements	May be emissions from thermal regeneration but these can be controlled with scrubbers or afterburners; where there is no regeneration spent carbon may be considered a hazardous waste	Highly developed and widely used	Moderate depending design and equipment quality; insensitive to toxics but subject to clogging with high SS and oil and grease; isotherms may give a artificial results of process
Chlorination	pH and temperature-dependent	Temperature and pH Contact time Mixing Presence of interfering compounds	Can cause formation of chlorinated organics and release of chlorine gas	Fully developed and widely used	High; operation is simple

Appendix F (Continued) **Summary of leachate treatment process units**

Treatment Method	Feed Stream Requirements and Limitations	Major Design and Performance Criteria	Environmental Impact	Technology Status	Reliability
Carbon Absorption	More amenable to treatment of certain classes of organics Treat organics to an upper limit of about 10,000 ppm TOC Oil and grease should be less than 10 ppm Suspended solids should be less than 50 ppm Where organics are being removed, concentrations of less than 500 ppm are advisable	Organic load Hydraulic load Contact time Regeneration and backwash requirements	May be emissions from thermal regeneration but these can be controlled with scrubbers or afterburners; where there is no regeneration spent carbon may be considered a hazardous waste	Highly developed and widely used	Moderate depending design and equipment quality; insensitive to toxics but subject to clogging with high SS and oil and grease; isotherms may give a artificial results of process
Chlorination	pH and temperature-dependent	Temperature and pH Contact time Mixing Presence of interfering compounds	Can cause formation of chlorinated organics and release of chlorine gas	Fully developed and widely used	High; operation is simple

APPENDIX 4G

SPACING PASSIVE HORIZONTAL GAS COLLECTION PIPES

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APPENDIX 4G
SPACING PASSIVE HORIZONTAL GAS COLLECTION PIPES

4G.1 INTRODUCTION

The control of methane gas migration to below dangerous levels should be the goal of any gas control system. The Washington State Department of Ecology's Minimum Functional Standards for solid waste handling (WAC 173-304-460) require methane concentrations less than the lower explosive limits (5% by volume) at the landfill property boundary or beyond and less than 100 parts per million methane by volume in off-site structures. Therefore, upon construction or closure of a landfill, facilities to reduce methane migration or provide for ready collection of methane within the landfill may be required.

4G.2 FLOW BY DIFFUSION

Methane moves by way of diffusive (concentration gradient) and convective (pressure gradient) mechanisms. Diffusive flow of gas is in the direction of decreasing concentration. Diffusion within a landfill may occur by ordinary diffusion, Knudsen diffusion, and surface migration (Schumacher 1983). While diffusion can be an important element in lateral migration of methane, its effect is minimal where naturally occurring pressures are, high within the landfill or when an induced exhaust system is used to increase the landfill pressure gradient (Moore 1979, Schumacher 1983).

4G.3 FLOW BY CONVECTION

In systems where a natural or induced pressure gradient occurs, convective mechanisms will be the primary means of gas flow (Schumacher, 1983). Therefore, the method of removing methane from a landfill is by producing a pressure/concentration sink to which the gas will flow. Darcy's Law has been used to characterize the flow of gas through the refuse (Findikakis and Leckie 1979). Using Darcy's equation and the assumption that as methane is produced it is simultaneously removed by convective mechanisms, the following mathematical expressions were derived:

Darcy's Equation:

$$q = K*m1*(1/s.w.)*((P2-P0/L) \quad (4G-1)$$

where: q = gas flow per unit width (ft2/hr)
K = refuse permeability (ft/hr) ml = depth of saturated gas flow (ft)
s.w. = specific weight of landfill f as (lbf/ft^3)
P1 = atmospheric pressure (lbf/ft

p^2 = landfill gas pressure (lbf/ft^2)
L = flow length (ft)

The total flow out of a given width of refuse is:

$$Q \quad K*ml*(l/s.w.)*((P2-Pl)/L)*w \qquad (4G.-2)$$

where: Q = gas flow (ft^3/hr),
w = width of flow (ft).

Rearranging terms and isolating flow length on the left:

$$L = K*ml*w*(l/s.w.)*((P_2/P_l)/Q) \qquad (4G-3)$$

Assuming gas flow is equal to gas production, the following equation applies:

$$Q = R*(L*w*m2)*D/(8760) \qquad (4G-4)$$

where: R = gas production rate ($ft^3/yr\text{-}lbm$),
m_2 = depth of refuse (ft),
D = refuse density (lbm/ft^3).
8760 = time conversion (hr/yr).

Substituting Equation 4G-4 into Equation 4G-3 and combining flow length terms on the left:

$$L^2 = (K*(m_l/m_2)*(l/s.w.)*(P_2-P_l)*(8760))/R*D \qquad (4G-5)$$

Because gas will flow to a trench from both directions within the landfill, the spacing of trenches will be twice the gas flow length or:

$$S = 2(L) \qquad (4G-6)$$

where: S = trench spacing (ft).

Darcy's equation has been used to describe the flow of gas in several landfill gas models. However, the equation applies only to laminar flow, not to -turbulent flow (Schumacher, 1983). In most systems, especially in a passive system without an induced pressure gradient, it has been shown that flow is indeed laminar.

4G. 4 APPLICATION

A passive system operates without artificially induced pressure gradients, such as a motor blower unit to create a negative pressure (vacuum) in extraction wells. Historically, passive venting systems have been designed primarily on judgment as to vent spacing and size. There is no well defined and accepted method in the literature that allows vent pipes to be spaced based on site specific conditions. The equations presented above were developed to calculate the required spacing of gas vent pipes given site specific conditions and a chosen maximum landfill, gas pressure. Typical

landfill parameters cited in several literature sources were substituted into the equations. These include the following:

Parameter	Value	Reference
Refuse permeability	$7.44x10^{-3}$ ft/hr	(Intrinsic perm. = 1.034 darcys) Fungaroli and Steiner, 1979
Depth ratio (ml/m_2)	1-0	assumed for shallow landfills
Specific weight	$7.89x10^{-2}$ lbf/ft^3	Schumacher, 1983
Gas pressure (P_2)	15.67 psf	Findikakis and Leckie, 1979
Gas production rate (R)	0.04 ft3/yr-lb	Schumacher, 1983
Refuse density	37 lb/ft3	Tchobanoglous, et al., 1977

The graph shown in Figure 4G.1 shows the required pipe spacing versus maximum landfill gas pressure. The curve was derived by inserting the parameter values listed above in Equation (4G-5). The calculation worksheet is included as Table 4G.1. Following is an example of how this equation could be used for a shallow landfill.

If typical landfill gas pressures (16 psf) are not to be exceeded, a pipe spacing of approximately 330 feet is required. The maximum flow distance that methane must travel to reach either a collection pipe or the edge of the landfill, where it can be collected in a perimeter trench, is less than 165 feet. Vertical risers, connected to the vent piping via tee couplings, could be used to vent the gas through the f inal cover. The risers would incorporate a flare to burn the gases and thereby eliminate potential odor problems.

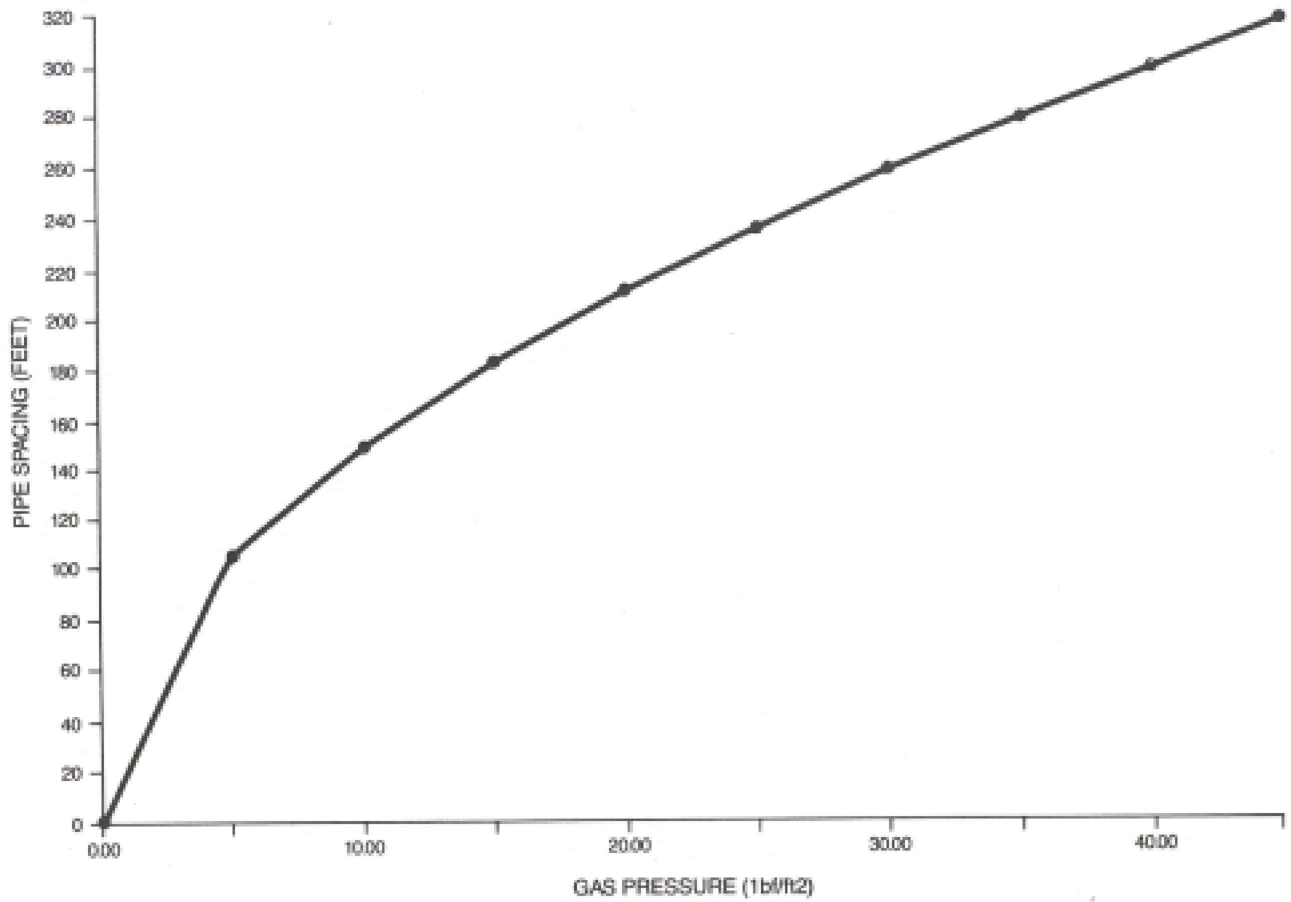

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Figure 4G.1
Gas Migration Control Pipe Spacing Versus Gas Pressure

TABLE G.1 GAS MIGRATION CONTROL - PASSIVE CONTROL SYSTEM TRENCH SPACING (BASED ON DARCY'S EQUATION)

K	7.44E-03	7.44E-03	7.44E-03	7.44E-03	7.44E-03	7.44E-03	7.44E-03	7.44E-03	7.44E-03	7.44E-03
m1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
m2	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
P2	2.09	5.57	6.38	11.50	15.67	21.73	50.00	100.00	150.00	211.70
l	15.3	24.9	26.7	35.8	41.8	49.2	74.6	105.6	129.3	153.6
L	31	50	53	72	84	98	149	211	259	307
K	7.44E-03	7.44E-03	7.44E-03	7.44E-03	7.44E-03	7.44E-03	7.44E-03	7.44E-03	7.44E-03	7.44E-03
m1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
m2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
P2	2.09	5.57	6.38	11.50	15.67	21.73	50.00	100.00	150.00	211.70
l	34.1	55.7	59.6	80.1	93.4	110.0	166.9	236.1	289.1	343.5
L	68	111	119	160	187	220	334	472	578	687
K	7.44E-04	7.44E-04	7.44E-04	7.44E-04	7.44E-04	7.44E-04	7.44E-04	7.44E-04	7.44E-04	7.44E-04
m1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
m2	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
P2	2.09	5.57	6.38	11.50	15.67	21.73	50.00	100.00	150.00	211.70
l	4.8	7.9	8.4	11.3	13.2	15.6	23.6	33.4	40.9	48.6
L	10	16	17	23	26	31	47	67	82	97
K	7.44E-03	7.44E-03	7.44E-03	7.44E-03	7.44E-03	7.44E-03	7.44E-03	7.44E-03	7.44E-03	7.44E-03
m1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
m2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
P2	0.00	5.00	10.00	15.00	20.00	25.00	30.00	35.00	40.00	45.00
l	0.0	52.8	74.6	91.4	105.6	118.0	129.3	139.7	149.3	158.4
L	0	106	149	183	211	236	259	279	299	317

K = refuse permeability (ft/hr)
m1 = depth of saturated gas flow (ft)
m2 = depth of refuse (ft)
P2 = landfill gas pressure (psf)
l = flow length (ft)
L = trench spacing (ft)

Chapter 5

Landfill Construction

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5. 1 INTRODUCTION

5.1.1 Scope

This chapter presents a discussion of the techniques and methods that should be used in the construction of the facilities at a solid waste landfill. Although the chapter is aimed at technical personnel involved in the design, construction, operation and regulation of solid waste landfills, it will be useful to non-technical persons and members of the public as well.

The discussion in this chapter is intended to provide a general outline of construction requirements and references for more detailed information. For those cases where the construction is more specific to solid waste landfills, the procedures and considerations are discussed in greater detail. Standard recognized and accepted engineering and. construction practices are described in order to effect uniformity of methods and results, to establish standard requirements and to serve as a guide to those involved in the construction of these types of facilities.

The Landfill Construction chapter is intended to be used in conjunction with all other chapters of this manual. Construction of solid waste landfill facilities is an on-going activity during the life of the landfill, with major construction often taking place at recurring intervals. This phased construction approach allows refinement of the design in future phases based on construction and operational experience with the previous phases, as well as an opportunity to distribute the high cost of landfill construction over many years. The other chapters of this manual can be consulted for possible refinements to a landfill project to improve the development of future phases.

5.1.2 Construction Versus Operation

The development of a solid waste landfill generally occurs in several phases over the entire life of the landfill, which often exceeds 20 years. Development begins in the initial construction phase and continues as landfill operation fills the prepared area. The next phase is excavated for daily cover and eventually becomes the next construction phase. This cycle is repeated throughout the landfill until construction and operation is complete. Because of this cycling construction, the development of a solid waste landfill can be considered a long-term (5-50 year) construction project.

For the purposes of this manual, it is important to distinguish between landfill construction and landfill operation, although in practice the two go hand-in-hand. Landfill construction refers to the construction of the facilities both necessary and incidental to the development and closure of a solid waste landfill. These facilities typically include site work, surface water controls, ground water controls, bottom and side liners, leachate collection and treatment systems, gas controls and final cover systems.

Landfill operation pertains to the actual land filling activities and waste disposal practices as well as the operation and maintenance of the above-mentioned facilities. Landfill operation is discussed as a separate topic in Chapter 6.

5.1.3 Landfill Development Phases

Solid waste landfills are generally developed or expanded in phases. The initial phase of construction will usually include the area for landfilling, site development, access roads, surface water and ground water controls, leachate control facilities and support facilities such as buildings and utilities. Certain facilities that can be readily expanded in the future, such as leachate treatment facilities, can also be constructed in phases, but those facilities that cannot be readily expanded, such as pipeline sizes for storm water control or leachate collection and transmission, should be constructed to provide the ultimate required capacity. Leachate collection systems may actually experience higher peak flows in the early stages of development because of the presence of lined, unfilled disposal areas.

The initial and subsequent landfill development phases should provide capacity to accommodate at least one to two years of solid waste disposal. To minimize costs of construction, administration and mobilization, capacity for greater periods is desirable. If a landfill is to be in operation for 20 years, a phased development plan that includes major construction every five years would provide economical construction and still allow flexibility to revise future phases based on operating experience or changed conditions in the waste stream. Each phase of construction after the initial phase should consider intermediate or final closure of the previous phase. However, areas that are completed between construction phases should be closed as soon as possible to minimize leachate generation. The final construction phase will consist of closing the last part of the landfill and preparing the site for the post-closure care period.

Typical phased development of a solid waste landfill is shown in Figure 5.1. Near the center of the figure a phased expansion of an existing landfill is underway. The expansion area includes a natural soil bottom liner, flexible membrane side slope liner and a leachate collection system. The active phase of the landfill is at the upper left in the figure. An older phase at the upper center of the figure has been closed and covered with a gas vent layer, natural soil barrier and topsoil cover, and is ready to be hydro-seeded. Future expansion will occur in the area at the right of the figure where cover material and other soils are being excavated.

5.1.4 Construction Implementation

The principal parties involved in the implementation of a solid waste landfill construction project consist of the regulatory agencies, owner-operator, design engineer, construction management and quality assurance engineer and the construction contractor. Except for the regulatory agencies, the principal parties will not necessarily be independent of each other. Regardless of the relationships among the parties, it is essential

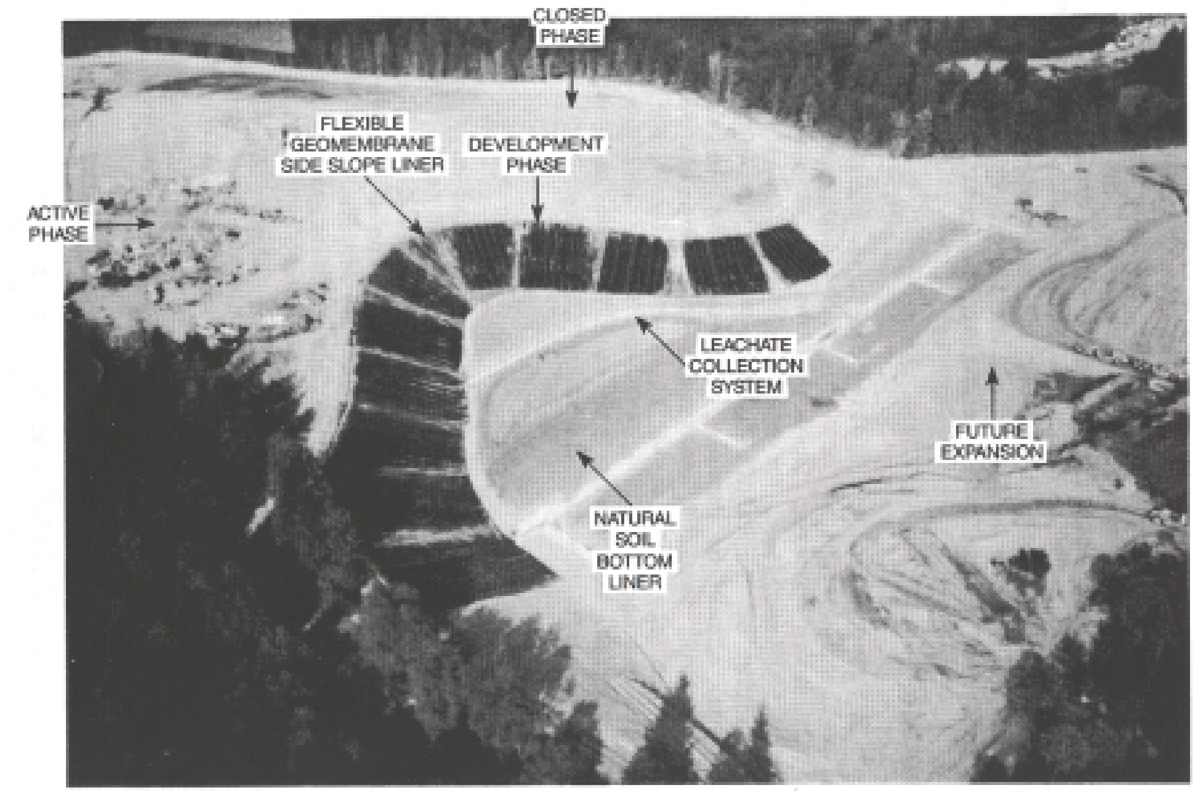


Figure 5.1
Phased Landfill Development

that the responsibilities and authority of each party be clearly established at the outset of construction implementation.

5.1.4.1 Regulatory Agencies

Chapter 70.95 of the Revised Code of Washington (RCW) requires that all solid waste disposal sites require a permit issued by the Jurisdictional health department. Both the Department of Ecology and the jurisdictional health department review and comment on the permit application. The jurisdictional health department has the responsibility to determine compliance with all applicable laws and regulations and to issue the permit when all requirements are met. The agencies also have the authority and responsibility to review and approve or disapprove of the solid waste landfill design and any revisions or variances requested during construction of the facility.

5.1.4.2 Owner-Operator

The owner-operator is responsible for obtaining and complying with the landfill permit as well as designing, constructing and operating the solid waste landfill. The owner-operator is authorized to select and dismiss parties providing design services, construction management and quality assurance, and construction of the landfill. Owner-operators using their own staff for these services should be capable of undertaking this work without impacting their responsibilities for management and operation of the landfill. If other parties are contracted to provide these services, the owner-operator has the authority to accept or reject design plans and specifications, construction management and quality assurance reviews and recommendations, and construction materials and workmanship.

5.1.4.3 Design Engineer

The primary responsibility of the design engineer is to design a solid waste landfill that fulfills the needs of the owner-operator and meets the requirements of the regulatory agencies. The design must meet WAC 173~304, Minimum Functional standards for Solid Waste Handling and should be based on the engineering principles presented in the Landfill Design Chapter and established state-of-the-art practices. The design engineer may be involved in construction management and quality assurance to resolve any construction or design problems identified during construction. The design engineer services may be provided by members of the owner-operator staff or by an outside party contracted by the owner-operator. Because of the special qualifications and experience required to perform this service, most owner-operators may find it desirable to contract an outside party to serve as design engineer.

5.1.4.4 Construction Management and Quality Assurance Engineer

The overall responsibility of the construction management and quality assurance engineer is to see that the solid waste landfill is constructed in conformance with the design plans and specifications. Because of the importance of involving the design engineer in the construction phase of the project, it is desirable to have the same party perform both the design and construction engineering services. Construction management and quality assurance may be provided by members of the owner-operator staff or through the services of an outside party contracted by the owner-operator. As with the design engineer, the special qualifications and experience required to perform the construction engineering services may make it desirable to contract this function to an outside party.

5.1.4.5 Construction Contractor

The construction contractor is responsible for constructing the solid waste landfill in accordance with the design plans and specifications, using standard construction procedures and techniques. The construction contractor may be a member of the owner-operator staff or an outside party contracted to perform the construction.

The personnel and equipment necessary for landfill construction is generally very similar to that used for the operation of a solid waste landfill. For this reason, it may be desirable and practical for the owner-operator to perform the construction rather than contracting with an outside party. The owner-operator should evaluate this approach carefully prior to committing his equipment and staff to construction roles in addition to operations. Key issues include scheduling, equipment needs and manpower requirements. Generally, major construction programs at a landfill are undertaken during favorable weather (summer months). This is also the period of greater waste stream deliveries, which require additional operations efforts. These conditions may not allow the owner-operator to meet required construction schedules and ultimately could affect both the operations and quality of completed work.

5.1.5 Public Issues/Relations

By the time construction of the solid waste landfill is ready to begin, the public should be well informed about the project and may have had a chance to participate in its development through a public involvement process similar to that described in the landfill siting chapter. Although opposition or support for the landfill project may continue to be expressed, most public issues during construction pertain to the disruption and inconvenience resulting from the construction activity itself.

To alleviate the concerns of the public during construction, the landfill owner, operator and construction contractor(s) should develop specific programs to reduce noise, dust, traffic, mud on approach roads, and other construction related inconveniences to a practicable minimum. This effort should also include a program to

deal with questions and/or complaints associated with the construction program. The landfill should strive to maintain its "good neighbor" policy during these periods of temporary inconvenience.

5.2 CONSTRUCTION QUALITY ASSURANCE

5.2.1 Introduction

Construction quality assurance (CQA) is an overview and inspection program. The purpose of this program is to assure, with a reasonable degree of certainty, that the construction of the solid waste landfill will meet the design specifications. The emphasis on quality assurance should begin early in the design of the landfill and continue throughout actual construction. The U.S. EPA has published a guidance manual for preparation of a construction quality assurance plan (U.S. EPA, 1985) that is largely applicable to solid waste landfill facilities.

Construction quality assurance for a solid waste landfill is needed to assure that the completed components of the landfill meet or exceed all project design criteria, plans and specifications. This involves monitoring and documenting the quality of materials and methods used and the manner in which the materials are placed or the work is done. Construction quality assurance serves to detect variations from design, and provides suitable corrective measures before wastes are placed in the landfill. Without proper CQA, problems with landfill components resulting from improper construction may not be discovered until the components fail during operation. Correction of problems at that time may be prohibitively costly.

The probability that the solid waste landfill facilities will perform successfully is greatly increased by using an effective CQA program. However, the program does not in itself guarantee perfect construction results, although its use minimizes the chance of failure of the landfill facilities. A committed CQA program has far reaching effects on the project and usually the knowledge that CQA will be implemented greatly improves the performance of both designers and contractors. This will enhance the potential for successful performance of landfill facilities.

5.2.2 Adherence to Project Design

The ability of a solid waste landfill to meet its designed and regulatory performance goals depends on adherence to approved design plans and specifications during construction. The plans and specifications should reflect conventional construction operations and standard criteria. Confidence in the ability of the solid waste landfill to perform properly is attained through a well -developed, well- implemented and well-documented CQA program. The CQA program should be developed by the design engineer who can focus the emphasis of quality assurance on those elements of design that are critical to landfill performance. Implementation of the CQA program should include participation by the design engineer to resolve construction or design problems identified during construction.

Confidence in the solid waste landfill is established through careful documentation of the following:

- Construction scheduling, conditions and progress
- Site inspection
- Material/equipment testing results and data verification
- As-built conditions
- Review, inspection and approval by appropriate regulatory and permitting agencies

5.2.3 Sensitivity of Solid Waste Landfill Facility Components to CQA

A solid waste landfill consists of numerous facilities, each of which consists of several components and subcomponents. These facility components are subject to failure, but not all would have the same effect on the performance of the landfill. The sensitivity of landfill facility components to construction problems and causes of failure of the facilities depends on several factors including:

- o Susceptibility of the facility component to improper installation and failure
- o Relative importance of the facility component in controlling the overall landfill performance
- o Costs and effort associated with correcting that failure

The CQA program should address all components of landfill facilities with emphasis on those components that are most sensitive to CQA. Sections 5.3 through 5.8 discuss construction of the various landfill facilities and will assist in identifying those components sensitive to CQA. Each CQA program should be developed based on the anticipated CQA sensitivity of the landfill facility components for the specific design and site conditions.

5.2.4 CQA Observations and Tests

The CQA process involves control of materials and workmanship. The purpose of any test or observation is to compare the material used or the work actually performed with the specified material or workmanship. The design specifications will establish the parameters that must be evaluated for acceptance of the materials and work. Testing of material during construction will determine whether the properties, composition, and/or performance of the material or installed components are within limits specified in the design. Testing of equipment may include evaluating the quality and assembly of materials and performance of the equipment under specified test conditions.

Observation and testing are important CQA activities throughout all phases of landfill construction. Observation of all landfill component materials as they are delivered to the construction site and installed in proper sequence will help ensure conformance with design specifications and procedures.

Testing should be performed on component materials as each component is installed.

5.2.4.1 Visual Observations

Visual observation can be utilized as a mode of testing to determine quality as well as a tool to control quality (i.e., inspection). The type of evaluation made via visual inspections may include:

- Correctness of material and equipment installation and operation
- Surface defects (e.g. cracks in pipe)
- The presence of undesirable work conditions such as excessive moisture or temperature

Experience and training of the observer are particularly important in controlling quality by visual inspection.

5.2.4.2 Non-Destructive Testing

Non-destructive testing is particularly desirable for testing of finished products or material such as pipe, manufactured structures or compacted soil. This form of testing does not usually require specially prepared specimens, making in situ testing more practical. Non-destructive testing may be used to determine dimensional, physical or mechanical characteristics and to locate defects. Tests to determine dimensional, physical and mechanical characteristics may include compaction and/or permeability analysis of soil, or physical measurements with scales, tapes, etc. Defects may be located using a variety of specialized devices, such as the nuclear densitometer used for measuring soil density-moisture content.

5.2.4.3 Destructive Testing

Destructive testing often involves specially prepared specimens, which are tested to either partial or complete destruction. Destructive testing is often performed to determine the tensile, compressive or ultimate strength of installed materials.

5.2.4.4 Testing Sequence

Pre-construction testing should be performed to verify that all materials and equipment purchased meet design specifications prior to delivery to the site. This type of test can also confirm that the material delivered to the construction site meets all of the design requirements. Pre-construction testing is most practical for soil materials, and possibly for pumps to verify performance.

Testing during construction should focus on verifying that material placement or installation proceeds according to the project specifications. Examples of this would include placement and compaction of soils or installation and connection of piping systems.

Post-construction testing should be performed to verify that materials and equipment would perform to specifications after they are installed. Examples of post-construction testing are verification that pumps operate at rated capacity, and that electrical controls and monitoring equipment perform their design functions. Post-construction testing should also confirm that the performance of entire systems at the landfill conform to design specifications.

5.2.4.5 <u>Field Versus Laboratory Testing</u>

Many tests, such as sieve analysis of gravel, can be performed in the field as well as in the laboratory. Certain testing such as verifying rated capacity and operation of installed pumps, controls, etc. must be performed in the field. Field-testing may be more difficult than laboratory testing due to hazardous working conditions, time limitations, and variable weather conditions. These factors may affect the degree of accuracy and precision obtained in the test.

Laboratory testing will be necessary where special sample preparation, apparatus, or testing conditions is required. An example of a test requiring laboratory work is the hydrometer analysis of soils, which determines particle size distribution smaller than 200 mesh. Laboratory testing may be expedited by setting up a field laboratory at the construction site.

Field and laboratory testing may be used to complement each other as a means of verifying test results. For example, laboratory measurement of soil moisture content using a drying oven and a scale is verified by field measurements using the non-destructive nuclear densitometer.

5.2.4.6 <u>Standard Tests</u>

Material and workmanship characteristics important in determining acceptable performance of the landfill facilities should be specified in the project specifications. Performance testing of these characteristics should be part of the CQA testing. All tests should be conducted by qualified engineers, hydrogeologists or testing laboratories.

Whenever possible, the CQA testing should be conducted in accordance with standard procedures and methods. Applicable procedures that are well established and generally accepted by professional consensus should be selected. Typical sources of consensus standards include the American Society for Testing and Materials (ASTM), American National Standards Institute (ANSI), American Association of State Highway and Transportation Officials (AASHTO), American Public Works Association-Washington State Chapter (APWA), Washington State Department of Transportation (WSDOT), American Water Works Association (AWWA), Federal Specifications (Fed. Spec.) and Military Specifications and Standards (MIL).

Non-standard test procedures to assess performance should be avoided. When it is necessary to use them, the test procedure should be fully described in the project specifications to assure consistent application of measurement throughout the CQA process.

Commonly used CQA testing procedures applicable to the major components of solid waste landfill facilities are summarized by type of materials in Appendix 5A. Additional specific CQA observations and tests for the applicable components of landfill facilities are described for the applicable components of landfill facilities in Sections 5.3 through 5.8.

5.2.5 Sampling and Inspection

Three methods of inspection and sampling are available to supplement the judgment of the project designer or field inspector in evaluating the quality of a unit of material or workmanship. They are: 100 percent inspection, sampling inspection and vendor certification.

When 100-percent inspection is used, the testing must of necessity be non-destructive and is usually accomplished visually, sometimes accompanied by simple measurements. Examples are observations of a freshly cut face of a trench, the integrity of a flexible membrane liner or of site preparation.

When 100-percent inspection is clearly not feasible due to the constraints of time and cost, sampling is used. The results of tests of a sample are used to represent the whole from which the sample was taken. It is recognized that there is a risk that the quality of the sample will not accurately reflect the quality of the whole.

Vendor certification, as a means of quality evaluation, involves the receipt of a certificate from the vendor stating that certain quality control procedures have been implemented and quality evaluation tests have been made. If the company is considered reliable and has established a good history of quality, such certificates are sometimes used as evidence of product quality in lieu of formal quality evaluation tests. Usually, the warranty of the company is given by the signature of a responsible management official. It must be recognized that the buyer who relies on this method of quality evaluation assumes a certain risk (Halpern, 1978). Additional testing of material at the construction site may be required.

5.2.6 Documentation

Effective CQA depends to a large extent on recognition of all the construction activities to be inspected and the assignment of responsibilities to personnel for the inspection of each activity. This is most effectively accomplished by the documentation of CQA activities. The CQA personnel should be made aware of the factors to be monitored, inspected, or tested, and should note, through descriptive remarks, data sheets, and checklists, that the inspection activity has been accomplished.

5.3 GENERAL SITE WORK

General site work for construction of a solid waste landfill typically includes a wide variety of general construction activities such as clearing and grubbing, removal of structures and debris, excavation and embankment, road building, installation of drainage facilities, building construction and other miscellaneous construction items. Depending on the particular item and its purpose in the overall landfill project, construction of general site work items can have varying effects on the overall success of the solid waste landfill project. Failure of excavations, embankments or drainage facilities could have a significant effect on the landfill, while unsatisfactory road construction may cause only slight inconveniences.

5.3.1 Clearing and Grubbing

Before starting earthwork operations, all trees, brush, abandoned buildings and other objectionable material must be removed from the construction area of the landfill. Surrounding areas of natural vegetation should be retained to serve as buffers and provide for erosion control. Both areas should be identified before starting construction. After the construction areas have been cleared, grubbing will provide for additional preparation of the work areas by removal of remaining stumps, roots and other deleterious matter that exists on or in the ground. Grubbing is important to the structural quality of earthwork construction and every effort should be made to obtain a thorough job.

5.3.2 Excavation

Excavation may be used in landfill construction to reach design subgrade in the landfill or to obtain materials necessary for borrow, soil liner, collection layers, etc. In either case, a copy of the soil report and the soil profile used in the design of the landfill should be available during the construction of the project. As the excavation progresses, newly exposed material should be examined and compared to the soil report and soil profile to confirm that the soils are suitable for their intended uses. This may require testing of the soil for various parameters such as particle size distribution, moisture content or permeability. Confirmation of the soils for 'these intended uses should be made as soon as possible and changing conditions anticipated in order that necessary changes can be made before the excavating equipment has been moved away.

5.3.2.1 Permanent Excavation

Normally, excavations will be made to the line and grade indicated on the project plans. When material shortages occur, additional quantities may be obtained from borrow sources or possibly from enlargement of the design excavations if borrow sources are not practical. Early determination of additional needs is desirable so that necessary enlargements can be made during the original excavation. If the excavation is deep it should be evaluated for stability prior to revising the design. When material excesses occur, the surplus should be segregated by soil type and stockpiled in a designated area for future use.

After the excavation has reached the design subgrade, it should be checked for soft areas. These should be removed by excavating them below the subgrade and refilling them with a suitable material. The completed subgrade should be checked for density, and if it is found to be less than the required density, the subgrade material should be worked and compacted as necessary to bring it up to the required density.

Ground water with potentially high flows or artesian conditions may be encountered in excavated areas. Dewatering ditches may be utilized to lower ground water; however, in severe conditions a permanent subdrain system may be required.

5.3.2.2 Temporary Excavations"

The safe slope for temporary excavations of all soil (i.e. utility trenches, foundation excavations, etc.) will depend on the following factors:

- Presence of ground water
- Type and density of the soils
- Depth of cut
- Surcharge loadings adjacent to the cut, from excavated material, existing structures and embankments, construction equipment
- Duration of exposure and season of year

Construction slope values required for stability and safety depend on a careful evaluation of all of the above factors. Because of the many variables involved, the actual slope values required for stability in open cuts can only be approximately estimated prior to construction. Actual sloping in soils should be made the responsibility of the contractor, since he is continuously present at the job site to observe the nature and conditions of the subsurface materials encountered, including ground water. Regardless of the construction method used, all excavation work should be accomplished in compliance with the applicable provisions established by the Department of Labor and Industries, Division of Safety.

5.3.2.3 CQA Procedures

The evaluation of the excavated soils to confirm their suitability for intended purposes will be the main CQA procedure during the excavation phase of construction. Generally, the primary observation will be visual, aided by field expedient tests for the description of soils. The material specifications for the various components of the landfill will define the parameters to be met by the soils for each intended use. Therefore, it will also be necessary to do formal sampling and testing continuously during construction for evaluation and documentation before each block of material is incorporated into a component of the landfill.

5.3.3 Embankment

Many facilities in a solid waste landfill require embankment construction for part of the installation of their components. Major facilities include the bottom liner; leachate collection system and final cover system. Construction of these facilities is discussed separately in subsequent sections. Other landfill facilities that require embankment construction include berms, dikes and roads. Occasionally embankments may be required to reach landfill design subgrade.

Construction of embankments should be accomplished in accordance with the plans and specifications using methods and equipment suitable for the type of work involved. All operations should be directed toward constructing a well-compacted embankment true to grade and cross section. Proper compaction of the embankment, as well as proper material and moisture content are of vital importance to the structural quality of the facility and it is therefore essential that the required density be obtained.

5.3.3.1 Structural Considerations

The two factors that most influence the behavior of embankments are settlement and stability. Settlement of embankments is a function of embankment height and compressibility of the underlying subgrade. Where hydraulic conductivity through the embankment is a concern, settlement should be carefully evaluated to determine resultant differential movements within the embankment. Differential movement can result in cracking and fissuring of the embankment soils, which would promote piping and increase the overall hydraulic conductivity. Mitigation measures for high embankments over compressible subgrades where fissuring is an issue include the use of high plasticity soils compacted wet of optimum to create a, more "flexible" embankment material and the use of a zoned embankment with a low permeability soil-bentonite mixture core.

Stability is a function of embankment height, material type, compaction and strength of subgrade soils. Adequate factors of safety with regard to slope stability should be incorporated into the design and construction of the embankment. On potentially unstable foundation soils, stability of the embankment can be increased by flattening the side slopes, by over excavation and replacement of the low strength foundation soils or by constructing the embankment slowly enough so that an increase in strength of the foundation soils can be achieved during construction. Such alternatives would require evaluation and selection during the geotechnical investigations and preparation of design plans and specifications. Success of the latter alternative depends on the characteristics underlying materials.

5.3.3.2 Construction Equipment Suitability

Considerable latitude may be given to the contractor in the types of equipment to be employed, as long as they produce the desired engineering properties in the constructed embankment. Material handling equipment of the greatest concern are those used for blending a second material into the embankment soil and for mixing to achieve a desired water content. Often, the hauling and spreading equipment may work, but specially designed soil mixers that work on the loose lift on the fill surface are also available.

Compaction equipment should be suited to the soil type. For cohesive (clayey) soil, a sheepsfoot roller or rubber tired roller should be used. A crawler tractor may be used for soft, wet soils placed in their lifts. For clean granular soil, a vibratory compactor is appropriate. A hand-held power tamper may be used in difficult access areas, using very thin lifts. The use of hauling equipment, such as scrapers, to compact under their wheel loads is generally not satisfactory. The high wheel loads cause severe rutting with inefficient compaction, particularly in soft, wet soils. Furthermore, it is difficult to obtain uniform coverage.

5.3.3.3 Embankment Construction

The construction of an embankment proceeds by placement of fill soils in horizontal layers, or lifts, starting at the lowest level in the embankment and proceeding upward. The embankment construction process varies slightly depending on the type of material but generally consists of:

- Preparing the embankment base
- Excavating the soil from the site or from a borrow pit
- Hauling the soil to the embankment site
- Spreading and discing, if necessary, to break up the soil into small particles
- Blending with a second material, if required
- Mixing to a predetermined water content and to the desired uniformity (adding water by sprinkling and mixing if too dry, discing and aerating if too wet)
- Spreading the soil in uniform layers of specified thickness
- Rolling the lift uniformly with the necessary number of passes of the correct roller to achieve the required density
- Following CQA acceptance, slightly scarifying the surface, if required, to accept the next lift

5.3.3.4 CQA Procedures

Construction of embankments involves control of materials and workmanship. The necessary engineering properties <i.e., those for shear strength, compressibility, and permeability) are rarely used for construction quality evaluation because of time, equipment and personnel constraints.

Instead, faster, simpler and more easily determined soil index properties are used. These test results correlate well with the engineering properties and their requirements should be defined in the project specifications.

Soil index properties commonly used in CQA evaluations of embankments are as follows:

1. Weight-volume relationships
   - Water content
   - Bulk density
   - Specific gravity
   - Calculated values are void ratio, porosity and degree of saturation

2. Soil classification
   - Grain size distribution
   - Atterberg Limits
   - Consistency (using simple field methods)
   - Calculated values are plasticity index, liquidity index, activity, and classification by USCS or other system

3. Laboratory soil compaction
   - Density-water content-compactive effort relationships for cohesive and "dirty" granular soils
   - Maximum and minimum density for clean granular soils

Materials to be used in construction of embankments should be evaluated before they are incorporated into the embankment. The soils should be tested for index properties included in the design specifications, which may include any or all of the following:

- Natural water content
- Specific gravity (rarely evaluated because of low variability)
- Atterberg Limits
- Grain size distribution
- Clay content
- Organic content
- Color

Workmanship involved in the construction of embankments on prepared foundations primarily involves conditioning the soil and compaction. Conditioning includes blending with a second material and adjusting water content to the desired level. Any or all of the following tests and observations may be required to evaluate workmanship:

- Uniformity of blending
- Water content

- Lift thickness
- Compactive effort (number and uniformity of passes)
- Climatic conditions
- Compacted density

5.3.4 Other Improvements

Other facilities generally installed at a solid waste landfill (e.g., drainage facilities, roadways, utilities, structures, buildings and miscellaneous improvements) involve construction of components such as pipelines, catch basins, manholes, pavements, electrical and telephone lines, retaining walls, curbs, gutters, building products, mechanical and electrical equipment, lighting, fencing and landscaping. Considerations for construction and quality evaluation for this type of work are readily available in several references (APWA, 1973; Washington State Highway Commission, 1970; ASCE and WPCF, 1982; ACI, 1980; AISC, 1973; Wood, 1977; AITC, 1974; Merritt, 1983; Winterkorn and Fang, 1975).

5.4 BOTTOM LINERS

5.4.1 Natural Soil

Natural soil liners are composed of in situ soils located on site or from a borrow source. In some situations the on-site soils may provide adequate protection without any remolding or compaction. Natural clay deposits with field permeability's of 10^{-7} cm/sec or less are an example. More often, the on-site or borrow source soils will require moisture conditioning, remolding and compaction to achieve the desired permeability's and strength.

5.4.1.1 <u>Excavation and Placement</u>

In some areas, landfills may be sited in natural deposits of clay or silt materials. In these cases, excavation for the landfill is performed using standard construction equipment (e.g., scrapers, bulldozers, loaders and dump trucks). Because landfills typically have side slopes steeper than 4H:lV, special measures may be necessary to assist equipment in moving safely up and down such slopes. Slope staking by surveyors will be required during construction to ensure that designed slopes and depths are achieved. Trenches for leachate collection pipes and sumps are also installed at this time. After excavation is complete, surface rolling of the soil surface should Be done to seal the surface and locate soft spots. Soft spots should be over-excavated, backfilled and compacted to achieve a firm working base. If in situ soils meet previously approved depth, permeability and strength requirements then, with the exception of CQA testing, the soil liner installation is complete.

The more typical case in landfill liner construction will require the placement, remolding and compaction of soil either previously excavated from the site and stockpiled nearby or imported from a borrow source. The soil is placed in lifts of specified thickness by scrapers or other earth moving equipment. The first lift should be less than eight inches thick for a loose lift, or less than two-thirds of the length of tamping feet if a sheepsfoot roller is used. Prior to compacting each lift, the emplaced material should be mixed and broken up into smaller clods using rotary tillers or similar equipment. Smaller soil clods make it easier to achieve desired moisture requirements, facilitate compaction and provide a more homogeneous layer. Table 5.1 includes recommended lift thickness' to achieve compaction of 95 to 100 percent of the Standard Proctor maximum dry density.

The placement of soil on slopes can be done continuously with the bottom if the slope is not steeper than about 3H:1V. Beyond this value, lifts may be installed in horizontal, terraced lifts up the face of the slope.

Moisture is normally added to the lift to achieve the moisture content specified in the design. For cohesive soils, moisture content is usually specified slightly wet-of-optimum to achieve a lower permeability. However, care must be exercised to ensure that the moisture content is not too far above the optimum so that the structural stability of the material is not affected. The soil should be mixed after water is added to distribute the water evenly throughout the lift. Sufficient time should be allowed between water application and compaction to allow the water to penetrate the soil clods and reach a uniform value in the lift. If the soil is too moist, aeration will be required to lower moisture content to the desired level.

The boundary conditions between successive soil lifts is an important consideration in the construction of soil liners. Conditions that favor a distinct boundary between lifts produce a liner with horizontal permeability's greater than desired. Ideally, the completed liner would be homogeneous and individual lifts would be undistinguishable. To help achieve this goal, the surface of the lower lift should be scarified slightly and the moisture content between the two lifts should be as equal as possible.

5.4.1.2 Compaction

Compaction and remolding of the soil is one of the most important aspects in soil liner installation. Typically, compaction improves the structural aspects of soils in construction and road building. In landfill liner construction, the principal purpose of compaction is the reduction in permeability achieved when the soil is densified and its particles realigned. Structural stability is also important for trafficability during operations, however. In clay soils, the realignment of particles is probably the most important factor in realizing low permeability's as shown in Figure 5.2, where the permeability rapidly decreases as the moisture content becomes wet-of-optimum. The increased moisture in the soil allows the particles to be arranged more easily.

Figure 5.2 also illustrates each effect of each method of compaction on achieving low permeabilities. Kneading compaction is more effective because it induces strains in the soil lift that enhance particle realignment. For

Table 5.1 Compaction Equipment and Methods

Equipment Type	Applicability	Compacted Lift Thickness, in. (cm)	Passes or Coverages	Dimensions and Weight of Equipment	Possible Variations In Equipment
		Requirements for Compact of 95 to 100 percent Standard Proctor, maximum density			
Sheepsfoot rollers	For fine-grained soils or dirty coarse-grained soils with more than 20% passing No. 200 mesh; not suitable for clean coarse-grained soils; particularly appropriate for compaction of impervious zone for earth dam or linings where bonding of lifts is important	6 (15)	4-6 passes for fine-grained soil. 6-8 passes for coarse-grained soil	Soil type / Foot contact area in.^{2} (cm^2) / Foot contact pressures psi (Mpa) Fine-grained soil PI>30: 5-12 (32-77); 250-500 (17-34) Fine-grained soil PI<30: 7-14 (45-90); 200-400 (1.4-2.8) Coarse-grained Soil: 10-14 (64-90); 150-250 (1.0-1.7) Efficient compaction of wet soils requires less contact pressures than the same soils at lower moisture contents.	For each dam, highway, and airfield work, drum of 60-in. dia. (152 cm), loaded to 1.5 – 3 tons per lineal ft (43.7 – 87.5 kN per lineal m) of drum generally is used; for small projects, 40-in, dia (101 cm) drum loaded to 0.75 to 1.75 tons per lineal ft (21.9-43.7 kN per lineal m) of drum is used; foot contact pressures should be regulated to avoid shearing the soil on the third or fourth pass.
Rubber tire rollers	For clean, coarse-grained soils with 4-8% passing No. 200 mesh. For fine-grained soils or well graded, dirty coarse-grained soils with more than 8% passing No. 200 mesh.	10 (25) 6-8 (15-20)	3-5 4-6	Tire inflation pressures of 60 to 80 psi (0.41-0.55 MPa) for clean granular material or base course and subgrade compaction; wheel load 18,000-25,000 lb (80-111 kN); tire inflation pressures in excess of 65 psi (0.45 MPa) for fine-grained soils of high plasticity; for uniform clean sands or silty fine sands, use large size tires with pressure of 40 to 50 psi (0.28-0.34 Mpa).	Wide variety of rubber tire compaction equipment is available; for cohesive soils, light-wheel loads such as provided by wobble-wheel equipment; may be substituted for heavy-wheel load if lift thickness is decreased; for cohesionless soils, large-size tires are desirable to avoid shear and rutting.
Smooth wheel rollers	Appropriate for subgrade or base course compaction of well-graded sand-gravel mixtures May be used for fine-grained soils other than in earth dams; not suitable for clean well-graded sands or silty uniform sands.	8-12 (20-30) 6-8 (15-20)	4	Tandem type rollers for base course or subgrade compaction, 10-15 ton weight (89-133 kN), 300-500 lb per lineal in. (3.4-5.6 kN lineal cm) of width of real roller. 3-wheel roller for compaction of fine-grained soil; weights from 5-6 tons (40-53 kN) for materials of low plasticity to 10 tons (89 kN) for materials of high plasticity.	3-wheel rollers obtainable in wide range of sizes; 2-wheel tandem rollers are available in the range of 1-20 tons (8.9-178 kN) weight; 3-axle tandem rollers are generally used in the range of 10 to 20 tons (89-178 kN) weight; very heavy rollers are used for proof rolling of subgrade or base course.

Vibrating baseplate compactors	For coarse-grained soils with less than about 12% passing No. 200 mesh; best suited for materials with 408% passing No. 200 mesh, placed thoroughly wet.	8-10 (20-25)	3	Single pads or plates should weight no less than 200 lb (0.89 kiN); may be used in tandem where working space is available; for clean coarse-grained soil, vibration frequency should be no less than 1,600 cycles per minute.	Vibrating pads or plates are available, hand-propelled, single or in gangs, with width of coverage from 1.5-15 ft (0.45-4.57 m); various types of vibrating-drum equipment should be considered for compaction in large areas.
Crawler tractor	Best suited for coarse-grained soils with less than 4-8% passing No. 200 mesh, placed thoroughly wet.	10-12 (25-30)	3-4	No. smaller than D8 tractor with blade, 34,500 lbs (153 kN) weight, for high compaction	Tractor weight up to 60,000 lb.
Power tamper or rammer	For difficult access, trench backfill; suitable for all inorganic soils	4-6 in (10-15 cm) for silt or clay; 6 in. (15 cm) for coarse-graded soils		30-lb (0.13 kN) minimum weight; considerable range is tolerable, depending on materials and conditions.	Weights up to 250 lb (1.11 kN); foot diameter 4 to 10 in. (1.57-3.93 cm).

Source: Coates and Yu (1977), pp. 90-91, In: U.S. EPA (1983), p. 226.

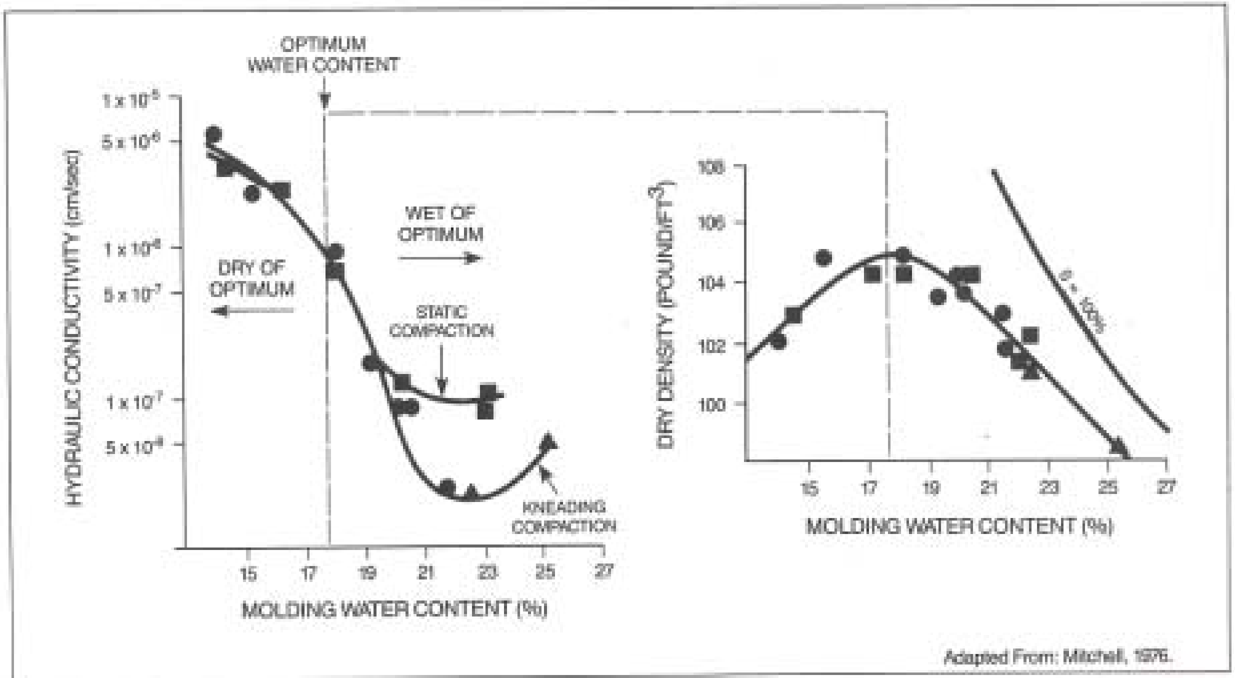


Figure 5.2
Effect of Method of Compaction on the Permeability (Hydraulic Conductivity) of a Silty Clay

● Kneading Compaction 1 Inch x 2.8 Inch Mold
▲ Kneading Compaction 3.5 Inch x 1.4 Inch Mold
■ Static Compaction 1 Inch x 2.8 Inch Mold

this reason, sheepsfoot rollers are preferred for compaction over smooth-wheeled rollers for natural soil liners.

The number of passes the equipment must make over the soil lift should be determined by trial and testing. The numbers provided in Table 5.1 can be used as a guide.

5.4.1.3 Construction Quality Assurance (CQA)

The importance of CQA cannot be overemphasized. All efforts to produce a good design is wasted if the construction does not follow the procedures and specifications developed in the design process. CQA in landfill liner construction can be divided into the following categories (U.S. EPA, 1983):

Soil Characteristics

- Control of soil moisture content
- Control of soil density
- Control of soil quality

Roller Characteristics

- Size, arrangement and safety features of the drums

- Number, location, length and cross-sectional area of the tamping feet
- Weight of the loaded roller

Characteristics of the Compaction Operation

- Number of passes
- Thickness of layers
- Thickness of layers in relation to tamping feet

Prior to beginning construction and ideally before bidding, a test fill area should be constructed using the equipment and specifications in the design plans. Two layers should be compacted and moisture, compaction and permeability tests performed on samples from the test area to determine if the required permeability is achieved and if the moisture, density and permeability relationships match those from the laboratory. If during this test, the required permeability cannot be achieved, then revisions to the design specifications may be necessary in order to achieve the required permeability.

Soil characteristics are monitored by visual inspection and field and laboratory tests. The quality of the soil being placed must be continuously monitored to ensure it meets the specified soil design requirements. Often samples used in the design phase are random samples from a large quantity of soil either in an undisturbed state or stockpiled near the site. These samples may not be representative of all the soil types present in the source area. If soil of a different nature is placed in the liner, it is unlikely it will have the expected permeability since the moisture content, compactive effort, density and permeability are a function of a particular type of soil. If soil of different characteristics is found, it should be tested to determine if it could be modified to meet the specifications. Until a determination is made, such soil should not be used in liner construction.

Moisture content must be maintained within a narrow range of optimum. This is essential to achieve the low permeability required and the ability to work the soil. If moisture content is allowed to drop below the specified value by even two percent, an increase in permeability by as much as one order of magnitude is possible, as seen in Figure 5.2. Compaction wet of optimum is advantageous for reaching lower permeabilities but the soil cannot be made so wet as to be unworkable. If the compacted liner is to be left exposed for any length of time, precautions should be taken to ensure that the material does not dry out. Failure to take such precautions could lead to desiccation cracking of the liner which would require repair prior to covering the liner.

Compaction tests should be made on the installed liner to ensure it is being compacted to the required density. For clayey and silty soils, the minimum acceptable field density should be based on permeability requirements, but generally is on the order of 95 percent of the Standard or Modified Proctor maximum density. Laboratory permeability tests on sample cores should be performed periodically along with compaction tests to determine if the required permeability is being achieved. Density tests alone may not be adequate to determine if the required permeability has been reached.

In performing both field tests and laboratory tests on samples from the soil, the number of samples chosen should be large enough to be representative and taken from random sampling locations. ASTM (1984) presents a method (E122) for selecting sample size based on confidence interval estimation.

Roller characteristics can be monitored by periodically inspecting the equipment to ensure it is properly loaded and operating safely. The compaction operation can be monitored by observing operations in the field and checking elevations by surveying to determine the depth of the liner.

5.4.2 Bentonite-Soil Admixture

The construction of a bentonite-soil admixture liner has many similarities to a natural soil liner. Excavation, placement of the base soil, moisture addition and compaction requirements are the same. Additional steps are required to incorporate the bentonite material into the soil. In addition to the material presented here, Lippy (1986) has a detailed discussion on construction of bentonite liners.

Bentonite can be delivered to a site in bulk form or in 100 lb. bags. A separate stockpile area should be provided if on-site storage is required prior to construction. The bentonite stockpile should not be placed directly on the ground to prevent mixing with dirt and should be covered or otherwise protected from rain and erosion.

5.4.2.1 Mixing and Placement of Bentonite

The quantity of bentonite to be added to the soil is determined during design based on base soil characteristics, moisture content and compaction density. If design permeabilities are to be achieved in the field, the proper amount of bentonite must be mixed into the soil. There are two basic methods available for achieving the required amount of bentonite in the admixture. The preferred method is on-site mixing of the, bentonite and soil in a pugmill. This method allows the most accurate control of the admixture and is less likely to produce areas in the liner lacking sufficient bentonite in the soil. After mixing in the pugmill, the soil-bentonite admixture can be placed using standard construction methods to achieve a uniform layer of proper depth.

The admixture may be deposited directly into trucks from the pugmill operation for transport to the construction area. Trucks will dump the admixture directly onto the prepared subgrade in lifts; additional earth-moving equipment will be required to place and grade the material to design specifications. Alternatively, the bentonite soil mixture may be placed using an asphalt paver. The admixed materials would be loaded into the hopper from the trucks. As the paver moves along the landfill subgrade, a uniform layer o f admixture is deposited.

The alternative mixing method is to spread the bentonite over the soil surface and then mix the bentonite into the soil to the proper depth. This method requires very careful control of both the spreading operation and the mixing operation to achieve the required percentage of bentonite in the soil. In place mixing may require repetition through a series of lifts, depending on the mixing depth of available equipment. The base soil, which must meet gradation requirements set in design, is first placed over the excavated surface. Base material should not be compacted prior to mixing in the bentonite. After the base material is in place, water should be added as necessary to achieve the required moisture content.

Bentonite can be spread over the surface using agricultural spreaders or trucks or tractors with various types of spreading attachments. CQA must be diligent in these operations to ensure that the proper amount of bentonite is being deposited on the soil surface. Additional bentonite may be spread to increase confidence in the operation.

After the bentonite is deposited on the surface, it must be mixed to the proper depth with the soil. Depth control is very important. If the mixing depth is too deep the percentage of bentonite in the mixed layer will be less than predicted for the given spreading rate. This reduction in the percentage of bentonite will increase the permeability, perhaps above specifications. If the mixed layer is too shallow, the low permeable layer will not be thick enough to restrict flow to the designed levels. Typical mixing methods include the use of agricultural discs, rototillers or pulvi-mixers. Adjustable depth rototillers or pulvi-mixers are recommended because the depth of mixing can be more accurately controlled. Figure 5.3 shows a pulvi-mixer mixing the bentonite with the soil during the construction of a final cover at the Lake Stevens Landfill in Snohomish County. Mixing depth was controlled within one inch using this method.

5.4.2.2 <u>Compaction and Covering</u>

After mixing and placement is completed, the layer of soil and bentonite should be compacted. Compaction equipment should be restricted to smooth-wheeled rollers or vibrating base compactors. Sheepsfoot compactors should not be used because they will disrupt the integrity of the seal. Manufacturers typically specify a minimum compaction of 85% of the Modified Proctor maximum dry density.

After compaction, the soil-bentonite layer should be immediately covered. Cover protects the liner from erosion and desiccation.

5.4.2.3 <u>Construction Quality Assurance (CQA)</u>

The same type of CQA employed for natural soil liners are applicable for soil-bentonite admixtures. Base soil characteristics and quality should be monitored and moisture content maintained at the specified value. However, additional CQA requirements are necessary to ensure proper spreading and mixing of the bentonite. This is particularly true if the bentonite is spread and mixed in-place. There are a number of mechanical field tests that can be conducted to monitor the amount of bentonite being spread on the soil. Pre-measured tarpaulins can be located at different locations on the surface and weighed after the spreading operation to determine the application rate. If this method is used, care should be taken to protect tarpaulins from

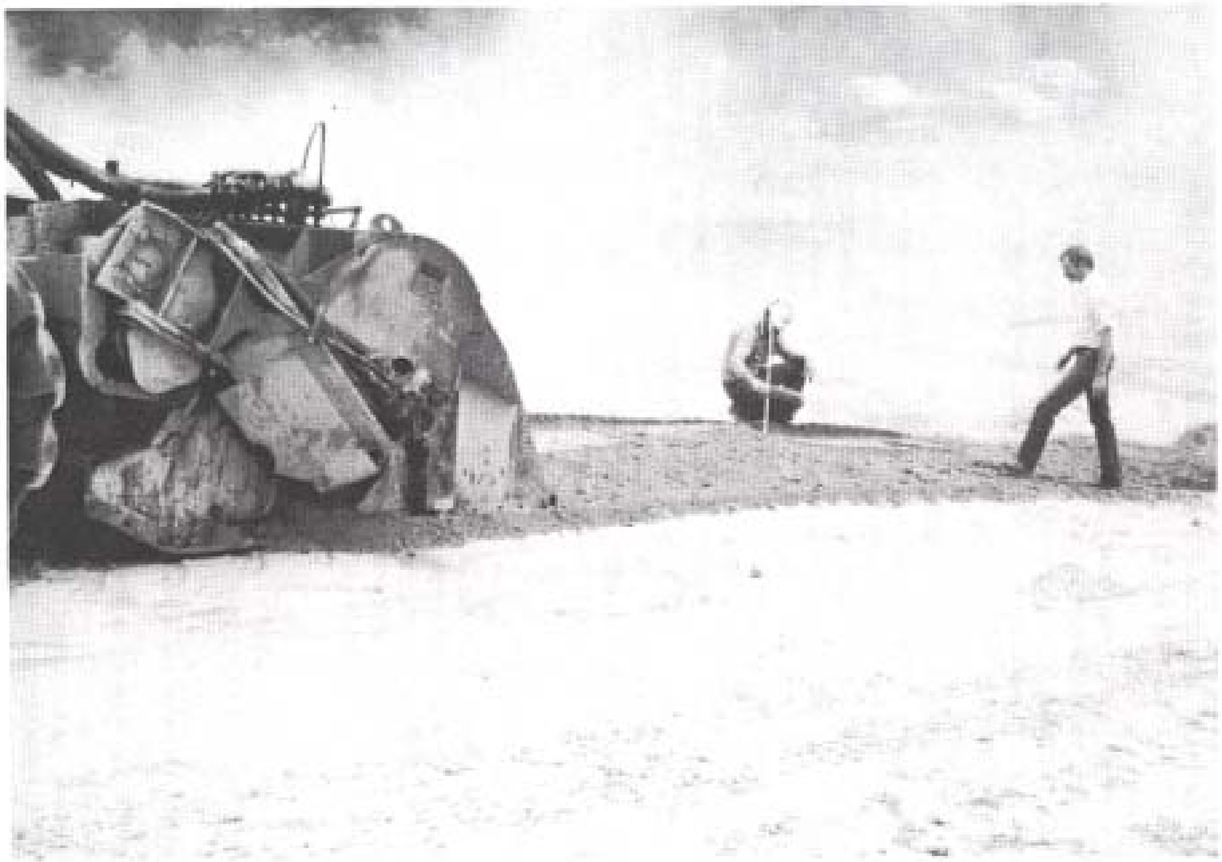


Figure 5.3
Mixing Bentonite Into Soil With a Pulvi-Mixer

damage from spreader tires. Modifications of this method using movable metal pans is also acceptable and not as susceptible to damage from machinery.

After mixing, additional CQA tests are necessary to ensure that an adequate percentage of bentonite exists throughout the mixed depth. The methylene blue test is recommended by bentonite manufacturers as an acceptable method of determining the percentage of bentonite in a soil sample. If tests are performed by different laboratories, it is important that the same grade of methylene blue crystals be used so they may correlate their results. Because this is a non-standardized test, it is recommended that a standardized procedure be described in the specifications and that several calibration tests be performed on mixtures of the base, soil material and various percentages of bentonite prior to starting construction.

5.4.3 Flexible Membrane Liners

The procedures followed in installing a flexible membrane liner (FML) are critical to the success of the project. There are numerous case histories where FML installation did not meet design standards because the procedures were followed incorrectly and poor CQA was practiced.

5.4.3.1 Subgrade Preparation

Proper preparation of the subgrade is the first step toward successful FML installation. The upper 6 inches of subgrade must be firm and free of large stones and other objects that could puncture the liner. The largest particles in the subgrade soil should be no greater than 3/4 inch in diameter and the fine finished surface should be smooth, rounded and have no particles greater than 1/4 inch in diameter. Fine finishing can be accomplished with a surface finisher and roller dragged by bulldozers or other suitable equipment.

The subgrade should be compacted from 90 to 95 percent of the Standard Proctor maximum dry density. Compaction should be accomplished with smooth-wheeled rollers or vibrating drum compactors to maintain a smooth surface. Sheepsfoot compactors are not recommended.

If there is a possibility of gas production beneath the liner, allowances must be made to vent gas to the atmosphere, as specified in the design. The impact on construction activities will include bottom slope grading requirements (minimum of two percent) from the center of the FML to the edges and a permeable subgrade material (refer to Section 4.12).

The subgrade soil may require sterilization against plant growth prior to the installation of the FML. Failure to do this at some installations has resulted in the plants growing through the liner. Sterilization is normally carried out through the removal of organic topsoil and/or application of herbicides to the soil surface. If local grass species include salt grass, nut grass or quack grass, herbicide application should be part of the sterilization process. The selection of the appropriate herbicide must be done carefully to be effective against the plant species of concern. During the application of herbicide, health and safety precautions should be taken to avoid inhalation and skin contact with the herbicide. Herbicides must be applied by operators holding an appropriate Department of Agriculture license. FML placement should not begin until several days after the herbicide application.

5.4.3.2 On-site Storage of Materials

The proper storage of a FML at the landfill site is important to ensure it is not damaged. The FML is subject to physical damage from construction activities, vandals, animals and weather. It is also vulnerable to ultraviolet light, infrared radiation and exposure to some chemicals. It should therefore be stored in a secure and protected facility prior to its installation.

Liner material is normally delivered to the site in large rolls or accordion folded panels. These rolls or panels may weigh from 2,000 to 5,000 pounds each. Exposure to direct sunlight and high temperatures should be avoided to prevent blocking. Blocking is the adhesion of liner surfaces to each other, which causes ripping or delamination of the liner when it is unrolled or unfolded.

Depending on the type of liner material used in the installation, a wide variety of solvents and chemicals may also be delivered to the landfill site. The containers should be labeled as to their contents and stored in a clean, dry area and sheltered from extremes in temperature.

5.4.3.3 FML Placement and Anchoring

Prior to the placement of a FML, the following items should be checked for completion and CQA:

- Anchor trench around the perimeter of the landfill completed and provisions for temporary anchoring made
- Subgrade preparations complete
- No standing water in the landfill
- Any structures that must be seamed around should be complete
- Any pipes or other necessary appurtenances should be in place

Liner sheets should be installed in accordance with a sheet layout detail drawing such as shown in Figure 5.4. Liner sheets must be placed so that field seams lie up and down the side slope. This orientation facilitates installation and relieves excessive stresses on the uncured seams.

The rolls or panels of liner material are typically maneuvered into place using front-end loaders or forklifts. Figure 5.5 shows a front-end loader unrolling a FML. If the rolls or panels are folded over they are normally unrolled lengthwise and then unfolded widthwise. Instructions on the outside of the rolls or panels should be carefully followed to ensure unfolding in

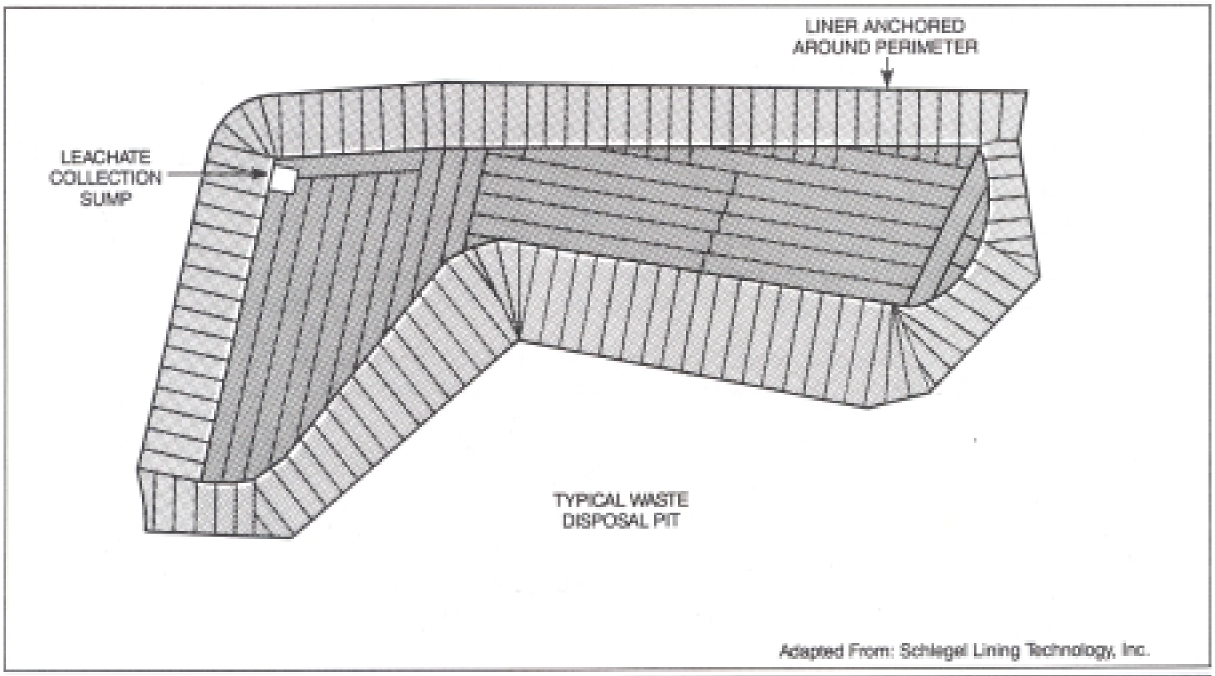


Figure 5.4
Sheet Layout Detail

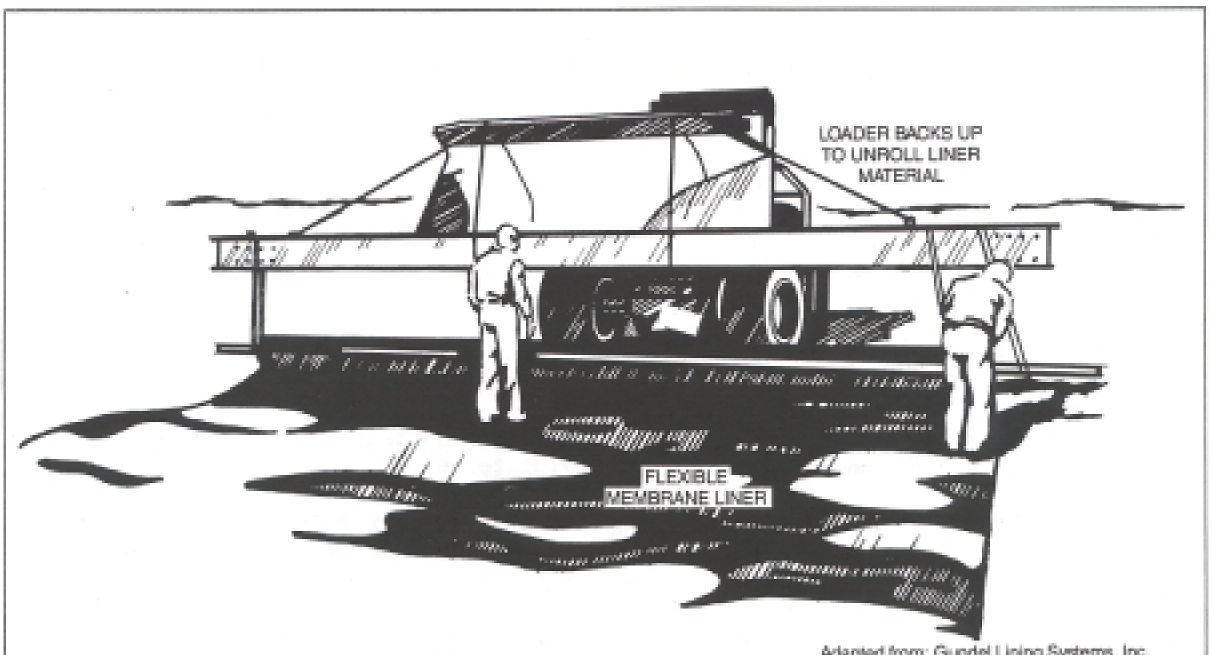


Figure 5.5
Unrolling a FML Using
a Front End Loader

the proper direction with the correct side exposed for seaming. After unfolding, the liner panels can be fine-adjusted into place by the liner installation crew. Sufficient overlap between panels must be maintained to achieve high quality seams. Manufacturers typically specify 4 to 12 inches of overlap between panels. The panels should be pulled smooth over the subgrade, but sufficient slack per manufacturers recommendations, should be left in the panels to account for shrinkage from temperature changes.

FML anchoring for a solid waste landfill is typically done at the top of the landfill side slope. Two common configurations for an anchoring system are shown in Figure 5.6. Provisions should be made for temporarily anchoring the liner panels immediately after their placement, especially important on windy days. Sandbags are often used for this purpose.

It is also necessary to anchor the liner to various appurtenances such as pipe penetrations, pipe flanges and sumps. Figure 5.7 illustrates a pipe flange anchoring system and a liner to sump anchoring system. Figure 5.8 illustrates a typical pipe penetration anchoring method.

5.4.3.4 Field Seaming

There is perhaps no single phase of installation more critical to the success of a FML project than the field seaming operation. If poor quality seaming occurs, the liner will leak and the liner system may fail.

Seaming methods vary according to the type of liner used. Table 5.2 lists various liner materials and seaming methods associated with them. Reputable liner manufacturers will provide recommended field seaming methods for their product and these recommendations should be followed. No matter what seaming system is recommended, there are certain precautions that should be taken to ensure a good quality seam listed below:

- Solvents and cements used for seaming should be stored in dry areas away from temperature extremes.

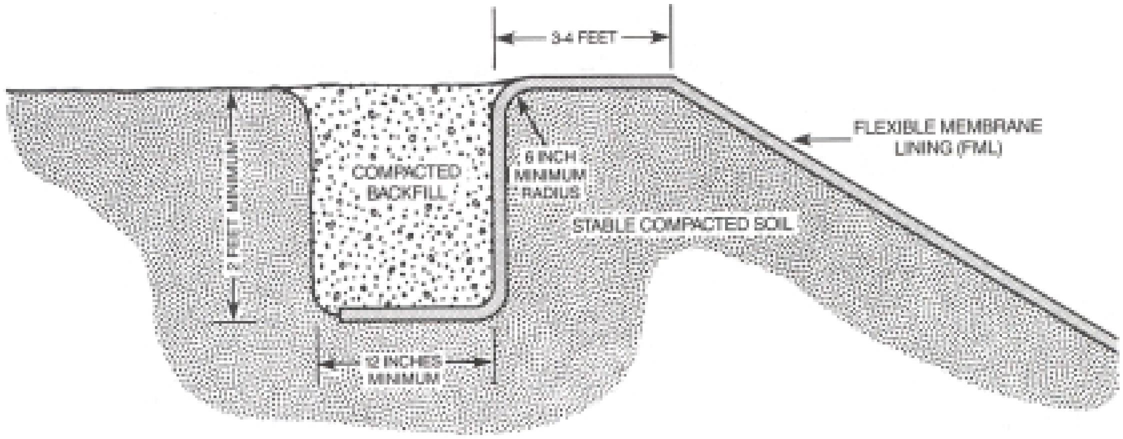
- Field seaming should be done during moderate weather. Most seaming methods work best at temperatures above 60° F with little or no wind. (U.S. EPA, 1983).

- Surfaces to be joined should be clean and dry. Typically, solvents are used to clean the surfaces before joining.

- Seams should be formed over a flat, hard surface. Often a board is slid along underneath the seam being formed.

- Wrinkles should be avoided in the seam. The preferred method is to start seaming at the center of the panels and work outward toward the edges.

- Panels on side slopes should be placed so that seams run perpendicular to the toe of the slope to avoid undue stresses on the uncured seams (Figure 5.4).



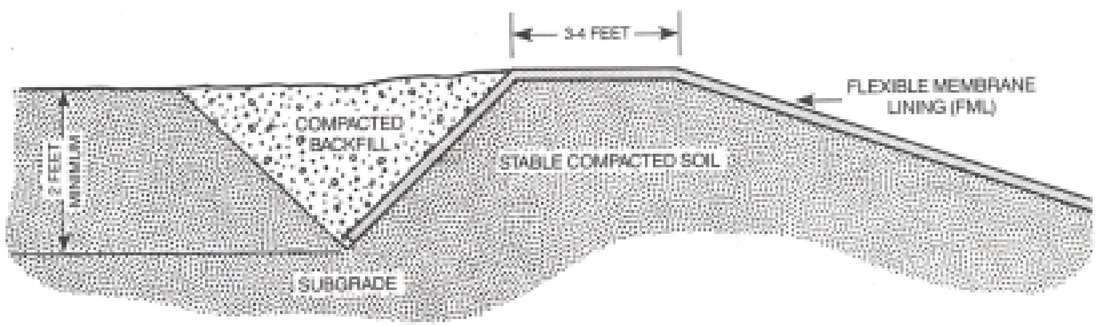
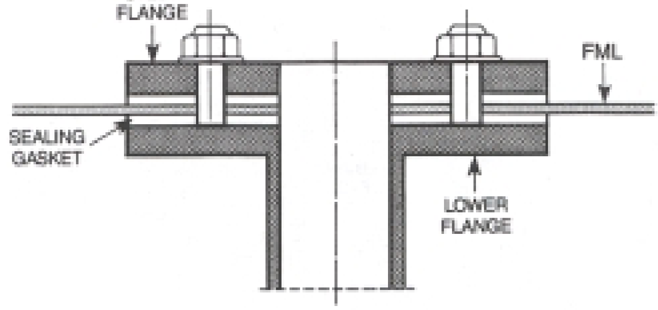
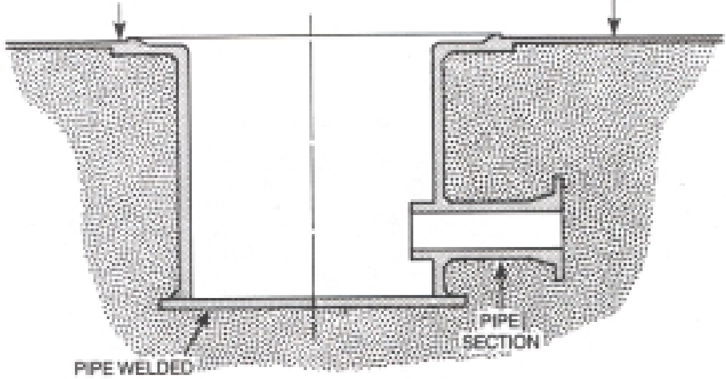


Figure 5.6
Typical Anchor Trenches



Flange Connection of FML to
Pipe Section



Connection of FML to
Prefabricated HDPE Sump

Adapted From: Schlegel Lining Technology, Inc.

Figure 5.7
Typical Anchoring Systems to Pipe Flange and Sump

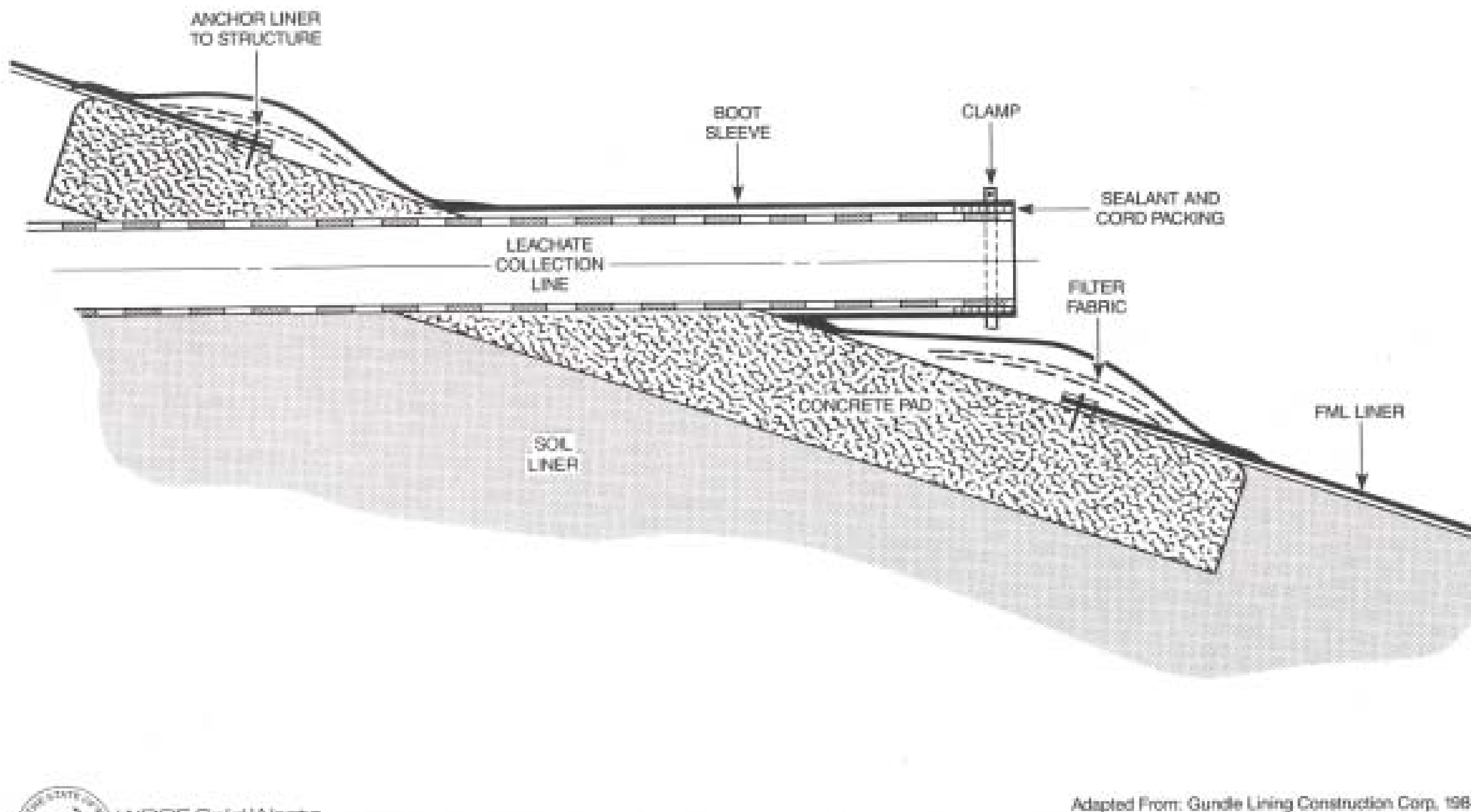


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Figure 5.8
Typical Pipe Penetration

Table 5.2 Bonding Systems Available for Field Seaming Polymeric Membrane Liners

	Solvents	Bodied Solvents	Solvent Cements	Contact Cements	Vulcanized Adhesives	Tapes	Heat Sealed	Fusion
Chlorinated polyethylene	X	X	X	X	…	X	X	…
Chlorosulfonated polyethylene	X	X	X	X	…	X	X	…
Elasticized polyolefin	…	…	…	X	…	….	X	…
Ethylene propylene rubber	…	…	…	X	X	X	…	…
Low-density polyethylene	…	…	…	X	…		…	…
High-density polyethylene	…	…	…	…	…	…	…	X
Polyvinyl chloride	X	X	X	X	…	X	X	…

- The number of panels placed during one day should not exceed the number that can be seamed in one day. At the end of the day the exposed panel edge should be temporarily anchored with sandbags to prevent damage from the wind.

- No heavy equipment should be allowed on liners.

Because any penetration of the liner is a potential weak spot, it is preferable to pipe over the liner. However, it is sometimes necessary to penetrate the liner with pipes or other appurtenances and for these situations the manufacturer will provide recommended sealing methods.

Figure 5.7 shows typical anchoring and sealing methods around a pipe flange and sump. Manufacturers will also often supply prefabricated boots for sealing around pipes as detailed in Figure 5.8. If the pipe and liner material is compatible (i.e.,PVC liner to PVC pipe), the seal can be made by bonding or welding the liner directly to the pipe using the method that the liner panels were seamed with. If these methods are used, the pipe and liner manufacturer should be consulted prior to seaming to verify compatibility.

5.4.3.5 Bridging

Bridging is the extension of the FML over a void in the subgrade causing localized stresses in the liner that can lead to failure. Such voids can be created by improper preparation of the subgrade or careless installation of the liner. Improper preparation of the subgrade includes discontinuities and depressions in the surface. More commonly, bridging occurs during the installation phase at penetrations through the liner or at the intersection of the steep side slopes and the bottom. During installation it is important to ensure that the liner is in full contact with the subgrade at these critical points.

5.4.3.6 Construction Quality Assurance (CQA)

CQA during the installation of a FML is particularly crucial. Lack of a good CQA program during this phase of the operation is almost guaranteed to lead to project failure.

The CQA program should focus on the following problem areas in FML installations:

- Use of materials with specifications other than those listed in the approved design

- Improper preparation of the subgrade

- Use of improper construction tools and equipment

- Use of improper construction methods and material handling

- Inadequate seals and anchors of the FML to pipes and other penetrations through the FML

- Installation of the FML during inclement weather

- Improper repair of defects in the installed FML resulting from manufacturing processes and contractor methods

CQA during subgrade preparation is much the same as for natural soil or soil-bentonite admixture liners. Additional effort is required to monitor the quality of the liner placement and seaming. As each roll or panel is moved into place, the identifying labels should be removed and saved for future reference. This information should also be transferred to the sheet layout drawing so that the location of each sheet is known (Figure 5.4).

Liner material and seam testing is generally divided into field testing and laboratory testing. A number of tests can be performed in the lab to monitor the quality of the liner material as it is delivered to the job site or the strength of seams made in the field or during prefabrication. The disadvantage of lab tests is their long turn-around time and the necessity to continue installation while tests are being done in the lab. If test results are negative, the contractor must suffer delays while repairs are made and the results of such repairs are often not as good as if the problem could have been determined sooner. To alleviate these problems, it is recommended that CQA be monitored through field tests as much as possible. Field tests are typically much easier to perform and they provide nearly instantaneous results.

Appropriate field tests include the following:

- Visual inspection

- Probe test

- Air lance

- Vacuum box

- Ultrasonic pulse echo

- Seam strength peel test

Visual inspections should be made of liner panels, seams, anchoring systems, seals to other materials and the materials and equipment used for seaming. Obvious damage and defects can be easily spotted and marked for correction or replacement.

The probe test and air lance test are simple procedures to examine the integrity of the edge of seams. Unbonded edges and leak paths can be detected, but these should not be the only tests used to determine seam quality.

The vacuum box test and ultrasonic pulse echo test are more sophisticated tests that can still be easily performed in the field. Both of these tests are more sensitive than the probe or air lance test and can detect small pinhole leaks or anomalies in the seam. Seams should be 100% tested for leakage using these or equally effective methods.

The seam strength peel test is a destructive test in which a sample seam is peeled apart. The condition of the surfaces peeled apart can be used to detect gross problems in the seaming process. The sample is cut from the installed liner. After curing, the pieces are peeled apart. If well bonded, reinforced liners will delaminate while unreinforced liners will tear in one or both sheets. Negative results from this test indicate gross problems in the seaming process that must be resolved quickly. Peel tests should be performed for at least every 500 feet of seam constructed in the field. Obviously, after the sample is obtained, the permanent seam must be repaired.

5.5 LEACHATE COLLECTION AND TRANSMISSION SYSTEM

The leachate collection and transmission system works in conjunction with other components of a solid waste landfill to prevent leachate from escaping the facility. Construction quality assurance (CQA). is necessary to verify that the completed system meets or exceeds the design requirements. Construction and CQA considerations for leachate transmission systems, which are similar to gravity and pressure sanitary sewers and pump stations, can be found in several references (ASCE and WPCF, 1982; WDOE, 1985). This section focuses primarily on construction and CQA considerations for the leachate collection system in the solid waste landfill.

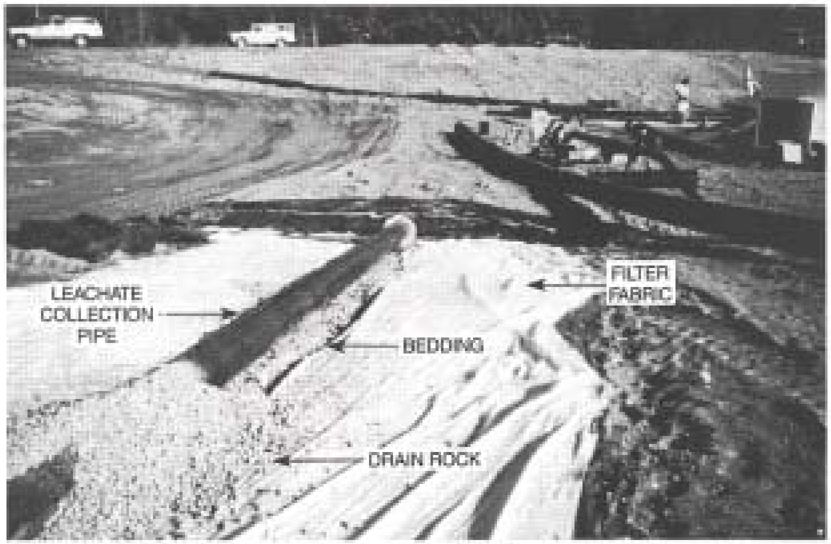
5.5.1 Installation of Leachate Collection Systems

A leachate collection system consists of several functional components working together to remove leachate from the landfill. The exact method of installation of a leachate collection system will be site and design specific, but all installations will use similar general construction procedures. A typical leachate collection system being installed in the bottom of a new landfill is shown in Figures 5.9 and 5.10.

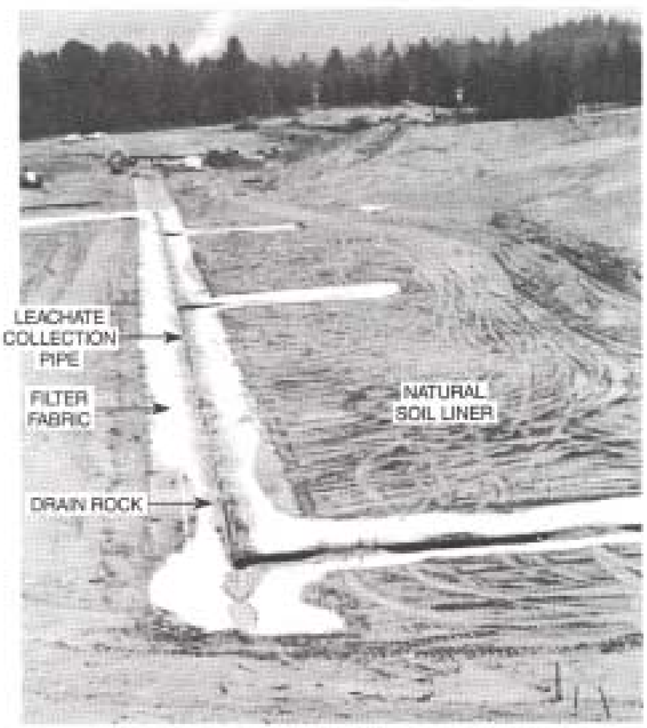
5.5.2 Potential Construction-Related Problems

Problems with the leachate collection system may not be discovered until the system fails during operation. At that time, correction of the problem may be very costly. It is important to recognize potential problems during construction and take immediate steps to avoid or correct them. Specific construction problems that can cause leachate collection failure include (Bass, 1984):

- Use of materials with specifications other than the ones in the approved design

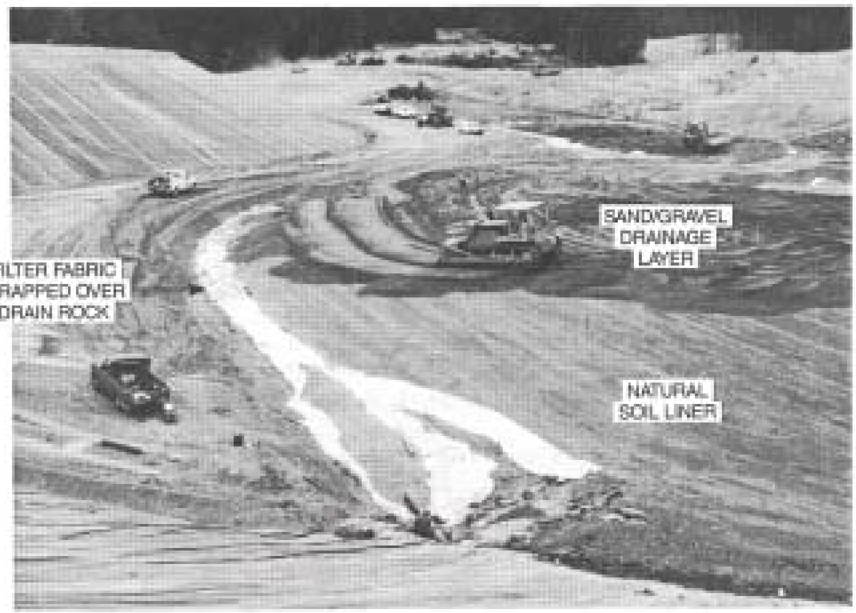


Bedding and Pipe Installed
on Filter Fabric



Filter Fabric,
Bedding and Pipe Installation

Figure 5.9
Leachate Collection System Construction



Placement of Drainage Layer

Nearly Completed Installation

Figure 5.10
Leachate Collection System Construction

- Foreign objects (e.g., rocks, clumps of soil, construction tools) left in drainage system piping which plug or restrict leachate flow and may not be removable using designed maintenance procedures

- Neglecting to install materials in the location specified in the design

- Neglecting to follow procedures specified in the design

- Siltation of filter or drainage layers resulting from improper upgradient drainage during construction and/or careless construction techniques; and/or improper drain gravel (i.e.: too many fines)

- Use of improper construction equipment and the improper placement of materials which cause damage to system components, such as crushing or misalignment of pipes due to vertical loading of heavy equipment or soil dumping

- Non-conforming layout of the leachate collection system, such as the misalignment of piping joints or improper slopes and elevations of piping causing inefficient drainage

Construction quality assurance can be very effective in detecting variations from design and other construction- related problems before the leachate collection system is completed and wastes are placed in the landfill. Without proper CQA, problems which cause failure of the leachate collection system components may go undetected until failure occurs.

5.5.3 CQA Procedures

The CQA program should address all components of the leachate collection system with emphasis on those most sensitive to CQA. CQA concerns of leachate collection system components are as follows:

<u>Soils</u>

Soils are the most construction-sensitive materials used in the leachate collection system. Inappropriate selection or installation can lead to plugging of drainage materials and clogging or structural failure of the collection piping system.

<u>Geotextiles and Collection Pipes</u>

Quality of these manufactured materials should be assessed prior to construction. Specified geotextiles should be tested in the laboratory to verify their performance. It is important to verify that the delivered material is the same as that specified and tested. Careful installation of these materials should be emphasized. Improper installation of geotextiles may result in migration of fine grain material into the drain gravel around the pipe, causing plugging of the media. Improper installation and backfilling of collection pipes could result in structural failure.

Transmission Pipes, Manholes and Structures

The quality of these materials should be assessed in the pre construction phase. Because these units can be readily inspected throughout their life and repair and replacement are less difficult than other components. CQA requirements are still not as critical and emphasis should be on placement, connection and backfill considerations.

Electrical and Mechanical Equipment

The least sensitive components of the leachate collection and transmission system are pumps, electrical equipment and related instrumentation which can be readily accessed for repairs or replacement. The COA considerations will confirm that installation and performance are in compliance with the facility design.

5.5.4 COA Observations and Tests

Observation and testing are important CQA activities throughout all aspects of the leachate collection system construction. Observation of all materials as they are delivered and installed will help ensure conformance with design specifications. Testing should be performed on component materials as each component of the collection system is installed. Observations and tests for the various components of the leachate collection system should include any or all of the following:

Drainage Layer

- Observations to see that correct procedures and equipment are used
- Testing for conformance to design grade, in-place density and in-place permeability

Collection Pipe, Filter Fabric and Drain Gravel

- Observations to confirm that filter fabric and the pipe size, type, and perforations conform to the design
- Observations of pipe installation to ensure proper workmanship in filter fabric placement, bedding placement, joining, grade and backfilling
- Visual inspection of pipe interior for obstructions
- Pressure testing of solid wall pipe to check for leaks and structural integrity

Structures

- Visual inspection of installation or cast-in-place procedures including form work, reinforcing steel, concrete quality, placement and curing process
- Testing of on-site concrete castings 'including consistency, unit weight, yield, air content and strength

Mechanical and Electrical Equipment

- Visual inspection for conformance to design specifications and for signs of damage when delivered
- Observation of equipment installation to ensure conformance with design requirements and manufacturer's installation procedure
- Start-up and performance testing to ensure proper system operation

5.6 LEACHATE TREATMENT AND, DISPOSAL

5.6.1 Introduction

Leachate treatment and disposal facilities provide a system of discharging treated leachate to the environment without endangering public health and safety. In general, the system is not unlike a sewage treatment plant except that instead of handling sewage, the facilities handle leachate generated from the landfill. For this reason, many of the construction and CQA considerations for leachate treatment and disposal systems are identical to those considered necessary for sewage treatment plants, which can be found in many references (ASCE and WPCF, 1982; WDOE, 1985). The remainder of this section however, will focus on construction and CQA considerations specific to leachate treatment and disposal systems.

5.6.2 Treatment Plant

A leachate treatment plant consists of a series of properly constructed and integrated unit treatment processes. Each unit process is normally accomplished in a separate structure, building or tank and the unit processes are integrated by pipes or conduits which carry the liquid waste between the units.

The primary concern during construction of the system is to Insure:

- That the quality of any delivered materials is consistent with the design plans and specifications

- These materials are installed in conformance with manufacturers' requirements, design plans and specifications

- That during placement or erection of these materials, damages and/or improper placement of the material does not occur.

Specific emphasis should be placed on insuring the corrosion resistance of all materials used in the plant because leachate can be an extremely corrosive environment in which to operate.

Adequate CQA can only be accomplished through full-time observation and complete testing of all aspects of the system during construction. This would include such items as regular concrete slump tests and cylinder tests during each concrete placement, structural tests of all steel, wood and/or other material components, compaction testing of all materials as appropriate and in situ performance testing of all components after installation and prior to plant start-up. These considerations are essential to any leachate treatment plant CQA program.

In particular, in situ performance testing of each unit process utilizing leachate wastes may be difficult if leachate wastewaters are not yet generated by the landfill operation. This may be due to the collection system not yet functioning, lack of refuse in the landfill or other reasons. In these cases, a simulated leachate type waste can be utilized to verify that each unit process functions as originally designed (Stanforth, Ham, & Anderson, 1979).

As part of a CQA program for leachate treatment, a plant start-up program should be initiated after construction of the facilities is completed. This process will result in debugging construction related problems and completing the necessary modifications to insure an operational facility.

Plant start-up involves operating the treatment plant and investigating the performance of each unit process using either the raw leachate or simulated raw leachate if leachate has not yet been generated. Each process unit is evaluated by detailed wastewater flow stream sampling and analyses. Then equipment or process adjustments are made and their effect on the performance is assessed. The most desirable process operational criteria are determined in this manner.

One technique utilized during plant start-up of a biological treatment process to enable effective treatment as rapidly as possible is seeding the biological treatment unit. Biological seeding involves the addition of bacteria to the unit process on start-up to hasten the acclimation of an activated sludge that will biodegrade the leachate wastes. Normally a thickened bacterial culture taken from a similar type treatment facility located close to the new leachate treatment plant is used.

5.6.3 Disposal Facilities

Treated effluent disposal facilities can vary widely from landfill to landfill. The degree of construction complexity determines to a large extent the type of CQA program necessary. A simple discharge pipe would require CQA observations and testing similar to those discussed in the applicable parts of Sections 5.5.3 and 5.5.4. A complex land application system on the other hand, would require CQA observations and testing similar to those described in that section, but in addition would require extensive performance testing similar to a treatment plant. The CQA considerations should be as rigorous as necessary to confirm that the installation and performance of the facilities are in compliance with the facility design.

5.7 GAS CONTROL/RECOVERY SYSTEM

5.7.1 Materials

Materials required for installation of a gas collection/venting system are relatively straightforward. For all systems, a permeable medium such as gravel is necessary to provide a pathway by which the gas can flow. Passive control systems which utilize a barrier will require either a flexible membrane liner, natural clay soils or other material impervious to the flow of gas. Both active control systems and gas recovery systems require piping and a motor blower to provide the required suction. All materials used should be compatible with the landfill environment and should be selected and prepared according to design specifications to ensure optimum functioning of the system.

5.7.2 Installation

In addition to choosing materials compatible with the landfill environment, it is important to ensure that all components of a gas control or recovery system are properly installed. Adequate field inspection and supervision should be available during construction to ensure that all components of the system are installed according to design specifications.

5.7.2.1 Vent/Barrier Trenches

Construction methods must prevent caving in of the walls of the trench prior to backfilling with the permeable medium. Trenches must extend to the depth of the refuse and to an underlying impermeable soil stratum or to the ground water table.

The selected barrier material must be carefully installed. Clay soil barriers should be installed to the specified thickness and compaction and be protected from drying out during installation. If admixes are to be used, care should be taken that all ingredients are in proper proportion. Synthetic membranes used in vent/barrier trenches require special protection during installation.

Where synthetic membranes are to control the movement of landfill gas, only rounded aggregate or sand should be used as the porous medium. Care should be taken when placing the membrane to avoid puncturing or tearing it. Methods of seaming and sealing the membrane must also be carefully considered (see Section 5.4). Attachment of membranes to dissimilar materials must also be undertaken with care. Most membrane manufacturers will provide literature and/or field assistance in solving such special problems.

5.7.2.2 Gas Collection Header

The gas collection header system, which conveys the gas to the collection point, may be installed either above or below ground, depending on the required performance of the pipe, the weather, the potential for vandalism, the end use planned for the site, and the cost. Exposed pipe may be protected from vandalism and ultraviolet light by a shallow soil cover. If the header piping is to be placed below ground, it can be laid in a trench or buried under a soil mound. Access to the header piping (e.g., for adjustment of flow rate or monitoring of gas quality) is then provided by means of precast vault boxes which should be locked to prevent unauthorized access.

The saturated gas will increase and decrease in temperature as it moves through the header piping, resulting in condensation. Since the header pipe may become partially or completely blocked if condensation is allowed to accumulate in low spots of the line, the piping must be carefully sloped and condensation drains must be located at all low points and at regular intervals along the header line. The typical spacing for condensation drains ranges from 200 to 700 feet, with the closer spacing preferred.

Header piping should be carefully joined, using the method recommended by the manufacturer. Plastic piping may require the use of specialized adhesives whose effectiveness may be impaired if installed under extremely cold or hot weather conditions.

5.7.2.3 Collection Wells

Well construction begins with drilling a borehole in the refuse, usually accomplished with a truck-mounted caisson or pier drilling rig with auger or core drilling bit. Choice of proper drill bit is essential to the progress of the work. For example, a core-barrel drill bit is best suited for refuse with construction debris or other difficult-to-drill material such as tires and large metal objects.

Borehole diameters should be drilled several times larger than the pipe casing and slightly deeper than the length of casing. If possible, the borehole should extend to the bottom of the refuse, and care must be taken to avoid puncturing the bottom liner. In very shallow landfills or those with high ground water or leachate levels, horizontal collection trenches may prove more efficient. Such trenches are excavated with backhoes. These trenches are also sometimes used in alternative lifts of active, deep landfills.

Following drilling of the borehole or excavation of the trench, perforated pipe is installed. The pipe may be perforated or slotted in the field, with careful attention to specifications, or factory-slotted pipe may be used. Upon installing the pipe casing, the borehole or trench is backfilled with washed, rounded or subrounded gravel 1.5 to 3 inches in diameter. The gravel should completely surround the perforated interval of the casing.

If the wells are to be used for gas recovery, they must be carefully sealed to prevent inflow of atmospheric air, which is toxic to methane- producing bacteria. Though inflow of oxygen is less important for control purposes, a good seal is also required for active control systems to function efficiently. A 2-foot-thick concrete or bentonite amended soil plug is normally poured into the vertical well around the casing and above the gravel back-fill. The concrete or clay-soil mixture should be relatively dry to prevent plugging of the gravel-filled gas collection interval of the well. A filter fabric can also be placed above the ground. The remainder of the well to ground surface is then backfilled with a fine-grained soil or soil mixed with bentonite.

Sealing of horizontal trenches used for gas recovery or active gas control is also extremely important due to the greater surface area of these collection devices. Clay soils or admixes may be used to provide the necessary seal. Horizontal trenches are often sealed under a final cover barrier layer. A filter cloth or graded filter layer may be required to prevent migration of fines from above into drainage material around the pipe.

5.7.3 Safety Precautions

The hazardous nature of landfill gas, as well as potential safety and health hazards associated with malodors, airborne particles, sharp objects and possible infectious and hazardous wastes, makes it extremely important for a number of safety precautions to be followed when excavating in landfill areas. All construction personnel should be thoroughly aware of the characteristics of landfill gas, its ability to migrate considerable distances through any permeable corridor, and its potential explosiveness if allowed to accumulate in a confined space.

Workers should be prohibited from working alone at any time. A field technician or engineer with appropriate portable detection equipment should be present during refuse excavation to test for the presence of methane and hydrogen sulfide in the excavation area.

Acid vapor masks should be available to protect construction workers from hydrogen sulfide gas. Hydrogen sulfide in concentrations greater than 10 parts per million is toxic. Oxygen supplies, such as escape capsules, should also be readily available to all workers, since oxygen deficiencies may occur in trenches or other excavations.

To reduce the risk of explosion or fire, smoking and welding should be prohibited in and adjacent to the excavation area. Construction equipment should be equipped with vertical exhaust and spark arresters and no equipment should be started up or shut down adjacent to operations in areas of exposed refuse for fire-fighting purposes. Portable fire extinguishers should also be readily available in active construction areas.

Provisions should be made for isolating portions of the system as it is constructed to minimize the possibility of methane gas migrating to the construction area. Newly constructed wells or pipes should be capped until they are joined to the collection system.

Refuse excavated in any trenching or drilling operation should be disposed of regularly and no open well or trench should be left exposed at the end of the working day. All wounds or abrasions to workers, even the most minor, should be promptly treated, since refuse is extremely septic.

All utility companies should be advised of the potential for migration of carbon dioxide and methane gases in the vicinity of landfills. Extreme caution should be exercised by utility company personnel when constructing improvements within 500 feet of a landfill, or when entering underground vaults, pipeline systems and excavations. Positive ventilation should be provided at all times.

Synthetic membranes, compacted clay or other types of barriers can be used to prevent migration of gas through bedding material or trench backfill. Penetrations into underground structures and vaults, as well as the spaces between utility lines and their conduits, should be carefully plugged or sealed to prevent gases from moving into such structures.

5.7.4 Construction Quality Assurance (CQA)

CQA for installing Gas Control/Recovery Systems should follow the same steps as discussed for similar materials in Sections 5.4 and 5.5. For example, installation of a synthetic membrane in a vent/barrier trench should incorporate the same CQA procedures that are described for the installation of a bottom FML. The installation of the gas collection header and collection wells should incorporate procedures described in the installation of collection pipes.

5.8 FINAL COVER SYSTEM

The final cover is made up of different layers of materials. Each layer has its own purpose and the material composing it may be soil, soil-bentonite admixture, geotextiles, flexible membrane liners or other specialized materials. The details for each layer will be specified in the design. Design specifications must be followed carefully during construction to ensure the cover will perform as desired.

The construction of a final cover will follow many of the same procedures as the bottom liner. Some of the unique aspects of final cover construction are presented in this section and include the subgrade layer, barrier layer, drainage layer and topsoil layer.

5.8.1 Subgrade Layer

The subgrade layer is placed over the refuse to provide intermediate cover and a smooth surface for subsequent final cover construction. This layer may be placed as part of the landfill operation or as part of final cover construction.

If a permeable material is available, the subgrade layer may serve as a gas vent layer. Placed on the side slopes, it will collect leachate as one element of a toe seep collection system. Compaction of this material should be accomplished at a low moisture content and only to the extent necessary to provide structural integrity and slope stability.

A less permeable material used as a subgrade layer would reduce surface water percolation into the landfill, reducing leachate production. This material should be compacted and graded to provide a smooth surface for later construction.

5.8.2 Barrier Layer

The installation of the barrier layer is very important, since it is this layer that reduces the percolation of precipitation into the refuse. If low permeable soils are used, the same installation procedures as used for a natural soil bottom liner are appropriate. However, particular attention must be given to compaction.

Compaction occurs differently than laboratory test results might predict. Figure 5.11 illustrates the compaction achieved in the field versus that in the laboratory. With the exception of the test at Byram, Mississippi, the 5-blow laboratory compaction test seems to be more reflective of compaction achieved in the field. The Bryam, Mississippi test apparently represents the original high density of the material used for cover (Lutton, et al., 1979).

To better control field results, a test pad should be installed over an area of refuse and the compaction procedure specified in the design performed. Tests can then be performed to determine whether desired densities and permeabilities are being achieved. If not, the procedures should be modified as necessary to achieve the desired density and permeability.

Procedures for installing a soil-bentonite admixture or a FML as a barrier layer are the same as for a bottom liner. In the installation of a FML, the material placed both below and above it must meet the gradation requirements that were specified for the subgrade in the bottom liner installation procedures.

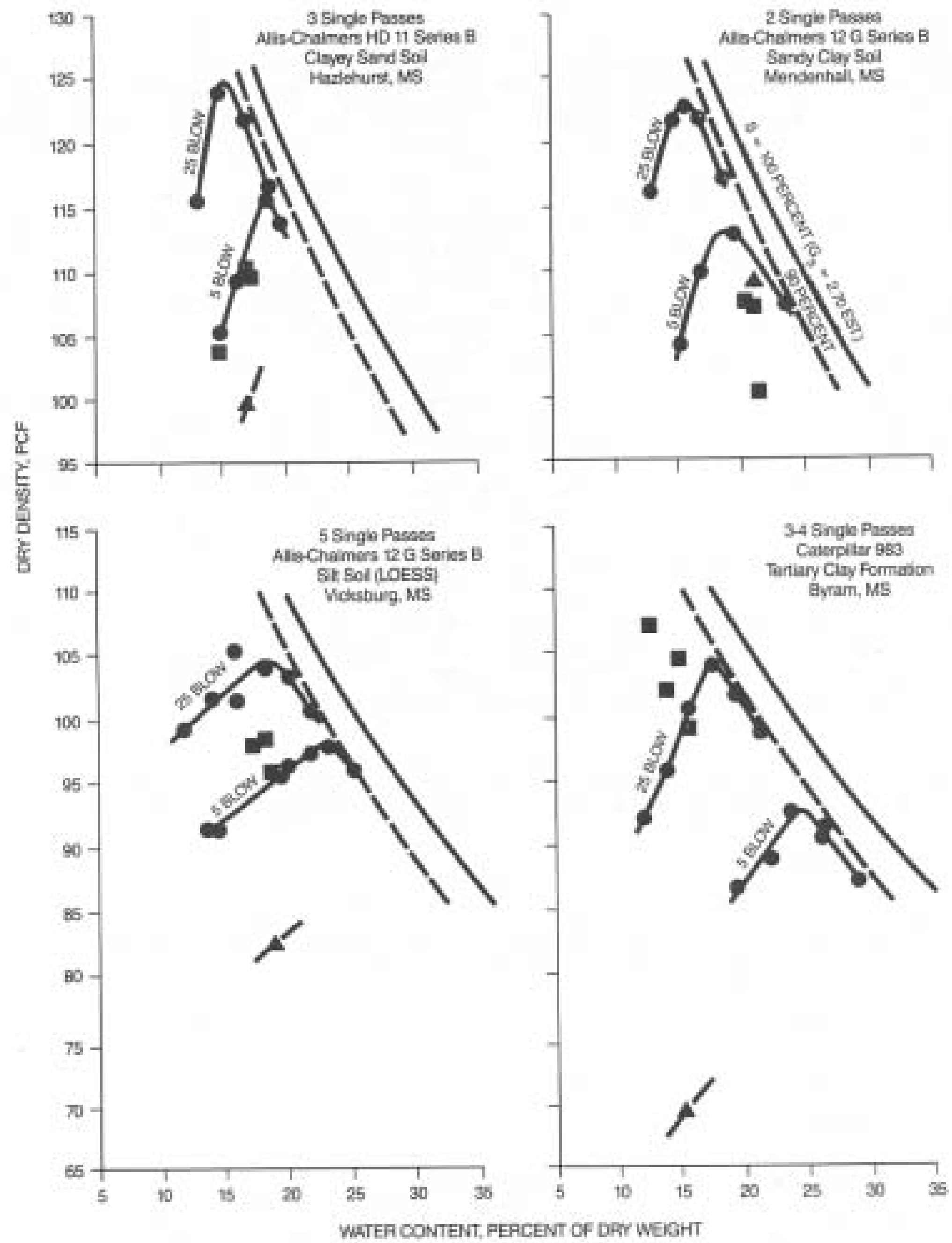
5.8.3 Drainage Layer

Installation of the drainage layer should follow the same procedures as used for a high permeable subgrade layer. If the barrier layer is a FML, material placement and compaction must be carefully carried out to prevent mechanical damage to the FML. Rapid covering of the barrier layer is also important to prevent desiccation and cracking of natural soil and soil-bentonite admixtures or to avoid long-term ultraviolet light exposure of a FML.

5.8.4 Topsoil Layer

The topsoil layer of the final cover system is unique and has no installation parallels in the landfill. The principal purpose of this layer is to provide soil moisture holding capacity and a suitable growing medium for ground cover plants. The topsoil layer reduces percolation by enhancing evapotranspiration, prevents the barrier layer from drying out, and through the support of plant life, reduces erosion problems and improves the visual impact of the landfill.

The topsoil is typically placed at depths of one to three feet and is only moderately compacted. The topsoil should be seeded as soon as possible to prevent erosion of the exposed soil surface. This requirement can place some restrictions on when a final cover is installed. Most landscaping professionals prefer to seed large areas like a landfill surface during the spring



Adapted from: Lutton, et al., 1979, p. 44

Figure 5.11
Compaction Over Solid Waste as Compared to Laboratory Test Results

- ● Compaction Test Result
- ▲ Handpacked Result
- ■ Field Compaction Result

or fall. During these periods, there is typically enough rainfall to provide sufficient moisture for the seeds without irrigation. It also allows the plants to become established enough to survive the dryness of summer of the cold of winter.

The fastest way to seed a large area is by hydroseeding. When seeded this way, the appropriate amounts of fertilizer, lime, mulch and seed can be applied during one operation. Another additive that is commonly used is a tack coat material. This material causes the mulch to stick together and form a mat that is less subject to water and wind erosion. The mat remains effective until the seeds germinate. Hydroseeding also allows easy seeding of steep slopes, whereas other seeding methods may have difficulty.

Where side slopes are steep on the landfill cover, special measures may be required to control erosion until vegetation is firmly established. Often this erosion control is provided in the form of a mulch and tack coat when the topsoil is seeded. More positive erosion control methods can be constructed and are discussed in more detail in Section 7.5.

5.8.5 Construction Quality Assurance (CQA)

CQA for installing the barrier layer and drainage layer should follow the same steps discussed for similar materials in Section 5.4. For example, the installation of a 50 mil flexible membrane as a barrier layer should incorporate the same type of CQA procedures described for the installation of a bottom FML.

Since the top soil layer and vegetation have no parallel to the bottom liner, a CQA program for their installation is presented below.

5.8.5.1 Topsoil Layer

The most important function of the topsoil layer is to provide a suitable growing medium for the establishment of a vegetative cover. To achieve this goal the topsoil layer must have the following:

- Adequate depth
- Adequate nutrient status
- Proper bulk density

The required depth of topsoil depends on the type of vegetative cover desired. Grasses and ground cover plants should have a topsoil depth of at least two feet while trees and shrubs would require at least three feet of topsoil (Gilman, et al., 1983). However, the Minimum Functional Standards require only six inches of topsoil and this depth has supported good grass growth at landfills in Washington. The appropriate depths should be specified in the design. To ensure that the required depth is achieved in the field, marked stakes should be placed in a grid pattern to indicate the required elevation prior to placement and holes should be dug at random locations to verify the depth of the topsoil after it is placed. A minimum of one hole per acre should be dug for large areas (> 50 acres) and two holes per acre for smaller areas.

The soil to be used as topsoil should be sampled and tested for the following (Gilman, et al., 1983):

- pH
- Nitrogen
- Potassium
- Phosphorus
- Conductivity
- Organic matter

Soil deficiencies are determined from these tests and appropriate levels of additives like fertilizer and lime are specified. It is important that the specified levels of additives are being achieved in the field. This can be monitored by using a small tarpaulin of known area and weighing it after the seeding operation. The weight can be compared to required application rates and adjustments to field application rates can be made as necessary.

The soil material source should be carefully monitored to avoid major changes in soil characteristics that formed the basis for determining the additive's application rates. If initial soil samples from the borrow source were taken within the A horizon of the soil profile, the nutrient and organic matter levels are higher than at greater depths. During excavation at the borrow site only soil from the A horizon should be taken. If it is necessary to go to greater depths, or should changes in the soil characteristics be observed, then additional soil tests should be performed and the amount of additives adjusted accordingly.

Bulk density is important because it impacts the root development of the plants. Soils with a high bulk density severely restrict the development of plant roots by inhibiting their ability to penetrate the soil. To avoid this problem, topsoil should be spread using methods to avoid compaction as much as possible. After the soil is spread samples should be collected and bulk density determined. This sampling can be done in conjunction with the testing for topsoil depth. If the bulk density exceeds specifications the topsoil should be scarified and organic matter added if necessary to reduce cohesion of clayey soils.

5.8.5.2 Vegetative Cover

The major aspects of a CQA program for seeding are listed below:

- Selection of landfill tolerant seed mixtures
- High quality seed

- Achievement of required seed, fertilizer, and mulch application rates

- Establishing an erosion control program

- Climatological factors

Little available information exists on which northwestern plants species are sensitive to landfill environments. Past seeding operations in Washington have typically used a grass seed mix similar to that used in establishing vegetation on highway earthwork slopes. Until more information is collected on the long term success or failure of these programs, the continued use of highway mixes is satisfactory. It may be advisable to establish seed mixture test plots on the landfill prior to commencing the seeding operation. Such test plots must be implemented at least four to six months before the actual seeding operation to be of much value in selecting the best mixture. The test plots could be evaluated by a qualified specialist and the optimum seed mixture selected.

Seed should be purchased only from a reputable dealer and should have a guaranteed germination percentage. If seed is required to be stored on site, it should be kept in a dry area. However, seed that is stored for long periods of time may deteriorate in quality and percentage of germination.

The application rate of seed should be monitored by comparing the amount used to the area covered. If hydroseeding is used the application rate can be monitored along with the other additives.

It is very important to prevent erosion of seeded areas. Mulch and tack coats are an effective means of providing erosion control until seed germination. Steep slopes may require scarification prior to seeding to provide a suitable surface for seed germination. Another effective temporary erosion control method is using a seed mixture with some seed of a rapidly germinating species.

The seeding operation should occur during climatologically favorable seasons, typically spring and fall. Even during these seasons, weather forecasts should be consulted prior to seeding to avoid periods of unfavorable weather. If dry conditions are expected after seeding, steps should be taken to set up an irrigation program.

5.9 ENVIRONMENTAL AND OTHER CONSIDERATIONS

5.9.1 Erosion and Sedimentation Control

Five major principles of erosion and sediment control are summarized as follows (WDOE, 1982):

- Keep disturbed areas small

- Stabilize and protect disturbed areas as soon as possible
- Keep runoff velocities low
- Protect disturbed areas from runoff
- Retain sediment within the corridor or site area

An understanding of these principles provides the foundation for developing and implementing a successful erosion and sedimentation control plan. Erosion control measures serve to (WDOE, 1982):

- Divert runoff from exposed soils and other vulnerable areas
- Safely convey runoff, either in surface or enclosed drainage systems by controlling runoff velocity and insuring that all surface channels and outlet points are adequately drained
- Stabilize exposed surface areas
- Control the volume and velocity of runoff discharge from the development area

Sedimentation control measures serve to (WDOE, 1982):

- Detain runoff to allow soil particles to settle out
- Filter runoff as it flows
- Intercept runoff containing sediment before it leaves the site

Erosion and sedimentation control measures can be either vegetative or mechanical. Vegetative measures include the planting of grasses and other vegetation to stabilize soil surfaces. Mechanical measures include the building of structures (e.g., check dams, sediment basins, diversions), paving, or the operation of equipment to achieve compaction or surface roughening.

Vegetative and mechanical erosion and sedimentation control measures can be temporary or permanent. Annual grasses, mulches, and netting, are temporary control measures. Perennial grasses, sod, shrubs, and trees are permanent vegetative control measures and should be established on all landfill developments.

Because landfills are generally long-term projects, permanent measures installed in the first phase of the landfill development will serve during the initial development and during development of subsequent phases. On large projects, where significant increases in runoff are inevitable, permanent structural measures for controlling the release of runoff will be necessary. Where erosion and/or sedimentation would do significant damage, measures to trap sediment and control runoff will be necessary.

Temporary measures should be used during the construction process. In some cases, temporary measures can be planned into the landfill development in such a way that they become permanent as the completion of various phases of the landfill occurs. For example, sediment basins will function as permanent storm detention ponds.

Seven categories of major erosion and sedimentation control problem areas have been identified by VDOE (1982) as follows:

- Slopes
- Streams and waterways
- Surface drainageways
- Enclosed drainage inlet and outfall control
- Large, flat surface areas
- Borrow and stockpile areas
- Adjacent properties

WDOE (1982) outlines the problems and principles of control and the associated control measures for each of these problem areas. Many, if not all, of the above problem areas will be encountered in the construction of solid waste landfills and the WDOE Erosion and Sedimentation Control Manual (WDOE, 1982) should be consulted for the appropriate control measures. Formulation and implementation of a control plan for these problems in the early stages of the project will reduce the risk of damage to the landfill site or downstream areas.

5.9.2 Dust Control

Construction of a solid waste landfill usually involves excavation and embankment of large quantities of earth materials. In certain climatic conditions, airborne dust can become a major nuisance if proper control techniques are not promptly employed. When conditions warrant, soil materials should be watered to alleviate dust nuisance. Generally, it is more effective to water at night or in the early morning hours when loss by evaporation is at a minimum. However, constant truck traffic may require continuous watering. Watering should be done by tank trucks equipped with spray bars, by hose and nozzle or by wetting materials in stockpile or excavation areas prior to excavating. A watering truck that is present at the site and used often contributes greatly to good public relations.

5.9.3 Noise Control

The large equipment used in landfill construction creates high noise levels. To minimize the impact of this noise, the construction should be conducted in accordance with all applicable laws and regulations governing construction noise, as well as ordinances or resolutions enacted or adopted by local authorities for the purpose of controlling construction noise and noise nuisance.

Typical means that should be used to control noise include limiting the work near occupied dwellings to certain hours, such as 6:00 a.m., to 10:00 p.m. on weekdays only, requiring muffled exhausts on all equipment and requiring all equipment to comply with pertinent EPA noise standards. If complaints are received during construction, it may be necessary to relocate stationary equipment, shut off idling equipment, reschedule construction operations, install acoustic barriers around stationary noise sources or place material stockpiles between noise sources and the affected dwelling. Nearby residents should be notified whenever extremely noisy work will be occurring. Provision for noise control should be included in the project specifications.

5.9.4 Traffic Control

Landfill construction is usually confined to a site that is not accessible to the general public and traffic control problems on the site should not be a major problem. However, when materials are imported to the site, the increased truck traffic can have significant impacts on the surrounding local roadways. It is important that a specific haul route be developed for large quantities of materials that are to be imported to the site. A traffic control plan complete with signing and in compliance with the latest edition of the "Manual on Uniform Traffic Control Devices" (U.S. DOT, 1984) should be developed. Where trucks are turning across roadways, such as at the entrance to the site, flaggers should be stationed during all periods of hauling. Provisions should also be made for cleaning dirt and mud from vehicles leaving the site, especially during rainy seasons.

5.9.5 Effects of Weather

Climatic conditions such as heat, cold, precipitation and freezing can have significant impacts on the methods and procedures used in construction of a solid waste landfill. Wet, cold or freezing weather conditions have detrimental effects on several components of landfill construction, particularly on excavation, embankment, bottom liner (flexible membrane and clay soil), leachate collection system and final cover system. Hot, windy weather may affect landfill construction by causing drying and cracking of fine grained soils in a clay bottom liner or cover layer. High winds can make placement of flexible membrane liners impossible. Vegetation placed for erosion control and landscaping needs moderate weather conditions for best growth.

It is important to recognize the effects of weather on construction of the landfill components and to take steps to prevent it from affecting the construction (i.e., covering or wetting the clay bottom liner, sprinkling vegetation, heating freshly placed concrete structures) or to reschedule the construction to a time when the weather will be more favorable for obtaining good results.

5.9.6 Existing Site Operations

Where an existing active landfill is being expanded, it will be necessary to schedule the construction activities to accommodate the operation of the landfill. The quality of the landfill operations should not be allowed to deteriorate because of the construction. The existing facilities must be protected during construction of the new area requiring close coordination and planning between the contractor and the operator of the landfill. In some cases it may be beneficial to both parties for each to assist in the work of the other. one example is hauling excavated material, from an expansion area to the active landfill area for use as daily cover rather than to a stockpile. Both the operator and the contractor participate in this operation and both benefit by having the other assist them in his work: the contractor receives assistance in the excavation of the expansion area and the operator receives assistance with the daily cover. This type of mutual assistance should be considered carefully, however. Neither the contractor nor the operator may have the proper equipment or experienced personnel to assist with the other's work. It should be clarified in the specifications who is responsible for tire and other equipment damage by running scrapers or trucks over refuse. Equipment operators should be cautioned about the potential for uneven surfaces and soft spots while working over refuse. For this reason, this type of arrangement is best used with non-critical aspects of landfill construction and operation.

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APPENDIX 5A

COHNONLY USED COA TESTS AND MONITORING PROCEDUR19S FOR SOLID WASTE LANDFILL CONSTRUCTION

APPENDIX 5A

COMMONLY USED CQA TESTS AND MONITORING PROCEDURES FOR SOLID WASTE LANDFILL CONSTRUCTION

Material	Parameter	Commonly Used Test Method	Reference Standard
Soils	Observation	Visual/Manual	ASTM D 2488
	Water Content	Standard Oven-drying	ASTM D 2216
		Standard Nuclear Gage	ASTM D 3017
		Calcium Carbide (Speedy)	AASHTO T 217
	Unit Weight-Density (Field Methods)	Standard Sand Cone Standard Water Balloon Standard Nuclear Gage Standard Drive Cylinder	ASTM D 1556 ASTM D 2167 ASTM D 2922 ASTM D 2937
	Particle-size Analysis	Standard Sieve Method (+200 fraction) Standard Hydrometer Method (-200 fraction)	ASTM D 422 ASTM D 422
	Liquid Limit	Standard Multipoint Method	ASTM D 423
	Plastic Limit	Standard Method	ASTM D 424
	Laboratory Compaction	Standard Proctor Modified Proctor	ASTM D 698 ASTM D 1557
	Permeability (Laboratory)	Fixed-Wall Method Flexible-Wall or Triaxial Cell method	No standard Method
	Permeability (Field)	Double Ring Infiltro-Meter Drum Test	ASTM D 3385 Federal Bentonite, 1983
	Cation Exchange Capacity	Methylene Blue Test	Federal Bentonite, 1983

Material	Parameter	Commonly Used Test Method	Reference Standard
Flexible Geo-membranes: CPE and CSPS (reinforced)	Thickness (overall)	- - -	ASTM D 751
	Breaking Strength	Grab Method A (CSPE)	ASTM D 751
	Tear Strength	Tongue Tear Method B *	ASTM D 751
	Ply Adhesion	Machine Method, Type A	ASTM D 413
	Dimensional Stability	212°F, 1 hr	ASTM D 1204
	Bonded Seam Strength	Grab Method A *	ASTM D 751
	Peel Adhesion	180 degree peel, 2 inch/min *	ASTM D 413
HDPE and PVC (non-reinforced)	Thickness	Para. 8.1.3	ASTM 1593
	Minimum Tensile Properties	HDPE	ASTM D 638
		PVC- Method A or B (1 inch wide)	ASTM D 882
	Tear Resistance	Die C	ASTM D 1004
	Dimensional Stability	212°F, 15 min	ASTM D 1204
	Bonded Seam Strength	Method A or B *	ASTM D 3083
	Peel Adhesion Peel	180 degree peel 2 inch min *	ASTM D 413

Material	Parameter	Commonly Used Test Method	Reference Standard
Geotextiles	Thickness	- - -	ASTM D 1777
	Tensile Properties	Grab Method	ASTM D 1682
	Tear Strength	- - -	ASTM D 1117 ASTM D 2263
	Burst Strength	Diaphragm	ASTM D 3786 ASTM D 774
	Puncture Resistance	Tension Machine	ASTM D 751 ASTM D 3787
Pipe	Leakage non-pressure pipe	Low Pressure Air	WDOT/APWA Sections 7-04 or 7-17
Concrete Structures	Sampling fresh concrete	- - -	ASTM C 172
	Consistency	- - -	ASTM C 143
	Making and curing concrete test specimens	- - -	ASTM C 31
	Unit weight, yield and air content	- - -	ASTM C 138

* Test method as modified by National Sanitation Foundation Standard Number 54, Appendix A.

Chapter 6

Landfill Operations

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6.1 INTRODUCTION

6.1.1 Scope and Objectives

The scope of this section is to set forth operating and maintenance procedures necessary to effectively dispose of solid wastes in a landfill. As part of the design process, the operating procedures for placing solid waste are selected and requisite facilities planned and designed. This chapter will be the link between the planning, siting and design functions and landfill operational activities.

The objectives of this chapter are to:

- Serve as a guide to develop an operations plan and operation and maintenance manual useful to, and understandable by operating personnel

- Present operation and maintenance details that are consistent and compatible with the site characteristics and are useful to, and understandable by operating personnel

- Protect the environment

- Meet the requirements of regulatory agencies

- Provide an efficient and economical operation

- Achieve an aesthetic appearance acceptable to the community

6.1.2 Operation Alternatives

The solid waste operations placement method is dependent on the site topography and availability of cover material. These methods of operation alternatives are classified as the area fill method, the trench fill method and modifications thereof. During the design phase the. appropriate operations alternative is selected. These alternatives are described and illustrated in Section 4.4 of the Landfill Design chapter.

Additional factors affecting the waste placement procedures include preparation of the solid wastes and the delivery mode. Shredding or baling of refuse can have major impacts on the equipment selection and operating procedures for waste placement, Also, if the waste is delivered in larger vehicles only, or a combination of commercial haulers and private vehicles, the operation area can be significantly affected. Both of these delivery modes are discussed in Section 4.4 of this manual.

6.1.3 Operations Plan

The operations plan prepared as part of the design procedure should specify and graphically display the elements necessary to operate a disposal site. These elements may include:

- The operating procedures to receive, process and place the solid wastes
- Daily and intermediate cover procedures
- The -procedures for operating surface and ground water management facilities
- Operation of leachate and gas control facilities
- Equipment selection
- Methods to control road mud and dust
- Maintenance programs for the site, facilities and equipment
- Environmental control and monitoring measures
- Required inspections and frequency
- Personnel considerations
- Vector control plan
- Noise control plan
- Litter control plan
- Safety program
- Contingency plans for fires, leachate leaks, surface or ground water contamination and methane migration beyond facility boundaries
- Recycling plan
- Records and reports
- Post-closure operations

Refer to Section 6.1.5, Operations and Maintenance Manual, for the coordination of information between the operations plan and the operations and maintenance manual.

To accomplish the aforementioned objectives, the plan, formulated as part of the design process, must be complete and thorough. Concise procedural descriptions easily understood by operating personnel have a higher probability of being performed correctly. Graphic displays of operations should be functional, easily interpreted and unencumbered by engineering details. The facilities design drawings can incorporate engineering design details for construction. Engineering calculations and analyses pertinent to the operations plan can be included in the appendices.

6.1.4 Phased Operations and Development

Development of a solid waste disposal site is a continuous construction and operations activity. As areas are prepared for receipt. of future refuse, active areas are being filled and completed areas are closed out. The design procedure and operational plan provides for phasing in the future areas to meet the projected waste stream. Depending on site size, waste stream flow rate and anticipated site life, the incremental phases could vary from one to several.

Phasing is also important in the management of leachate quantities, particularly in the high precipitation areas of western Washington. When an area is lined and made ready to receive solid waste,- any precipitation falling on that area will be collected and diverted to the leachate treatment and disposal system. This creates high peak flows and larger volumes for treatment.

Phasing can be designed to minimize this effect. Lined areas can be constructed for a shorter site life, such as two to three years, to reduce the area exposed to precipitation. Within lined areas, diversions in the leachate collection may be possible such that precipitation that does not come in contact with solid waste can be discharged without passing through the treatment system.

For a small rural site the total waste placement area may be prepared for receipt of refuse. More typically however, the phasing scheme will provide for closing out a filled area, placing waste in the active area and constructing future placement areas.

Initial development may require construction of site facilities such as access roads, fencing, buildings, surface and ground water control systems and leachate management facilities together with earthwork and stockpiling of materials for waste placement. As phases of the site are developed, these facilities may need to be extended and/or enlarged. Final cover systems and additional gas control works should be installed as the filled areas are closed.

Consideration should be given to coordinating the phased development with the construction season and assuring that provisions are made for wet and cold weather operations.

6.1.5 Operations and Maintenance Manual

As a solid waste disposal site is being prepared to receive waste, facilities are constructed and operating equipment is selected. A manual should be prepared detailing the operating procedures and maintenance requirements. The operations plan previously discussed could be included in the, operations and maintenance (0 & M) manual.

Small rural sites may need only one document incorporating the operations plan into the 0 & M manual. In this case, as final equipment is required and facilities are completed, the document may need amending to include specific operation and maintenance information.

At larger sites, it may be appropriate to include in the operations plan only those items necessary for development and operation of the landfill as discussed in the previous section. Then all the other required elements would be included in a separate 0 & M manual. At even more complex operations, it may be appropriate to have separate 0 & M manuals for each major element, such as the leachate treatment system and gas control system.

6.1.6 Environmental Monitoring

To ensure that landfill operations are in compliance with standards, environmental monitoring is conducted. It must commence during development of a site and continue during its active and post-closure phases. Although environmental monitoring is an operations procedure, its requirements are discussed in Chapter 8.

6.2 LANDFILL OPERATING PROCEDURES

6.2.1 General Procedures

6.2.1.1 Hours of Operation and Entrance Signs

The hours of operation for a solid waste disposal site depend on the schedule of waste delivery. For a small rural site this may be a limited time each week to coincide with local refuse collection schedule. A rural site will typically be serving individuals hauling their own refuse and should be open during the weekend.

Larger sites serving more urban areas will be operating during the week and on the weekend. For cities, this operation can be on a 24 hour basis. Commercial and industrial collection may occur during the night provided noise regulations can be met both at the disposal areas and access roads.

Other considerations in establishing operation hours include local traffic patterns, cost of operations, availability of transfer stations and storage containers. With storage containers at the entrance, it would be possible to operate with an attendant only to monitor dumping and collect charges. It will be desirable to close the landfilling operation before dark to allow time to place daily cover. Otherwise, a lighting system will be required.

A sign at the entrance is required by the Minimum Functional Standards and is needed to provide operational information. Information should include:

- Site permit number
- Name of site
- Days and hours of site operation

- Unacceptable materials
- Fees charged
- Name, address and telephone of operating entity
- Emergency telephone number
- Directions to site tipping areas and special handling areas (this
- may be a separate sign located inside the site if the travel route
- at the entry is obvious)

For larger sites, a site display map can be useful to provide directions. .Posted sign information should be kept current.

6.2.1.2 Accepted and Prohibited Wastes

Generally, most residential, commercial and industrial wastes are accepted at a solid waste landfill. Special, dangerous and extremely hazardous wastes as defined by Chapter 70.105 RCW, Hazardous Waste Disposal, and Chapter 173-303 WAC, Dangerous Waste Regulations, are prohibited at all but specially permitted sites. Some of these wastes do occur in limited quantities in the mixed municipal waste stream. Other more common wastes that may or may not be accepted include demolition and construction wastes, wood wastes, tires, large appliances, furniture, tree stumps, dead animals, manure, sludges, septage pumpings, incinerator residue and fly ash, hospital wastes, and dredge spoils depending on chemical content.

The jurisdictional health agency may require a special permit prior to acceptance of dead animals, asbestos, septage pumpings, hospital wastes, and dredge spoils. Dredge spoils must be analyzed for chemical content and may be classified as demolition waste, problems wastes, dangerous, or hazardous wastes. The latter two classifications would prohibit dredge spoil disposal at a solid waste landfill. Methods for disposal of special wastes will be discussed in Section 6.2.2, Disposal Procedures. These procedures may be a factor in determining acceptability. Some landfill sites are designated for special wastes only. These normally are for demolition and construction wastes, wood wastes, tree stumps, etc.

6.2.1.3 Waste Stream Accounting

The MFS includes requirements for waste stream accounting in Sections 173304-405(3) and 173-304-460(3)(g)(iii). Accurate waste stream accounting provides useful information for evaluating the efficiency of placing and compacting disposed wastes, predicting future space requirements and anticipated site life estimating cover material need and settlement to be expected. Two methods of accounting for delivered wastes I are:

- Weighing all wastes received

- Counting loads and fee s received and estimating volume of loads

For landfills with permitted capacity greater than 10,000 cubic yards per year, solid waste tonnage must be measured to plus or minus five percent. Scales greatly facilitate this operation and provide a high degree of accuracy. The use of a computer with the scale will also reduce bookkeeping requirements.

When planning installation of a scale system, consideration should be given to the number of vehicles to be weighed. An automated system can handle a higher rate of incoming loads, but at a higher capital cost. Curbing, markings, transverse bumps or automatic gates are useful to assure proper positioning on the scales. Maintenance of scales is minimal if-proper care is taken and the facilities kept clean of dirt, water, snow and ice.

Counting loads and/or fees charged can provide data on waste received, but must be used with care. The density of loads can vary widely and route collection vehicles may not always be fully loaded. Where local residents deliver their own wastes to the tipping area, the fees charged can be used to estimate refuse received. If on-site containers or a transfer station at the disposal site are used for self-hauled waste, a count of the containers may be more accurate.

Landfills having yearly capacities less than 10,000 cubic yards must also keep records of, incoming waste by volume or weight. However, accuracy requirements are less stringent due to the smaller quantities . of waste involved.

6.2.1.4 Traffic Control

Control of traffic entering and traveling on the site is essential for orderly operation. It should be planned and designed to:

- Provide directions from public thoroughfares to site entrances
- Prevent unauthorized entry
- Direct appropriate vehicles to correct activity and to exit
- Minimize accidents
- Minimize vehicles becoming stuck and provide for prompt removal of stuck and inoperable vehicles
- Control unloading and special waste handling

Off-site signing to guide users to the site can be coordinated with the local road agency. At the entrance, a sign should be posted with the information previously discussed. A gate is vital to restrict entry during non-operating hours. From the entrance, traffic should be directed to the first activity, usually a toll booth and/or scale. The vehicles should then be guided to the waste processing or disposal areas.

A variety of materials is often available at a disposal site for fabricating traffic control devices including barrels, tires, auto wheels, logs, waste lumber, concrete pylons, etc. By posting signs, placing barricades and guard rails, control can usually be maintained. In some instances, at larger operations or during construction activities, a flagman may be needed.

The waste delivery mode of incoming vehicles can vary from an automobile to a large transfer truck. As discussed in detail in Section 4.4.5, the delivery mode affects the time of unloading and the area required. Normally, the unloading activity is enhanced by separating manual unloading from mechanical unloading. This may be accomplished by using a transfer operation for small loads or a separate tipping area at the working face.

As the frequency of vehicles arriving at the tipping area or transfer station increases, it is useful to have a "spotter" directing and controlling traffic. This will avoid accidents, allow the waste to be placed close to the working face and speed the unloading process. The "spotter" should be well-trained and wear highly visible clothing.

6.2.1.5 Salvaging

Salvaging activities at a disposal site are commendable for reducing waste, lowering environmental impacts and conserving resources and energy. But this activity must be well planned and evaluated for effects on the disposal operation and economic viability. Strict control of this operation must be exercised to prohibit scavenging.

A salvage operation requires environmentally sound working areas and facilities. The salvage personnel must be trained to recognize dangerous and hazardous wastes, be cognizant of safe working practices, and be trained to render aid to injured co-workers. Salvaging at the working face requires more time to sort out usable materials and more area to hold the incoming loads and salvage containers than an operation without salvaging.

To minimize time and area needed, sorting should occur promptly and salvage material removed frequently. Salvaging should be performed away from the working face, requiring a sorting area and transfer equipment.

6.2.1.6 Recycling

Similar to a salvage operation, recycling activities at a disposal site reduce waste and environmental impacts, and conserve resources and energy. This activity must be well planned and evaluated for economic viability and effects on the disposal. operation. Good control of this operation must be exercised to prohibit scavenging. Recycling may be done near the entrance gate for convenience, but must be in an environmentally sound working area.

Recycling activities have been implemented at landfills in various forms. Bins may be located so aluminum cans, paper, glass and other typical wastes can be presorted by the individual and deposited. Automobile hulks and white goods are often flattened and transported to metal processors. These larger waste items can be stored until sufficient quantities accumulate for economic processing. The effectiveness of these operations depends on the quantity and condition of wastes delivered, current market prices, proximity to processors and handling costs.

6.2.2 Disposal Procedures

6.2.2.1 Refuse Unloading

Refuse unloading procedures are important to a smooth functioning disposal operation. Unloading at the toe or the top of the working face depends on the type of fill operation selected, the need to control wind blown litter, the access road layout and the operator use of compaction equipment. If a trench fill method is planned, unloading may be required from the top. Normally, in an area fill method, unloading is at the toe. Refer to Section 4.4, Operations Alternatives, for a description of filling methods.

Where wind blown litter is a problem it may be desirable to unload refuse at the toe. It is possible in the trench fill method to unload at the toe by providing a ramp down to the trench bottom for disposal vehicles. In this situation, the trench must be wide enough to accommodate the delivering vehicles and compacting equipment. Blowing litter may also be controlled by portable litter fences. However, these may require frequent repositioning and their limited height may be insufficient in some installations.

The appropriate size of refuse unloading area dependents on the:

- Waste stream flow rate
- Number, size and type of delivery vehicles
- Compacting equipment requirements

Most route collection compactor trucks and transfer trucks have unloading mechanisms and can discharge their load rapidly. Some transfer trucks use a front movable bulkhead that must be pulled out by the landfill equipment to unload. Others are designed to have specialized handling equipment perform the tipping function. To avoid conflict, it is usually preferable to provide separate areas for mechanical unloading vehicles and manual unloading disposers. These self-haulers should be directed to the separate area.

However unloading is accomplished, it is essential that it take place as close as possible to the working face. This minimizes landfill equipment efforts, controls litter and allows for more effective daily cover.

6.2.2.2 Spreading and Compaction

Proper compaction of solid waste at a landfill can provide more benefits to the total operation than any other activity. Some of these benefits include:

- Conserving space
- Minimizing and controlling litter

- Allowing for easier and more economical covering" '

- Provide for less settlement which occurs more evenly

- Creation of a more aesthetic operation

Achieving good compaction is dependent on the waste characteristics, equipment used for compaction and operating procedures implemented.

Solid waste is a very heterogeneous material, but can be expected to be within typical ranges. Refer to Table 4.6, Chapter 4, for density ranges for various classes of waste. The expected density of material received will be from 200 to 800 pounds per cubic yard. In-place compacted densities in excess of 1,000 pounds per cubic yard can be achieved.

Spreading and compaction at a landfill can best be performed with specially designed compactors. Tracked dozers and loaders are often used also. In some instances, wheeled loaders may be used, but should be equipped with special tires for use on refuse. Larger equipment is more effective in compacting refuse to a higher density. Compactors are equipped with load concentrating cleats, bars or lugs. The most effective compaction occurs with these compactors operating on levelly spread refuse. Unfortunately, spreading the refuse level does not lend itself to a tight operation and would require a larger working area. Therefore, a compromise is usually made and the refuse is spread on a slope not in excess of 3 horizontal to 1 vertical, and preferably not this steep.

Refuse should be spread in thin layers and compacted to eliminate cushioning and bridging. Testing has indicated a sharp drop in density for layer thicknesses above 1.5 feet and it is generally recommended waste not be spread in over a 2 foot thickness. The number of passes by the equipment is important in reaching higher densities. Normally 3 to 5 passes should be made over each layer. More than 6 or 7 passes will not produce significant compaction for the effort expended; however, there should always be a minimum of 2 passes. Figure 6.1 illustrates the relationship between compaction and lift thickness. Figure 6.2 illustrates relation between density and number of passes.

Consistency of the compaction effort together with mixing of various types of waste will contribute to more even settlement. Compacting the top of a cell lift to a smooth surface will allow for easier covering with less material. Routing waste delivery vehicles over in-place refuse can provide additional compaction in dry weather on previously well-compacted refuse or on all-weather roads. This could be accomplished where intermediate cover is placed, but should not be done where the final cover system is compacted.

6.2.2.3 Cell Configuration

Typical daily landfill cell configuration is illustrated in Figure 4.13, Chapter 4. Each day's refuse is spread and compacted in layers and a continuous cover soil layer applied at the end of the day. The higher the

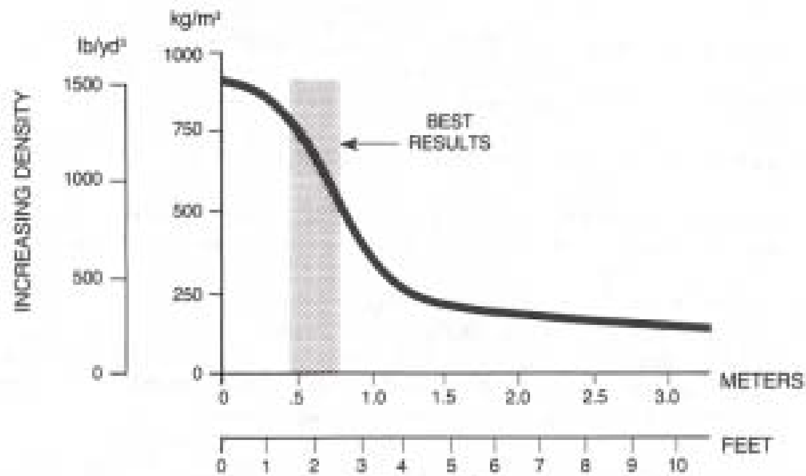


Figure 6.1
The effect of individual lift thickness on landfill compaction.

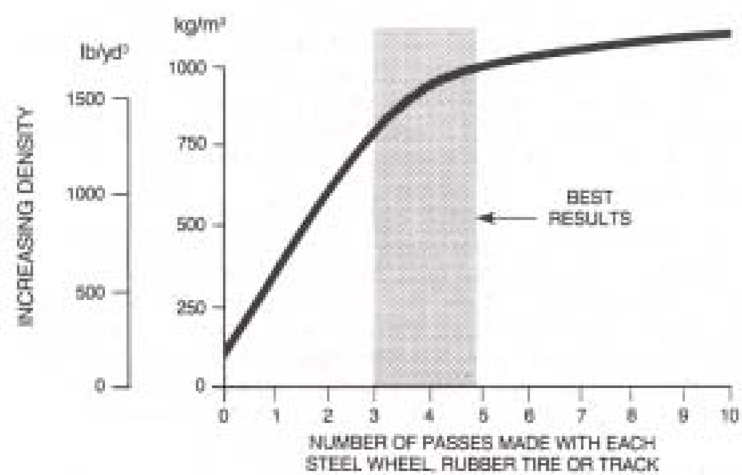


Figure 6.2
The effect of the number of equipment passes on landfill density.

cell, the less cover soil will be required for a daily volume of refuse. The width of the working face should be kept to a minimum, but be wide enough to allow delivery vehicles prompt access for unloading and sufficient room for compaction equipment operation. The cell height and length must then be selected based on the daily volume of refuse received. The height is also influenced by the slope on which the refuse is placed and the area available for operating. The cell end side slopes should be kept as steep as possible (20 to 30 degrees).

6.2.2.4 Cover Material Placement

Cover material is usually classified as daily, intermediate and final. The selection and use of this material will be based on availability and function. The final cover system typically includes the use of a low permeable cover material. However, a low permeable material placed as daily or intermediate cover in a multiple lift situation could cause horizontal migration of leachate which could be detrimental. Also, the first layer of the final cover system may be a gas venting or leachate seep collection layer that must be permeable. Finally, low permeable materials may not be trafficable in wet weather.

Daily cover is required to a minimum depth of six inches in MFS regulations, Section 173-304-460 (4)(d). However, daily cover practice may vary depending on climate, waste types, waste stream, etc. Daily cover practices will be outlined in the Operations Plan and approved by the jurisdictional health department.

Daily cover controls fly propagation and presents an aesthetically pleasing appearance. To a more limited extent, it helps to control blowing paper, vectors and fires. These latter problems are more adequately avoided by performing proper compaction and special handling of "hot loads".

Intermediate cover is used to close off a cell that will . not receive additional lifts of refuse or final cover for some time. It is typically 12 inches thick and functions to control odors and moisture. Depending on the material characteristics, the intermediate cover may be useful in limiting
percolation of surface water. If intermediate cover of this nature is used, it should be removed prior to placement of additional lifts of refuse. The cover should always be sloped and graded to prevent ponding of water. The intermediate cover may also become a gas vent or leachate seep collection layer and should conform to design requirements discussed in Section 5.'8.1.

The final cover system is an engineered part of the landfill and should be installed with care. The design of this system is discussed in Section 4.16, Chapter 4, and Section 5.8, Chapter 5, and illustrated in Figure 4.39.

the type of materials available for daily cover can significantly affect the ease and cost of the cover operations. Some of the usual soils types and their operational characteristics are listed in Table 6.1.

Table 6.1. Daily Cover Soil Material Comparison.

	Ease of Excavation	Traffic-ability	Reduce Leachate Generation	Wet Weather Usage	Gas Permeability	Odor Control
Sands/ Gravels	G	G	P	M/G	G	P
Glacial Till	M/P	M/P	M	M/P	M/P	M/P
Silts/ Clays	M/P	P	G	P	P	M

(P) Poor (M) Medium (G) Good

The placement of the cover material depends on the operation method, source and type of cover material, access roads, and equipment used for transporting and placing. Where the cover material is excavated ahead of the working face, it may be possible for the waste compacting equipment to excavate, move, spread and compact the cover. More typically, the cover material will be transported to the cell area from an on-site source, a stockpile or imported from off-site. In these cases, the hauling equipment will be scrapers or trucks.

Placing the cover materials can be accomplished by dumping at the top and/or toe of the active area and spreading with the compacting equipment or a bulldozer. When the cover material is transported in scrapers, the material can be spread on the refuse as it is deposited. Final shaping and compaction is then accomplished with the refuse compacting equipment. When using this latter procedure, consideration must be given to the slope of the working face . . A steep face can cause a scraper to "belly out", which hinders the mobility of the machine and adversely loosens the previously compacted refuse.

Cover material requirements for specially processed refuse such as shredded or baled waste may differ. Each situation should be evaluated for needs and coordinated with the local health agencies for any lest restrictive procedures considered.

Alternative materials for daily cover may be considered for a site with limited cover materials or where imported soil is required. Where soil cover material is available it may be the most economical procedure, but where proposed sites do not have adequate soils or existing sites need to be extended in life, alternative materials could be evaluated. Materials to consider are wood wastes, dried sludges and artificial covers.

Wood wastes, when available in adequate sup ply, may provide the needed daily cover. Wood wastes include wood pieces or particles generated as a byproduct of manufacturing wood products (i.e. sawdust, chips, bark, pulp and log sorting yard waste). However, there may be special problems associated with wood wastes, such as continuous supply, trafficability and handling expenses. Large supplies of industrial sludges may be available. The sludges must be dry enough to function as a cover and tested to insure heavy metal concentrations and chemical pollutants are within acceptable limits. Also, trafficability on the dried sludge may be a factor.

Artificial foam products have been developed, tested and approved for use as interim cover in some states. The non-hazardous and non-explosive material produces no leachate and is compatible with landfill gases. In a test application of 1-1/2 to 2 inches, the foam eliminated flies and insects; controlled odors, dust and blowing litter, and deterred rodents. Future waste placement on the foam will compress and break the material into small pieces. This will conserve space in the filling operation and reduce the quantities of cover material. The cost of the foam, application equipment, and labor to apply the covering should be compared to the cost of soil placement. Artificial foam products should be tested and evaluated on a case by case basis and will require a variance from WAC 173-304-460 (4)(d) and approval of Washington State Department of Ecology and the local health department. Further information pertaining to the use and effectiveness of foam products may be obtained from Kmet (1983).

6.2.2.5 Stockpile Requirements

Provisions for stockpiling cover materials should be an integral part of the operating procedures. During the design period, fill placement areas are identified and excavation requirements detailed. Stockpile areas are designed for various material types and adequate areas assigned. The type of selected fill method significantly impacts stockpiling requirements.

Where it is necessary to excavate all cover and other materials from the fill area, more extensive stockpiling areas are needed. Also, when multiple lifts are planned, on-site material must be stockpiled or imported materials stored for contingency conditions.

The layout and staging of earthmoving operations are extremely important in controlling costs of operation. Transport costs are minimized by locating stockpile areas near the waste disposal area. Also, access to stockpiled material should be via all-weather roads.

6.2.2.6 Inclement Weather Operations

Cold, wet, hot and dry weather conditions all require special operating procedures to accommodate incoming wastes. Hot and dry weather conditions can create additional odors, dust and equipment problems. Control of these conditions is discussed in Section 6.2.4. Preparations must be made for cold and wet weather conditions to provide a continuous, well managed operation.

In anticipation of wet weather operations, the following important considerations must be dealt with:

- Temporary drainage and erosion control systems
- Wet weather tipping pad
- Granular soil stockpile (cover)
- Access road maintenance
- Truck washing
- Contingency planning

To effectively operate during rainy seasons, thorough preparation must be made early enough so no tasks are left undone at the onset of wet weather.

Temporary drainage facilities should be installed to divert surface 'Water away from the working area, stockpiles, and access roads. This water can be routed to the permanent drainage facilities provided by the site design and construction. Completed areas should be hydroseeded and temporary erosion control measures implemented where necessary (see Section 4.16).

A wet weather tipping pad constructed prior to the rainy season will allow delivery trucks to tip without becoming stuck. The access road leading to this pad should be of all-weather construction. Useful materials are acceptable demolition debris like concrete rubble and on-site or imported granular materials. The operating procedures should designate whether this all-weather tipping pad is incorporated into the normal working area or whether a separate area is provided.

The cover soil used during wet weather operations must be granular to allow placement and compaction. It will usually be necessary to stockpile this material in advance, as excavation and hauling can be difficult and often impossible during wet periods. If necessary, the stockpile can be covered with plastic to minimize moisture content. Silts and clay materials will be totally unworkable when subjected to excess moisture.

Access roads should be maintained frequently to provide a sound, smooth, free drainage surface. Ditches along the roads should be cleaned of debris, vegetation, silt buildup and shaped to drain properly.

During rainy periods, refuse trucks may track considerable mud onto nearby streets and roads. At these times, washing the truck wheels may be accomplished with either manually operated equipment or a more complex automated wheel washing systems.

Cold weather conditions create special problems with equipment operation, personnel comfort and frozen earthwork. Starting cold equipment is enhanced by a good maintenance program. In extremely cold weather, block heaters are useful and inside storage may be appropriate. operating equipment with heated cabs will contribute to operator comfort and a more effective work effort. Warm clothing and heated employee facilities also are recommended for comfort and effectiveness.

Handling soil materials requires consideration. ' While frozen ground can be worked by equipment, thawing periods disturb the soil structure. Firm access roads and tipping areas are necessary for continuous operation. Where frost penetrates below 6 inches, rippers on the dozers may be used to excavate cover material. Frozen ground below 12 inches becomes unworkable and stockpiling should be planned. Stockpiling free draining material will provide a source of cover material. It may be useful to cover the material with insulating leaves or straw. A dark colored tarpaulin could serve to keep rain out and absorb the sun's heat.

6.2-2.7 Special Waste Handling

The form and content of wastes delivered to a disposal site vary considerably depending on the community's residential, commercial, industrial and agricultural activities. The form could be liquid, semi-liquid, or solid. Liquid and semi-liquid wastes could include sludges, septage wastes, volatile and flammable liquids, pesticides, or hazardous chemicals. Solid waste causing special problems might be powdery, bulky, or contain hazardous chemicals. Other special wastes are dead animals, hospital wastes, animal manures, and industrial wastes. Dangerous or hazardous wastes cannot be accepted and the generator or hauler must arrange for their delivery to an approved facility.*

Radioactive and explosive wastes are very special categories. Radioactive materials are controlled by the U.S. Nuclear Regulatory Commission and are not accepted. Explosives should only be handled by an explosives expert and those organizations involved with such materials.

Dredge spoils may be a semi-liquid waste. Some liquid may be removed b y dewatering procedures; however, these often take an excessive area and a large amount of material handling. Contaminated spoils present the additional problem of hazardous chemicals and the excess water may require treatment and disposal according to applicable regulations.

Certain sludges, septage wastes, dead animals and hospital wastes may carry pathogenic microbes and must be handled and disposed only with the guidance and approval of the local health authority. Large dead animals are often taken to rendering plants and small animals may be incinerated. When they are accepted at a landfill, they should be covered promptly to contain any health hazards and reduce odors.

Acceptable sludges, manures and other liquid and semi-liquid wastes must be mixed with drier wastes to limit moisture content and to be workable. Properly digested water and wastewater treatment plant sludges may be used for soil conditioning. This may require checking to assure that excessive concentrations of heavy metals do not occur.

Bulky wastes may include auto hulks, appliances, demolition and construction wastes, furniture and tree stumps. Usually, auto hulks and large appliances are collected and recycled by metal salvaging companies. In remote areas however, . this may not be economical. In this case, the items should be crushed on a hard surface and buried at the toe of the working face. Tree stumps should also be buried at the toe to ensure coverage.

Industrial wastes can be liquid, semi-liquid, powdery, granular, in sheets, shavings, or be defective manufactured products. Some materials may be salvaged and recycled. Some items may not be safe to handle and should be so recognized. Industrial wastes must be evaluated on a case-by-case basis for proper disposal in compliance with the applicable law and regulations.

6.2.3 Waste Placement Plan

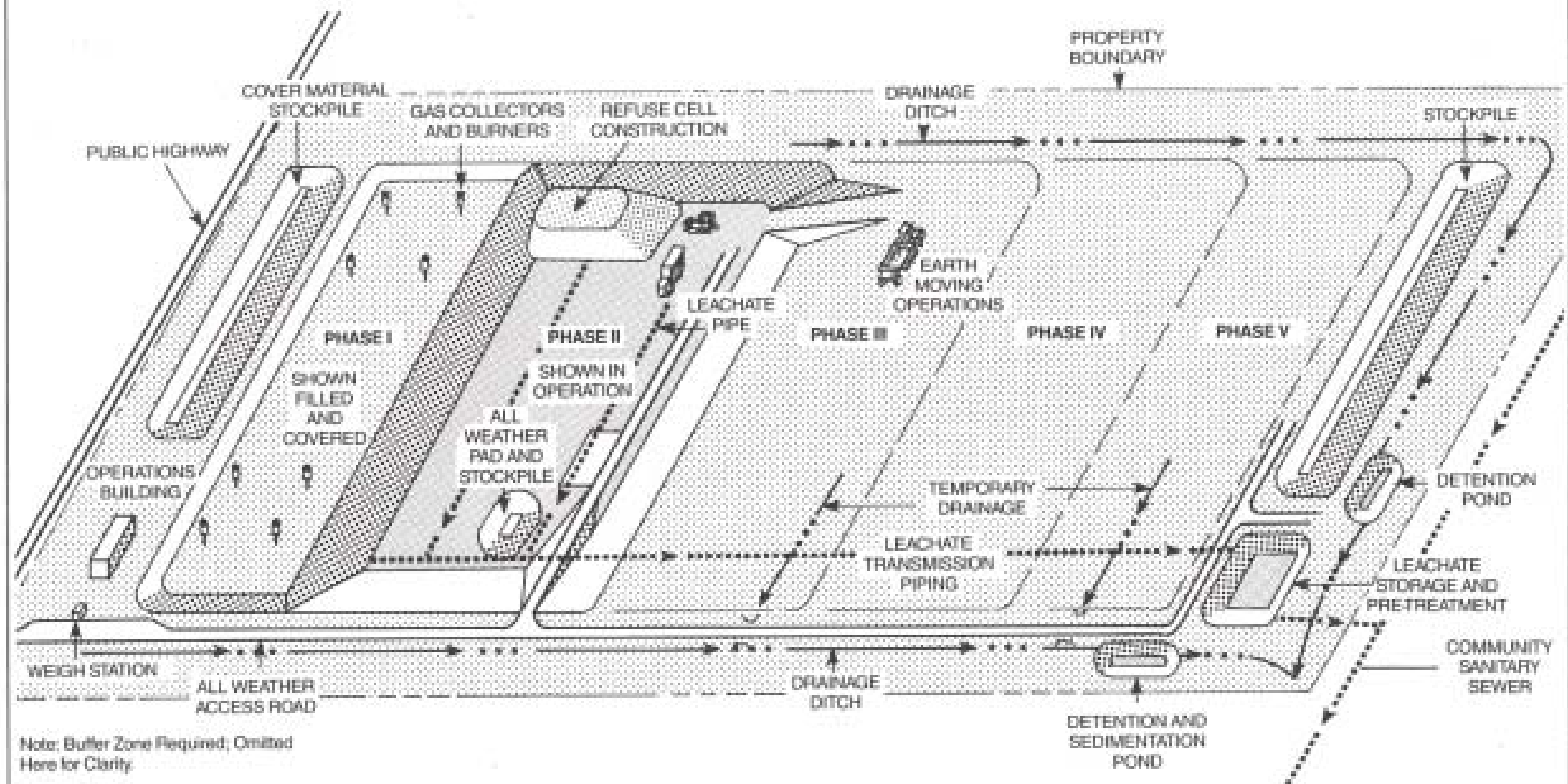
The waste placement plan, developed as part of the design process, describes the phased plan to prepare a fill area to receive solid waste, the filling sequence and the final closure of the filled area. Integral elements of this plan are the bottom liner/leachate collection system, gas control system, surface water drainage, access roads and tipping pads, cover material source and stockpiling needs and the final cover system. The proper combination of these elements results in an operating landfill that effectively disposes of waste with minimal environmental effects and cost.

6.2.3.1 Phased Placement and Filling Sequence

The phased placement of refuse is requisite for orderly operations at a landfill. The factors affecting this phasing are discussed in detail in the design section. These include:

- Site topography
- Refuse rate delivery
- Refuse characteristics
- Soils availability and characteristics
- Ground and surface waters
- Climatic conditions
- Operations equipment selection (discussed in Section 6.3)

A simplified landfill development plan is illustrated in Figures 6.3 and 6.4. These figures demonstrate the need to develop one area while another area is in use and a previous area is being closed. The size and phasing of each area must be such that the capacity is available for wastes received and to span inclement seasons when construction is curtailed. The phasing plan should be flexible and periodically checked and adjusted to accommodate varying delivery rates. Also, the compaction achieved, cover material used, and other unforeseen circumstances can alter the phasing.



Note: Buffer Zone Required; Omitted Here for Clarity

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Figure 6.3
Sample Landfill Development Plan

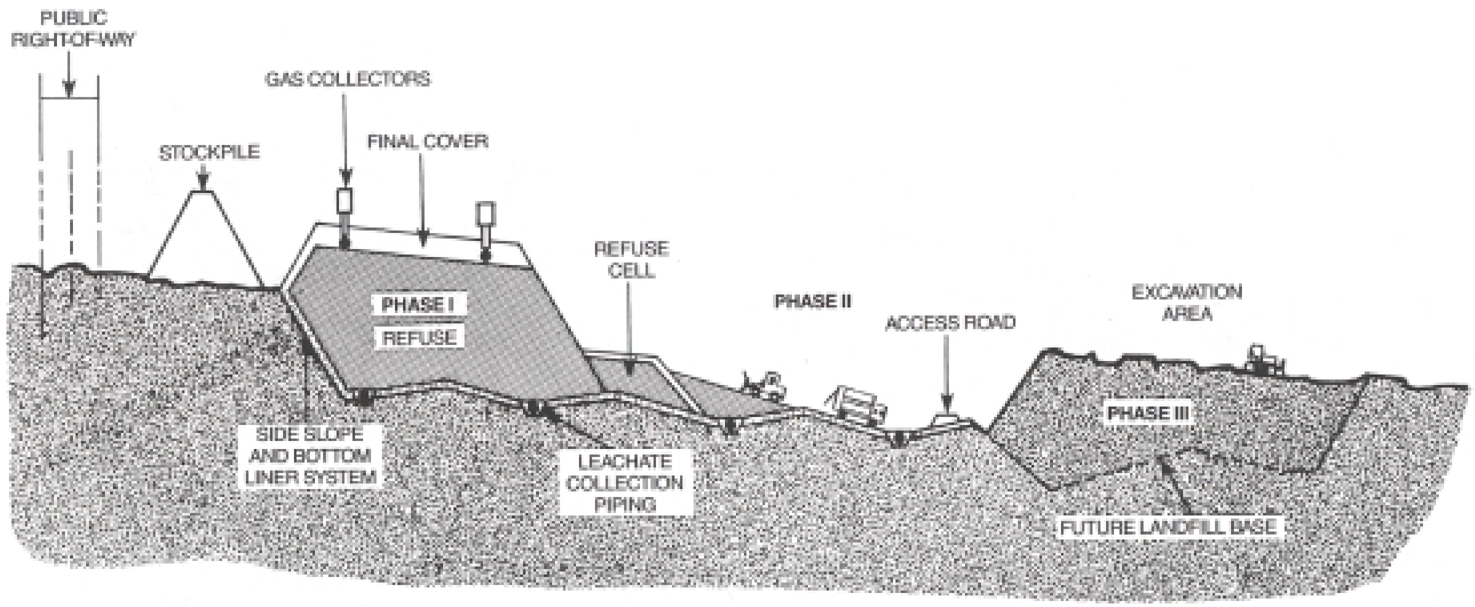


Figure 6.4
Sample Landfill Development Plan Profile

Volumes of on-site materials for the liner system, operations cover and final cover need to be computed. This will assist in delineating the time and phase limits, space needed for refuse, the need for imported materials or availability of excess materials, stockpiling requirements and the anticipated site life.

The daily cell configuration and size will influence the filling sequence. A possible sequence is shown in Figure 6.5. Such a graphic display will assist in conveying to the operational staff the planned operation.

6.2.3.2 Source of Cover Material

The source of cover material has a significant impact on the operations. The most ideal source is the next phase to be developed. This will result in the minimum of earthmoving work. In many situations, cover material will be removed from the waste placement area, stockpiled, and then used as needed. The material may be' on-site, but from an area not planned for waste placement. The most undesirable situation is the need to import cover material at high transport costs. This should be an important factor in siting a solid waste landfill.

The quantities and distances cover material must be hauled will dictate the equipment selected. This is discussed in Section 6.3, Landfill Equipment.

6.2.3.3 Access Roads and Tipping Areas

The layout and construction of access roads and tipping pads must be carefully executed to minimize road building and provide adequate access to tipping areas. During good weather conditions the delivery vehicles can be backed into the working face area without as much preparation of access roads and tipping areas. Well-compacted waste with sufficient cover should provide a hard driving surface without causing tire damage. When wet weather occurs, the waste can be tipped from an all-weather pad and pushed to the fill area if within a reasonable distance, say 100 to 200 feet.
Criteria for good roads are as follows:

- Good drainage
- Proper structure
- Adequate width
- Frequent maintenance

Adequate drainage and the road structure should be planned to maintain 3-foot vertical distance between top of road and top of surrounding water. A crown

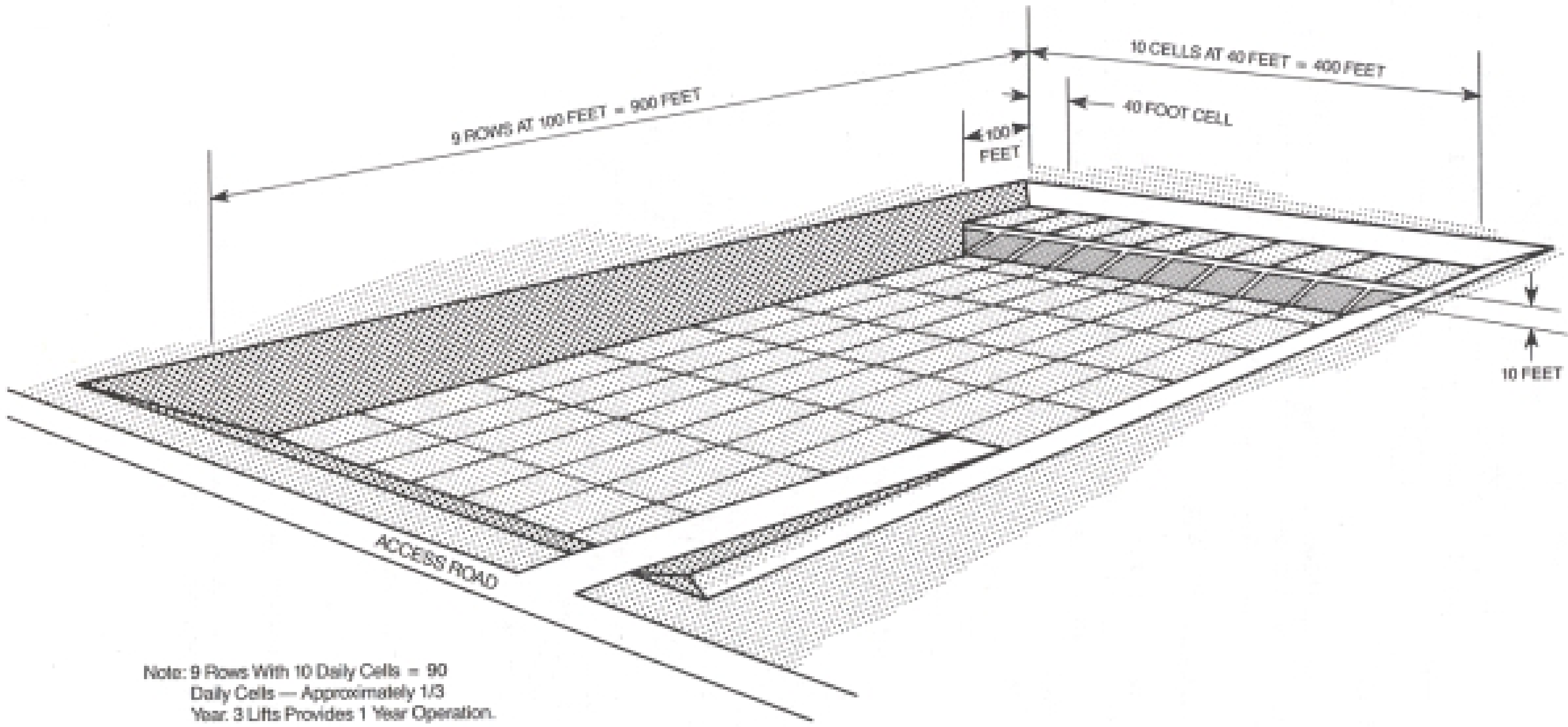


Figure 6.5
Sample Waste Placement Plan Filling Sequence Phase II — Lift 1.

on the road surface of 1/4 inch per foot (2 percent) will carry water off. Side ditches at a minimum slope of 0.5 percent will conduct water away. Culverts are needed to prevent ponding on the high side of the road.

The road structure consists of three parts: subgrade, base course and driving surface. A natural subgrade of granular material may be shaped to form the base. See Figure 6.6 for typical access road sections. Compacting and shaping a crown on the subgrade will provide a good surface for base materials. A fine-grained subgrade like sand, silt or clay may require a thin, 3 to 4 inch course of 1/4 inch material to prevent base material from working into subgrade. A 2 foot thick base course of granular material, broken concrete, or similar materials will allow free drainage. This should not contain fine materials. A driving surface, 4-inch minimum thickness, is constructed of gravel or crushed stone. Also, for permanent roads not built on refuse, concrete or asphaltic surfaces may be used. The width of the road should be a minimum of 24 feet to allow two vehicles to pass. Near the entrance, a 30-foot width permits traffic to flow with a disabled vehicle in the roadway.

It is generally not good practice to operate tracked and lugged equipment and scrapers on refuse delivery access roads. This will usually cause rough and rutted surfaces that require additional maintenance.

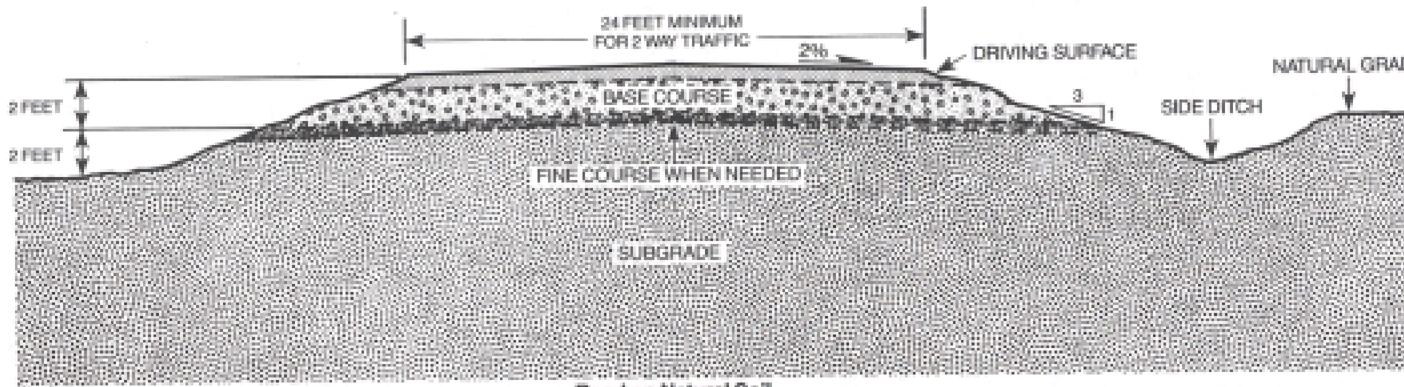
6.2.3.4 Drainage

Drainage is paramount to maintaining good roads, limiting leachate production, and permitting good waste placement in wet weather. Permanent drainage facilities will be, constructed in accordance with the site design. Temporary drainage works must be constructed as the filling operation progresses and be adapted to any changes in the waste placement plan. Ditches and culverts are the two most used drainage conveyances. Normally, culverts are 12-inch minimum to allow cleaning and should be sized for higher capacity flows. A ditch with a minimum slope of 0.5 percent will be needed to convey local surface water away without excessive ponding. Over refuse, the recommended slope is between 2% and 7%. Maximum side slopes of three horizontal to one vertical are desirable to control erosion. More detailed drainage considerations are discussed in Section 4.8 and 4.11, Surface Water Management.

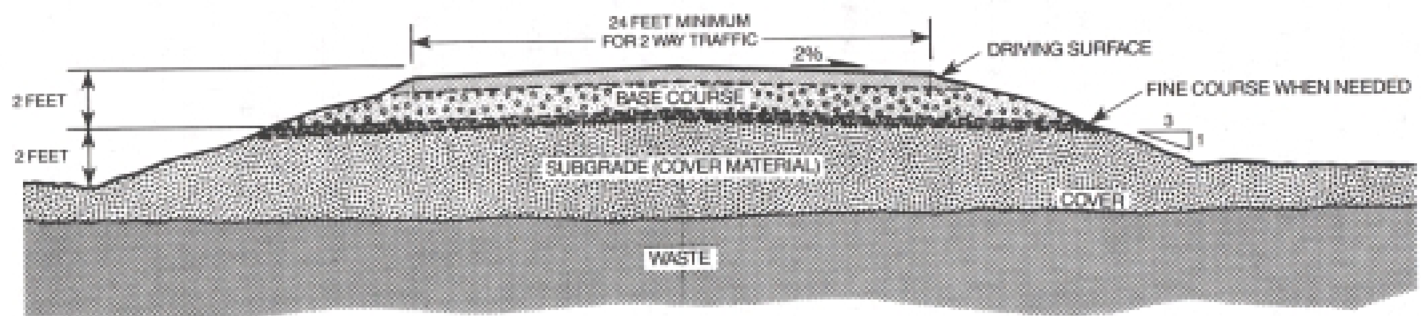
6.2.3.5 Liner/Leachate Collection System

As a new area is opened for waste placement, the bottom liner and leachate collection system is constructed to conform to the design plans and specifications. This is coordinated with the phased placement plan and may occur on a yearly basis. Placing a low permeability soil liner and/or a membrane liner can most effectively be accomplished in the summer construction season.

Construction of the liner and leachate collection system may be accomplished by the operating agency or completely or partially by contract with a construction company. This choice will be influenced by availability of personnel and equipment, complexity of design, schedule for other work, and



Road on Natural Soil



Road Over Landfilled Area

Adapted From: "Waste Age", September 1982.

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Figure 6.6
Cross-Section of Access Roads.

cost. No matter who performs the construction, careful scheduling must be made to assure continuity of operation. The construction procedures are more thoroughly discussed in Chapter 5.

Construction by contract will require preparation of plans and specifications, agency approval, advertising for bids, selecting and awarding contract(s), managing construction, quality assurance and final preparation for use. Construction by the operating agency also will require plans and technical specifications and agency approvals. In addition, material must be ordered and construction quality assured.

6.2.3.6 Gas Collection/Venting System

Time must be allocated during the placement of the waste for the construction of gas system components, especially for multiple-level, horizontal collection systems. Before a component of the system can be constructed, the area needs to be prepared for construction and operations must be scheduled to eliminate conflicts with the construction. Future operations should also be planned to minimize or eliminate the potential for damage to the installed gas system.,

6.2.4 Environmental Controls

6.2.4.1 Dust

Control of dust is important to enhance public relations, prevent traffic accidents, reduce equipment maintenance costs and protect the health and comfort of employees. Dust can occur on access roads, operating areas and any place earthwork is being handled and transported. Most dust originates from movement of equipment and vehicles over access and haul roads. Occasionally, loads of dusty waste will be delivered to the site. The contents of these loads should be identified to assure they are not hazardous.,

Dust control measures useful at the working face include:

- Careful moving of dusty wastes and soils
- Prompt covering of light powdery wastes with other waste
- Orienting working face into wind if feasible
- Dampening dusty wastes and cover materials
- Minimizing earthwork activities during windy periods

Dampening of waste should be controlled to assure excess water is not applied.

When final or interim cover is placed, the area can be seeded with rapid growing vegetation such as rye grass. In some instances, it may be appropriate to cover exposed areas with plastic and weights to control 'both wind and water erosion.

Control of dust on access and haul roads contributes significantly to vehicle and equipment operating life. Dust can clog radiators and filters and cause overheating. Dust penetrating between moving parts and into bearings increases wear requiring more frequent maintenance and repair.

Employees subjected to dusty conditions will be more prone to accidents, particularly when visibility is obstructed. During busy periods of earthmoving operations, operators should limit travel speeds for safety and comfort. Enclosed cabs will improve conditions for employees.

Methods to control dusts on roads include:

- Permanent surfacing of heavy use access roads with concrete and asphalt
- Crushed gravel surfacing
- Calcium chloride applications
- Water spraying
- Grading fine soils from roads in wet periods
- Control vehicle speeds

Calcium chloride is a deliquescent chemical that can be helpful for dust control if the relative humidity is over 30 percent. Recommended application rates are 0.4 to 0.8 pounds per square yard to be mixed with the top 3 inches of road surface. Frequent applications are required to replace the chemical which is water soluble and leaches , out. Water spraying procedures are discussed in Section 5.9.2 of this manual.

6.2.4.2 Litter

Controlling litter at the disposal site requires continuous attention and, at best, only contains the problem. Advantages of an effective program are presenting a good public image and avoiding a nuisance to nearby properties and roadways.

Techniques to control litter at a site can be categorized as:

- Waste handling and disposal methods
- Wind shielding
- Catching
- Collecting

Solid waste delivered via public roads must be properly contained to prevent scattering. This requirement should be maintained until the waste is placed at the working face. Placing waste at the toe where the wind is diminished or is calmer as a result of detached air currents reduces wind-blown litter. Prompt spreading, compaction and covering of the refuse greatly reduces the opportunity for the wind to scatter the light wastes.

Hills, trees, berms and depressions can all contribute to shielding from the winds. As phases of a landfill are developed over the site it may not always be possible to utilize shielded areas. It may be practical at some sites to have special protected areas designated for operations during windy periods. If developing the site from the prevailing windward to downwind direction is consistent with other requirements, it will be possible to use completed areas as windbreaks.

A variety of techniques has been used to catch litter with varying degrees of success. Included are trees, shrubs, fences and wind screens. Trees, shrubs and permanent fences can be effective if well planned, but are limited in that they cannot be moved in close to the downwind side of the working area. Portable fences and windscreens are mounted on skids they can be easily moved with the working area and changing wind direction.

The last measure is to manually collect wind blown litter. If the other measures are effective this effort can be minimized. In any event, collection should be routinely carried out at the required frequency to maintain a good image. A program to donate funds to community service groups and youth organizations for their labor in collecting litter can be effective and generate considerable good will.

6.2.41.3 Odors

Landfill odors occur from various stages of decomposition of refuse. This may start prior to delivery of the waste and continue for some time after placement. Delivered wastes, particularly in hot weather, often will have objectionable odors. These will primarily be food wastes. Also, special wastes such as manure, fermented grains and food processing wastes can create strong odors.

Decomposing wastes left uncovered can become very objectionable and should not be allowed., As the wastes are buried and decomposition occurs, gases and leachate are formed, both of which can produce odors. Uncontrolled venting of gases allows the odors to spread throughout the area. one of the products of anaerobic decomposition is hydrogen sulfide, which in small concentration causes strong odors. Leachate surfacing on the ground or in collection and treatment facilities may be undesirable source of odor if not aerated.

Control of these various odor sources is necessary to prevent off-site and on-site nuisances and to project a positive image of a well run operation. Detection of odors should be used as an indicator that a component of the landfill system is not designed, constructed or operated properly.

Incoming waste odors can be most effectively controlled by prompt spreading, compaction and covering. When on-site waste containers are used for receipt of small residential- type loads, they should be emptied at the working face frequently enough to control odors. During warmer seasons this may be more frequent than normal. Also, washdown of the containers may be occasionally required for good odor control. In warmer climates where odors can form rapidly, chemical deodorants may be useful.

A properly designed and constructed cover system and a gas collection and flaring system can be effective in controlling odors. A tight cover cap overlaying a porous vent layer will convey the gases to the collector system. Usually, the gases are vented through well placed standpipes and properly designed burner heads sustaining a flame which is effective in destroying odors. For larger sites, a more complex system to collect methane gas for energy recovery may be feasible. Such a system would also be designed to control unwanted odors.

Leachate collection and treatment systems should be designed and operated to avoid unnecessary odors. A good cover system will prevent leachate from surfacing on filled areas. Toe seep collection piping can be effective in controlling and removing leachate from an area prone to surface breakouts. Siting and design of leachate storage and treatment facilities should consider odor problems and methods to alleviate this. Adequate aeration is usually effective in controlling leachate odors.

6.2.4.4 Vectors

Vectors which can create health hazards and nuisances include flies, mosquitoes, rodents and birds. Flies and rats are most effectively controlled by proper spreading, compaction, and covering of incoming wastes. Fly propagation is controlled by applying daily cover. In well compacted refuse, rats cannot fin ' d harborage and will not survive. Daily cover will provide an additional defense to limit rat propagation.

If a rat population does develop it should be dealt with immediately as rats can pose potential health risks to animals and humans. In this circumstance, a control program may be required and should be coordinated with the local health district.

Mosquitoes are effectively controlled by avoiding ponding stagnant water through proper grading of surfaces and installing needed drainage facilities.

Bird populations, often very large at landfills, create nuisances on-site and off-site, but are not considered a health or public safety hazard, except in the case of low flying aircraft. Landfill siting in the proximity of an airport is subject to certain regulations as discussed in Chapter 3, Landfill Siting. A varied control program is useful to respond to the adaptation of the birds.

Seagulls, crows, and starlings are the predominant birds found at disposal sites. Several control methods have been used and are being developed. Some of these methods have met with limited success, but are used for what effect they have on reducing the bird population. These methods can be categorized as follows:

- Operations
- Chemical baiting
- Distress call broadcasting
- Explosive devices
- Aerial cables

None of these methods is exclusively effective for all bird species nor all birds. Gulls, because they are the largest and most visible species, usually create the greatest *nuisance. It* may be desirable to prioritize bird control by species. Chemical baiting of seagulls to limit bird population has been reported to be effective at one landfill site. This treatment causes vocal and visible flock frightening distress symptoms and calls resulting in the dispersion of seagulls from the vicinity. Prior to using this procedure, a permit must be obtained from the U.S. Fish and Wildlife Service as the seagull is a protected species by law (White and Weintraub, 1983). This procedure may not be effective on smaller bird species and may cause an unfavorable reaction from the public. Recordings of bird distress calls are available for purchase. These can be broadcast and have some effect on disturbing the flocks temporarily.

Water reservoirs, fish hatcheries, and some landfills in southern California have used aerial cable to discourage bird flocks. The cables are fine filaments, invisible to birds, which disrupt their flight to the extent that they will avoid the area. Stringing of such cables at a landfill will pose more difficulties than for reservoirs and hatcheries, because the cables must be strung high enough (35 foot high moveable towers) and cover an area large enough to allow tipping, placement, and covering of the waste. Spacing of cables depends on how determined the gulls are and may be as close as 40 feet on a crossed pattern. Also, this active area moves *continuously, thus* requiring that the cable system be portable. Use of this system at landfills in' California has met with some success *controlling gulls* and has some promise where bird control, is essential. Some gulls may walk under the wires, requiring hazing with small explosives. For details of application refer to Mathias (1984).

Small explosive devices make noise which frighten the birds. They include firecrackers, blank shells, propane detonators and "cracker shells" shot from a shotgun into the air where they explode. Birds disturbed by these methods fly to nearby trees or open areas and return to the acting face as quickly as ten minutes after detonation when they get accustomed to the use. Therefore, an explosive program must be applied frequently, continuously and in varied locations to be effective. Noise levels from this could be in violation of local ordinances and/or cause a negative public reaction, depending on the distance to the site boundary, the noise level of the device, land configuration and vegetation. Ear protection devices should be worn by personnel nearby.

The refuse placing operation should be confined to as small an area as practical to discourage bird flocks from forming. Placing cover routinely and promptly will limit the available food source for the birds.

Control of large animals is not usually a problem. Domestic animals are usually controlled by the owners. Wild animals such as deer, bear, and elk will usually be frightened away during active periods. Daily cover will help restrict access to food. In special instances, fencing may restrict domestic animals, but will not be very effective against wild animals, particularly deer. In these cases, it may be advisable to contact wildlife experts for assistance.

6.2.4.5 Noise

Noise control at a landfill site is needed for comfort and safety of on-site personnel and to avoid nuisance to the surrounding community. The latter is particularly important when the landfill is near residential areas.

Noise limitations imposed by the Department of Labor and Industries must be observed to protect workmen from hearing damage.

Measures to limit noise include:

- Maintain proper mufflers on vehicles and operating equipment
- Provide ear protection devices for operators
- Maintain perimeter buffer zones of trees, shrubs, solid fences, and berms
- Route delivery vehicles away from populated areas
- Limit operating hours

6.3 LANDFILL EQUIPMENT

6.3.1 Functional Requirements

6.3.1.1 Waste Handling

The functional requirements for waste handling equipment at the working face area are:

- Spreading the delivered wastes
- Crushing, burying, and compacting the spread wastes
- Applying, spreading and compacting daily and interim cover

The types of equipment most commonly used for these functions are the landfill compactor, tracked dozers and loaders, and rubber-tired dozers and loaders. Equipment maintenance will be more costly than for similar equipment in other applications. See Figures 6.7 and 6.8 for typical machines.

Landfill compactors, some of which are modifications of road compactors and log skidders, are specifically designed for waste handling functions. They are the most effective equipment for the purpose, using steel wheels studded with load concentrators. The wheels tear, crush, and compact the waste, achieving maximum densities up to 50 percent more than tracked bulldozers. Compactors operate best on a level surface and well on moderate slopes. For stability on slopes up to 3H:1V, they should be of the four, wide-spaced wheel design. They lack traction for pushing refuse up steep slopes and for excavating. They are faster than tracked machines, but not as fast as rubber-tired machines (up to 23 mph). Available compactors range in weight from 34,000 pounds to 82,000 pounds.

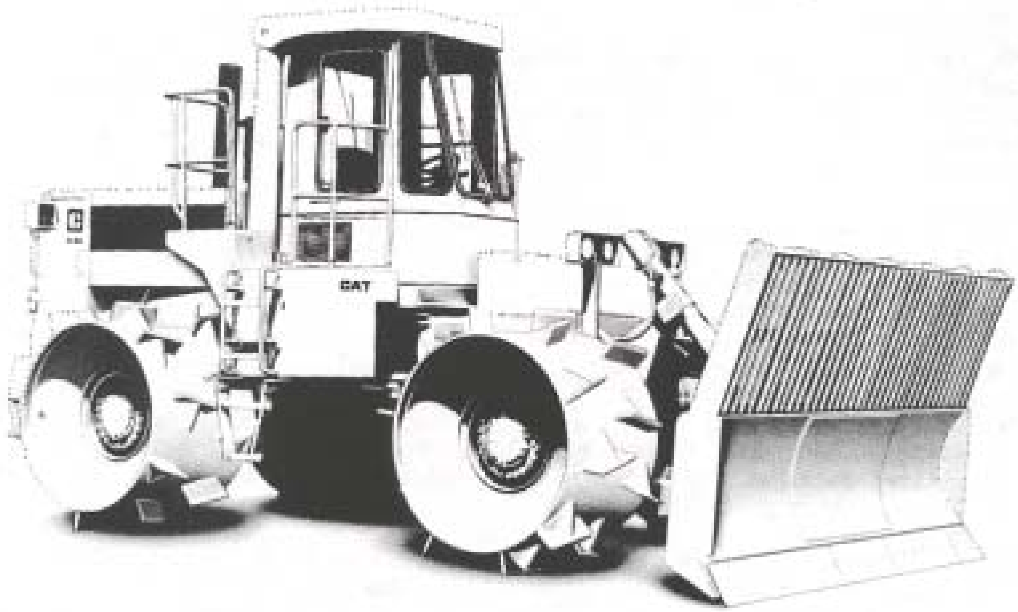
Tracked dozers and loaders used for waste handling accomplished good compaction and can be used for excavation. The loader can be used to lift material off the ground. The tracked dozer is excellent for grading and normally considered economical for moving earth up to 300 feet. Tracked equipment is limited by a much slower speed of 6 to 8 mph maximum. They are more versatile machines than compactors and are useful for small operations and as backup machines.

Rubber-tired dozers and loaders are not used as extensively as tracked machines for waste handling. They do operate at higher speeds (up to 29 mph) but are not as suitable for spreading and evenly compacting refuse. These may be applications where they perform dual functions of compacting and loading cover materials and must travel between these functions. In such a situation, a rubber-tired loader may be the appropriate selection. When used for compacting refuse, rubber-tired equipment should have steel guarded rock tires or special landfill tires.

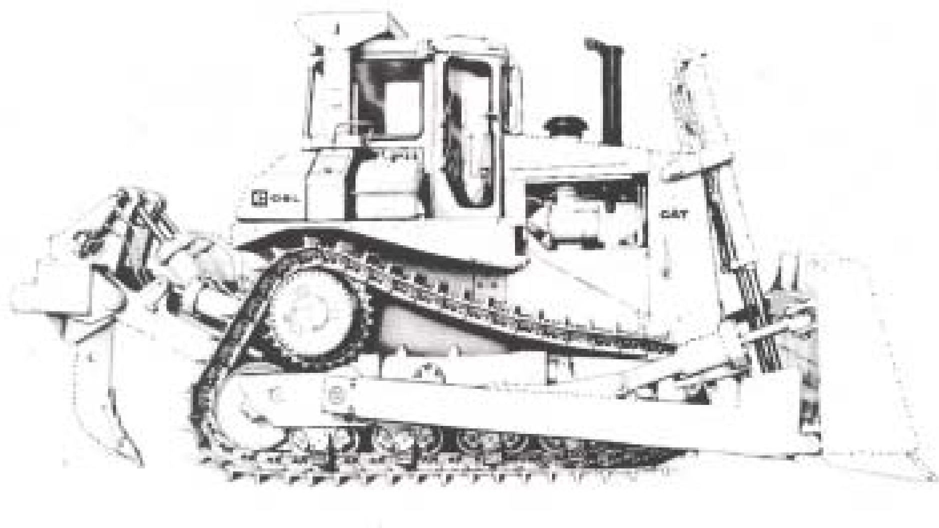
6.3.1.2 Cover Material Handling

Functional requirements for cover material handling include:

- Excavation
- Loading
- Transporting
- Spreading and grading
- Compacting and grading



Landfill Compactor



Twin Engine

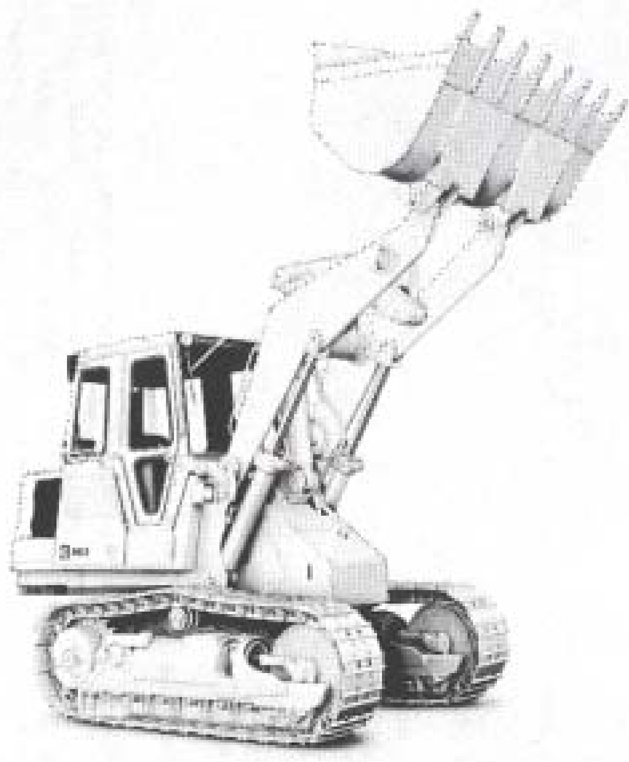
WDOE Solid Waste

Courtesy of Caterpillar Tractor Company

Landfill Design Manual

Figure 6.7
Landfill Equipment

Rubber Tired



Track Mounted

Courtesy of Caterpillar Tractor Company.

Figure 6.8
Landfill Equipment-Front End Loaders

These functions are similar to earthmoving construction activities and a variety of equipment types are available. The selection will be influenced by:

- Excavation difficulty
- Topography and geology
- Transport distances
- Quantities of cover materials
- Multiple uses of equipment
- Weather conditions

Excavating and transporting of cover material for distances up to 300 feet can be economically accomplished by tracked machines. Where difficult materials are being excavated, a tracked machine with a ripper may be required. Sand, gravel, some loamy clays, and silts may be excavated with rubber-tired equipment, which can economically move the material up to 600 feet.

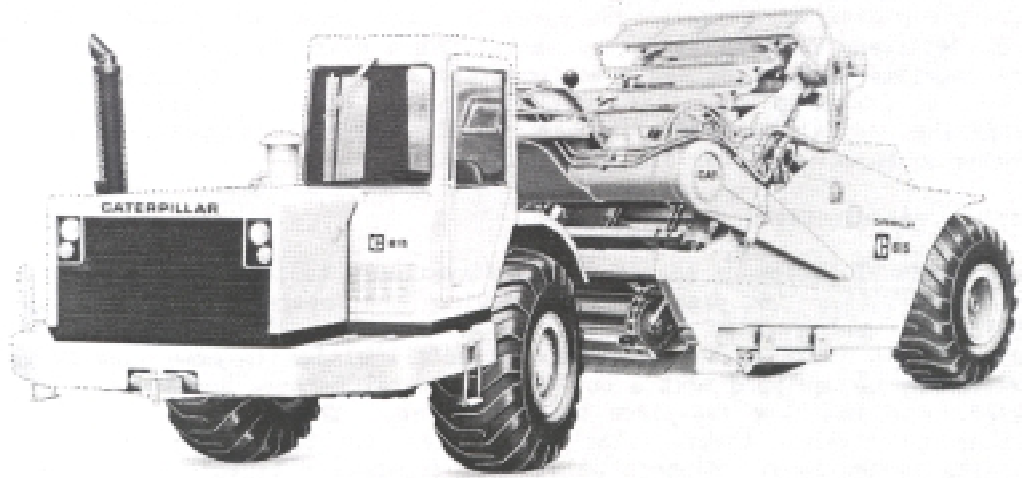
For longer distances and larger soil volume requirements, self-propelled and towed scrapers are used to excavate, haul, and spread cover material (see Figure 6.9). Scrapers range in size from 10 to 40 cubic yards. By routing heavily loaded scrapers over the fill area, additional compaction is achieved. In many instances, it may be necessary to use a "push" dozer to assist the scrapers in excavating, loading and climbing steep grades. Scrapers larger than 40 cy make haul roads "pump" in wet climates and are not recommended.

A dragline may be economical for large excavations. It is capable of digging moderately hard soils and useful in wet areas for extracting soils. It is particularly applicable for large operations using the trench method or at a borrow pit.

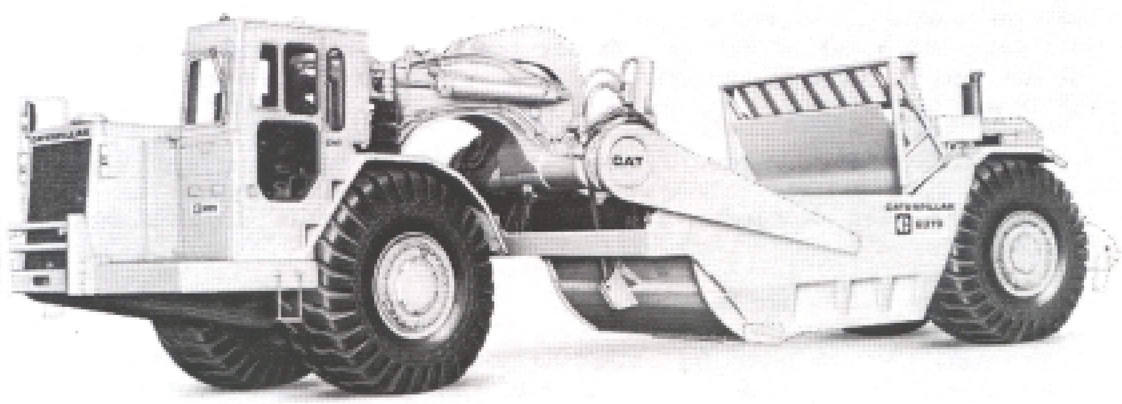
When cover material is imported from off-site it must be excavated, loaded and hauled. If hauling is over permanent paving and public thoroughfares, highway trucks are needed. It is best to avoid this expensive operation. However, at some sites, contractors may be willing to deliver soil at little or no cost if the soil is not suitable for construction and they need a disposal area. As previously, discussed, tracked machines are useful for spreading, grading and compacting. Compactors can also be used for these functions.

6.3.1.3 Support and Special Purposes

Support and special purpose equipment requirements will vary considerably from site to site. With increasingly stringent requirements being imposed on



Single Engine/Self Loading



Track Mounted Dozer

Courtesy of Caterpillar Tractor Company.

Figure 6.9
Landfill Equipment-Earthmovers

solid waste disposal sites, more complex facilities must be constructed and operated, thus requiring a broader range of equipment.

Where a municipality operates the site, this equipment may be available from other department s on an as-needed basis. When usage is limited, it may be more feasible to rent or lease equipment or contract for performance of the work. At larger sites, there will be greater economic justification for purchasing special purpose equipment. Table 6.2 lists support and special purpose equipment and possible uses for each.

6.3.2 Accessories

A multitude of equipment accessories are available to increase effectiveness and versatility, to protect the machine and operator and to reduce maintenance and repair. Landfill compactors and dozers are typically equipped with large U-shaped trash or landfill blades to push more refuse. Loaders may be equipped with a one-piece, general purpose bucket of landfill blades or a bullclam two-piece hinged bucket. The latter is useful for picking up sizable items. The accessories may be attached with quick coupling connections. Rippers on tracked dozers are capable of excavating hard and frozen soils. Counterweights may be desired for compactors and dozers. Engine screens and radiator guards prevent clogging pores and subsequent engine overheating. A reversible fan can assist in keeping the radiator clean. Guards under the chassis of equipment prevent damage to the engine, hydraulic lines and other parts.

Operator comfort, safety, and efficiency can be improved by incorporating roll bars and a cab or canopy. An air conditioned/heated cab is desirable for hot, dusty, or cold conditions. Back-up warning signals are a required safety device.

Automatic fire suppression systems on landfill equipment can prevent extensive fire damage. The advent of microprocessor control is being incorporated into equipment for sophisticated operation and *malfunction* diagnosis.

6.3.3 Type and Number Required

Many factors contribute to the selection of equipment types, accessories and number of machines. Following is a list of some of the significant factors:

- Quantity and type of refuse received
- Quantity and type of soils handled
- Method of fill
- Special waste handling and processing activities
- Availability of standby, support, and special purpose equipment from other departments, rental agencies or area contractors

- Equipment reliability, local parts and maintenance support
- Purchase and operating costs

The selection of the waste placement equipment depends primarily on the daily quantity of refuse delivered. A large operation can afford larger, more effective compactors. For smaller operations, the prime equipment may have to perform several functions. A compromise may be necessary when selecting equipment to stay within reasonable operating budgets. It is essential that the compacting equipment be heavy enough to attain the specified design compaction density. For small operations, this may mean spreading thinner layers and making more passes. An evaluation of the increased operating costs versus the reduced capital expenditures should be made to assure an optimum total cost.

Table 6.2. Landfill Support and Special Purpose Equipment.

Equipment	Uses
Road Grader	Maintain roads and ditches; grade bottom liner and cover system
Water Truck and Pressurized Sprayer	Control dust and blowing paper, moisture condition earthwork; fight fires; water seeded areas and plantings, transport leachate; clean equipment, culverts and pipe lines
Road Sweeper	Maintain clean on-site and off-site roads
Backhoe	Construct drainage facilities, pipelines for leachate and gas systems, and other facilities; dig soil test pits
Transfer Truck	Handle on-site containers
Hydroseeder	Seed final cover areas
Service Truck	Maintain equipment
Dump Truck	Import materials

Table 6.3 can be used as a guide for equipment selection based on performance characteristics. Manufacturers provide equipment specifications useful in the evaluation of equipment for use in solid waste landfills. Waste-Age magazine publishes an annual guide to landfill equipment that lists various

models of compactors, dozers, loaders, graders and scrapers together with their dimensional, performance and operating characteristics. Table 6.4

Table 6.3. Performance Characteristics of Landfill Equipment.

	Solid Waste			Cover Material		
Equipment	Spreading	Compacting	Excavating	Spreading	Compacting	Hauling
Crawler dozer	E	G	E[b,c]	E	G	NA
Crawler loader	G	G	E	G	G	P
Rubber-e tired dozer		F	F	F[b,c]	G[c]	F NA
Rubber[-e] tired loader		F	F	F	G[c]	F P
Landfill compactor		E	E	P	G	E NA
Scraper	NA	NA	G	E[d]	F	E
Dragline		NA	NA	E	F	NANA

Adapted From: Brunner, 1972, p. 45.

a Basis of evaluation: Easily workable soil and cover material haul distance greater than 1,000 ft. Rating Key: E, excellent; G, good; F, fair; P, poor; NA, not applicable
b Use limited to pushing scrapers, building stockpiles, ripping (crawler only)
c Not able to spread cover on slopes steeper than 30 percent dry and 20 percent wet
d Except on steep slopes in wet weather
e Not commonly used in wet climates

presents a guide to equipment required for solid waste landfill operations based on the amount of refuse received. The actual selection of types and numbers of equipment will depend on site specific conditions and the operating agency needs. Table 6.4, intended as a guide only, has been constructed from a review of various operation guidelines and equipment manufacturer recommendations.

The type, quantity and location of the soils used, the design of the bottom liner and final cover system, and the decision to either construct these and other facilities with on-site personnel or contract out the work will all be major factors in selecting excavation, hauling and compacting equipment. This determination must be made carefully, as much of the work is seasonal and can result in large capital expenditures for limited equipment operating time.

Table 6.4. Landfill Equipment Needs.

Daily Tonnage	Suggested Equipment
0 - 20	One 20,000 pound dozer or one 20,000 to 25,000 pound loader
20 - 50	one 20,000 to 25,000 pound dozer or one 25,000 to 30,000 pound loader
50 - 130	One 30,000 pound dozer or one 40,000 pound loader plus one 40,000 to 50,000 pound compactor
130 - 250	One 45,000 pound dozer or one 50,000 pound loader plus one 40,000 to,50,000 pound compactor
250 - 500	One 80,000 to 90,000 pound dozer plus one 40,000 to 45,000 pound compactor
500 +	One 80,000 to 90,000 pound dozer plus one 70,000 to 80,000 pound compactor plus variety of support equipment.

Equipment reliability at a landfill is of utmost importance to avoid operating interruptions and minimize costs. There will be breakdowns requiring repairs and periods for preventive maintenance. During these times, it is essential to have standby equipment available, possibly through local contractors. Parts availability and prompt maintenance support are essential to a well-run site operation. Without this support, even the best equipment available cannot be used effectively.

6.3.4 Maintenance

A well scheduled preventive maintenance program will contribute to more fuel efficient operation, reduced repair work, less down time, reduced costs, safer equipment operation and improved operator performance. This program can only be implemented with a well-equipped and staffed maintenance shop.

The requirements and procedures for a maintenance program should be detailed in the operation and maintenance manual for the site.

Equipment manufacturers and representatives provide periodic maintenance instructions and are available to assist with more difficult maintenance repairs.

The operating conditions for landfill equipment can be severe including dust, mud, cold weather, hot weather, various waste types, long working hours, and heavy loads. Dust, grit and water intervening between moving parts and bearings, and entering into engines, can contribute to increased wear. It is imperative that air, fuel and oil filters to be maintained as recommended or more frequently to exclude foreign materials. Guards, screens and protective devices must be kept in place. Wheel cleats on landfill compactors are subjected to continual wear. Routine surface hardening with appropriate weld material can extend the cleat life considerably.

Periodic washing of equipment can contribute to reduced wear, easier maintenance and fire prevention. A visual inspection of equipment prior to start up can afford an opportunity to spot weak and frayed hydraulic hoses, frayed belts, leaking fluids, and deformed operating mechanisms and structural elements.

An enclosed shop allows winter and spring maintenance and repairs in preparation for extended summer construction work. Periodic servicing should be implemented and records kept to document costs and to assure thorough maintenance to spot unusual failure patterns.

'The basic criteria for a maintenance schedule is to keep the equipment operating satisfactorily, with minimum downtime and for a reasonable lifetime. Servicing of equipment includes general and safety inspections, lubrication, adjustments and required repairs. Inspections and lubrication are based on specific time or distance intervals. At these times, adjustments and repairs are made when malfunctioning, wear or deterioration of parts is detected.

The manufacturer's recommended schedules can be used initially as guidelines to develop inspections and servicing schedules and forms. These can later be amended from operating experience with the equipment. Refer to Section 6.7 for suggested equipment maintenance records.

6.4 FACILITY OPERATION AND NAINTENANCE PROCEDURES

6.4.1 Surface Water Control System

In most instances, a surface water system will operate by gravity flow and subsequently require little operational attention. There may be infrequent applications of diversion control and pumping facilities for storm water operations. One example when a diversion device might be used is for a newly developed area prior to waste placement. If the storm water collected by the leachate piping system does not come into contact with refuse, it could be diverted to the storm water system. Also, 'storm water retention and detention facilities may utilize active control methods. When active methods are constructed, the operating procedures should be developed and incorporated into the operation and maintenance manual. A useful reference for operation and maintenance of pump stations is "Design of Wastewater and Stormwater Pumping Stations" (VPCF, 1981).

Temporary and interim surface water control facilities such as ditches, culverts, and sedimentation ponds will be constructed on an as needed basis. Temporary erosion control measures may have to be used to control excessive soil erosion. This may include bale dams, plastic sheeting, matting, etc.

Because landfill operations involve continuous earthwork activities, more soil erosion may be encountered than for normal drainage facilities. Routine inspection and cleaning of culverts, catch basins, control structures and storm severs should be conducted to maintain proper flow. Detention and retention facilities should be checked to assure basins are not being filled with sediment. If so, they should be excavated to original design grades.

Ditches and channels receiving soil sediments should be cleaned. Excessive erosion in ditches requires repair with rock or permanent lining. Growth of vegetation in ditches and channels may need cutting to maintain proper flow conditions. Roadside ditches can be maintained when grading roads. Seeding may be appropriate in washed out ditches.

6.4.2 Ground Water Control System

Control measures to restrict horizontal ground water movement into refuse include impermeable barriers, trenches, buried drainage piping and wells with pumping equipment. Operation and maintenance for impermeable barriers will be limited to monitoring for leakage and implementing repairs. As the barriers are underground, this will be difficult. If leakage is detected, careful investigation must be made to assure adequate repair.

Trenches, catch basins, manholes and outlets on drain pipes can be checked for proper functioning. Cleaning procedures can be undertaken as necessary.

Water levels in wells must be routinely checked as part of the environmental monitoring program. Maintenance, operation and repair of pumping equipment and pump stations should be detailed in the operations and maintenance manual. The procedures for this are similar to a water or wastewater pump station. An applicable reference for this is "Design of Wastewater and Stormwater Pumping Stations", (WPCF, 1981).

6.4.3 Berms, Liners and Cover Systems

Landfill liners installed to restrict vertical migration of leachate into the ground water are normally constructed of synthetic membranes and/or low permeable soils which may have an additive to reduce permeability. A cover layer of permeable soil performs the dual function of allowing horizontal migration of leachate to collection piping and protecting the liner from placement of the refuse. Until this liner system is covered with refuse, it must be maintained and protected from damage.

All surrounding surface waters should be routed away from the liner and leachate collection system. If fine grained materials become deposited on the drainage layer, they must be removed prior to placing refuse. Fine-grained soils on the drainage layer may have contaminated the drainage layer itself and it should be inspected and replaced where necessary. A properly installed and compacted permeable layer is normally 2 feet minimum in thickness and will not be susceptible to erosion from direct rainfall. If erosion does occur, repairs must be made prior to placing refuse.

Initial refuse placed on the liner system should be free of large bulky items or long, sharp objects that could penetrate the liner. Consideration may be given to using a tracked dozer for initial waste placement in lieu of a studded compactor or rubber-tired machine. The latter two pieces of equipment can effect more penetration into the protective layer. A tracked machine is designed to distribute weight more evenly and tends to "float" over the refuse.

A program to monitor the effects of leachate on synthetic membrane liners should be considered. Initial testing of the liner material upon installation will be the basis for future evaluation of liner properties. At specified times in the future, liner material "coupons" should be removed from the landfill in a previously designated area and tested. Any deviation from the initial test results should be noted. The coupons would need to be buried in the landfill in a manner that allows them to be easily retrieved, or alternatively they could be placed in leachate collection system manholes.

Berms and final cover systems are seeded to:

- • Prevent erosion
- • Facilitate evapotranspiration
- • Provide a pleasing appearance

Until the ground cover becomes firmly rooted, erosion may occur, particularly during heavy rainfall. Erosion must be repaired, stabilized and reseeded promptly to avoid extensive damage. When final cover systems are allowed to erode, the low permeable cover cap may be penetrated allowing uncontrolled discharge of leachate and gases.

The cover system will also be subjected to uneven, differential settlement. Refuse may be unevenly compacted, the waste type may vary, or decomposition may proceed at uneven rates. When there is a disruption of the cover system, repairs must be made. It will be necessary to excavate to the cover cap and place the new soil so a tight continuous layer is achieved. Final soil cover and top soil are then placed and the area is reseeded.

Where gullies and rivulets form on a final cover slope, it may be necessary to collect surface runoff using berms, dikes, bales and other devices. The flow can be directed into a temporary pipe strung down the slope to a surface water drainage ditch.

Sufficient stockpiles or sources of soil materials used in the cover system. should be maintained for repairs as they are needed. Temporary erosion control measures would have to be implemented to prevent unacceptable erosion from the stockpiles.

6.4.4 Leachate Control System

6.4.4.1 Leachate Collection and Transmission Facilities

Facilities for leachate collection and transmission may include perforated collection piping, gravity and force main transmission piping and pumping stations.

Transmission piping requires no operation unless diversion devices are installed. The operation of a pump station and force mains should be set forth in an operation and maintenance manual.

Manholes can be routinely checked to observe flow conditions. Changes may indicate a clogged line or pipe structural failure. Sewer cleaning equipment and water flushing may be used to reestablish flow. When the piping is installed under deep fills of refuse, repairs may be most difficult. To alleviate this potential problem, flushing and inspection of the leachate collection system immediately after placing the first lift of refuse is recommended, assuring that the piping has not been broken during refuse placement. If a break or collapse has occurred, it can be uncovered before excessive depths of refuse have been placed.

Regular flushing on a yearly basis will help prevent buildup of growths and clogging. Biochemical precipitation of iron can be removed by high pressure flushing early on, but becomes impossible with age. Periodic monitoring of leachate flows and leachate levels within the waste associated with precipitation can indicate possible pipe failures and clogging. Direct inspection by television or photographic pipe cameras and continuity checks with sewer cleaning equipment may be appropriate. Chemical cleaning methods using acids may be harmful to the pipe, depending on the pipe material.

Leachate piping is surrounded by a free draining material which can become clogged with biological growth over time. This may interfere with the free flow of leachate into the collector piping. Under these circumstances, injecting oxidants such as hydrogen peroxide may be helpful. This has been applied to leaching fields for wastewater disposal with some success.

Pumping stations require routine operation and maintenance and occasional repairs. The procedures for this should be documented in a facility operation and maintenance manual, and general practices are discussed in manuals previously noted (WPCF, 1981).

6.4.4.2 Leachate Treatment and Disposal Systems

Depending on the processes used, operation and maintenance of leachate treatment and disposal systems may be the single most complex aspect of operating a solid waste landfill facility. Treating the leachate to the level required for the method of disposal may entail complex biological, physical-chemical and/or other processes. Even relatively simple treatment systems, such as aerated lagoons, use highly complex biological processes that must be closely monitored an controlled to ensure proper functioning of the treatment facility.

Fortunately, there are several extensive manuals available that address the techniques of wastewater treatment process operation and control, such as the WPCF Manual of Practice No. 11 (WPCF, 1976), the Texas Wastewater Operations Manual (Texas Water Utilities Association, 1975) and the Ken Kerri Wastewater Treatment Plant Operations Manual (Kerri, 1980). Although these manuals are intended primarily for municipal wastewater, they are also applicable to leachate treatment facility operations. These manuals, along with the operations and maintenance manual prepared specifically for each leachate treatment facility, should be used regularly and frequently to guide the daily operation and maintenance of the facility.

The variation in quantity and characteristics of leachate makes flow measurement and sampling important aspects of leachate treatment facility operation. Flow measurements should be taken regularly and correlated with precipitation and other climatic conditions to verify assumptions made during design of the leachate collection system. Sampling and testing of the raw leachate will serve to vary design assumptions and identify any potential problem characteristics in the leachate. Sampling and testing of the treated leachate is necessary to assess treatment efficiency and to ensure that the required level of treatment is being attained. Specific requirements for flow measurement, sampling and testing should be identified in the operation and maintenance manual.

The special characteristics of leachate can cause problems in the operation of leachate treatment facilities. For instance, some leachates may contain considerable quantities of surface active materials capable of flotation, which can contribute significantly to carryover of floating materials from biological aeration basins to clarifiers. Floating sludge in the clarifier can be reduced through the use of a baffle on the clarifier inlet and use of surface mechanical skimmers. Activated sludge in a leachate treatment facility may have a propensity to become anaerobic and rise to the surface of the clarifier due to denitrification. Correction of this problem may require additional aeration facilities in the basin ahead of the clarifier. A large amount of chemicals may be necessary for precipitation and neutralization in physical-chemical processes.

A complete discussion of all the problems that could be encountered with any of the processes used to treat leachate is beyond the scope of this manual. Wastewater treatment manuals, such as those previously noted, should be consulted for a discussion of these potential problems and steps to correct them.

6.4.5 Gas Control System

6.4.5.1 General Operation and Maintenance Considerations

Gas control systems must be operated at a rate of withdrawal that will prevent lateral migration and odors. It is undesirable to extract excess gas because this may result in drawing air into the fill which can result in a landfill fire.

Gas recovery systems are operated to insure the production of high quality gas. Gas recovery systems that extract gas for upgrading to pipeline quality must be operated so that very little or no air is drawn into the system. Most pipeline quality installations can tolerate no more than 1 or 2 percent air by volume.

Recovery systems for medium BTU applications, such as boilers or engine electric generators, can usually tolerate poorer quality gas. However, an excessive amount of air drawn into the fill can cause portions of the fill to become aerobic and may result in a significant reduction in the quantity of methane generated. In many cases, collection systems for control purposes are not compatible with recovery options and may require composite systems to maintain gas migration and odor control where a recovery system is in operation.

All systems should have a comprehensive operations and maintenance (0 & M) manual. A typical 0 & M manual includes an introduction, general safety precautions, system start-up instructions, system operating instructions, methods or forms for recording data, an inspection and maintenance program, a troubleshooting section, as-built drawings and equipment and instruction and data sheets.

Gas collection systems should be regularly inspected. The major problem encountered in these systems is pipe breakage due to differential settlement, often detectable by visual observation of the surface. Other problems are failure of control components such as valves and gauges, and accumulation of condensate in the pipelines due to failure of a water trap or differential settlement. Vandalism may be another problem at some sites.

6.4.5.2 Passive Systems

Although passive gas control systems require little if any maintenance to ensure their effective operation, care should be taken to ensure that the porous medium used to vent gas to the atmosphere remains unblocked. Drainage slopes and cover soil should be **adequately** maintained to minimize infiltration of rainwater or snow melt. This could increase the gas production rate, and/or development of cracks through which gas could vent in an uncontrolled manner to the surface. Pipe pressures and flow rates should be checked and recorded to indicate any pipe damage or blockage.

6.4.5.3 Active Systems

Active control systems, particularly those utilizing gas collection headers, are subject to several possible maintenance problems. Breakage of the header pipe may occur due to thermal contraction or expansion of the pipe, differential settlement or damage by heavy equipment or vandals. Needed equipment and materials should be readily available to facilitate prompt repair of any damaged system components.

Another potential problem occurs when differential settlement of the fill results in adverse slopes, accumulation of condensate at low points in the system, and subsequent partial or total blockage of gas flow. routine checking and adjustment of pipe slopes should therefore be performed. Care should also be taken to maintain an adequate liquid reservoir in the drip leg of the condensate drains. This can be accomplished by periodic addition of water.

Motor blowers used to extract landfill gas should be regularly maintained to ensure efficient operation, and gas flow adjustments should be made periodically at each well and for the entire well field to ensure effective control of landfill gas migration.

6.4.6 Roads and Other Site Facilities

Maintenance of roads must be routinely performed to contribute to a well functioning operation. Smooth driving surfaces allow vehicles to travel at recommended speeds without undue wear and damage. A hard, sound road structure prevents vehicles from becoming stuck and impeding traffic. Control of dust limits a source of foreign matter in machine joints and bearings, reduces accidents, and improves employee working conditions.

Permanent, hard surfaced roads require minimal attention. They should be kept clean of mud, dirt, dust, snow and ice. Plowing and sanding of access roads may be required during cold weather. As soon as surface failure occurs, patching and repair should be implemented to limit damage. Gravel surfaced roads are routinely graded for a smooth surface and a crown maintained at a slope of 1/4 inch per foot to drain surface water. When necessary, additional surface material should be added for maintenance of a good wearing surface.

Tracked machines, studded compactors and heavy earthmoving equipment should have haul roads separate from delivery access roads. Because these haul roads must be continuously extended and/or relocated, they are constantly being constructed and repaired. Maintaining a smooth surface free of mud and with dust controlled, allows the equipment to travel unimpeded at operating speeds. When the roads are not maintained, haul speeds and productivity will be impaired, equipment wear increased and operator comfort and efficiency diminished.

Entrance gates and perimeter fencing should be repaired when damaged to control unauthorized entry. Proper maintenance of roads, fences, building, landscaping and traffic control devices and informational signs all contribute to positive public image and staff morale.

6.5 PERSONNEL REQUIREMENTS

6.5.1 Administrative Responsibilities

The basic responsibility for solid waste disposal in the State of Washington lies with the county and the municipalities therein. Each county, in cooperation with the various cities, has a coordinated, comprehensive solid waste management plan as required by Chapter 70.95 RCW, Solid Waste Management - Recovery and Recycling. The requirements for permits and procedures to operate a solid waste disposal site or facility as permitted by the jurisdictional health department are set forth in the Minimum Functional Standards.

Upon application to and approval by the health department and Ecology, any public or private entity may operate a disposal site or facility. this must comply with the comprehensive solid waste management plan, zoning requirements and other local policies and plans, and meet all applicable laws and regulations. Thus, a disposal site may be owned and operated by a public or a private entity, or be owned by one and operated under contract by the other. Many factors influence this selection which are outside the scope and purpose of this manual. Once this selection is made there are definable administrative responsibilities relating to personnel requirements.

A public entity operating a solid waste disposal site may be a solid waste division within a public works department. In this situation, many support and administrative functions may be performed by the department on an as-needed basis. These functions could include accounting, engineering, construction, and equipment maintenance. For larger sites, these functions may be incorporated into the on-site operations staff functions. Whatever mode of support activities is selected, the responsibilities should be clearly defined to assure adequate support as needed.

a private entity operating a disposal site may be a self-contained organization with the sole purpose of operating that site. Or it may be a, larger waste management firm capable of providing off-site staff support similar to a public works department. Again, the various responsibilities must be well defined for an effective operation.

6.5.2 Manpower Requirements

Manpower requirements on-site will be affected by site size and waste stream quantities, the complexity of the waste placement plan and the support functions performed on-site. Some typical positions at a disposal site include:

- Supervisor

- Foreman
- Heavy equipment operator
- Light equipment operator/truck driver
- Laborer
- Weighmaster/attendant
- Mechanic/assistant
- Administrative/clerical

When leachate treatment facilities are installed on-site, operating personnel, certified in accordance with the State of Washington Programs, will be required.

Because of the many factors affecting a site operation, it is difficult to relate the number of personnel to staff a site to the incoming waste quantity. A very small rural site may require only part-time operation by an equipment operator. The supervisor may be responsible for other public works functions and make occasional visits to the site. Some small sites may be operated by one person, although this is not recommended for safety reasons. It would be best to have two persons on site during operations.

Per MFS Section WAC 173-304-460 (4)(b) (vi), a landfill site open to the public with a permitted capacity greater than fifty thousand cubic yards per year must have at least two personnel on site with one at the active face. Table 6.5 indicates the number of personnel suggested for various quantities of refuse received.

6.5.3 Qualifications

The successful operation of a solid waste disposal site requires motivated supervision aware of the importance of a positive public image and detecting and. minimizing environmental impacts. The landfilling tasks can be repetitive creating frustration and boredom in employees. These special problems require good management -employee relations and particular attention to employee needs, motivation and training.

The planning, design, and operational procedures must be understood by management and interpreted and communicated to the staff for proper implementation. This requires knowledgeable supervision, trained in many aspects of solid waste management.

A variety of tasks is performed at a disposal site. Although provisions for employee absence for sick time, vacation and holidays must be made, solid waste continues to be delivered and operations must not be interrupted. It is essential that employees be well trained and flexible to perform these tasks.

Table 6.5. Landfill Site Personnel.

Position	0-50	50-130	130-250	250-500	500+
Supervisor	Part Time	Half Time	1	1	1
Foreman			0-1	1	2
Equipment Operator					
Heavy	la	1-2[a]	1-2[a]	2	2 or more
Light		0-1	1	1	2 or more
Laborer	0-1	1	1-2	2	3 or more
Mechanic	As Needed	As Needed	1	1	1 or more
Mechanic Helper				1	1 or more
Weighmaster	1	1	1	1-2	2 or more
Clerical		Part Time	Half Time	1	2 or more
Technician					1 or more
Total	2+ - 3+	3+ - 5+	6.5 - 9.5	11-12	17+

[a]Equipment operator may serve as operating foreman or leadman.

6.5.4 Training Program

The training program of an organization can make a large contribution to the overall competence, efficiency and morale of individual members. This program is a primary responsibility of management and will lead to improved operations and produce dependable, well trained employees and reduced turnover of the permanent staff. By defining employee goals, training can be directed to those positions for which openings will occur in the future. It may be the desire of a laborer to gain training and experience as an operator, mechanic, or foreman. His efforts can be directed through on-the-job training, specialized community courses and vocational training.

Assistance and materials for implementing training programs are available from the U.S. Environmental Protection Agency, the American Public Works Association, and the Governmental Refuse Collection and Disposal Association.

Equipment suppliers are an excellent source of instruction and literature on the proper use and care of their products. The operations plan and operations and maintenance manuals for site facilities are useful in instructing new employees and refreshing all employees.

A very important function of the training program is to assure the safety of personnel. Employee and community education of possible substances that may be disposed of in a landfill is administered under 1984 state legislation entitled Workers and Community Right to Know. The Departments of Labor and Industry and Ecology are jointly responsible for carrying out this code.

6.5.4.1 Supervisor

The supervisor oversees personnel in the operations necessary to receive, process and dispose of solid waste. He understands, interprets and communicates the intent and requirements of all planning, design, operational and maintenance documents prepared for the disposal site and is responsible to management for budgeting, scheduling, procurement, personnel, , recording and reporting, and operational functions associated with the site.

Typical Tasks

- Employ, schedule, assign and supervise administrative, semi
- skilled and skilled workers and machine operators and maintenance
- personnel
- Schedule, assign and coordinate use of operating equipment
- Procure equipment, materials and supplies
- Procure, coordinate and monitor contract work
- Inspect work to assure compliance with design and operation
- procedures
- Maintain records and make reports
- Plan, conduct and supervise training
- Implement safety program
- Assist with budgeting
- Evaluate personnel and make recommendations

Capabilities

- Skilled in management implementation

- Knowledgeable in solid waste management practices

- Understand office procedures

- Understand heavy equipment operations and maintenance procedures
- Knowledgeable in financial planning and budgeting
- Capable of writing reports
- Knowledgeable in interpreting plans and specifications
- Understands leachate and gas management systems operation and
- function

Education, Training & Experience

- High school education or equivalent
- Heavy equipment operation experience desirable
- Experienced in supervising personnel
- Trained in accounting
- Thoroughly trained in safety

6.5.4.2 Foreman

The foreman directly assigns and supervises working crews, operation and maintenance personnel. He interprets operating procedures with assistance from the supervisor and assists the supervisor in managing. He also performs work tasks when required to fill in for absent employees or when increased work load occurs. Finally, he inspects and checks on work tasks being performed and provides on-the-job instruction.

Typical Tasks

- Assigns and supervises workers and equipment
- Perform work tasks as needed
- Keep records
- Check time cards
- Initiate orders for supplies and materials
- Evaluate work

Capabilities

- Capable of directing and instructing workers
- Operate landfill equipment

- Understand equipment maintenance procedures
- Be capable of understanding and operating site facilities
- Record keeping
- Knowledgeable in extinguishing refuse and equipment fires

Education, Training & Experience

- High school education or equivalent
- Heavy equipment operator
- Safety training
- Experience in directing workers

6.5-4.3 Heavy Equipment Operators

The heavy equipment operator operates all landfill equipment for constructing facilities, placing refuse and installing cover material. His work is performed under supervision.

Typical Tasks

- Land clearing
- Excavation
- Hauling, spreading and compacting earthwork
- Spreading and compacting refuse
- Trenching, placing pipelines, backfilling.
- Road and ditch maintenance

Capabilities

- operating landfill equipment
- Inspect, service and make minor adjustments and repairs to
- equipment
- Follow oral and written instruction
- Knowledge of occupational hazards and safety precautions
- associated with heavy equipment operation
- Knowledgeable of traffic laws and regulations

- Knowledgeable in extinguishing refuse and equipment fires

Education, Training & Experience

- Eighth grade recommended
- Heavy equipment operator training
- Heavy equipment operation experience
- Safety training

6.5.4.4 Light Equipment Operator

The light equipment operator operates light equipment and trucks at a ,landfill site. His work is also performed under supervision.

Typical Tasks

- Operates truck hauling earthwork, refuse, materials and supplies
- on and off site
- Operates small loader and backhoe
- Operates miscellaneous small equipment
- Performs service and minor repairs on equipment
- Operates medium and heavy equipment as a trainee

Capabilities

- Operate light equipment and trucks
- Inspect, service and make minor adjustments and repairs to
- equipment
- Follow oral and written instructions
- Knowledge of occupational hazards and safety precautions
- associated with light equipment operation
- Knowledge of traffic laws and regulations

Education, Training & Experience

- Eighth grade recommended
- Light equipment operation training
- Safety training

6.5.4.5 Laborer

Laborers perform unskilled manual work under immediate supervision.

Typical Tasks

- Direct traffic
- Loads and unloads materials, supplies, equipment, salvage,
- refuse, etc.
- Maintains ditches, drainage facilities, lawns, building, etc.
- Assists with trenching, pipe laying and other construction work
- Collect litter, debris, etc.
- Assists with land clearing
- Drives truck on occasion
- Operates light equipment as a trainee

Capabilities

- Perform manual labor all day in all weather conditions
- Understand and follow oral instructions
- Be capable of safety training

Education, Training & Experience

- Eighth grade desirable
- Manual labor experience desirable

6.5.4.6 Weighmaster/Attendant

The weighmaster weighs incoming waste loads, records quantities and assesses charges.

Typical Tasks

- Operate scale or note size of loads
- Record weights or volume measures
- Collect fees and maintain records
- Provide directions and instructions to customers

- Answers phone and relays message
- Receive complaints and comments
- Maintain toll office

Capabilities

- Operate standard office equipment
- operate scale
- Maintain records and make reports under supervision
- Communicate effectively with employees and public

Education, Training & Experience

- High school desirable

6.5-4.7 Mechanic

The mechanic will service, maintain and repair all landfill equipment. In addition, he will organize and equip the shop maintenance area and assist the supervisor in ordering equipment, tools, and operating supplies.

Typical Tasks

- Service equipment
- Perform preventative maintenance
- Keep equipment maintenance records
- Order fuel, lubricants, parts and supplies
- Inspect equipment and instruct operators and oilers in proper
- operation and maintenance
- Maintain a library of equipment manuals

Capabilities

- Service, maintain and repair heavy and light equipment and vehicles
- Prepare records and reports on equipment maintenance

Education, Training & Experience

- High school education desirable

- Specialize training in equipment maintenance and repair
- Experience in repairing equipment

6.5-4.8 Assistant Mechanic

The assistant mechanic services landfill equipment, makes minor repairs and assists with major repairs. He works under the supervision of the mechanic.

Typical Tasks

- Starts equipment in morning
- Fuels equipment
- Services equipment
- Assists mechanic

Capabilities

- Understands basic operation of equipment
- Understands and follows oral and written instructions

Education, Training & Experience

- Eighth grade education desirable
- Equipment service training and experience desirable

6.5.4.9 Administrative

The administrative qualifications at a landfill site can vary considerably depending on the size and sophistication of the operation. For very large sites, an administrative manager may be employed to oversee accounting, secretarial, data processing and clerical staff. Conversely, at a small site, the limited administrative tasks may be performed by the gate attendant and the supervisor. The qualifications for these positions would be similar to other office operations.

6.6 SAFETY

The implementation of a safety program is an expression of concern to protect life and property from injury and damage. The benefits to be derived from such a program are higher morale and efficiency of personnel and avoidance of costly time delays and claims. WAC 173-304-405(2)(i) requires a safety plan or procedure be included in the plan of operation.

6.6.1 Legal Requirements and Standards

The legal requirements for employee safety are mandated by the Washington Industrial Safety and Health Act (Chapter 49-17 RCW). This statute is implemented by safety and health standards adopted by the Washington State Department of Labor and Industries, Division of Industrial Safety and Health. The applicable chapters of the Washington Administrative Code are:

- Chapter 296-24 WAC General Safety Standards
- Chapter 296-27 WAC Record Keeping and Reporting
- Chapter 296-62 WAC General Occupational Health Standards
- Chapter 296-155 WAC Safety Standards for Construction Work
- Chapter 296-350 WAC Resumption of Jurisdictions
- Chapter 296-360 WAC Discrimination, Pursuant to RCW 49.17.160

These standards are prepared to be at least as effective as those adopted by the U.S. Department of Labor and administered by the Occupational Safety and Health Administration.

Some important provisions of the General Safety and Health Standards Chapter 296-24 WAC are:

- Management's responsibility to establish and supervise:
  - A safe and healthful working environment
  - An accident prevention
  - Training program.
- A preliminary investigation of an accident that causes serious injury
- Reporting within 24 hours to the Department of Labor and Industries a fatality of multiple hospitalization (2 or more employees) resulting from an employment accident
- A system for maintaining records of occupational injuries and illnesses
- A safety and health committee when eleven. or more persons are employed
- A safety bulletin board when eight or more persons are employed
- Employees shall be afforded quick and effective first-aid attention if an injury occurs on the job

- Requirements for first-aid kits, first-aid stations and first-aid rooms

The standards also provide detailed requirements for such safety elements as protective equipment, sanitation, hazardous materials, hand and portable tools, working platforms, compressed gas, electrical and other elements.

Occupational Health Standards, Chapter 296-62 WAC, apply where employees are exposed to toxic substances or harmful physical agents.

The Safety Standards for Construction Work, Chapter 296-155 WAC, apply to any and all work places where construction, alteration, demolition, and/or maintenance and repair work, including painting and decorating are performed.

Assistance may be obtained from the Department of Labor in the following areas:

- Accident Prevention Programs
- Safety Committees
- Safety Consultations
- Health Consultations
- First Aid Requirements
- Injuries/Illness Recordkeeping

Also, most counties and many municipalities have safety divisions which will participate in the development of programs for employee safety.

6.6.2 Training

The safety training program should be directed toward those work functions at a landfill that can lead to injury and damage. Particular areas of concern include:

- Fire protection
- Entry into closed spaces
- Hazardous wastes
- Lifting injuries
- Operating equipment

Safety training sessions conducted at routine intervals can ensure that all operating personnel are familiar with safety procedures and safety equipment use.

6.6.3 Fire Protection

Equipment fires and landfill fires can occur at a disposal site. The best remedy is prevention, but in the event of a fire prompt action can limit injury and damage.

Equipment fires generally are started by an electrical failure and subsequent spreading to oil and grease on the machine and to refuse in the area. Preventative maintenance on the machines will reduce leakage of burnable fluids. Frequent inspections will reveal excessive leaks and damaged and frayed hydraulic hose. Routine cleaning of the equipment will contribute to fire prevention.

Each piece of equipment should be filled with portable, dry chemical fire extinguishers affording the opportunity to respond rapidly to a fire. Two 15 to 20 pound fire extinguishers are recommended for each operating machine. Operators and other personnel should be alert for equipment fires, know where extinguishers are carried and be able to call for assistance. This initial action can limit the damage and avoid possible injury and costly repairs.

Automatic fire control systems installed on dozers and compactors provide a quick response to fires. These are particularly useful that they are activated promptly and often prior to the operator being aware of the fire. The cost of the system can easily be offset by avoided fire damage to the machine. Because the automatic system discharge may not completely extinguish the fire, and the burning area should be thoroughly wetted, and built-up refuse removed and checked. The hand-held extinguishers are frequently required in addition to the automatic system discharge. Operation of equipment before the automatic system is recharged risks a fire without the same level of protection. Attempting to extinguish fires with handheld extinguishers has resulted in major equipment damage.

Landfill fires can be started by "hot loads", underground spontaneous combustion, unknown flammable material subjected to sparks and by equipment fires. Again, the most appropriate remedy is prevention. The gate attendant, load spotter and equipment operator must always be on the lookout for "hot loads" and flammable materials. These should be handled separately if allowed on-site. By spreading in area where there is no refuse, or refuse has interim cover, and permitting to cool a hot load can be extinguished. A safe practice is not to smoke or light fires near the working face, any enclosed spaces or near gas collecting systems.

Spontaneous combustion may start within a landfill when a combustible material is present, oxygen is available and sufficient heat buildup occurs to achieve the ignition temperature of the combustible materials. The heat required is first generated by aerobic decomposition of the waste and the local area is insulated by the refuse. Air is made available to the location by open cracks and fissures, gas piping, permeable cover, etc. Evidence of a subsurface fire is noted by:

- Unusual or rapid settlement
- Venting of smoke
- Combustion residues in landfill gas header lines, especially
- carbon monoxide above the norm for that landfill
- Elevated landfill gas temperatures

Locating and determining the extent of the fire can be difficult. This may be done using thermographic scan, excavations, borings and test wells.

A landfill fire on or near the surface may be extinguished by covering with dirt. A water truck standing by can also be effectively used. If the fire extends below the immediate, excavating the burning material will be necessary. This may have to be done in layers to be assured that all burning and smoldering materials are excavated and cooled. Care must be taken to assure injury to the operator and damage to the equipment does not occur. Equipment should not be operated across exposed burning refuse. A large backhoe may be used to excavate burning refuse. The operators may need to wear full-face respirators or self-contained breathing apparati.

For deeper, fires where excavation is not practical, or at old developed landfills, it may be necessary to extinguish the fire by cooling the burning mass in place and/or restricting available oxygen by closing off cracks, fissures and piping systems. Injection of water or inert gas can both cool and displace oxygen.

6.6.4 Hazardous Environments

Hazardous environments at a landfill may be caused by the physical handling of wastes, hazardous materials being deposited or the off products of decomposition. Whatever the cause, the hazardous conditions must be recognized and appropriate action taken to eliminate injury and damage.

Personnel working around solid waste must be continually aware of sharp and jagged items, moving machines and falling objects. Manual salvaging operations can be particularly hazardous. Protective clothing can be effective in reducing and eliminating injury. This would include safety shoes, glove, hard hats, safety glasses and goggles, respirators, bright colored reflective vests and clothing. When lifting items, using correct posture can avoid serious back injuries.

Hazardous wastes are prohibited from being deposited at all but specially designated landfill sites. It is possible such wastes may inadvertently or illegally be delivered with other wastes or in carelessly discarded containers. Incompletely drained or emptied containers can pose hazards to personnel, cause fires or contribute to pollution.

Landfill employees should be suspicious of drums, bags or boxes containing any solid sludge or liquid materials. Label's may be an indication of the material, but should not be totally relied upon. If hazardous or unknown wastes are delivered to the site they should be isolated, the driver and truck identified and questioned and the Department of Ecology and local health authority contacted.

Decomposition of solid waste creates leachate and gases. Landfill leachate will normally have a very high organic content and elevated chemical levels. It is recommended that personnel contact with leachate be avoided. Rashes and burns have resulted from contact in some instances. The landfill gases, can also create hazardous conditions. Upon depletion of oxygen in the landfill, decomposition becomes anaerobic, producing methane and some limited amounts of hydrogen sulfide. Methane is explosive when present in air at concentrations between 5 and 15 percent. It is odorless and colorless and by itself can be difficult to detect. Other gases produced can be detected by odors produced. Hydrogen sulfide has an especially strong odor and is produced when sulfates, such as in gypsum board, are present or brackish water infiltrates the landfill. A note of caution, potentially fatal concentrations of hydrogen sulfide may be undetectable by smell because of olfactory desensitization. Testing of potentially dangerous areas such as excavations in refuse and utility spaces should be conducted.

Any work in and around enclosed underground spaces such as manholes, catch basins, holding tanks, vaults, tunnels, etc., can always be hazardous. This is particularly true at a landfill with the organic materials available to produce toxic and explosive gases and displace oxygen.

The following safety rules must always be followed:

- Employees working in and around closed spaces be trained in
- safety procedures and detailed use of equipment: They should be
- trained in cardiovascular pulmonary resuscitation (CPR) and be
- cognizant of the emergency response program.
- No smoking or open flames should be allowed near the space. Only
- non-sparking tools and rubber shoes should be used.
- The air should be tested for **explosive gases, hydrogen sulfide**
- and oxygen deficiency.
- The space should be ventilated 15 to 20 minutes prior to entry
- and until testing shows sufficient oxygen and no toxic or
- explosive gases.
- Never work alone and always use a safety line manned by two other
- persons capable of pulling or carrying the worker to safety.
- Use a self-contained oxygen breathing apparatus in a low oxygen
- environment. A gas mask will not provide oxygen.
- Do not attempt a rescue by entering the same atmosphere without:

- using self-contained breathing apparatus
- wearing safety line.

- Maintain safety equipment in good working order and check it prior to each use.

6.6.5 Emergency Response

When emergency situations occur, a prompt, appropriate response can often limit the extent of property damage and counteract the effects of injury to personnel. A knowledge and awareness of potential hazards will be most useful in identifying causes and conditions of an ' emergency. A proper safety program should incorporate the following elements for an effective emergency response:

- Trained personnel capable of responding to fire, poisoning, accidental injury and damage, and life threatening occurrences.
- Safety equipment maintained in proper working order and in designated locations.
- Plan initial responses, assign responsibilities for actions and routinely review these plans and assignments.
- Maintain a current Emergency Response Directory.

The Emergency Response Directory should include telephone numbers and locations of all appropriate emergency units such as:

- Local Police
- State Police
- Fire Department
- Ambulance and rescue services
- Poison Control Center
- Hospitals
- Supervisor of Operations
- Power Authority
- Local Health Authority
- State Department of Ecology for:
  - oil spills
  - hazardous wastes

6.7 RECORDS AND REPORTS

The recording and reporting procedures initiated for a solid waste disposal site will have an important bearing on the operating phases and future planning and are required by the Minimum Functional Standards. The system adopted will make it possible to comply with regulatory requirements and effectively operate the landfills by:

- Allocating costs properly
- Routinely evaluating cost effectiveness
- Projecting and scheduling improvements needed
- Planning financial needs and preparing meaningful budgets
- Comparing site capacity and life with planned capacity and life
- Evaluating effectiveness in abating environmental pollution, health hazards, nuisances, injuries and damages
- Providing for facility and equipment maintenance
- Providing for proper personnel administration and management
- Comply with regulatory requirements for reporting job related accidents and illnesses
- Providing defense against complaints and suits
- Keeping and reporting results from environmental monitoring program

6.7.1 Information Management

The size and complexity of operations of a disposal site will in large measure determine the extensiveness of the information system. For a small, rural site the system must be kept as simple as possible, but still allow for the aforementioned needs. A large municipal operation will require a well ,planned system that is effective in providing timely information to management. A sample management organization is illustrated in Figure 6.10.

With the advent of the microcomputer and reasonably priced data processing systems, it is possible to streamline the information management system. Some tasks particularly adaptable to electronic data processing are:

- Billing routine refuse delivery organizations

- Recording delivered refuse tonnages automatically upon weighing

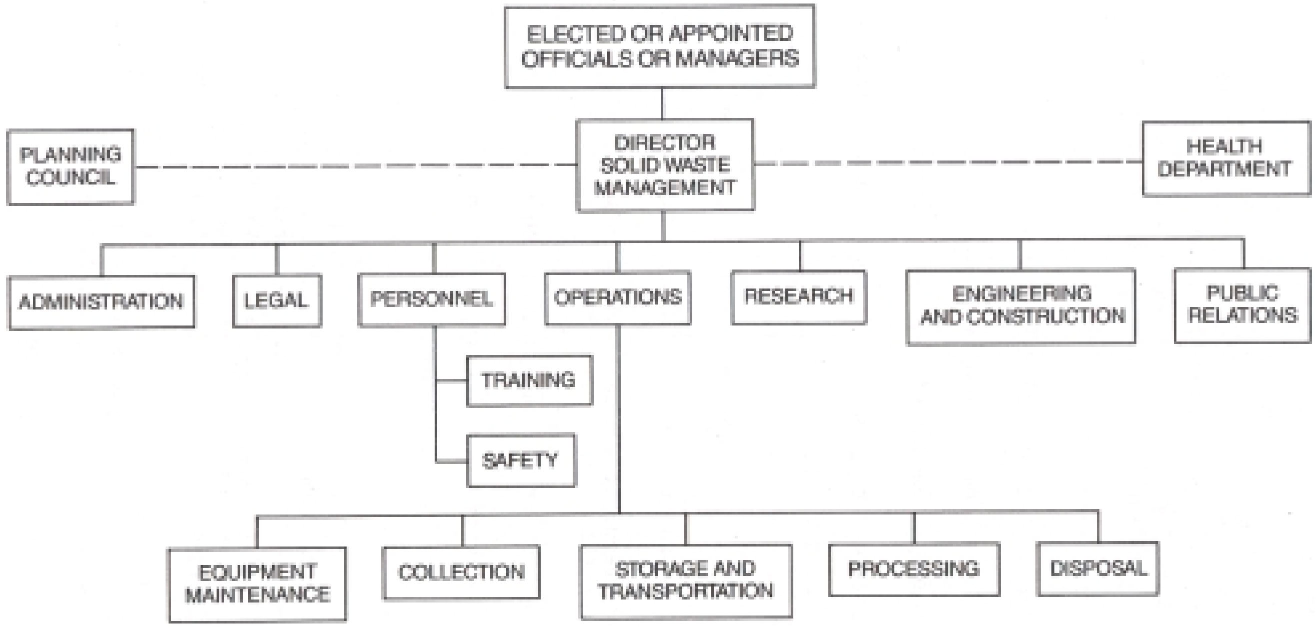


Figure 6.10
Sample Solid Waste Management Organization

- Accounting for employee hours
- Tracking vehicle and equipment operation and maintenance costs
- Maintaining inventory of parts and supplies

A suggested information management system is shown in Figure 6.11.

6.7.2 Record Types and Reports

The specific records kept and reports made will be unique for each site and be influenced by the site size and the operating entity's support staff.
Minimum required records and reports are specified in the MFS. As a guide for operational and accounting records Zausner (1969) can be consulted

Other types of records which should be considered for incorporation into the information system include:

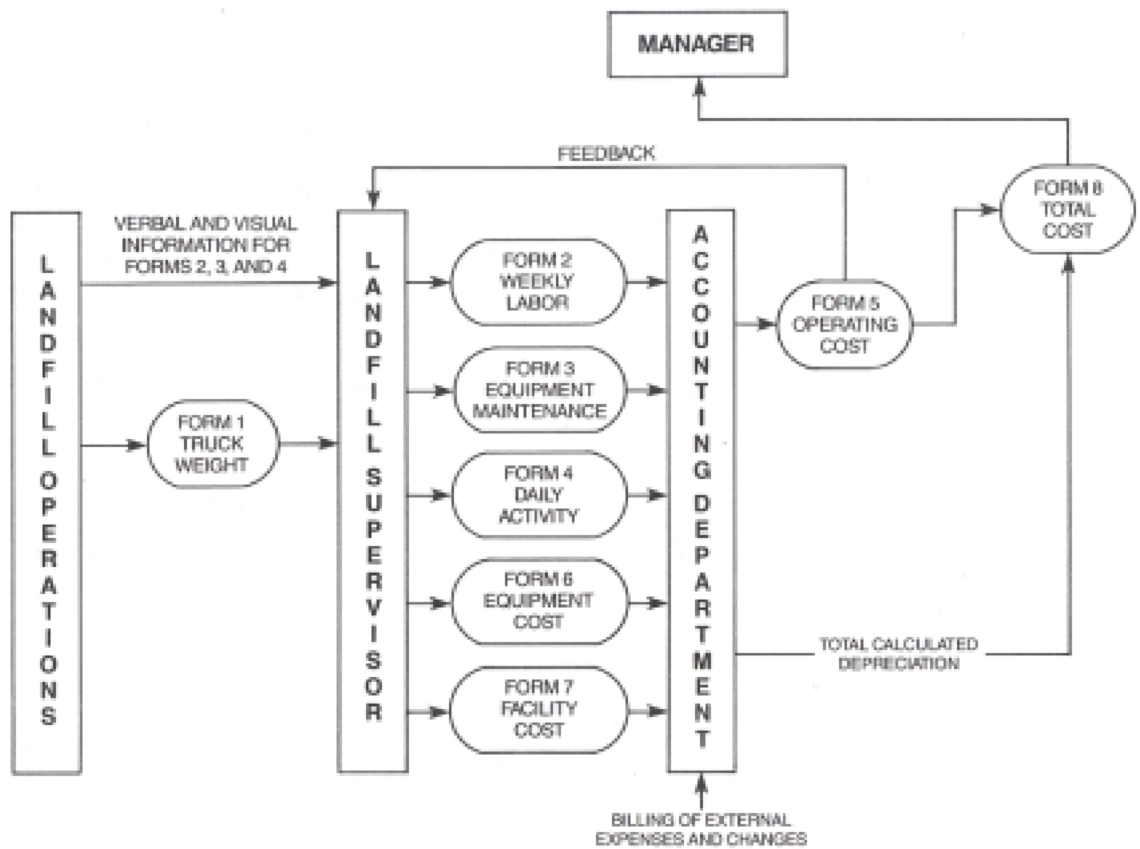
- Vehicle and equipment maintenance and inventory records
- Facility operation and maintenance records
- Environmental monitoring records (see Chapter 8)
- Waste placement and site utilization records
- Personnel records
- Emergency conditions reports

A sample equipment daily inspection form is shown in Figure 6.12. Other maintenance records are illustrated in Figures 6.13 and 6.14.

When pump station and leachate treatment facilities are installed, operation and maintenance records must be kept. There are similar to those for wastewater management facilities. When treated leachate i-s discharged to a receiving water body or on land, the discharge permit will require monitoring and submittal of records.

Plotting of waste placed in a landfill on site maps can be very useful. This will allow comparison of actual waste placed and space utilized to planned quantities. Correlations between volume and weight of refuse received, in-place density and space used can be made. A waste placement history and record of special waste locations may be of assistance when environmental pollution occurs, complaints are made or suits are filed.

Employee records are an integral part of any employer -employee relationship. There will normally be a formalized part of the operating agency's administrative procedure.



Adapted From: Zausner, 1969.

WDOE Solid Waste

Landfill Design Manual

Figure 6.11
Information Flow Diagram

Direction of Flow

Report

MACHINE NO. ______________

REMARKS

BEFORE STARTING CHECK:

WATER ☐ ______________
ENGINE OIL ☐ ______________
TRANSMISSION ☐ ______________
FUEL ☐ ______________

WATER ADDED FRONT	☐	______	WATER ADDED REAR	☐	______
ENGINE OIL ADDED FRONT	☐	______	ENGINE OIL ADDED REAR	☐	______
TRANSMISSION OIL ADDED FRONT	☐	______	TRANSMISSION OIL ADDED REAR	☐	______
HYDRAULIC OIL ADDED FRONT	☐	______	FINAL DRIVE OIL	☐	______

AFTER STARTING LEVEL MACHINE AND CHECK:

ENGINE OIL ☐ ______________
TRANSMISSION ☐ ______________
HYDRAULIC OIL ☐ ______________
ANY LEAKS ☐ ______________
BRAKES ☐ ______________
STEERING ☐ ______________
TRANSMISSION ☐ ______________
- PRESSURE ☐ ______________
- GAUGE ☐ ______________
- SHIFTING ☐ ______________

ENGINE ☐ ______________
- TEMPERATURE ☐ ______________
- OIL PRESSURE ☐ ______________
- WATER TEMPERATURE ☐ ______________

UNDERCARRIAGE ☐ ______________
- TRACK ADJUSTMENT ☐ ______________
- ROLLER WEAR ☐ ______________
- TIRES ☐ ______________

BLADE ☐ ______________
- CUTTING EDGES ☐ ______________
- TRUNNIONS ☐ ______________

HYDRAULICS ☐ ______________
- PUMP ☐ ______________
- JACKS ☐ ______________

OTHER ☐ ______________
- AIR CLEANERS ☐ ______________
- RADIATOR CLEAN ☐ ______________
- TRACK CLEAN ☐ ______________
- TIRES FREE OF MUD ☐ ______________

____
OPERATOR'S SIGNATURE

Adapted From: ASCE, 1976.

Figure 6.12
Equipment Daily Inspection Form

Work and Cost Record

SERVICE METER READING — DATE

	AMOUNT USED	UNIT COST	TOTAL COST
DIESEL FUEL			
GASOLINE			
OIL/QUARTS			
GREASE/POUNDS			
FILTERS			
TIRES			
REPAIR PARTS			
REPAIR LABOR			
TOTAL			

DESCRIPTION OF WORK DONE

TRANSFER THIS DAY'S COST
TO YOUR MONTHLY WORK AND COST RECORD

Work and Cost Record

SERVICE METER READING — DATE

ENGINE

DIESEL/GAS ADDED (GALLONS)	FUEL FILTER CHANGED	AIR FILTER CHANGED	BATTERY	
			CHECKED	REPLACED

MACHINE LUBED	OIL ADDED OR CHANGED (GALLONS)	OIL SAMPLED	OIL FILTER CHANGED

TRANSMISSION AND CONVERTER

OIL ADDED OR CHANGED (GALLONS)	OIL SAMPLED	FILTER CHANGED

FINAL DRIVE/DIFFERENTIAL

OIL ADDED OR CHANGED (GALLONS)	OIL SAMPLED	FILTER CHANGED

HYDRAULIC CONTROL

OIL ADDED OR CHANGED (GALLONS)	OIL SAMPLED	FILTER CHANGED

AVAILABILITY

SCHEDULED CLOCK HOURS	CLOCK HOURS NOT WORKED DUE TO ON-SHIFT		TOTAL CLOCK HOURS WORKED
	REPAIRS	MAINTENANCE	

REMARKS

Courtesy of Caterpillar Tractor Company.

Figure 6.13
Equipment Daily Work and Cost Records

Time and Cost Record for the Month of ______________ Year ________

DATE	MACHINE HOURS WORKED	FUEL		GASOLINE		LUBE OIL		GREASE		FILTERS		MISCELLANEOUS COSTS		HYDRAULIC OIL		REPAIR PARTS		REPAIR LABOR		OPERATOR		SERVICE METER READING	TYPE OF WORK DONE
		AMOUNT USED	TOTAL COST	AMOUNT USED	TOTAL COST	AMOUNT USED	TOTAL COST	AMOUNT USED	TOTAL COST	NO. AND TYPE	TOTAL COST	KIND OF COST	COST	AMOUNT USED	TOTAL COST	TYPE OF REPAIRS	TOTAL COST	TIME	TOTAL COST	TIME	TOTAL COST		
1																							
2																							
3																							
4																							
5																							
6																							
7																							
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24																							
25																							
26																							
27																							
28																							
29																							
30																							
31																							
TOTAL																							

HOURLY OPERATING COST = $\frac{\text{TOTAL MONTHLY COST}}{\text{TOTAL MACHINE HOURS WORKED}}$ = COST PER HOUR

SERVICE METER TOTAL
LAST READING ________
FIRST READING ________
DIFFERENCE ________

Courtesy of Caterpillar Tractor Company.

Figure 6.14
Equipment Monthly Time and Cost Record

An emergency condition report should be made on all events of significance. This will assist management in planning to avoid or respond to future emergencies. The minimum information to report would be:

- Date and time of emergency
- Description of emergency condition
- Description of probable causes
- Length of time emergency condition existed
- Remedial action taken
- Recommendations for preventing such emergencies in the future

When personal injury or death occurs, the reporting shall comply with the Washington State Department of Labor and Industries requirements.

6.8 POST-CLOSURE OPERATIONS

Post-closure operations are an extension of the applicable operation procedures of an active landfill. Leachate and gas will continue to be generated for years and must continue to be managed as previously described. Settlement will occur and the final cover will need to be properly maintained. Surface and ground water control systems will continue to function and roads and other facilities must be maintained. For a more detailed discussion of landfill closure and post-closure, refer to Chapter 7.

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Chapter 7

Landfill Closures

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7. 1 INTRODUCTION

Landfill closure carries with it the connotation of completion or cessation of operation. In reality, the only major activity that stops at final closure is the delivery and placement of wastes. Other functions typical of solid waste landfills go on, including leachate and gas management, erosion controls, surface water management and environmental monitoring. The length of time these activities continue to be required at a particular site is unknown. Critical elements, such as gas and leachate management, may continue for 20 to 30 years or more after landfill completion. However, there is little documented history to predict a specific time base.

Regardless of the time, closure and post closure care is extremely important in the life cycle approach to solid waste landfills. Two of the more important reasons are:

- Closure and post closure care completes the environmental management requirements
- Closure and post closure care is costly

The economics of site closure and post closure care programs are significant. For currently operating sites which have not addressed the issue in their operations plan, capital costs could range up to $75,000 or more per acre of landfill, and operating costs could reach into the hundreds of thousands annually. The important point here is that these expenses will be incurred without a revenue base (tipping fees) to support them. The consensus conclusion to this dilemma is that closure/post closure care requirements must be identified early in the landfill's life cycle and adequately planned and funded.

This chapter identifies specific closure and post closure requirements related to both new and existing facilities, integrates these requirements with other elements of solid waste disposal and provides guidance for economic planning of funding needs. Because of the large number of existing solid waste landfills in Washington, an additional section discusses a range of corrective action techniques available for controlling environmental problems at existing landfills.

7.2 FINAL LAND USE CONSIDERATIONS

7.2.1 Land Use Options

Landfill sites have been used for a wide variety of functions in the past. Major land use categories include:

- Residential development
- Commercial development
- Active recreation areas

- Passive recreation areas or open space

Residential development has included mobile home parks and conventional housing and apartments. Commercial development options that have been pursued include material storage areas, vehicle parking lots, light weight metal buildings and drive-in theaters. Experience has shown, however, that such development is subject to serious problems from differential settlement and the explosive hazard associated with methane collecting in enclosed spaces.

Common active recreation uses have been athletic fields and golf courses. Passive recreation uses include parks and green belts.

A final end use for a landfill operates under a conditional use permit and is subject to local zoning ordinances in effect for that area. Other important considerations include the viability of certain types of development on landfills because of the unique problems the landfill environment presents. The following section discusses the issues unique to landfills that affect development options.

7.2.2 Development Issues

The final land use envisioned for a solid waste disposal site is important in developing the closure plan and gaining the acceptance of the regulatory agencies and the public. The nature of a solid waste landfill limits certain development options. The following aspects of a closed landfill influence final end use plans:

- Low load bearing capability
- Differential settlement
- Production of methane that can collect in confined spaces to explosive concentrations
- Production of malodorous gases
- Public opinion/acceptance

End uses that do not require the construction of buildings are simpler, and avoid many of the potential problems associated with using covered landfills. Such land uses include recreational open space, parks and golf courses. These uses are relatively unaffected by differential settlement and methane cannot be contained in buildings. Although LFG may not present a hazard to public health, it can stress vegetation growing over the landfill. Plants resistant to LFG should be considered if these types of uses are planned. Recreational land uses that require irrigation, such as golf courses, have the potential for increasing leachate generation, and should be given careful consideration where leachate management is a problem. Ideally, the final land use should minimize the potential for leachate generation.

A closed landfill often represents valuable property, especially in urban areas. In such cases, the owner may wish to develop the property more intensively than recreational open space. There are a wide variety of development options. Most would involve the construction of some kind of permanent structure. However, this kind of construction presents the greatest problems.

The low load bearing capacity of compacted solid waste limits foundation loads to no greater than 500 to 800 pounds per square foot (Sovers, 1968). Figure 7.1 illustrates four types of foundation failure that can occur over solid waste because of the settlement of the waste. Solid waste will typically settle from 10 to 30% of its original thickness under its own weight. Under induced loads, settlement will be even greater. Refer to Section 4.5 for additional information regarding landfill settlement.

Special design methods can be employed to reduce the effects of settlement of the waste. The most reliable method is to drive pilings through the waste into solid geologic material beneath the waste. However, piling materials like steel and concrete are subject to degradation from chemicals in the refuse. If the degradation is severe enough, the support capabilities of the pilings may be reduced. If the landfill is equipped with a liner and leachate collection system, this method is not viable since it will rupture the liner.

Differential settlement can cause other problems besides foundation difficulties. Underground utility services can be affected when differential settlement causes large stresses in pipelines or structures which can lead to their malfunction or failure. In one instance, settlement caused a gravity sewer line to flow backwards (Sowers, 1968).

Actual construction in a landfill environment can also be very difficult and require special precautions to ensure the health and safety of the construction crew. Because of the nature of the waste, excavation in a landfill produces large, irregularly shaped holes. This may lead to a much greater excavation size than would normally be required for foundation piers and similar structures. Pile driving can become difficult if large obstructions are encountered. Such obstructions can stop the penetration and force the contractor to abandon the foundation and move to try to avoid the obstruction. Also, any excavation through the surface of the landfill will disrupt the final cover system.

Excavation also releases confined, odorous gases, some of which can be toxic and can make workers in the immediate vicinity ill. The odor problem must be carefully evaluated if the landfill has businesses or residences nearby. The contractor must be advised of the hazardous nature of working in a solid waste environment and a worker health and safety program must be implemented. In a recent incident at a landfill in Washington State, several workmen on a drilling rig became ill from landfill gas as they were drilling through the refuse. In another state, workmen in a pipe trench were asphyxiated by hydrogen sulfide escaping from the refuse. (Sowers, 1968).

PUNCHING SHEAR

ROTATIONAL SHEAR

Bearing Capacity Of Foundations On Soil Cover Over Landfill

NORMAL DISHED-IN SETTLEMENT

IRREGULAR SETTLEMENT FROM HARD ZONES IN THE FILL

Settlement Of Building Supported On Soil Cover Underlain By Landfill

Adapted From: Sowers 1968, p. 109.

Figure 7.1
Bearing Capacity Failure and Settlement of Foundations in Landfills With Thin Soil Covers

Because methane is also present in these gases, precautions must be taken to prevent its potential accumulation in explosive concentrations. Special design measures are also necessary to protect building occupants from accumulation of explosive concentrations of methane in enclosed spaces. Such measures are discussed in Chapter 4.

A recent article (Stearns and Petoyan, 1984) reported the development of two closed landfills; one as a drive-in theater and the other as a truck sales and service center. Both of these installations included pile foundations ' foundation ventilation systems to prevent accumulation of methane in the buildings, and active methane extraction wells interspersed throughout the site to prevent the migration of methane beyond site boundaries or into the site structures. Continued maintenance has been required around the buildings to account for differential settlement. In 1981, a subsurface fire at the drive-in site was initially controlled by filling cracks and adjusting flow rates on the extraction system. However, continued settlement opened up new pathways for oxygen into the landfill and the fire regenerated. It was finally extinguished by locating 8 injection wells in the vicinity of the fire and injecting 25 tons of liquid carbon dioxide into the wells.

More intensive development of closed solid waste landfills is possible. However, as discussed above, there are hazards associated with such development that dramatically increase development costs and financial liability. Before any final land use plans are made, these aspects should be carefully considered and integrated into any economic comparisons of site development options.

7.3 CLOSURE PLAN

A closure plan provides a procedure to ensure that:

- The landfill is closed according to applicable federal, state and local regulations
- Appropriate controls are in place for leachate, landfill gas, and surface drainage management
- The approved final land use is achieved

New landfills that have followed the design procedures of this manual will already have complete design aspects of a closure plan. Existing landfills will require hydrogeologic, hydrologic, and site engineering investigations to form the basis for the development of an adequate closure plan for the landfill. The investigations and design work should follow the procedures discussed in Chapter 4.

Typical elements of a landfill closure plan include:

- Hydrogeologic report

- Final site topographic plan
- Final cover design
- Source of final cover material
- Final landscaping plan or site plan
- Specification of construction details for on-site structures
- Operating plan for phased closure of the landfill
- Surface water management plan
- Ground water management plan
- Leachate management plan
- Landfill gas management plan'
- Environmental monitoring system
- Cost estimate to implement the closure plan
- Implementation schedule and notification procedures
- Procedures for inspection by regulatory agencies

Not all sites will require every element; an element may be eliminated when lack of need is demonstrated based on adequate data and analysis. Some elements presented above are discussed in other chapters in this manual, and the reader is referred to those chapters for procedures on how to develop those elements.

The closure of a solid waste landfill may have a significant impact on the county's solid waste management plan (SWMP). Alternative disposal facilities must be in place and operational when a landfill is closed. This requires close cooperation between the landfill owner and the county. The development of alternative disposal facilities can be a long-term effort, and requires that closure of existing facilities be foreseen and planned several years in advance.

Closure of a landfill requires a great deal of preplanning and preparation. If hydrogeological and other studies are required, it is common for a closure plan to take over one year to develop and meet regulatory agency approval. After the plan is approved, detailed specifications and plans are developed, and the project is constructed, preferably timed to take advantage of favorable weather.

The date of closure is based on an estimate of the waste stream volume and remaining available capacity in the landfill. However, the uncertain nature of the waste stream and remaining capacity make closure date estimates very approximate until the landfill approaches the end of its active life. Then the closure date can be estimated accurately enough to allow the owner to estimate the date of closure several months in advance. When this date is known, the owner should notify:

- Washington Department of Ecology
- Jurisdictional Health Department
- Site users by letter if they are municipalities or contract haulers or by a published announcement for the general public

At closure, the owner should post a sign that indicates the site is closed and list alternative disposal facilities. Maps and a statement concerning the location of the disposal site will be recorded as part of the deed with the county auditor no later than three months after closure. Records and plans specifying solid waste quantities, location and periods of operation will be submitted to the local land use/zoning authority and be made available for inspection. Additionally, all solid waste facilities must comply with all state and local requirements such as zoning, land use, fire protection, water and air pollution prevention, nuisance and aesthetics. The site is considered closed when an independent professional engineer can verify the closure has been carried out according to the design specifications, and the regulatory agencies have inspected the site and are satisfied with the closure.

7.4 POST/CLOSURR PLAN

A post-closure plan is necessary to ensure the long-term integrity of the closed landfill. Typical elements of a post-closure operation and maintenance plan include:

- Maintenance of surface drainage control structures
- Maintenance of leachate management facilities
- Maintenance of gas control/recovery facilities

0 Maintenance of final cover including revegetation, restoration of eroded areas and regrading of areas experiencing settlement

- Surface water monitoring program
- Ground water monitoring program
- Landfill gas monitoring program
- Cost estimates for plan implementation
- Deed clause changes, land use, and zoning restrictions

Procedures for developing these elements are described in other chapters of this manual. It is common for the post-closure and closure elements to be combined into a single plan.

7.5 ECONOMICS OF CLOSURE AND POST-CLOSURE

Concurrent with closure/ post -closure plan preparation, a detailed economic analysis should be prepared to document capital expenditures, operation and maintenance costs, and develop an incumbrance schedule for future cash flows. The accuracy and level of detail of these cost estimates should be similar to any estimate prepared for an engineering project of similar scale, especially in view of the fact that many of these expenses would be deferred for many years. Four basic sources which might be used in developing costs for closure/post-closure activities are:

- Costs based upon experience of the owner/operator
- Contractor estimates
- Cost estimate handbooks
- Cost workups from labor, material and equipment requirements

The importance of these closure/ post -closure cost estimates lies in their ability to allow the owner/operator to accrue these costs and to establish current landfill tipping fees which include these future expenses. Federal legislation made it clear that closure expenses for land disposal facilities may be considered as business expenses at the time they are accrued, that is, when the waste is actually placed in the landfill.

A second factor is the rate making policy itself, which affects both public and private landfills equally. Documented closure and post-closure cost estimates with accompanying incumbrance schedules allow the landfill owner to establish a rate policy to generate incremental (per ton or per cubic yard) revenues to fund future expenditures. This is especially important because capital costs can vary greatly from year to year and post-closure expenditures occur without the benefit of tipping fees to support them.

The idealized goal for a new landfill would be the development of closure/post-closure plans and cost estimates during the design phase. These future costs would then be apportioned over the life and capacity of the facility on a per ton or per cubic yard basis, and the tipping fee adjusted accordingly. As specific closure elements are completed, regulatory requirements change, or time elapses (approximately every 5 years), the closure program would be reevaluated and tipping fees adjusted accordingly.

With existing landfills, the strategy is the same. However, the impact on tipping fees may be more dramatic. Key factors include the magnitude of anticipated costs and the remaining site life. Tables 7.1 and 7.2 illustrate the importance of pre-planning to finance closure and post-closure costs. Table 7.1 shows the estimated costs of closure and post-closure for a

Table 7.1. Pre-planned Landfill Closure/Post-Closure Funding Plan Example. a

Year	Capital Costs	O&M Costs	Price Index at 4% Inflation	Cost in 1985 $	Present Worth[b]	Future Value	Annual Revenue Requirements
1985	0	0	1.000	0	0		$ 395,878
1986	0	0	1.040	0	0		395,878
1987	0	0	1.082	0	0		395,878
1988	0	0	1.125	0	0		395,878
1989	0	0	1.170	0	0		395,878
1990	300,000	50,000	1.217	425,829	264,406	$ 2,416,875	
1991	300,000	50,000	1.265	442,862	249,984		
1992	300,000	50,000	1.316	460,576	236,348		
1993	300,000	50,000	1.369	478,999	223,457		
1994	300,000	50,000	1.423	498,159	211,268		
1995	0	50,000	1.480	74,012	28,535		
1996	0	50,000	1.539	76,973	26,978		
1997	0	50,000	1.601	80,052	25,507		
1998	0	50,000	1.665	83,254	24,116		
1999	0	50,000	1.732	86,584	22,800		
2000	0	40,000	1.801	72,038	17,245		
2001	0	40,000	1.873	74,919	16,305		
2002	0	40,000	1.948	77,916	15,415		
2063	0	40,000	2.026	81,033	14,574		
2004	0	40,000	2.107	84,274	13,779		
2005	0	40,000	2.191	87,645	13,028		
2006	0	40,000	2.279	91,151	12,317		
2007	0	40,000	2.370	94,797	11,645		
2008	0	40,000	2.465	98,589	11,010		
2009	0	40,000	2.563	102,532	10,410		
2010	0	40,000	2.666	106,633	9,842		
2011	0	40,000	2.772	110,899	9,305		
2012	0	40,000	2.883	115,335	8,797		
2013	0	40,000	2.999	119,948	8,318		
2014	0	40,000	3.119	124,746	7,864		
2015	0	40,000	3.243	129,736	7,435		
	$ 1,500,000	$ 1,140,000		$4,279,489	$1,500,689		

[a] Assuming five years prior to beginning closure and all closure and post-closure b costs to be funded from sinking fund available at the end of five years.
[b]Assuming a 10% interest rate.

hypothetical landfill. Capital costs are estimated at $300,000 per year starting in 1990 and ending in 1994. This type of dispersement represents a phased closure schedule. Operation and maintenance costs related to closure

Table 7.2. Unplanned Landfill Closure/Post-Closure Funding Plan Example. a

Year	Capital Costs	O&M Costs	Price Index at 4% Inflation	Cost in 1985 $	Present Worth[b]	Future Value	Annual Revenue Requirements
1990	300,000	50,000	1.217	425,829			$559,752
1991	300,000	50,000	1.265	442,862			576,785
1992	300,000	50,000	1.316	460t576			594,449
1993	300,000	50,000	1.369	478,999			612,922
1994	300,000	50,000	1.423	498,159			632,O82
1995	0	50,000	1.480	74,012	45,956	$817,616	
1996	0	50,000	1.539	76,973	43,449		
1997	0	50,000	1.601	80,052	41,079		
1998	0	50,000	1.665	83,254	38,838		
1999	0	50,000	1.732	86,584	36,720		
2000	0	40,000	1.801	72tO38	27,774		
2001	0	40,000	1.873	74,919	26,259		
2002	0	40,000	1.948	77,916	24,826		
2003	0	40,000	2.026	81,033	23,472		
2004	0	40,000	2.107	84,274			
2005	0	40,000	2.191	87,645	20,981		
2006	0	40,000	2.279	91,151	19,837		
2007	0	40,000	2.370	94,797	18,755		
2008	0	40,000	2.465	98,589	17,732		
2009	0	40,000	2.563	102,532	16,765		
2010	0	40,000	2.666	106,633	15,850		
2011	0	40,000	2.772	110,899	14,986		
2012	0	40,000	2.883	115,335	14,168		
2013	0	40,000	2.999	119,948	13,396		
2014	0	40,000	3.119	124,746	12,665		
2015	0	40,000	3.243	129,736	11,974		
	$1,500,000	$1,140,000		$4,279,489	$507,674		

[a]Assuming closure beginning immediately and phased over a five year period with funds for the post-closure sinking fund and annual capital and operation expenses generated from tipping fees collected during the five year closure period.
[b]Assuming a 10% interest rate.,

and post-closure are also expected to begin in 1990 and continue for 20 years. Since the cost estimates were prepared based on data in 1985, the future expenses must be increased by an estimated inflation factor; in this example an annual inflation rate of 4% was assumed. To estimate revenue requirements needed to establish an annuity fund by 1990 that will finance all closure and post-closure costs through 2015, the total present worth of all future expenditures is computed and converted to an equivalent future value in 1990. Annual revenue requirements needed to accrue this amount in a sinking fund are estimated using a sinking fund factor. In this example, an interest rate of 10% was used for the present worth factor, compound amount factor and sinking fund factor. In the example presented in Table 7.1, the total present worth of all closure and post-closure expenses is $1,500,689, which has a future value in 1990 of $2,416,875. The annual revenue requirement to achieve this future value in five years at 10% is $395,878. If this example were for a 500 ton per day waste facility, $2.17 per ton would be required to finance closure and post-closure.

Table 7.2 illustrates the effect on disposal fees if closure and post-closure costs are not included in disposal fees until closure actually begins. The annual revenue requirements to establish a sinking fund of $817,616 in 1990 to only finance post-closure is $133,923. Added to this is the annual capital, operations and maintenance costs shown in the zero date dollars column of Table 7.2 for 1990 through 1994. The per ton cost to fund these obligations for an assumed 500 ton per day site would increase from $3.07 per ton in 1990 to $3.46 per ton by 1994, the last operational year for the landfill. These are significantly higher disposal fees than for the first example, when only five years of pre-planning was involved. If pre-planning is done even further in advance, the required annual revenue for closure and post-closure decreases even more. If pre-planning were conducted 10 years in advance for the hypothetical landfill used in the above example, the per ton revenue requirement would be only $1.00. The Minimum Functional Standards require that a closure and post-closure funding mechanism be identified for a landfill.

This manual cannot establish accounting and/or auditing requirements for solid waste landfill operations, either public or private. However, since closure/ post -closure programs are relatively new concepts, recommendations are offered to assist both the public and private sector in implementation of closure fund programs.

A publicly owned landfill will normally utilize a financial accounting system appropriate to the agency, either county or city, which is consistent with the state auditor requirements (RCW 43.09.200 and 43.09.230). This method establishes identifiable reserve funds which may be accrued from one accounting period to another, and expended through an interfund transfer as money is needed. After closure of the landfill, there may be no revenues (operating income) and the post-closure costs would be reported as non operating income to support ongoing expenditures. The need to establish a separate funding mechanism for a public agency to support closure may not be needed due to the ongoing utility accounting programs maintained by these agencies.

A privately owned landfill will also operate with well organized and documented accounting procedures which are subject to audit by federal tax programs and possibly by the Washington Utilities and Transportation Commission if the landfill is classified as an affiliated business. However, upon cessation of operations and landfill closure, the private company may elect to also dissolve, either voluntarily or otherwise. The post-closure care fund, which may have been established for many years and amount to a substantial cash reserve, represents the contribution by all previous landfill users to maintain and operate the site after closure. This fund must be protected from other creditors who may have legitimate financial claims against the original operating entity.

One solution to this potential problem is to establish a post-closure trust fund with specific fiduciary responsibilities. This funding program would protect assets, strict auditing credibility and the ability to transfer fund management to a public agency should closure/ post -closure implementation responsibilities shift.

7.6 CORRECTIVE ACTION TECHNIQUES

7.6.1 Introduction

Corrective action techniques are implemented to correct or mitigate an undesirable environmental impact caused by a landfill. If a landfill is properly designed, the need to implement corrective measures will not likely arise. For many landfills in the State of Washington, however, the need for corrective action measures occurs often, because many landfills were designed and constructed before their environmental impacts were understood. Most do not have any leachate management system, although they are located in areas with high levels of precipitation. Other landfills originally constructed in rural areas with little or no development around them, now find themselves being encroached upon by commercial and residential land uses. Such encroachment may require the addition of gas migration controls or other measures.

The implementation of a particular corrective action procedure is very site specific. Corrective action procedures should be based on sound engineering principles, but innovation and adaptation of existing methods should not be avoided. There is no step-by-step procedure to follow to develop a good corrective action plan. The remaining sections of this chapter provide general guidelines for developing a corrective action plan, and list commonly employed corrective action techniques. More detailed procedures are provided by the U.S. EPA (1982).

7.6.2 Problem Identification

Prior to instigating corrective action measures, it is imperative to have a thorough understanding of the landfill and its surrounding environment. This requires the collection of large amounts of data concerning both the operation of the landfill and the characteristics of the environment in which the landfill is located. Table 7.3 outlines typical data needed to prepare a sound corrective action program.

Methods for collecting this data are discussed in other chapters of this manual. If no previous data exists at the site, this phase of the corrective action program can be both time consuming and expensive.

Table 7.3. Typical Data Requirements for Corrective Action Plans.

---

1. Geologic, Geochemical and Hydrogeologic Information

    - Geologic setting and generalized soil profiles
    - Soil physical and chemical characteristics
    - Depth to bedrock
    - Depth to groundwater and aquifers
    - Existence of perched zones
    - Groundwater flow patterns and volume
    - Existing monitoring well locations and installation procedures
    - Contamination test results and frequency

2. Climatic Information

    - Rainfall - maximum, minimum, average, number of events, intensity
    - Temperature - maximum, minimum, averages
    - Evapotranspiration data

3. Site Location

    - Topography
    - Proximity to population centers
    - Proximity to surface water
    - Site access
    - Site size
    - Area of contamination

4. Waste Characterization and Disposal Practices

    - Availability and type of characterization information
    - Variability of wastes in site
    - Amount and form of wastes in site
    - Fill methods
    - Fill thickness
    - Cover material and vegetation
    - Length of time site was active

5. Other Information

- Corrective actions previously undertaken (if any)
- Type of studies performed (by whom)
- Definition of current contamination - groundwater, surface water,
- leachate production, soil contamination, migration

Source: Kastman (1981), p. 137

7.6.3 Defining Alternatives

After the initial data collection effort, it should be determined whether any needed data is missing, and if so, efforts implemented to obtain it. With all the required data on hand, the source of the problem can be identified, along with conceptual ideas on how to deal with it. The next step is to develop cost estimates for each of the proposed alternatives. This is a very important step since there is likely to be a large variation in implementation costs for the proposed alternatives. Available monies for implementation should be investigated to define an affordable limit for the alternatives.

With completion of the above steps, it is possible to select the most cost-effective corrective action measure. It is important to examine the alternatives and their costs carefully. Often an alternative that costs an order of magnitude or more than another alternative will provide only slightly better control. Whether this added control is worth the additional cost is an issue that must be considered in cooperation with the regulatory agencies.

7.6.4 Some Corrective Action Alternatives

In developing a corrective action plan for a solid waste landfill, it is necessary to be familiar with various corrective action options applicable to general problem areas. The following tables list typical corrective action options available to correct or mitigate common environmental problems at solid waste landfills:

Table	Title
7.4	Surface Water Run-on Control
7.5	Ground Water Infiltration Control
7.6	Erosion Control
7.7	Leachate Generation and Movement Off-site
7.8	Methane Gas Migration Off-site

Surface water run-on to a landfill occurs from flooding, landfills being located in natural drainage channels, and failure of previously constructed diversion structures. Such run-on increases leachate generation, can contaminate downstream water resources, and, if severe enough, could wash out landfill areas and expose covered refuse.

Ground water infiltration is the movement of subsurface water into the buried refuse. This problem often occurs in shallow ground water areas where the refuse is placed below the ground water' table. The old practice of reclaiming swampy areas by filling them with solid waste has resulted in many landfills having a ground water infiltration problem. The infiltration of ground water increases leachate generation. If there is ground water movement through the site, this contaminated water can be transported offsite.

Erosion of slopes and drainage channels is a common problem at many landfills. Severe erosion can cause surface runoff from the site to exceed standards of water quality in terms of total suspended solids. It can also cause buried waste to be exposed to contaminate the runoff even further. If mild erosion is allowed to proceed unchecked, it can reduce the efficiency of the final cover and increase the amount of leachate generated.

Leachate generation and movement off-site is often the most serious problem at existing landfills. Many older sites were constructed without leachate collection and treatment systems. In these cases, leachate either leaves the site through the bottom of the landfill and enters the ground water flow system, or, if the geologic material beneath the site has a very low permeability, the leachate will exit the landfill through surface seeps or minor local ground water flow systems and enter nearby surface water drainages. It is safe to assume that any landfill lacking an effective leachate management system located west of the Cascade Mountains is generating leachate in sufficient quantities to cause migration through ground or surface water systems.

Landfill gas is generated at most landfills in sufficient quantities to present a potential gas migration problem. Often the gas vents harmlessly through the surface and does not present a problem. However, if landfill gas cannot vent through the surface of the landfill, it will migrate laterally until it can find a path to the atmosphere. If it is venting through the surface of the landfill, it may be accumulating in buildings located on the site. Federal regulations limit the concentration of methane, a major component of landfill gas, to no greater than 5% by volume at the boundary of the landfill and no greater than 1.25% by volume in any building. If final land use plans include intensive development of the closed site, particular attention should be paid to control of gas migration problems. Landfill gas also contains components that are very odorous. If these gases are present in sufficient concentrations to be noticed by nearby residences or businesses, action will be required to control the odors.

Table 7.4 Corrective Action Alternatives for Surface Water Run-on Control

Technique	Functions	Application/Restriction
Diversion structures	Located upslope of landfill; divert surface runoff around landfill via dikes, channels, etc. or through solid waste via culverts	Landfills subject to flooding or run-on from other sources; most applicable for small watersheds; should be designed for 100 year storm since failure could lead to catastrophic environmental damage
Detention/retention basins	Located upslope of landfill; attenuates peak flow rates to prevent unmanageable flow rates downstream; retention basins prevent any downstream runoff	Landfills subject to run-on from upstream drainage; periodic maintenance of basins to maintain their efficiency; retention basins require high evaporation rates or highly permeable substrate to allow seepage

Table 7.5 Corrective Action Alternatives for Groundwater Infiltration Control

Technique	Functions	Application/Restriction
Impermeable barriers	Located upgradient or around perimeter of landfill; prevents movement of uncontaminated groundwater into refuse; slurry trenches, grout curtains or sheet piling used to construct barrier	For landfills located in shallow groundwater flow system; barriers must be deep enough to ensure groundwater cannot pass beneath barrier and flow up into refuse; more effective if it can be keyed into underlying low permeable layer; not effective in groundwater discharge area
Interceptor trenches	Located upgradient or around perimeter of landfill; captures groundwater and diverts it around landfill; effective in lowering water table near landfill; perforated collection pipes are backfilled with gravel	For landfills located in shallow groundwater flow systems; trenches must be deep enough to effectively lower water table; discharge area required for flow collected by pipes; not effective in groundwater discharge areas nor in soils of low permeability
Groundwater pumping	Located upgradient of landfill; lowers local water table below refuse level; well point or deep extraction wells used	For landfills located in shallow groundwater flow systems; can be effective in groundwater discharge areas; not effective in low permeable soils; discharge area required for pumped groundwater; high maintenance costs associated with wells and pumps

Table 7.6 Corrective Action Alternatives for Erosion Control Problems

Technique	Functions	Application/Restriction
Channel lining	Line channel to prevent excessive erosion; lining can be grass, rock, flexible membrane liners, asphalt, or other man-made materials	For unlined drainage channels experiencing erosion of bottom and/or sides; certain techniques expensive; larger channels require more resistant lining
Channel grade control	Reduce flow velocity to non-erosive levels; check dams, drop structures and erosion checks used	Natural or artificial channels experiencing high flow velocities due to steep gradients; sedimentation and flooding impacts should be evaluated when check dams employed; drop structures more costly for flows less than 100 cfs and drops greater than 8 to 10 feet; erosion checks require trenching perpendicular to channel flow direction, backfilling, compaction and capping required
Channel realignment	Alter channel alignment to improve stability of channel bottom and banks	For natural channels experiencing erosion from changes to watershed; may require extensive earthwork if realignment required for long length of stream; effects of realignment must be carefully modeled and evaluated
Energy dissipators	Reduce flow velocity and energy of discharges from channels, culverts and ditches; level spreaders, hydraulic jumps, discharge aprons and drop inlets used	For outlets discharging on erodible soil; discharge from energy dissipators must be onto stabilized surface; hydraulic jump only effective when inlet flow is supercritical; drop structure used at head of channel or culvert to reduce hydraulic gradient

Table 7.6 Corrective Action Alternatives for Erosion Control Problems (Continued)

Technique	Functions	Application/Restriction
Benching slopes	Provides series of small terraces to slow overland flow and provide flat surface for seed and mulch to prevent them from being washed off; scarifying of slope can be done with special attachment on bulldozer or other grading equipment; horizontal surfaces typically 10 inches wide	For steep slopes subject to overland flow; should be combined with establishing vegetation; effective in cohesive soils only
Establishing vegetation	Provides protective cover over soil and root system helps bind soil particles and prevents their washoff; wide variety of seed mixes and methods of application available; hydroseeding combines seeding, fertilization, and mulching in one operation	For exposed slopes, channels and other areas where soil is subject to erosion; subject to climatic restrictions; time of year importan in seeding; some plant species may be sensitive to landfill gas accumulating in ro zone, compatibility should be demonstrated prior to seeding whole area

Table 7.6 Corrective Action Alternatives for Erosion Control Problems
(Continued)

Technique	Functions	Application/Restriction
Detention/retention basins	Attenuate peak flow rates from watershed; allows controlled release of water to prevent excessive flows through drainage ways	For channels subject to erosion from high flows during major storm events; periodic removal of sediment required to maintain design efficiency of basin; costly solution appropriate only if landfill grading significantly increasing runoff from site
Dikes and interceptor ditches	Divert and route runoff away from slopes; can be either temporary or permanent structures	For slopes subject to overland flow; flow must be diverted to controlled drainage path; ditches must be lined to prevent channel erosion
Slope drains	Direct runoff down slope in controlled structure; may be temporary or permanent structures; flexible down drains, pipe drops and chutes used	For slopes subject to concentrated runoff; runoff must be directed to inlet of slope drain; outlet of slope drain often requires energy dissipator or stabilized surface to prevent erosion from high flow velocity
Mulches	Provide protective cover over soil to dissipate the erosive force of rainfall and overland flow; straw, wood chips, sawdust, chemicals and other materials can be used	For exposed slopes subject to rainfall impact and overland flow; many mulches require anchoring or slopes steeper than 3H:1V with netting or similar material; should be combined with establishing vegetation; can be applied with seed, fertilizer and lime in one operation by hydroseeding technique

Table 7.7 Corrective Action Alternatives for Leachate Generation and Off-Site Movement (Continued)

Technique	Functions	Application/Restriction
Groundwater pumping	Create cone of depression beneath landfill to prevent leachate from migrating with groundwater flow system beyond site boundary; deep extraction wells used	For landfills experiencing subsurface migration of leachate in groundwater flow system; located beneath landfill or on down gradient side of groundwater flow system; extracted water must be transferred to leachate treatment system; maintenance and long-term operating costs are high

Table 7.7 Corrective Action Alternatives for Leachate Generation and Off-Site Movement

Technique	Functions	Application/Restriction
Covering	Decrease the amount of precipitation infiltrating into the waste and generating leachate; low permeable barrier layer placed over waste in conjunction with other layers of total cover system (see Section 4.16)	Applicable to closed landfills or filled areas of operating landfills; cover must include landfill gas vent system and erosion control protection; increased runoff from cover must be managed; expensive procedure that should be part of an overall closure plan
Subsurface drains	Collect leachate migrating from landfill beneath the surface or through seeps on the surface; trenches laid with perforated pipe and backfilled with gravel and covered are used	Located around perimeter of landfill or at base of slopes experiencing leachate seeps; leachate must be transported to treatment system
Ditches	Collect surface seeps of leachate	Located at base of leachate seeps; leachate must be transferred to treatment system; increases treatment costs since ditches also capture surface runoff which becomes contaminated in ditch and must be treated; ditch should be lined; useful only for
temporary control		
Impermeable barriers	Prevent migration of leachate site; slurry trenches, grout curtains, sheet piling, and flexible membrane liners are used	Around perimeter of landfill; effective against only shallow, subsurface leachate flow; must be keyed into underlying low permeable layer; must be combined with some type of collection system to remove leachate generated within landfill

Table 7.8 Corrective Action Alternatives for Landfill Gas Migration Problems

Technique	Functions	Application/Restriction
Pipe vents	Provide flow path for LFG to atmosphere or to header pipe for burning or recovery; vertical or horizontal perforated pipe in borings or trenches backfilled with gravel	Located in or around perimeter of landfill; must be active system to be effective in controlling lateral migration; monitoring required to ensure system is effective
Trench vents	Provide flow path for LFG to atmosphere or collection system; narrow trench backfilled with gravel; should be combined with impermeable liner on one trench wall	Located around perimeter of landfill; can be free venting or part of collection/recovery system; can be passive or active although active is more effective; depth should be 2 feet below water table, low permeable layer or bottom of landfill, whichever is shallower; monitoring required to ensure effectiveness
Impermeable barriers	Prevent lateral migration of LFG; slurry trench, clay, flexible membrane liner used	Located around perimeter of landfill; same depth requirements as trench vents; should be combined with vent system to be effective; monitoring required
Gas burning	Oxidizes volatile, odorous gases to non-odorous components; flaring of gases at controlled combustion points used	For landfills generating nuisance levels of odorous gases; maintenance of flares required; adequate methane must be present in gas to support combustion

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Chapter 8

Environmental Monitoring

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8. 1 INTRODUCTION

This chapter discusses the basic factors to be considered in the design, installation and operation of a successful and cost effective monitoring program. A complete monitoring program would include routine, periodic sampling of surface water, ground water and subsurface landfill gases.

Several publications describe monitoring technology and contain literature reviews and additional details not included in this chapter. For more information refer to Barcelona, et al. (1983), Gibb, et al. (1981), Gillham, et al. (1983), GeoTrans, Inc. (1983), Scalf, et al. (1981), U.S. EPA (1977), EMCON Associates (1982), Schumacher (1983) and the other references cited in the text.

The environmental monitoring program focuses primarily on leachate and its effect on ground or surface water and on landfill gas (LFG), primarily methane, and 'its potential to accumulate in explosive concentrations in confined spaces. Water, usually precipitation, that contacts waste in the landfill will generate leachate. If leachate leaves the site in an uncontrolled manner either through surface or subsurface pathways, contamination of aquifers, streams or other water resources may occur. Methane, generated during the decomposition of organic waste, is explosive in concentrations of 5 to 15% by volume. Explosions in buildings and utility trenches in the past have been traced to the undetected migration of methane and its accumulation to explosive concentrations. Monitoring is conducted to detect and assess water contamination and migration of landfill gas and is required to develop remedial action alternatives should such alternatives be required.

The objectives of the monitoring system should be clearly identified prior to design and installation, so that the system can provide the needed information and controls. The objectives of a typical monitoring program are to:

- Comply with the Minimum Functional Standards (MFS) for Solid Waste Handling (WAC 173-304)
- Detect the presence or absence of water contamination or LFG
- Assess the nature and extent of contamination or LFG if detected
- Develop remedial action plans
- Protect drinking water supplies, other water resources and the public health and safety
- Protect the operator and reassure the public
- Assist and support legal actions

8.2 GROUND WATER (SATURATED ZONE) MONITORING

Ground water monitoring systems are designed to collect subsurface water samples from zones that have been affected or could be affected by a landfill. The requirements for ground water monitoring at landfills in Washington state are contained in the Minimum Functional Standards, Section VAC 173-304-490. Generally these standards require . that the monitoring system:

- Consist of at least four wells, one upgradient and three downgradient from the landfill
- Provide ground water samples representative of background water quality and water quality at the downgradient point of compliance, within the uppermost aquifer and underlying hydraulically connected aquifers
- Consist of properly constructed wells
- Implement an approved monitoring plan describing sampling frequency, monitoring parameters, analytical methods and procedures and techniques for:
  - decontamination of drilling and sampling equipment
  - sample collection, preservation and shipping (including chain of custody)
  - quality assurance
  - safety
  - statistical evaluation of data
  - reporting

Five basic questions should be addressed, which provide a framework to design or evaluate a monitoring system (Gillham, et al., 1983):

1. Is ground water in the immediate vicinity of the sampling well representative of either background water quality conditions or ground water quality passing through the compliance point?

   Wells must be located and screened at points within the potential or existing contaminant flow path. Contaminant migration pathways can be complex and are affected by both geohydrologic and geochemical factors. Geohydrologic factors include the types of geologic materials, regional and local flow system hydraulics, and variations in hydraulic conductivity (permeability). Geochemical factors include the waste type and the processes which act to differentially attenuate the various contaminants (i.e. not all contaminants migrate at the same rate).

2. Is the ground water quality entering the sampling well representative of ground water quality adjacent to the well?

   Ground water quality can be altered by the installation of the sampling well. Drilling can introduce foreign materials into the subsurface if drilling fluids are used or can cause carry-down of contamination if drilling proceeds through contaminated zones into less contaminated or uncontaminated zones. Well seals should be installed to prevent interaquifer transfer of contaminants and sand pack materials should be selected so as not to introduce additional contaminants. Appropriate well materials should be selected to minimize the potential for sample bias caused by leaching or sorption of contaminants from the well materials or by geochemical processes that occur within the well casing.

Minimum standards for construction and maintenance of water wells for Washington state are contained in WAC 173-160. These standards provide some guidance on how monitoring wells should be installed. However these standards were not developed specifically for monitoring wells. This situation has been recognized within the Department of Ecology and monitoring well standards should be available in 1987.

3. Is ground water quality in the sample container representative of water in the sampling installation?

The actual sampling of well water can also alter the chemical quality of the data by changing the geochemical conditions from those in the aquifer. These changes can be caused by creating turbulence during sampling, allowing contact of the sample with gases used to drive the sampling equipment or with the atmosphere, and by changing ambient temperature and pressure. Changes in Eh (oxidation potential) and pH, or degassing or volatilization of trace organics can alter contaminant concentration. I Contact with sampling materials can also cause sorption or leaching of contaminants.

4. Has the water sample been affected by alterations between the time it was collected and the time it is submitted to the laboratory?

The chemical nature of a water sample can change with time as a function of its handling. Some contaminants, especially in low concentrations, are unstable and can be altered by microbial activity, sorption onto the container sidewalls, leaching of constituents from the container sidewalls, diffusion of gases into or out of the container, or by chemical reactions with particulate matter that were contained in the water sample.

5. To what extent is the analytical result representative of the chemical concentrations in the sample?

Once a water sample has made it to the laboratory, the sample preparation and analytical technique can cause alterations to the chemical constituents.

8.2.1 Data Requirements

A thorough knowledge of site conditions and waste types is necessary to design an effective monitoring system. The factors which should be considered when designing a monitoring system are varied and complex, even for relatively simple hydrogeologic conditions:

- Waste type, and landfill design and operation

- Topography and surface water drainage patterns
- Geologic material types
- Aquifer properties and variability
- Depth to ground water and effect of seasonal fluctuations
- Groundwater flow directions and rates
- Relative hydraulic heads if more than one aquifer is present
- Ambient water quality
- Annual precipitation and site water balance

Generally a phased approach to site characterization is necessary to obtain the required data:

- Review proposed design and operating procedures for new landfills
- Prepare detailed site histories for existing landfills
- Assess regional and local geohydrologic conditions

Based on collected data, the monitoring system can be designed and installed considering the regulatory requirements, objectives of monitoring, the physical characteristics of the ground water flow system, and the physical and chemical characteristics of the anticipated contaminants.

The design of a monitoring well system for a particular physical setting will depend to a large degree on the monitoring objectives and the site characteristics. There is no general means to strictly define the appropriate scale of a system because of the extremely wide variations in natural conditions that can be expected. Wells must- be properly located and constructed, and sampling procedures must be tailored to the specific monitoring objectives.

The design of monitoring well systems will depend on whether the monitoring is being conducted at new or existing landfill sites. At new landfills, monitoring systems can be installed prior to commencement of landfill operation,. The potential for cross contamination of aquifers by drilling, or wells through sampling, is minimal and ambient water quality trends both upgradient and downgradient of the landfill can be established.

At existing landfills, monitoring well system design, installation, and interpretation of data is typically more complex. Additionally, health and safety issues can be a serious concern-during monitoring system installation and ground water sampling where drilling through solid waste may be required. Where contamination may already be present, drilling though contaminated areas can cause contamination of underlying zones and cross contamination between wells through sampling can be significant. Determination of the presence of contamination must rely solely on a statistical comparison of data from wells located upgradient and downgradient of the landfill.

8.2.2 Well Location and Screen Placement

To detect ground water contamination, sampling wells must be located within the contaminant flow path, both horizontally and vertically. Generally, wells are located both upgradient (at least 1) and downgradient (at least 3) of the landfill and are screened in the first relatively permeable water bearing zone, or upper aquifer, as shown in Figure 8.1. This well placement allows data to be collected within the water bearing zone most, likely to be affected and detects changes in water quality caused by natural variations or other contaminant sources. Monitoring of aquifers below the upper aquifer may also be necessary at some sites. This may be warranted (or required) to provide assurances that the aquifer is not being adversely affected, or when it is suspected that the lower aquifers are hydraulically connected to the upper aquifer.

Multiple wells, or a relatively long well screen, may be required in relatively thick aquifers (greater than 10 feet). A long well screen may be appropriate when the monitoring objective is to simply detect the presence of contamination. However, long screens can bias the data because maximum contaminant concentrations (which may be present over a relatively thin aquifer thickness) can be diluted when mixed with uncontaminated or less contaminated water. Long well screens in these cases can also promote vertical mixing of contaminated and uncontaminated ground waters during non-sampling periods by providing a vertical conduit for flow. In most cases, well screens should be no more than 20 feet in length. In cases where the objective is to delineate the nature and extent of contamination, appropriate screen lengths will likely be 5 to 10 feet or less (Barcelona et al., 1983).

Where the objective is to monitor aquifer zones greater than 20 feet in thickness to detect contamination, and where contaminant flow paths are not well known, several relatively long well screens installed at different depths, are required. To delineate the nature and extent of contamination over a given depth interval, multiple well screens are also required.

The screen settings shown in Figure 8.1 are ideal and assume that the vertical position of the contaminant plume is known. Often contaminant flow pathways are not well known, especially during the early stages of a field sampling program, and the plume can shift in response to changes in aquifer conditions and from variations in precipitation. Uncertainty generally requires that multiple wells be installed at some locations to ensure that monitoring is sufficient to provide reliable and representative data with respect to both areal extent and depth.

8.2.2.1 Effect of Ground Water Flow System Characteristics

The distribution of contaminants about a landfill will be determined by the flow system characteristics. In a regional context, the flow system can be

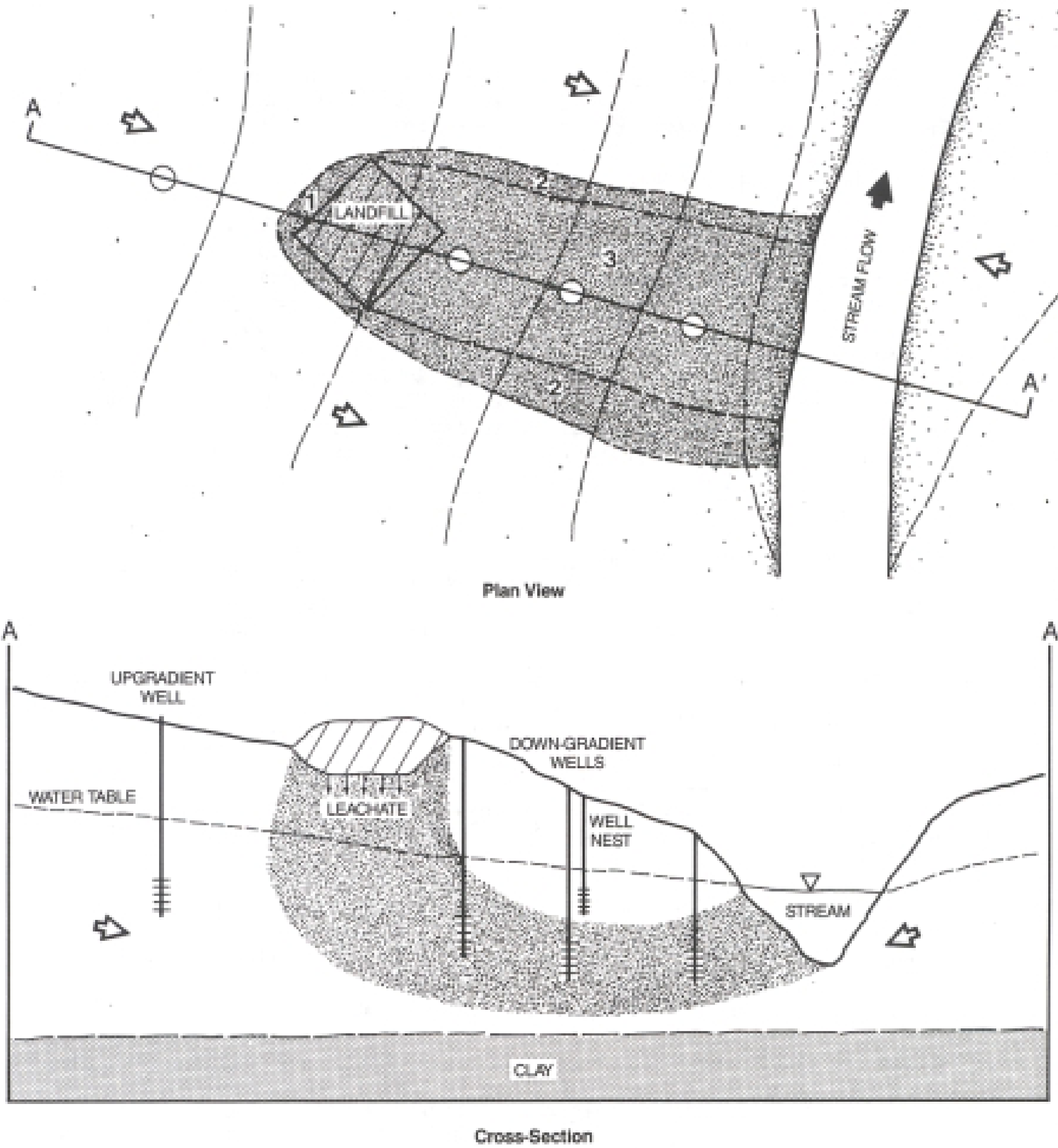

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**Figure 8.1
Idealized Monitoring
Well Layout**

1 Migration Due To Diffusion

2 Lateral Migration Due to Transverse Dispersion

3 Longitudinal Migration Due to Advection and Longitudinal Dispersion

- - - - - Ground Water Contours

Contaminant Plume

Ground Water Flow Direction

Well Screen

segmented into local, intermediate and regional flow systems (Todd, 1980). The distinctions between the systems are conceptual, but are important because they affect decisions pertaining to the location and depth of monitoring wells. Local flow systems tend to be shallow and limited in areal extent while regional systems tend to be widespread and relatively deep. Intermediate systems lie between the two. The conceptual relationships are shown on Figure 8.2.

The depth and areal extent of the various flow systems can be expected to vary widely depending on site specific geohydrologic conditions. Areas having high topographic relief will generally have more numerous local and intermediate flow systems compared with areas where topographic relief is more gentle.

Each flow system can be further divided into recharge and discharge zones (Freeze and Cherry, 1979). Recharge zones exhibit ground water moving downward away from the water table while in discharge zones ground water is moving upward toward the water table. The zones are defined by the direction of the hydraulic gradient. Hydraulic gradients are downward, in recharge zones and upward in discharge ~ zones. The relative hydraulic head relationships for wells installed in recharge and discharge zones are presented in Figure 8.2.

On a conceptual scale, regional, flow system recharge likely occurs along portions of the Cascade Foothills and regional flow system discharge occurs to Puget Sound and the Columbia River. Intermediate flow system recharge areas comprise portions of the uplands adjacent to the major river valleys in Western Washington with the river valleys themselves being the intermediate flow zone discharge areas. Local flow system recharge and discharge areas are associated with the many small lakes and streams, and their immediate surrounding uplands which are present throughout the state.

The flow lines shown in Figure 8.2 illustrate contaminant migration through the subsurface. If landfills are located within local recharge areas or discharge areas, contaminant migration pathways will be relatively shallow and shallow wells would be required for monitoring. However, contaminant migration pathways could be deeper (which would require deeper monitoring wells) if the landfill were located over intermediate or regional flow system recharge areas.

8.2.2.2 Effect of Permeability (Hydraulic Conductivity)

Hydraulic conductivity (permeability) has a significant effect on contaminant migration pathways, especially with regard to migration into the deeper subsurface. Permeability is a measure of the ease with which ground water moves through geologic formations and, in most cases, measures how easily contaminants move through the formations. As discussed in Section 4.2, the hydraulic conductivity of geologic materials can naturally vary by more than twelve orders of magnitude.

The following example illustrates the effect of permeability on the rate of movement of water through the ground.

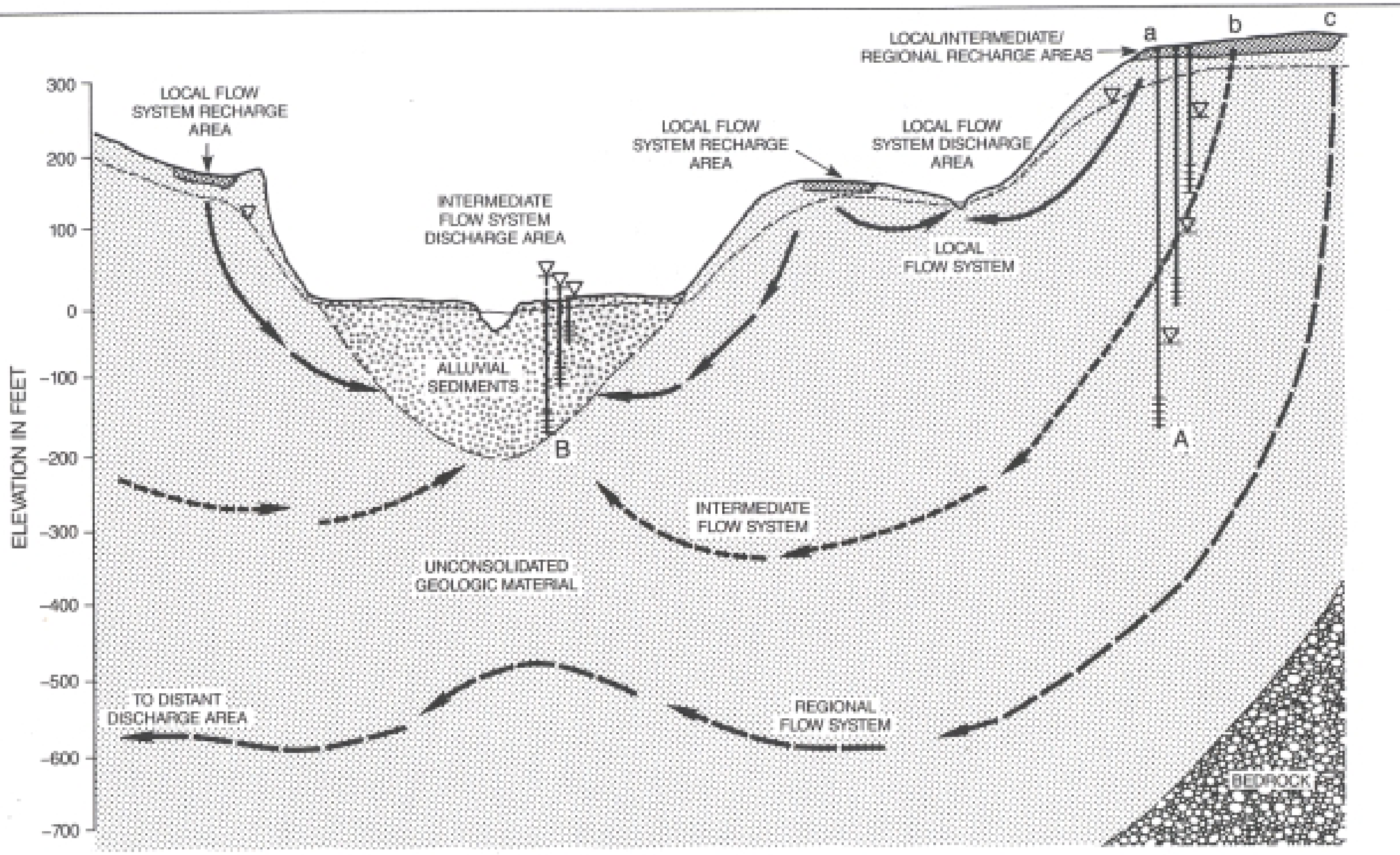

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Figure 8.2
Ground Water Flow Systems and Recharge/Discharge Zones

Equation (8-1) is a modified form of Darcy's law, which gives the velocity of water through saturated soil (Freeze and Cherry, 1979).

$$v \quad \frac{K\,(dh)}{n\,(dl)} \qquad (8\text{-}1)$$

where:

where:	v	velocity (ft/yr)
	K	hydraulic conductivity (ft/yr)
	n	porosity (ft3/ft3)
	$\frac{dh}{dl}$	hydraulic gradient (ft/ft)

To compare the difference between flow through clay and flow through gravel, assume a hydraulic gradient of 0.001, n = 0.40 for clay and n = 0.25 for gravel, K = 10-7 cm/sec (0.10 ft/yr) for clay, and K = 1 cm/sec (1.03 x 106 ft/yr) for gravel. By equation (8-1):

$$^{v}clay \;=\; \frac{0.10}{0.4}\;(0.001) \;=\; 0.00025 \text{ ft/yr}$$

$$^{v}gravel \;=\; \frac{1.03 \times 10^{6}}{0.25}\;(0.001) \;=\; 4120 \text{ ft/yr}$$

Thus in one year, water in the clay will have moved only 0.00025 feet or less than one inch, while the water in the gravel will have moved 4120 feet or almost one mile. These results represent the effects of seven orders of magnitude difference in hydraulic conductivity.

Gross variations in hydraulic conductivity will affect well placement in both a horizontal and vertical sense. In highly permeable formations, a more wide-spread monitoring system may be appropriate because contaminants can potentially migrate faster and disperse over greater distances compared with migration in low permeability units, as illustrated in the above example.

Low permeability units can restrict the vertical migration of contaminants. Again, with a knowledge of the hydraulic conductivity, hydraulic gradient (in this case vertical gradient), and the porosity, ground water flow velocity through the low permeability unit can be estimated and compared with the horizontal flow velocity. It should be noted that based solely on gradient considerations, a landfill site may be situated in a recharge zone, but the potential for vertical migration may be small because of the low hydraulic conductivity of underlying units.

8.2-2.3 Effect of Variation In Soil Properties

Most natural materials display variations in soil properties such as hydraulic conductivity and thickness. These variations can have a pronounced effect on local and regional flow patterns (direction and rate of ground water flow) and the variations can be large or small in scale. Large-scale variations might include the stratigraphic relationships between major

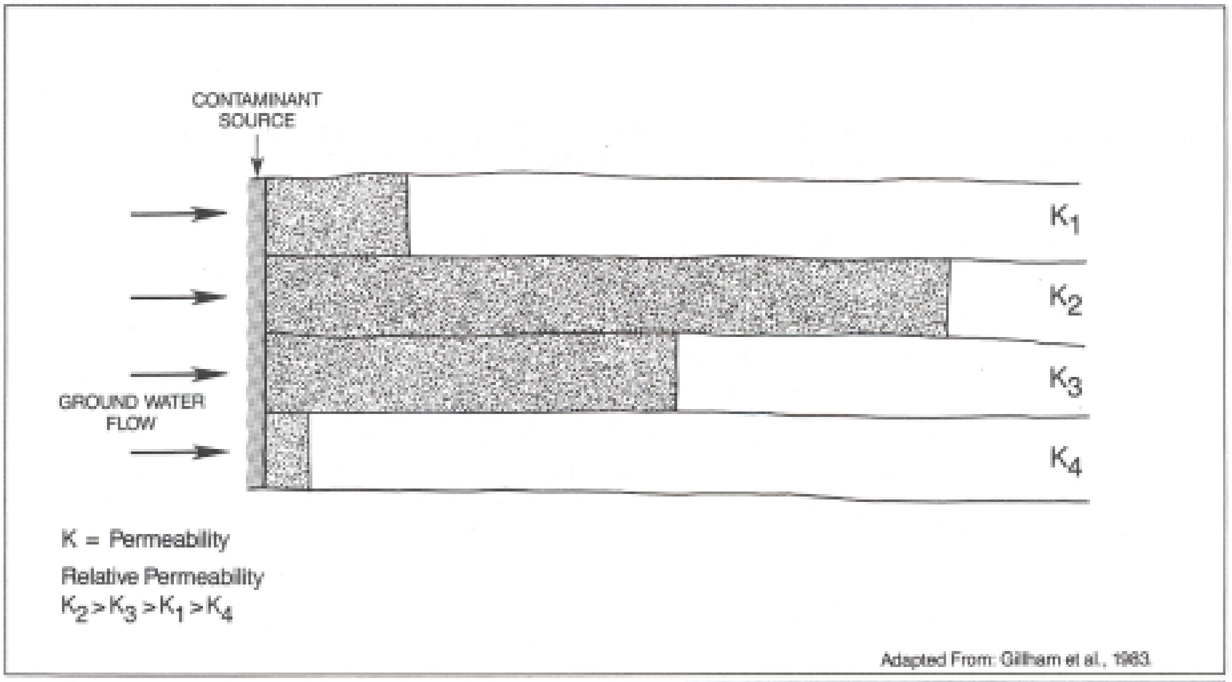


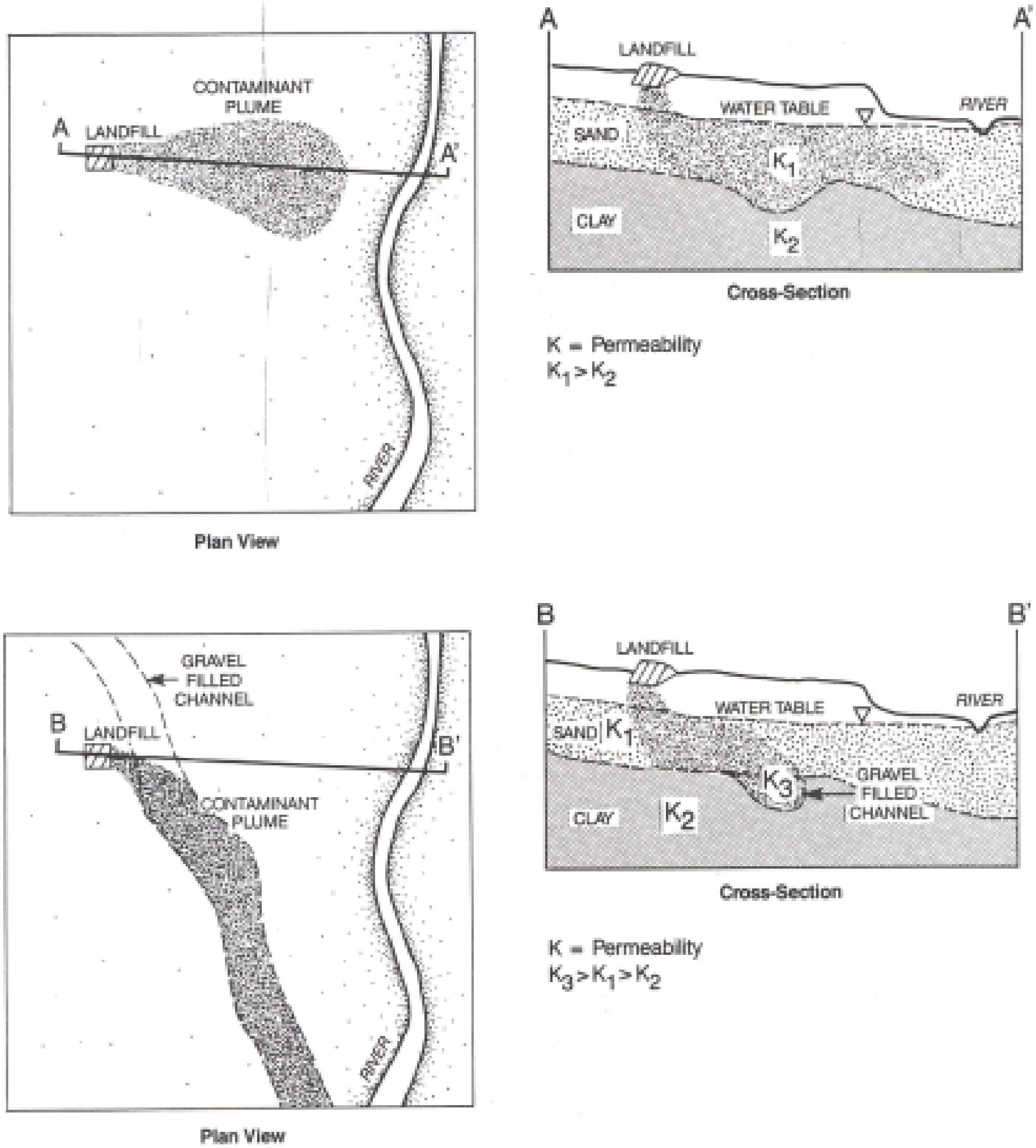
Figure 8.3
Effect of Small Scale Horizontal Permeability Variations on Contaminate Migration

Contaminated Zone

geologic units, such as the relationship between low permeability clay and overlying permeable sand, as shown in Figure 8.1. Large-scale variations are typically assessed during the initial site explorations and are generally known when designing a monitoring system.

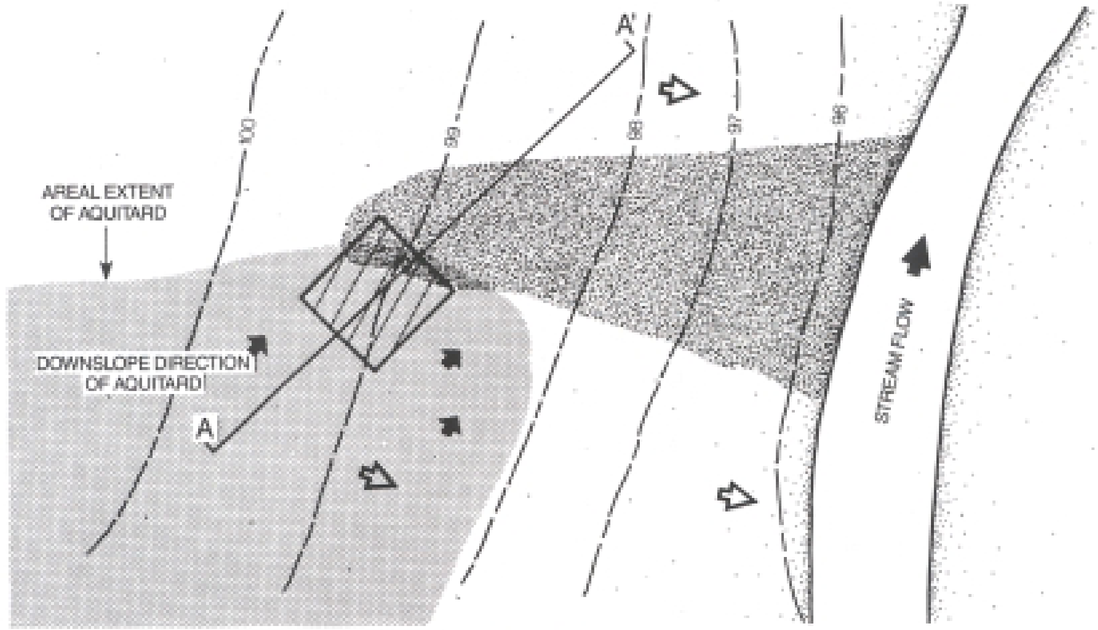
Variations in hydraulic conductivity of less than an order of magnitude, within units which vary by a few millimeters to less than a meter in thickness, are considered small in scale. These variations are likely not significant on a regional scale but can affect the lateral extent of contaminant migration or assessment of maximum contaminant concentrations as shown on Figure 8.3.

In most cases, variations on an intermediate scale pose the greatest difficulty in designing an effective monitoring system. These might include buried stream channels, low permeability layers overlying the water table that slant in a direction contrary to the regional flow direction or openings ("windows") through low permeability layers (Figures 8.4, 8.5, and 8.6). Often their size is difficult to practically detect during field explorations, but it can have a significant effect on contaminant flow paths.

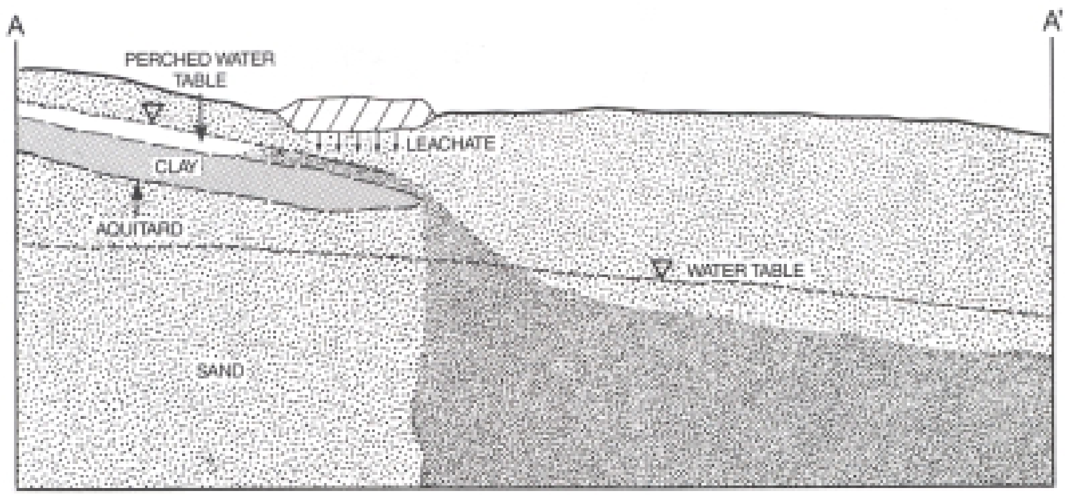


Adapted From: Scalf et al., 1983.

Figure 8.4
Effect of Permeability Variations Caused by Buried Channel on Contaminant Migration



Plan View



Cross-Section

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Figure 8.5
Effect of Aquitard Located Below Landfill but Above Water Table on Contaminant Plume.

Contaminant Plume

Ground Water Flow Direction

— — Ground Water Contours

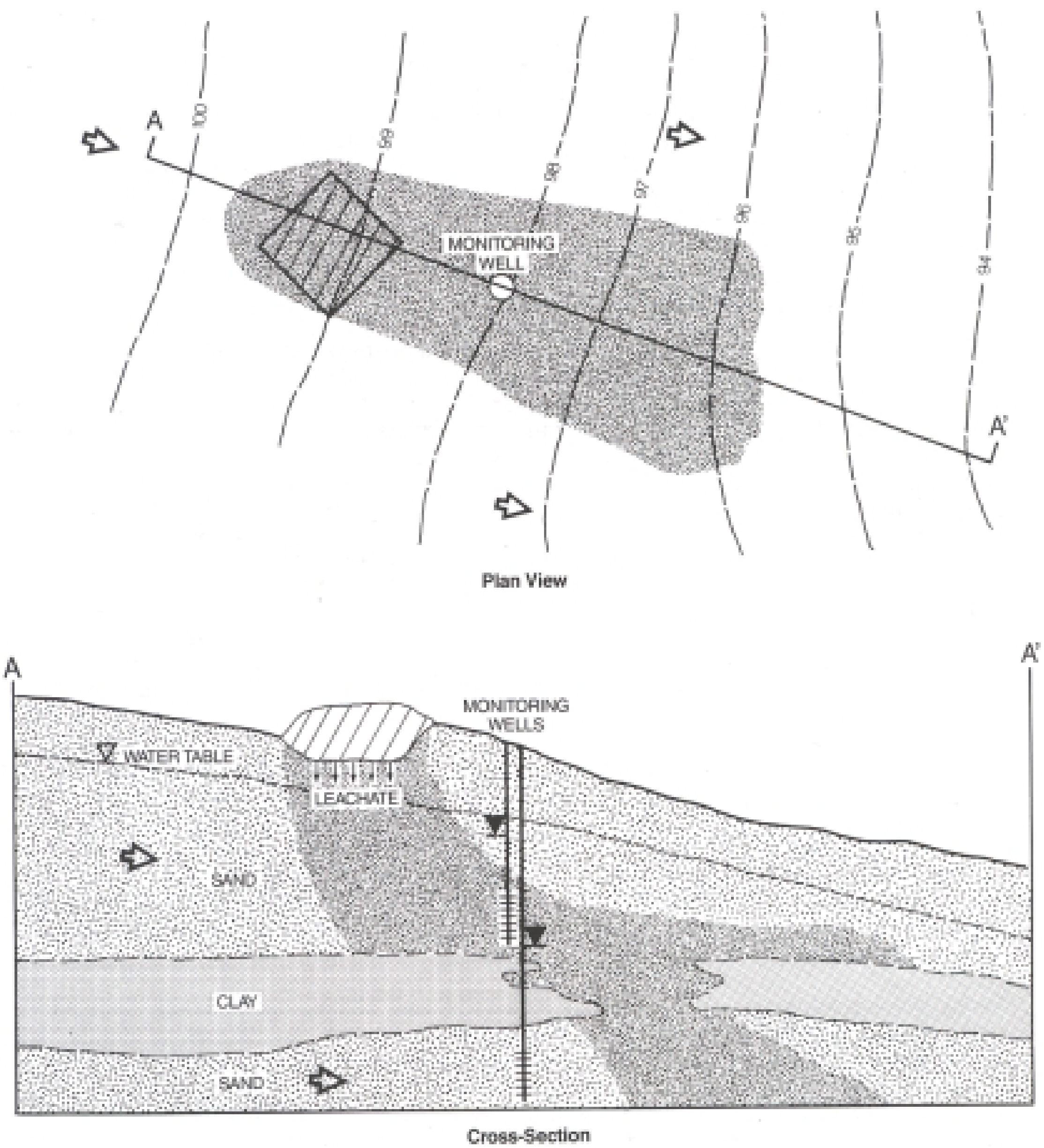

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Figure 8.6
Effect of Window Through Aquitard (Clay) on Contaminant Plume Migration

Ground Water Flow Directions

Water Level

Well Screen

Contaminant Plume

Ground Water Contours

8.2.2.4 Effect of Geologic Material and Type

Geologic materials vary over a wide range. In most areas in Washington, landfills will likely be located over strata composed of porous media (sands, gravels, silts, and clays). In some areas, landfills may be located over fractured consolidated rocks. In these cases, *monitoring systems* are generally more difficult to design because flow patterns are less predictable.

8.2.2.5 Effect of Geochemical Factors

Contaminants introduced into the subsurface environment move at varying velocities. This affects the location of wells, if the objective of monitoring is to characterize a contaminant plume. Wells located further away from the landfill may detect the more mobile constituents, like chloride that migrate at about the same rate as ground water. However, other contaminants, such as heavy metals, generally migrate at a rate considerably less than the rate of ground water flow. To properly characterize the contaminant plume, wells located at varying distances from the landfill (within the *contaminant flow* path) are required.

When contaminants are soluble in water and do not change the density and viscosity of ground water, they are transported by advection and dispersion. Advection refers to the process by which contaminants are carried with the moving ground water. The rate and direction of movement is the same as that of the ground water flow.

Dispersion causes solutes to spread in directions of decreasing concentrations by molecular diffusion and small scale variations within the porous media. Dispersion can be viewed as a process which is superimposed on the advection process. Dispersion processes generally cause a contaminant plume to spread in a direction transverse to the ground water flow direction. For this reason, field measurements of contaminant plume widths are typically wider than those predicted based solely on ground water flow considerations (Freeze and Cherry, 1979).

Certain contaminants which are not miscible and differ in density from water require special consideration. Substances such as petroleum products are less dense than water and migrate in the general direction of ground water flow, but on top of the water table. Depending on the substance, water soluble constituents may enter the ground water system from the "floating" phase and migrate with ground water. If lighter-than-water chemicals are of concern, the wells should be screened across the water table so that the chemical can enter the well.

Various classes of immiscible organic solvents are denser than water and will tend to migrate downward below the water table until a relatively low permeability layer is encountered. Migration may then occur in the downslope direction of the low permeability layer which may be contrary to the direction of ground water flow. If this class of chemicals is of concern in designing a monitoring system, then the slope of the low permeability unit should be determined and well screens situated immediately above the unit in the downslope direction from the landfill.

8.2.3 Well Installation and Design

8.2-3.1 Casing and Screen Sections

Historically, monitoring wells have been constructed of a variety of materials. Teflon, PVC, and stainless, galvanized, carbon and low-carbon steels have been used with varying success.

Contamination caused by direct contact with the well casing material is generally of little concern with respect to major ions, pH or specific conductivity (Gillham et al., 1983). However, casing materials can strongly affect concentrations of trace contaminants such as heavy metals or organic chemicals by leaching or absorptive processes, although absorptive bias may not be significant in a properly sampled well (Barcelona et al., 1983).

Work conducted by the Illinois State Water Survey (Barcelona et al., 1983) provides a preliminary ranking of casing materials as to suitability in several chemical environments as listed on Table 8.1. The mineral-acid/high-solids category is most similar to landfill leachate. The results of their work are summarized in Table 8.1. As shown for the general case, teflon, stainless steel and PVC-1 are ranked as the preferred materials for casing and screens. However, for-mineral-acid/high-solids, PVC-1 ranked as high as teflon.
NAW
Monitoring wells have been constructed using various diameter well casings and screens. With the advent of sampling equipment effective in relatively small diameter well bores, well casings two inches in diameter should be sufficient for most applications.

Well screen length depends on the thickness of the zone to be monitored and the objective of the monitoring program. Relatively long screens (10 to 20 feet) can be used in relatively thick water bearing zones where the objective is to detect contamination. In relatively thin water bearing zones or where the objective is to determine the specific nature, extent, and maximum Concentration of the contaminants, shorter screen lengths (10 feet or less) should be used. Well screens should be designed to prevent the transfer of water and contaminants between water bearing zones.

Well screen slot size should be selected so that the well will produce clear, particle-free water. Methods of slot selection used in the water well industry (Johnson UOP, 1974) have proven successful in determining monitoring well screen slot sizes. It should be kept in mind that in designing a water well the goal is to maximize the efficiency of the well, whereas in monitoring wells the goal is to produce clear water. In most cases, a smaller slot size for a monitoring well screen is suitable compared to what would be used in a water well at the same location.

Table 8.1 Ranking of Rigid Well Casing and Screen Materials[1]

	PVC	Galvan-ized steel	Carbon steel	Lo-carbon steel	Stain-Less steel 304	Stain-less steel 316	Teflon
Buffered Weak Acid	100	56	51	59	97	100	100
Weak Acid	98	59	43	47	96	100	100
Mineral Acid[2] High Solids	100	48	57	60	89	82	199
Aqueous/Organic Mixtures	64	69	73	73	98	100	100
Percent Overall Rating	91	58	56	59	93	96	100

Preliminary Ranking of Rigid Materials

Teflon*
Stainless Steel 316
Stainless Steel 304
PVC 1
Lo-Carbon Steel
Galvanized Steel
Carbon Steel

Source: Barcelona, et al. (1983)

[1]Numbers in matrix refer to relative ranking of casing/screen materials.
[2]Most similar to mixed municipal landfill leachate

8.2.3.2 Sand Pack Surrounding the Screen

Often it is desirable to place a sand pack around a monitoring well screen to improve the hydraulic efficiency of the well and to minimize the migration of fines into the well. As with slot sizes, methods used in the water well industry to determine the grain size of filter packs are suitable in monitoring well design with the same caution discussed above. If the well is to be used to obtain water samples, the composition of the sand pack should be considered. In most cases, a silica sand should be used.

8.2.3.3 Annular Space Seal

Seals should be installed in monitoring wells to prevent the vertical migration of water and contaminants along the well bore and to prevent the downward migration of surface water. Well seals should extend from several feet above the screen to above the highest seasonal water table and from ground surface to a suitable depth. In some cases it may be practical to extend the seal from the water table to the ground surface. Surface sealing requirements for Washington state are discussed in WAC-173-160 (WDOE, 1973).

The sealing mixture should retard the migration of contaminants, not shrink, and not affect the chemical composition of the sampled ground water. Typical materials include cement or bentonite/cement grout which, if properly installed, will be effective in most monitoring well installations. Bentonite and other substances can be added to cement to provide for expansion of the mixture. Other sealing materials are being developed and improvements in sealing materials and installation techniques can be expected in the next few years.

The material used in seals can affect the chemical quality of the sampled ground water. These effects include raising the pH or causing ion exchange if water comes in contact with bentonite.

Bentonite pellets have been used to install seals in monitoring wells. In most cases the pellets are very difficult to place down the hole and have led to the installation of ineffective seals. If the seal is to be placed below the water table, the seal should be trimmed into place.

8.2.3.4 Well Head

After the well is completed, a secure well head should be installed and the high point on the well casing surveyed to establish a reference point for future water level measurements. Surveying also allows the water levels from several wells to be adjusted to a common datum. A secure well head should prevent the migration of surface or rain water down the inside of the well casing and prevent the unauthorized introduction of materials down the hole or other types of vandalism.

Typical monitoring well designs are shown on Figure 8.7. In some instances, monitoring of discrete depth intervals at a single location is necessary which requires that several zones be screened. This can be accomplished by drilling several boreholes to various depths of interest and installing a single well in each borehole. This type of installation is termed a well nest.

A second alternative is to install several wells in a single borehole and to seal the space between screened zones. However, this type of installation requires the use of a large borehole. Depending on borehole diameter, and on the number of wells to be installed, sealing between wells can be difficult, and often the effectiveness of the seals is unknown. Therefore, whenever possible, multiple installations in a single borehole should be avoided.

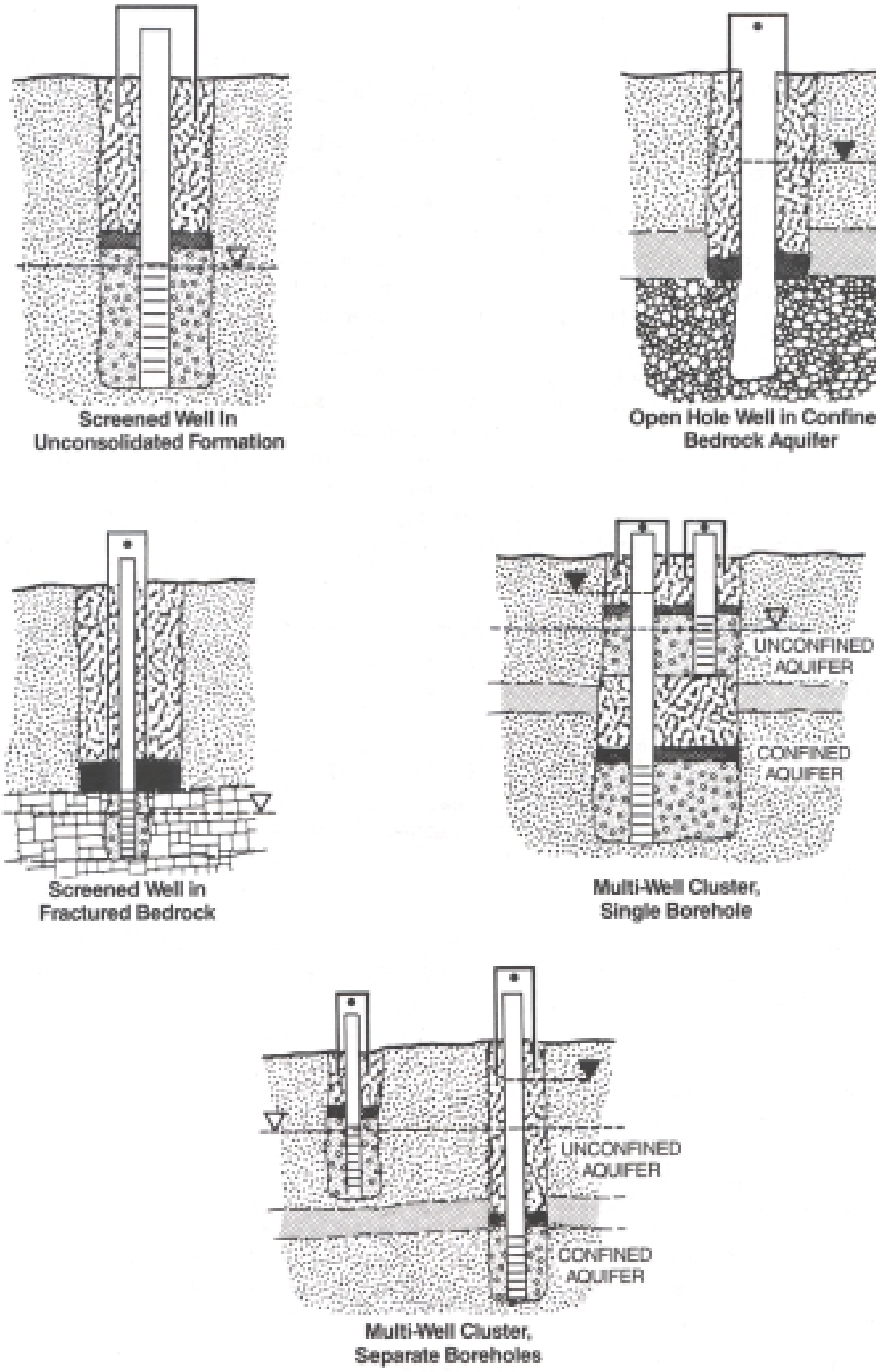

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Figure 8.7
Examples of Monitoring Well Construction

8.2.3.5 Drilling Methods

Drilling methods used in monitoring well construction are discussed in Chapter 4, Appendix 4A. The selection of an appropriate drilling method will depend on the geologic materials to be penetrated and on the objectives of the monitoring program. Some of the most common types of drill rigs used for well installation include:

- Hollow-Stem Augers
- Cable-tool
- Air Rotary
- Mud Rotary

In most cases, the use of drilling additives, such as those used in mud rotary drilling, should be avoided. These additives can alter the chemistry of ground water entering the well and can be very difficult to purge from the well prior to sampling. Drilling mud can, in some instances, be classified as a dangerous waste.

The selected method should also minimize the transfer of contamination between zones. If contamination is present, it can be carried down into lower formations with an auger or casing. If downward hydraulic gradients are present, contaminants can also move downward prior to installing a proper seal.

Under many conditions, the hollow-stem auger is the preferred option for installing wells, especially where existing contamination is present. The method does not require the use of drilling additives, can generally provide high quality soil samples, and wells can be easily installed through the auger center. However, this method is limited to a depth of approximately 100 to 150 feet and cannot be used in hard rock or in the presence of very coarse gravel or boulders. There is some controversy over the use of the hollow-stem auger, particularly with regard to the effectiveness of seals. For this reason, particular attention must be given to installing adequate seals when using this method.

Cable tool and air rotary drilling have also been used successfully in installing monitoring wells. Cable tool drilling provides high quality soil samples with a good operator and discrete zones can be sampled during drilling. The method is slow, however. In addition, because of the nature of the cable tool method, carry-down of contaminants is a particular concern. Therefore, extra precaution must be exercised in areas of existing contamination.

Air rotary drilling is significantly faster than cable tool and can penetrate to deeper depths than auger drilling. However, samples are returned as cuttings which can be difficult to interpret. Barrel-type samplers can be used, but drilling rods must be removed from the hole prior to sampling which can be time consuming and very expensive. Also, at sites where contamination may be present, the health and safety of the operator is of particular concern because of the method of sample return.

8.2.3.6 <u>Well Development</u>

After the wells are installed, the well screens should be developed to remove drilling fluids (if used) and particulates that are present in the well from drilling. Available techniques that do not introduce fluids into the well include jetting with compressed air, mechanical surging and bailing or pumping.

8.2.4 Monitoring Parameters and Methods

Consideration and selection of monitoring parameters is an important aspect of any monitoring program. Monitoring parameters for landfills in Washington state are specified in the Minimum Functional Standards (MFS) as listed in Table 8.2. Sampling constituents and interim primary drinking water standards are included. The sampling constituents generally are indicators of leachate contamination while the interim primary drinking water standards are used as a "first cut" to assess whether contamination has occurred (see Section 8.2.8 for interpretation of monitoring data).

Flexibility exists within the Minimum Functional Standards to either reduce or increase the number of required parameters depending on the nature of the waste. Also the list of interim primary drinking water parameters, and the allowable maximum contaminant level (MCL) will likely change in the future as Ecology establishes ground water quality standards for all types of

Table 8.2 activities impacting ground water (WAC 173-304-9901). Additional leachate indicator parameters are presented in Table 8.3.

8.2.4.1 <u>Selection of Monitoring Parameters</u>

The selection and use of monitoring parameters should be based on:

- Objective and type of monitoring system
- Susceptibility of parameter to attenuation
- Background water quality
- Sampling location
- Cost
- Regulators requirements
- Expected leachate constituents
- Precision of determination

Table 8.2 Monitoring Parameters Specified by the Minimum Functional Standards

---

Sampling Constituents (WAC 173-304-490)

- Temperature
- Conductivity (or specific conductivity)
- pH
- Chloride
- Nitrate, nitrite and ammonia (as nitrogen)
- Sulfate
- Dissolved iron, zinc and manganese
- Chemical oxygen demand
- Total organic carbon
- Total coliform

Interim Primary Drinking Water Standards (WAC 173-304-9901, WAC 248-54)

Arsenic	Endrin
Barium	Lindane
Cadmium	Methoxychlor
Chromium	Toxaphene
Fluoride	2;4, D
Lead	2, 4, 5-TP Silver
Mercury	Radium (226 and 228)
Nitrate as N	Gross Alpha
Selenium	Gross Beta
Silver	Coliform Bacteria

It is not. necessary to monitor a vast number of parameters on a routine basis to detect changes in water quality caused by leachate contamination of ground water. Routine monitoring using the MFS parameters and a reliable statistical test should be sufficient to assess whether -changes in ground water quality have occurred. Should changes in concentration of one or more of the parameters be detected, additional analyses for the drinking water standards must be done.

Selection of additional monitoring parameters should be based on which key monitoring parameters changed. For example, if specific conductance and chloride concentrations increased and TOC and TOH concentrations did not change, then analysis for additional inorganic parameters may be warranted. Extensive analysis for organic chemicals is probably not warranted. However, if TOC and TOH concentrations increased, then analysis for specific organic chemicals should be considered.

Table 8.3 Typical Leachate Indicators

Physical	Chemical		Biological
Appearance	<u>ORGANIC</u>	<u>INORGANIC</u>	Biochemical
PH*			Oxygen Demand
Oxidation-	Phenols	Total Bicarbonate	(BOD)
Reduction	Chemical Oxygen	Solids (TSS, TDS)	Coliform
Potential (Eh)	Demand (COD)*	Volatile Solids	Bacteria
Conductivity*	Total Organic	Chloride*	(Total*,
Color	Carbon (TOC)*	Sulfate*	fecal;
Turbidity	Volatile Acids	Phosphate	fecal
Temperature*	Tannins, Lignins	Alkalinity and	strepto
Acidity	Organic-N	Nitrate-N*	coccus)
Odor	Ether Soluble	Nitrite-N*	Standard
	(oil & grease)	Ammonia-N*	Plate
	MBAS	Sodium	Count
	Organic Functional		Potassium
	Groups as Required		Calcium
	Chlorinated	Magnesium	
	Hydrocarbons	Hardness	
		Heavy Metals (Pb, Cu,	
		Ni, Cr, Zn*, Cd, Fe*,	
		Mn*, Si, Hg, As, Se,	
		Ba, Ag)	
		Cyanide	
		Fluoride	

Adapted from: U.S. EPA (1977)

*Monitoring parameters (sampling constituents) contained in MFS, Section 490

Selection of monitoring parameters should also consider the ground water flow system. Increases in the key monitoring parameters may indicate that contamination has occurred in several wells located downgradient of the landfill. Generally, it is Justified to complete more extensive analyses on wells which show the greatest degree of contamination to characterize the contaminant plume. The results of these analyses could be used to select other site specific indicator parameters that could be evaluated at other well locations.

8.2.5 Ground Water Sampling

Ground water sampling is typically the weak link in the monitoring system. In general, equilibrium chemical conditions in the subsurface environment are not the same as they are above ground. Once the sampling well is installed, chemical alterations in the sample caused by the sampling operation must be taken into account. Contact with the materials of the sampler, the gases used to drive the sampling pumps, and the atmosphere, as well as degassing and volatilization **of** the sample itself, are the primary sources of quality changes in the sample.

Use of proper filtering and preservation techniques will generally minimize alteration of monitoring parameters caused by sampling if the parameters are within the part -per-million range. However, major alterations can occur to trace contaminants such as heavy metals or volatile organic chemicals. In these cases, specially tailored sampling tools and techniques are warranted.

8.2.5.1 Materials

The sampling devices themselves are typically constructed of rigid materials such as those used for well casings and screens and general guidelines for material selection for well casings and screens (Section 8.2.3) should be adequate. However, in most cases a portion of the sampling device is constructed of semi-rigid or elastomeric materials which are more susceptible to leaching (especially of trace organic chemicals) compared to rigid materials. A general ranking of suitability of these materials has been prepared by Barcelona et al., (1983) and is presented in Table 8.4.

8.2.5.2 Sampling Techniques

A variety of sampling techniques have been developed to obtain ground water samples from monitoring wells. The advantages and disadvantages of each have been discussed by numerous authors (Gillham et al., 1983; Morrison, 1983; Scalf et al., 1981).

In many cases, it will be desirable and cost effective to dedicate sampling devices to individual wells. This procedure will reduce the possibility of cross contamination between wells and reduce the required decontamination effort during well sampling. Sampling techniques fall into several categories:

Bailers. Bailers typically consist of a cylindrically-shaped container which is lowered down the well by a rope or cable. They can be fitted with check valves at either end to allow water to flow into the bailer from the bottom and/or to prevent sample contact with the overlying water column in the well as the bailer is raised. Examples of common bailers are shown on Figure 8.8.

Bailers can be constructed of a variety of materials, are simple to use, economical, easy to transport and clean, and do not require power. The major disadvantage is that the technique is time consuming and impractical if a large amount of water must be removed from the well prior to sampling. However, this can be minimized if a different technique is used to purge the well. The rope or cable must be kept clean which can be difficult in relatively deep wells or in sampling between wells. The cost of bailers is low enough that if this technique is used, it may be appropriate to dedicate a bailer to each sampling well.

Table 8.4 Ranking of Semi-Rigid or Elastomeric Materials Used in Sampling Devices[1]

General Categaory[2]	PVC flexible	PP	PE conv.	PE linear	PMM	Viton*	Sili-cone-	Neo prene	Teflon
Buffered Weak Acid	97	97	100	97	90	92	87	85	100
Weak Acid	92	90	94	96	78	78	75	75	100
Mineral Acid2/ High Solids	100	100	100	100	95	100	78	82	100
Aqueous/Organic Mixtures	62	71	40	60	49	78	49	44	100
Percent Overall Rating	88	90	84	88	78	87	72	72	100

Preliminary Ranking of Semi-Rigid or Elastomeric Materials

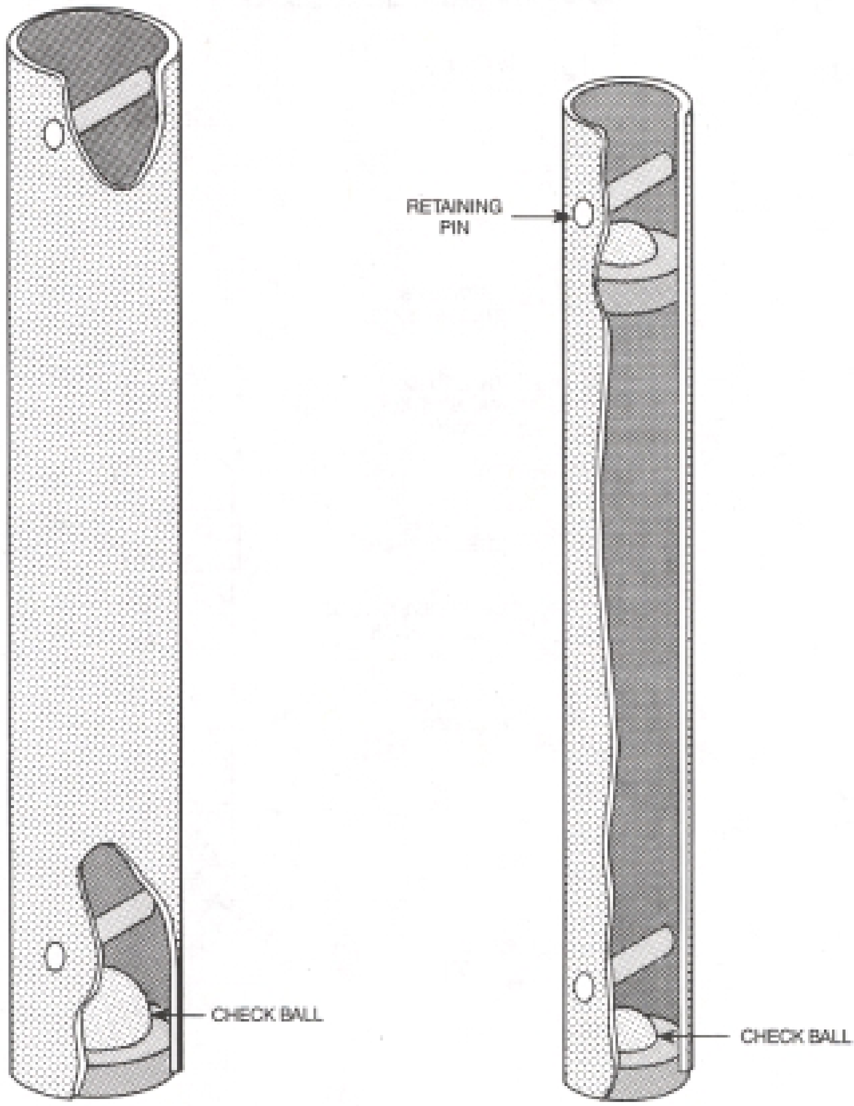
Teflon*
Polypropylene (PP)
PVC flexible/PE linear
Viton*
PE conventional
Plexiglas/Lucite (PMM)
Silicone/Neoprene

Source: Barcelona, et al. (1983)

[1]Numbers in matrix refer to relative ranking of semi-rigid or elastomeric materials.
[2]Most similar to mixed municipal landfill leachate.

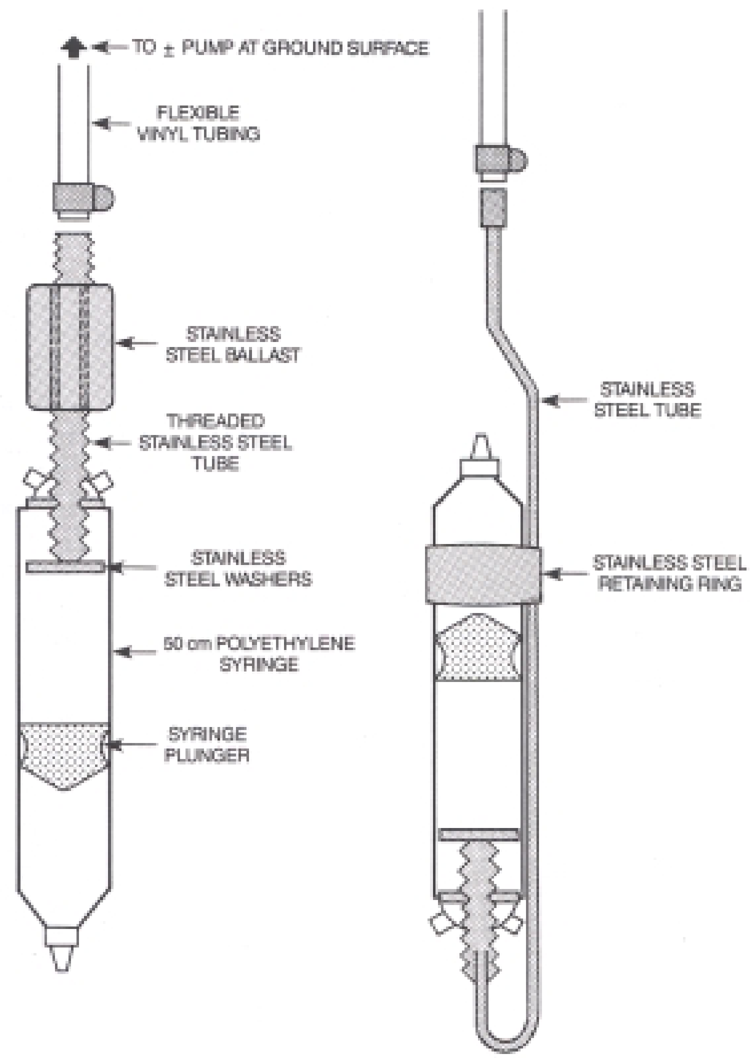
Sample bias can be introduced during transfer of the sample from the bailer to the sample containers. Sample aeration and volatilization/degassing of the sample can occur, which can be significant if analysis of volatile trace organics is of interest (Gillham et al., 1983). Bottom-draw bailers with dual check valves can minimize this source of sample bias (Barcelona et al., 1983).

Syringe Samplers Syringe samplers are similar to bailer samplers. They consist of a tube with a plunger that can be held in place by positive surface pressure (Figure 8.9). When the desired depth is reached, the pressure can be released behind the plunger allowing water to enter the sampler and the entire sampler can then be raised to the surface. In some cases, the sampler can be used as a storage container.



Adapted From: Gillham et al., 1983.

Figure 8.8
Typical Bailer Design



Adapted From: Gillham et al., 1982.

Figure 8.9
Syringe Sampler

This type of specialized sampler is most applicable for collecting ground water samples for trace volatile organic chemical analysis. The technique minimizes the potential for sample volatilization or degassing and contact with the atmosphere. However, it will likely require use in conjunction with other pumping techniques used to flush the well bore or to collect larger sample volumes.

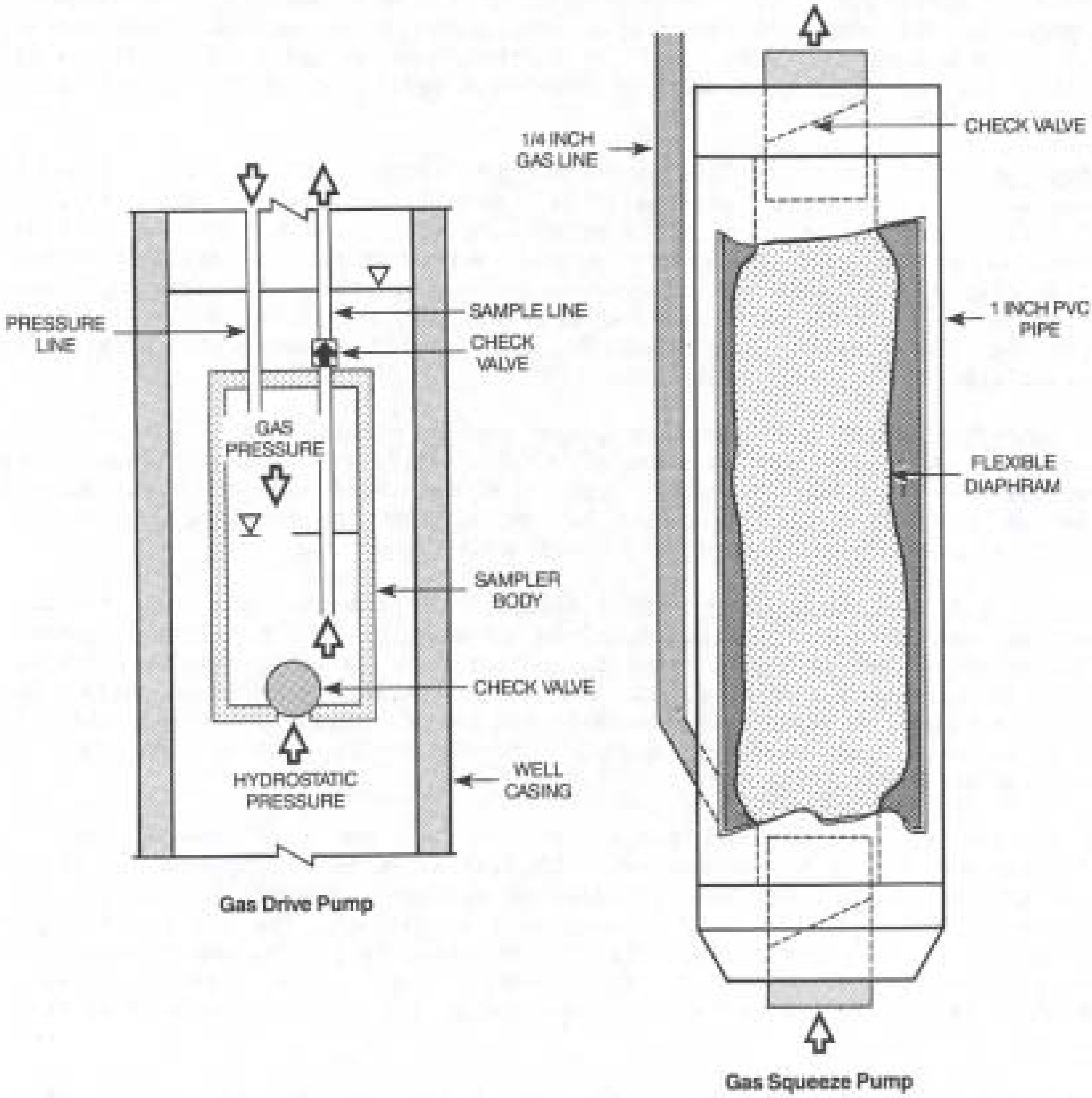
Suction Lift. Suction lift pumps include centrifugal or peristaltic- type pumps. These pumps are portable, readily available, and reliable. Centrifugal pumps can pump at rates of 5 to 40- gpm and can be used to flush well bores as well as obtain ground water samples. Peristaltic pumps typically are capable of low volume pumping suitable for sampling small diameter wells. The major disadvantages are that the technique is limited to pumping from depths less than 20 feet and the potential exists for volatilization or degassing.

Submersible Pumps. Submersible pumps are in general use in water supply wells. The pumps are capable of a wide variety of pumping rates from relatively deep depths. Pumps have been developed that will fit down a 2-inch diameter well. Their use may be limited for sampling for organic chemical analysis because of pump construction materials.

Positive Displacement Pumps. This category of pump uses positive pressure, usually compressed air or nitrogen, to force water from a sampling chamber. The drive gas may or may not come in contact with the water sample. Pumps may include submersible centrifugal and piston pumps, gas drive pumps, gas squeeze pumps, or gas operated submersible piston pumps. The pumps generally are portable, can be used in small diameter wells, and a wide range of pumping rates and lifts can be achieved.

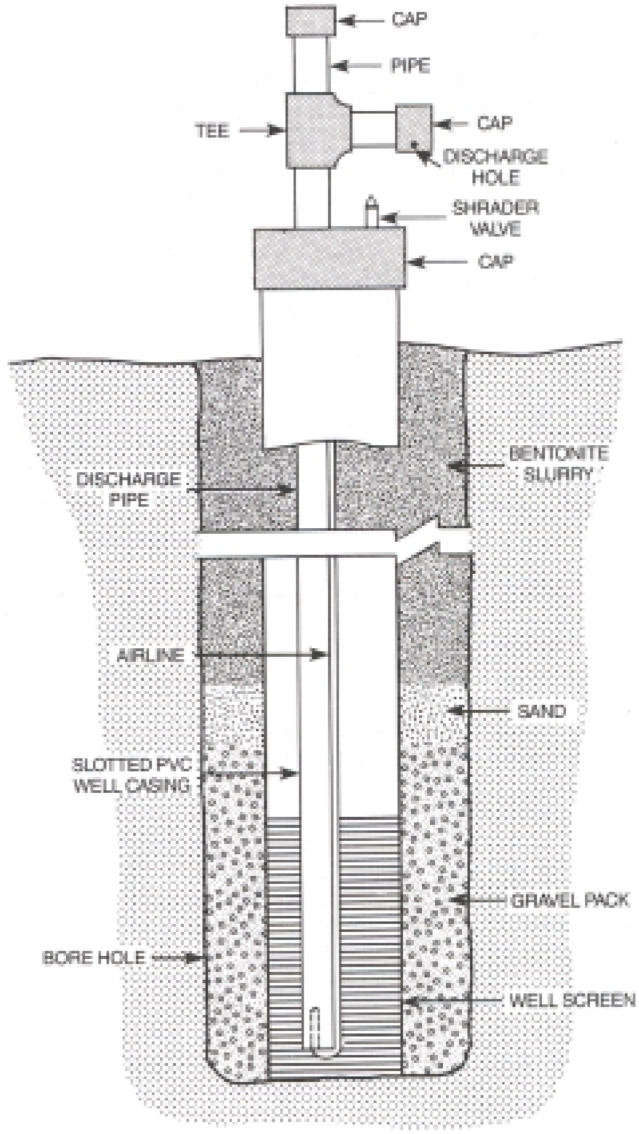
Gas-drive and gas-squeeze pumps are two of the more common positive displacement pumps in general use. The gas-drive pump (Figure 8.10) allows the gas to contact the sample, although the contact surface area to water volume is low. Little data is available to evaluate the effect on sample integrity of this gas contact (Gillham et al., 1983). The gas squeeze pump uses a similar technique as the gas-drive pump but a flexible internal bladder is used to prevent the gas from contacting the water samples as shown in Figure 8.10.

Compressed Gas Lift Samplers. Compressed gas can be used to lift water samples to the surface. A typical compressed gas lift pump installation is shown in Figure 8.11. Gas is used as a carrier and is discharged with the water leaving the well. The advantages of the technique are that the pumps are portable or can be permanently installed in the well and can be used to flush the well bore. However, a high potential exists for sample alteration, especially of pH-sensitive or volatile monitoring parameters..



Adapted From: Gillham et al., 1983 and Scalf et al., 1981.

Figure 8.10
Common Designs of Positive Displacement Pumps



Adapted From: Walker, 1974.

Figure 8.11
Gas-Lift Sampler

8.2.5.3 Sampling Frequency

The Minimum Functional Standards require that ground water samples be collected and analyzed on a quarterly basis and that the ground water flow rate and direction be reported on an annual basis. Sampling on a more frequent basis may be warranted based on several factors (EPA, 1977):

- The rate of ground water flow is the principal factor in selecting a sampling schedule. High ground water flow rate systems will generally require more frequent sampling as compared to relatively low-rate ground water flow systems.
- The distance and depth of the monitoring point from the landfill influence the sampling frequency. Sampling frequency would typically be greater the closer the sampling point is to the landfill. Distant sampling locations or deep wells may require periodic sampling to establish background water quality but would be sampled less frequently compared to closer or shallower sampling points.
- Sampling schedules can be correlated with ground water recharge periods when the potential for leachate generation is greatest. This scheduling consideration can be evaluated using a site water balance.
- Monitoring schedules should be flexible to account for data trends which may indicate that a modification to the sampling schedule is warranted.
- Legal and institutional data needs (such as for enforcement actions) may affect sampling frequency. For example, sampling wells on a quarterly basis is done to satisfy the requirements of the Minimum Functional Standards.
- Statistical procedure used to evaluate ground water quality data may require more samples.
- Good public relations may require more sampling.
- A high degree of risk or adverse effect if leachate contamination occurs may necessitate more sampling
- Significant climatological events, unusual operational occurrence (such as improper waste disposal), or the identification of another adjacent pollution source may increase monitoring frequency

8.2.5.4 Sample Collection, Preservation, Test Methods, and Storage

The appropriate sampling technique will depend on the monitoring objective and the monitoring parameters of interest. Prior to actually collecting the sample, the well bore should be flushed to remove stagnant water in the well casing. Stagnant water in the well may not be representative of the ground water quality conditions in the aquifer immediately adjacent to the well. During well bore flushing, on-site tests for pH and Eh can be made to assist in determining when a sample should be taken (Barcelona et al., 1983).

Typically, pumping 4 to 6 casing volumes should be adequate to flush the well bore. The Illinois Water Survey (Barcelona et al., 1983) recommends that at least 95% of the sampled water be from the aquifer. They present a technique to estimate pumping durations to achieve this objective. To use the method, it is necessary to determine aquifer transmissivity from pumping tests or slug tests.

Sample integrity can be seriously compromised by handling once it has been collected. Degassing and volatilizing, leaching and sorption, changes in pH and Eh, and microbiological activity can reduce or increase contaminant concentrations. Certain parameters should be directly measured in the field (pH, Eh) while other parameters require in-field sample filtration and sample pH adjustment (heavy metals).

Descriptions of sample volumes, appropriate containers, and preservation and storage procedures are contained in various publications (Scalf et al., 1983; U.S. EPA, 1979; U.S. EPA, 1982; APHA, 1981). The receiving laboratory is also a very good source of this information and usually provides the sample containers and preservatives.

Approved laboratory procedures should be used. The Minimum Functional Standards require that methods described in EPA publication SW-846 "Test Methods for Evaluating Solid Waste-Physical/Chemical Methods" be used for sampling constituents listed in Table 8.1 except for total coliform. For total coliform the method described in the latest edition of "Standard Methods for the Examination of Water and Waste Water" should be used. Analyses for interim primary drinking water standards should use the methods described in the code of Federal Regulations 40 CFR Part 141.

8.2.6 Quality Assurance (QA)

The Minimum Functional Standards require that a quality assurance plan be prepared as part of the ground water monitoring program. Environmental Protection Agency document OAMS-005/80 provides guidelines for plans prepared by and specifically for the agency and may be of some use in designing plans for landfill monitoring systems. The overall objective of a quality assurance plan is to- assure the precision, accuracy, completeness, and representation of project data are known and documented.

OA procedures should be implemented for all phases of a ground water monitoring program. Adequate training should be provided to those collecting the samples. Sampling procedures and sample handling should be documented in detail and the procedures should be reviewed on a periodic basis.

Field blanks and blind prepared samples can be used to check laboratory performance. Laboratory quality control procedures should be documented with the analytical results.

8.2.7 Chain of Custody

A chain of custody system should be established for all samples collected as part of a monitoring program. This system documents the origination of the sample containers through sample collection and completion of the chemical analyses. Most analytical laboratories have an established chain of custody systems, including appropriate forms and securable chests or coolers for sample transport.

8.2.8 Laboratory Selection

The selection of a qualified laboratory is an important aspect of an environmental monitoring program. Factors which should be considered in this process include:

- Analytical method capabilities
- Performance with respect to established standards
- Documentation of analytical methods in reporting results,
- Turn-around time for results

Some guidance on laboratory selection may be made based on laboratory participation in the EPA contact laboratory program or laboratory audits conducted by the Army Corps of Engineers or other agencies. It is very important that the laboratory have a quality assurance program that is consistent with accepted practices. Data from the laboratory will be used to assess environmental risk and may be used in legal actions.

8.2.9 Records and Data Reporting

Complete sampling records from the field and laboratory are an essential part of a monitoring program. Appropriate field forms should allow convenient recording of key sampling information, including sample number, location, date and time, weather conditions, field measurements, field observations, method of collecting the sample, and preservatives added. The laboratory should document the analytical methods used, quality assurance testing, instrument calibration, monitoring parameter concentration and detection limits. The chain of custody form should be included in the laboratory report.

As with all data associated with environmentally sensitive projects, the possibility exists that the data and records will be used to support court actions. This should be recognized at the on-set of a project and an appropriate project documentation system should be set up.

8.2.10 Data Interpretation

Ground water quality monitoring data is used to determine whether a landfill has caused:

- A monitoring parameter to increase in concentration

- "Contamination" of ground water as defined in WAC 173-304-100

It is possible that a monitoring parameter concentration may increase, but not "contaminant" ground water according to the regulatory definition. In either case, it is required that the data be reported in a timely fashion as specified in the Standards, which. may trigger additional sampling and analysis and/or development and implementation of a corrective action program.

The definition of "contamination" in the Minimum Functional Standards require that the data be interpreted in a more complicated fashion than just comparing water quality data to a set of water quality standards. Water quality data is to be statistically analyzed to determine whether a "significant increase over background has occurred".

Background concentrations are defined by sampling well(s) located upgradient of existing landfills, or by sampling and analyzing all in-place wells before startup of new landfills. Usually one to two years of quarterly monitoring data are required to define the average (mean) concentration and the variability of the concentration and the variability of the concentrations about the average (variance or standard deviation). The actual number of sample analysis required to achieve a given confidence level will depend on the degree of variability within the sample set. Sample variability can be caused by variations in the geohydrologic system (such as recharge and fluctuating water tables), sampling, and analytical procedures among others.

A specific statistical procedure is not prescribed in the Minimum Functional Standards. A procedure is to be approved by the jurisdictional health department with the guidance of Ecology.

A variety of statistical methods are available to statistically interpret ground water quality data (Geotrans, 1983). The procedures to be used should be developed by persons who are familiar with both geohydrology and statistics. Several researchers (Miller and Kohout, 1984), who evaluated the "Student t Test" specified in the federal RCRA regulations, have demonstrated that improper application of a statistical test can result in positive indications of contamination when, in fact, no contamination has occurred. It is for this reason that repetitive sampling is required if the initial sample indicates a significant increase. Repetitive sampling greatly reduces the risk of a false positive indication. If the Student t Test proves to be too powerful, non-parametric statistical tests should be attempted.

Interpretation of ground water quality data should not only include evaluation of the chemical concentration data but should also consider physical data such as well water level measurements, and geohydrology of the area. Using this data will assist in evaluating whether the landfill has actually affected ground water quality should the statistical procedure indicate that a monitoring parameter has increased.

Should the statistical procedure indicate that a significant concentration increase of a monitoring parameter has occurred, the concentration data should be compared with the criteria defining "contamination". In the context of the landfill standards, "contaminate" is defined as:

- The concentration of the substance (monitoring parameter) in ground water exceeds the maximum contaminant levels (MCL's) specified in WAC 173-304-9901 (see monitoring parameters Section 8.2.4)

- A statistically significant concentration increase has occurred in downgradient wells compared to upgradient wells for substances where the existing concentration of that substance exceeds the MCL's specified in section 9901

- A statistically significant concentration increase has occurred in a substance not specified in VAC 173-304-9901, but is present in the solid waste and has been determined to present a substantial risk to human health or the environment in the concentrations found at the point of compliance

8.2.11 Earth Resistivity Monitoring

The basic principles of earth- resistivity monitoring are discussed in Appendix 4A of this manual. This technique can be used at solid waste landfills to assess the probable position of a contaminant plume or to monitor changes in water quality with time. Since changes in earth resistivity can also be caused by variations in geologic properties as well as water quality, a knowledge of the geohydrologic system is required to establish the applicability of the method and to interpret the results. In this regard, electrical earth resistivity networks are most effective when used in conjunction with monitoring wells.

8.3 VADOSE (UNSATURATED) ZONE MONITORING

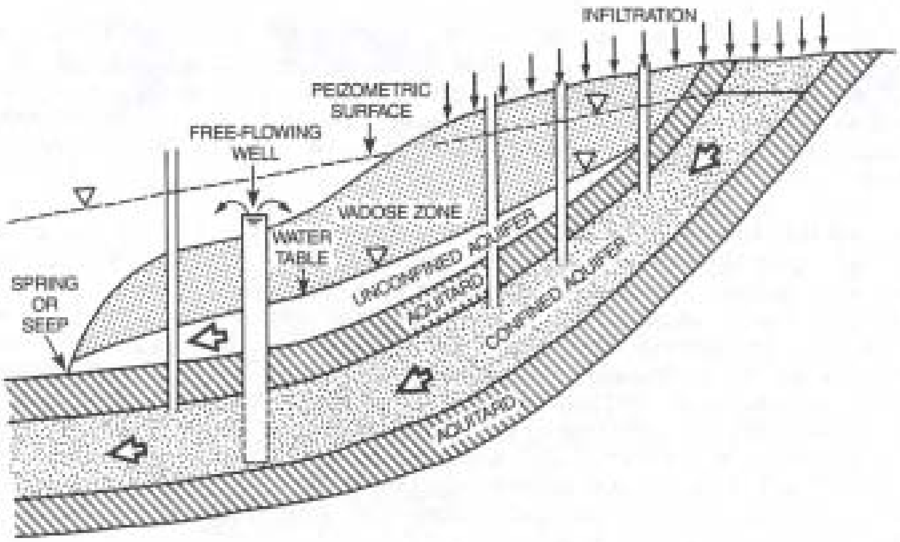
8.3.1 Definition

Vadose (unsaturated) zone monitoring is conducted between the bottom of the landfill and the water table to detect the presence of landfill leachate. Vadose zone soils may be dry, moist, damp or even wet. However, they are not water bearing as regional aquifers are commonly called..

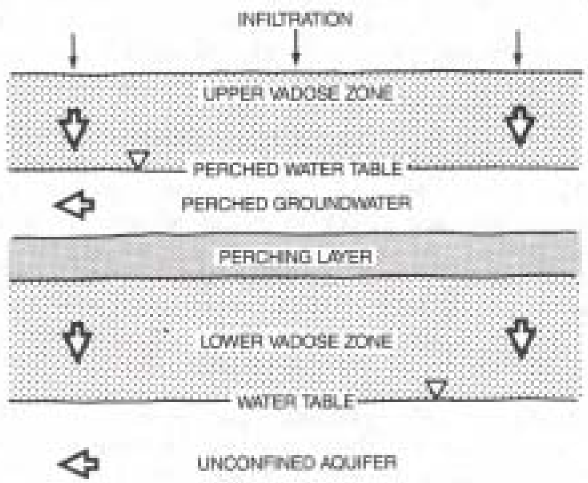
8.3.2 Water Flow in the Vadose Zone

8.3-2.1 <u>Dynamic Approach</u>

Water first enters the ground through infiltration (Figure 8.12). During and soon after a' precipitation event, water in the ground is usually concentrated in a saturated or very wet zone the surface. In the hours following precipitation, tension forces in the soil distribute the water over a larger



Schematic of Vadose Zone, and Unconfined and Confined Aquifer



Perched Groundwater Due to Infiltration Into Soil With Restricting Layer

**Figure 8.12
Groundwater Flow in
Aquifers and Vadose Zones**

Direction of Groundwater Flow

thickness of soil, similar to water spreading from a wet to a dry sponge until both sponges have similar moisture content. Therefore, in most soils beyond a depth of several feet, changes in moisture from precipitation events or seasons tend to be relatively minor compared to the large changes at ground surface. Soils at depth tend to have relatively constant moisture content.

After tension forces have equalized moisture distribution in the ground, the force of gravity tends to move the moisture slowly downward, while evapotranspiration at ground surface tends to move the water upward. The effect of evapotranspiration is very strong, but limited to the upper few feet of soil penetrated by plant roots. Below the plant root zone, the gravity force will usually predominate and water will move downward. The moisture at depth is still under tension (the opposite of pressure), but under steady state conditions (not influenced by precipitation), there is little difference between the tension from one soil zone to the next. Therefore, the tension component of the hydraulic gradient is relatively small. The net effect is that below the root zone water tends to move downward when averaged over a year.

Water tends to move more slowly in the vadose zone than in aquifers because water can only move through the films of water that surround the soil particles. This condition causes the unsaturated permeability of given soil to always be less than the saturated permeability. The thickness of water films may increase as additional water from precipitation infiltrates the soil, but rarely equals the size of the pores. Maximum permeability of any soil exists when all the pore space is filled with water (saturated), such as below the water table.

Changes in soil type in the vadose zone influence permeability and rate of water flow in unexpected ways. For instance, the permeability of saturated gravels is usually high, but an unsaturated gravel may have very low permeability to water because relatively few water films surround the large (but not numerous) gravel particles. A saturated silt or clay on the other hand has a low permeability, and the permeability of each under unsaturated conditions decreases relatively little because of the numerous water films surrounding the tiny soil particles. Under unsaturated conditions, it is possible to have a silt that is more permeable than a gravel.

Unsaturated permeability of various geologic materials has important implications for monitoring in the vadose zone, where extraction of a water sample is at best difficult. It also has important implications to backfilling borings around vadose zone monitoring devices. The usual approach to backfilling around wells (installing well seals) is to use clay and cement. However, for vadose installations, it may be advisable to consider gravel layers in the seal, or to use native soil materials.

In a sequence of unsaturated soil layers, fine-grained layers are commonly wetter than coarse-grained layers. This can be verified by measurements of moisture content. Differences in moisture content occur under steady state conditions because fine-grained soils have more surface area and smaller pores than coarse-grained soils. The water has greater affinity for the fine-grained soil, bound to its larger surface area by surface tension. The less water that a soil contains, the greater the tension under which that water is held. In the absence of both gravitational effects and differences in tension between soil layers, the layer with finer grains will have greater moisture content. Conversely, if two layers of differing grain size have the same moisture content, they will likely have different tensions. 'Water will be flowing from the layer with the lesser tension (coarser) to the layer with the greater tension (finer), again assuming no gravitational effects. . The tension of the soil at monitoring locations will influence the choice of technique. For instance, one popular vadose zone monitoring technique is lysimetry. However, lysimeters are limited in their ability to extract samples from soils at tensions of more than one or two atmospheres.

The discussion above is based on the simplest cases of vadose zone f low
Many additional phenomena can occur besides slow, uniform, steady downward flow, and some of these are important to monitoring. Infiltrating ground water can perch on relatively impermeable layers and cause saturated conditions to develop (Figure 8.12). These perched zones are usually thin, may be seasonal or may occur only in response to unusual infiltration events. Water in perched aquifers often flows faster horizontally than vertically and this can influence the optimal location of monitoring devices.

Water can also accumulate above an unsaturated coarse-grained layer because of its low hydraulic conductivity. In these cases, when water saturates finer-grained soils overlying a coarse-grained layer, the water is sometimes suddenly forced into the large pores of the coarse layer, leaving adjacent areas of the coarse-grained soil relatively dry. This phenomenon is termed fingering. Placement of a monitoring device in coarse-grained soil should be avoided, because a finger could develop some distance away from it and remain undetected.

8.3.2.2 Field Capacity Approaches

In some instances, flow of water in the vadose zone can be predicted using a concept commonly referred to as field capacity. Field capacity is defined as the amount of water remaining in soil two or three days after the soil has been saturated during which time free gravity drainage has occurred. This approach assumes that no water flow occurs at moisture contents below field capacity and distinguishes between free water (in large pores that drain easily), capillary water (in small pores that remain after drainage), and other categories of water in the soil. Actually, these categories represent water held in soil under different potential energy ranges. However, in the case of water and leachate movement in soil, the range of potential energy is continuous, from the high volumes expected during wet conditions to low volumes in dry conditions. Therefore, the field capacity approach to calculating water movement in the vadose zone is commonly not utilized because a significant portion of water flow can sometimes occur at moisture contents below field capacity. Discussions of leachate generation and water balances (see Section 4.10) are handled by the field capacity approach because of their simplicity and acceptable accuracy for those calculations.

8.3.3 Sampling Point Density

Most of the monitoring devices discussed in the following sections have relatively small radii of influence (at most several feet, except for the four electrode method). This, coupled with the large areal extent of landfills, means that very large numbers of installations would be required to monitor 100% of -the landfill bottom area. Fortunately for monitoring purposes, most plumes develop over large regions of a landfill and not at one tiny point. Theoretically, one monitoring device within the region developing leachate is sufficient to provide detection.

Figure 8.13 presents relationships between the detector spacing (assuming a square installation pattern of point measurement devices), the size of the leachate plume in the vadose zone at the depth of the detectors (assuming a round plume), and the probability of detecting the leachate (Savinski, 1965). When determining the appropriate spacing, it is necessary to know the leachate plume size and the acceptable probability of detection.

The relative benefits of decreasing detector spacing becomes less at about 80 to 90 percent detection probability, the upper limit appropriate for most landfills. Assuming 80 to 90 percent detection probability as a goal, the question of appropriate detector spacing is only dependent on the size of the plume that is expected.

It is recommended that for medium to large landfills (greater than 10 acres), plume sizes be assumed to be 300 to 800 feet in diameter. Referring to Figure 8.13, detectors should be about 300 to 800 feet apart in a square pattern.

Relatively large plume sizes (and therefore large detector spacings) are appropriate for landfills where the arid liner design will be used because they will not be lined and the probability of point-source leachate generation is small.

Research in England indicates that over a limited area of a new municipal landfill, gas and leachate generation were uniform enough to influence all installed vadose zone monitoring devices, although different migration rates were indicated (Lucas and Robinson, 1983). Leachate migration from an existing landfill in Canada was modeled assuming uniform leachate generation rates over the entire landfill (Sykes, et. al., 1982). The landfill was extensively monitored and the monitoring data apparently supported the uniform leachate generation assumption. The modelers reasoned that leachate generation rates for all wastes placed above the seasonal high water table should be relatively uniform and dependent on the amount of precipitation that percolates into the waste.

The regions of a landfill identified during the hydrogeologic characterization to be most prone to leachate should be targeted for detector installation. These could include low areas where water accumulates and infiltrates, areas where low permeability soils or rocks were removed in preparation for filling, areas of liquid waste or sludge disposal or areas that were filled with solid waste during wet periods.

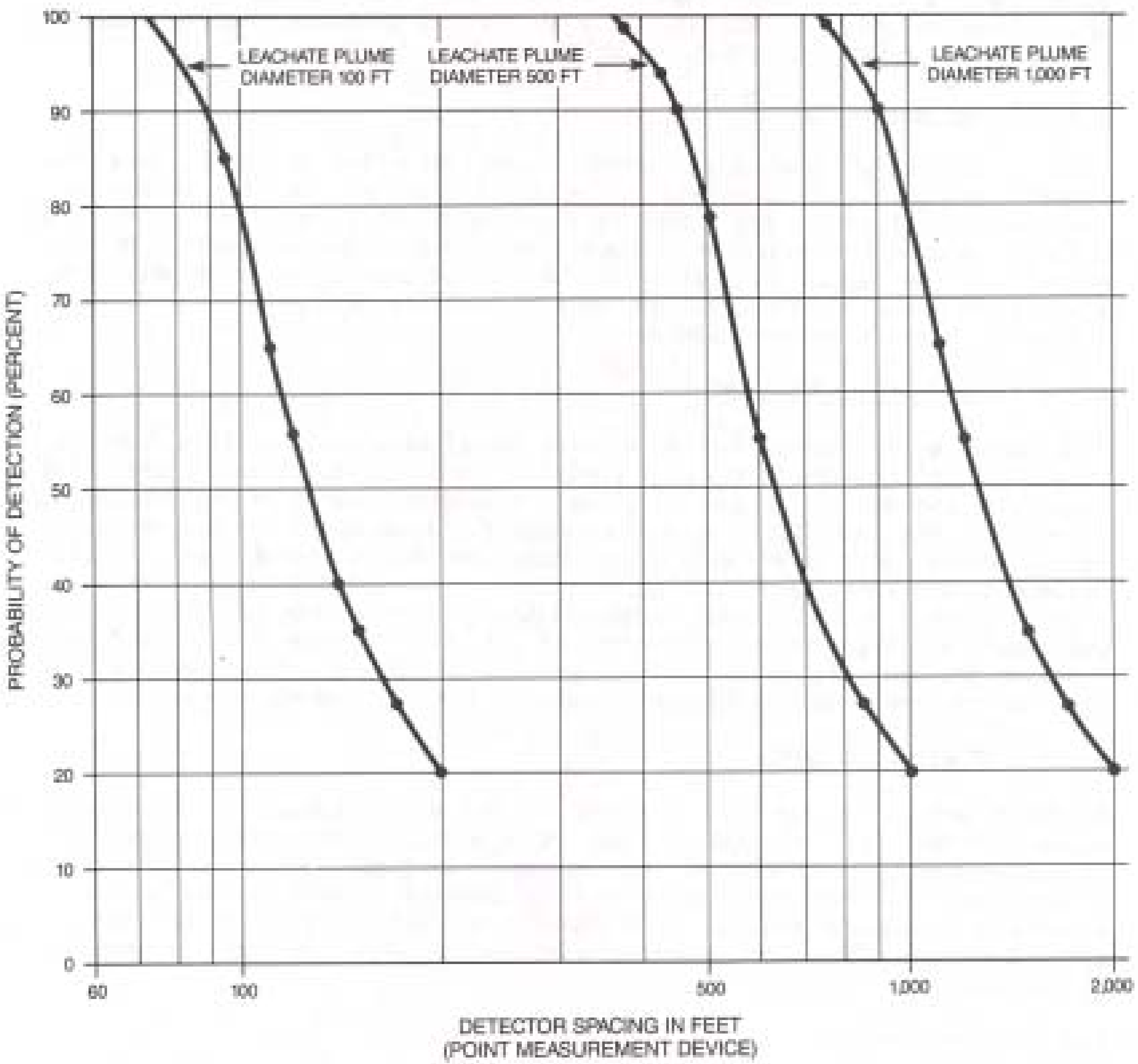


Figure 8.13
Probability of detecting a leachate plume in the vadose zone with point measurement devices.

8.3.4 Approach to Monitoring System Design

Three categories of vadose zone monitoring are described in this section. The categories are differentiated by type of data generated and how directly the data can be used to detect the presence of leachate.

8.3.4.1 Direct Method

Direct methods of monitoring involve the collection of soil water for chemical analysis. Samples are collected at the same location through the same device each time. The method is the most direct of the three monitoring methods because the essential property of leachate is chemistry and this method provides samples of soil water that can be chemically analyzed. Also, minimal judgment is required to relate possible changes in soil water chemistry to performance standards.

8.3.4.2 Semi-Direct Methods

Semi-direct methods involve chemical analyses of samples other than pure soil water. A typical example is total chemistry of a wet soil sample (containing both water and soil). In soil sampling, successive samples are not collected at exactly the same location nor through the same device. Another semi-direct method is soil gas monitoring where the air is pumped from the soil, collected, and chemically analyzed to infer the presence of aqueous leachate. These methods are semi-direct because although direct chemical analyses are performed, a calculation or estimation of soil water chemistry must performed based on the analysis of the soil or gas sample. These methods provide data one step removed from data directly comparable to performance standards.

8.3.4.3 Indirect Methods

Indirect methods measure a parameter of the earth sensitive to chemical changes in soil water chemistry; however, no actual chemistry is analyzed. A typical example is electrical resistivity. Indirect methods require more calibration than the other catagories in order to correlate the parameter measurement to expected soil water chemistry. They therefore require the most effort to relate the parameter measurement to ground water performance standards.

8.3.5 Direct Method

The technique of direct vadose zone soil water quality monitoring is lysimetry. The technique is relatively expensive for coverage of large areas and may not work well in relatively dry soils which are common in arid environments. For these reasons, a detailed discussion of lysimetry is referred to Appendix 8A. The technique may still be appropriate for specific cases in arid environments, or in non-arid environments if vadose zone monitoring is attempted there.

8.3.6 Semi-Direct Methods

8.3-6.1 Soil Sampling

Drilling into the soils beneath a potential contamination source and collecting samples of the soil for chemical analyses is a very common way of identifying the presence of leachate. The same approach can be used at landfills to detect the presence of leachate or to verify the results of indirect methods.

A drilling rig is usually used to advance a boring into the soils to be sampled. Depending on soil type, one of several different soil sampling tools is lowered into the boring and driven, pushed, or cored into the undisturbed soils beneath the boring. The soil sample is then retrieved and the hole advanced to the next sampling depth. When finished, the borings are either converted into monitoring wells, other monitoring devices, or backfilled with low permeability materials.

Although boreholes can be advanced through garbage of existing landfills, precautions must be taken to prevent drawdown of solid waste or leachate. Angled boreholes drilled from the edge of the fill are another way of accessing soil directly beneath a landfill. This requires special drilling equipment and is likely to be more expensive.

The number of soil samples required to make a reasonably assured decision on the presence of leachate is usually larger than the number of measurements required for direct technique. This is because the natural variability of soil chemistry is very high and a large number of samples is often required to distinguish contaminated from uncontaminated soils. The number of samples required per acre can range from a couple to many tens. The samples should be collected from several boreholes spaced throughout the landfill and at different depths in each borehole. Usually, relatively fine-grained soil horizons are targeted for sampling. Screening tests such as pH, specific conductivity, or head space organic vapor concentration can. be used to identify samples most likely affected by leachate. These samples would generally be selected for further chemical analyses.

An area separate from, but with similar soil properties as the landfill, should be identified as a control area. Soil samples should be taken in this area in the same fashion as beneath the landfill and analyzed for the same parameters. The difference in chemistry between the natural soil (control) and landfill soil can be analyzed to assess whether leachate is present. Data from the control area could also be used to refine the performance standard for indirect methods over the years of monitoring.

Chemical analysis of soil samples requires extraction of the chemicals from the soil solution and conversion into pure liquid form before the actual determination of concentration can be made. There are different types of extraction procedures and each is designed to -extract a different portion of the chemicals in the combined soil-soil solution sample. The best extraction procedure for measurement of leachate presence would extract only the chemicals contained in the soil solution without affecting the equilibrium between the soil and soil solution. Unfortunately, no such extraction procedure exists. One technique that comes close to extracting only water soluble (and therefore only soil solution) chemicals is the U.S. EPA "Elutriate Procedure", commonly called 11EP Toxicity Test". A modification of this test might be appropriate for landfill monitoring. This type of extraction is most suited to naturally occurring ions such as nitrate, sulfate, and numerous metals because these are the chemicals which vary greatly in natural soils (and it is desirable to eliminate the variable of natural soil variation). Analyses for exotic organic chemicals could be performed using a more complete extraction procedure because natural soils have no background for these chemicals and any such chemicals in soil beneath a landfill may indicate the presence of leachate. In any case, careful consideration of the type of extraction procedure is warranted.

The advantages of soil sampling include a well understood and locally available technology and applicability in nearly all hydrogeologic environments. Disadvantages include the necessity of mobilizing drilling equipment every time sampling is conducted, difficulty in accessing soil below existing landfills and natural soil chemistry variability.

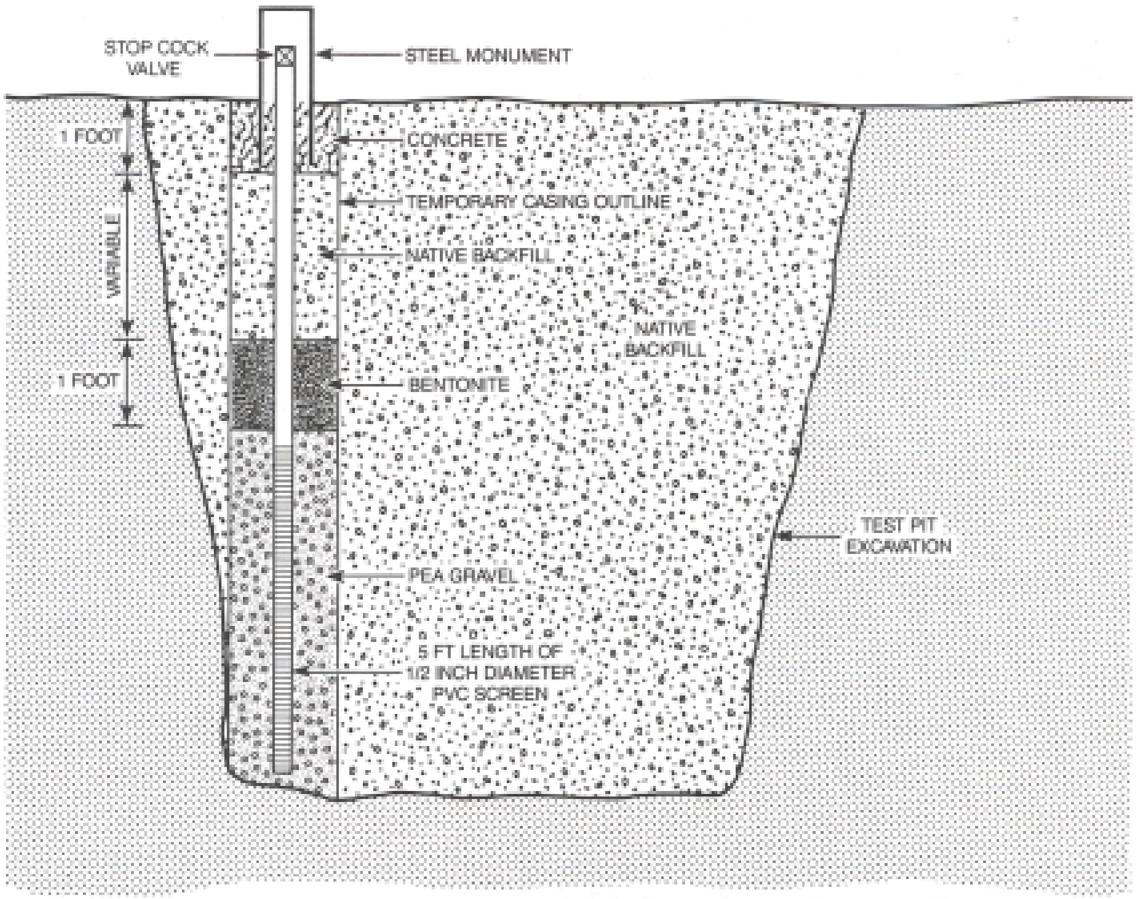
The technique is probably best suited for verification of results of other methods. For instance, if another technique indicated the presence of leachate, samples of soil might be collected for verification. This use is discussed further in Section 8.3.7. Soil sampling should also be conducted while drilling borings for installation of other monitoring techniques.

8.3-6.2 <u>Soil Gas Monitoring</u>

Contaminants in the ground are distributed between the solid soil particles soil solution (water), and soil gas. These are called the "phases" in which the contaminants can occur. Each chemical will tend to distribute in unique proportions between the three phases. For chemicals tending to favor the gas phase (volatile compounds), samples of soil gas can be collected to infer the presence of leachate. This soil gas monitoring method is considered semi-direct because chemical analyses are performed, but no direct measurement of soil solution concentration is made.

The 'method consists of installing probes into the vadose zone. The probes are constructed like monitoring wells, but with the well screens placed above the water table (Figure 8.14). They are typically made of PVC and are three-quarter or one inch in diameter with screen lengths of five to ten feet. Probes installed for methane monitoring below the fill or laterally away from the fill may be used.

Gas probes should be placed in areas of the vadose zone where leachate migration would likely occur when intended to detect leachate presence. It is recommended that vadose monitoring programs include installation and monitoring of control devices to act as a control on sampling and climatic changes. They should be installed and monitored in the same fashion as units below the landfill and placed in an area where no filling or other activity could affect monitoring results.



Note: Installations can also be made in borings.

Figure 8.14
Typical Gas Probe Installation in Test Pit

Samples are collected by pumping air out of the probe directly into analysis devices or in packed columns or bags that can be taken to a laboratory for analysis. Other gas parameters can be measured directly in the field and include oxygen, hydrogen sulfide, and methane.

Gas monitoring can detect the presence of volatile organic compounds that are difficult to detect by indirect means. For instance, soil resistivity is not affected by moderate concentrations of organic chemicals. Although volatile organic compounds are not specified as monitoring parameters in WAC 173-304, they could be required as additional parameters if the history of waste deposition indicated their likely presence. The technique would usually be used in conjunction with a method to verify the presence of leachate, such as soil and or ground water sampling.

8.3.7 Indirect Methods

8.3.7.1 Background

Discussion of indirect monitoring techniques will focus on two properties of soil that may change in the presence of leachate. These properties are moisture content and electrical conductivity. Moisture content of soils in the path of leachate migration may increase because of an increase in infiltration associated with placement of wet fill, ponding in low areas of excavations, or from consolidation of clays under the fill. Increases or cyclic changes in moisture content can also occur from natural causes and for this reason moisture content measurements need to be used in conjunction with other methods.

The electrical conductivity of the soil will increase when leachate containing an abnormally high concentration of ions flows into an area. Where moisture content increase is expected, electrical conductivity techniques should probably be used in conjunction with moisture content techniques because electrical conductivity will also increase if the moisture content increases. Electrical conductivity techniques include resistivity, because resistivity is the inverse of conductivity.

Because of the difficulty in verifying indirect techniques,-it is recommended that duplication be built into the monitoring systems, such as installing more than one monitoring device at each monitoring location.

8.3.7.2 Resistance Blocks

Resistance blocks are small blocks placed in boreholes and kept in close contact with the soil so that moisture and chemicals pass between the soil and the block (Figure 8.15). Two metal wires, plates, or cylinders embedded within the block serve as electrodes. An electrical voltage difference is placed across the electrodes causing electric current to flow. The amount of current that flows depends on the configuration of the electrodes and the resistance (or conductivity) of the solution in the block. The probe is sensitive to the presence of leachate because leachate is generally more conductive than natural infiltrating water.

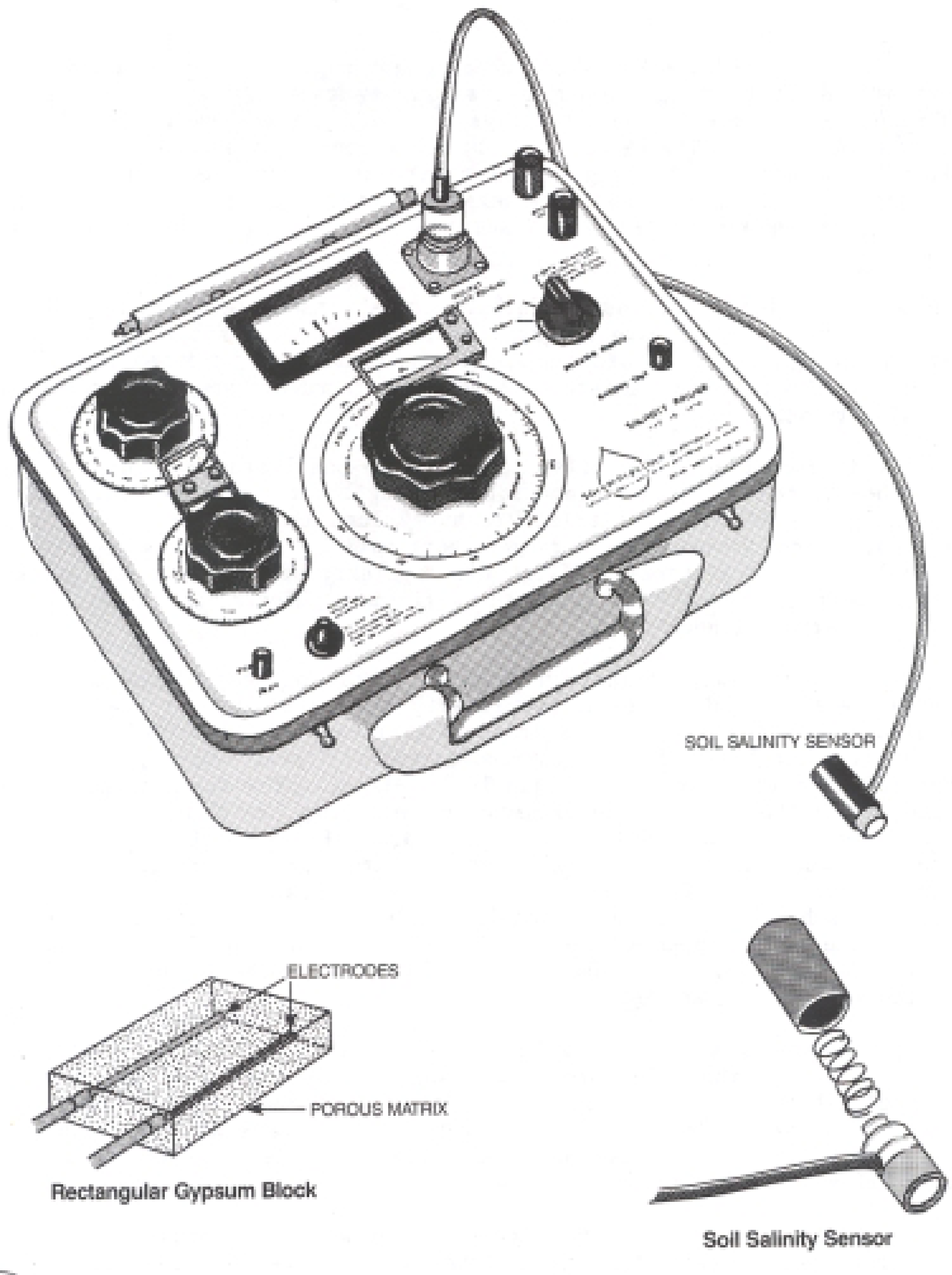


Figure 8.15
Resistivity Blocks

Several types of blocks have been used. Buffered blocks are usually made of gypsum. Because the gypsum dissolves slowly over a few years, the water surrounding the electrodes is always very conductive and relatively small changes in conductivity resulting from other sources are damped out (such as might occur because of changes in natural water conductivity or leachate). The buffered probes are therefore sensitive to changes in water content, but not water conductivity (salinity) and are sometimes referred to as moisture blocks.

Non-buffered blocks are made of other porous, insoluble material. They do not dissolve and thus have longer lives. They are sensitive to changes in both water content and water conductivity (salinity) because they are not buffered. Non-buffered resistance blocks are therefore sometimes referred to as salinity sensors.

Many resistance blocks are often installed in one borehole. This technique might be particularly appropriate for existing landfills 'Where monitoring the downward movement of an existing leachate plume through the vadose zone is desired. The probes are arranged horizontally within the borehole or borehole sidewall previously filled with a slurry of fine sand and water. A single borehole should accommodate resistance blocks and other desired instrumentation if necessary.

The depth of placement below the landfill should be deep enough to minimize seasonal effects and local changes in soil water quality, but shallow enough to allow early recognition of a leachate problem. Placement only a few feet above the water table is not recommended because direct sampling ground water monitoring wells could just as easily be placed. The distribution of soil types should be strongly considered in selecting the depth of placement. Relatively fine-grained soils are recommended. In areas of shallow bedrock, such as in certain areas of the Columbia Plateau, placement of probes above bedrock may not be possible. In these cases, zones of the bedrock, such as interflow ash beds or old buried soil horizons, should be identified and used for placement. In mountain areas with non-layered bedrock, zones that are finely fractured should be used. Installation of control devices away from the landfill is recommended.

Resistance blocks work best in relatively wet soil conditions and their applicability to the drier areas of Washington State is not assured. Non-buffered fiberglass blocks may provide the widest range of applicability in the drier ranges. Gypsum moisture blocks are not recommended for long term monitoring purposes because of their limited life . expectancy and poor suitability to dry soil where most vadose monitoring will likely occur.

One limitation of resistance blocks includes insensitivity to leachate containing only organic compounds (that do not change soil resistivity). Another drawback is the small sample volume. The moisture in the block will be in equilibrium with a small sample of the natural soil and borehole backfill materials that surround it. The small-sample volume increases the chances that the sample properties are not representative of overall soil properties.

Use of resistance blocks requires calibration if quantitative assessments are to be made with the data. Calibration consists of relating the resistivity reading of the sensor to the moisture content of the soil and the salinity of the soil water. This can be accomplished in the laboratory using a representative sensor, a soil sample from intended installation horizons, a pressure plate soil moisture extractor and solutions of varying salinity.

As with other indirect methods, the level of effort required for calibration of the sensors and development of performance standards related to potential ground water contamination is relatively high. The best use of these indirect methods is for routine monitoring, with verification by soil sampling if the performance standard is exceeded.

8.3.7.3 Four Electrode Method

The four electrode method is a well-established geophysical exploration technique that has numerous variations. One variation well suited to monitoring in the vadose zone below landfills involves burying four electrodes beneath the landfill with relatively short spacing, as shown in Figure 8.16. If many sets of electrodes are installed, the possible combinations of arrays that could be used for monitoring becomes very large and monitoring confidence would be increased (Figure 8.16).

The outside two electrodes (A and B) supply current to the ground and the inner two electrodes (M and N) are used to measure the voltage drop between the two inner electrode locations. The response of the system would be similar to the resistance blocks; as leachate enters the region monitored by the installation, the resistivity of the soil-soil. solution will decrease because of the increased electrical conductivity of the leachate.

Electrodes should be placed beneath the landfill in areas of potential leachate generation and infiltration. They should generally be placed by advancing a boring to the maximum electrode depth, installing the lowest electrode, backfilling the boring to the location of the next highest electrode, installing the second electrode and so on. Backfilling materials and procedures should ensure that accelerated downward migration of leachate is not caused by the presence of the borehole. Use of both fine-grained and coarse-grained materials may be appropriate.

The relationship of electrode spacing to electrode depth will be critical in assuring that the system monitors only for leachate migration in the soil of the vadose zone. The addition of fill materials and changes in land surface configuration could change the resistivity read by the electrodes if they are not deep enough or if the electrodes are too far apart. The farther apart electrodes are, the larger the monitoring zone. Optimal electrode depths, spacing, electrical currents, necessary number of electrodes and other factors must be established based on site specific conditions. Installation of control devices is recommended.

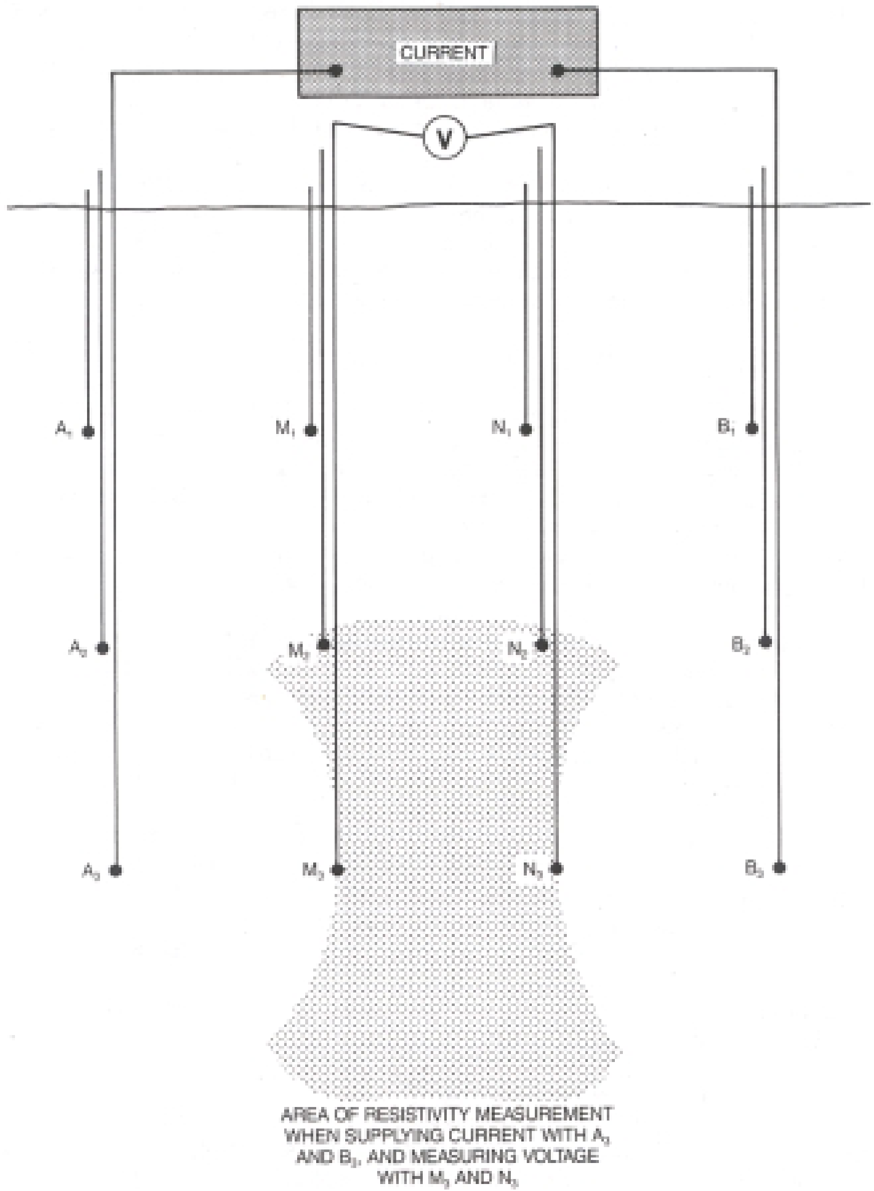


Figure 8.16
Four Electrode Method

one advantage of the four electrode method over resistance blocks is the sample size. The effective sample size in the four electrode method is on the same order as the spacing of the two voltage electrodes (many feet or more), whereas the sample volume of the resistivity blocks is much smaller. This could be important in areas where leachate migration downward in the vadose zone is uneven. In these cases the larger sample volume of the four electrode method may enable it to detect leachate migration occurring some distance from the electrodes. However, the method may not be effective in identifying fingering leachate that occupies only a small volume.

Requirements of site characterization, calibration, and theoretical relationship of resistivity readings to possible ground water contamination are similar to those for the resistance blocks and other indirect methods. Laboratory work, as discussed under resistance blocks calibration, should be augmented by field scale trials because of the large sample volume of the four electrode array. Because the soil resistivity is sensitive to both moisture content and salinity, the resistivity techniques may require simultaneous monitoring of moisture content in addition to resistivity. This will allow identification of increases in soil salinity alone, which is the desired leachate indicator.

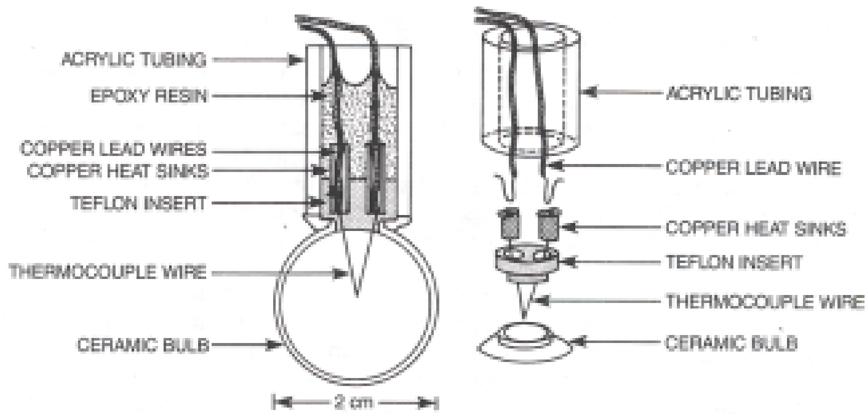
8.3-7.4 Psychrometers

A psychrometer is a small device installed in a borehole to measure soil moisture potential in the dry range (Figure 8.17). The instrument measures the sum of the soil tension potential and the osmotic potential of the soil solution. This is an important distinction for vadose monitoring because changes accompanying the movement of leachate into a soil zone include possible increases in moisture content and soil solution salinity. The effects of an increase in soil moisture content (reduction in soil moisture tension potential) and simultaneous increase in soil solution salinity (increase in osmotic potential) will tend to offset each other. For this reason, the likelihood of both of these occurrences happening, and their relative impacts on psychrometer readings must be assessed on a site specific basis.

Soil psychrometers contain a chamber where air comes to equilibrium with the potential of the surrounding soil. The humidity of the air within the chamber increases as the soil gets wetter and decreases as the soil gets saltier. Two wires are strung through the chamber; one is cooled such that water condenses on it and then evaporates. The characteristics of the condensation and cooling of the wet wire compared to the temperature of the dry wire are related to soil moisture potential. This can be related to soil moisture content if the osmotic potential is known. Measurements are taken by connecting a control box to a set of wires at land surface.

Calibration of psychrometers involves use of baths of different salinity and temperature. Calibration is performed in the laboratory.

Boreholes are installed by drilling or by installation methods similar to other point measurement devices. Hollow stem augers or other techniques where water is not required are preferred. The psychrometers can be



Soil Psychrometer (After Rawlins and Dalton, 1967)

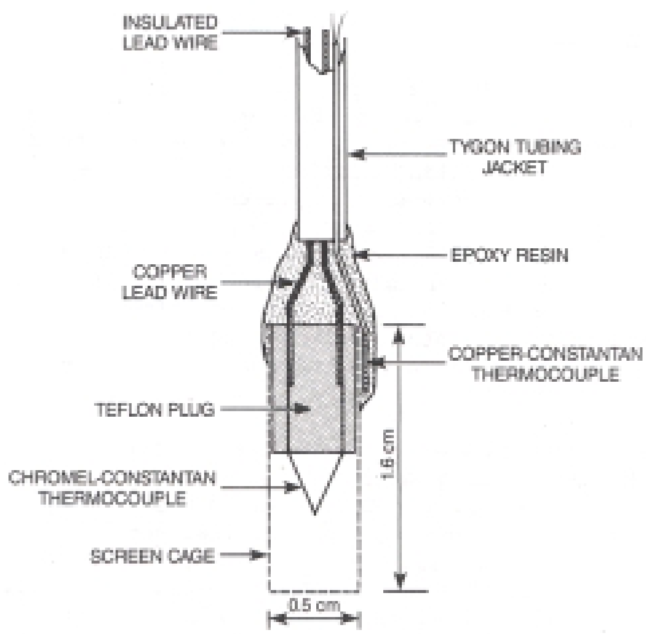


Figure 8.17
Soil Psychrometers

installed at the bottom of PVC riser pipes that protect the lead wires running to ground surface. Many such installations could be in one borehole. Backfill materials should be a combination of native materials, densified to native conditions or greater, and bentonite and gravel plugs to prevent the borehole from becoming a preferred route of leachate migration.

Installation should be below the landfill in areas of expected leachate migration. Optimal soil type and depths are the same as for other point measurement devices, and control devices are recommended.

Psychrometers are one of the few in-situ devices that work for monitoring moisture content in dry soils and they are therefore suited for use in the arid central and eastern portions of Washington where most vadose zone monitoring is likely to occur. They could be used to monitor increases in salinity if the moisture content remains fairly constant, or could be used to measure moisture content if the soil solution remains fairly constant in salinity. However, careful assessment of their response under changing moisture and salinity conditions must be made on a site specific basis if both of these changes are expected. Also, experience with very long term (years) installations is scant and discouraging. Calibration and sensitivity of the instruments may change over time as a result of salt buildup on the wires.

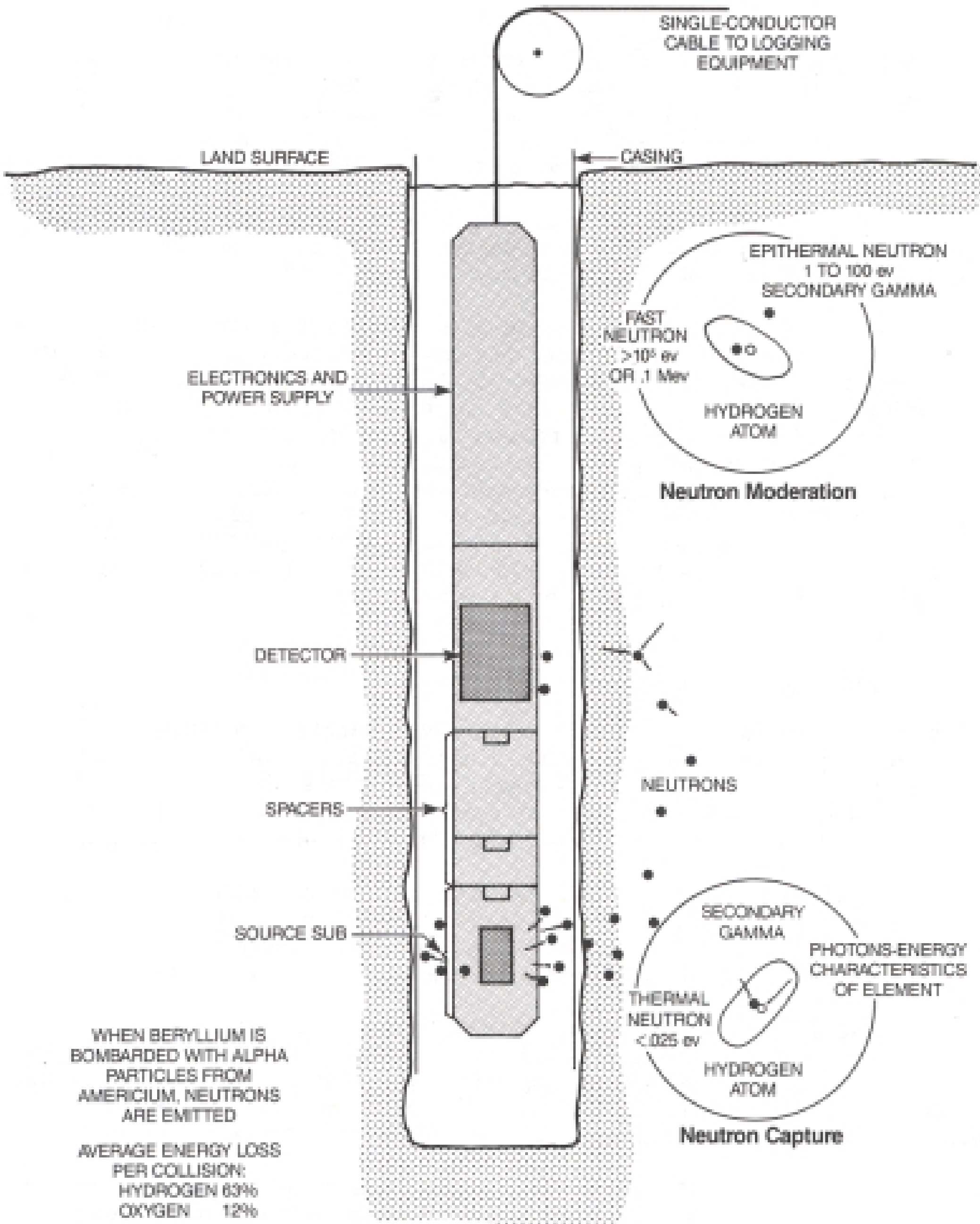
8.3.7.5 Neutron Logging

The neutron logging method most suitable for landfill monitoring measures moisture content by moving a probe slowly up and down a well casing that extends through the zone of interest. The probe contains a radioactive source of neutrons and a sensor that counts the neutrons that hit it (Figure 8.18). As neutrons leave the source they exit the well casing into the soil.

Because hydrogen atoms are about the same mass as neutrons, a neutron slows down when hit by a hydrogen atom. Some of the slowed neutrons are deflected back towards the sensor in the meter and counted. The count rate of slowed neutrons at the sensor is calibrated to the soil moisture content.

Boreholes used for neutron logging should be constructed without drill fluids and the access tube casing should be firmly seated against the soil.
'Aluminum is the most common casing material. The depth of the boreholes should extend from ground surface to well below the fill, preferably to just below the water table (to check calibration) or to bedrock.

The presence of PVC, other chloride sources, non-water hydrogen sources such as organic matter in the soil, and moisture condensed within the access tube can all cause erroneous readings. Calibration of the instruments is often supplied by the manufacturer, but additional calibration is possible using laboratory, field, or theoretical approaches.



Equipment and Principles of Neutron Moisture Logging (After Keys and MacCary, 1971)

Figure 8.18
Neutron Moisture
Logging Probe

The method provides a quick and reliable means of continuously logging moisture content over thick soil sections. Although easy -to operate, the materials in the probe include a radioactive source of neutrons. Special training of operators, precautions against over-exposure to radiation and special permits are required.

Neutron logging at landfills might require, that the access tubes extend up through the fill area. Special precautions while filling around -the tubes are required, as well as special sealing requirements to reduce the possibility of preferred leachate migration around the casing. Installation of slanted access tubes would reduce these problems, but would be more difficult to install.

In most cases, neutron logging would not constitute a sufficient leachate monitoring method because the method measures only moisture content. it would normally be used in conjunction with a salinity or resistivity monitoring device. Boreholes drilled for neutron logging access tubes would not be appropriate for installation of other monitoring devices. Installation of control tubes beyond the influence of the landfill is recommended.

8.3.8 Relationship to Ground Water Performance Standard

8.3.8.1 <u>Background</u>

Unlike ground water monitoring data, details of the way in which vadose zone monitoring data are to be used is not specified in the Minimum Functional Standards. The arid liner designi as specified in WAC 173-304-460(3)(c)(iv) states:

"Any evidence of leachate or waste constituents detected in the vadose zone that violates or could be expected to violate the performance standard of WAC 173-304-460(2) shall cause the owner or operator to take corrective action, close the facility according to these rules, or for all future expansions at that facility, meet the liner requirement of (c)(i) or (ii) of this section."

This section addresses the establishment of performance standards for vadose zone monitoring data. As used herein, a vadose zone performance standard means a reading or measurement that has been determined by theoretical calculation and field calibration to indicate the presence of leachate in the vadose zone in sufficient volume and concentration to eventually cause violation of saturated zone monitoring performance standards at the point of compliance. Such performance standards would presumably be established as part of a permit and serve as a measure of "How much leachate in the vadose zone is a problem?" The concepts discussed here are intended to relate with the saturated zone performance standards defined in WAC 173-304-490.

The following work elements would be required to estimate this level of contamination in the vadose zone:

- Establish the saturated zone performance standard

- Characterize the hydrogeology of the site
- Predict the rate of recharge to the aquifer from the immediate landfill site
- Characterize the vadose zone attenuation capacity
- Predict the ground water flux, mixing and attenuation characteristics of the aquifer beneath the site
- For direct vadose monitoring method: calculate that concentration of contaminants at the location of monitoring that would cause violation of the ground water performance standard in the aquifer at the point of compliance.
- For semi-direct or indirect methods: calibrate the methods to relate readings to soil moisture content and contaminant concentration; calculate the concentration at the location of the probe or other device that would cause violation of the ground water performance standard in the aquifer at the point of compliance, identify that reading on the monitoring device that indicates the unsaturated zone performance standard.
- Continue to refine the performance standard as additional field data become available.

The conceptual approach to establishing first cut performance standards for vadose zone monitoring is outlined in the list above. Mathematical approaches range from relatively simple calculations that can be performed on paper, to more complex approaches that might require a computer. Within each of these approaches, wide latitude is available in deciding what phenomena will be accounted for. Usually, accounting for more phenomena gives a chance that a higher performance standard could be defended, but this increases the cost of testing and analytical effort.

The initial approach to establishing vadose zone performance standards should be based on simple calculations using "worst case" assumptions. If the worst case analysis yields a performance standard well above the natural variability of the parameter being monitored, then no additional analysis is necessary until field data from the system become available to refine the performance standard. If however, the worst case analysis provides an unacceptable or marginally acceptable performance standard, then additional factors should be included in the calculations to account for attenuating phenomena. An unacceptable or marginally acceptable performance standard is one that is not sufficiently different (higher) than natural conditions, including natural variability. If this. still results in either an unacceptable or marginally acceptable performance standard, then further considerations should include:

- Field tests to collect more accurate data for calculating the performance standard, or

- A different method of monitoring.

- If neither of these options is viable, consideration should be given to abandoning the arid liner design and selecting another liner option as described in Section 4.12.

Figure 8.19 provides a flow chart that summarizes the appropriate steps in establishing a vadose monitoring program.

Many of the phenomena that affect leachate migration and performance standard calculations are reviewed in the following sections. The equations and mathematics required to perform the analyses are not presented and interested readers are referred to Freeze and Cherry (1979), Wilson (1980), Todd (1980), or other basic texts on ground water hydrology and vadose zone processes.

Because of the uncertainties involved in even the most sophisticated calculations and predictions, any indication of contamination with an indirect vadose zone monitoring system should be verified prior to initiating corrective action. In most cases, this step would involve soil sampling.

8.3.8.2 Establish Ground water Performance Standard

Ground water performance standards should be established based on procedures outlined in WAC 173-304-490 and discussed in Section 8.2. The procedures include general well construction, sampling, parameter and analysis guidelines.

8.3-8.3 Hydrogeologic Characterization

Basic hydrogeologic characterization is addressed in Sections 4.2 and 8.2 of this manual. The following topics are expanded because they are specific to vadose zone monitoring and use of vadose monitoring data:

- Ground water recharge estimations

- Vadose zone flow and contaminant migration predictions

- Aquifer ground water flux and contaminant migration calculations

Estimating ground water recharge based on climatic and near surface soil conditions is one way to predict the amount of water moving downward through the vadose zone. What goes into the soil must go out of the soil either upward through evapotranspiration or downward into the aquifer. Water budget methods generally account for rainfall, evapotranspiration and runoff, and yield a monthly estimate of remaining water, assumed to be ground water recharge. These methods, based on field capacity estimates, are explained in Section 4.10.

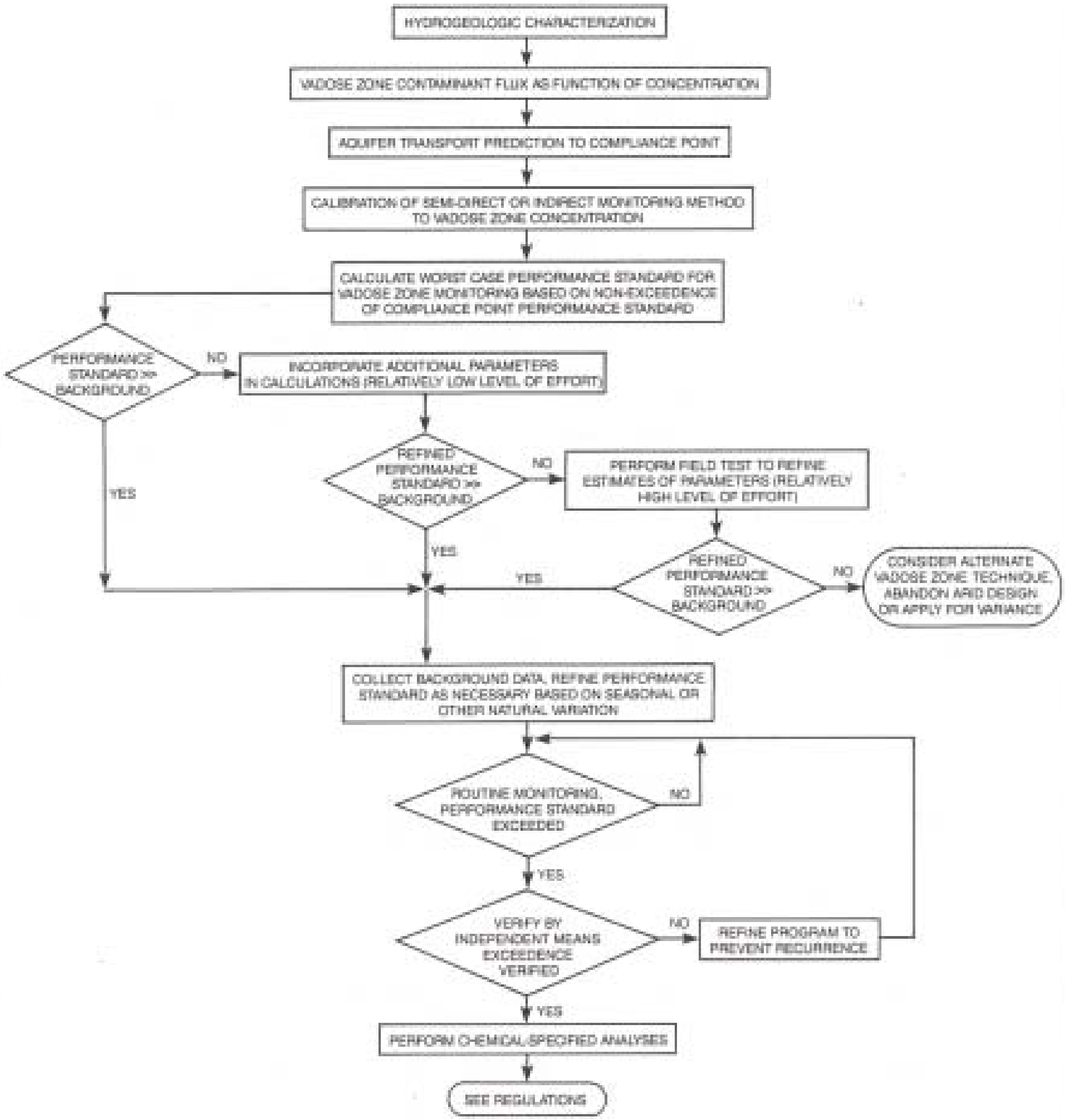


Figure 8.19
Vadose Zone Monitoring Procedures

Recent work performed by instrumenting field sites in arid climates indicates that the water budget approaches described above may underestimate ground water recharge (Kirkham and Gee, 1983; Lewis and Stephens, 1985; Stephens and others, 1985). Some of the work indicates that recharge occurs even in areas where during every month of the year there is more potential evaporation than there is precipitation. This occurs presumably because precipitation is very non-uniform and water infiltrates to considerable depths before the sun comes back out after a precipitation event. The average rate of recharge in the arid climates studied was 20% to 25% of total precipitation. This value is probably an upper bound on recharge in arid areas of Washington State.

The two approaches described above will probably yield lower and upper bounds of recharge estimates based on data available without instrumenting a site.
Further refinement of the recharge estimate will likely require installing instruments or tests in the soil that can measure recharge. Such instruments include some of those discussed as vadose zone monitoring devices. If vadose zone monitoring is to be conducted, this data could be used to refine recharge estimates. Other testing might also be required. A simple tracer test is described by Lewis and Stephens (1985). Refinement might occur during an agreed upon background period before the final vadose zone performance standard is established. The costs and benefits of refining recharge estimates based on site specific testing should be evaluated based on potential changes in performance standards (either up or down) versus the costs of performing the work.

8.3.8.4 Vadose Zone Flow and Transport Predictions

One of the most important parameters in vadose zone leachate migration is the recharge rate discussed above. Because of continuity considerations, water that enters the vadose zone must also exit it, usually downward into aquifers. By estimating the recharge rate, the average flux of water throughout the vadose zone is also estimated. Because it will generally take a relatively long time for leachate to reach the first aquifer in arid regions, the average (yearly) recharge rate will probably be appropriate as the basis for leachate migration estimates. However, if a shallow water table and sandy soil are present, or other factors indicate relatively quick travel times, recharge estimates for seasons, months, or even individual precipitation events might be required.

The rate of leachate migration is not usually equal to the recharge rate. Many chemicals have an affinity for soils and tend to adhere to the soil instead of moving at the same speed as the water. This process is called adsorption, one component of attenuation discussed in Section 4.7. Chemical precipitation in the vadose zone may also be important in removing chemicals from the water and depositing them on the soil. Adsorption and chemical precipitation will slow contaminant migration. If these parameters are quantified as a part of the hydrogeologic characterization, they could be incorporated to increase the calculated unsaturated zone performance standard (a benefit to the operator).

Hydrodynamic dispersion (spreading out) of contaminants results from differences in flow path lengths and the inherent nature of unsaturated flow (in terms of contaminant concentration as a portion of soil mass, but not water mass). It causes contaminant levels to slowly build at a location because contaminants are dispersing out in front of the main plume. However, it does not affect the long term contaminant flux because, eventually, the maximum steady state concentration arrives at all points downgradient as long as the source of contaminants is constant.

Analysis of dispersion may help estimate a realistic performance standard when source strength varies at 'about the same time frame as travel time of contaminants to the water table and point of compliance. For instance, ignoring dispersion might lead a person to conclude that from a given large recharge event, such a rapid melting of snowpack, the ground water performance standard should be exceeded because of the leachate the recharge created. If dispersion were included in the calculations, it might be demonstrated that the performance standard would never be exceeded because the spike of contaminants was spread out over time as it crossed the point of compliance. The total mass of contaminants would be the same, but the peak concentration under the dispersed plume would be lower than that for the undispersed plume.

The horizontal extent of vadose zone leachate migration will depend on the:

- Extent of the leaching landfill
- Layering and soil texture of the vadose zone soils
- Presence and character of rock layers
- Depth to the first aquifer

This parameter could be incorporated into calculations of performance criteria if the information were available before the problem occurred. Unfortunately, this is seldom the case. An assumption that the entire landfill is leaching will probably be necessary until site specific data indicate otherwise. This type of information can be interpreted from monitoring data if many measurement points are available. Verification of routine monitoring results such as obtaining soil samples could also be used. Although knowledge of leachate distribution will not be available during the permit process, it will become available during monitoring and verification.

The size of a leachate plume is also a critical parameter in determining an appropriate monitoring network density. The assumption recommended above, that the whole landfill is leaching uniformly, is not appropriate for network density determinations because it is not conservative. It would always indicate that only one device was needed per landfill. Section 8.3.3 discusses appropriate network densities.

Gas phase leachate may move faster than the ground water recharge rate. Since gas will move in the open pore space, it moves most rapidly in dry soil. The rate of movement is usually controlled by diffusion, rather than advection which dominates waterborne contaminants. Diffusion occurs in response to chemical concentration differences, causing contaminant migration toward the least contaminated area. Since soil, air, water, and solid particles will distribute contaminants among themselves, it is possible for contaminated air to contaminate water and soil particles before liquid leachate reaches an area.

8.3.8.5 Ground water Flow and Contaminant Migration in Aquifers

Ground water flow rates and fluxes within the uppermost aquifer area also important in calculating vadose zone performance standards. The water in the aquifer provides a very large body of moving water in which the leachate is migrating. This large body of water dilutes the leachate and may cause other changes as well. All of the attenuation mechanisms discussed for the vadose zone also occur in aquifers and, if characterized, they could be included in calculations.

8.3.8.6 Calibration of Semi-Direct and Indirect Techniques

Method-specific calibration procedures are addressed in discussions of monitoring technique. All these techniques have a common requirement to relate a measured soil property to leachate concentration. Because leachate varies greatly in chemistry from site to site, and even from location to location within a single landfill, it will not be possible to calibrate monitoring methods to the actual leachate that the monitoring device may encounter. Calibration should be based on the best available information on leachate properties, or, if no data are available, on compounds with predictable chemistries such as sodium chloride, potassium chloride, sulfate, nitrate or other solutions (for the case of resistivity measuring devices). Similar concepts should be used for other necessary calibrations.

8.3.8.7 Verification

Verification of vadose zone monitoring results is necessary because of the uncertainties in establishing the vadose zone performance standards and relating them to saturated zone performance standards. Indirect vadose zone monitoring results need to be verified by semi-direct or direct methods. If exceedance of the vadose zone performance standard is confirmed, corrective action as required by the arid liner design alternative would have to be implemented.

8.4 SURFACE WATER MONITORING

8.4.1 Regulatory Requirements

The Minimum Functional Standards do not permit the discharge of any liquid associated with a landfill that would violate the receiving water quality standards or Chapter 90.48 RCW. Potential sources of discharges that would violate receiving water quality standards include:

- Leachate emerging as seeps or other surface discharges and flowing into the surface drainage system

- Discharge of contaminated ground water as springs or recharge into streams and lakebeds (Figure 8.1)

- Runoff from unprotected slopes high in sediment and other contaminants

The regulations that determine what constitutes a violation of receiving water quality consider both public health and environment. Criteria for the protection of public health are contained in WAC 248-54-175, Maximum Contaminant Levels for Public Water Supplies. Criteria for the protection of surface water quality are contained in Water Quality Standards for Waters of the State of Washington (WAC 173-201). The regulations protecting public health simply limit the concentration of certain constituents that make up the primary and secondary drinking water standards (see Table 8.2). The regulations in WAC 173-201 are much more stringent and include an antidegradation policy which:

- Maintains and protects existing beneficial uses

- Permits no degradation of any waters lying within areas of national ecological importance (includes parks, recreation areas, etc.)

- Does not permit discharge of water into receiving waters which will reduce the existing quality unless overriding considerations of the public interest will be served and that all known, available and reasonable methods of treatment have occurred prior to discharge

WAC 173-201 classifies the waters of the State as follows:

- Class AA (Extraordinary)
- Class A (Excellent)
- Class B (Good)
- Class C (Fair)
- Lake Class

Each classification includes water quality criteria. Some of the criteria are clearly defined and limits are set. Other criteria may include subjective evaluations, such as aesthetics.

8.4.2 Monitoring System Design

8.4.2.1 Sampling Locations

As in ground water monitoring, potential or existing contaminant migration pathways must be known before designing a surface water monitoring system. Overland flow paths can generally be assessed using site topographic maps and visual observations made during a 'field reconnaissance. At an existing landfill where near-surface leachate contamination is severe, vegetation stress patterns may indicate contaminant flow paths.

Surface water sampling locations will depend on prevailing drainage patterns. Sampling at the point of discharge is an obvious location. Often, upstream and downstream locations are also selected. The distance downstream of a probable contaminant discharge point into the surface water body should consider contaminant dilution by increasing stream flow and the chemical behavior. In so-me instances, sample collection at discrete depth intervals may be desirable.

The simplest type of permanent sampling station usually includes a survey marker to permit duplication of the sampling location and measurement of a water level with respect to an elevation datum. More detailed sampling stations can involve flow measurement devices and sample/transverse location marked with buoys on lakes.

8.4.2.2 Sampling Frequency

The quality of surface water runoff is more sensitive to individual storm events and therefore no routine schedule can be established since the events of interest will occur at random. However, the following guidelines are provided to assist in the selection of sampling times.

- At least four sampling events should be conducted per year.
- At least three sampling events should be conducted between the months of October and April.
- Sampling events should be a minimum of one month apart.
- One sampling event should occur during the first storm event of the water year (after October 1) producing a measurable flow.
- Sampling should be conducted within six to eighteen hours after the beginning of the storm event.

8.4.2.3 Sample Parameters

No required sample parameters for surface water monitoring are included in the Minimum Functional Standards. Therefore, each surface water monitoring program will require its own unique set of parameters. The use of indicator parameters is encouraged. Selected parameters should be compatible with the class of the receiving water. A list of sampling parameters for monitoring discharges to a Class AA receiving water may include:

- PH
- Temperature
- Dissolved oxygen

- Fecal coliform
- Turbidity
- Hardness

8.4.2.4 Sampling Equipment

Sampling equipment is generally less complex compared to the equipment used to obtain ground water samples. Bailers and suction lift pumps (peristaltic) are often used. The chemical processes that can introduce bias into the sample are similar to those associated with ground water sampling. Sample handling procedures are generally similar to those for ground water.

8.4.2.5 Evaluation of Sample Results

Statistical evaluation of surface water samples is usually not feasible because of the extreme variability of storm events creating the runoff. Usually the results are simply compared to the receiving water quality standards and if the discharge into the receiving water exceeds those standards, some type of corrective action is initiated. Samples taken in the receiving water usually include an upstream and downstream location from the point of discharge into the receiving water. These two samples can be compared to determine if these has been a measurable impact on the receiving water. This comparison is somewhat subjective since statistical tests are not normally included.

It is important that both the jurisdictional health district and Ecology are involved in the review and approval of the methods of evaluating the sample results since no clear guidance is provided in the regulations. A clear understanding between the landfill owner/operator and the regulatory agencies on interpretation of the results and appropriate responses will ensure the success of the program.

8.4.2.6 Other Factors

Quality assurance of sample collection and analysis is essential to the success of the monitoring program. The methods described in Section 8.2 for ground water monitoring are appropriate for use in the surface water monitoring program.

Results and interpretations must be reported to the regulatory agencies. This information can be forwarded using an approved format. The information can be summarized in the annual report to the jurisdictional health district required by the Minimum Functional Standards.

8.5 LANDFILL GAS MONITORING

Ecology has set forth allowable limits for landfill gas both on and off landfill sites (WAC 173-304). Monitoring of landfill gas is required in order to evaluate the performance of landfill gas control measures and compliance with MFS regulations. Consequently, landfill gas monitoring plans should be designed to determine:

- Landfill gas concentrations at the landfill boundary
- Landfill gas concentrations within on-site and off-site structures and enclosed utility facilities (utility vaults, sewer lines, and manholes, etc.)
- The efficiency of landfill gas recovery systems and/or on-site gas migration control wells
- The effectiveness of off-site gas migration control wells

This section of the Design Manual is intended to aid the engineer in the design and implementation of a landfill gas monitoring plan which will assure effective performance of landfill gas systems on and off the landfill site.

8.5.1 Modeling Gas Movement

In recent years several mathematical models have been developed to simulate the flow of landfill gas through refuse and soil. These models use approximations of the differential equations that describe gas movement through soil to predict gas concentrations as a function of time and distance. Detailed discussions of these models can be found in Moore, et al. (1979), Moore (1979), Mohsen, et al. (1977), and Findikakis and Leckie (1979). The results derived from these models are subject to uncertainty and decisions concerning public safety should not be based solely on their results. A comprehensive monitoring program is needed to ensure that predicted migration path boundaries and limits are not exceeded.

8.5.2 Designing a Landfill Gas Monitoring Program

The dangers to public health and safety posed by landfill gas migration are often of a more immediate nature than the water quality degradation created by leachate migration. The principal dangers associated with landfill gas include the:

- Accumulation of explosive concentrations of methane
- Exposure of workers near landfills to high concentrations of hydrogen sulfide and other toxic gases
- Exposure of workers to atmospheres lacking sufficient oxygen due to its displacement by landfill gas

There are three situations where monitoring requirements are different. These situations include:

- Monitoring for off-site subsurface migration

- Monitoring either on or off-site buildings for the accumulation of landfill gas

- Monitoring for construction activities in the vicinity of landfills

The first two situations require long-term monitoring programs while the third requires only a temporary program during the construction activities.

8.5.2.1 Monitoring for Subsurface Migration

The objective of a landfill gas monitoring plan is to collect valid data representative of conditions in monitoring wells at the perimeter of the site. The desired outcome of implementation of this plan at a 'Landfill is a demonstration that the off-site migration of landfill gases has been controlled to a level which meets the MFS requirements. Typically, gas migration control systems consist of a line of gas extraction wells located near the perimeter of landfilled refuse, and a series of monitoring wells located along a line parallel to the line of wells. The monitoring wells are normally located as near as possible to the landfill property line, and are approximately equidistant from each pair of extraction wells. The result is a triangular spatial relationship between each pair of extraction wells and the monitoring well between them. Any proposed extraction wells may be located in refuse or in native soil; however, the monitoring wells must be located in native soil.

A monitoring well used in conjunction with a gas migration control system will demonstrate the capability of each extraction well to independently influence gas movement through the soil zone between the monitoring well and 'the extraction well. The influence of the extraction well on the monitoring well is indicated in two ways:

- A reduction of gas concentration

- The presence of a vacuum in the soils surrounding the monitoring well as a result of the vacuum applied at the extraction well

The results of the monitoring are useful in determining that the influence of each extraction well extends a sufficient radius to eliminate voids between the areas of influence of two adjacent extraction wells.

Monitoring for subsurface migration of landfill gas is designed to detect the movement of the gas beyond the boundaries of the landfill site. The component of landfill gas of principal concern in this situation is methane. The MFS require that the concentration of methane at the property boundary not exceed the lower explosive limit for the gas, which is 5% by volume (WAC 173-304-460(2)(b)).

As discussed above, monitoring wells should be installed around the periphery of the site, usually at or very close to the property boundary. The depth of the wells depends on the distance of the well from the refuse boundary, and is typically calculated as follows:

- Wells located less than 200 ft from refuse boundary. Depth of the well equals the greatest.depth of refuse measured within a 500-foot radius of the well location.

- Wells located further than 200 ft from refuse boundary. Depth of the well equals the greatest depth of refuse measured within a 500-foot radius of a point 200 ft from the refuse boundary located between the well location and the refuse boundary.

Table 8.5 Criteria for Determining the Number of Probes Required in a Given Monitoring Well Installation.

Depth of Well	Number of Probes in Well
10 ft	1
20	2
30	2
40	3
50	3
75	3
100	4
150	4
200	5

In either case, a well does not need to be any deeper than the historical minimum ground water level, unoxidized bedrock, or 25 ft below structures and roads with underground utilities and/or manholes that are located within 250 ft of the well. One to as many as five probes may be placed within a given well; Table 8.5 presents the criteria 'for selecting the number of probes per well boring. Sampling of gas at multiple depths is recommended to intercept all migrating gas and to determine at which general depth the gas movement is taking place.

For a passive gas migration control system, which typically consists of a perimeter trench system, individual gas well efficiency data are not necessary. Consequently, the spacing of monitoring wells for these installations depends primarily upon two parameters:

- Distance of the well from the refuse boundary
- Degree of protection required in the well vicinity (i.e., land use, development density)

Table 8.6 presents the criteria for development and the recommended well spacing.

Table 8.6 Criteria for Landfill Gas Monitoring Well Spacing.

Proximity of Developed Property	Well Spacing
Development < 200 ft	100 ft
200 ft < Development < 500 ft	200
500 ft < Development < 1,000 ft	300
1,000 ft < Development < 2,000 ft	600
Development > 2,000 ft (adjacent land ,barren/unoccupied)	1,000

Landfill gas does not usually travel laterally more than 500 ft, but there have been some instances where gas has migrated over 1,000 ft (i.e. Midway Landfill in King County). Therefore, each site should be individually evaluated for gas migration potential, taking into account geography, geology, and proximity of structures or other facilities needing protection.

Landfill gas wells are installed in much the same manner as ground water monitoring wells. The major difference is the zone of monitoring. Ground water wells (saturated zone) are installed below the ground water table while landfill gas monitoring wells are installed above the water table, since the water table forms an impermeable boundary to the migration of landfill gas. A typical landfill gas monitoring well with multiple probes is shown in Figure 8.20.

The monitoring schedule should 'be flexible enough to accommodate changing site conditions which may affect gas generation and migration. Af ter a monitoring system is installed, each probe should be checked at least twice daily for a short duration. This provides information on any daily

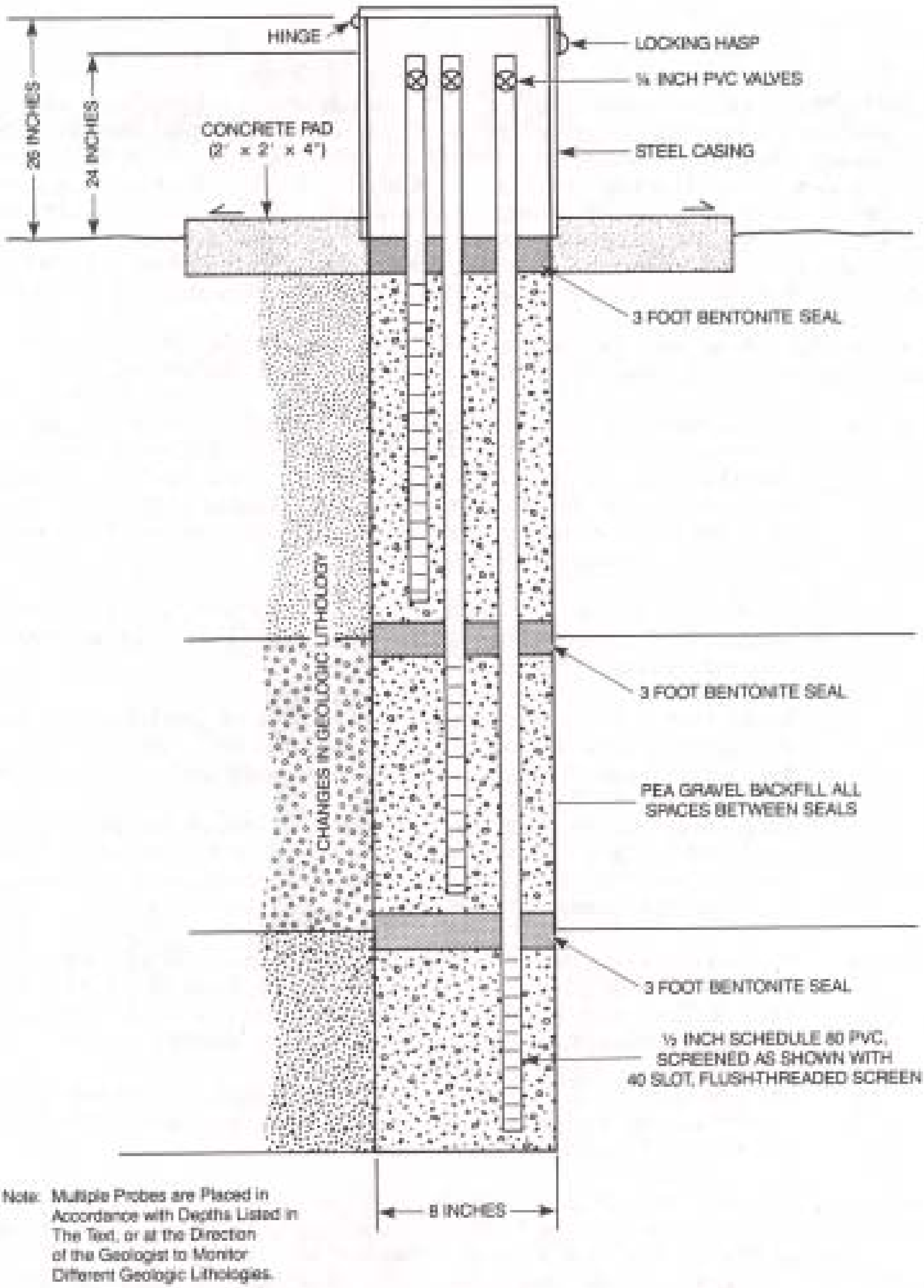


Figure 8.20
Methane Monitoring
Probe Detail

NOT TO SCALE

fluctuations of gas quality. Usually the highest readings are found in the afternoon, especially during periods of decreasing barometric pressure. Initially, monitoring intervals should be relatively short, but lengthened as confidence in monitoring results is gained. After the initial analysis, if no gas or very low concentrations of gas are found, a monitoring frequency of once per week for a month, once a month for a quarter, and quarterly thereafter is acceptable. However, when significant quantities of gas are detected, monitoring intervals for the affected area should be shortened.

Monitoring should not be limited to use of detection equipment, but should also include visual observations of site conditions listed below:

- Development of surrounding areas: the placement of impermeable ground covers (i.e., paved parking lots, building slabs) can force landfill gas to remain underground and promote lateral migration. Additionally, off-site structures and utility facilities can provide enclosed areas in which landfill gas can collect and pose a health and safety danger.

- Heavy irrigation, or rainfall: saturated soil can provide an impermeable barrier to landfill gas (particularly methane), thus causing lateral migration of the gas.

- Excavation activities: excavation may cause landfill gas to escape through the excavation, or, more importantly, the landfill gas may displace oxygen within the excavation, endangering worker safety.

- Surface cracks or settlement: these can cause uncontrolled venting of landfill gas or air intrusion into the landfill which could reduce landfill gas quality (decrease methane concentration) or increase the potential for a landfill fire.

- Barometric pressure, wind, and temperature: all of these items can affect the net pressure of landfill gas present in the landfill. At a higher net pressure, more landfill gas will tend to escape through the landfill cover or surrounding surface.

- Snow and/or frozen ground cover: as with saturated soil, this condition can reduce surface permeability and thus increase lateral migration of landfill gas.

Results of the monitoring program should be reviewed by a designated employee who is not only knowledgeable in the area of methane gas hazards and control systems, but who is familiar with the terrain and local site conditions. The monitoring program should continue until all gas generation within the landfill has ceased (at least 20 to 30 years after closure of the landfill). Even if no gas is detected for a long period of time, the program should continue, since gas generation and movement may rapidly change under certain conditions.

8.5.2.2 Monitoring in Buildings

All on-site facilities should be periodically monitored for the presence of landfill gas. The MFS limit the presence of methane gas in on-site facilities to 25% of the lower explosive limit of the gases, which is 1.25% methane by volume. This requirement excludes gas control or recovery system components. Although features to prevent entry of gas into buildings and other on-site facilities may exist, the monitoring program is necessary to confirm that gas control features are effective.

Where facilities are regularly occupied by persons and the risk may be high, continuous monitoring and alarm systems may be warranted. These systems are readily available from a number of manufacturers and usually consist of a remote detector and a controller/alarm for each detection point. Usually where more than one detector is installed, all controller/alarms are located in a centrally occupied location.

The MFS require that landfill gas concentrations within off-site structures be no more than 100 parts per million by volume of hydrocarbons (expressed as methane). Therefore, off-site facilities may also require monitoring. This would be true for buildings located close to landfills or where modifications to the surface over the landfill promote more extensive lateral migration. Continuous monitoring and automatic alarm systems are preferred in these instances since they do not depend upon periodic readings to detect a potentially dangerous situation. The alarms can be set to go off at a safe level of methane which would allow time for appropriate corrective action to be taken. The detectors must be periodically recalibrated according to the manufacturers recommendations, to maintain an adequate level of safety.

8.5.3 Landfill Gas Monitoring Well Sampling Methods and Equipment

When obtaining a gas sample from a monitoring probe, such as shown in Figure 8.20, it is desirable to obtain a sample representative of conditions at the probe tip. To do this it is necessary to extract the entire air volume of the probe between its tip and the top of the casing. Samples extracted from the probes can be analyzed either in the field or in the laboratory. Unless studies are being conducted to investigate the potential of a landfill for methane gas recovery, it is common to rely on simple field measurements to detect the presence of landfill gas. The most common field equipment used in measuring landfill gas is portable gas detection instruments. These instruments detect methane concentrations from just above 0% to 100%. Gas samples are drawn into the instrument by an electric pump or a hand-aspirated bulb. Most instruments have two scales, a 0% to 5% scale for detecting trace amounts of methane and a 0% to 100% scale for detecting higher concentrations. Many instruments have a low range scale that operates on a different principle than the high range scale and will actually register 0% methane event if the actual concentration is high. Misinterpretation of this reading can lead to false conclusions about the presence of methane. For this reason, when taking gas samples, it is best to first use the high range scale. If no gas is indicated, switch to the low range scale to check for methane at low concentrations.

Other field gas detection equipment include the following:

- Combustible gas analyzers with oxygen meter
- Portable gas chromatographs
- Infrared detectors for methane-carbon dioxide analysis
- Flame ionization detectors

8.5.4 Quality Control

The instruments used for detecting landfill gas are sensitive and require frequent calibration. Calibration procedures should follow those recommended by the instrument's manufacturer. The gas used to calibrate the instrument should be certified to contain a certain percentage of gas. For example, a 2.5% methane mixture is often used to calibrate the low range scale of a combustible gas instrument. It is good practice to have a field calibration kit available so that the instrument can be checked in the field immediately prior to its use.

Other important considerations in using gas detection equipment include ensuring that batteries are fully charged and all routine, pre-use adjustments are made according to the manufacturer's instructions.

8.6 USE OF COMPUTERS FOR DESIGN AND INTERPRETATION OF DATA

Sampling network design and interpretation of monitoring data can often be expanded and expedited through the use of computer based statistical techniques and mathematical models.

There are several computer systems and programs for handling data, evaluating the validity of sampling network, and for modeling of the hydrologic, hydrogeologic and soil refuse gas migration systems. The success of computer-based systems depends upon the quality of input data, the relevance of the model to actual conditions, and the skill and understanding of the computer operator. Data base systems can often be developed so that little technical knowledge is required to provide the necessary input. Usually, the more sophisticated computer models require that the operator be technically qualified to understand the input and output of the system.

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Appendix 8A

USE OF LYSIMETERS IN THE VADOSE ZONE

APPENDIX 8A

USE OF IN THE VADOSE ZONE

Lysimeters are typically tubes with Teflon (TM) or ceramic porous tips installed in the vadose zone (Figure 8A.1). They are typically installed in vertical or angled auger borings which are backfilled with silica flour (very fine silica particles) around the porous tip. Remaining backfill from above the silica flour to land surface includes native materials, bentonite, or mixtures of these with gravel layers. Another type of lysimeter is shaped like a plate, with the porous surface being the surface of the plate. A vacuum is created inside the body (pipe) by pumping from land surface through tubing. The vacuum inside the lysimeter must be stronger than the tension holding the water in the soil to force water from the soil through the porous tip into the body of the lysimeter. However, the vacuum cannot be so strong as to make air flow through the porous tip and destroy the vacuum. The water that has collected in the lysimeter after many hours is pumped to land surface either by suction or positive pressure, depending on depth.

Placement of lysimeters must be directly beneath the landfill since typical flow is downward in the vadose zone. The area to be monitored is therefore as large as the landfill areal dimensions. The radius of capture of lysimeters is on the order of feet or meters. Based on the limited capture radius of lysimeters and the large area to be monitored in typical situations, it is not possible to get complete coverage of the soil beneath the landfill. The recommended approach is to characterize the soils and infiltration conditions at the landfill in sufficient detail to identify zones of relatively similar properties. The radius of capture for each zone should then be estimated, and lysimeters spaced in the soil beneath the landfill in sufficient density to achieve the desired percent coverage.

Lysimeters should be placed sufficiently deep to minimize seasonal effects and local changes in soil water quality, but shallow enough to allow early recognition of a leachate problem. Placement of lysimeters just a few feet above the water table is not recommended because ground water monitoring wells could just as easily be placed. The distribution of soil types should be 'strongly considered in selecting the depth of placement. From very coarse-grained and very fine-grained soil layers, samples will be hard to extract because of low permeability. Medium textured sands and silts are better for lysimeter placement. In areas of shallow bedrock, such as in certain areas of the Columbia Plateau, placement of lysimeters above bedrock may not be possible. In these cases, zones of the bedrock such as interflow ash beds or old buried soil horizons should be identified and used for placement of the lysimeters. In mountain areas with non-layered bedrock, fine fracture zones should be used.

Although lysimeters provide the most direct way of monitoring soil water quality beneath landfills, they are restricted to certain soil environments. They will extract samples only from soils in which the water is held under weaker tensions than the vacuum applied to the lysimeter. One or two atmospheres tension is the limit for most lysimeters. Another practical

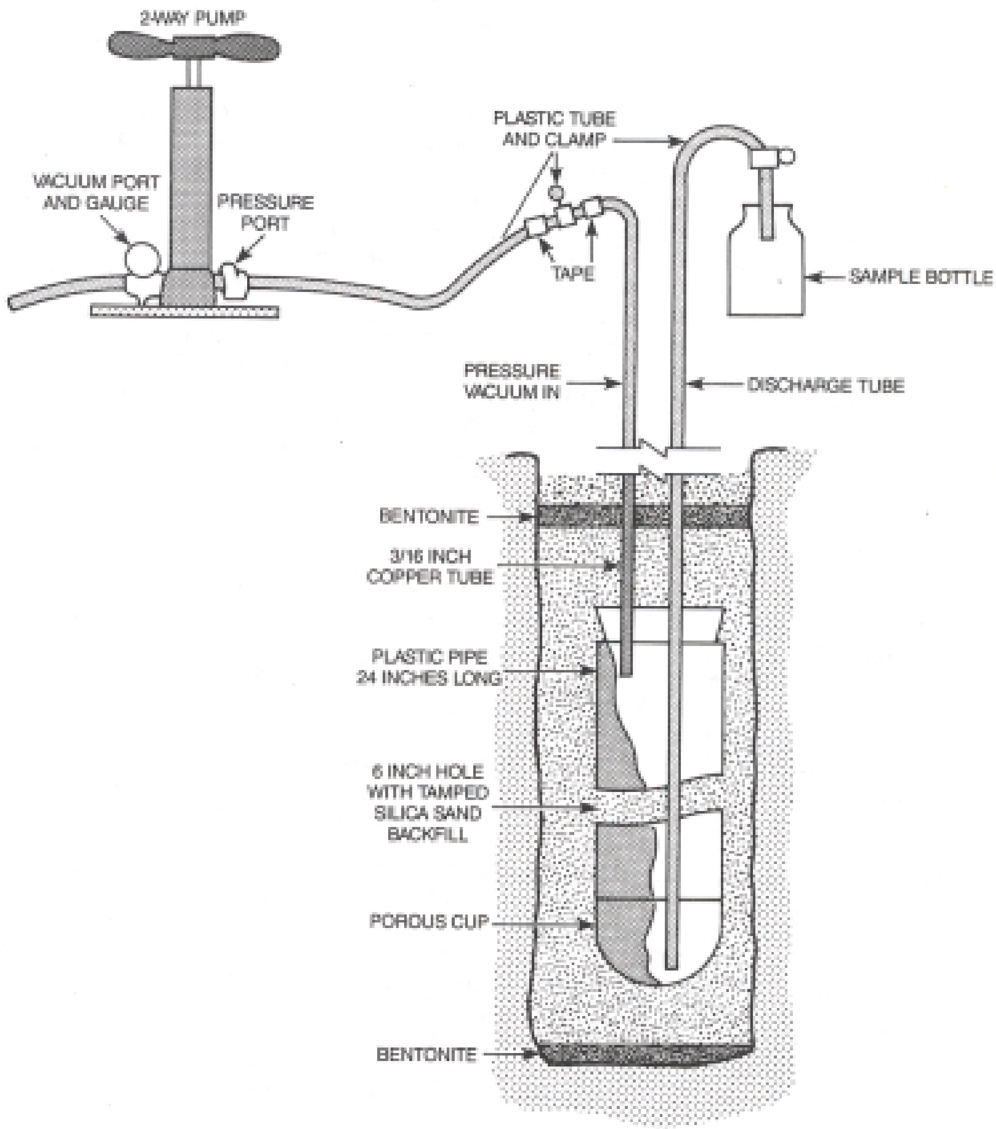

Figure 8A.1
Vacuum Pressure Lysimeter

limitation is that the permeability of the soils cannot be so low as to make the sample collection time excessive. In terms of common descriptors of soil type and wetness, lysimeters work well in moist to wet soils that are neither too clayey or too gravelly. In terms of geography, they can be expected to work best in the Cascade Mountains and western portions of Washington State. The soils of eastern Washington may often be too dry for lysimeters to work well.

Chapter 9

The Minimum Functional Standards Facility Requirements

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9. 1 INTRODUCTION

The current State standards for disposal of solid wastes were promulgated in November ~1985 as Chapter 173-304 WAC, Minimum Functional Standards for Solid Waste Handling. These regulations present existing standards by which a landfill must be designed, operated, and monitored. This section is not intended to replace the text of the Minimum Functional Standards, but rather to outline the regulations and discuss where in the Design Manual to find the guidance to implement the staRdards.

9.2 PERMIT REQUIREMENTS

9.2.1 Geohydrological Studies

Landfill design requires an adequate understanding of the subsurface conditions beneath a site. Site suitability, design, construction, operation, closure and environmental monitoring are all affected by these conditions. Consequently, WAC 173-304-600(3)(b)(i) (Permit Requirements for Solid Waste Facilities) requires that applicants for new landfills, or expansion of existing landfills, submit a permit application containing a geohydrological assessment of the facility. This assessment must address:

1. Local/regional geology and hydrology, including faults, unstable slopes and subsidence areas on site.
2. Bedrock and soil types and properties.
3. Depths to ground water and/or aquifer(s).
4. Direction and flow rate of local ground water.
5. Direction of regional ground water.
6. Quantity, location and construction (where applicable) of private and public wells within a two thousand foot radius of site.
7. Tabulation of all water rights for ground water and-surface water within a two thousand foot radius of the site.
8. Identification and description of all surface waters within a onemile radius of the site.
9. Background ground and surface water quality assessment, and for expanded facilities, identification of - impacts -of existing facilities of the applicant to date upon ground and surface waters from landfill leachate discharges.
10. Calculation of a site water balance.

11. Conceptual design of a ground water and surface water monitoring system, including proposed installation methods for these devices and where applicable a vadose zone monitoring plan.

12. Land use in the area, including nearby residences.

13. Topography of the site and drainage patterns.

Geohydrological investigations are discussed in Section 4.2 of this Design Manual.

9.2.2 Engineering Studies.

Upon completion of the geohydrological assessment of the landfill site, a thorough engineering evaluation is required to determine the most appropriate landfill design to meet the specific needs of the site. Consequently, VAC 173-304-600(3)(b)(ii) requires the preparation of a preliminary engineering report/plan and specifications to address:

1. How the facility will meet the locational standards of WAC 173-304-130.
2. Relationship of facility to county solid waste comprehensive plan and the basis for calculating the facility's life.
3. The design of bottom and side liners.
4. Identification of borrow sources for daily and final cover and soil liners.
5. Interim/final leachate collection, treatment, and disposal.
6. Landfill gas control and monitoring.
7. Trench design, fill methods, elevation of final cover and bottom liner, and equipment requirements.
8. Closure/ post -closure design, construction, maintenance, and land use.

Plans and specifications are prepared using the technical background derived during the preparation of the geohydrological and engineering studies, as well as the permit application. Approval of these plans and specifications is required prior to construction of the landfill. This Design Manual is partially intended to aid the engineer in designing the landfill and preparing the engineering report.

9.2.3 Permit Application Requirement

As presented in WAC 173-304-600(3)(b)(iii-v), the permit application requires an operations plan, a closure plan, and a post-closure plan. The operations plan must address:

1 Operation and maintenance of leachate collection, treatment, and disposal systems.

2. Operation and maintenance of landfill gas control systems.

3. Monitoring plans for ground water, surface water, and landfill 'gases to include sampling. technique, frequency, handling, and analysis requirements.

4. Safety and emergency accident/fire plans.

5. Routine filling, grading, cover, and housekeeping.

6. Record system to address records on weights (or volumes), number or vehicles and types of waste received.

7. Vector control plans.

8. Noise control.

The closure plan must address:

1. Estimate of closure season/year.

2. Capacity of site In volume and tonnage.

3. Maintenance of active fill versus completed, final covered acreage.

4. Estimated closure construction timing and notification procedures.

5. Inspection by regulatory agencies.

The post-closure plan must address:

1. Estimated time period for post-closure activities.

2. Site monitoring of landfill gas, ground water, and surface water.

3. Deed clause changes, land use, and zoning restrictions.

4. Maintenance activities to maintain cover and run-off systems.

5. Identification of final closure costs including cost calculations and the funding mechanism.

Operations, closure, and post-closure plans are discussed in Chapters 6 and 7. More detailed information on individual elements of these plans may be found in Chapter 4.

9.3 PERFORMANCE ELEMENTS (ENVIRONMENTAL MONITORING)

9.3.1 Ground Water

WAC 173-304-490 presents the following ground water monitoring requirements for solid waste landfills:

1. The ground water monitoring system must consist of at least one background or upgradient well and three down gradient wells, installed at appropriate locations and depths to yield ground water samples from the upper most aquifer and all hydraulically connected aquifers below the active portion of the facility.

    a. Represent the quality of background water that has not been affected by leakage from the active area.

    b. Represent the quality of ground water passing the point of compliance. Additional wells may be required by the jurisdiction health department in complicated hydrogeological settings or to define the extent of contamination detected.

2. All monitoring wells must be cased in a manner that maintains the integrity of the monitoring well bore hole. This casing must allow collection of representative ground water samples. Wells must be constructed in such a manner as to prevent contamination of the samples, the sampled strata, and between aquifers and water bearing strata and in accordance with Chapter 173-160 WAC, regarding minimum standards for construction and maintenance of water wells.

When the landfill is opened, ground water monitoring is to commence with quarterly or more frequent sampling. The constituents to be sampled for include:

- Temperature
- Conductivity
- PH
- Chloride
- Nitrate, nitrite, and ammonia as nitrogen
- Sulfate
- Dissolved iron
- Dissolved zinc and manganese
- Chemical oxygen demand
- Total organic carbon

- Total coliform

In addition, the owner/operator shall use a statistical procedure approved by the jurisdictional health department to determine whether a significant change over background has occurred. Ground water monitoring is discussed in Section 8.2.

9.3.2 Surface Water

The Minimum Functional Standards do not specifically state requirements for surface water monitoring. However, they do state that an owner/operator of a landfill shall not cause a violation of any receiving water quality standard nor violate Chapter 90.48 RCW from.discharges of surface run-off, leachate or any other liquid associated with a landfill [WAC 173-304-460(2)(c)]. Surface water monitoring typically involves streams, rivers, lakes, and ponds. Additionally, run-off from the landfill would be analyzed to determine if contaminations had occurred. Typically, monitoring is performed quarterly (at the same time as ground water monitoring) and would test' for the same constituents as ground water, or a modified list as approved by the jurisdictional health department. surface water monitoring is discussed further in Section 8.4.

9.3.3 Landfill Gas

Monitoring of subsurface landfill gas movement may be required by the Jurisdictional health department (WAC 173-304-460(3)(g)(ii)]. Additionally, the landfill gas migration control system must meet the standards discussed in Section 9.4.5; in order for*these standards to be met, a site specific landfill gas monitoring plan is required. Gas flow and generation at the surface would typically be sampled using well-point monitoring probes. Landfill gas monitoring is discussed in Section 8.5.

9.3.4 Ambient Air

WAC 173-304-460(3)(g)(ii) as cited above, states that *monitoring of* ambient air at the landfill site may be required by the jurisdictional health department. For example, the Puget Sound Air Pollution Control Authority (PSAPCA) has air quality standards for -landfills under its jurisdiction and may require ambient air monitoring for these landfills.

9.4 DESIGN ELEMENTS

9.4.1 Recycling Facilities

Recycling of certain solid waste components is a cost-effective method of reducing solid waste volume and increasing resource recovery. WAC 173-304460(4)(f)(i) requires that recycling facilities be available at landfills. Specifically, landfills to which the general public delivers household solid waste shall provide an opportunity for the general public to recycle cans, bottles, paper, and other marketable waste. Such facilities should be convenient to the public (i.e., near an entrance) and accessible during normal hours of operation. Additionally, "Owners or operators may demonstrate alternative means to providing an opportunity to the general public to recycle household solid waste."

9.4.2 Bottom Liner

State regulations require that all landfills be adequately lined to eliminate the percolation of leachate into the ground water beyond the solid waste. WAC 173-304-460(3)(c) requires the use of one of four liner designs:

Standard Design. "The liner shall be constructed of at least a four feet thick layer of recompacted clay or other material with a permeability of no more than jx10-7 cm/sec and sloped no less than two percent."

Alternative Design. This design calls for the use of two liners: "An upper liner of at least fifty mils thickness made of synthetic material; and ... a lower liner of at least two feet thickness of recompacted clay or other material with a permeability of no more than jx10-6 cm/sec and sloped no less than two percent."

Equivalent Design. "The design shall use alternative methods, operating practices and locational characteristics which will minimize the migration of solid waste constituents or leachate into the ground or surface water at least as effectively as the two previous designs."

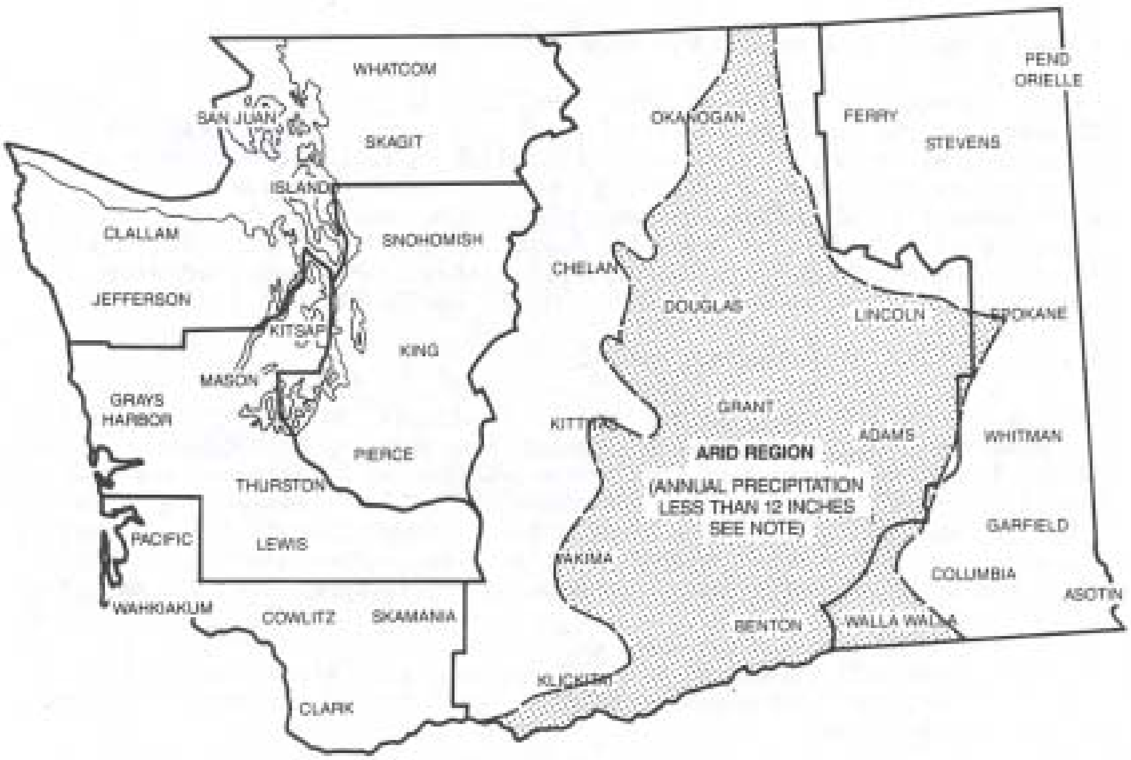
Arid Design. "This design will apply to locations having less than twelve inches of precipitation annually," and, in lieu of the three previous designs, "shall consist of vadose zone moisture monitoring," with provisions for environmental protection.

Figure 9.1 presents a map of Washington outlining the approximate area included within the arid region, as defined by the Minimum Functional Standards. This map is based on average annual precipitation for the region as reported by the National Climatic Data Center (1982). Precipitation records from nearby, local weather recording stations should be consulted to confirm whether or not a site is within the arid region. Borderline landfill sites may want to consider installing their own precipitation measuring instruments to see if they can qualify for the arid liner design concept. Guidance on how to set up such instruments can be provided by the National Weather Service, U.S. Geological Survey or other agencies who routinely record weather information.

Bottom liner design is discussed in Section 4.12. The design of a vadose zone monitoring program, required as part of the arid liner design concept, is presented in Section 8.3.

9.4.3 Leachate Collection System

The primary purpose of the leachate collection system is to collect and remove leachate from the bottom of the landfill. WAC 173-304-460(3)(b) requires that landfill operators "install a leachate collection system sized



Note: Boundary locations are only approximate and local weather recording stations should be checked to verify precipitation amounts.

Source: National Climate Data Center, 1982.

Figure 9.1
Approximate Boundaries of Arid Region

according to water balance calculations or using other accepted engineering methods either of which shall be approved by the jurisdictional health department", and "install a leachate collection system so as to prevent no more than two feet of leachate developing at the topographical low point of the active area." Leachate collection system design is discussed in Section 4.13.

9.4.4 Leachate Treatment and Disposal System

After leachate is collected from the landfill, it must be treated ~ and disposed of in an environmentally safe manner. WAC 173-304-460(3)(b) requires that the owner/operator of a landfill "install a leachate treatment, or pretreatment system if necessary in the case of discharge to a municipal waste water treatment plant, to meet the requirements for permitted discharge under Chapter 90.48 RCW and the Federal Clean Water Act (PL 95-217).11 Several leachate treatment and disposal systems have been used around the country in the past and are discussed in Sections 4.13 and 4.14.

9.4.5 Landfill Gas Management System

The generation of methane gas in landfills is caused by the natural decomposition of putrescible wastes in the absence of oxygen. As the landfill begins to stabilize, methane production will decrease, and will be greatly reduced 25 years after placement of the last refuse. WAC 173-304460(2)(b) places limits on the methane gas concentration which is allowed to migrate from the landfill property: "An owner or operator of a landfill shall not allow explosive gases generated by the facility whose concentration exceeds:

1. Twenty-five percent of the lower explosive limit for the gases in facility structures (excluding gas control or recovery system components).

2. The lower explosive limit for the gases at the property boundary or beyond.

3. One hundred parts per million by volume of hydrocarbons (expressed as methane) in off-site structures-"

Additionally, "an owner or operator of a landfill shall not cause a violation of any ambient air quality standard at the property boundary or emission standard from any emission of landfill gases, combustion or any other emission associated with a landfill." In order to meet these standards, WAC 173-304-460(3)(f) states that "all owners and operators shall design landfills, having a permitted capacity of greater than ten thousand cubic yards per year, so that methane and other gases are continuously collected, purified for sale, flared, or utilized for its energy value."

The regulations also state that "collection and handling of landfill gases shall not be required if it can be shown that little or no landfill gases will be produced or that landfill gases will not support combustion; in such cases installation of vents shall be required." Landfill gas management and control system design are discussed in,Sections 4.7 and 4.15, respectively.

9.4.6 Surface Water Management System

The surface water management system has three primary requirements:

- Prevent run-on of surface waters to'the site
- Collect run-off from the site
- Protect the integrity of the final cover system

Recognizing these needs, WAC 1 1 73-3047460(3)(a) states that "all owners or operators of landfills shall minimize liquids admitted. to active areas of landfills by:

1. Designing the landfill to prevent all the run-on of surface waters and other liquids resulting from a maximum flow of a twenty -five year storm into the active area of the landfill.

2. Designing the landfill to collect the run-off of surface waters and other liquids resulting from a tventy-four hour, twenty-five year storm from the active area and the closed portions of a landfill."

Landfill design elements required for control of surface water run-on, runoff, and erosion are presented in Sections 4.8 and 4.11.

9.4.7 Final Cover Systems

Upon closure, a landfill must be covered to reduce percolation of precipitation into the placed refuse, and to provide a stable, aesthetically pleasing cover. WAC 173-304-460(3)(e) states that "all owners and operators shall design landfills so that at closure:

1. At least two feet of jx10-6 cm/sec or lower permeability soil or 'equivalent shall be placed upon the final lifts unless the landfill is located in an area having mean annual precipitation of less than twelve inches in which case at least two feet of jX10-5 cm/sec or lower permeability soil or equivalent shall be placed upon the final lifts. Artificial liners may replace soil covers provided that a minimum of fifty mils thickness is used.

2. The grade of surface slopes shall not be less than two percent, nor the grade of side slopes more than thirty-three percent.

3. Final cover of at least six inches of topsoil be placed over the soil cover and seeded with grass, other shallow rooted vegetation or other native vegetation."

Final cover performance analysis techniques are presented in Section 4.10, while design is discussed in Section 4.16.

9.4.8 General Facility Requirements

Several general facilities are required for 304 Facilities, primarily for safety, aesthetics, and record keeping, as follows:

- Fence and Gate. The landfill shall 11 ... be fenced at the property boundary or use other means to impede entry by the public and animals. A lockable gate shall be required at the entry to the landfill." [WAC 173-304-460(3)(g)(i)]

- Scales. The landfill shall 11 ... weigh all incoming was'te on scales for landfills having a permitted capacity of greater than ten thousand cubic yards per year or provide an equivalent method of measuring waste tonnage capable of estimating total annual solid waste tonnage to within plus or minus five percent." [WAC 173-304460(3)(g)(iii)]

- Roads. The landfill shall "provide approach and exit roads to be of all-weather construction, with traffic separation and traffic control on-site, and at the site entrance." [WAC 173-304460(3)(g)(ix)]

- Signs and Communications. The landfill shall "erect a sign at the site entrance that identifies at least the name of site, if applicable, the hours during which the site is open for public use, unacceptable materials and an emergency telephone number. Other pertinent information may be required by the jurisdictional health department;" [WAC 173-304-460(3)(g)(v)] and "provide communication between employees working at the landfill and management offices ,on-site and off-site (such as telephones) to handle emergencies." [WAC 173-304-460(3)(g)(x)]

- Employee and Fire Protection Facilities. The landfill shall 11provide employee facilities including shelter, toilets, hand washing facilities and potable drinking water for landfills having the equivalent of three or more full-time employees," [WAC 173-304460(3)(g)(iv)] and "provide on-site fire protection as determined by the fire control jurisdiction-" [WAC 173-304-460(3)(g)(vi))

The design and construction of these facilities is discussed in several sections of this manual. The reader should consult the Table of Contents in Chapters 4 and 5 for the appropriate section.

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