Office of
Solid Waste
Washington DC 20460

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EPA

Draft Environmental Impact Statement

On the Proposed Guidelines for the Landfill Disposal of Solid Waste

DRAFT

ENVIRONMENTAL IMPACT STATEMENT

PROPOSED REGULATION

GUIDELINES FOR LANDFILL
DISPOSAL OF SOLID WASTE
(40 CRF PART 241)

PREPARED BY
OFFICE OF SOLID WASTE
U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

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SUMMARY

DRAFT ENVIRONMENTAL IMPACT STATEMENT ON THE PROPOSED GUIDELINES FOR THE LANDFILL DISPOSAL OF SOLID WASTE

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF SOLID WASTE

1. Name of Action
   Administrative Action (regulatory)

2. Brief Description of Action

Under authority of Section 1008(a) of the Solid Waste Disposal Act as amended by the Resource Conservation and Recovery Act of 1976 (RCRA) (Public Law 94-850), EPA has issued a proposed set of "Guidelines for the Landfill Disposal of Solid Waste". The proposed action presents recommended considerations and practices for the location, design, construction, operation, and maintenance of solid waste landfill disposal facilities. Application of these recommended practices on the case-by-case basis should assist such facilities in meeting the provisions contained in EPA's "Criteria for Classification of Solid Waste Disposal Facilities".

3. Summary of Beneficial and Adverse Environmental Impacts

   a. Foremost, application of the proposed Guidelines will contribute to significant overall improvements in environmental quality. Specifically, beneficial impacts can be expected for groundwater quality, surface water quality, and air quality, as well as in the areas of increased protection of public health and safety.

   b. Existing facilities employing Guidelines recommended technologies to upgrade operations should eliminate or reduce to acceptable levels the adverse environmental effects resulting from present practices.

   c. Utilization of the Guidelines' recommendations should enable new and planned landfill disposal facilities to be sited, constructed, operated, and maintained in a manner that ensures a reasonable degree of protection for environmental resources and for the public welfare.

   d. Incorporation of the Guidelines recommended considerations and practices in landfilling solid wastes will increase energy usage for the design, installation, and operation of new technologies and consequently, increase the economic cost of landfill disposal of solid wastes.

4. Alternatives Considered

   a. No action

   b. Delay of action

   c. Proposed action (technical and approach alternatives)

   d. Alternative action

5. Federal, State, and Local Agencies From Which Written Comments Have Been Requested

The proposed guidelines are being distributed to hundreds of individuals and organizations representing all sectors of our society. The draft EIS is also being distributed to a diverse group of individuals and organizations including, but not limited to, the following examples:

Other Federal Agencies

Department of Interior (U.S.G.S., Fish and Wildlife, Bureau of Mines, MESA, Office of Surface Mining)

Department of Health, Education, and Welfare (Food and Drug)

Department of Agriculture

Department of Commerce

Department of Energy

Department of Defense

State Government

All 50 State solid waste management offices

National Governors' Association

National Conference of State Legislators

National Association of State Attorneys General

Conference of State Sanitary Engineers

Local Government

National Association of Regional Councils

National Association of Counties

National League of Cities/U.S. Conference of Mayors

International City Management Association

Solid Waste Management Professional Groups

National Solid Waste Management Association

Governmental Refuse Collection and Disposal Association

American Public Works Association

Association of Metropolitan Sewerage Authorities

Professional Associations

American Society of Civil Engineers

Water Pollution Control Federation

American Water Works Association

National Water Well Association

Environmental, Health, and Citizens Groups

Citizens for a Better Environment

Environmental Action, Inc.

Environmental Defense Fund

Natural Resources Defense Council

National Wildlife Federation

National Environmental Health Association

Izaac Walton League

League of Women Voters

6. Date Statement Available to the Public

The Draft Environmental Impact Statement has been provided to the Office of Federal Activities, EPA, for the purpose of publishing an official public notice of availability in the Federal Register. This notice is anticipated by March 1, 1979. The 60-day public comment period for the Draft EIS will be concurrent with the public comment period on the proposed Guidelines. Copies of the Draft EIS may be obtained by writing: DRAFT EIS, Office of Solid Waste, WH564, U.S. EPA, Washington, D.C. 20460, Attention: Bernard Stoll. Comments should be sent to the same address.

ACKNOWLEDGEMENTS

This EIS was prepared by Fred C. Hart Associates, Inc., under EPA contract number 68-01-4895. The major contract personnel contributing to this EIS were:

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1.0 EXECUTIVE SUMMARY

This summary provides a brief description of subsequent sections 2.0 through 7.0 as contained in this EIS.

Section 2.0 of this analysis identifies the nationwide problem of improper landfill disposal as it relates to consequent air, surface water, and groundwater pollution. The Resource Conservation and Recovery Act of 1976 (herein referred to as the "Act" or "RCRA") legislates a potential solution to those problems by requiring identification and upgrading of those sites responsible for threats to the public safety and welfare. Section 1008 of the Act provides the legal basis for the preparation of technical and economic guidelines for the disposal of solid waste. In response EPA is promulgating "Guidelines") and has voluntarily prepared this environmental impact statement (EIS) to identifiy potential environmental and economic effects of implementing this proposed administrative action.

In effect the Guidelines provide descriptions of alternative siting, design, operating leachate control, gas control, surface runoff control, and monitoring approaches and technologies which may be utilized to meet site specific levels of environmental protection. As such, the environmental impacts of implementation of the Guidelines are positive in nature since greater levels of air, surface water, and groundwater protection should result.

The scope of this analysis is limited to the landfill disposal of solid waste, excluding hazardous waste disposal in accordance with regulations to be promulgated under RCRA Subtitle C. Separate guidelines are being prepared for landspreading and surface impoundment disposal technologies.

Section 3.0 describes specific methodology approaches utilized in the analysis. In general, reliance was placed on an extensive literature search and contact with EPA, State, industry, and other knowledgeable sources. Economic approaches required evaluation of reference sources to determine baseline costs of existing landfill operations, and development of a model format to estimated landfill upgrading costs. The model development necessitated selection of model types, and identification of baseline and required upgrading technologies. For the model landfills selected, unit upgrading technology costs and increased disposal rates were identified. Results indicated a potential range of increase in landfill disposal costs from approximately 40 to 90 percent. Existing baseline costs ranged from approximately \$3.95 to \$11.15 per ton (\$4.42 to \$12.49 per metric ton).

Section 4.0 identifies the rationale for selecting the proposed "guidance" format as the most suitable approach for presenting the landfill Guidelines. Subsequent subsections identify functions, design considerations, economic costs, and environmental impacts of utilizing the variety of techniques available to mitigate or avoid potential pollution problems.

Section 5.0 identifies overall impacts of implementing the Guidelines with respect to siting, design, operation, leachate control, surface runoff control, and monitoring approaches. The economic analysis briefly described in Section 3.0 is presented in detail and indicates that disposal costs could increase on the order of approximately $1.80 to $9.85 per ton ($2.01 to $11.02 per metric ton) if the recommended practices of the Guidelines are applied.

This section also presents estimates of increased construction energy utilization based upon estimates of increased construction costs. The energy impacts summary section also indicates that operating energy expenditures will increase depending on specific technologies employed at each site.

Section 6.0 identifies irreversible and irretrievable uses and short-term uses versus long-term productivity of the environment. In effect while short-term impacts and expenditures will be required to implement upgrading technology and operations, long-term benefits will accrue in terms of prevention of air, groundwater, and surface water pollution in minimization of risks to the public health and welfare, and in increased productivity of the environment.

Section 7.0 provides a summary of the public participation process.

2.0 LANDFILL EIS INTRODUCTION

2.1 PROBLEM DESCRIPTION

The national problem of solid waste disposal has been dramatized by the increasing amounts of solid wastes produced today, and the environmental consequences for past disposal practices that have proved to be inadequate for present needs. Enormous amounts of solid wastes are generated by every sector of society. Important classes of waste generation include municipal solid wastes, industrial waste, pollution control residues, construction and demolition waste, and agricultural wastes. As the nation grows in population and level of technology utilization, the amount and composition of wastes in each of these categories is constantly increasing and changing.

A majority of this refuse is disposed of on land. Lack of planning, finance, public interest, and availability of comprehensive technical guidance has led to a situation wherein disposal methodologies have often resulted in air, surface water, and groundwater pollution problems.

Although proper landfilling is a controlled method of land disposal, adverse environmental effects can still result from lack of planning, provisions of adequate environmental safeguards, and maintenance of high quality daily operations. The major problems associated with improper landfilling that need to be addressed are possible groundwater pollution, air pollution, surface water pollution and public health and safety hazards.

As solid wastes in a landfill degrade, chemical and biological reactions produce a variety of solid, liquid, and gaseous products. Biological activity within a landfill generally begins with aerobic degradation and produces carbon dioxide, water, sulfates, nitrates, and a broad mix of organic and inorganic compounds. When the available oxygen supply is depleted, anaerobic microorganisms predominate and, consequently, generate methane, carbon dioxide, alcohols and organic acids, and a variety of other substances. Significant amounts of these inorganic and organic substances and microbial agents can be leached from decomposing refuse by moisture produced in and/or infiltrating through the landfill. The resulting liquid solution, consisting of dissolved and suspended solids, is termed leachate.

Groundwater and surface water pollution can result from landfill leachate percolating into subsurface soil and water systems. The composition and quantity of leachate produced is important in determining the effect on resultant water quality. Leachate characteristics vary with the solid waste composition and time as decomposition reactions proceed. The quantity of leachate also varies with time, waste type, incident precipitation, and operational controls. In order to minimize or control water pollution from landfill sites, it is advisable to reduce the production of leachate and to prevent or minimize the movement of contaminants away from the landfill sites.

A fraction of waste decomposition product includes a gaseous mixture composed of methane and carbon dioxide, with traces of nitrogen, oxygen, and hydrogen sulfide. The level of gas production depends primarily on the amount and type of organic material in the wastes, moisture content, and temperature variations in the landfill. In the early stages of aerobic degradation, carbon dioxide is the most commonly produced gas with only small amounts of methane being generated. Concentrations of carbon dioxide decrease when anaerobic degradation begins to dominate the decomposition process, resulting in increasing amounts of methane production.

These gases are important considerations in evaluating the environmental effects of a landfill because they migrate outward from the site, and can travel large distances laterally through permeable soils. Methane represents a pollution and safety hazard because it is explosive when present in air at concentrations between 5 and 15 percent. In addition, damage to surrounding vegetation can be caused by low oxygen concentrations in the root zone when CO_2 and other gases replace the oxygen normally occupying the interstices of soil. Landfill generated gas movement can be controlled by several engineering methods to minimize these adverse effects.

Another potential source of water pollution from landfill sites is surface runoff. Direct runoff from the active face and uncontrolled runoff from incident precipitation may erode the soil cover and entrain solid wastes, as well as other suspended or dissolved solid matter. These contaminants may ultimately be received by adjacent surface water systems. Proper surface runoff control can present direct contamination of the runoff and minimize the possibility of off-site pollution of receiving waters.

An improperly constructed or inadequately maintained landfill can pose additional health and safety hazards. If decomposing solid wastes are left accessible, they can attract rodents, flies, and other carriers capable of transmitting pathogens. Other safety considerations which may affect site employees and visitors include explosion and fire hazards. Proper site operation and access control can minimize potential health and safety problems.

In recognition of the seriousness of existing and potential problems, and the large numbers of sites which have exhibited the types of problems described above, Congress in October of 1976 passed the Resource Conservation and Recovery Act (RCRA), Public Law 94-580.

2.2 LEGAL BASIS FOR ACTION

The 1965 Solid Waste Disposal Act marked the beginning of Federal regulation of solid waste disposal. Under this act, grants were made available to conduct surveys of solid waste disposal practices, and to establish a national reserach and development program to improve methods of disposal. In 1970, the Resource Recovery Act amended the Solid Waste Disposal Act. This measure provided specific funding for resource recovery programs. In 1976 an expansive and highly significant piece of environmental legislation was enacted that finally attempted to address the scope of the nation's solid and hazardous waste disposal problems, and the accompanying role of resource conservation. This act, the Resource Conservation and Recovery Act (RCRA), proposed to:

1. provide technical and financial assistance for improved solid waste disposal practices;

2. provide training grants in solid waste disposal occupations;

3. prohibit open dumping;

4. regulate hazardous wastes;

5. promulgate guidelines for solid waste collection, transport, recovery, and disposal;

6. promote a national reserach and development program;

7. promote demonstration and construction projects utilizing improved solid waste and resource recovery technologies; and,

8. establish cooperative solid waste management among all levels of government and private enterprise.

In particular, RCRA Sections 1008 and 4004 address the problems of environmentally acceptable solid waste disposal. Section 4004 required EPA to establish criteria for determining which solid waste disposal facilities shall be classified as having no reasonable probability of adverse effects on health or the environment. The classification criteria as proposed identify environmentally seisitive disposal locations (wetland, floodplains, permafrost areas, sole source aquifers, and critical habitats) and require that groundwater, surface water, and air resources be adequately protected. Section 1008 required EPA to develop guidelines which:

1. "provide a technical and economic description of the level of performance that can be attained by various available solid waste management practices;"

2. describe levels of performance, including appropriate methods and degrees of control, that will result in the protection of public health, ground and surface water quality, ambient air quality, disease and vector control, safety, and aesthetics; and,

3. provide minimum criteria to define solid and hazardous waste dumping.

With respect to landfill disposal EPA has prepared "Proposed Guidelines for the Landfill Disposal of Solid Waste". This accompanying EIA analyzes the technical, economic, and enviornmental impacts of implementing these guidelines.

2.3 SUMMARY OF PROPOSED ACTION

As directed by Section 1008(a) of RCRA, EPA has begun developing guidelines to aid in meeting Section 4004 solid waste disposal criteria. The first set of guidelines, under discussion here, deals specifically with the landfilling method of solid waste disposal. The stated purpose of the proposed guidelines is "to suggest preferred methods for the design and operation of landfill facilities for disposal of solid wastes." By examining the various available technologies and expected levels of performance, EPA is providing guidelines that should assist disposal facilities in meeting required levels of environmental and public health protection.

In keeping with the stated goals and objectives of the Act, the scope of the "Guidelines for the Landfill Disposal of Solid Waste" encompasses seven areas, as follows:

SECTION	TOPIC
241.200	Site Selection
241.201	Design
241.202	Leachate Control
241.203	Gas Control
241.204	Runoff Control
241.205	Operation
241.206	Monitoring

In summary, the Guidelines identify a variety of approaches and technologies which may be implemented, on a site specific basis, to provide or maintain the required levels of environmental protection. As such, the following provides a very brief summary of the major sections of the proposed Guidelines:

1. The site selection section of the Guidelines indicates that site selection should be based on thorough consideration of hydrogeologic, economic, and environmental factors. Site selection should aviod environmentally sensitive areas, identified as wetlands, floodplains, permafrost areas, critical habitats, and recharge zones of sole source aquifers. The Guidelines also suggest that zones of active faults and karst terrain be avoided as landfill sites. Site evaluations should include consideration of possible incorporation into existing or future regional solid waste disposal systems.

2. The Guidelines design section emphasizes that design of a facility should analyze tradeoffs among environmental impacts, economic considerations, future use alternatives and nature of the wastes. The

2. (con't)
major goal of maintaining ground and surface water quality can be attained by controlling leachate and gas as a prime objective.

3. The leachate control section is concerned with controlling production of leachate and its escape from the site, and consequent impact on the environment. Synthetic and natural clay liners are technologies that are available to control leachate production by restricting groundwater intrusion into the site, and to prevent leachate escape into the environment. Leachate collection techniques also assist in minimizing leachate escape from the site, while leachate treatment and recycling techniques more directly minimize the impact of leachate on the surrounding environment.

4. The gas control section is concerned primarily with reducing methane gas production by minimizing moisture infiltration, with controlling escape of gases into the atmosphere, and with minimizing the migration of gases into adjacent soils. These objectives can be achieved by utilizing various combinations of vertical impermeable barriers, vertical pipe vents, horizontal gravel trenches, and other gas collection technologies.

5. Recommended practices in the runoff control section include diversion of runoff through channeling devices such as dikes or other runoff diversion techniques, and maxmizing runoff from the landfill surface by the use of cover material, grading and revegetation. Ponding can be used to remove eroded sediment or other solid materials suspended in runoff that may otherwise contaminate receiving waters.

6. The section on landfill operation encompasses the full range of landfilling from construction of waste cells to personal safety on the site. Compaction, shredding, and baling are specific technology alternatives employed in the construction of waste cells that are identified in the Guidelines. Other operating

6. (con't)
   techniques which are discussed further include access control, safety, fire control, vector control, and litter control.

7. The monitoring section indicates that monitoring of leachate and gas production should continue during construction and after completion of a landfill facility. Once baseline conditions are established for groundwater supplies, leachate generation and migration should be monitored regularly. Explosive and toxic gas generation and migration should also be monitored regularly in the adjacent soils and in structures adjacent to the landfill.

Although the Guidelines recommend these methods to satisfy the "Criteria for Classification of Solid Waste Disposal Facilities," they are not intended to be "exclusive or discourage or preclude the development or use of equally effective and economical technologies." In effect the Guidelines provide a set of technologies which may be available for incpropration into landfill operations for a variety of waste types and environmental settings. Since the primary objective is adequate protection of the environment, which is generally achievable by providing the necessary air, groundwater, and surface water controls, the actual technologies required at any one location are highly site specific. In a large number of sites a variety of combination of technologies may be available to meet the fixed goal of environmental protection.

2.4 PURPOSE OF EIS DOCUMENT

In the past, the lack of technical guidance, coupled with the lack of uniformly enforceable regulation concerning methods of land disposal of solid wastes, has resulted in a widespread national problem of environmental degradation affecting air, water, and land resources. The health and environmentally related problems that are facing us today due to inadequate disposal serve to underline the need for guidelines that will promote a consistent level of environmental protection commensurate with the variety of siting and disposal requirements present across the country. The purpose of preparing this document is to identify the environmental impact of implementing those proposed Guidelines. As a result it has been useful to individually summarize, analyze, and evaluate the performance of a major available technologies suggested by the Guidelines. As a result, the technologies can be examined with respect to their possible impacts on environmental, energy, and economic resources. Although there are numerous site specific considerations that must be included in planning a landfill facility, this generalized discussion of the Guidelines' recommendations will assist the EPA, the states, and representatives of individual landfill sites in comparing trafeoffs among alternative technologies. Preparation of the EIS will also enable the public to understand EPA decisions and participate in the agency decision-making process.

2.5 EIS SCOPE OF WORK

The Solid Waste Disposal Act, as amended by the Resource Conservation and Recovery Act (RCRA) of 1976, directs the EPA to develop and publish guidelines for comprehensive solid waste management. In order to implement this legislation, recommended practices for landfilling, impoundment, and landspreading techniques are being prepared in three separate sets of guidelines. This document is intended to summarize the technical, environmental, economic, and energy impacts of implementing the landfill Guidelines. As such, this EIS excludes consideration of impoundment and landspreading methods and focuses solely on the Guidelines pertaining to the landfill method of solid waste disposal.

3.0 APPROACH

3.1 BACKGROUND INFORMATION AND SOURCES

A major research effort was initiated in developing the detailed descriptions and analyses of the currently available landfilling practices. This effort incorporated pertinent background information acquired from a variety of sources including contact with regulatory agencies and private concerns. Special emphasis was placed on obtaining data on current research and development areas in landfill technology.

The literature search, which formed the major segment of the data collection work, covered previous environmental impact analyses, various EPA studies, state-of-the-art analyses, technical references, and a variety of other sources. The extensive information base thus accumulated, was supplemented by contacts with EPA regions, appropriate state and local agencies, and private organizations and individuals. In addition to reviewing all aspects of landfilling technology and relevant environmental and public health considerations, particular attention was paid to recent documents on newer technologies provided by the Solid and Hazardous Waste Research Division of the Municipal Environmental Research Laboratories, Office of Research and Development, Cincinnati EPA.

3.2 EVALUATION METHODS AND APPROACH

3.2.1 Introduction

The remainder of this EIS provides detailed technical and environmental evaluations of potential landfill technologies; environmental, economic and energy impacts of Guidelines implementation; identification of short and long-term impacts and irretrievable committments of resources due to Guidelines implementation; and a summary of the public participation process. The following sections provide a more detailed summary of the specific methodologies utilized in identifying environmental, economic and energy impacts.

3.2.2 Environmental Methodology

Technical and environmental descriptions and impacts as identified in Section 4.0 were developed primarily via the literature review process described in Section 3.1

3.2.3 Economic Methodology

To estimate the per ton increase in disposal costs which may occur as a result of the increased use of a variety of technologies to achieve adequate levels of environmental protection, a three-step methodology was employed. The following is a summary of the methodology that was developed in "Analysis of the Technology, Prevalence and Economics of Landfill Disposal of Solid Waste in the United States" - Volume II by Fred C. Hart Associates, Inc.

The first step was the selection of model landfills. Existing data on landfill types and sizes were utilized to characterize the set of real world model landfills. In essence, three model waste types were chosen: municipal, industrial, and pollution control residue. Three model sizes were chosen including 10 ton per day, 100 ton per day, and 300 ton per day sites. For all sites, differences in environmental conditions were assessed by evaluating each model type and size in environmentally sensitive and non-sensitive settings. As per the "Criteria for Classification of Solid Waste Disposal Facilities (43 Fed. Reg. 49R) sensitive settings are identified to be wetlands, floodplains, permafrost areas, critical habitats, and recharge zones of sole source aquifers. All other land settings are identified as non-sensitive. Additional details regarding the selection of model landfills are provided in Section 5.2.

The second step was to identify baseline costs for facilities within each of the three model sizes. Baseline costs are defined as the unit costs incurred by facilities with the mix of technologies and operating procedures currently in use. Case histories and general cost references were analyzed to estimate per ton costs for disposal sites in each of the above three size categories.

The third step was to estimate the costs of implementing alternative technologies as described in the Guidelines. This first required estimation of the type of technologies which on average best represent those technologies currently in use for each of the waste types in both sensitive and non-sensitive environs. Secondly, a set of upgrading technologies were assumed which would best meet requirements for environmental protection and which would be most representative of expected upgrading costs. Instrumental in this analysis was the development of cost estimates for potential upgrading technologies. Estimates were based upon an examination of a variety of case studies and engineering cost estimates. Section 5.0 presents technology per ton cost estimates for each of the three size categories. Appendix A presents technology unit costs and calculation assumptions for the same technologies.

3.2.4 Energy Methodology

Section 5.3 presents an estimation of potential increased energy consumption that will result from both construction and operating phases of landfill operations. Construction energy impacts were estimated by assuming that energy use was directly proportional to increased capital expenditure. For operating energy impacts, estimates on increased energy expenditures has been related to specific technology incorporation. The results of these analyses were originally presented in "Analysis of the Technology, Prevalance, and Economics of Landfill Disposal of Solid Waste in the United States" (Volume II) by Fred C. Hart Associates, Inc.

4.0 EVALUATION OF ALTERNATIVE TECHNOLOGIES

In developing the "Proposed Guidelines for the Landfill Disposal of Solid Waste" the Office of Solid Waste has evaluated a variety of alternatives to the proposed action. These alternatives include no action, delay of action, and alternative emphasis, as well as the proposed action.

The no action alternative is clearly not an appropriate option. The Resource Conservation and Recovery Act (RCRA) of 1976 was passed "to provide technical and financial assistance for the development of management plans and facilities for the recovery of energy, and other resources from discarded materials and for the safe disposal of discarded materials, and to regulate the management of hazardous waste." In keeping with those goals Section 1008 required EPA to publish suggested guidelines for solid waste management which would provide technical and economic descriptions of available solid waste management practices. In completing the Guidelines, EPA is fulfilling in part this legislative mandate.

Similarly, the delay of action alternative is not viable. Section 1008 of the Act specified a limited time frame in which EPA was required to publish the Guidelines. Current problems being experienced throughout the country demonstrate the immediate need for a unifying set of guidelines designed to provide the required levels of environmental protection.

In evaluating alternative emphases or approaches to be potentially utilized in the Guidelines' development, it is first essential to understand the basic implications of the proposed Guidelines. In fact, the word "Guideline" embodies the central theme of this document. As such, the Guidelines are intended to function in an advisory capacity by providing detailed information on planning approaches and detailed technologies which might be utilized in meeting the goals of air, surface water, and groundwater protection identified in the "Criteria for Classification of Solid Waste Disposal Facilities" and as embodied in the Act. As such, the Guidelines have attempted to define a variety of technological alternatives which might be utilized to meet individual, site specific requirements for air, surface water, and groundwater protection, as well as for the broader goal of protection of public health and safety.

In this respect, alternative approach terminologies such as less restrictive vs. more restrictive, mandatory vs. suggested, prescriptive vs. descriptive, etc., have no real significance. The Guidelines provide only potential approaches and methodologies to meet the goals of environmental protection and as such are not enforceable by law. Enforceability provisions and other implications suggested by the terminologies listed above are intended to be managed at the state level. In essence this is the only viable approach due to the widely varying disposal conditions experienced from state to state across the country.

With the above in mind, the remainder of this section attempts to acquaint the reader with the functions, design considerations, economic costs, and environmental impacts of available landfilling technologies. Section 5.0 also provides insights on the effects of providing comprehensive landfilling Guidelines in terms of the resulting improved levels of environmental protection in the air, surface water, groundwater, and public health and safety sectors.

4.1 COMPACTION

4.1.1 Introduction

Compaction of solid wastes to achieve volume reduction can significantly increase the capacity and life of a sanitary landfill. Compaction also results in minimization of vectors and potential fire hazards.

The Guidelines recommend that "in order to conserve landfill disposal site capacity and preserve land resources solid wastes should be incorporated into the landfill in the smallest practicable volume." While compaction occurs to some degree in the placement of wastes in the daily cell, special landfill compaction equipment may be necessary for maximum volume reduction. The following sections describe in more detail the technology and environmental impacts of compacting solid wastes.

4.1.2 Technology Summary

4.1.21 Operation

Solid waste compaction can be achieved via utilization of appropriately selected standard landfill equipment. However, more efficient compaction can be achieved via utilization of specialized equipment.

Mobile waste compaction equipment includes a variety of machine types and power train components which have been modified to produce a machine type which is excellent for spreading and compacting solid wastes on a relatively level terrain at moderate speed ranges (up to 23 mph). Steel wheels as generally provided on landfill compactor equipment, result in significantly greater compaction (10 to 15%) that rubber-tired or tracked machines of comparable weight.

Solid waste compaction in the landfill is achieved by the compressive forces developed by repeated passes of a landfill machine on the waste mass. Depending on waste type and moisture content, two to five passes are completed over each layer of waste placed during the daily operations.

Mobile landfill compactors should be equipped with the appropriate accessories to alleviate the problems associated with overheating due to clogged radiators, broken fuel and hydraulic lines, tire punctures, and damage incurred when waste becomes lodged in the tracks or between the wheels and the machine body.

4.1.22 Current Economic Costs

Current economic costs of this technology average $1.90 ($2.12), $0.20 ($0.22), and $0.05 ($0.06) per ton (per metric ton) for 10, 100, and 300 ton per day landfill sites, respectively.

4.1.3 Environmental Impact Summary

1. Volume reduction through solid wastes compaction allows utilization of smaller volume capacity landfills in a given waste management region. Therefore, the landfill siting process is simplified as a smaller area of land must be selected possibly resulting in reduced adverse environmental impacts.

2. Compaction of solid wastes serves to reduce landfill fire hazard, since it minimizes waste oxygen content in the landfill.

3. Increased compaction improves vector and litter control.

4. Compaction potentially slows gas and leachate production by deterring waste decomposition. However, this potentially extends the period during which the landfill will continue to generate gas and leachate possibly requiring long-term post-closure landfill monitoring and management.

4.2 SHREDDING

4.2.1 Introduction

Shredding is a solid waste volume reduction technique which consists of milling the wastes to reduce waste constituents to smaller, more uniformly sized particles. The Guidelines recommend that in order to conserve landfill disposal site capacity and preserve land resources, solid wastes should be incorporated into the landfill in the smallest practicable volume. The Guidelines state that compaction or other volume reduction may take place at or before delivery to the landfill, by utilizing balers, shredders, or stationary compactors." The Guidelines add that "Compaction of solid waste and cover soil also aids in minimization of rodents, vectors and fires."

The following sections describe in more detail the technology and environmental impacts of shredding.

4.2.2 Technology Summary

4.2.21 Operation

A shredding operation normally consists of a shredding unit, a transport network, and the shredfill (landfill accepting shredded wastes). Several types of shredding devices are used; including vertical and horizontal axis hammer mills, vertical axis grinders, and horizontal axis impactors. These shredders also usually include a variety of conveyors for waste routing scales, truck loading and unloading platforms, and storage bins or areas.

In the shredding process, solid wastes are milled to produce uniform particle sizes on the order of two to four inches in diameter. Waste size reduction results in up to 30 percent greater in-place waste density at the shredfill site. On a site specific basis, daily cover may not be required, since litter and vector problems are reduced. Decreased settlement and improved operation during cold and wet weather have also been noted. Negatively, mechanical difficulties can occur with the shredder unit, and rapid wear of contact components requires a high level of maintenance effort.

4.2.22 Current Economic Costs

Full scale shredder technology is currently economically unfeasible at small disposal sites. For a 300 TPD facility, current costs are on the order of \$7.00 per ton (\$7.89 per metric ton).

4.2.3 Environmental Impact Summary

1. Volume reduction through solid waste shredding reduces disposal volume requirements for existing and planned facilities and consequently reduces environmental impacts associated with landfill expansion or initiation. Siting difficulties are also minimized due to the smaller amount of land required.

2. The potential for reducing daily cover material requirements for shredfills also minimizes impacts associated with obtaining cover material and reduces related siting considerations.

3. Solid waste shredding improves landfill aesthetics by potentially reducing odor and litter problems typically associated with non-shredded landfills.

4. Shredding reduces vector problems and consequent potential health related problems.

5. Shredded solid waste presents less risk of landfill fire and consequent air pollution and safety hazards.

6. Waste decomposition, and therefore leachate and gas production, initially may occur at a faster rate in a shredfill due to the increased waste surface area. Thus, shredding may be considered advantageous in that it promotes rapid landfill stabilization.

7. Shredding units pose a danger to employees from flying objects, explosions, fires, and noise.

8. Shredding is often the first step in implementation of a resource recovery facility, which in turn can result in significient reduction of impacts due to disposal processes.

4.3 BALING

4.3.1 Introduction

Baling is a solid waste volume reduction technique which consists of compacting solid wastes in high density, (approximately 1800 lbs/cu. yd.) rectangularly shaped bales. The Guidelines recommend that "in order to conserve landfill disposal site capacity and preserve land resources solid wastes should be incorporated into the landfill in the smallest practicable volume." The Guidelines state that "compaction or other volume reduction may take place at or before delivery to the landfill, by utilizing balers, shredders, or stationary compactors." The Guidelines add that "compaction of solid waste and cover soil also aids in minimization of rodents, vectors and fires."

The following sections describe in more detail the technology and environmental impacts of incorporating baling into a landfill disposal site.

4.3.2 Technology Summary

4.3.21 Operation

An on-site solid waste baling operation includes a baling plant and a specially designed balefill (landfill accepting baled wastes). Alternatively, the baling plant may be located at a large quantity source of solid waste or at a waste transfer collection point.

A typical baling plant may consist of stationary equipment such as horizontal and inclined conveyors, a load-cell scale, a high density baler, a central control tower with control panels, hydraulic bale push rams, and a bale truck loading platform. Mobile equipment might include an articulated front-end loader, a small general purpose "bobcat" loader, and a forklift.

Once processed, the bales are stacked for disposal at the active face. Soil cover may be applied periodically.

The basic advantages of the process include reductions in required landfill volume, ease of waste transport and placement,vector and litter reduction, decreased settlement, and reduced requirements for cover material. A potential disadvantage is that the compaction process slows the decomposition process, thus potentially extending the period of time during which the landfill will continue to generate gas and leachate. Accordingly, the conditions which favor this alternative are in areas in which long hauls are needed to reach the landfill, and in areas in which there is a shortage of landfill sites thus requiring maximum utilization of available land.

4.3.22 Current Economic Costs

Full scale baling technology is currently economically unfeasible at small disposal sites. For a 300 TPD facility current costs are on the order of $5.00 per ton ($5.60 per metric ton).

4.3.3 Environmental Impact Summary

1. Since solid waste baling can double the potential volume capacity of a landfill site, the adverse impacts related to landfill development and expansion can be decreased. Similarly, siting problems can be minimized since the site selection process need not be as constrained by limited site availability.

2. Since solid waste baling reduces cover material requirements, impacts normally associated with cover material acquisition can be minimized. Less siting dependence on obtaining suitable cover supplies can also permit the siting selection process to more adequately address other environmental considerations.

3. Similarly, since volume reduction achieved at transfer stations by baling facilitates waste transport, consequent possibilities for longer haul routes to disposal sites permits additional flexibility in the siting process.

4. The increased compaction resulting from baling of solid waste serves to reduce landfill fire potential by minimizing atmospheric oxygen intrusion to the landfill.

5. Baling of solid waste results in improved vector and litter control.

6. With the current level of technology,resource recovery as a disposal option is not feasible once the waste is baled and landfilled.

4.4 SURFACE RUNOFF DIVERSION

4.4.1 Introduction

Surface runoff diversion utilizes a variety of techniques or combination of techniques to minimize the infiltration of surface water into the solid waste cells. In addition, surface drainage systems incorporate design features that help control significant erosion of cover material. These drainage techniques are utilized not only to prevent runoff from adjacent areas from penetrating the site, but also to control on-site runoff, particularly in minimizing runoff onto the active face.

The Guidelines recommend that landfill disposal facilities be equipped with suitable channeling devices, such as ditches, berms, or dikes to divert surface runoff from land areas contiguous to the landfill. More specifically, the surface runoff structures constructed should be capable of diverting all surface water runoff from a 10 year, 24 hour storm.

4.4.2 Technology Summary

4.4.21 Runoff Control

Surface Runoff Diversion Functions. Two main functions in the area of runoff control are served by surface runoff diversion techniques. Soil erodibility is primarily a result of soil grain size distribution, soil structure and soil permeability (see the Section 4.8 discussion of daily and final cover). However, erodibility is also dependent upon surface runoff velocity, water flow characteristics and other hydraulic factors. By reducing on-site runoff flow and velocity, diversion of surface drainage and control of on-site drainage reduce the sediment load of runoff waters and minimizes siltation of adjacent receiving water bodies. Additionally, minimization of cover erosion helps the cover material to maintain its integrity and to resist percolation of surface waters.

Design and Construction. The actual design features of a system including the type of diversion structures selected, the actual dimensions of the structures, and the specific construction techniques, are dependent upon a number of interrelated site specific factors. These design considerations include the site's topographic, hydrogeologic and hydraulic features. Major topographic considerations include slope steepness, slope length and slope shape. Other important factors are rainfall intensity, soil water content and surface permeability.

A number of structures can be used singly or in combination to achieve leachate control through runoff diversion including: surfaced channels, natural drainage ditches, dikes, berms, collector pipe systems, and pump installations.

There is a variety of construction techniques for open channels and drainage ditches that can be located upland of the site to intercept and direct surface waters around or away from the site (e.g., Figures 4-1 and 4-2). Depending on substrata permeability and soil erodibility, drainage channels can be constructed of earth, lined with sod, stone, asphalt or rubble, or fabricated from half sections of concrete or corrugated metal pipe. In addition to permanent drainage structures, temporary channels and ditches can be utilized to minimize on-site runoff onto the active face.

In addition to the ditches and channels that form the basis of a runoff diversion system, structures such as berms, dikes, and check dams can be utilized to increase control of runoff by reducing flow intensities. Natural or artificially constructed berms reduce runoff velocity and minimize erosion across the landfill surface by decreasing the slope of the flow. While berms do not divert surface runoff, a series of berms can decrease flow velocities.

Check dams are constructed within the drainage channels where a heavy flow is anticipated to allow more control over diverted surface runoff. By providing runoff storage capacity, runoff can be regulated to maintain acceptable hydraulic discharge characteristics.

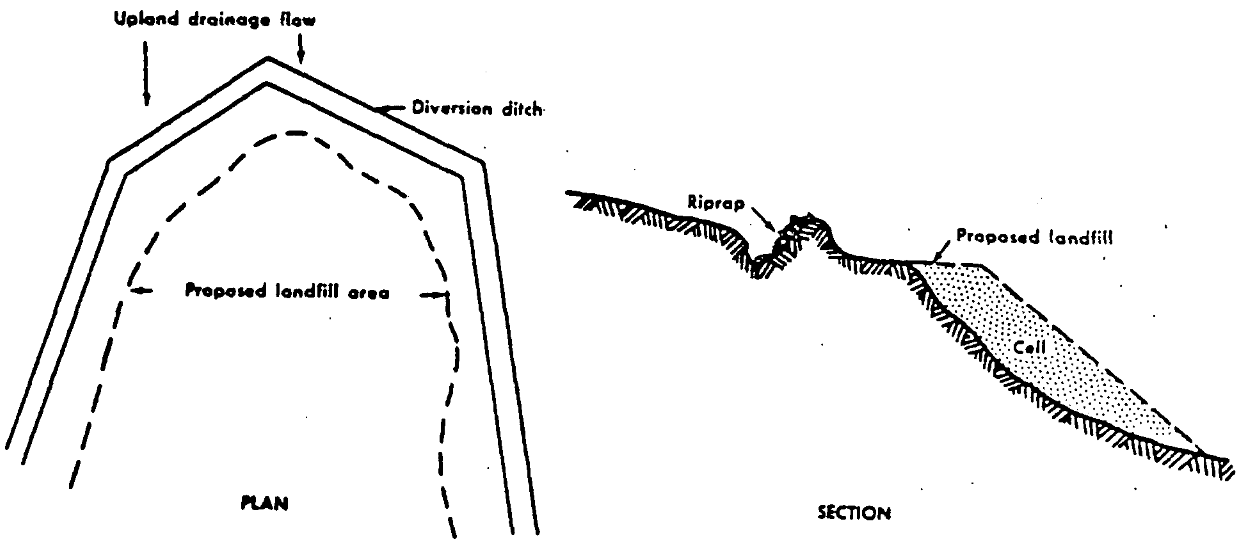
4.4.22 Leachate Control

A system of surface runoff diversion structures can assist in accomplishing the function of leachate control. In effect, diversion channels or ditches act to minimize the volume and rate of surface runoff flow across a landfill site, which in turn reduces uncontrolled infiltration of precipitation and other surface water into the solid waste. Since waste moisture content is a major factor in the rate of waste decomposition and the amount of leachate generated, surface runoff diversion techniques, by acting to reduce the moisture content, may also potentially result in reduced rates of degradation, reduced rates of contaminant escape, and decreased volume of leachate generation.

As previously mentioned, runoff diversion structures are utilized in two capacities: at locations upgrade from a landfill facility to intercept and prevent natural drainage of surrounding off-site areas from

FIGURE 4-1

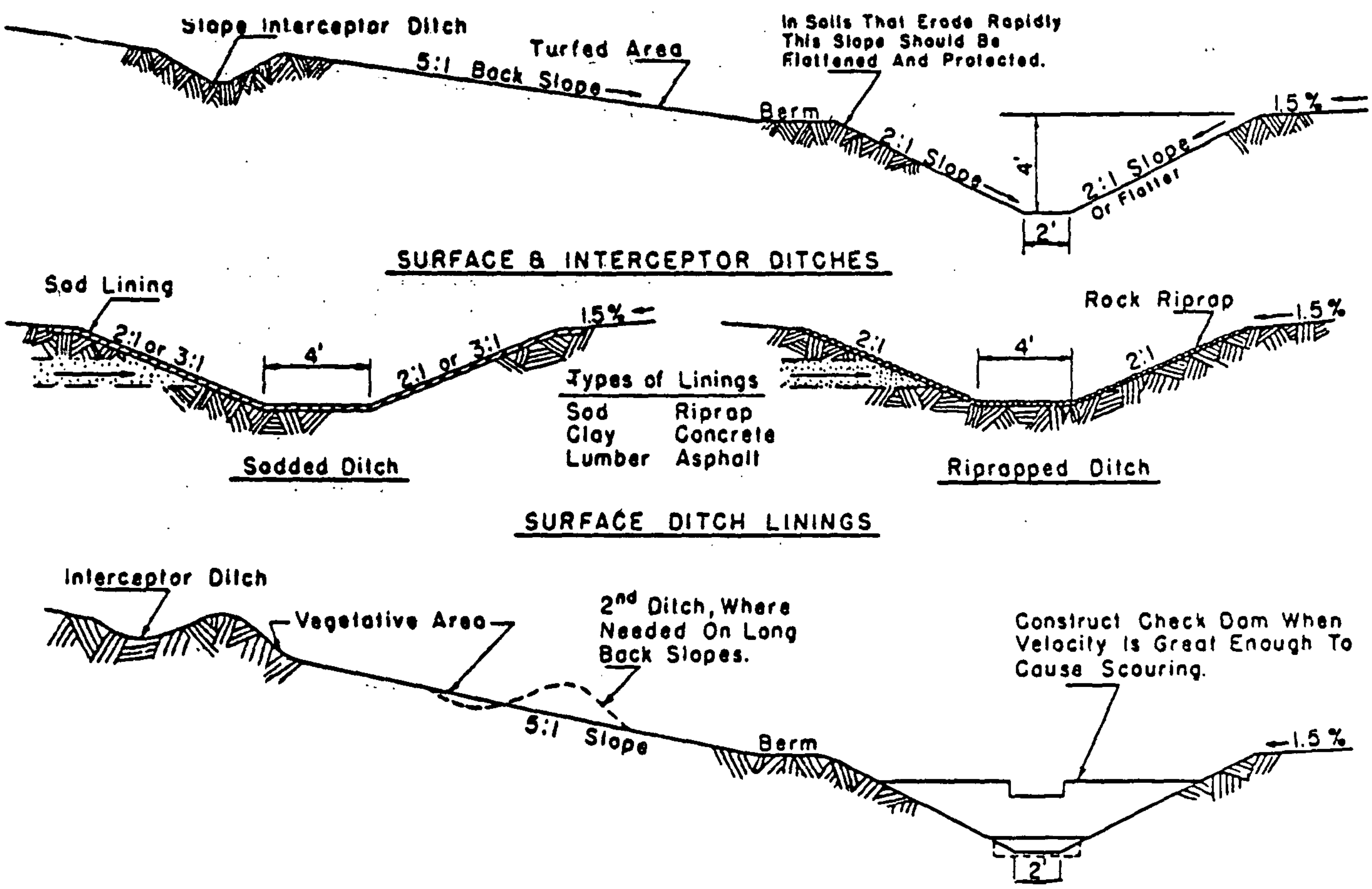
SURFACE RUNOFF DIVERSION DITCH
PLAN AND SECTION VIEWS



Source: Reference 1.

FIGURE 4-2

SURFACE AND INTERCEPTOR DITCHES



Source: Reference 2.

entering the site, and at on-site locations to control runoff and minimize surface runoff onto and off of the active face. Since runoff design procedures focus on minimizing on-site runoff and infiltration, no specific leachate function design considerations are required.

4.4.23 Gas Control

Surface runoff diversion measures can potentially result in decreased problems associated with methane gas generation and migration. Namely, by reducing the volume and intensity of runoff flow across the landfill cover and reducing erosion that weakens cover integrity, channels, dikes, and other structures act to minimize precipitation infiltration. Since waste moisture content is an important factor in gas generation, provision of surface runoff controls ultimately influences rates of waste degradation and landfill gas production.

The same considerations and design factors relevant to reducing infiltration and consequent leachate generation are also applicable to minimizing waste moisture content and consequent gas generation.

4.4.24 Current Economic Costs

For a 10 TPD site, a 100 TPD site, and a 300 TPD landfill site, surface runoff control measures currently cost $0.15 ($0.17), $0.04 ($0.04), and $0.02 ($0.02) per ton (per metric ton) respectively.

4.4.3 Environmental Impact Summary

1. Surface runoff diversion structures channel runoff from precipitation and other sources around or away from landfill sites, thereby minimizing uncontrolled infiltration of moisture into the waste mass. Diversion structures also provide surface drainage away from the active face of fill construction and if necessary, can divert runoff from the active face to leachate treatment facilities. These measures ultimately reduce rates of waste degradation, reduce rates of contaminant leaching and minimize impact of landfill generated leachate on adjacent water systems.

2. Surface runoff diversion techniques also function in the same manner to minimize waste moisture content, reduce rates of waste degradation, and therefore, reduce rates of gas generation.

3. Runoff diversion structures, by diverting and reducing the intensity of surface flows, can significantly control the erosion of landfill cover material. This results in increased cover stability and integrity, as well as minimizing siltation of adjacent receiving water bodies by runoff discharge.

4. Considerations relating to the provisions of surface runoff diversion can impact the siting of a landfill disposal facility. For example, the Guidelines recommend that localized high ground areas such as ridges and divides should be selected for disposal sites to minimize or avoid the potential for surface drainage onto the landfill from contiguous areas.

4.5 GRADING

4.5.1 Introduction

Incident precipitation at a landfill will either evaporate, runoff or infiltrate into the landfill mass. The Guidelines suggest, in order to minimize leachate generation from infiltrated moisture, that landfills should be covered with soil materials which are graded such that water does not pool on the landfill surface. Surface slopes can be graded to maximize runoff while still minimizing the potential effects of erosion processes. In order to minimize erosion the final grade should not exceed approximately 30%. The Guidelines also suggest that slopes longer than 25 feet may require additional erosion control measures such as construction of horizontal terraces, of sufficient width for equipment operation, for each rise in elevation of approximately 20 feet.

The following sections will discuss grading in terms of leachate control, gas control, and runoff control, its function in each of these areas, and appropriate design and construction considerations. These discussions are followed by an assessment of current economic costs of implementation and a summary of the attendant environmental impacts.

4.5.2 Technology Summary

4.5.21 Leachate and Gas Control

Grading Functions. Grading affects the environment surrounding a landfill facility in essentially the same manner as does surface runoff diversion techniques (see details in Section 4.4). To briefly summarize, construction of sloped or graded daily and final cover soils serves to:

1. reduce ponding and minimize infiltration of surface water;

2. reduce soil erosion and help maintain cover integrity, which further influences percolation;

3. minimize waste moisture content, resulting in a reduced rate of aeaerobic waste degradation; and

4. reduce the rate of leaching of landfilled waste contaminants.

Grading, therefore, functions to minimize the volume of landfill generated leachate and reduce the severity of its impact on adjacent groundwater supplies. Additionally, grading functions to ultimately reduce the rate of decomposition, the rate of gas generation and minimizes hazards due to accumulation of explosive and/or toxic gases in adjacent structures.

Grading Design and Construction. The design of graded cover materials must be based upon a variety of interrelated hydrogeologic and hydraulic factors. Some of these factors include general site topography, soil type, runoff intensity, size of drainage area, vegetative type, slope stability, planned final site use, etc. In general, the attempt is to maximize runoff while maintaining cover integrity and efficiency of operations.

Studies indicate that surface grades between a minimum of 2% and a maximum of 10% to 12% are most effective for both promoting runoff to reduce infiltration and reducing surface flow velocities to minimize soil erosion. Figure 4-2, Section 4.4, illustrates possible slope ratios for use in conjunction with surface runoff diversion systems to channel runoff around a landfill site or off the active face of fill construction. The active grading contouring requirements of a site are dependent upon the afore-mentioned site specific factors and should complement the planned final use of the facility.

4.5.22 Runoff Control

Surface grading as a runoff control measure mainly impacts surface water quality by reducing the potential for stream siltation from sediment-laden surface runoff waters. This is accomplished in part, by minimization of runoff and erosion at any landfill location and in part by directing runoff to on-site runoff diversion and sedimentation control structures.

4.5.3 Environmental Impact Summary

1. Grading influences the quality of adjacent groundwater supplies by minimizing quantities of landfill leachate and leachate contaminants on subsurface systems. Since waste degradation rates are moisture dependent, grading may possibly function in inhibiting surface ponding, and subsequent infiltration and leachate generation.

2. Similarly, grading techniques may potentially reduce landfill gas generation rates and minimize potential hazards from accumulations of explosive and/or toxic gases in the atmosphere and adjacent structures.

3. Carefully graded landfill cover also functions to minimize erosion and therefore, impacts surface water quality by reducing the potential for siltation of surface water systems receiving landfill runoff discharges.

4. Joint usage of grading with surface runoff diversion techniques increases the efficiency of channelingrunoff waters away from the site or away from the working face.

5. Long-term maintenance to resurface and regrade final cover subject to differential subsidence or erosion may be required to maintain adequate site runoff patterns and the implied positive environmental impacts.

4.6 DIKING

4.6.1 Introduction

Diking involves construction of a low wall or embankment from relatively impermeable material such as clay soils. Dikes can be used as part of a runoff control program, but are primarily incorporated to prevent potential flooding. Flood waters pose a larger, if less constant, problem in leachate and gas generation and cover erosion than incident precipitation. This section discusses diking in the context of flood water protection, while surface runoff diversion is discussed separately in Section 4.4.

In this regard the Guidelines define a floodplain to mean "the lowland and relatively flat areas adjoining inland and coastal waters, including flood-prone areas of off-shore islands, which are inundated by the base flood." Correspondingly, the base flood is defined as "a flood that has a 1 percent or greater chance of recurring in any year or a flood of a magnitude equalled or exceeded once in 100 years on the average over a significantly long period." The Guidelines therefore suggest if all or part of a landfill facility lies within a 100-year floodplain, a suitable dike of sufficient height to prevent inundation should be included in the site design. Because a floodplain has been designated as an environmentally sensitive area, siting of a landfill facility in a floodplain may require additional measures for minimizing potential impacts on surrounding ecosystems.

The remainder of this evaluation will discuss the functions, design and construction of diking for the purposes of leachate, gas and runoff control. The section concludes with an assessment of the current economic costs for implementation and a summary of possible environmental impacts of diking at a floodplain location.

4.6.2 Technology Summary

4.6.21 Runoff Control

Diking Functions. The functions of diking in runoff control are similar to those performed by surface runoff diversion systems in redirecting upland drainage (Section 4.4), except that diking and diversion systems differ in magnitude. Unlike the effects of runoff from precipitation sources, flood waters that can inundate a landfill facility will potentially result in large scale erosion of cover materials, subsequent loss of cover integrity and increased possibility of siltation of adjacent water bodies receiving runoff flows. The loss of cover integrity has significant implications, particularly in the area of leachate control.

Diking Design and Construction. The design and construction of impervious perimeter dikes are dependent upon a variety of interrelated site specific factors. Diking can be designed to act in conjunction with other surface runoff diversion techniques. The actual dimensions of the structure and the specific construction techniques can be determined by hydraulic considerations and the site topography. Additionally, construction techniques may also be dependent upon the type and availability of materials for diking. One of the most common and preferred materials utilized is clay soil, due to relative impermeability and stability characteristics.

4.6.22 Leachate and Gas Control

Flooding of a landfill site will likewise result in larger scale problems in leachate and gas control. The major consideration is prevention of large scale erosion of the cover and waste materials. Secondarily, inundation of solid wastes by flood waters will potentially produce larger quantities of contaminants leached, larger volumes of leachate, and potentially greater volumes of gas generated.

4.6.23 Current Economic Costs

Current economic costs for dike construction average \$2.40 (\$2.69), \$0.55 (\$0.62), and \$0.30 (\$0.34) per ton (per metric ton) for 10, 100, and 300 ton per day landfill sites, respectively.

4.6.3 Environmental Impact Summary

1. Diking around a facility located in a floodplain impacts groundwater quality by preventing potential long-term leachate contamination problems that could result from large scale erosion and inundation of landfilled solid wastes by flood waters.

2. Since landfill gas generation rates are also related to waste moisture content, diking serves to minimize gas volumes and developement of hazardous conditions.

3. Diking functions to divert flood waters around a landfill site and minimize large scale erosion of cover material, thereby reducing the potential for sedimentation of surface waters that receive runoff discharge.

4.7 PONDING

4.7.1 Introduction

Surface water, from precipitation events, that runs off the landfill surface will invariably erode the soil surface to some degree, and in the process may entrain significant amounts of suspended sediment and solids. Design of landfill surface runoff controls can include ponding, the use of stilling or sedimentation basins to separate the suspended solids from the surface runoff before it is discharged to a receiving body of water. This technique can remove sufficient sediment to minimize siltation of downstream surface water systems. Ponding requires the conjunctive use of other surface runoff diversion techniques to channel runoff waters to the ponding basins.

The Guidelines suggest that ponding may be the only treatment necessary for surface runoff before final discharge. The runoff, however, must not be contaminated by contact with the active face or via intermingling with other leachate sources.

4.7.2 Technology Summary

4.7.21 Runoff Control

Ponding Function. The primary function of settling ponds in a system of landfill runoff controls is to remove suspended sediment from surface runoff, thereby minimizing its potentially deleterious impact on receiving surface waters. The velocity and turbulent flow characteristics of surface runoff determine the maximum size and amount of solid particles which can be retained in suspension. In other words, the greater the velocity and turbulence, the greater the erosive capacity of any runoff channel. Ponding achieves its function by reducing velocity and turbulent flow thereby allowing sediment particles to settle out of suspension.

Ponding Design and Construction. There are no rigid guidelines for the actual design and construction of sediment settling ponds for landfill runoff control due to the dominant influence of site specific factors. In general the size and depth of sedimentation basins or series of basins should accomodate the anticipated rate and volume of surface runoff. The volume and intensity of runoff, and therefore the required size and depth of the ponds, is influenced by numerous factors including:

1. area climate and resulting water balance of site;
2. intensity and seasonal amounts of precipitation;
3. total drainage area of site;
4. site topography and slope features; and
5. vegetation type and density.

Additionally, the basin depth and required holding time should be determined by the effective sedimentation rate, which in turn is affected by characteristics of the suspended particles and the type of settling basin provided.

4.7.22 Current Economic Costs

Ponding construction costs are approximately $0.10 ($0.11), $0.05 ($0.06), and $0.04 ($0.04) per ton (metric ton) for 10 TPD, 100 TPD and 300 TPD sites respectively.

4.7.3 Environmental Impact Summary

1. Utilization of ponding prevents the discharge of suspended solids to streams from surface runoff sources, minimizing possible siltation of downstream surface water systems and other secondary negative impacts.

2. Additionally, ponding intercepts surface runoff and controls runoff intensity thereby potentially reducing further off-site erosion and stream siltation.

3. Ponding places additional constraints on siting because supplementary landfill acreage is required. This may become a restrictive factor in areas of limited land availability.

4. Sedimentation basin construction and the required periodic dredging may engender a number of secondary environmental impacts.

4.8 DAILY AND FINAL COVER

4.8.1 Introduction

Daily cover is defined as the placement, at the end of each day's operation, of a compacted layer of soil over the solid waste on the working face. Intermediate or final cover is a thicker soil layer designed for long-term landfill protection after intermediate or final cell completion. The Guidelines call for 15 centimeters (cm.) (6 inches) of daily cover, and 30 cm. (12 inches) of cover on landfill cells "which will not have additional wastes placed on them for one month or more." The Guidelines also recommend for final cover 15 cm. (6 inches) of clay with permeability less than 1×10^{-7} cm/second or the equivalent, followed by a minimum cover of 45 cm. (18 inches) of top soil to complete the final cover and support vegetation. A more impermeable final cover might require a minimum of 60 cm. (24 inches) of low permeability soil.

The principal functions of cover in the context of the Guidelines are leachate, gas, and runoff control. Other functions include vector, odor, litter, fire hazard, wind erosion, and dust control, and support of vehicular traffic, vegetation, and post-closure construction. Daily and final cover must accommodate the planned final use of the completed landfill site.

This section is organized by cover function: leachate control, gas control, runoff control, and other controls. Each section identifies the cover properties and processes critical in serving the cover function, and discusses the various cover design and construction techniques for attaining these goals. A final section summarizes the implications of daily and final cover for landfill siting, design, operation, and joint use of different landfill technologies. In addition, the summary section identifies environmental, energy and economic impacts of daily and final cover.

4.8.2. Technology Summary

4.8.21 Leachate Control

Cover Functions. Several properties of cover material act in concert to accomplish the function of leachate control. Principally, the cover material reduces water movement from the landfill surface into the buried waste. Lower permeability cover soil decreases infiltration into the waste mass and increases the opportunity for runoff and evaporation (see Table 4-1). More specifically, depending on the specific overall site strategy of leachate control, cover selection, design, and application acts to minimize or maximize infiltration, snowmelt, or surface drainage. Minimizing water movement into the waste via utilization of a cover soil maintains a lower waste moisture content which, in turn, plays a role in minimizing the rate of anaerobic waste degradation. Reduced waste decay rates result in reduced rates of landfill leachate generation and thus might decrease the ultimate contaminant load in leachate.

Alternatively, when recycling is the chosen leachate control technology, it may be desirable to facilitate water movement through the cover soil. Collection or recycling of the generated leachate material may result in accelerated stabilization of the landfilled waste. Greater quantities and concentrations of leachate may result, but the time frame over which contaminated materials may escape may be significantly shortened.

In addition to soil permeability, there are several other, more secondary, cover soil properties which should be considered for effective leachate control. In general, these other properties relate to maintaining cover continuity and integrity, thus preventing any hydraulic connection between landfill surface water and buried waste. Specifically, the cover should not subside and must resist cracking upon wetting and drying or upon freezing and thawing. The selected cover material must also minimize wind and water erosion, and must be capable of maintaining stable slopes.

Cover Design and Construction Techniques. A variety of cover design and construction techniques exist to achieve the function of leachate control. To minimize infiltration and percolation, the cover soil should be fine-grained and have a small coefficient of permeability and vice versa to maximize infiltration and percolation. To resist dessication and cracking, the soil should have a low shrink-swell potential upon wetting and drying. For instance, a soil with low clay content or soil whose clay component is largely kaolinite or illite, as opposed to montmorillonite, resists dessication and cracking under typical landfill conditions. Frost heave rates are related to

TABLE 4-1

RANKING OF USCS SOIL TYPES ACCORDING TO PERFORMANCE OF COVER FUNCTIONS

USCS Symbols	Typical Soils	Trafficability: Go-No Go, RCI Value*	Trafficability: Stickiness, Clay (%)	Trafficability: Slipperiness, Sand/Gravel (%)	Water Percolation: Impede (K, cm/s)*	Water Percolation: Assist (K, cm/s)*	Gas Migration: Impede (H_c, cm)*	Gas Migration: Assist (H_c, cm)*
GW	Well-graded gravels, gravel-sand mixtures, little or no fines	I (>200)	I (0-5)	I (95-100)	XII (10^{-1})	I	X (6)	I
GP	Poorly graded gravels, gravel-sand mixtures, little or no fines	I (>200)	I (0-5)	I (95-100)	X (10^{-2})	III	IX ---	II
GM	Silty gravels, gravel-sand-silt mixtures	III (177)	III (0-20)	III (60-95)	VII (5×10^{-4})	VI	VII (68)	IV
GC	Clayey gravels, gravel-sand-clay mixtures	V (150)	VI (10-50)	V (50-90)	V (10^{-4})	VIII	IV ---	VII
SW	Well-graded sands, gravelly sands, little or no fines	I (>200)	II (0-10)	II (95-100)	XI (5×10^{-2})	II	VIII (60)	III
SP	Poorly graded sands, gravelly sands, little or no fines	I (>200)	II (0-10)	II (95-100)	IX (10^{-3})	IV	VII ---	IV
SM	Silty sands, sand-silt mixtures	II (179)	IV (0-20)	IV (60-95)	VIII (10^{-3})	V	VI (112)	V
SC	Clayey sands, sand-clay mixtures	IV (157)	VII (10-50)	VI (50-90)	VI (2×10^{-4})	VII	V ---	VI
ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity	IX (104)	V (0-20)	VII (0-60)	IV (10^{-5})	IX	III (100)	VIII
CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	VII (111)	VIII (10-50)	VIII (0-55)	II (3×10^{-8})	XI	II (180)	IX
OL	Organic silts and organic silty clays of low plasticity	X (64)	V (0-20)	VII (0-60)	---	---	---	---
MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	VIII (107)	IX (50-100)	IX (0-50)	III (10^{-7})	X	---	---
CH	Inorganic clays of high plasticity, fat clays	VI (145)	X (50-100)	X (0-50)	I (10^{-9})	XII	I (200-400+)	X
OH	Organic clays of medium to high plasticity, organic silts	XI (62)	---	---	---	---	---	---
Pt	Peat and other highly organic soils	XII (46)	---	---	---	---	---	---

Water Percolation, Assist column: Same K values as for Impede Water Percolation

Gas Migration, Assist column: Same H_c values as for Impede Gas Migration

(continued)

TABLE 4-1 (continued)

USCS Symbol	Side Slope: Stability	Side Slope: Seepage	Side Slope: Drainage	Discourage Burrowing	Impede Vector Emergence	Discourage Birds	Support Vegetation	Future Use: Natural	Future Use: Foundation
GW	Determine on basis of laboratory testing	Same ranking and values as for Impede Water Percolation	Same ranking and values as for Assist Water Percolation	Same ranking and values as for Slipperiness Trafficability	X	All soils are suitable	X	Same ranking as for Support Vegetation	Same ranking and values as for Go-No Go Trafficability
GP					X		X		
GM					VIII		VI		
GC					V		V		
SW					IX		IX		
SP					IX		IX		
SM					VII		II		
SC					IV		I		
ML					VI		III		
CL					III		VII		
OL					VI		IV		
MH					II		IV		
CH					I		VIII		
OH					---		VIII		
Pt					---		III		

* RCI is rating cone index, K is coefficient of permeability, H_c is capillary head, and K-Factor is the soil erodibility factor.

TABLE 4-1 (concluded)

(continued)

USCS Symbol	Fire Resistance	Erosion Control: Water, K-Factor*	Erosion Control: Wind Sand/Gravel (%)	Dust Control	Reduce Freeze Action: Fast Freeze (Hc, cm)*	Reduce Freeze Action: Saturation, Heave (mm/day)	Crack Resistance, Expansion (%)
GW	Same as Impede Gas Migration	I (< .05)	I (95-100)	Same ranking and values as for Wind Erosion Control	X	I (0.1-3)	I (0)
GP		I ---	I (95-100)		IX	I (0.1-3)	I (0)
GM		IV ---	III (60-95)		VII	IV (0.4-4)	III ---
GC		III ---	V (50-90)		IV	VII (1-8)	V ---
SW		II (.05)	II (95-100)		VIII	II (0.2-2)	I (0)
SP		II ---	II (95-100)		VII	II (0.2-2)	I (0)
SM		VI (.12-.27)	IV (60-95)		VI	V (0.2-7)	II ---
SC		VII (.14-.27)	VI (50-90)		V	VI (1-7)	IV ---
ML		XIII (.60)	VII (0-60)		III	X (2-27)	VI ---
CL		XII (.28-.48)	VIII (0-55)		II	VIII (1-6)	VIII (1-10)
OL		XI (.21-.29)	VII (0-60)		---	VIII ---	VII ---
MH		X (.25)	IX (0-50)		---	IX ---	IX ---
CH		IX (.13-.29)	X (0-50)		I	III (0.8)	X (>10)
OH		VIII ---	---		---	---	IX ---
Pt		V (.13)	---		---	---	---

(continued)

Source: Reference 2.

silt-clay content as shown in Figure 4-3. To slow freezing and to avoid freezing to great depth, fine grained soils should be used. However, coarse soils are more workable in cold climates, since these drain freely, therefore retaining less water to act as a bonding agent under freezing conditions.

Several other cover design and construction techniques serve to impede water infiltration including;

1. increasing surface slope to facilitate runoff;

2. mixing cover soil to achieve uniform permeability;

3. blending other soils for better gradation;

4. using additives;

5. increasing cover thickness;

6. compacting (with special compacting equipment); and

7. using a layered cover system.

Increasing surface slope results in increased runoff rates and consequently in less infiltration. Mixing of cover soil to achieve uniform permeability is useful where cover soil is obtained from a source consisting of soil layers of varying permeability. Similarly, blending impedes infiltration and percolation by combining soils of different grain sizes to broaden cover soil grain size distribution. This decreases overall soil porosity (void ratio) and lowers permeability. Blending is expensive and energy consuming, but can produce an increased source of acceptable cover soil if well-graded soils are not readily available.

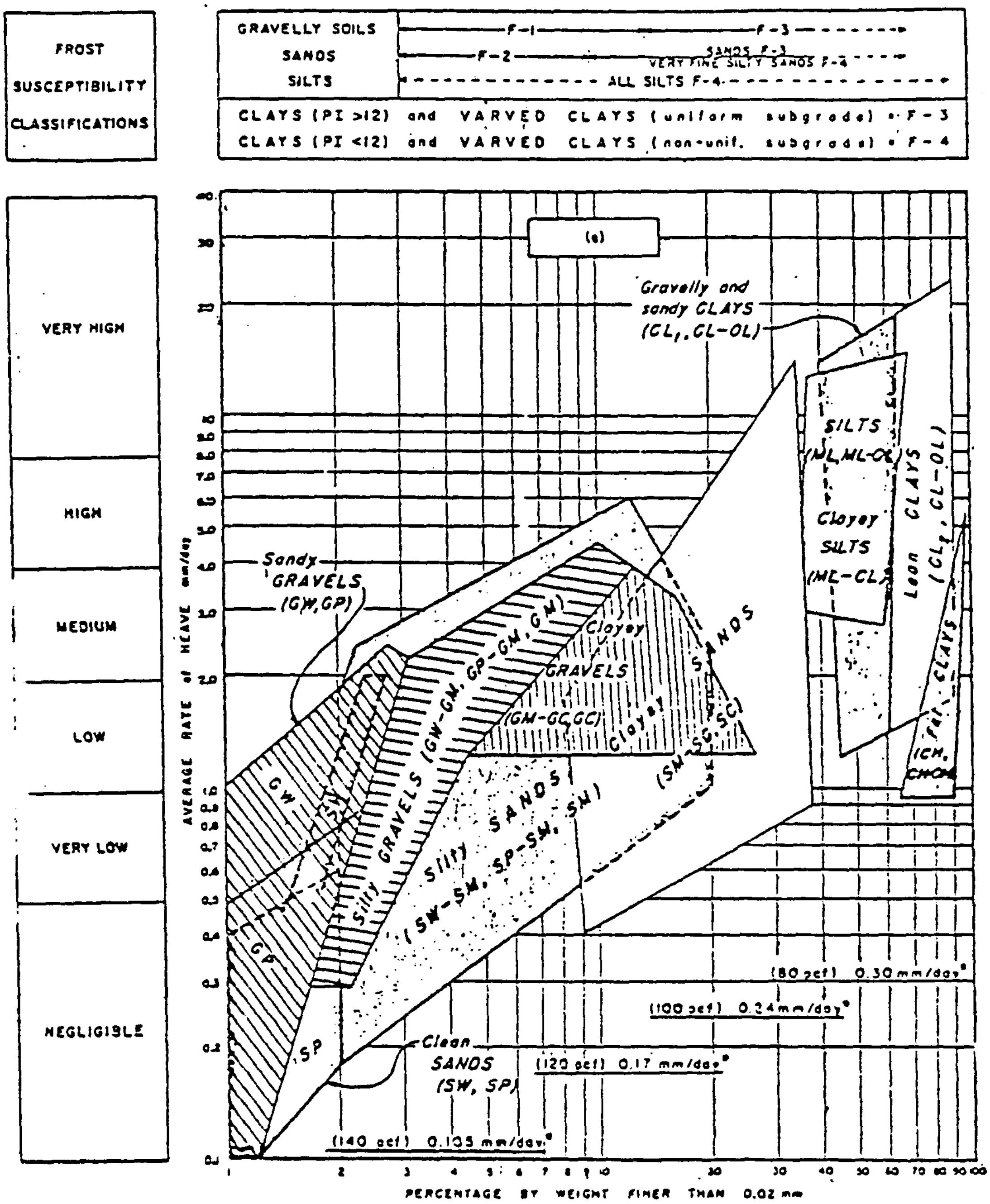
Utilizing additives can result in a lower permeability soil. The process may permit utilization of a soil type which otherwise might be unacceptable for cover material.

Increasing cover thickness can result in a less direct contact of waste with incident precipitation during the daily operation. A greater depth of cover soil can also support a larger variety of cover vegetation species and consequently may promote higher evapotranspiration rates and surface runoff rates.

Compaction impedes infiltration and percolation by reducing porosity and thus permeability. Some compaction is generally achieved during routine waste and cover application. Additional compaction is achievable via utilization of special compaction equipment.

FIGURE 4-3

RATES OF HEAVE AS RELATED TO SILT-CLAY CONTENT



SUMMARY OF ENVELOPES FOR THE VARIOUS SOIL GROUPS

NOTES: *Standard tests performed by Arctic Construction and Frost Effects Laboratory; specimens 6in. dia by 6in. high, frozen at penetration rate of approximately 0.25 in per day, with free water at 38°F continuously available at base of specimen. Specimens compacted to 95% or better of applicable standard, except undisturbed clays. Saturations before freezing generally 85% or better.*

** Indicated heave rate due to expansion in volume, if all original water in 100% saturated specimen were frozen, with rate of frost penetration 0.25 inch per day.*

Source: Reference 2.

Layering of separate soils or other materials in the final cover achieves a level of leachate control not obtainable with one material. For most situations, it is sufficient to compact a layer of very impermeable clay beneath a layer of silty sand to provide soil erosion protection and to help retain capillary water in the clay layer.

To assist infiltration and percolation for the recycling option potential techniques include:

1. selection of high permeability cover soils;

2. reducing surface slope;

3. decreasing cover thickness; and

4. decreasing compaction efforts.

4.8.22 Gas Control

Cover Functions. Cover material functions in a number of ways to control landfill gas generation, build-up, and migration. Principally, the cover may be designed and constructed to either impede or assist the passage of gas from landfill to atmosphere. This choice depends on whether the particular landfill design requires an active system of gas collection and venting or a passive system permitting gas migration. An active system may be preferred when leachate control dictates an impermeable cover, when neighboring land uses pose relatively few problems, or when gas is collected and used for its energy value. Otherwise, a passive system in combination with vertical gas movement through the cover material may suffice as least complicated and least expensive.

Besides directly regulating gas diffusion processes, the cover must be designed and constructed to maintain its continuity and integrity to prevent more direct escape of methane and other gases. More importantly though, those cover leachate control measures that minimize the rate of waste decay also minimize the consequent rate of gas production. This, in turn, may increase the period of time over which gas is produced.

Cover Design and Construction Techniques. The most important technique for controlling gas migration through the cover is the selection of the appropriate cover soil. A very fine impermeable soil impedes gas movement, while coarse granular soil assists gas movement (see Table 4-1). Maintaining a high degree of cover soil saturation also impedes gas migration. Incorporating gas venting or barrier systems, or combinations thereof, restricts gas movement to specific paths or areas.

4.8.23 Runoff Control

Cover Functions. Cover design and construction can result in control of surface runoff and accompanying erosion processes. Cover selection can minimize the potential erodibility of the cover soil. For example, gravels, gravel-sand mixtures, and sands are resistant to erosion effects. Proper cover design and application can also reduce erosion by reducing surface runoff rates. Erodibility and runoff depend on a number of interrelated factors including topographic features, soil water content, rainfall intensity, compaction, vegetation, and general cover management. Important topographic features include slope steepness, slope length, and slope shape. Soil erodibility depends on soil particle-size distribution, organic matter content, soil structure and soil permeability.

Cover Design and Construction Techniques. There are several cover design and construction techniques available to achieve the water erosion control functions discussed above. First, an erosion resistant soil should be selected using published tables of erodibility (K-factor) values for different soil grain sizes (see Table 4-1) Other techniques include:

1. specifying coverages and compactive effort;
2. reducing surface slope;
3. establishing vegetation quickly;
4. providing mulch and other temporary slope protection; and
5. using additives;

Compaction, used to control gas and leachate movement by reducing infiltration, also reduces erosion. The value of reducing surface slope to control erosion must be weighed against the value of maintaining some surface slope to prevent surface ponding and increased infiltration. Vegetation should be established as quickly as possible on final and, if feasible, on intermediate cover. Likewise mulch or other suitable materials should be placed on bare intermediate or final cover soil, especially in the interval before vegetation emerges. Additives such as chemical soil stabilizers and cement-stabilized soils can also be effective against erosion, but are more costly than straw mulch treatment followed by natural grass cover. In general, interior and perimeter surface drainage controls are also used in concert with general cover management to minimize the effects of surface runoff.

4.8.24 Other Functions

Landfill cover also serves a variety of other landfill functions. These include:

a. Health considerations:

1. minimizing vector breeding areas and animal attraction by controlling:

a) fly and other insect emergence and entrance.
b) rodent burrowing for food and harborage.
c) bird scavenging.

b. Minimizing fire hazard potential by:

1. controlling movement of atmospheric oxygen.

2. providing barrier cell walls.

c. Asthetic considerations:

1. minimize blowing paper.

2. control noxious odors.

3. provide sightly appearance to the landfill operation.

4. minimize wind erosion and dust generation.

d. Site usage considerations.

1. minimizing settlement and maximizing compaction to:

a) assist vehicle support and movement.
b) insure equipment workability under all weather conditions.
c) provide for future construction.

2. Providing for vegetable growth..

Table 4-1 ranks cover soil types for these cover functions.

4.8.25 Current Economic Costs

Current economic costs for implementina these technologies for the three landfill site classes, as estimated utilizing the methodology outlined in Section 5.0, are presented in Table 4-2.

TABLE 4-2

CURRENT COVER COSTS

Technology	10 TPD $ Cost/Ton	($ Cost/Metric Ton)	100 TPD $/Ton	($/MT)	300 TPD $/Ton	($/MT)
Impermeable Daily Cover (On-site source)	0.75	(0.84)	0.35	(0.39)	0.25	(0.28)
Impermeable Daily Cover (Off-site source)	5.30	(5.94)	2.65	(2.97)	1.75	(1.96)
Permeable Daily Cover (On-site source)	0.60	(0.67)	0.30	(0.34)	0.20	(0.22)
Permeable Daily Cover (Off-site source)	1.90	(2.13)	0.95	(1.06)	0.65	(0.73)
Final Impermeable Cover (On-site source)	0.45	(0.50)	0.20	(0.22)	0.20	(0.22)
Final Impermeable Cover (Off-site source)	3.20	(3.58)	1.50	(1.68)	1.35	(1.51)
Final Permeable Cover (On-site source)	0.40	(0.45)	0.15	(0.17)	0.15	(0.17)
Final Permeable Cover (Off-site source)	1.30	(1.46)	0.60	(0.67)	0.55	(0.62)

Source: Summarized from Tables 5-2 and 5-3.

4.8.3 Environmental Impact Summary

1. Landfill cover soil selection and cover design and construction techniques which impede or reduce infiltration of incident precipitation, snowmelt, and surface drainage into the waste mass result in improved water quality. Decreased infiltration serves to maintain a lower waste moisture content, thus minimizing the rate of anaerobic waste degradation and the rate of contaminant generation. These controls affect primarily the readily decomposed organics and biotic pollutants such as coliform bacteria.

2. Landfill cover soil selection, and cover design and construction techniques which impede or reduce infiltration of landfill surface water (discussed under No. 1 above) also minimize the rate of decomposition gas generation and control vertical gas migration. This reduces the likelihood of gas migration to and build-up of explosive concentrations in buildings on or near the landfill site. Since some plant species are adversely affected by landfill gas, it also allows a greater variety of cover plant species to be planted to control cover soil erosion and surface runoff. Finally, the mineralization of groundwater is reduced, since the amount of carbon dioxide dissolving in leachate is minimized.

3. Landfill cover soil selection and cover design and construction techniques which assist infiltration of landfill surface water into the waste mass, and therefore facilitate leachate recycling, result in accelerated stabilization of the landfilled waste. Greater quantities and concentrations of leachate and gas may result, but the time frame over which these substances may escape may be significantly shortened. A permeable cover also permits a passive system of gas control with vertical gas venting safely to the atmosphere.

4. Landfill cover soil selection and cover design and construction techniques which minimize surface runoff and cover soil erosion serve to minimize siltation of surface waters adjacent to the landfill site.

5. Landfill cover soil selection and cover design and construction techniques which protect the cover from subsidence, dessication, cracking, and wind and water erosion serve to prevent any hydraulic connection between landfilled waste and surface water. This minimizes direct contamination of surface waters by leachate.

6. Use of daily and final cover also: minimizes fire hazard potential; maximizes the safety of the landfill site operations; minimizes vector breeding areas and animal attraction; minimizes wind erosion and dust generation; preserves slope stability; provides efficient operating surfaces; minimizes differential settlement and maximizes compaction; provides for vegetative growth and subsequent site use; and provides an aesthetic appearance to the landfill site.

7. The extraction, transport, and application of cover soil causes a variety of secondary environmental impacts. Furthermore, any manufacturing, transportation, construction, or maintenance activity associated with any of the aforementioned cover selection, cover design or construction techniques also has secondary environmental impacts.

4.9 SYNTHETIC LINERS

4.9.1 Introduction

Groundwater and infiltrating precipitation, in conjunction with liquid waste constituents, can produce leachate, a solution consisting of dissolved and suspended solid matter and microbial waste products. Depending on specific site conditions, natural attenuation characteristics may not be adequate to provide the required degree of protection for adjacent groundwater systems. Physical containment of the leachate generated over the life of a site may be possible by using a synthetic liner.

In this light, the Guidelines call for "a suitable structure which allows the desired volumetric release of leachate for the maximum leachate storage capability without failure due to liner placement." This requires incorporation of a number of specific design and engineering features. For instance, according to the Guidelines, the practical minimum thickness for membrane liners is 20 mils. The Guidelines also recommend careful liner subgrade preparation and liner protection above grade. And finally, the Guidelines suggest that the liner be sloped to one or more points and incorporate easily drained granular material to facilitate leachate removal.

The following sections discuss the function of synthetic liners in leachate control and gas control. The liner properties required to achieve each function are identified, and the available materials and construction methods to provide these properties are briefly evaluated. A final section summarizes the major environmental impacts of synthetic liners utilization as leachate and gas control measures.

4.9.2 Technology Summary

4.9.21 Leachate Control

Liner Functions. Because of the potential for ground and surface water pollution, solid waste and groundwater must not be allowed to interact. Maintaining a separation of several feet may effectively prevent direct contact between the waste and the seasonal high groundwater table. However, the effects of downward movement of leachate into the groundwater system may result in substantial pollution of the groundwater system. Consequently, a liner installation may be utilized to prevent downward migration of leachate constituents and to provide a greater measure of safety with respect to direct groundwater intrusion into the waste.

Proper liner selection, design, and construction depend on several factors, including waste type, subsurface soil conditions, landfill type, current and projected regional water resource uses, the potential effect of leachate on groundwater quality, direction of groundwater movement, and the interrelationship of the aquifer with other aquifers and with surface water. To be effective in controlling leachate, all liners must be relatively impermeable to leachate, and must be sufficiently durable to maintain their integrity over the expected period of landfill leachate generation. Specifically, the liner must be capable of withstanding the stresses associated with: wetting and drying, freezing and thawing, periodic shifts of the earth and subgrade settling, and liner installation and initial operation of equipment on the lined base. It must resist attack from ozone, ultraviolet radiation, soil bacteria, mold, fungus, and vegetation. Furthermore, a liner must resist laceration, abrasion, and puncture by any waste material landfilled above it. The liner must be amenable to field splicing and to repair as necessary. Finally, the liner should be as economical as possible given the specific job it must perform.

Liner Selection, Design, and Construction. There are several broad categories of synthetic liners: admixed and asphaltic materials, treated soils, soil sealants, and polymeric membranes. A number of each of these liner types have been developed and are being evaluated by industry and by EPA for their effectiveness and feasibility for controlling both hazardous and non-hazardous solid wastes. Of these liner categories, the admixed and asphaltic materials and polymeric membranes have received the most attention, and tentative conclusions have been drawn regarding their overall effectiveness.

Admixed and Asphaltic Materials. Admixed and asphaltic liner materials include:

1. modified bentonite and soil;
2. asphalt concrete;
3. soil asphalt;
4. soil cement;
5. sprayed asphalt membranes; and
6. bituminous seals.

Admixed materials are normally formed in place. Asphalts are placed using conventional roadway paving equipment, and are sealed with a number of passes using spray bar equipment. Appendix A contains descriptions of a number of the major admixed materials listed above, and lists specific advantages and disadvantages.

Admixed liner material evaluations in simulated landfill situations over short periods of time have so far concluded:

1. admix liners containing asphalt maintain their impermeability to leachate, but significantly lose compressive strength;

2. to avoid inhomogeneities and leakage, paving asphalt and soil asphalt liners should be greater than 2 to 4 inches thick;

3. soil cement becomes less permeable to leachate over time, but loses compressive strength initially;

4. wholly asphaltic membrances maintain their impermeability to leachate, but swell slightly;

5. oily wastes cannot be safely contained by asphalt-based liners;

6. bentonite and polymeric modified bentonite liners may not be satisfactory for confining strong acids and bases and concentrated brines; and

7. wastes containing both aqueous and oily phases may pose special problems because of the need of the liner to resist simultaneously two fluids inherently different in their compatibility with materials.

Polymeric Membranes. A large variety of polymeric membrane liners are being developed and evaluated, including:

butyl rubber
chlorinated polyethylene
chlorosulfonated polyethylene
elasticized polyolefin
ethylene propylene rubber
neoprene
polyester elastomer
polyvinyl chloride

Appendix A contains descriptions for the more commonly utilized membranes and lists specific advantages and disadvantages.

Basic liner materials can be strengthened by laminating fabric between layers of the liner material. Typical reinforcing "scrim" materials include nylon, dacron, polypropylene, and fiberglass fabrics. The reinforced liner material exhibits better puncture resistance and overall loading capacity than liner materials alone. Disadvantages include less flexibility and elongation prior to rupture, and greater cost.

Liner installation requires a number of specialized construction techniques. The base upon which the liner will be placed must be even and free from objects capable of rupturing the liner. Six inches of graded sand are commonly used as a liner base. Actual liner installation requires joining large membrane sheets over the landfill base and adjacent to such features as vents, sampling wells, collection pipes, etc. A number of adhesives and solvents are used for this field splicing. Specific instructions must be carefully followed to maintain the structural integrity of the liner.

Once the liner installation is complete, continued emphasis must be placed on maintaining liner integrity. The most common approach is to provide a two foot graded sand or soil layer over the liner to prevent rupturing of the liner by waste materials and to permit operation of landfill equipment on the lined base. The first layer of waste should be relatively free of large objects.

4.9.22 Gas Control

A secondary role for synthetic liners is the control of decomposition gas movement. Downward or lateral gas movement may occur as landfill gas is generated. If the gas migrates through permeable substrata it may collect in dangerous concentrations in buildings near the landfill. Synthetic liners may be placed horizontally or on a slope to block downward and lateral gas movement, respectively.

The liner properties required to successfully perform this role are essentially the same as for leachate control with the exception that a liner material's permeability to gas may differ from its permeability to water or leachate. Recent synthetic liner evaluations have not dealt with gas control effectiveness.

^.9.23 Current Economic Costs

Current economic costs for synthetic liners average $4.00 ($4.48), $1.90 ($2.13), and $1.65 ($1.85) per ton (metric ton) for 10, 100, and 300 ton per day landfill sites, respectively.

4.9.3 Environmental Impact Summary

1. Synthetic liners prevent downward migration of leachate pollutants from the waste to groundwater supplies, thus protecting groundwater from pollution.

2. Synthetic liners also prevent groundwater from directly intruding on the waste mass, thus protecting groundwater from pollution.

3. Synthetic liners may reduce the likelihood of a groundwater mound from forming beneath a landfill, since a liner minimizes the flow of water directly through the landfill to the groundwater table below. This, then, minimizes the chances that the groundwater table will intersect the waste mass.

4. Installation of a synthetic liner requires collection and removal of the contained leachate. This permits leachate treatment or leachate recycling, the ultimate consequence being minimization of groundwater and surface water pollution.

5. Synthetic liners control downward and lateral gas movement, or provide a base for vertical impermeable gas barriers. The control of gas movement out of the landfill reduces the chances of gas migration through permeable strata and build up in explosive concentrations in buildings on or near the landfill site.

6. The manufacture, transport, and installation of synthetic liners results in a variety of secondary environmental impacts.

7. Use of a synthetic liner allows more flexibility in landfill site selection, since natural soil pollutant attenuation is not relied upon, nor is an on-site source of natural liner material required. Consequently, potential reduction in waste transport distances can result in positive secondary environmental impacts.

4.10 NATURAL CLAY LINERS

4.10.1 Introduction

Landfill leachate, an effluent generally high in dissolved and suspended solids, is produced when groundwater and precipitation percolate into the solid waste and combine with waste liquids and degradation generated moisture. When natural hydrogeologic characteristics of a site would not result in adequate leachate containment, additional measures may be required to protect adjacent groundwater systems. Natural clay liners can facilitate the containment of leachate to the on-site environs and potentially may offer the possibility of attenuation of various leachate contaminants.

In this light, the Guidelines call for "a suitable structure which allows the desired volumetric release of leachate for the maximum leachate storage capability without failure due to liner placement." This requires incorporation of a number of specific design and engineering features. For instance, according to the Guidelines, natural soil liners should have a low permeability (1×10^{-7} cm./sec., or less) and a practical limiting thickness of 12 inches. The Guidelines also suggest that the liner slope to one or more points and incorporate easily drained granular material to expedite leachate removal.

The following sections discuss the function of natural clay liners in leachate control and gas control. The liner properties essential to achieving each function are identified, and the materials available and construction techniques to provide these properties are briefly evaluated. A final section summarizes the major environmental impacts of using natural clay liners as leachate and gas control measures. The evaluation assumes an off-site source of natural clay materials since on-site conditions were not initially suitable to provide the required levels of leachate containment.

4.10.2 Technology Summary

4.10.21 Leachate Control

Liner Functions. Maintaining a physical separation between solid wastes and groundwater reduces the potential production of leachate and the potential contamination of surface water and groundwater by leachate. Vertical separation of the waste above the historical high groundwater level can prevent intrusion of groundwater into the waste and consequent leachate contamination. However, leachate has the potential for downward migration into groundwater systems and therefore, physical separation of the waste and groundwater supply is not generally adequate to prevent groundwater contamination. The technique discussed here utilizes a natural clay liner which can both minimize the downward movement of leachate pollutants and prevent direct intrusion of groundwater into landfilled solid wastes.

Several site specific factors, particularly landfill type, solid waste type, subsurface soil conditions, direction of groundwater flow, possible interconnection between the aquifer and other aquifers, the effects of the specific leachate on the groundwater supply and the current and projected regional water resource uses, must be considered in the selection, design and construction of natural clay liners. In addition, since natural clay materials also may exhibit attentuation properties for specific leachate constituents, selection of a natural liner based upon specific attenuation properties for a particular waste type can provide an additional degree of protection for adjacent groundwater supplies.

Liner Selection, Design, and Construction. Natural clay minerals are among those materials most commonly used for lining landfill sites. Montmorillonite, illite and kaolinite are the three most common clay minerals that are used singly or in combination for landfill liners. The physical properties of clay soils, and therefore of natural clay liners, are primarily dependent on clay particle sizes and on the clay's mineralogy or crystalline structure. Chemically, all clay minerals consist of hydrous aluminum silicates and therefore, all possess certain common features. However, individual clay minerals incorporate differing amounts of water and accessory ions such as calcium and magnesium which result in other features that depend upon the individual characteristics of the particular clay minerals. Table 4-3 gives several examples of variable clay properties, specifically, with respect to permeability and attenuation characteristics.

Clay liners have a relatively low permeability attributable to small constituent grain sizes and the reduction of the sediment/pore space ratio under wet conditions. The ability of clay aggregates to swell and expand derives from the existence of ionic charges that attract surficial layers

TABLE 4-3

ATTENUATION AND PERMEABILITY PROPERTIES OF CLAYS

Percent[a]	Material	Cation Exchange Capacity (meq/100g)[b]	Bulk Density (g/cm^3)	Initial Hydraulic Conductivity[c] (cm/sec)
0	Montmorillonite	0.0	1.71	1.27E-03
2	Montmorillonite	1.7	1.71	9.45E-04
4	Montmorillonite	3.3	1.77	4.34E-04
8	Montmorillonite	6.8	1.79	4.70E-04
16	Montmorillonite	13.3	1.87	1.22E-05
32	Montmorillonite	27.3	1.55	1.27E-05
64	Montmorillonite	50.7	1.23	3.05E-07
100	Montmorillonite	79.5	0.84	7.26E-07
2	Kaolinite	0.2	1.68	7.44E-04
4	Kaolinite	0.5	1.76	4.78E-05
8	Kaolinite	1.0	1.80	9.90E-04
16	Kaolinite	2.2	1.87	2.86E-05
16	Kaolinite	-	1.94	1.09E-06
32	Kaolinite	4.3	1.66	2.40E-06
64	Kaolinite	8.2	1.22	5.45E-07
100	Kaolinite	15.1	0.90	2.98E-07
4	Illite	0.7	1.80	8.17E-04
16	Illite	2.7	1.83	2.68E-05
8	Montmorillonite + 8 Kaolinite	7.6	1.95	5.35E-07
8	Kaolinite + 8 Illite	2.8	1.95	1.48E-06
8	Kaolinite + 8 Illite + 8 Montmorillonite	9.2	1.64	8.08E-06

a. Quartz sand added to make 100%.
b. Meq equals milliequivalents.
c. Exponential notation: E-03 means x 10^{-3}

Source: Reference 5

of molecular water, as well as the tendency of some clays, particularly montmorillonite, to absorb additional interlayer water molecules. Therefore, when clay particles contact water, the effective diameter of the particles is increased and concurrently available pore space is diminished, resulting in decreased permeability rates. Maintaining moisture content is therefore relevant to ensuring low permeability and liner effectiveness in containing leachate. Moisture content is also important to the degree to which clays can be compacted in order to achieve the lowest permeability possible. Some clays such as montmorillonite have a greater tendency to absorb water than other types. For each clay type, an optimum moisture level exists for maximum compaction.

The particular ability of clay minerals to absorb moisture is congruent with an equivalent tendency to dewater and shrink. Therefore, prolonged exposure of clay liners to air will increase shrinkage and result in cracking which would increase passage of leachate through and accelerate failure of the liner. As a consequence of these properties, natural clay liners should be installed only as fill construction progresses.

The base upon which the liner will be placed should be cleared and graded. Actual construction of the liner requires placement of layers of clay material on the landfill base and compaction with appropriate equipment until the desired liner thickness is obtained. Moisture may be added as needed to ensure hydration of clay minerals, to allow optimum compaction for maximum density, and to prevent drying and cracking. Until waste placement occurs, continued emphasis must be placed on maintaining clay moisture content and liner continuity. Careful operation of landfill equipment and deposition of the first layer of waste on the lined base is required to maintain liner integrity.

In addition to containing landfill generated leachate, natural clay liners have a limited capability to provide in-site treatment or attentuation of leachate constituents. Due to the liner's low permeability, leachate movement is extremely slow and allows physical, chemical, and biological interaction between leachate constituents and clay minerals and pore water. This results in attentuation of pollutant elements by filtration, adsorbtion, ion-exchange processes, chemical precipitation, complexation and biodegradation. The relative dominance of one mechanism over another is not well documented. However, some studies indicate that the cation exchange capacity (CEC) of clay minerals is the major removal mechanism for substances such as ammonium, potassium and magnesium. As such, CEC is the principal property utilized to estimate potential attenuation effects of natural clay liners.

The cation exchange capacity arises from the fact that clay minerals consist of interlocking layers of silica and aluminium oxides with interlayer water molecules and cations such as sodium, calcium, and potassium. This structure lends itself to the existence of unbalanced molecular bonds and therefore to the capacity to adsorb ions that may be contained in the leachate. Of the three clay minerals mentioned here, montmorillonite has the greatest CEC, followed by illite and kaolinite. Cation exchange capacities also depend upon the composition and pH of the leachate. Therefore, natural clay liners can be chosen and constructed to selectively attenuate particular leachate pollutant elements. Table 4-4 provides differential CEC's for three sample clay minerals.

4.10.22 Gas Control

A secondary role for natural clay liners is the control of decomposition gas movement. Downward or lateral gas movement may occur as landfill gas is generated. If the gas migrates through permeable substrata, it may collect in dangerous concentrations in buildings near the landfill. Natural clay material can be placed as a horizontal liner or installed as a semi-vertical or vertical wall to block downward and lateral gas movement, respectively. In actual practice, clay liners as discussed in this section can primarily provide an impermeable base for alternate gas control measures such as venting systems or perimeter barrier systems.

The liner properties required to successfully perform this role are essentially the same as for leachate control with the exception that a clay material's permeability to gas will differ from its permeability to leachate or water. Certain features incorporated into the design and construction of a natural clay liner will help minimize gas movement. Selection of a natural soil type should aim to maintain a high degree of saturation which will reduce liner porosity and minimize gas movement. Additional compactive effort will also decrease permeability and reduce gas migration. Another direct and effective procedure is to increase the thickness of the liner.

4.10.23 Current Economic Costs

For a 10 TPD site, 100 TPD site, and 300 TPD site natural clay liners cost \$3.20 (\$3.58), \$1.50 (\$1.68), and \$1.35 (\$1.51) per ton (per metric ton) respectively.

TABLE 4-4

CHEMICAL CHARACTERIZATION OF THE CLAY MINERALS USED IN ATTENUATION STUDIES OF LEACHATE POLLUTANTS

Element	Kaolinite (Pike County, Illinois Exch.*(ppm)	Kaolinite Total	Montmorillonite (American Colloid Co., southern bentonite) Exch.*(ppm)	Montmorillonite Total	Illite (Minerva Co. Mine) Exch.*(ppm)	Illite Total
Ca	2,592	3,700	13,120	22,300	5,248	23,350
Mg	76.8	1,800	680	25,500	800	10,430
Na	43.2	929	24.0	178	115.2	1,050
K	87.2	8,200	240	1,100	800	56,270
NH_4	13.0	40	43	38	50	62.5
Fe	2.0	6,600	2.0	25,500	2.0	28,730
Mn	0.06	29	0.02	25	0.37	390
Pb	2.0	46	2.0	15	2.0	93.8
Cd	0.2	3	0.2	3	0.3	18.8
Zn	0.80	20	1.00	40	2.5	37.5
B	-	46	-	3	-	43.8
Al	-	221,800	-	95,600	-	130,100
Si	-	217,700	-	284,800	-	226,500
Ti	-	14,700	-	1,300	-	4,010

	Kaolinite	Montmorillonite	Illite
Total Carbon (%)	0.54	0.93	2.19
Organic Carbon (%)	0.51	0.92	1.81
Inorganic Carbon (%)	0.03	0.01	0.38
CEC (meq/100g)	15.1	79.5	20.5
Surface area (m^2/g)	34.2	86.0	64.6

Source: Reference 6.

4.10.3 Environmental Impact Summary

1. Natural clay liners can minimize downward migration of leachate pollutants from waste mass to groundwater supplies, thus protecting groundwater aquifers from pollutant effects.

2. Natural clay liners may reduce the likelihood of a groundwater mound from forming beneath a landfill, since it minimizes the flow of water directly through the landfill to the groundwater table below. This, then, minimizes the chances that the groundwater table will intersect the waste mass.

3. Installation of a natural clay liner may require collection and removal of the contained leachate. This may require incorporation of treatment technologies which ultimately result in minimization of groundwater and surface water pollution.

4. Natural clay liners control downward and lateral gas movement by providing a base for semi-vertical or vertical impermeable gas barriers. The control of gas movement out of the landfill reduces the chances of gas migration through permeable strata and build-up in explosive concentrations in buildings on or near the landfill site. Additionally, controlling gas migration minimizes mineralization of groundwater by minimizing the amount of carbon dioxide that contacts and dissolves in groundwater.

5. Use of a natural clay liner allows more flexibility in landfill site selection, since sites with previously unacceptable subsurface characteristics can potentially be utilized for solid waste disposal. Consequently, for example, landfill siting can better minimize waste transport distances, resulting in positive secondary environmental impacts.

6. The excavation, transport, and installation of off-site natural clay materials results in a variety of secondary environmental impacts.

4.11 LEACHATE COLLECTION

4.11.1 Introduction

Groundwater and infiltrating surface water percolating through landfilled solid waste may produce leachate, a solution of dissolved and suspended matter and microbial waste products. Depending on its composition and concentrations, this leachate may pose a danger of severe contamination of underlying groundwater and/or adjacent surface water.

A number of the landfill unit technologies evaluated in this EIS influence leachate control in a variety of ways. These include daily and final cover (Section 4.8) and synthetic and natural clay liners (Sections 4.9 and 4.10). However, the most effective insurance against leachate pollution is leachate collection and treatment or recycling. In actuality, the emplacement of a synthetic or natural clay liner to protect water resources from leachate usually dictates some form of collection and removal of the accumulated leachate. Once removed, the leachate must be disposed of in an environmentally acceptable manner.

The Guidelines suggest that "removal of collected leachate for disposal should be incorporated into the design of lined landfills to avoid overflowing of collected leachate". The Guidelines go on to recommend that "all liner materials should be sloped to one or more points and covered with a layer of granular material to facilitate removal of leachate."

The following pages describe in more detail the technology and environmental impacts of leachate collection.

4.11.2 Technology Summary

4.11.21 Leachate Control

Leachate collection is normally accomplished by gravity drainage with a synthetic or natural clay liner designed to slope to one or more sump collection points. The liner can be overlain by a layer of porous material, such as sand or gravel, to facilitate drainage. This material may be six inches to two feet in thickness and usually also serves to protect the liner from mechanical damage by solid wastes and landfill equipment. Alternatively, the liner can incorporate clay tile drainage systems designed to channel leachate to the collection sumps. Once collected, the leachate may be treated immediately or pumped to a storage tank where it is held for eventual treatment or recycling.

4.11.22 Current Economic Costs

Current economic costs for leachate collection for 10, 100 and 300 ton per day landfills are: $0.95 ($1.06), $0.40 ($0.45) and $0.30 ($0.34) per ton (per metric ton) respectively.

4.11.3 Environmental Impact Summary

1. Since leachate collection presumes and facilitates leachate treatment and/or leachate recycling, its environmental impacts are essentially comparable to those for leachate treatment and/or leachate recycling. These impacts, generally, are reductions in the contamination of ground and surface water.

4.12 LEACHATE TREATMENT

4.12.1 Introduction

To avoid contamination of soil, groundwater, and surface water by high concentrations of organic matter and inorganic ions in landfill leachate, the percolating leachate can be collected and treated. This section evaluates leachate treatment methodologies which are generally one of two types: biological and/or physical-chemical. Land application of raw leachate and piping leachate to a municipal secondary wastewater treatment plant are alternative disposal methodologies.

The Guidelines point out that any leachate treatment system effluent discharge to surface water will require a National Pollutant Discharge Elimination System (NPDES) permit under Section 402 of the 1977 Clean Water Act (Public Law 95-217). The Guidelines identify a variety of wastewater treatment techniques which may potentially be adequate to meet the provisions of an NPDES permit, depending on a variety of factors, including age of the fill and the influent leachate's chemical oxygen demand (COD). See Table 4-5 for an indication of potential treatment methodologies.

TABLE 4-5

LEACHATE TREATABILITY BY ALTERNATE TREATMENT METHODS

Leachate Quality		Treatment Efficiency						
Age of Fill	COD, mg/l	Biological	Chemical Precipitation	Chemical Oxidation	Ozonation	Reverse Osmosis	Activated Carbon	Ion Exchange
Young (5 year)	10,000	G	P	P	P	F	P	P
Medium (5-10 year)	500-10,000	F	F	F	F	G	F	F
Old (10 year)	500	P	P	F	F	G	G	F

Source: Reference 8.

* (COD removal: G = Good; F = Fair; P = Poor)

The Guidelines conclude that:

1. "Leachates containing a significant fraction of high molecular weight organic compounds (i.e. those in excess of 50,000) are best treated by physical-chemical methods such as lime addition followed by settling";

2. "Leachate containing primarily low molecular weight organic compounds are best treated by biological methods such as activated sludge";

3. "Leachates treated by combinations of chemical, physical and biological methods are often the most effective in achieving discharge standards".

The following sections describe in more detail the technology and environmental impacts of incorporation of leachate treatment.

4.12.2 Technology Summary

4.12.22 Leachate Control

Several wastewater treatment techniques have been tested, primarily on a laboratory scale, for their effectiveness in treating landfill leachate contaminated by organic matter and inorganic ions. These techniques are broadly categorized as physical-chemical, biological treatment processes, land application, and combinations thereof. While many researchers have been involved in landfill leachate treatability studies, this evaluation relies most heavily on the more recent and comprehensive investigations by Chian and DeWalle. (References 7 and 8).

To estimate leachate strength and leachate treatment efficiency, most researchers have measured influent chemical oxygen demand (COD) and percent COD removal in effluent, respectively. COD is a relatively accurate and simple measure of a wastewater's water-soluble organic compounds. In addition, Chian and DeWalle have proposed ratios of influent leachate biological oxygen demand (BOD) to COD, and of COD to total organic carbon (TOC), to approximate landfill leachate organic matter composition. BOD/COD and COD/TOC ratios can be used in turn to predict the effectiveness of biological versus physical-chemical leachate treatment methods. The COD/TOC ratio decreases with landfill age, since the organic carbon becomes more oxidized and less readily available for microbial growth as degradation of landfill waste proceeds. Therefore, older leachate is less amenable to biological treatment, since such treatment is simply a controlled microbial degradation process. Similarly, BOD reflects leachate organic matter composition. A high BOD indicates a high proportion of low molecular weight, free volatile fatty acids in the leachate. These high energy compounds are subject to microbial degradation and, therefore, are indicative of a relatively young landfill. Thus, a high BOD/COD indicates a young landfill or a biologically unstable refuse whose leachate is amenable to biological treatment, and vice versa.

Table 4-5, summarizes the implications of this concept by comparing the relative efficiencies of various leachate treatment methods for varying landfill ages and their corresponding leachate strengths and compositions. The following paragraphs briefly describe each of these leachate treatment techniques.

Physical-chemical treatment methods, which have been tested to date, include activated carbon and ion exchange adsorption, reverse osmosis, chemical oxidation, chemical precipitation, and various combinations of these processes. In general, physical-chemical treatments have not proven to be effective on raw leachate generated from a recently installed landfill, since this leachate contains a high proportion of low molecular weight, volatile fatty acids which are more amenable to biological treatment processes (Reference 8). Table 4-6 summarizes the results of several physical-chemical treatment investigations.

Activated carbon and ion exchange adsorption resins have not been able to adsorb the volatile fatty acids and have resulted in unsatisfactory effluent concentrations. As Table 4-6 indicates, literature reports of COD removal in raw leachate of young landfills has ranged from 34 percent using activated carbon batch treatment to 71 percent using activated carbon column treatment. Activated carbon treatment of various biological treatment effluents and leachate from relatively stabilized landfills using known chemical dosages, however, has resulted in COD removal ranging from 70 to 91 percent. Ion exchange treatment of an activated sludge effluent resulted in only a 58 percent COD removal.

Reverse osmosis at pH 8.0 using a cellulose acetate membrane has yielded 89 percent COD removal from raw leachate of a young landfill, while only 56 percent COD removal was possible at pH 5.5 using the same method. However, the necessary upward pH adjustment may be economically unattractive. Reverse osmosis of biological treatment effluent was more successful, averaging over 95 percent COD removal. Severe membrane fouling creates significant operating diffulties and may require incorporation of biological pre-treatment techniques.

Chemical oxidation, including chlorination and ozonation, of both raw leachate and biological treatment effluent resulted in values for COD removal ranging from 0 to 18 percent (Reference 8). Oxidation of the prevalently acidic landfill leachate is generally too slow to be effective. Also, use of some oxidants results in large amounts of sludge to be handled.

TABLE 4-6

RESULTS OF TREATMENT EFFICIENCIES OBTAINED IN DIFFERENT PHYSICAL-CHEMICAL TREATMENT STUDIES

Treatment Process	Author	Inital COD	BOD/ COD	COD/ TOC	Treatment System	Percentage COD Removal	Dosages
Chemical Precipitation	Cook and Foree Ho. et al. (15) (24)	14,900	0.45	3.45	Lime	13	2,760 mg/l $Ca(OH)_2$
		9,100	0.75	-	Ferric Chloride	16.3	1,000 mg/l
		9,100	0.75	-	Alum	5.3	1,000 mg/l
		10,800	0.74	-	Lime	3.5	1,840 mg/l
		558	0.27	-	Lime treatment of anaerobic digestor effluent	7.7	2,700 mg/l
		366	0.11	-	Lime treatment of anaerobic digestor effluent polished by aerated lagoon	29	1,400 mg/l
	Karr (28)	4,800	0.66	2.73	Alum and lime	40	2,250 mg/l $Al_2(SO_4)_3$ and 800 mg/l CaO
					Ferrosulfate	13	2,500 mg/l $FeSO_4$ $7H_2O$
	Roy Weston Inc.	139	0.04	2.1	Lime	0	1,000 mg/l
	Rogers (44)	3,400	0.81	-	Lime	0	1,000 mg/l
	Simensen and Odegaard (45)	1,240	0.66	2.78	Lime and aeration	8	210 ml saturated lime/l leachate
		1,234	0.68	2.88	Iron and aeration	0	200 mg/l $FeCl_3$
		1,234	0.68	2.88	Alum and aeration	11	180 mg/l $Al_2(SO_4)_3$
	Thornton and Blanc (50)	5,033	0.60	-	Lime	24	1,350 mg/l
		12,923	0.57	-	Lime	26	1,200 mg/l
	Van Fleet et al (51)	2,000	0.36	-	Alum	31	2,700 mg/l
	This study	2,820	0.65	2.89	Lime	26	450 mg/l
Activated Carbon and Ion-Exchange Adsorption	Cook and Foree (15)	330	0.07	2.57	Activated carbon batch treatment of aerated lagoon effluent	70	
		3,290	0.45	3.45	Activated carbon column treatment of lime pretreated leachate	81	15 min HRT, after initial volume turnovers

TABLE 4-6 (continued)

Treatment Process	Author	Initial COD	BOD/ COD	COD/ TOC	Treatment System	Percentage COD Removal	Dosages
	Ho, et al. (24)	4,920	0.75	-	Activated carbon, batch	34	16,000 mg/l
		7,213	0.75	-	Activated carbon column	59	45 min HRT after volume turnover
	Karr (27)	5,500	0.66	2.73	Activated carbon, batch	60	160,000 mg/l
	Pohland and Kang (38)	184	0.18	1.5	Carbon batch treatment of activated sludge effluent	91	10,000 mg/l
		120	0.18	1.5	Ion exchange treatment of activated sludge effluent	58	5,000 mg/l cation and anionic mixture
	Roy Weston, Inc.	127	0.04	2.1	Activated carbon, batch	85	10,000 mg/l
	Van Fleet, et. al. (51)	2,000	0.36	-	Activated carbon column treatment of leachate	71	
					Activated carbon column treatment of alum pretreated leachate	94	
	This study	632	0.65	289	Activated carbon column treatment of leachate	70 decreased to 13 after 140 Bv	
		546	0.1	2.55	Activated carbon column treatment of effluent of aerated lagoon	70	-

TABLE 4-6 (continued)

Treatment Process	Author	Initial COD	BOD/COD	COD/COD	Treatment System	Percentage COD Removal	Dosages
		527	0.1	2.46	Ion exchange column treatment of effluent of aerated lagoon	50	
		932	-	2.9	Activated carbon column treatment of effluent of anaerobic filter	50	
		522	0.1	2.7	Activated carbon column treatment of aerated effluent of anaerobic filter	70	
Chemical Oxidation	Cook and Foree (15)	330	0.07	2.57	Chlorination	33	65 ml bleach/l sample
	Ho, et.al.(24)	1,500	0.75	-	Chlorination with calcium hypochlorite	8	8,000 mg/l $Ca(ClO)_2$ after 2 hr
		7,162	0.75	-	Ozonation	37	4 hr, 7,700 mg O_3/l-hr
	Karr (28)	4,800	0.66	2.73	Chlorination	22	2,000 mg/l Cl_2
	Roy Weston, Inc.	139	0.04	2.1	Chlorination with calcium hypochlorite	0	1,000 mg/l $Ca(ClO)_2$
		139	0.04	2.1	Ozonation	22	4 hr 34 mg O_3/l-hr
	This study	1,250	-	2.9	Ozonation of anaerobic filter effluent	37	3 hr, 600 mg/l-hr
		627	-	2.5	Ozonation of aerated lagoon effluent	48	3 hr, 400 mg O/l-hr
Reverse Osmosis	Roy Weston, Inc.	265	-	2.1	Reverse osmosis	80	80% Permeate yield
	This study	53,330	0.65	2.89	Reverse osmosis of leachate at pH 5.5, cellulose acetate membrane	56	50% Permeate yield
		53,300	0.65	2.89	Reverse osmosis of leachate at pH 8.0, cellulose acetate memb.	89	50% Permeate yield

TABLE 4-6 (concluded)

Treatment Process	Author	Initial COD	BOD/ COD	COD/ COD	Treatment System	Per-centage COD Removal	Dosages
		900	-	2.9	Reverse osmosis of anaerobic filter effluent DuPont B-9	98	77% Permeate yield
		536	-	2.5	Reverse osmosis of aerated lagoon effluent, cellulose acetate membrane	95	50% Permeate yield

Similarly, chemical precipitation (including lime, alum, alum and lime, ferric chloride, ferrosulfate, lime and aeration, alum and aeration, and iron and aeration processes) of both raw leachate and biological treatment effluent achieved COD removal values ranging from 0 to 40 percent (Reference No. 8). Using chemical precipitants normally generates large amounts of sludge and additional disposal costs and often requires significant operation and maintenance expenditures.

Aerobic biological treatment of leachate has been studied using laboratory scale aerated lagoons and activated sludge tanks seeded with sludge from municipal wastewater treatment plants (Reference 9). These processes have resulted in up to 99 percent COD removal in raw leachate in two studies (See Table 4-7). In addition, investigators have commonly achieved 95 to 99 percent BOD reduction, 60 to 70 percent removal of volatile suspended solids (VSS), and excellent odor reduction. Further, Chian and DeWalle report high removals of heavy metals in aerated lagoons, especially for iron (99.9%) zinc (99.9%), calcium (99.3%), and magnesium (75.9%), due to chemical precipitation and flocculation. Problems identified in some investigations of aerobic treatment include: high sludge yield, poor solids-liquid separation, foaming, high power requirements, lower removal efficiencies with increased process loadings, and process failure with detention times of two and five days.

Effluent from an anaerobic digester treated in an aerated lagoon in one study achieved sufficient BOD removal, but still required physical-chemical treatment to remove resistant organics and lower COD. For influents with high COD concentrations, aerobic treatment may require additional physical-chemical treatment to remove resistant organics and lower the COD.

Biological treatment of leachate by anaerobic digester and anaerobic filter processes has resulted in COD removals ranging from 89 to 98 percent (Reference 9). These values compare favorably with COD removals achieved with aerobic methods, but reflect longer detention times. One investigation concluded that anaerobic treatment of leachate is superior to other treatment technologies since anaerobic digestion units are readily adapted to treatment of landfill leachate, the landfill gas generated can be recovered, and the longer detention times are suited to the relatively small volumes of leachate generated at a landfill site.

Studies of rotating biological discs and aerobic trickling filters, to date, have resulted in only low COD removal.

Land application of landfill leachate has sustained little actual testing or experience to date as a viable leachate treatment process. However, results from land application of municipal wastewater can to some extent be extended to land application of landfill leachate. Key variables in evaluating the potential of this type of process include: soil type, depth to groundwater, topography, application rates, season of application, and the limitations that certain leachate constituents might place on the process.

TABLE 4-7

RESULT OF TREATMENT EFFICIENCIES OBTAINED IN DIFFERENT BIOLOGICAL TREATMENT

Biological process (1)	Author (2)	Initial COD (3)	BOD/COD (4)	TOD/TOC (5)	Treatment system (6)	Percentage COD removal (7)	Detention time (8)
Aerobic	Boyle and Ham (5)	8,800	0.80	—	Aerated lagoon	74	5 d
	Cook and Force (19)	15,800	0.45	3.45	Aerated lagoon	98	10 d
	Karr (28)	3,550	0.64	3.20	Aerated lagoon	77	0.6 d
	Pohland and Kay (37)	500	0.52	1.56	Aerated lagoon	58	0.3 d
	Roy Weston Inc.	139	0.03	2.1	Aerated lagoon	0	7.7 d
	This study	30,000	0.65	2.9	Aerated lagoon	99	7 d
Anaerobic	Boyle and Ham (5)	10,600	0.79	—	Anaerobic digester	93	10 d
	Force and Reid (20)	12,900	0.45	2.81	Anaerobic digester	92	10 d
	Karr (28)	16,500	0.62	2.92	Anaerobic digester	99	15 d
		5,500	0.78	2.82	Anaerobic digester	93	10 d
	Rogers (44)	1,300	0.81	—	Anaerobic filter using lime treated leachate	87	1.2 d
	This study	30,000	0.65	2.90	Anaerobic filter	97	27 d
Aerobic/Anaerobic	Boyle and Ham (5)	—	0.18	—	Aerated lagoon treatment of anaerobic digester effluent	40	5 d
	Force and Reed (20)	510	—	2.53	Aerated lagoon treatment of anerobic filter effluent	22	1 d
	This study	1,000	—	2.35	Aerated lagoon treatment of anerobic filter effluent	17	7 d

Source: Reference 8.

4.12.23 Current Economic Costs

In general, leachate treatment costs range from \$5.80 (\$6.50), \$1.10 (\$1.23), and \$0.50 (\$0.56) per ton (per metric ton) for 10, 100, and 300 ton per day landfill sites respectively.

4.12.3 Environmental Impact Summary

1. Leachate treatment serves to remove organic matter and inorganic ions, as well as odor and color, from collected landfill leachate before it is discharged to surface waters. If properly and effectively implemented, leachate treatment technology ensures that any landfill leachate discharge to surface waters will meet the provisions of the NPDES permit which would be required under Section 402 of the 1977 Clean Water Act (Public Law 95-217). The consequent environmental impacts of uncontrolled discharges are thereby avoided.

4.13 LEACHATE RECYCLING

4.13.1 Introduction

Leachate recycling is the controlled collection and recirculation of leachate through the landfill for the purpose of promoting rapid stabilization of refuse and leachate constituents. Recycling may also result in reduction of leachate strength and thus may serve as a pretreatment arrangement prior to leachate treatment processes or direct leachate discharge.

The Guidelines indicate that "recirculation of collected landfill leachate onto active or completed sections of the landfill can reduce leachate constituent concentrations by chemical, physical and biological processes and may be effective in reducing leachate volume." The following discusses in more detail the technology and environmental impacts of leachate recycling. Since leachate recycling is a relatively new landfill technology, the following evaluation must be considered preliminary in nature.

4.13.2 Technology Summary

4.13.21 Leachate Control

The precise mode of operation of leachate recycling is still poorly understood since it has only been recently investigated in experimental landfill simulations and very little practical application of the concept has yet been achieved. The generally hypothesized and accepted explanation is that recirculation of leachate through a landfill promotes faster development of an active population of anaerobic methane forming bacteria, which effect the bulk of the waste decomposition process. This, in turn, increases the rate and predictability of biological stabilization of the organic constituents in the waste. While initial recycling may result in higher leachate constituent concentrations than would normally be experienced, the potential increase in degradation rates theoretically should result in reduction of leachate constituents in a short time frame. A variety of constituents, particularly non-organics, such as metallic ions, may remain relatively unaffected. Depending on site specific considerations, requirements for long-term post-closure landfill leachate monitoring and management may be reduced in certain instances.

While actual development of and experience with leachate recycling systems is limited, some alternative arrangements can be described. First, the leachate must be collected using one of the techniques identified in Section 4.11. The actual recirculation technique utilized depends on whether the landfill section through which the leachate is to be recycled is active or completed, and on the permeability of the cover material. For permeable covers, the most practical system for leachate recycling is to distribute the leachate by utilizing a truck equiped with a spray bar. Alternatively, the leachate can be recycled by utilization of a spray irrigation system or a number of well points. Landfills incorporating impermeable final covers may be more amenable to leachate distribution via pressure or gravity lines to a system of perforated pipes buried beneath the cover material.

The rate of biological stabilization can be accelerated by adding sewage sludge to the cover material to seed a methane forming bacteria population and/or by initially neutralizing the landfill pH through addition of lime, etc. so that optimum conditions for immediate development of a bacteria population can be achieved. These measures can reduce landfill stabilization time to a matter of months as opposed to a matter of years.

Once the leachate has been recycled, it may be suitable for direct discharge to surface waters, depending on the condition of the receiving waters and/or on the specific applicable regulatory requirements. In some cases, the landfill may completely reabsorb the recycled leachate, resulting in zero leachate discharge. This is particularly true where leachate generation has primarily resulted from short-circuiting of leachate through the waste mass. In many cases, however, the effluent leachate will require further treatment by separate biological and/or physical-chemical processes (see Section 4.12, Leachate Treatment) to remove residual organics, inorganics such as hardness, chloride, and calcium, and odor, color and metals, etc.

4.13.22 Current Economic Costs

Current economic costs for this technology average \$0.45 (\$0.50), \$0.10 (\$0.11), and \$0.04 (\$0.06) per ton (per metric ton) for 10, 100, and 300 ton per day landfill sites respectively.

4.13.3 Environmental Impact Summary

1. Leachate recycling, especially with pH control and initial sludge seeding, may increase the rate and predictability of biological stabilization of the readily available organic pollutants in landfill refuse and leachate.

2. Since leachate recycling accelerates landfill stabilization and may reduce the requirements for long-term post-closure leachate monitoring and management, the completed landfill site may be reclaimed for final use much more rapidly.

4.14 IMPERMEABLE BARRIERS

4.14 Introduction

A major product of landfill waste decomposition processes is a gaseous mixture consisting largely of methane (55 percent) and carbon dioxide (45 percent), with trace amounts of elemental nitrogen, hydrogen and oxygen, and varying trace constituents such as ammonia, carbon monoxide, ethylene and water vapor. The extent of gas production depends primarily on landfill age, percent and type of waste organic materials, cover material permeability and thickness, landfill temperature variation, waste density and moisture content. Once generated, methane can migrate radially by diffusion and convective flow processes through the gas permeable waste and the adjacent and overlying soil. Under certain conditions, the methane can collect in explosive concentrations (5 to 15 percent in the presence of air) in conduits or buildings adjacent to the landfill. The presence of methane can also result in damage to a variety of plant species due to reduced oxygen concentrations in the plant root zone. Carbon dioxide will dissolve in groundwater forming carbonic acid, therefore mineralizing and contaminating it. A common methodology utilized to predict the potential extent of methane migration is to assume that ten feet of horizontal methane migration may occur for each foot of landfill depth. The resulting value is only a very general estimate, since site specific subsurface conditions such as an impermeable cover and porous substrata can result in methane migration on the order of hundreds of feet.

One method of methane gas control is to to minimize waste decomposition rates by minimizing waste moisture content, thus reducing gas generation rates. Many of the landfill unit technologies discussed in this report aid in minimizing infiltration of moisture into the waste mass and consequently potentially result in reduced gas generation rates. Given adequate methane gas control measures, an alternative approach is to provide more optimum decomposition conditions, i.e. by shredding (increasing waste surface area) or by increasing moisture content (leachate recycling), consequently resulting in more rapid gas generation over a decreased time frame.

The primary methane gas control methodologies involve physical channelling or containment of the gas itself. In some cases, natural soil, hydrologic, and geologic site conditions combined with a permeable landfill cover can result in venting of the decomposition gases directly into the atmosphere. Where these conditions do not occur and where adjacent land use patterns dictate, installation of gas control systems engineered to vent decomposition gases safely into the atmosphere is required. These systems include impermeable barriers, vertical risers, permeable trenches, gas collection systems, and a variety of combination systems.

With regard to impermeable barriers, the Guidelines suggest using compacted moist clays, asphaltic materials or polymeric materials which are gas impermeable. The Guidelines further recommend that the cutoff wall extend from the ground surface down to a gas impervious layer below the bottom of the landfill.

The following sections describe in more detail the technology and environmental impacts associated with utilizing impermeable barriers for gas control.

4.14.2 Technology Summary

4.14.21 Gas Control

Impermeable barriers function by blocking the lateral migration of landfill gas through the surrounding more permeable material. An impermeable barrier is normally constructed around the periphery of a landfill where subsurface conditions might lead to potential migration. The barrier should be installed to a depth below the maximum depth of waste deposition and preferably to an impervious layer (see Figure 4-4). This bottom seal could include certain bedrock types, the groundwater table, or an impermeable landfill liner such as a natural clay liner or a synthetic liner.

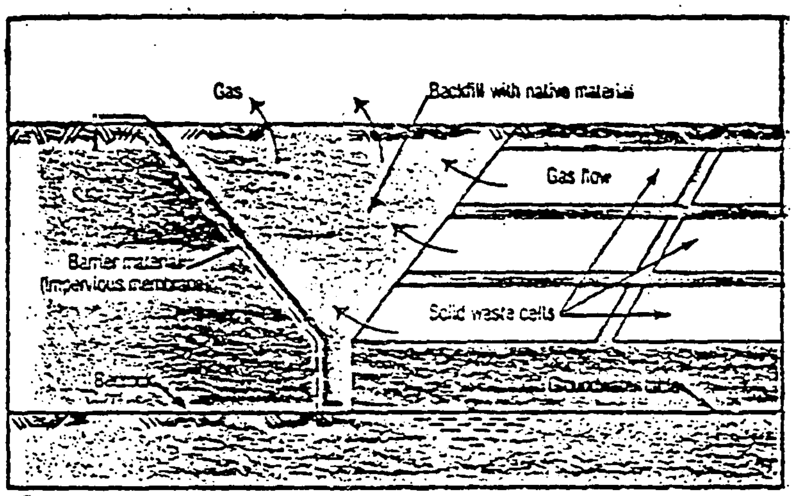
While an impermeable barrier can be effective under certain conditions, an adjoining permeable pathway located on the interior edge of the impermeable barrier may result in more positive methane controls. For instance, an adjoining trench can be backfilled with gravel to the same depth as the impermeable barrier. In turn, the permeable trench results in vertical gas movement to the atmosphere (see Section 4.16). This approach may be required even in relatively permeable substrata where the adjacent land uses require strenuous gas control measures. Vertical risers (see Section 4.15) may also be installed in the permeable trench if there is a danger of the trench being sealed off by freezing of the land surface.

4.14.22 Current Economic Costs

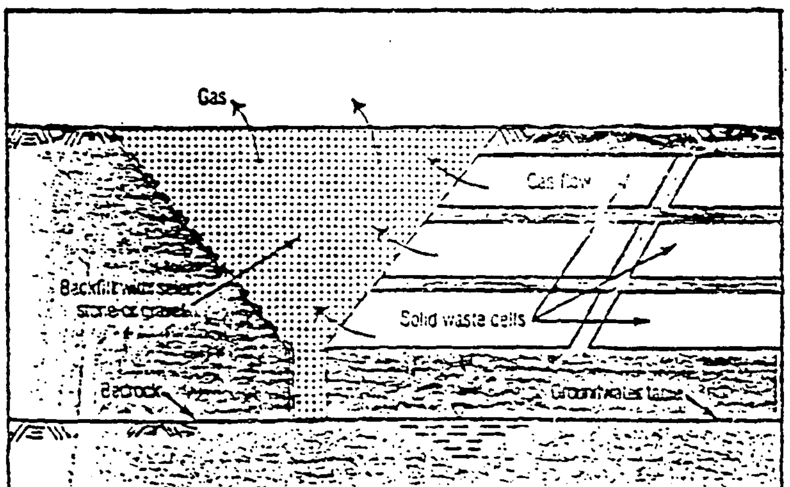
Current economic costs for impermeable barriers average $1.30 ($1.46), $0.30 ($0.34), and $0.15 ($0.17) per ton (per metric ton) for 10, 100, and 300 ton per day landfill sites, respectively.

FIGURE 4-4

BARRIER AND TRENCH GAS CONTROL SYSTEMS



a Barrier system. Migrating gas is unable to cross impermeable barrier and is forced to vent to atmosphere. Trench is excavated to continuous bottom seal (bedrock or water table); barrier membrane is installed; trench is backfilled. Barrier can be impervious membrane or clay.



b Trench with granular backfill. Gas travels to trench and is vented to surface because granular backfill is more permeable than surrounding soil. Trench is excavated to bottom seal (bedrock or water table) and backfilled with crushed stone or clean gravel.

Source: Reference 10.

Environmental Impact Summary

If effective at controlling gas migration to offsite areas, vertical impermeable barriers can have several environmental impacts:

1. Gas buildup in explosive concentrations in nearby offsite buildings or conduits is minimized, therefore reducing fire and explosion hazard.

2. Vegetation kills due to landfill gas creating deleterious anaerobic conditions in plant root zones are minimized.

3. Gas movement control minimizes mineralization of ground water due to the formation of carbonic acid caused by the dissolution of landfill generated carbon dioxide.

4. Manufacture, transport, and installation of a barrier system may have a variety of secondary negative environmental impacts.

4.15 PERMEABLE TRENCHES

4.15.1 Introduction

A gas permeable, gravel-filled trench can also be utilized to control the lateral migration of landfill generated gas, and thus to minimize landfill explosion and fire hazards, vegetation kills, and potential groundwater mineralization. (See Section 4.14 for a more detailed discussion of the causes, characteristics, and control of landfill gas generation and migration.)

Under certain conditions permeable trenches can provide adequate control of methane movement. However, the trenches still may permit gas migration through diffusion processes and are susceptible to clogging due to infiltration, snow or ice cover or biomass growth. The Guidelines indicate that gravel-filled trenches equipped with vertical perforated pipes functioning as methane vents have been shown to reduce the effect of temporary covers such as ice or snow. The Guidelines also recommend equipping trenches for removal of water or leachate from the trench bottom to facilitate gas movement.

The following sections describe in more detail the technology and environmental impacts of permeable trenches.

4.15.2 Technology Summary

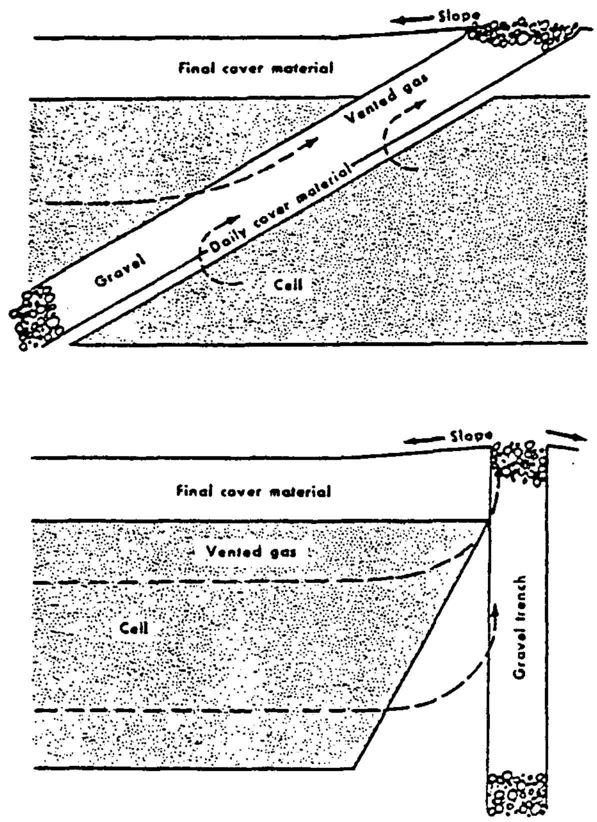
4.15.21 Gas Control

Permeable, gravel-filled trenches are usually located on the landfill perimeter or occasionally incorporated between daily cells. These trenches operate by intercepting laterally migrating landfill gas and by providing a low resistance path to the atmosphere. These trenches should normally extend to at least the bottom of the landfill. They may be excavated vertically or placed diagonally (see Figure 4-5). The trench should drain naturally, and the filler material should be graded to avoid infiltration and clogging by sediment washed in from surface runoff. The upper surface of the trenches should be maintained free of soil and vegetation to maximize gas access to the atmosphere.

Permeable trenches are most effective at existing landfills in which the surrounding soil is relatively less permeable than the trench backfill material and the water table is relatively deep. For somewhat permeable subsurface

Figure 4-5

GRAVEL VENT AND GRAVEL-FILLED TRENCHES



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

Source: Reference 2

soils, the trench should be backed up by an impermeable barrier of the type discussed in Section 4.14. Furthermore, if freezing of the land surface and resultant sealing of the trench is a possibility, vertical pipes may be utilized as vents. These vents may or may not be equipped with pump or blower units for induced exhaust.

As in the case of impermeable barriers, Stone (Reference 10) reports that in certain cases permeable barriers may not provide adequate gas control if utilized alone. Failure detection is also difficult; however, maintenance of the barrier is relatively simple.

4.15.22 Current Economic Costs

Per ton (per metric ton) costs for perimeter gravel trenches are $1.60 ($1.79), $0.35 ($0.39), and $0.20 ($0.22) for 10 TPD, 100 TPD and 300 TPD sites, respectively.

4.15.3 Environmental Impact Summary

Utilization of permeable trenches can result in a number of positive environmental impacts including:

1. Gas buildup in explosive concentrations can be minimized, therefore reducing potential explosion hazards.

2. Vegetation kills due to gas migration can be minimized.

3. Groundwater mineralization due to carbon dioxide dissolution can be minimized.

4. Odors, particularly from hydrogen sulfide generation, can be confined to the immediate landfill area.

5. The transport and installation of barrier materials may result in secondary environmental impacts such as energy use, air emissions due to transport, site specific impacts due to gravel quarrying, etc.

4.16 VERTICAL RISERS

4.16.1 Introduction

Vertical risers provide a low resistance path to the atmosphere for laterally migrating landfill gas. Vertical riser construction can consist of perforated pipe vents or gravel-filled well systems. Section 4.14 provIdes a more detailed discussion of the rationales for control of landfill gas generation and migration.

The Guidelines do not recommend utilizing perforated pipes alone for methane control since venting effectiveness is generally limited to the immediate vicinity of the pipe. For more effective control a closely spaced grid of vents or wells could be installed.

The Guidelines also distinguish between natural ventilation using vertical risers and induced exhaust wells equipped with a pump or blower. The Guidelines state that properly designed and installed exhaust well systems are substantially more effective than natural ventilation systems. Additionally, the Guidelines state that induced exhaust systems are not limited to shallow landfills on shallow impermeable strata, and that induced systems may potentially be used to recover exhaust gases. However, induced exhaust systems require significant operating expenditures and maintenance.

4.16.2 Technology Summary

4.16.21 Gas Control

Vertical risers can operate either by providing a low resistance path to the atmosphere for laterally migrating landfill gas, or, if equipped with a pump or a blower, by inducing gas ventilation by creating a negative pressure gradient within the waste mass. Vertical risers are usually utilized when the final cover is relatively impermeable. Risers can be installed around the landfill perimeter, but are most effective when also placed in the landfill interior. In areas adjacent to building structures, discharges should be limited to above the roof line.

The riser sizes and spacings depend on the type and severity of waste deposition, the rate of gas production, and the gas permeability of both cover and surrounding soil. The recommended spacing is 30 to 60 feet on centers (Reference 11). Once drawn through the riser, landfill gas is vented to the atmosphere, flared, or recovered and cleaned for on-site or off-site energy use.

Actual construction of vertical risers (see Figure 4-6) involves: (1) drilling the wells to a continuous bottom seal such as bedrock or the groundwater table; (2) inserting the perforated pipes into the wells and backfilling with gravel, or simply backfilling the well with gravel; and (3) if desirable, connecting each riser to a pump or blower to induce ventilation. Section 4.17 discusses gas collection systems whereby vertical risers are connected via a header to a central pump or blower. As mentioned in Section 4.15, risers can also be installed in permeable trenches when there is a danger of freezing and sealing of the trench surface.

As in the case of permeable trenches, Stone (Reference 10) reports that vertical risers depending only on natural ventilation have been shown to be ineffective at many sites. Alternatively, there are two types of forced flow or induced exhaust systems: high flow and low flow. High flow systems cause large volumes of gas to flow laterally through the landfill and, consequently, through the exhaust system. The negative pressure gradient created is also sufficient to draw atmospheric air through the cover material into the landfill. This type of system provides an effective barrier to gas migration. However, high flow systems entail several disadvantages:

1. explosion hazards are increased by reducing methane concentrations from the normal 50% found in landfills toward the explosive range (5-15%);

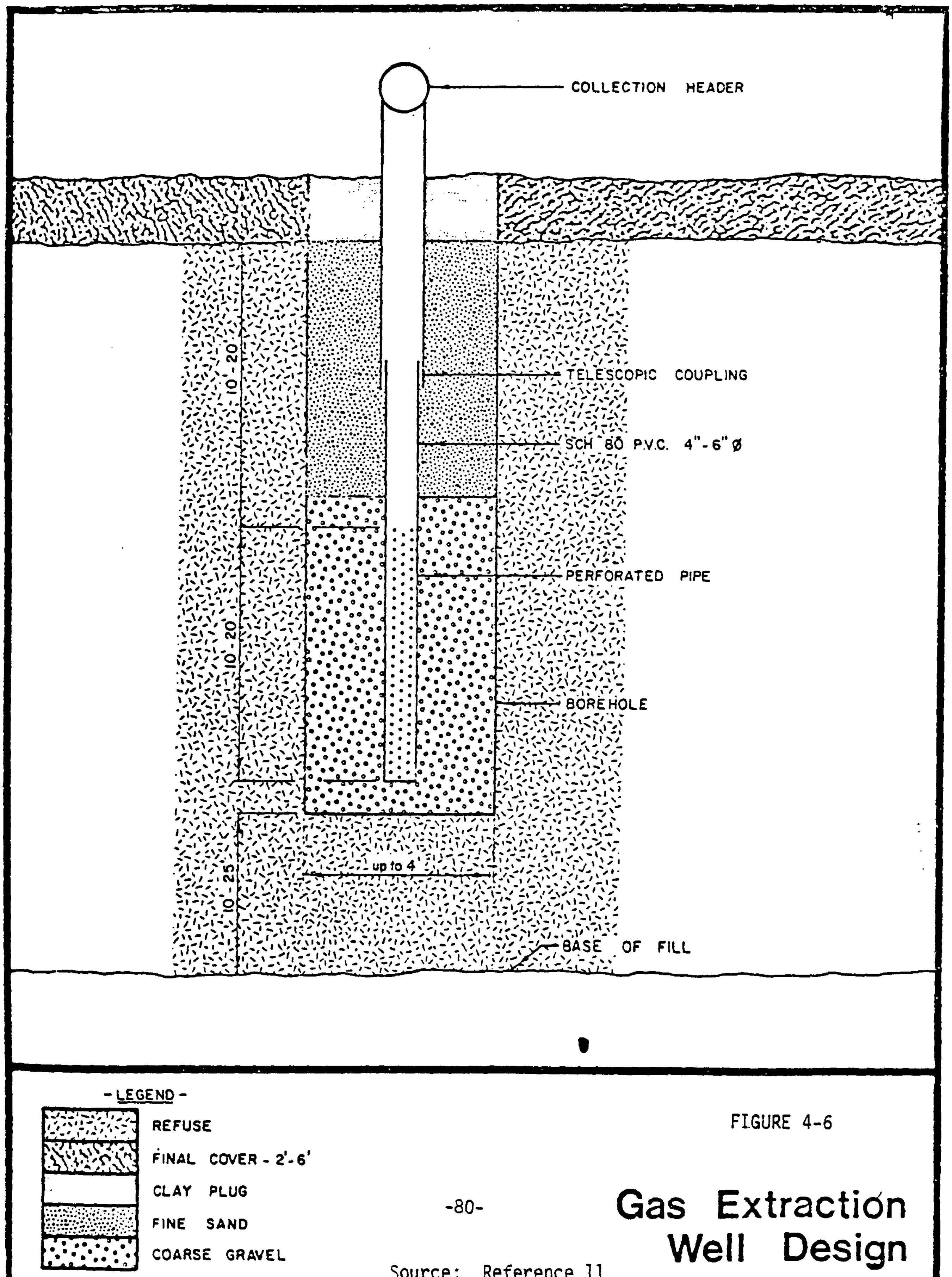


FIGURE 4-6

Gas Extraction Well Design

Source: Reference 11

2. fire hazard from spontaneous combustion within the fill is increased by drawing oxygen into the normally anaerobic environment,

3. methane recovery is made more difficult and expensive by dilution with air; and,

4. energy requirements, and, therefore, operating costs, are higher.

Low flow systems also work by creating a negative pressure system between wells which result in gas movement towards the riser venting points. This system differs from the high flow system by providing only the minimum head differential required to establish a negative pressure gradient towards the risers. The low pumping requirements and consequent lower difference in pressure between the atmosphere and the waste mass result only in minimum intrusion of atmospheric air into the landfilled waste. Consequently, low flow systems as compared to high flow systems reduce potential fire and explosion hazards, require less energy expenditures, and are more conducive to methane gas recovery operations.

Stone (Reference 10) compares induced exhaust systems to natural ventilation vertical riser systems in terms of effectiveness, maintainability, and controllability. When adequately designed and installed, an induced exhaust system is considered a "fail-safe" means of methane migration control, especially when wells are also installed in the interior of the landfill. While forced flow systems require more maintenance, it is easier to detect failures and maintenance is less hampered by lack of assessibility.

It is also possible to control lateral gas migration by forcing air into the landfill. Such an induced recharge system can be designed very similarly to induced exhaust systems. Such systems generally consist of a perforated header pipe in a surface-sealed, gravel-filled trench connected to a central pump or blower. The system operates by displacing gases to the atmosphere by providing a positive gradient in the landfill interior. While the recharge system generally requires less energy, and thus less operating expense, and does not require incorporation of final gas disposal technologies, it does preclude recovering the gas for energy use. Furthermore, forcing air into the landfill increases the likelihood of explosion and fire hazards as explained above for high flow induced exhaust systems (Reference 10). Additionally, under certain conditions, it is theoretically possible for forced air systems to result in methane migrations over longer distances than would normally be expected. To some degree this could be alleviated by the presence or provision of impermeable barriers or permeable escape routes at the landfill site perimeter.

4.16.22 Current Economic Costs

Current economic costs for these technologies average $0.90 ($1.01), $0.45 ($0.50), and $0.40 ($0.45) per ton (per metric ton) for 10, 100, and 300 ton per day landfill sites respectively.

4.16.3 Environmental Impact Summary

1. Naturally vented vertical risers and low flow induced exhaust systems can be effective at controlling lateral landfill gas migration and therefore minimize both fire and explosion hazards in buildings and conduits adjacent to the landfill site.

2. High flow induced exhaust systems and induced recharge systems can also effectively control lateral gas migration, thus reducing both fire and explosion hazards at and adjacent to the landfill site. However, these systems also force air into the landfill, thereby reducing the methane concentration from the normal 50% found in the landfills toward the explosive range (5-15%). These systems, then, increase the explosion hazards of the landfill site itself. Both systems also increase the fire hazard from spontaneous combustion at the landfill site by supplying oxygen to the normally anaerobic environment.

3. All of the vertical riser systems minimize vegetation kills which are due to landfill gas creating deleterious anaerobic conditions in the root zones.

4. All of the vertical riser systems minimize the mineralization of ground water due to the formation of carbonic acid by dissolution of landfill generated carbon dioxide.

5. All of the vertical riser systems minimize odor pollution of off-site areas due to the controlled, on-site release to the atmosphere of hydrogen sulfide and other gases.

6. The manufacture, transport, and installation of all of the vertical riser systems entail a variety of secondary negative environmental impacts.

4.17 GAS COLLECTION SYSTEMS

4.17.1 Introduction

Gas collection systems consist of vertical risers connected via header pipes or permeable surface-sealed trenches generally equipped with perforated header pipes. Both types of systems are generally equipped with a central pump or blower to facilitate gas collection. Otherwise, these systems are designed, constructed, operated, and maintained similarly to vertical risers, permeable trenches, and induced exhaust or induced recharge systems. Likewise, gas collection systems can minimize methane explosion hazards, vegetation kills, and mineralization of ground water. (See Section 4.14 for a fuller discussion of the causes, characteristics, and control of landfill gas generation and migration.)

The Guidelines describe induced exhaust well collection systems as very effective when properly designed and installed; as not limited to shallow landfills or shallow impermeable substrata; as allowing the options of flaring or recovering the exhaust gases; and as requiring significant maintenance. The Guidelines describe induced exhaust trenches:as consisting of surface-sealed, gravel-filled trenches equipped with perforated header pipes connected to a pump or blower; as more effective than induced exhaust wells, especially at shallow landfills; as requiring more extensive construction; as potentially requiring significant maintenance; and as less likely to be useable with recovery systems due to the introduction of air.

The Guidelines describe induced recharge trenches as being of the same design as induced exhaust trenches, but operating in reverse, suppressing horizontal migration of methane via provision of a positive pressure gradient beneath the landfill surface. This results in dispersion of gases to the atmosphere across the trench and ground surface. The Guidelines claim induced recharge trenches require less energy than exhaust trenches, and that flaring is not necessary since the gases are not concentrated.

The following sections describe in more detail the technology and environmental impacts of gas collection systems.

4.17.2 Technology Summary

4.17.21 Gas Control

Given the technologies for permeable trenches, vertical risers, and for induced exhaust and induced recharge systems (see Sections 4.15 and 4.16), the technology of gas collection consists of: (1) connecting the vertical risers via a header pipe to a central pump or blower for induced exhaust; or (2) in the case of surface-sealed induced exhaust or induced recharge trenches, connecting a perforated header pipe to a central pump or blower. With the exception of one or the other of these additional elements, gas collection system design, construction, operation, and maintenance is very similar to that of its component technologies of vertical risers or permeable trenches, and induced exhaust or induced recharge. For this reason, gas collection systems involve virtually the same advantages and disadvantages in terms of effectiveness, maintainability, and controllability as those listed for individual components in Sections 4.15 and 4.16.

4.17.22 Current Economic Costs

Current economic costs for these technologies average $2.50 ($2.80), $0.55 ($0.62), and $0.30 ($0.34) per ton (per metric ton) for 10, 100, and 300 ton per day landfill sites, respectively.

4.17.3 Environmental Impacts Summary

1. Low flow induced exhaust collection systems can be effective at controlling lateral landfill gas migration and therefore minimize both fire and explosion hazards adjacent to the landfill site.

2. High flow induced exhaust collection systems can also effectively control lateral landfill gas migration, thus reducing both fire and explosion hazards in buildings and conduits adjacent to the landfill site. However, this type of system can draw air into the landfill, thereby reducing the methane concentration from the normal 50% found in landfills toward the explosive range (5-15%). Therefore, the high flow systems increase the on-site explosion potential. Both the low flow and the high flow induced exhaust collection systems increase the fire hazard from spontaneous combustion at the landfill site by drawing oxygen into the normally anaerobic environment (Reference 10).

3. All of the gas collection and recharge trench systems minimize vegetation kills which are due to landfill gas creating anaerobic conditions in subsurface soil layers.

4. All of the gas collection and recharge trench systems minimize the mineralization of ground water by restricting movement of carbon dioxide.

5. Gas collection and recharge trench systems minimize odor pollution of off-site areas due to the uncontrolled release to the atmosphere of hydrogen sulfide and other gases.

6. The manufacture, transport, and installation of gas collection and recharge trench systems entail a variety of secondary negative environmental impacts.

4.18 ACCESS CONTROL

4.18.1 Introduction

Because of the nature of landfill operations and the potential hazards involved, it is important to control access to the site in order to ensure the safety and health of personnel and visitors. The Guidelines specify that a disposal facility should be designed, constructed, and operated to permit strict supervision of site access. Access to the site should be controlled and should be only by established roadways. Additional controls include traffic signs or markers to direct traffic to and from the discharge area.

The following section will detail the functions of access control and specify design and construction methods. The costs of providing access control are also presented. A final section will assess the environmental impacts of access control on various aspects of landfilling.

4.18.2 Technology Summary

4.18.21 Access Control Functions

The primary aim of access control is to prevent trespassing and unauthorized use of the disposal site, which will enable landfill operators to maintain safe working conditions and protect the health of personnel and visitors. Peripheral fences are commonly used to control or limit access, thereby preventing trespassing, keeping children and animals out of potentially hazardous areas, and discouraging vandalism and scavenging. Fences also serve to prevent unauthorized use of disposal sites and limit the types of wastes accepted to those for which the landfill was specifically designed. Finally, certain fence types can provide a visual screen for landfill operations and can consequently result in localized aesthetic improvement.

Additional access control is furnished by providing permanent and temporary roadways, and traffic signs or markers that promote an orderly traffic flow to and from the discharge area. In combination proper fences and road systems provide the measure of access control that will enable site operators to maintain efficient operating conditions.

4.18.22 Access Control Design and Construction

Fencing used to control or limit access to landfill disposal facilities may be permanent or portable, and may be constructed of wood or chain links, wood, or other similar materials. At some locations it may be desirable to install several strands of barbed wire on fence tops, projecting at an angle, to further discourage trespassing and vandalism. Peripheral fencing should limit access to one or two gates that are clearly marked and can be locked when the site is unattended. Landfill sites should be open only when operators or other supervisory personnel are on duty.

Fencing requirements are dependent on the degree of isolation of the site location. In areas adjacent to urban centers and residential developments, more expensive fencing may be required to protect residents and children, and to screen landfill operations. Landfills located in more isolated rural areas may need less expensive fencing or fencing only at entrances and other places of possible unauthorized access.

Permanent, all-weather roads should be constructed from the public road system to the site. Design of the roads should accomodate the anticipated volume of delivery vehicles and other vehicular traffic. Construction and maintenance of the grade of access roads should accomodate the limitations of the equipment. Permanent on-site roads represent a higher initial cost than temporary roads. However, this cost can be balanced by overall savings in equipment repair and maintenance. Temporary roads are more often used to connect permanent road systems to the constantly changing location of the working face.

4.18.23 Current Economic Costs

Provision of fencing as an upgrading technology currently costs $0.90 ($1.01), $0.20 ($0.22), and $0.10 ($0.11) per ton (per metric ton) for 10, 100, and 300 ton per day landfill sites, respectively.

4.18.3 Environmental Impacts Summary

1. Use of access control techniques aids in siting landfills in more densely populated areas by mitigating possible hazards to the health and safety of surrounding populations. This results in positive environmental impacts because waste transport distances are minimized.

2. Proper access controls limit trespassing, vandalism, scavenging and other disruptions to landfill operations, and prevent unauthorized dumping, thus allowing more efficient and environmentally beneficial use of the disposal facility.

3. Strict access controls, by limiting trespassing, not only promote efficiency in operations, but also contribute to maintaining safe working conditions, and the health and safety of personnel and visitors.

4. Access controls can be employed to visually screen landfill sites, and therefore promote a more aesthetic appearance to the landfill operations.

4.19 SAFETY

4.19.1 Introduction

A variety of operation and maintenance procedures contribute towards providing safety for personnel and visitors, and towards efficient working conditions. In addition to measures for fire control (Section 4.20), vector control (Section 4.21), and access control (Section 4.18), the Guidelines present a number of specific recommendations for ensuring safety at the disposal site. For example, the Guidelines recommend that personal safety devices such as hard hats, gloves, safety glasses, and footwear should be provided to facility employees. In general, the Guidelines suggest that a landfill site be designed, constructed, and operated in a manner so as to protect the health and safety of personnel and users through compliance with relevant provisions of the Occupational Safety and Health Act of 1970 (OSHA) (Public Law 91-596) and regulations promulgated thereunder.

The following sections further summarize applicable Guideline recommendations and associated environmental impacts.

4.19.2 Technology Summary

4.19.21 Operation

The main objective of implementing safety procedures is to maintain the health and welfare of facility personnel and site visitors. Additionally, safety measures contribute to lower costs through increased efficiency of operations and decreased equipment maintenance. In conjunction with the aforementioned recommendations, the Guidelines specifically suggest the following:

1. safety manuals should be provided and employees instructed in application of its procedures;

2. safety devices such as rollover protective structures and seat belts should be provided on all equipment used to spread and compact solid wastes;

3. communications equipment should be available on site for emergency situations;

4. quantitative and qualitative records of solid wastes received and location of disposal should be maintained;

5. a source of water should be provided on-site for fire and dust control and for employee convenience; and,

6. following closure of a completed landfill a long-term maintenance program should be initiated.

4.19.3 Environmental Impact Summary

1. Incorporating safety measures in the design, construction, and operation of a landfill facility serves to promote the safety of landfill personnel and users.

4.20 FIRE CONTROL

4.20.1 Introduction

Although the open burning of wastes is prohibited at all landfills, fire hazards can still result from a variety of conditions. Dumping of hot or burning waste loads or sparks from vehicles and landfilling equipment can accidently ignite solid wastes. Additionally, the potential for heat energy generation by exothermic chemical reactions in decomposing wastes results in conditions favoring spontaneous combustion. Therefore, solid wastes that can smolder or burn even after being covered necessitate the on-site availability of some method of fire control.

The Guidelines, besides prohibiting open burning, recommend the following measures to minimize fire hazards:

1. provisions should be made to extinguish any fires in wastes being delivered to the site or which occur at the working face or within equipment or personnel facilities;

2. a source of water should be provided at the disposal facility and safety devices should include fire extinguishers to be provided on all equipment used to spread and compact solid wastes or cover material; and,

3. cover material should be applied, as necessary, to minimize fire hazards.

These measures, particularly the application of cover material as a fire control method are discussed in more detail in subsequent sections.

4.20.2 Technology Summary

4.20.21 Operation

The major functions of fire control are to maintain safe working conditions and to promote efficient fill construction by minimizing the initiation and spread of waste combustion. Secondarily, fire control protects air quality by minimizing contributions of particulates and other constitutents from burning wastes.

In addition to supplying water and equipment to extinguish fires, proper landfill design and construction can manipulate the two main conditions that contribute to fire hazards:-the availability of flammable material in the waste cell, and the availability of an oxygenated air supply necessary to combustion. With regard to the first condition, landfills can be operated so that wastes regarded as highly flammable may be excluded or disposed of in a separate area utilizing special disposal procedures such as immediate encapsulation with cover materials, wetting, etc. However, due to the highly variable nature of solid wastes, and particualarly of municipal wastes, some flammable type materials always exists in waste cells, so that this measure by itself is not totally effective in controlling fire hazards.

The second condition, the availability of oxygen for combustion, can be successfully restricted by judicious and regular application of cover material. Well-compacted daily soil cover, as utilized to form the floor, sidewalls, and top of a waste cell during fill construction, tends to constitute an effective barrier to oxygen migration and also provides for physical containment of any fire outbreak.

The moisture content of cover material and of constituent solid wastes is also important in minimizing initiation and spread of fire. A fine grained soil such as clay, which can absorb more water and maintain a higher degree of saturation than coarse soils, results in reduced oxygen migration into the waste mass. Saturated cover soils are also temporarily effective in stabilizing landfill conditions approaching spontaneous combustion or in extinguishing an existing fire. The moisture content of waste fill is also an important factor in spontaneous combustion. Although it is difficult to estimate the specific or average water content of variable solid wastes, some studies indicate that when moisture levels drop below 50% of the original water content, conditions are favorable for spontaneous combustion. However, maintaining high soil water content by regular additions of water for the life of site may not be feasible due to leachate generation considerations.

4.20.22 Current Economic Costs

Current economic costs for fire control average \$0.04 (\$0.04), \$0.01 (\$0.01) and \$0.01 (\$0.01) per ton (metric ton) for 10, 100, and 300 ton per day landfill sites, respectively.

4.20.3 Environmental Impact Summary

1. Fire control serves to minimize the accidental or spontaneous initiation and spread of waste combustion, resulting in improved safety of landfilling operations and personnel, and improved efficiency of operations.

2. Secondarily, fire controls aid in rapid extinguishing of fires, which in turn protects air quality by reducing contributions of particulates and gaseous emissions from burning refuse.

4.21 VECTOR CONTROL

4.21.1 Introduction

The constituents of solid wastes, especially municipal wastes, may provide a potential source of food and harborage for a variety of vectors. These vectors, generally defined by the Guidelines as agents capable of carrying and transmitting disease pathogens, can include rats, flies, mosquitoes, and occasionally birds. While a properly designed and constructed sanitary landfill minimizes animal attraction and vector breeding, it may be necessary to institute additional vector control measures to ensure the health and safety of persons on and around the disposal site.

Towards this goal, the Guidelines suggest that disease and nuisance vectors should be controlled at landfill disposal facilities through minimization of food and harborage, by judicious application of cover materials and through initiation of eradication programs if vector populations become established.

The remainder of this evaluation presents an overview of various aspects of vector control methods and their impact on the environment.

4.21.2 Technology Summary

4.21.21 Operation

The control of vector breeding and harborage functions mainly to ensure the health of on-site personnel and adjacent communities by minimizing carriers of disease pathogens. The main objective of such control then is to restrict the availability of food and harborage. Along these lines, daily and intermediate cover soils can be instrumental in implementing effective vector control because they can provide durable and complete coverage of solid wastes.

Daily or more frequent applications of cover material are necessary to deter burrowing animals such as rats and control the breeding of flies and mosquitoes. Rats and other burrowing animals are attracted to landfills by the availability of waste food scraps and shelter. While daily cover application can eliminate open exposure of solid wastes, burrowing can continue, and the resulting tunnels damage the structural integrity of the cover and may provide pathways for infiltration of surface waters. This problem can be alleviated by selection of soil types that will not structurally support tunneling.

Flies are also attracted by the availability of breeding areas and food sources. Well-graded and well-compacted soil cover will impede vector larvae emergence. Studies have shown that 6 inches of daily cover is of sufficient thickness to serve vector control functions.

Since mosquitoes utilize water-filled areas for propagation, mosquito control is best achieved by preventing development of stagnant water bodies on the surface of the site. Continuous grading may be required to fill in depressions resulting from incomplete compaction or differential settling of wastes.

Additionally, birds are attracted in large numbers by the availability of food. The problem can be minimized by quickly covering wastes with a thick layer of cover material sufficient to discourage bird scavenging.

In the event vector populations become established or show a seasonal increase, extermination using insecticides and rodenticides may be necessary. Such programs should be carefully controlled and monitored so that they do not pose a health or safety hazard.

4.21.3 Environmental Impact Summary

1. Vector control serves to promote safe working conditions and the health of persons on and around the disposal site by minimizing potential disease transmitting agents.

4.22 LITTER CONTROL

4.22.1 Introduction

Due to the amounts of solid wastes handled and the nature of landfill operation methods, disposal sites must contend in varying degrees with the problem of controlling litter on and around the site. In regard to litter control, the Guidelines specify only that, along with its other functions, cover material can be applied to minimize blowing litter. However, the Guidelines generally recommend that the landfill facility should be maintained in an aesthetic manner. In addition, containment and cleanup of litter contributes to the safety of operations and personnel.

The function of litter control and the various techniques that function in that capacity are detailed in the following sections. The evaluation concludes with a summary of the current economic costs and the environmental impacts of litter control.

4.22.2 Technology Summary

4.22.21 Operation

Solid waste, particularly paper and other light density wastes, may be subjected to wind or other elements as it is being transported, discharged, and compacted prior to actual incorporation into the waste cell. This situation results in problems with blowing litter. Containment and periodic cleanup of such litter on and around the landfill facility contributes mainly to maintaining an aesthetic appearance and consequently contributes towards promoting public acceptance of the facility.

The major objective in controlling blowing litter is to minimize the amount of refuse exposed to wind and weather. This can be effected by a number of techniques including limiting the size of the working face, proper application of cover materials in daily operations, provision of temporary fencing, provision of regular maintenance operations, and prohibition of indiscriminate dumping.

Blowing litter can be minimized by keeping the size of the working face at a nimimum; covering portions of the waste cell as it is constructed serves the same function.

To contain wastes that escape coverage at the working face, litter fences can be placed downwind of the working face. Since the location of the working face is constantly shifting, such fences are usually portable. As a general rule, trench operations require less fencing because the walls of the trench usually aid in confining solid wastes. At a very windy trench site, a 4-foot fence will usually be sufficient for litter control. Area operations usually present a greater litter problem and may require fences as high as 6 to 10 feet in order to contain blowing wastes.

Additionally, litter control requires periodic cleanup near the operating area and along roadways on or near the disposal site. The refuse picked up, as well as any resulting from indiscriminate dumping, should be returned to the working face to be covered near the daily close of operations.

4.18.22 Current Economic Costs

Current economic costs for the provision of litter control are \$0.05 (\$0.06), \$0.01 (\$0.01), and \$0.01 (\$0.01) per ton (metric ton) for 10, 100, and 300 ton per day landfill sites, respectively.

4.22.3 Environmental Impact Summary

1. Litter control measures enable landfill facilities to present a more aesthetic appearance which may facilitate public acceptance of the site.

4.23 GAS MONITORING

4.23.1 Introduction

A landfill gas monitoring program evaluates methane gas migration to evaluate the effectiveness or requirements for on-site gas control measures. The Guidelines call for monitoring all on-site enclosed structures to detect potential hazardous explosive conditions. The Guidelines also recommend monitoring gas migration and explosive conditions at the landfill property boundary.

4.23.2 Technology Summary

4.23.21 Gas Control

Methane monitoring should occur at regularly spaced intervals around the landfill perimeter and at any buildings or other enclosed structures on or immediately adjacent to the landfill site, where feasible. Samples should be taken at depth intervals from the immediate subsurface down to the landfill base. Points below the water table or otherwise similarly isolated do not require monitoring.

Sampling frequencies must be determined on a site-by-site basis but should generally be completed at least quarterly. Monthly monitoring should occur when gas migration is more probable as for example during periods of frozen cover. More urgent situations where landfill gas is posing a potential hazard may require daily monitoring.

Gas sampling devices include both permanent probe installations (See Figure 4-7) and portable probe samplers. (See Figure 4-8). Both types draw samples from the soil pore spaces by utilizing vacuum force. Permanent probe installations must be sealed at the surface to prevent air contamination of the soil air sample. Care must be exercised not to cross contaminate samples taken at several depth intervals in the same sampling location. Portable samplers are hand-driven and can normally extract samples to only 5 feet deep.

Detailed gas analysis generally occurs in a laboratory via utilization of a gas partitioner. Several constitutents, however, such as methane, carbon dioxide, and oxygen can be analyzed in the field utilizing portable devices incorporating electrovoltaic components.

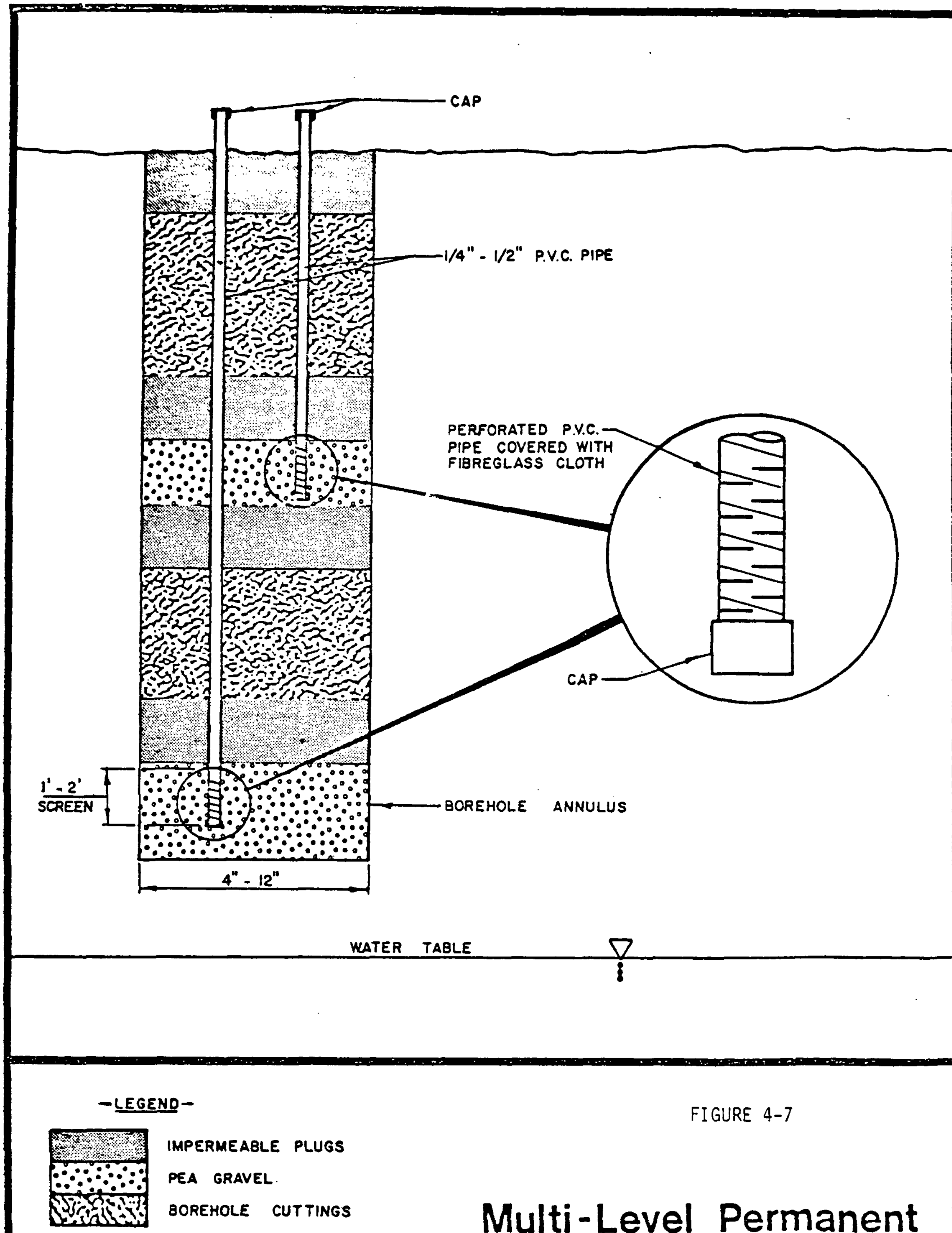
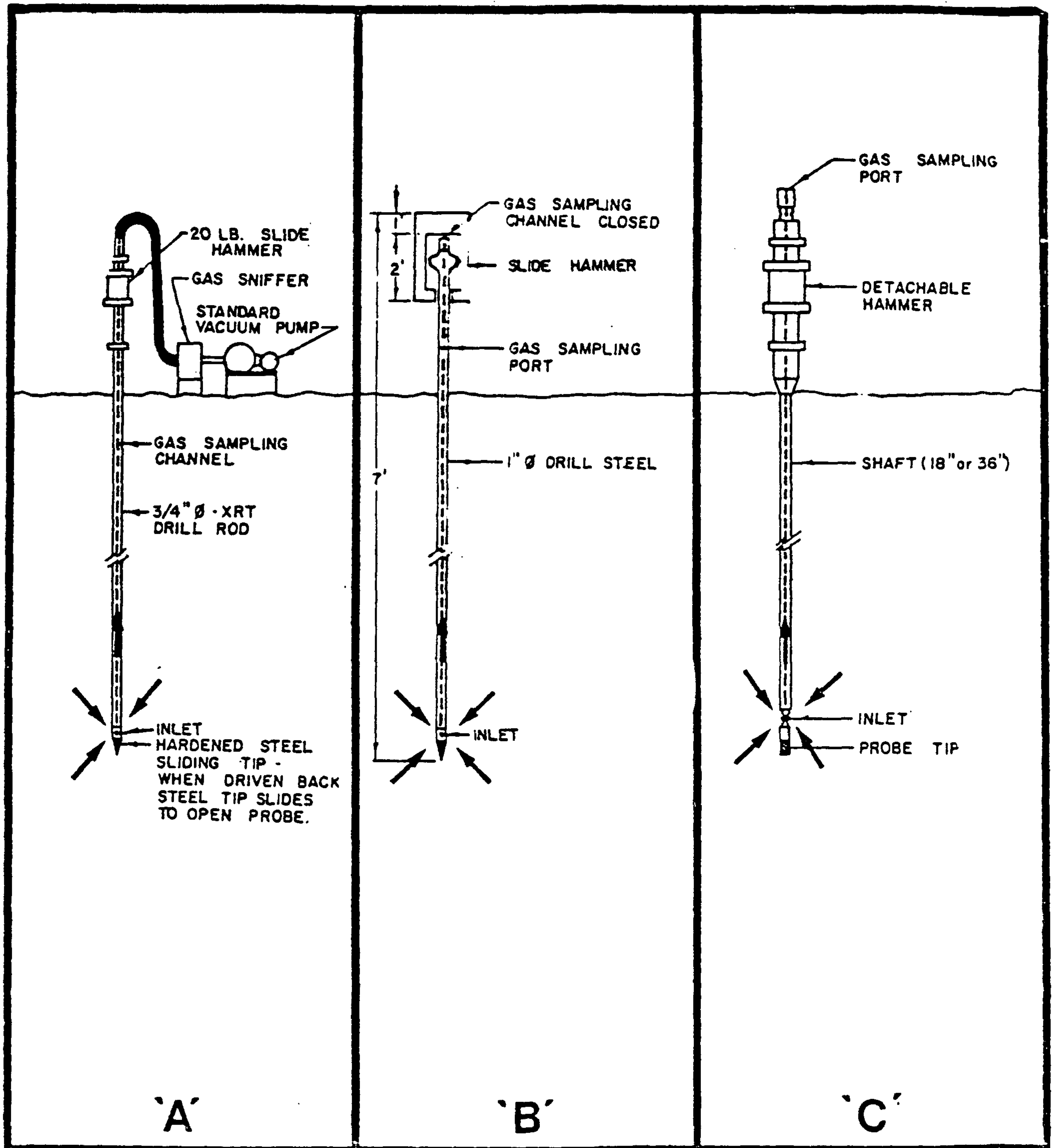


FIGURE 4-7

Multi-Level Permanent Gas Probe Installation

Source: Reference11



- LEGEND -

← GAS MOVEMENT

FIGURE 4-8

Portable Gas Sampling Probes (Schematics)

Source: Reference 11.

4.23.22 Current Economic Costs

Current economic costs for the technology average $0.15 ($0.17), $0.03 ($0.03), and $0.01 ($0.01) per ton (per metric ton) for 10, 100, and 300 ton per day landfill sites, respectively.

4.23.3 Environmental Impact Summary

To the extent that a landfill gas monitoring program improves the effectiveness of the implemented landfill gas control measures, it:

1. Minimizes fire and explosion hazard in buildings and other enclosures on or near the landfill site.

2. Minimizes vegetation kills due to the creation of anaerobic conditions in the root zones of some oxygen-sensitive plant species.

3. Minimizes the mineralization of ground water due to the dissolution of carbon dioxide in groundwater to form carbonic acid.

4. Minimizes odor pollution of off-site areas due to the potential off-site release of hydrogen sulfide to the atmosphere.

4.24 LEACHATE MONITORING

4.24.1 Introduction

Landfill leachate is monitored primarily to facilitate the protection of ground and surface water resources beneath and adjacent to the landfill site before, during and after landfill operation. A leachate monitoring program detects and evaluates existing or potential pollution caused by leachate by periodically measuring the extent and rate of leachate migration from the landfill site, and the degree and nature of leachate contamination. This information can aid in determining the need for and nature of leachate controls, and in evaluating their effectiveness once they are implemented. As such, leachate monitoring functions in long-term landfill site environmental protection and in the detection and abatement of imminent contamination hazards.

The Guidelines call for monitoring groundwater and leachate parameters at those landfill sites having the potential for discharge to drinking water supply aquifers. The Guidelines refer to EPA's "Procedures for Groundwater Monitoring at Solid Waste Disposal Facilities" for further information (Reference 12). In that document, EPA recommends leachate monitoring prior to landfill operation to obtain baseline data, and at least annual leachate sample analysis from all monitoring wells. Finally, the proposed Guidelines suggest following the leachate sample analysis methods described in EPA's "Guidelines Establishing Test Procedures for the Analysis of Pollutants" (40 CFR Part 13G).

The following discusses in more detail the technology and environmental impacts of leachate monitoring.

4.24.2 Technology Summary

4.24.21 Leachate Control

Leachate monitoring aids in developing long and short term predictive models for environmental impacts of landfills under varying hydrogeological and climatic conditions. Several types of leachate monitoring technologies can be identified, including both active and passive types. Active monitoring involves continuous pumping at wells intercepting potentially contaminated groundwater flow, and is best suited for point source groundwater contamination due to spills or tank leaks. Several disadvantages of active leachate monitoring include (Reference 12):

1. the larger (in area) the contaminant source, the greater the number of pumping wells required to intercept groundwater flow;

2. disposal of the pumped water can pose a problem, especially when the water is contaminated;

3. over a period of years, cumulative pumping costs and well maintenance costs may be high;

4. pumping may accelerate the spread of leachate through the aquifer, and the monitoring system may eventually become a pumped withdrawal system; and,

5. improper selection of screen depth could prevent the well from intercepting the leachate plume.

Passive leachate monitoring techniques include well monitoring in the zones of both aeration and saturation, field inspection and other methods. These approaches minimize groundwater flow pattern disruptions, and are discussed more completely herein.

Passive monitoring involves periodical sampling at stations located in the path of groundwater flow for changes in the concentrations of chemical constituents of groundwater. Prior to monitoring, hydrogeologic studies, especially geophysical resistivity studies should be conducted to establish the setting and most effective permanent monitoring system design. Data to be gathered include (Reference 12):

1. groundwater flow direction;

2. distribution of permeable and impermeable ground material;

3. permeability and porosity;

4. present or future effects of pumping on the flow system; and,

5. background water quality.

The information is best determined by field inspection, but can be obtained more economically from already published information. From this site specific data, a monitoring station network can be designed. EPA suggests that a minimally acceptable monitoring network should consist of (Reference 12):

1. one line of three wells downgradient from the landfill and situated at an angle perpendicular to groundwater flow, penetrating the entire saturated thickness of the aquifer;

2. one well immediately adjacent to the downgradient edge of the filled area, screened so that it intercepts the water table; and,

3. a well completed in an area upgradient from the landfill so that it will not be affected by potential leachate migration.

The size of the landfill, hydrogeologic environment, and budgetary restrictions are factors which will dictate the actual number of wells used. However, every effort should be made to have a minimum of three wells at each landfill and no less than one downgradient well for every 250 ft. (76 meters) of landfill frontage.

A station, located in or adjacent to the landfill, can act as an early warning that leachate is reaching the groundwater table and monitoring at downgradient points should be intensified, possibly by adding more sampling locations or by utilizing more comprehensive analysis techniques.

The particular type, design, installation, and use of individual monitoring stations varies and depends upon site hydrogeologic conditions, economics, and the purpose of the monitoring. For example monitoring in the zone of aeration may occur when (Reference 12):

1. scientific research such as measurement of attenuation is involved;

2. there are unusual geologic or hydrologic considerations;

3. extremely toxic chemicals are suspected in the leachate which would demand closer attention; and,

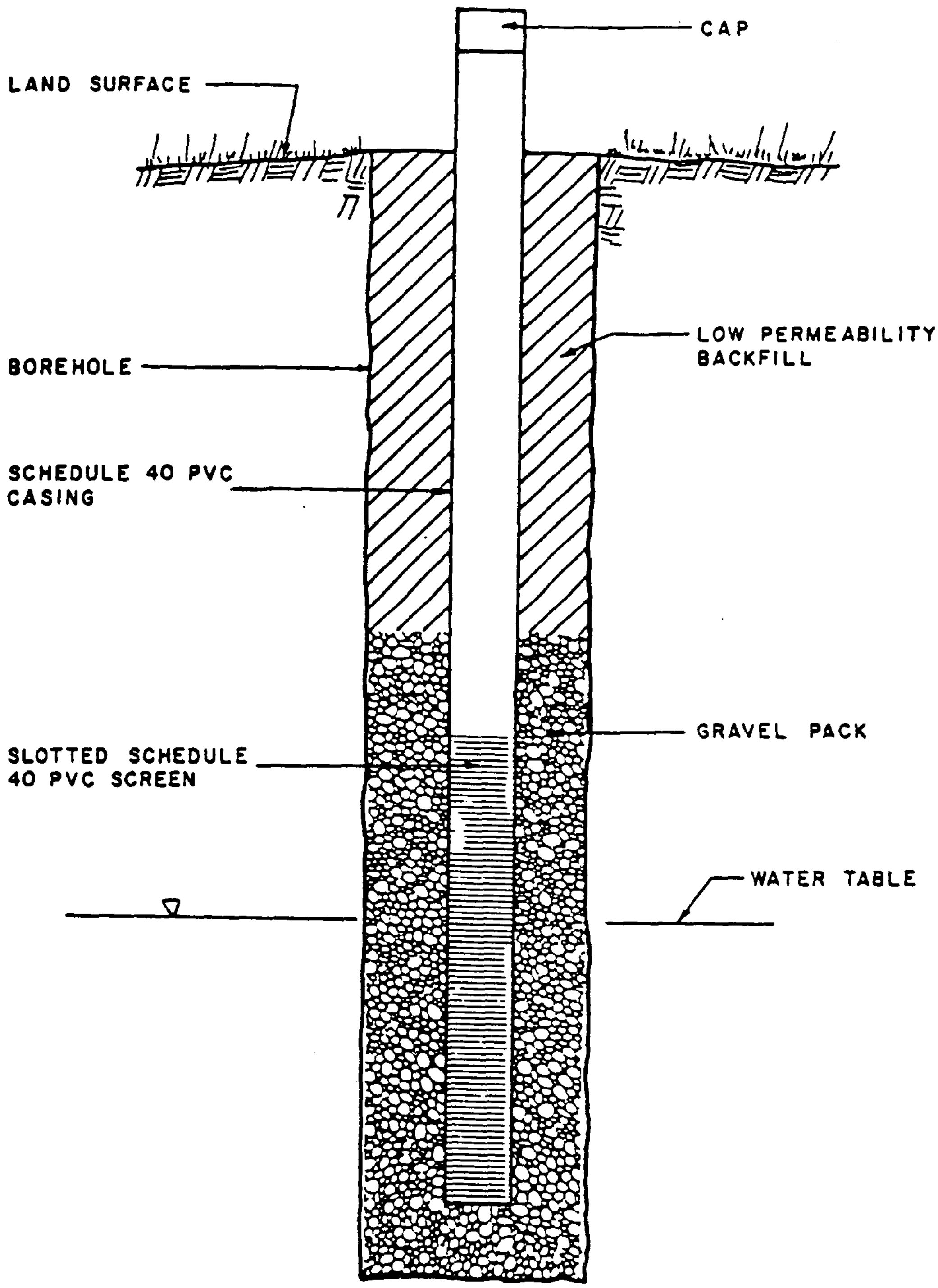
4. sampling is to be used as an early-warning system to check the effectiveness of engineering techniques.

Aeration zone monitoring techniques include soil analysis, pressure vacuum lysimeters, and trench lysimeters.

Monitoring in the zone of saturation must consider groundwater flow characteristics as well as soil-leachate interactions. Techniques include: (1) wells screened or open over a single vertical interval (Figure 4-9); (2) piezometers (Figure 4-10); (3) well clusters (Figure 4-11); (4) single-wells with multiple sample points; (5) sampling during drilling, and (6) pore-water extraction from core samples. Detailed descriptions of the design, installation, and sampling methodologies for each of these techniques is beyond the scope of thie EIS (the reader is referred to Reference 12). Table 4-8 presents EPA's evaluation of the advantages and disadvantages of each of the above techniques.

FIGURE 4-9

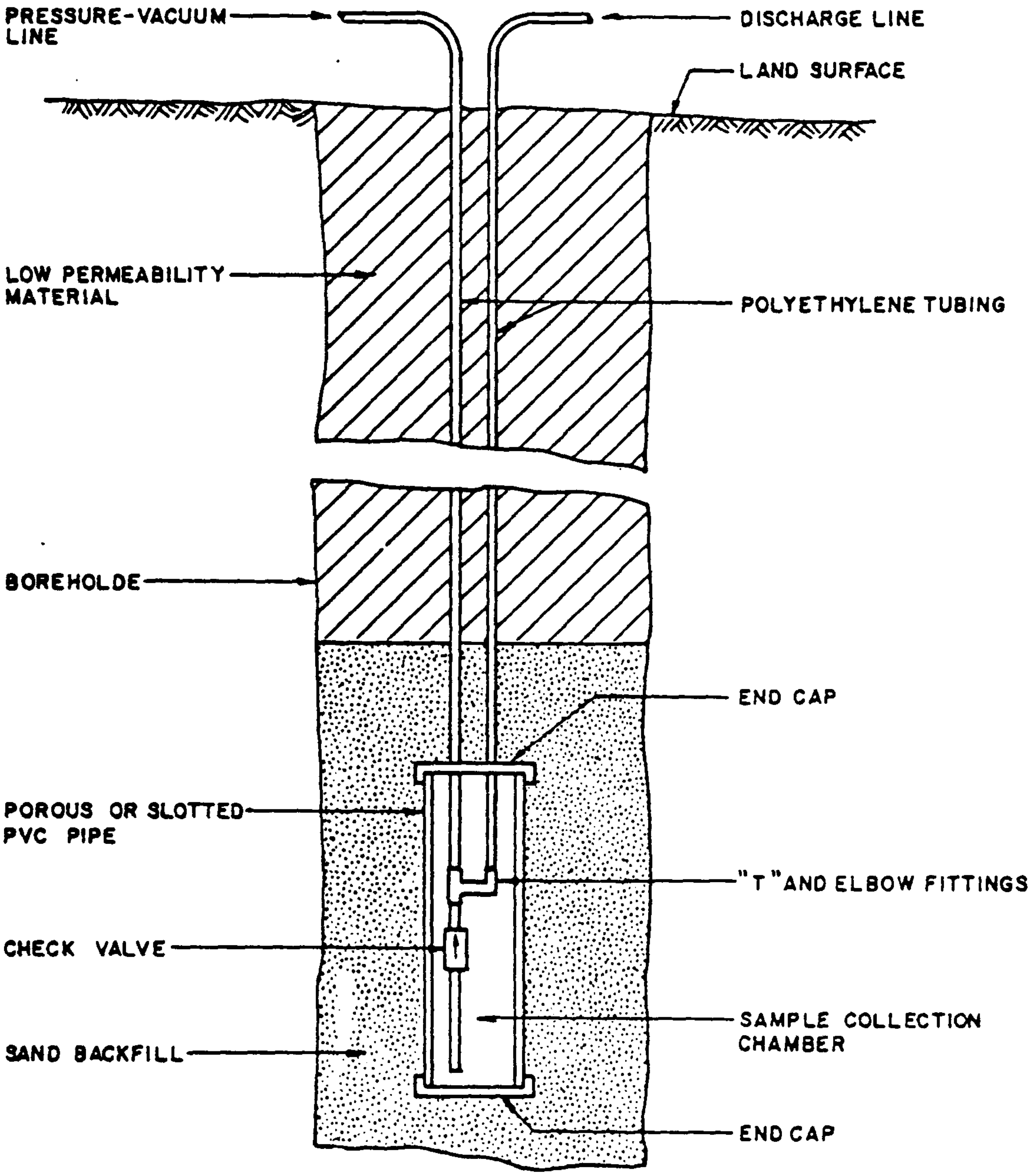
TYPICAL MONTIORING WELL SCREENED
OVER A SINGLE VERTICAL INTERVAL



Source: Reference 12.

FIGURE 4-10

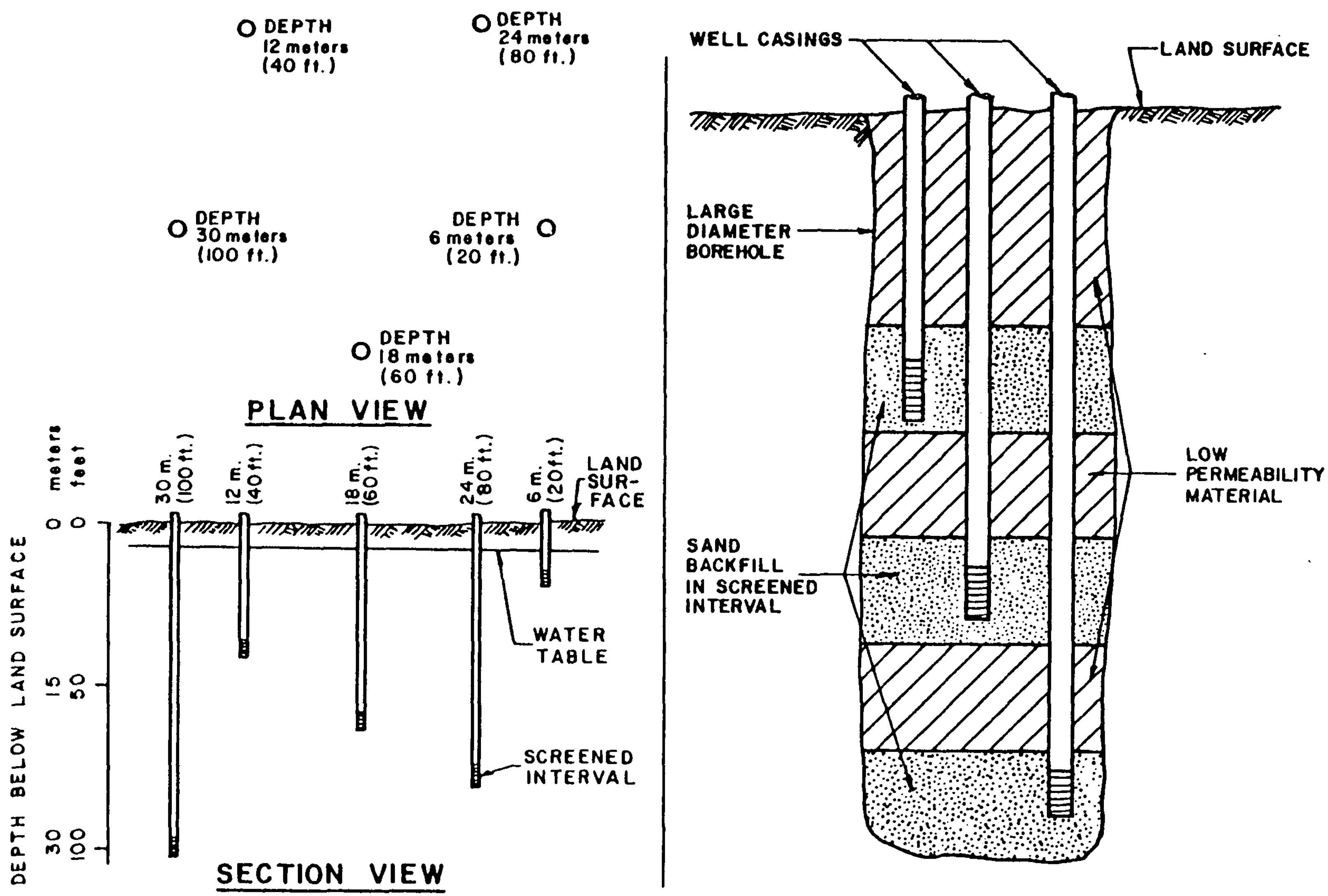
DETAILS OF A LOW COST PIEZOMETER
MODIFIED FOR COLLECTION OF WATER SAMPLES



Source: Reference 12.

FIGURE 4-11

TYPICAL WELL CLUSTER CONFIGURATIONS



(After Yare, 1975) 24

Source: Reference 12.

TABLE 4-8

PASSIVE LEACHATE MONITORING WELL TECHNIQUES FOR SAMPLING IN THE SATURATED ZONE, ADVANTAGES AND DISADVANTAGES

Well Screened or Open Over a Single Vertical Interval

Advantages	Disadvantages
1. Small diameter, shallow wells are quick and easy to install.	1. No information is given on the vertical distribution of the contaminant.
2. Can provide composite ground-water samples if screen covers saturated thickness of aquifer.	2. Improper completion depth can cause error in determining leachate distribution.
3. Can be drilled by a variety of methods.	3. Screening over much of the aquifer thickness can contribute to vertical movement of contaminant.
	4. Leachate may become diluted in the composite sample, resulting in lower than actual concentrations.

Piezometers

Advantages	Disadvantages
1. Sample is collected from a selected vertical section of the aquifer.	1. Restricted number of drilling methods.
2. If properly constructed, technique prevents downward migration of leachate in borehole.	2. Improper completion depths can cause error in determination of leachate distribution.
3. Can be installed inexpensively and rapidly if casing diameter is small.	3. Improper construction can contribute vertical migration of contamination.
4. Modification of an engineering piezometer will allow vertical sampling of contaminant.	

TABLE 4-8 (continued)

Well Clusters

Advantages	Disadvantages
Simple installation does not always require hiring a drilling contractor.	1. If only a few wells are installed, large vertical sections of the aquifer are unsampled. Artificial constraint on data by completion depths.
2. Excellent vertical sampling made possible if sufficient number of wells are constructed.	2. If jetting rigs or augers are used, installations are usually limited to total depths of 38 to 46 meters (125 to 150 feet).
3. "Tried and true" methodology, accepted and used in most contamination studies where vertical sampling is required.	3. Small diameter wells can be used only for monitoring. They cannot be used in abatement schemes.
4. Low cost if only a few wells per cluster are involved and if the drilling contractor has equipment suitable for installation of small-diameter wells.	4. In small-diameter wells, development and sample collection become tedious and difficult if water level is below suction lift.

Single Well -- Multiple Sample Points

Advantages	Disadvantages
1. Excellent information is gained on vertical distribution of the contaminant.	1. Expensive.
2. If necessary, well diameter is large enough to use in a pumped-withdrawal pollution abatement program.	2. Proper well construction and sampling procedures are critical to successful application.
3. Sampling depths are limited only by the size of the sampling pump.	
4. Rapid installation possible.	

TABLE 4-8 (concluded)

Sampling During Drilling

Advantages	Disadvantages
1. The best technique currently available for defining vertical distribution of contaminants in thick aquifers.	1. Considerably expensive.
2. Completed well can be used for water-quality monitoring and/or pumped withdrawal of contaminant.	2. Careful supervision of drilling and sampling is necessary.
	3. Potential cross-contamination of samples exists.

Pore-Water Extraction from Core Samples

Advantages	Disadvantages
1. Generally inexpensive.	1. Quantitative analysis requires careful control during sample collection.
2. Pore water extract is amenable to field chemical analyses such as: chloride concentration and specific conductivity.	2. Interstitial water can drain from unconsolidated sand and gravel reducing volume of the collected water sample.
3. Excellent vertical sampling when mud invasion into core sample is monitored.	3. Core recovery in coarse sand and gravel can be difficult and time consuming.
4. Samples can be obtained from almost any depth when wireline coring apparatus is used.	4. Small sample volume available for chemical analysis.
5. Qualitative use of pore water extract allows for presence/absence determination.	5. Can be expensive.
6. Can be used with consolidated rock as well as unconsolidated sediment samples.	

Source: Reference 12.

Leachate monitoring in the aerated and saturated zones can be economically supplemented by field inspection techniques for evidence of leachate contamination. These methods include inspection for seeps and vegetation stress, determination of soil specific conductance, temperature, and electrical earth resistivity, and seismic surveys. Table 4-9 lists the advantages and disadvantages of each of the above. Additional leachate monitoring techniques include surface water quality measurements, aerial photographic interpretation, and geophysical well logging (see Table 4-10).

A program for leachate monitoring must specify sampling frequencies and sampling parameters. According to EPA, sampling frequency depends on such factors as (Reference 12):

1. Characteristics of groundwater flow;
2. The location and purpose of the particular monitoring well;
3. Trends in the monitoring data;
4. Legal and institutional data needs; and
5. Climatological characteristics.

Environment and Fisheries Canada, however, has generalized potential sampling frequencies for sites where groundwater contamination has not been evidenced, as follows (Reference 13):

Calculated Groundwater Velocity (ft/yr)	Sampling Frequency
75	annually
75 to 150	semi-annually
150	quarterly

Prior to landfill operation, seasonal samples should be collected and analyzed for nitrogen, heavy metals, sulfates, hardness, alkalinity, pH, BOD_5, COD (or TOC) and specific conductance. When the landfill operation has commenced, samples should be taken especially at wells nearest the operation. Initial routine sampling need consider only such key parameters as total dissolved solids, electrical conductivity, chlorides, and possibly hardness. If a change of significance occurs in one or more of these key variables, then a more comprehensive sample analysis should be performed for hardness, alkalinity, pH, iron, sulfate, chloride, specific conductance, BOD_5, COD (or TOC), and any other site specific chemicals which may reflect landfill content and condition. A long-term, post-closure leachate monitoring scheme may extend several

TABLE 4-9

PASSIVE LEACHATE MONITORING FIELD INSPECTION TECHNIQUES, ADVANTAGES AND DISADVANTAGES

General

Advantages	Disadvantages
1. Can be carried out quickly and inexpensively.	1. Untrained inspector may overlook subtle but valuable data.
2. Helps place the overall problem in perspective.	2. Findings are not always conclusive in detecting groundwater contamination.
3. Establishes the extent of additional investigations which may be required.	3. Time factors are not indicated relative to condition changes.
4. When combined with a literature survey on available data, inspection procedure may be used by an experienced hydrologist to roughly establish the overall situation.	4. Few, if any, analyses or actual physical measurements are made.

Seeps

Advantages	Disadvantages
1. Where present, definite indication of leachate generation.	1. May not indicate presence of contaminated groundwater
2. Convenient point of collection for leachate sample.	2. Chemical quality not necessarily representative of bulk of leachate in the landfill or entering the groundwater
3. Changes in flow rates or locations of seeps are indicative of internal landfill changes.	

Source: Reference 12.

TABLE 4-9 (continued)

Vegetation Stress

Advantages	Disadvantages
1. Qualitative indicator of leachate and gas contamination.	1. Evidence of stressed vegetation, especially in early stages, is not always evident except to a trained botanist.
2. Mapping extent of stressed vegetation may provide an indication of the limits and source of contamination.	2. Stress may be caused by many factors, some unrelated to the presence of the landfill. Determination of the responsible factor or factors is usually extremely difficult.
3. Stressed vegetation can be mapped remotely by aerial photographic methods, allowing wide coverage in a short period of time.	3. Certain stresses will not occur unless physical or chemical change occurs at the surface or within the vadose zone. Therefore, it provides no indication of problems at depth.
4. Stress change is a good indicator for monitoring purposes. More effective if selected species are planted, then observed.	

Specific Conductance and Temperature Probes

Advantages	Disadvantages
1. Providing equipment is properly calibrated and insertion procedures carefully implemented, positive determination as to presence and degree of contamination can be made.	1. Not an absolute method. Equipment subject to malfunctioning, causing erroneous information. Equipment must be checked for malfunctioning against a standard solution.
2. Provides accessibility to otherwise restricted areas, such as marsh or swampland.	2. Requires hiring personnel trained in the use and handling of the equipment.

TABLE 4-9 (concluded)

Electrical Earth Resistivity

Advantages	Disadvantages
1. Definition of subsurface geology and contaminated water bodies can be derived at a faster and cheapter rate than drilling.	1. Indirect method. Requires some substantiation by drilling.
2. Greatly reduces the number of sampling wells required.	2. Many natural and man-made field conditions preclude resistivity surveys.
3. Surveys can be duplicated periodically to provide monitoring data.	3. Data interpretation in complex situations is often questionable.
	4. Background data on natural-water quality are prerequisite.

Seismic Surveys

Advantages	Disadvantages
1. Can provide subsurface geologic information must faster and cheaper than drilling.	1. Provides no direct information about leachate.
2. Can be used to extend geologic data over broad areas on a limited budget.	2. Requires more direct substantiation such as drilling.
3. Can be used in certain areas where access for a drilling rig would be difficult.	3. In complex geologic formations, interpretation is difficult and substantial errors may occur.
	4. Requires the hiring of a trained person and the use of a computer to reduce and interpret data.
	5. Subject to noise interference in many field situations.

Source: Reference 12.

TABLE 4-10

OTHER PASSIVE LEACHATE MONITORING TECHNIQUES, ADVANTAGES AND DISADVANTAGES

Surface Water Quality Measurements

Advantages	Disadvantages
1. Useful in locating leachate discharge points.	1. Surface water may be subject to contamination from other sources not defined.
2. Can be a quick and inexpensive means of estimating environmental impact of the landfill.	2. Dilution may be too great to provide useful information.

Aerial Photography

Advantages	Disadvantages
1. Frequently can detect stressed vegetation which indicates contamination.	1. Availability of aerial photographs and photographic services is sometimes limited.
2. Can be used to prepare contour maps relatively inexpensively. Also provides certain geologic information.	2. Little information concerning sub-surface conditions.
3. Much less costly than a detailed ground survey of vegetation stress.	3. Little indication as to precise causes of detected surface changes.
4. Yearly photographs can provide unbiased and indisputable evidence of surface changes such as: landfill configuration, vegetation conditions, and surface water body locations.	
5. Can be used to precisely map key wells and sampling points of the landfill site.	
6. Enables a quick familiarization of the landfill site conditions without visiting the site.	

TABLE 4-10 (concluded)

Geophysical Well Logging

Advantages	Disadvantages
1. Provides back-up data to substantiate driller's and geologist's log of borehole.	1. Requires special equipment and the hiring of trained operators; thus, adding considerable expense.
2. Allows a more accurate determination of depth to formation change than might be achieved with routine sampling.	2. Is not an absolute for quantitative hydrogeologic determinations.
3. Allows a rough geological log to be constructed from an existing well that was not logged when drilled.	
4. May be useful in locating top and bottom of a contaminated groundwater body.	

Source: Reference 12.

decades. If long-term monitoring takes place, a thorough sample analysis of the kind discussed above should be performed at least every two years (Reference 13). It has been suggested that leachate monitoring can be terminated if, at the landfill property boundary or other agreed upon distance from the landfill, the chloride concentration is reduced or has stabilized to 50 parts per million above background, or if drinking water standards are met, whichever test is more restrictive (Reference 12).

Details of leachate sample withdrawal, preservation, storage, and analysis are beyond the scope of this EIS. The reader is referred to Reference 12 and 13.

4.24.23 Current Economic Costs

Current economic costs for leachate monitoring average $ 0.60 ($0.67), $0.10 ($0.11), and $0.05 ($0.06) per ton (per metric ton) for 10, 100, and 300 ton per day landfill sites, respectively.

4.24.3 Environmental Impacts Summary

Leachate monitoring data can aid in determining the need for and nature of leachate controls at new or existing landfill sites, and can facilitate the evaluation of their effectiveness once they are implemented. The ultimate environmental effect of leachate monitoring, then, is the protection of ground and surface water resources adjacent to the landfill site.

4.25 REVEGETATION

4.25.1 Introduction

Natural vegetation serves several vital functions including physically stabilizing earth materials, reducing precipitation infiltration, and enhancing the appearance of a site. Revegetation is the process of reestablishing viable grasses, shrubs, trees, and other vegetation after the completion of a waste fill and placement of the final earth cover.

The Guidelines recommend that a "completed landfill should be covered with 15 cm of clay with permeability less than 1 X 10-7 cm/sec or the equivalent, followed by a minimum cover of 45 cm of top soil to complete the final cover and support vegetation." Depending on the depth of vegetation roots, an even greater depth of top soil may be required. The Guidelines further specify that vegetation aids leachate control by minimizing erosion and maximizing evapotranspiration, and aids runoff control by encouraging runoff while still minimizing erosion of cover soil on sloped surfaces.

The following sections will discuss in more detail the specific functions fulfilled by revegetation, and the design and construction considerations necessary for successful revegetation implementation. In conclusion, the evaluation summarizes the current economic costs of and the environmental impacts of revegetation.

4.25.2 Technology Summary

4.25.21 Leachate Control

Revegetation Functions. Revegetation plays a role in leachate control by reducing precipitation infiltration via evaporative processes and by minimizing rates of runoff. Lack of vegetative cover results in uncontrolled water and wind erosion of cover material. Vegetation functions to stabilize cover materials, impede erosion, and maintain cover integrity, consequently, infiltration into the waste mass due to loss of cover integrity is minimized.

Revegetation Design and Construction. The design and implementation of revegetation processes begins with preparation of the final cover to provide support for vegetative growth. It is the uppermost layer of top soil that is most important in designing revegetation plans for completed landfill sites. Relevant factors to be considered include the composition or type of soil utilized, the soil's physical, chemical, and biological properties, and the depth or thickness of the top soil layer. Soil type should be compatible with the planned vegetations nutrient and other requirements. Soils such as clay loam or silty loam have been suggested as suitable for a large variety of plant growth. Analyses of soil sample fertility and pH may be useful in determining plant type for optimum growth.

The required depth of soil for effective revegetation depends upon the type of cover vegetation selected. Plants such as native grasses have shallow root systems and may need only 2 feet or less of top soil, while larger trees with deep tap root systems may require as much as 8 to 12 foot thicknesses of top soil.

The nature of plant root systems is also important in determining the speed of vegetation establishment and the degree of cover soil stabilization that can be achieved and maintained. Vegetation with shallow but dense root systems such as hay, meadow grasses, rye, and other native grasses, lend themselves to revegetation because they establish quickly, are more effective for surface stabilization, are inexpensive and are easy to maintain. Table 4-11 lists examples of grasses and shrubs with extensive shallow root systems that can provide these desired properties. Other plants, including legumes such as clover, or crops such as alfalfa, have deeper lateral root systems usually requiring up to 4 feet of top soil, and are more effectively used for stabilizing sloped areas. Shrubs and trees with large tap root systems are generally not recommended for landfill revegetation because planned depths of top soil layers are usually not thick enough to sustain these root systems.

In addition, plants must be selected to accomodate a number of local growth factors. Climate and soil fertility are two major factors affecting the success of revegetation efforts. Native species are more likely to be acclimated to the amount of rainfall and other seasonal conditions unique to the site. On the other hand, soil fertility can be influenced by adding nutrients in the form of organic or commerically prepared fertilizers. Organic fertilizers are preferred because they improve the soil structure and release nutrients at a slower rate.

Finally, the actual process of revegatation entails preparation of the soil surface prior to planting, including grading and spreading fertilizer, and the application of some cover such as mulch following planting to provide interim soil stabilization. Where grasses or crops have been selected, hydroseeding, a technique of spraying a mixture of seeds, soil supplements, and water, is an efficient and cost-effective method of planting.

4.24.22 Runoff Control

While it is desirable to maximize surface runoff in order to reduce infiltration, increased runoff can pose substantial erosion and pollution problems. Revegatation addresses these problems because it can assist in control of runoff while stabilizing landfill cover material, especially on sloped surfaces. Its main function in runoff control, then, is to reduce potential erosion and minimize the amounts of sediment that are accumulated in surface runoff.

TABLE 4-11

SOME GRASSES AND SHRUBS WITH EXTENSIVE ROOT SYSTEMS

Alpine Rockcress	Henry Honeysuckle	Prarie Rose
Arrowwood Viburnum	Japanese Barberry	Red Osier Dogwood
Bittersweet	Japanese Spurge	Rock Cotoneaster
Bristly Locust	Kentucky Bluegrass	Scotch Broom
Chinese Matrimony Vine	Kudzu Vine	Silver Vein Creeper
Creeping Cotoneaster	Leadwort	Thyme
Drooping Leucothoe	Lowbush Blueberry	Turfing Daisy
Dryland Blueberry	Moss Phlox	Virginia Creeper
English Ivy	Mountain Sandwort	Virginia Rose
Fragrant Sumac	Nannyberry Viburnum	White Chinese Indigo
Grape	New Jersey Tea	Wintercreeper
Heather	Periwinkle	Yellowroot

Source: Reference 14

4.25.23 Other Functions

In addition to leachate, gas, and runoff control, revegetation techniques serve an aesthetic function in enhancing the final appearance and use of the completed site. Landfill design and planning can provide vegetation that will complement the planned ultimate use.

In a different vein, problems with revegetation can function as an indicator of landfill generated gas migration or other degradation related problems. Some of these are:

1. concentrations of methane, carbon dioxide, and other toxic gases can migrate vertically to the atmosphere through cover soil or laterally through permeable substrata to areas adjacent to the site. These gases can displace oxygen supplies necessary to plant growth, and can alter soil properties and quality. Studies show many instances of correlation between subsurface concentrations of gases and damage to vegetation on and around the site; and,

2. elevated soil temperatures resulting from subsurface spontaneous combustion reactions have also been correlated to poor vegetation growth.

4.25.24 Current Economic Costs

Revegatation of 10 TPD, 100 TPD, and 300 TPD landfill sites currently costs approximatley $0.25 ($0.28), $0.10 ($0.11), and $0.10 ($0.11) per disposed ton (per metric ton).

4.25.3 Environmental Impact Summary

1. Revegatation techniques physically stabilize surface soil and minimize water erosion, therefore reducing the potential for siltation of receiving surface waters by surface runoff discharge.

2. Potentially reduced infiltration due to evaporative processes resulting from revegetation also serves to minimize leachate and gas generation and subsequent impacts on the adjacent environment.

3. Revegetation improves the aesthetic appearance of the site and enhances its final use.

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5.0 SUMMARY EVALUATION OF GUIDELINES IMPACTS

The following sections present a summary analysis of the environmental, economic, and energy impacts associated with implementing the proposed Guidelines.

5.1 ENVIRONMENTAL IMPACT SUMMARY

The following paragraphs provide an analysis of the environmental impacts of the proposed Guidelines in terms of implementations for landfill siting, design, leachate control, gas control, runoff control, operation, and monitoring.

5.1.1 Site Selection

Past landfill site selection processes have, in many cases, not adequately considered environmental protection. The siting recommendations contained in the proposed Guidelines, however, should result in greater avoidance and protection of environmentally sensitive areas (ESA), and greater environmental protection in terms of selecting landfill sites in general. Guidelines' recommendations regarding landfill technologies additionally have implications for landfill siting which can also impact the environment.

The Guidelines recommend the avoidance of environmentally sensitive areas, such as wetlands, floodplains, permafrost areas, critical habitats, and recharge zones of sole source aquifers. Karst terrian and active fault zones are also identified as areas to avoid in landfill siting. Such considerations will lead to a number of positive environmental impacts associated with each type of ecosystem:

1. Wetlands: Maintenance of wetland ecological functions and values, including downstream flood protection, regional aquifier recharge or discharge, suspended sediment filtration, nutrient absorption, terrestrial wildlife and aquatic habitat, provision of recreational and open space.

2. Floodplains: Maintenance of floodplain functions and values, such as flood protection, and regional aquifier recharge or discharge.

3. Permafrost areas: Protection of a fragile ecosystem based upon the integrity of the permafrost layer.

4. Critical habitats: Protection of endangered species.

5. Recharge zones of sole source aquifers: Protection of ground water drinking supplies.

6. Karst terrian or active fault zones: Avoidance of areas which are particularly amenable to potential leachate migration and subsequent pollution effects.

Several other Guidelines siting recommendations can result in positive environmental impacts. Incorporating the landfill site into an existing or future regional solid waste disposal system can facilitate solid waste processing (baling, shredding, compacting) and resource recovery, thus increasing landfill life and minimizing environmental degradation.

Finally, several Guidelines recommendations for environmental control technologies have implications for landfill siting. Leachate, gas, and runoff controls may depend, in many cases, on either natural or artificial materials. When natural materials, such as natural clay liner material, are to be utilized transport costs may dictate that sources of those materials must play a role in the site selection process. Alternatively, when artificial materials are used, more siting flexibility is possible. However, there may be secondary impacts involved in the manufacture, transport, and installation of these materials. Additionally, the alternative technologies identified in the Guidelines may permit utilization of sites that may not have been suitable for landfill use without modification. This similarly adds flexibility to the site selection process and offers the potential to maximize considerations of site specific environmental factors.

5.1.2 Design

The Guideline's landfill design recommendations emphasize environmental protection considerations. The design provisions in particular, recommend comprehensive design procedures, provide a consistent framework for design, and present a variety of alternative environmental control technologies from which a landfill environmental protection strategy can be developed to meet a set of specific requirements.

5.1.3 Leachate Control

The Guidelines provide several recommendations regarding leachate control that will result in positive environmental impacts. Recommended practices relate to cover selection, design, and construction; on-site and off-site surface runoff controls; landfill depth relative to the groundwater table; liner selection, design, and construction; natural leachate attenuation mechanisms; landfill closure; leachate collection methods; leachate treatment techniques, including leachate recycling; and leachate monitoring. The result of these Guidelines' recommendations and information will be an overall reduction in contamination of ground and surface water resources by landfill leachates.

5.1.4 Gas Control

The Guidelines provide several alternative landfill gas control measures which improve landfill operation, safety, and environmental protection. These measures relate to cover selection, design, and construction; acceptable waste types; leachate and runoff control measures; and passive and active gas barriers and gas venting systems. Gas control measures generally result in the prevention of gas migration and build-up in explosive concentrations in nearby enclosed structures; the minimizing of vegetation kills; and the prevention of groundwater mineralization. Objectionable landfill odors will also be reduced.

5.1.5 Runoff Control

The Guidelines recommend a variety of surface runoff and erosion control measures which should result in improved levels of environmental protection. These measures include provision of surface runoff diversion structures; grading of landfill slopes; selection of cover soil type; revegetation of landfill surfaces; and ponding to prevent stream siltation. Implementation of these measures generally reduce infiltration at the landfill site, thus minimizing consequent landfill gas and leachate generation. In addition, on-site surface runoff is controlled such that erosion and subsequent stream siltation are minimized.

5.1.6 Operation

The Guidelines make numerous recommendations regarding landfill operation which will result in positive environmental impacts with respect to health, safety, and environmental considerations. These measures cover waste type acceptability; waste pre-treatment; waste compaction or other volume reduction methodologies; cover selection, design, and construction; employee health and safety; site traffic controls; record-keeping; etc. As a whole, these types of controls minimize landfill accidents, fires, explosions, rodents, vectors, litter, noise, and odors, and contribute to the efficiency of the landfill operation. Similarly, adequate operating control minimizes the potential for pollutant discharges to the environment, and consequently directly reduces air, water and groundwater pollution.

5.1.7 Monitoring

The Guidelines recommend that landfill monitoring operations include both groundwater and leachate monitoring and gas monitoring. In effect, then, monitoring results in positive environmental impacts resulting from the reductions in air, groundwater, and surface water pollution.

5.1.8. Summary

In general, the Guidelines will result in improved environmental protection of landfill sites. The recommended practices regarding landfill siting, design, leachate control, gas control, runoff control, operation, and monitoring will:

1) protect environmentally sensitive areas; 2) minimize ground and surface water pollution due to leachate contamination; 3) minimize explosion hazards and vegetation stress due to landfill gas migration; 4) minimize erosion and subsequent stream siltation due to surface runoff; and 5) minimize landfill litter, vectors, rodents, odor, noise, and accidents.

5.2 ECONOMIC IMPACT SUMMARY

5.2.1 Development of Upgrading Costs

Development of upgrading costs for the three selected waste types and the three representative size categories followed a multiple step methodology. The first step in the analysis was to identify model landfills to be used as the basis of cost estimates. Several factors were considered in choosing the models: (a) typical waste types; (b) prevalence of the model types; (c) differences in costs due to scale eonomics; and (d) compatability with the models utilized in the "Draft Environmental Impact Statement for Proposed Criteria for Classificaiton of Solid Waste Disposal Facilities" under Section 4004 of RCRA. Since cost estimates for both Section 4004 Criteria and Guidelines require many of the same technologies and operating procedures, choosing a compatible model made possible a comparison of these estimates.

Final selection of model types included municipal, industrial and pollution control residues for both environmentally sensitive and non-sensitive areas, for 10 ton per day, 100 ton per day, and 300 ton per day landfill sites. Two additional waste types were evaluated: agricultural wastes and construction and demolition debris. In both cases, only a very limited number of single purpose sites potentially existed and further cost analysis was not considered significant.

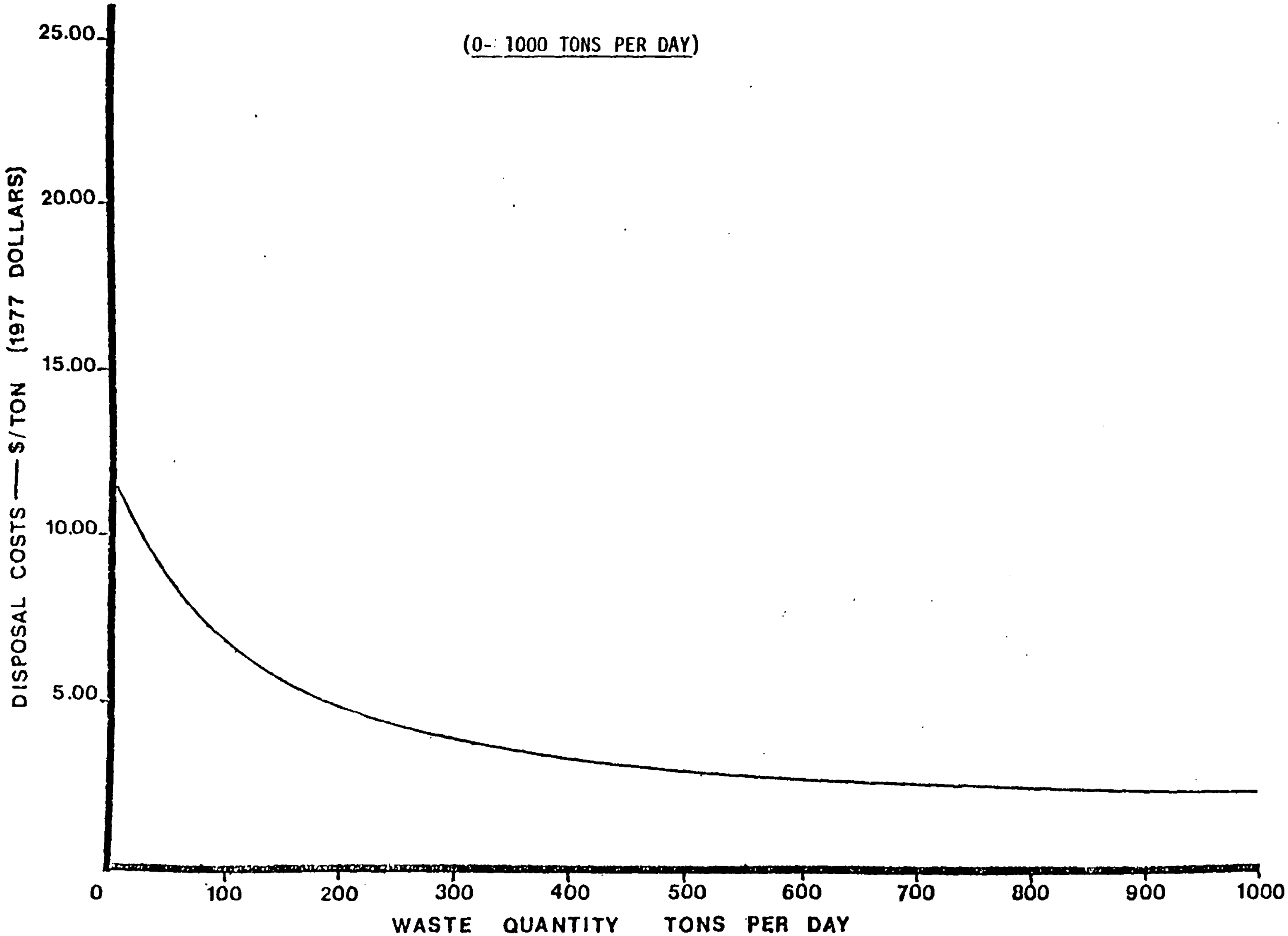
A second step in the analysis is the development of baseline cost data for capital and operating and maintenance expenses for landfills. Several of these sources graphically portrayed this information in a cost per ton vs. daily waste tonnage chart. To estimate current landfill costs a composite graphical approach was utilized. To accomplish this, the graphical data presented in Sanitary Landfill, 1974; Public Works, 100 (3): 79, March 1969; Handbook of Solid Waste Management, 1974; and Sanitary Landfill: Planning, Design, Operation Maintenance, 1971, were updated to 1977 dollars. Figure 5-1 presents a composite curve development by avenging per ton costs in the range of 0 to 1000 tons per day.

As indicated in Figure 5-1, current disposal costs (including capital and operating expenses) range from approximatley $2.00 to $12.00 per ton ($2.24 to $13.44 per metric ton). Disposal costs at ten ton per day sites average approximately $11.15 per ton ($12.49 per metric ton). One hundred ton per day sites exhibit economy of scale effects with disposal costs averaging $6.65 per ton ($7.45 per metric ton). Similarly, 300 ton per day sites average approximately $3.95 per ton ($4.42 per metric ton). Approximately 20 to 30 percent of these costs represent design and construction expenses with the remaining 70 to 80 percent representing operating expenditures.

FIGURE 5-1

COMPOSITE LANDFILL COSTS

(0- 1000 TONS PER DAY)



To determine upgrading costs for the landfill models previously identified, both existing technologies and assumed upgrading technologies were identified. The existing practice of Guidelines level technologies can be broadly sorted by waste type and site characteristics. Table 5-1 was based on an assessment of available literature and provided a checklist of environmental protection technologies currently employed by a "typical" landfill for a given type of waste in both environmentally sensitive and non-sensitive areas. Table 5-1 also presents the upgrading technologies which have been assumed as representative of required upgrading and average upgrading costs.

Following the identification of upgrading technologies, unit costs for each technology were developed via examination of case studies and via utilization of an engineering estimation methodology. Appendix B presents the design assumptions and calculations utilized to identify technology unit costs and disposal costs per ton of waste. Tables 5-2 and 5-3 present disposal costs per ton for each of the upgrading technologies. The set of technologies identified on Table 5-2 were previously identified in Table 5-1 as technologies selected for developing upgrading costs for each of the model landfills. Table 5-3 presents cost alternatives as presented in the Guidelines.

By comparing the additional costs of upgrading technologies to baseline costs, an estimate of increased landfilling costs can be developed. Tables 5-4 through 5-7 present dollars and percent increase in disposal costs for the model landfills previously selected. Increases in disposal costs for 10 ton per day sites range from 53 to 88 percent, for 100 ton per day sites from 41 to 55 percent, and for 300 ton per day sites from 46 to 58 percent.

Projections for increased disposal costs at the nationwide level can be completed by estimating the total number of landfills for each landfill type, size, and sensitive/non-sensitive category, and by applying increase in costs of disposal as generated above. An analysis completing the above was previously completed in the background documents "Analysis of Technology, Prevalence, and Economics of Landfill Disposal of Solid Waste in the United States (Volume II) "by Fred C. Hart Associates, Inc. This nationwide estimate is formally presented in the Criteria EIS document. The implicit assumption is that costs generated by upgrading of landfills are Criteria induced costs.

TABLE 5-1

EXISTING TECHNOLOGY LEVELS AND ASSUMED UPGRADING TECHNOLOGY

Assumed Current Technology Levels		Assumed Upgrading Technologies
MUNICIPAL (Sensitive)		
Waste Processing:	None	
Gas Control:	None	Vertical Impermeable Barriers
Leachate Control:	Clay Liner Daily Cover	Impermeable Cover Leachate Collection & Treatment (New Facility)
Surface Runoff:	Ditching	Ponding Dike Construction
Monitoring:	None	Gas & Leachate
MUNICIPAL (Non-Sensitive)		
Waste Processing:	None	
Gas Control:	None	Vertical Impermeable Barriers
Leachate Control:	Permeable Cover	Impermeable Cover
Surface Runoff:	Ditching	None
Monitoring:	None	Gas & Leachate
INDUSTRIAL (Sensitive)		
Waste Processing:	None	
Gas Control:	None	None
Leachate Control	Infrequent Permeable Cover	Impermeable Cover Liner (New Facility) Leachate Collection & Treatment (New Facility)

TABLE 5-1 (concluded)

INDUSTRIAL (Sensitive) (continued)

Surface Runoff:	None	Ponding Dike Construction
Monitoring:	None	Leachate

INDUSTRIAL (Non-Sensitive)

Waste Processing:	None	
Gas Control:	None	None
Leachate Control:	Infrequent Permeable Cover	Impermeable Cover Liner (New Facility)
Surface Runoff:	Ditching	Ponding
Monitoring:	None	Leachate

POLLUTION CONTROL RESIDUES (Sensitive)

Waste Processing:	None	
Gas Control:	None	None
Leachate Control:	None	Impermeable Cover Liner (New Facility) Leachate Collection & Treatment (New Facility)
Surface Runoff:	Ditching	Ponding Dike Construction
Monitoring:	None	Leachate

POLLUTION CONTROL RESIDUES (Non-Sensitive)

Waste Processing:	None	
Gas Control:	None	None
Leachate Control:	None	Impermeable Cover Liner (New Facility)
Surface Runoff:	Ditching	None
Monitoring:	None	Leachate

TABLE 5-2

UPGRADING TECHNOLOGY COSTS

Technology	10 TPD Cost/Ton	10 TPD (Cost/Metric Ton)	100 TPD Cost/Ton	100 TPD (Cost/Metric Ton)	300 TPD Cost/Ton	300 TPD (Cost/Metric Ton)
Vertical Impermeable Barrier	$1.30	($1.46)	$0.30	($0.34)	$0.15	($0.17)
Dike Construction	2.40	(2.69)	0.55	(0.62)	0.30	(0.34)
Impermeable Daily Cover* (on-site source)	0.75	(0.84)	0.35	(0.39)	0.25	(0.28)
Impermeable Daily Cover* (off-site source)	5.30	(5.94)	2.65	(2.97)	1.75	(1.96)
Ponding	0.10	(0.11)	0.05	(0.06)	0.04	(0.04)
Gas Monitoring	0.15	(0.17)	0.03	(0.03)	0.01	(0.01)
Groundwater Water Quality Monitoring	0.60	(0.67)	0.10	(0.11)	0.05	(0.06)
Natural Clay Liner (off-site source)	3.20	(3.58)	1.50	(1.68)	1.35	(1.51)
Leachate Collection Dacilities	0.95	(1.06)	0.40	(0.45)	0.30	(0.34)
Leachate Monitoring, Removal and Treatment	5.80	(6.50)	1.10	(1.23)	0.50	(0.56)

* "Impermeable" refers to a cover type with relatively low permeability i.e.,1 X 10^{-7} cm/sec.

TABLE 9-3

ALTERNATE UPGRADING TECHNOLOGY COSTS

Technology	10 TPD Cost/Ton	10 TPD (Cost/Metric Ton)	100 TPD Cost/Ton	100 TPD (Cost/Metric Ton)	300 TPD Cost/Ton	300 TPD (Cost/Metric Ton)
Shredding	-	-	-	-	$7.00	($7.84)
Baling	-	-	-	-	5.00	(5.60)
Permeable Daily Cover (on-site source)	$0.60	($0.67)	$0.30	($0.34)	0.20	(0.22)
Permeable Daily Cover (off-site source)	1.90	(2.13)	0.95	(1.06)	0.65	(0.73)
Vertical Pipe Vents	0.90	(1.01)	0.45	(0.50)	0.40	(0.45)
Perimeter Gravel Trenches	1.60	(1.79)	0.35	(0.39)	0.20	(0.22)
Gas Collection	2.50	(2.80)	0.55	(0.62)	0.30	(0.34)
Synthetic Liner	4.00	(4.48)	1.90	(2.13)	1.65	(1.85)
Leachate Recycling (not including collection)	0.45	(0.50)	0.10	(0.11)	0.05	(0.06)
Ditching	0.15	(0.17)	0.04	(0.04)	0.02	(0.02)
Final Impermeable Cover* (on-site source)	0.45	(0.50)	0.20	(0.22)	0.20	(0.22)
Final Impermeable Cover* (off-site source)	3.20	(3.58)	1.50	(1.68)	1.35	(1.51)

* "Impermeable" refers to a cover type with relatively low permeability, i.e., 1 X 10^{-7} cm/sec.

TABLE 5-3 (concluded)

Technology	10 TPD Cost/Ton	10 TPD (Cost/Metric Ton)	100 TPD Cost/Ton	100 TPD (Cost/Metric Ton)	300 TPD Cost/Ton	300 TPD (Cost/Metric Ton)
Final Permeable Cover (on-site source)	$0.40	($0.45)	$0.15	($0.17)	$0.15	($0.17)
Final Permeable Cover (off-site source)	1.30	(1.46)	0.60	(0.67)	0.55	(0.62)
Revegetation	0.25	(0.28)	0.10	(0.11)	0.10	(0.11)
Fire Control	0.04	(0.04)	0.01	(0.01)	0.01	(0.01)
Access Control	0.90	(1.01)	0.20	(0.22)	0.10	(0.11)
Litter Control	0.05	(0.06)	0.01	(0.01)	0.01	(0.01)
Compaction	1.90	(2.12)	0.20	(0.22)	0.05	(0.06)

TABLE 5-4

IMPACT OF GUIDELINES ON OPERATING COSTS OF MUNICIPAL SOLID WASTE LANDFILL COSTS (COSTS/TON)

	Site Size Categories					
	10 TPD		100 TPD		300 TPD	
Required Technologies	Sensitive	Non-Sensitive	Sensitive	Non-Sensitive	Sensitive	Non-Sensitive
Gas Control						
Vertical Impermeable Barriers	$1.30	$1.30	$0.30	$0.30	$0.15	$0.15
Leachate Control						
Imper. Daily Cover (off-site source)	5.30	5.30	2.65	2.65	1.75	1.75
Dike Construction[1]	1.20	--	0.28	--	0.15	--
Surface Runoff						
Ponding	0.10	--	0.05	--	0.04	--
Dike Construction	1.20	--	0.27	--	0.15	--
Monitoring						
Gas Monitoring	0.15	0.15	0.03	0.03	0.01	0.01
Groundwater Quality Monitoring	0.60	0.60	0.10	0.10	0.05	0.05
Total Incremental Costs	$ 9.85	$ 7.35	$ 3.68	$3.08	$2.30	$1.96
Baseline Costs	11.15	11.15	6.65	6.65	3.95	3.95
Total Post-Guidelines Costs	$21.00	$18.50	$10.33	$9.73	$6.25	$5.91
Percent Increase	88%	66%	55%	46%	58%	50%

[1] Dike construction costs were divided equally between leachate and surface runoff control functions.

TABLE 6-5

IMPACT OF GUIDELINES ON OPERATING COSTS OF INDUSTRIAL WASTE LANDFILLS (COSTS/TON)

Required Technologies	Site Size Categories					
	10 TPD		100 TPD		300 TPD	
	Sensitive	Non-Sensitive	Sensitive	Non-Sensitive	Sensitive	Non-Sensitive
Gas Control	-	-	-	-	-	-
Leachate Control						
Imper. Daily Cover (off-site source)	$5.30	$5.30	$2.65	$2.65	-	-
Surface Runoff						
Ponding	0.10	-	0.05	-	-	-
Dike Construction	2.40	-	0.55	-	-	-
Monitoring						
Gas Monitoring	0.15	0.15	0.03	0.03	-	-
Ground Water Quality Monitoring	0.60	0.60	0.10	0.10	-	-
Total Incremental Costs Due to Guidelines	$8.55	$6.05	$3.38	$2.78	-	-
Baseline Costs	11.15	11.15	6.65	6.65	-	-
Total Post-Guidelines Costs	$19.70	$17.20	$10.03	$9.43	-	-
Percent Increase	77%	54%	51%	42%	-	-

TABLE 5-6

IMPACT OF GUIDELINES ON OPERATING COSTS OF POLLUTION CONTROL RESIDUE WASTE LANDFILLS (COSTS/TON)

	Site Size Categories					
	10 TPD		100 TPD		300 TPD	
Required Technologies	Sensitive	Non-Sensitive	Sensitive	Non-Sensitive	Sensitive	Non-Sensitive
Gas Control	--	--	--	--	--	--
Leachate Control	$5.30	$5.30	$2.65	$2.65	$1.75	$1.75
Imper. Daily Cover (off-site source)						
Surface Runoff						
Ponding	0.10	--	0.05	--	0.04	--
Dike Construction	2.40	--	0.55	--	0.30	--
Monitoring						
Groundwater Quality Monitoring	0.60	0.60	0.10	0.10	0.05	0.05
Total Incremental Costs Due to Guidelines	8.40	5.90	3.35	2.75	2.14	1.80
Baseline Costs	11.15	11.15	6.65	6.65	3.95	3.95
Total Post-Guidelines Costs	$19.55	$17.05	$10.00	$9.40	$6.09	$5.75
Percent Increase	75%	53%	50%	41%	54%	46%

TABLE 5-7

SUMMARY OF IMPACT OF LANDFILL GUIDELINES ON OPERATING COSTS OF LANDFILLS (COSTS/TON)*

	Site Size Categories					
	10 tpd		100 tpd		300 tpd	
	Sensitive	Non-Sensitive	Sensitive	Non-Sensitive	Sensitive	Non-Sensitive
Landfill Baseline Costs	$11.15(12.49)	$11.15 (12.49)	$6.65 (7.45)	$6.65 (7.45)	$3.95 (4.42)	$3.95 (4.42)
Waste Types						
Municipal						
Post-Guidelines Costs	21.00(23.52)	18.50 (20.72)	10.33 (11.57)	9.73 (10.90)	6.25 (7.00)	5.91 (6.62)
Percent Increase	88%	66%	55%	46%	58%	50%
Industrial						
Post-Guidelines Costs	19.70 (22.06)	17.20 (19.26)	10.03 (11.23)	9.43 (10.56)	-	-
Percent Increase	77%	54%	51%	42%	-	-
Pollution Control Residues						
Post-Guidelines Costs	19.55 (21.90)	17.05 (19.10)	10.00 (11.20)	9.40 (10.52)	6.09 (6.82)	5.75 (6.44)
Percent Increase	75%	53%	50%	41%	54%	46%

* Costs in parentheses are costs/metric ton

5.2.2 Economic Effects of Increased Landfill Disposal Costs

The data presented in the previous section outlined the probable impact of increased technology utilization on unit operating costs of such facilities. However, it is the reaction to these additional costs by those commercial, industrial and government sectors directly and indirectly affected that will determine the long-run net costs and overall effectiveness of the Guidelines. When a particular business or government agency is faced with higher operating costs, it can adjust through one of the following routes:

1. change operating methods or technologies to avoid the costs;

2. absorb the higher costs in the form of lower profits (higher subsidies);

3. shift the higher costs backward on to suppliers (e.g., lower wages); and

4. shift the cost forward in the form of higher rates or prices to its customers.

These four methods are of course not mutually exclusive, and typically occur in various combinations as the affected parties search for ways to minimize the burden of the added costs. In the landfill "industry" this type of situation is complicated by the fact that much of the nation's solid waste handling capacity is publicly owned (although frequently privately operated), so the profit element is essentially replaced by various public mandates or regulations dealing with subsidy limits, bond retirement guarantees based on user changes, and numerous other economic, financial or political constraints. Because of the multiple objectives of the public sector, an analysis of the impact of additional costs is more difficult.

The overall incidence patterns of these costs, that is who bears the burden of those costs, will be determined by the particular mix of reactions outlined above. These can be roughly divided into two categories which are discussed in the following sections:

1. Supply Effects: reactions by the suppliers of the landfill services.

2. Demand effects: reactions by those demanding these landfilling services (i.e., solid waste generators).

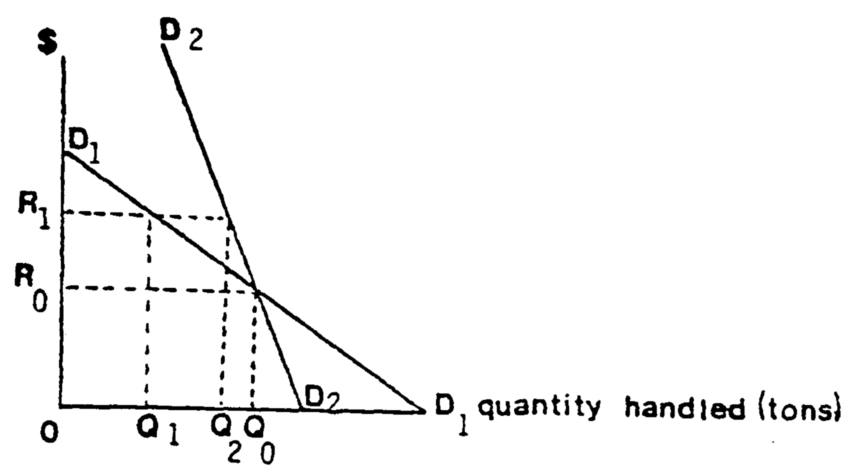
5.2.21 Supply Effects

The landfill operator faced with higher operating costs can either absorb the costs or seek out some method of avoiding them or shifting them elsewhere. The analysis of these reaction patterns is similar in nature to those dealing with the incidence of various government taxes or fees; both depend principally on the financial conditions of the firms and the characteristics of the markets in which they are involved. Any increases in business costs will eventually be borne either by those who provide the various factors of production (labor, capital, equipment), or by those buying the business's goods or services. The only remaining alternative is to revise the technological or institutional structure of the firm (i.e., new equipment, consolidation with other firms, etc.) to avoid or minimize the impact of these costs by lowering costs in other areas. The following sections address five major market and operational effects most applicable to landfill operation.

Increase Disposal Fees For Landfill Users. The ability of landfill operators to pass costs forward in the form of higher user charges typically depends on the nature of the demand for their services. If the demand is very price elastic, the potential increase in revenue will be minimal as many of the landfill users will find alternative methods of meeting their waste handling needs. This is demonstrated in Figure 5-2:

FIGURE 5-2

DEMAND IMPACT OF HIGHER USER CHARGE



A hypothetical landfill is used by two waste generators represented by demand curves D_1 and D_2 each of which disposes of Q_0 tons of waste annually at the site. As the landfill raises its rates from R_0 to R_1, the more price-sensitive of the two, represented by demand curve D_1, reduces its demand from QQ_0 to QQ_1. The more price inelastic generator, represented by curve D_2, shows a more modest drop from QQ_0 to QQ_2.

The principal effect of the increase in rates is a decline in quantity disposed and, if demand is elastic, a decline in total revenues for specific landfills. However, the problems created by a highly elastic market demand go beyond those of insufficient revenue generation. All wastes formerly handled by the landfill must either be deposited elsewhere or not disposed of. The first of these options raises the possibility of illegal dumping as well as the increased likelihood that various landfill operators might avoid compliance, both of which are serious enforcement problems. The second option would be that generators might reduce their waste generation rates and/or expand recycling efforts. This question is covered in more detail in a later section.

Higher Taxes For Landfill Support. A response available to public landfill operations is to pass the additional costs on to taxpayers in the form of higher subsidies for landfill operations. Some municipalities that have formerly assumed that all or a specified portion of landfill costs would be paid by landfill users may be faced with the problem of maintaining operating ratios (operating revenues/operation costs) while not wanting to provide any significant disincentives to those generators who should be using these facilities. As the portion of total costs covered by user charges drops, other public revenue sources would be required. Some private landfill operating costs could also be indirectly subsidized by taxpayers through investment, tax credits or loan guarantees for landfill upgrading or construction, research and development grants, or other forms of subsidy. The specific policy of the agencies involved, the prevailing methods used to finance everyday operating costs or retire bonds, and numerous other factors would have to be considered with the eventual reaction tending to be highly site specific.

Decreases In Supplier Costs. The theoretical possibility exists that landfills could reduce their additional costs through decreases in supplier costs (i.e. lower wages, fuel costs, etc.). This possibility is raised for the sake of completeness only. It is not considered a practical possibility for most landfill operations, except as a part of a regionalization and consolidation effort.

Change In Profits Of Private Landfill Operators. If a landfill operator cannot recover all of its additional costs through rate increases, subsidies, or decreases in supplier costs, the impact will be borne by the firm's stockholders in the form of a lower return on invested capital. Small impacts in the area will probably not cause any substantial adjustments by these firms, especially in the short run, but the decreased profitability could reduce the level of investment in such operations and make it more difficult to raise the capital necessary to upgrade existing operations or build new ones. For those landfills that are publicly owned but privately operated, the situation would entail a pass-through of costs to the relevant public agency with whom the operator has contracted. The affected agency would then be forced to either authorize higher user charges, provide alternative financial support to the operator to cover the extra operating costs, or implement a substantial revision in its operation.

Change In Profits Of Industries With On-Site Disposal. For those firms that handle part or all of their solid wastes at sites owned and operated by the firm, the higher disposal costs may mean a substantial financial loss if the firm has a high waste generation rate and their disposal represents a significant element in their overall operating costs. Conversion from open dump operations to landfill operations could, in extreme cases, mean closure for some financially vulnerable firms. Others would be left virtually unaffected. Industries that would be expected to face relatively substantial solid waste handling costs include food processing, apparel, wood products, fabricated metals and non-electrical machinery.

Regionalization And Consolidation Of Waste Handling. The analysis of economics of scale in landfill operations previously presented showed that disposal cost savings could be realized through consolidation of smaller sites into one large landfill operation. The implementation of the RCRA landfill Criteria and Guidelines will probably increase the benefits of consolidation due to lower unit disposal costs of large sites and the sharing of the initial financing burden of landfill capacity among more waste generators.

The major economic factors that affect the consolidation decision are the potential for scale economics, the density, dispersion, and total volume of the waste sources, and the relevant costs of transportation.

5.2.22 Demand Effects

Source Reduction. The previous section demonstrated how higher disposal costs (or rates) can reduce the demand for landfill services. Either an alternative waste disposal method will then be used (larger landfill, landspreading, illegal dumping, etc.) or the volume of the waste stream will be reduced. Adjustments in the raw materials used in production processes, changes in food packaging techniques, bottle deposit regulations, and similar actions could be used to reduce the volume of waste produced from various industrial, commercial or residential activities. Part of this may occur as the disposal costs are internalized into various operations which then independently adjust their waste generation; other areas may only occur if given the impetus of State or Federal regulations. Increased disposal costs should make legislation aimed at source reduction more attractive.

Energy And Resource Recovery. The combined forces of higher waste disposal costs and increased petroleum cost and concern over possible disruptions in energy supplies have improved the cost-effectiveness of many resource and energy recovery systems and approaches. The number of existing, under-construction, or planned recovery plants across the country has increased substantially in recent years. The added costs of RCRA will encourage this trend, especially in or near large urban areas where suitable landfill sites are scarce and expensive and the waste density exists that is necessary for large scale recovery plants. Much of this same type of activity may occur in the industrial sectors that also face similar disposal cost increases. In combination with waste reduction, energy and material recovery techniques will be applied more frequently, depending on the market for the received materials, the incremental production costs of the recovery processes, and the regional costs of electricity and other energy forms.

Other Legal Waste Disposal Methods. Other legal disposal methods that will continue to exist after implementation of the Guidelines are surface impoundment and landspreading. The costs of these two disposal methodologies options will also be affected by RCRA. Decisions concerning waste disposal options by industry and municipalities will change to reflect the changing costs of these options. Since the costs of future surface impoundment and landspreading activities are not yet determined, it is not yet possible to estimate how the increases in the cost of landfilling identified in this report will affect the choice of these other legal disposal options.

Illegal Dumping. One option that is unfortunately available to generators and landfill operators is the continued use or operation of disposal facilities not meeting the provisions of the criteria. The enforcement problem will be most severe for the thousands of very small sites in rural areas that would face very large increases in disposal costs. The enforcement costs for such operations, due to their geographic dispersion, small sites, the overall detection difficulty, will be rather high as well, forcing agencies to concentrate only on large sites.

5.3 ENERGY IMPACTS SUMMARY

5.3.1 Introduction

Guidelines implementation will result in increased energy consumption for both the construction (including upgrading) and operating phases of landfill operations. Construction energy use will increase due to the requirements for improved levels of environmental protection with the concommittant use of more complex technologies such as liner installation, gas venting and collection systems, leachate collection and treatment systems, etc. Similarly, energy use associated with the operating phase will increase due to energy requirements for leachate pumping, more frequent cover application, etc. As previously referenced, Table 5-1 presents those technologies which have been defined as required upgrading technologies and which will result in increased construction energy use. The table also indicates those technologies which will, in addition, be required for new facilities. Similarly, Table 5-9 indicates those technologies which will result in increased energy use associated with landfill operation.

5.3.2 Estimating Construction Energy Impacts

Data detailing construction energy use (gas, oil, diesel fuel, electricity) for construction of landfills is currently unavailable. To estimate the potential increase in construction energy use, the assumption has been made that increased energy use is directly proportional to increased capital expenditure. The baseline costs for existing landfill operations, as previously develped in Section 5.2, are $11.15, $6.65 and $3.95 per ton for 10 TPD, 100 TPD and 300 TPD facilities, respectively. Approximately 25% of those costs are attributable to construction costs, as follows: 10 TPD - $2.78; 100 TPD - $1.66; 300 TPD - $0.99.

By utilizing required upgrading unit costs for the technologies identified in Table 5-2, total upgrading capital costs can be determined. Table 5-10 presents the capital costs for those technologies incorporated into existing facilities. Increased construction energy use has been assumed to be proportional to increased capital costs of the required upgrading technologies. A more detailed explanation can be found in "Analysis of Technology, Prevalence and Economics of Landfill Disposal in the United States (Volume II) "by Fred C. Hart Associates, Inc. Consumption use is expected to be primarily in the form of gas, oil, and diesel fuel utilization.

5.3.3 Estimating Operating Energy Impacts

Table 5-9 describes upgrading technologies which will result in

TABLE 5-8

UPGRADING TECHNOLOGIES RESULTING IN INCREASED ENERGY OPERATING COSTS

SENSITIVE FACILITIES

Municipal*	Industrial	Pollution Control Residues
Groundwater Water Quality Monitoring	Impermeable Daily Cover	Impermeable Daily Cover
Gas Monitoring	Groundwater Water Quality Monitoring	Groundwater Water Quality Monitoring

NONSENSITIVE FACILITIES

Municipal*	Industrial	Pollution Control Residues
Groundwater Water Quality Monitoring	Impermeable Daily Cover	Impermeable Daily Cover
Gas Monitoring	Groundwater Water Quality Monitoring	Groundwater Water Quality Monitoring

* Daily cover assumed as existing technology; no increased energy use.

TABLE 5-9

TOTAL INCREASED CAPITAL COSTS PER TON AND PERCENT INCREASE IN ENERGY USE FOR UPGRADED FACILITIES

	10 TPD		100 TPD		300 TPD	
	Increased Capital Cost/Ton	% Increase	Increased Capital Cost/Ton	% Increase	Increased Capital Cost/Ton	% Increase
Municipal: Sensitive*	$3.99	144%	$0.93	56%	$0.51	52%
Nonsensitive	1.49	54%	0.33	20%	0.17	17%
Industrial: Sensitive	2.62	94%	0.62	37%	0.35	35%
: Nonsensitive	0.22	8%	0.07	4%	0.05	5%
Pollution Control						
Residues: Sensitive	2.62	94%	0.62	37%	0.35	35%
: Nonsensitive	0.12	8%	0.02	1%	0.01	1%

* Baseline construction costs: 10 TPD, $2.28; 100 TPD, $1.66; 300 TPD, $0.99.

increased energy use during landfill operation. For existing facilities the primary energy consuming technology is that of impermeable cover. It has been assumed that municipal facilities for both sensitive and non-sensitive areas apply daily cover. Consequently, energy costs will not increase. For the remainder of the waste types, it has been assumed that daily cover is not a common practice and that impermeable cover application is energy intensive, a 100% increase in energy requirements for those sites which currently do not apply daily cover might be a reasonable estimate. Consumption is primarily in the fuel energy resource area.

6.0 IRREVERSIBLE AND IRRETRIEVABLE USES; SHORT-TERM USE VS. LONG-TERM PRODUCTIVITY

6.1 IRREVERSIBLE AND IRRETRIEVABLE USES

Since the Guidelines focus on improving environmental conditions, it is important to examine the nature of the changes that they will induce. Implementation of the Guidelines would involve the irretrievable expenditure of certain resources. The technologies selected over and above those currently used to meet Guidelines objectives would necessitate the increased use of manpower and energy to design, install and operate landfill facilities. Once expended, this energy and labor would be irretrievable for other uses.

Certain materials are required for implementing specific technologies such as cover soils, impermeable liners or barriers, leachate and gas collection devices, and monitoring devices. Under the Guidelines, these materials would be committed to use at the site for at least the lifetime of the landfill and until potential pollution problems have abated. Given the difficulty in determining when the landfill has completely stabilized, and the fact that certain materials will suffer varying degrees of deterioration within the site, these materials should be considered as irreversibly incorporated into the landfill.

Waste materials buried in a landfill undergo varying amounts of decomposition. The heterogenous nature of many landfills contributes to the difficulty in recovering recyclable materials. Given the current state of resource recovery technology and the high cost of excavating a site, metals and other elements would potentially not be retreivable for recycling or other resource recovery programs.

In addition to materials, the costs incurred by landfill owners and operators to initiate and maintain improved construction and operating procedures, as well as the increased administrative and managerial costs incurred by all levels of government for inspection, surveillance, and monitoring of facilities, would be irretrievable.

In summary, certain irreversible commitments of resources will be required as a result of Guidelines implementation. In effect, however, the reduction or elimination of potential negative environmental impacts in the air, surface water, and groundwater arenas, will result in an increase in the long term productivity of the nation's environs and will result in increased levels of protection of public health and safety.

6.2 SHORT-TERM USE VS. LONG-TERM USE

Certain short-term demands on the environment, in addition to irretrievable usage of some resources, are necessary to meet the Guidelines requirements of promoting long-term environmental protection.

Planning requirements involved with implementing the Guidelines necessitate some short-term economic and manpower expenditures. As a result of planning and incorporating additional technology, increases can be expected in the capital energy expenditures of operating a landfill disposal facility. Increases in the economic costs of disposal can therefore be expected. However, these initial short-term uses potentially can be mitigated by the eventual energy savings and overall economic savings in reduced diposal problems, and in reduced air and water pollution cleanup efforts that are now required by presently inadequate disposal methods.

These and other short-term uses, such as construction effects associated with installing additional control techniques, may increase noise levels, create dust, temporarily disrupt the environment and place immediate demands on particular resources, but they will result in minimizing the widespread effect of groundwater, surface water, and air pollution and will protect certain environmentally sensitive areas.

Increased economic costs of landfilling will also affect research and development in resource recovery areas. While more efficient and effective landfilling practices may reduce the need for alternative disposal methods, the initial increased cost of meeting the Guidelines and the growing limitations on land availability, especially in densely populated urban areas, can give added incentive to long-term resource recovery programs.

In summary, while a variety of short term requirements and impacts in the environment will ensue as a result of technology implementation, in the long-term the result will be an increased level of protection for the environment, which in turn implies best use of the nation's environmental resources. Additionally, increased costs of landfilling provide additional impetus towards resource recovery technology development, which in turn results in reduced environmental demands due to landfilling disposal requirements.

7.0 SUMMARY OF PUBLIC PARTICIPATION

7.1 ORGANIZATIONS AND PERSONS CONSULTED

As per the Summary statement, this impact statement has been distributed to a substantive number of organizations for public comment.

7.2 PERTINENT PUBLIC HEARING QUESTIONS AND RESPONSES

Public hearings on this draft impact statement have been scheduled as follows:

Washington, D.C.	May 15, 1979
Houston, Texas	May 17, 1979

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APPENDIX A

LINER MATERIALS EVALUATIONS

Admixed and Asphaltic Materials

(Source: Reference 3)

Asphalt Concrete

Asphalt concrete is a carefully controlled mixture of asphalt cement and graded aggregate that is placed and compacted at elevated temperatures. Asphalt concrete is especially well adapted to the construction of linings for all types of hydraulic structures. It may be used for the entire lining structure, or it may be a principal part of a more complex lining. Depending on mix design and placement, it may serve as an impermeable layer or as a porous layer. Properly mixed and placed, asphalt concrete forms a stable, durable, and erosion-resistant lining.

Asphalt cements of 40 to 50 or 60 to 70 penetration grades are preferable for hydraulic concrete linings. The lower penetration grades produce harder asphalt concrete linings that are more resistant to the destructive action of water, the growth of vegetation, and extremes of weather. They are more stable on side slopes than linings made with sulfur asphalt cements, but they retain sufficient flexibility to conform to slight deformation of the subgrade.

Mix design of asphalt concrete for hydraulic linings follows general principles such as those described in publications of the Asphalt Institute. Table 11 lists some typical mix compositions. The maximum stone size will generally be from 1.27 to 2.54 cm (1/2 to 1 in.) in size, and the amount of mineral filler passing a No. 200 sieve will usually be from 8% to 15%. The mix should have 6% to 9% asphalt content by weight of the total mix. The aggregate gradation and asphalt content should be such that the mix will be stable, yet easily compacted to less than 4% air voids.

Soil Asphalt

Soil asphalt embraces a wide variety of soils, usually those of low plasticity mixed with a liquid asphalt. Generally, soil asphalt mixtures are avoided for lining purposes. There are always exceptions, but soil asphalt mixes containing cutback asphalts are usually not suitable for linings. (Cutback asphalts are liquid solutions of asphalt in a volatile solvent. Upon evaporation of the solvent, cutback asphalts assume a heavy consistency typical of the base asphalt.) Those soil asphalts containing emulsified asphalts require a waterproofing seal, membrane, or asphalt concrete to be placed on top of them. (Asphalt emulsions are dispersions of microscopic asphalt particles in a continuous aqueous phase containing small amounts of chemicals or clay as emulsifiers. They can be classified as anionic, cationic, or nonionic, depending on the electrical charge on the asphalt particles. Asphalt emulsions are normally liquid, reverting to the solid or semisolid state of the base asphalt after application by means of evaporation or breaking out of the water.)

Sprayed Asphalt Membranes

An asphalt membrane lining (hot-sprayed type) consists of a continuous layer of asphalt, usually without filler or reinforcement of any kind. It is generally covered or buried to protect it from mechanical damage and to prevent weathering (oxidation) of the surface. Its cover may be another layer of a multilayer lining structure, but generally it is native soil, gravel, asphalt macadam, or other substances specifically placed for this purpose. Asphalt membranes are placed to thicknesses of 0.48 to 0.79 cm (3/16 to 5/16 in.) and constitute continuous waterproof layers extending throughout the length and breadth of the structure being lined. Asphalt of special characteristics is used to make these membranes into tough, pliable sheets that readily conform to changes or irregularities in the subgrade. Buried under a protective coating, an asphalt membrane will retain its tough, flexible qualities indefinitely. It is one of the least expensive types of current liners.

Asphalts used to make membranes must have very low temperature susceptibility and a high degree of toughness and durability. Furthermore, asphalt for membrane linings must have a high softening point to prevent sagging or flow down a slope if the cover material should be accidently removed and the membrane exposed to the sun. The material must also be sufficiently plastic at operating temperatures to minimize the danger of rupture from earth movement. Also, it must not exhibit excessive cold flow tendencies in order to effectively resist the hydraulic head to which it is subjected.

Considerable laboratory research and field trials have gone into the selection of suitable asphalts. Those that meet the requirements are usually asphalts produced from selected feedstocks by the use of air-blowing techniques. (Some manufacturers employ chemical modifiers, which are most often termed catalysts, in the blowing process.)

Bituminous Seals

Bituminous seals are generally used to seal the surface pores of an asphalt mixture serving as a lining or to provide additional assurance for waterproofing. They are also considered in some cases where there may be some reaction between the aggregate in the mix and the liquid to be stored. There are basically two types of bituminous seals. One is simply an asphalt cement (sometimes emulsified asphalt is used instead) sprayed over the lining surface at a rate of about 1.1 liter/m^2 (1 qt/yd^2). This method provides a film approximately 0.18 cm (1/32 in.) thick. The second type of seal consists of an asphalt mastic that may contain 25% to 50% asphalt cement. The remainder is a mineral filler such as limestone dust or an inexpensive reinforcing fiber such as asbestos. This mixture is generally squeegeed on at an application rate of about 2.7 to 5.4 kg/m^2 (5 to 10 lb/yd^2).

BENTONITE/SOIL

High-swell clay minerals have been widely used to control excessive seepage in natural soils by decreasing their permeability. Bentonite, one of the most widely used clays, is a heterogeneous substance composed of montmorillonite and small amounts of feldspar, gypsum, calcium carbonate, quartz, and traces of other minerals. Bentonite has colloidal properties because of its very small particle size and the negative charge on the particles. About 70% to 90% of the particles are smaller than 0.6 micron.[25] Bentonite has the capacity of absorbing approximately five times its weight in water and occupies a volume of 12 to 15 times its dry bulk volume at maximum saturation.[26] It is this swollen mass that fills the voids in soils that normally would permit water seepage. These high-swell bentonites are found in Wyoming, South Dakota, Montana, Utah, and California.

The level of ionic salts found in certain industrial wastes is often sufficient to reduce the swelling of bentonite and therefore impair its usefulness as a sealant. Since the water that initially contacts the bentonite is most critical to its effectiveness, swelling of the bentonite can often be effected by prehydrating the bentonite in fresh water. This forms an effective seal in the presence of contaminated wastewater. But in the presence of high quantities of dissolved salts, the prehydrated clay eventually deteriorates. The use of a specially formulated form of bentonite (Saline Seal) reportedly assures that after prehydration, the bentonite will remain swollen for a long time and will not deteriorate as rapidly when exposed to a high level of ionic contaminants.

Saline Seal bentonite can be distributed over a prepared lagoon surface at a rate of about 1.82 kg/0.09 m^2 (2.0 lb/ft^2) and mixed thoroughly into the top 5.1 to 15.2 cm (2 to 6 in.) of soil. The area is then covered with a minimum of 1 in. of fresh water to effect prehydration. After 2 to 4 days, industrial waste can be put into the lagoon.

Saline Seal can also be placed on unstable or wet soil surfaces as a slurry. Slurries are made by mixing approximately 0.23 kg (1/2 lb) of Saline Seal per 3.8 liters (gal) of water. When distributed over the soil surface, the slurry will effectively seal the soil surface.

Table 18 compares the relative performance of a bentonite and Saline Seal, both of which were prehydrated with fresh water. The soil tests were performed on sandy soil, with 3.6 kg (4.0 lb) of each applied per 0.09 m^2 (ft^2) and thoroughly mixed into the top 5.1 cm (2 in.) of soil. As the data indicate, the prehydrated bentonite seal showed signs of deterioration on the second day and failed completely on the seventh day, whereas the Saline Seal maintained and even improved the seal. The contaminated water used in the test contained 3.1% sodium chloride and 3.6% sodium sulfate.

COMPARATIVE PERFORMANCE OF BENTONITE AND SALINE SEAL BENTONITE IN A SOIL TEST[27]

Day	Prehydrated Bentonite: Permeability* (cm/sec)	Prehydrated Bentonite: Leakage Rate# cm (in.)	Prehydrated Saline Seal: Permeability* (cm/sec)	Prehydrated Saline Seal: Leakage Rate# cm (in.)
1	1.0×10^{-6}	0.318 (0.125)	1.0×10^{-6}	0.318 (0.125)
2	2.0×10^{-6}	0.635 (0.250)	1.0×10^{-6}	0.318 (0.125)
3	5.0×10^{-6}	1.905 (0.750)	0.8×10^{-6}	0.254 (0.100)
4	1.0×10^{-5}	3.18 (1.25)	0.9×10^{-6}	0.284 (0.112)
5	6.0×10^{-5}	19.1 (7.5)	0.7×10^{-6}	0.221 (0.087)
7@	1.0×10^{-4}	31.8 (12.5)	0.7×10^{-6}	0.221 (0.087)

*1.0×10^{-6} cm/sec represents an effective seal (equivalent to 1 ft of compacted native clay).

#Loss of water at a 1.22-m (4-ft) head.

@Seal failed.

Low-swell clays such as hydrated mica and kaolin have had limited use as sealants. However, some research has been conducted on their sealing characteristics,[28] and perhaps additional investigations are needed. The low-swell clays are affected less by increased concentrations of magnesium or calcium in water, and the damage from drying may be less severe. Low-swell clays are generally found in Nevada and other western states.

The cost of bentonite-type clays varies from about $10/ton to more than $25/ton (FOB the clay-processing plant), with $20/ton a typical cost.[28] The price variation is a function of the quality of the clay, the degree of carried out processing, and the quantity purchased. In addition to the basic cost, shipping is expensive unless the site is located near the clay-processing plant. Typical shipping costs range from $20 to $30/ton, depending on the mode of transportation and the distance traveled. Note, however, that if clay suitable for an impoundment site lining is available on the site itself, the cost could be as low as $1.00/0.8 m^2 (yd^2) if the clay can be bulldozed into position.[29]

SOIL CEMENT

Soil cement is prepared by compacting a mixture of Portland cement, water, and a wide variety of soils. As the Portland cement hydrates, the mixture becomes a hard, low-strength Portland cement concrete. Soil cement is sometimes used to surface pavements with low-volume traffic, and it is extensively used for the lower layers of pavements, where it is generally referred to as cement-treated base. Soil cement is also widely used in water control construction, more specifically to protect the slopes at earth dams and other embankments. See Appendix D for information regarding contract awards for soil cement water control projects.

Strong soil cement linings can be constructed using many types of soils, but the permeability of the resulting liners varies with the nature of the soil: The more granular it is, the higher the permeability. By using fine-grained soils, soil cements with permeability coefficients of about 10^{-6} cm/sec can be obtained. In actual practice, surface sealants are often applied to soil cement linings to obtain a more waterproof structure. Aging and weathering characteristics of soil cement linings are fairly good, especially those associated with the wet-dry and freeze-thaw cycles. Some degradation of soil cement linings can be expected in an acidic environment, however.

Polymeric Membranes

(Source: Reference 4)

Butyl Rubber

Butyl rubber is a copolymer of a major amount of isobutylene (97%) and a minor amount of isoprene to introduce unsaturation in the rubber as sites for vulcanization. A vulcanized butyl rubber compound is used in the manufacture of the sheeting, which is available in either unsupported or fabric-reinforced versions of 20 to 125 mil thickness. Butyl rubber has excellent resistance to permeation of water and swelling in water. This rubber has poor resistance to hydrocarbons, but is quite resistant to animal and vegetable oils and fats. Butyl rubber compounds generally contain low amounts of extractable material and swell little in water. Overall they age very well, although some butyl compounds ozone crack. Some recent compounds contain minor amounts of EPDM to improve ozone resistance. In outdoor exposure in water management use, butyl rubber liners have shown no degradation after 20 years of service. Obtaining good splices of butyl sheeting, particularly in the field, continues to be a problem, as cold curing adhesives are required.

Chlorinated Polyethylene (CPE)

This relatively recently developed polymer is an inherently flexible thermoplastic produced by chlorinating high density polyethylene. Sheeting of CPE makes durable linings for waste, water, or chemical storage pits, ponds, or reservoirs. CPE withstands ozone, weathering and ultraviolet and resists many corrosive chemicals, hydrocarbons, microbiological attack, and burning. Compounds of CPE are serviceable at low temperatures and are nonvolatile. Membranes of CPE are available in 20 to 40 mil thicknesses in supported and reinforced versions. They are generally unvulcanized and are spliced with solvent adhesives by solvent welding.

Chlorosulfonated Polyethylene

This synthetic rubber is made by the chlorosulfonation of polyethylene. It can be used in both vulcanized and unvulcanized compounds; however, liners of this rubber are generally based on unvulcanized compounds containing at least 45% of the rubber. They are available in sheeting of 30 to 45 mil thicknesses; most are made with fabric reinforcement of either nylon or polyester scrim. Liners of this rubber have good puncture resistance, are easy to seam in the factory or field with solvents, cements, or heat, and have excellent resistance to weathering, aging, oil, and bacteria. Membranes of this material have been used in the lining of pits and ponds where highly acid-contaminated fluids are encountered.

After polyvinyl chloride, this is the most used polymeric material for liners.

Elasticized Polyolefin

Membrane liners of an elasticized polyolefin have been recently introduced. This material is unvulcanized and thermoplastic and can be easily seamed with heat either in the field or factory. It features excellent resistance to weathering and oils. Films of this material are supplied in 20-foot widths in 20 to 30 mil thickness.

Ethylene-Propylene Rubber (EPDM)

This synthetic rubber is a terpolymer of ethylene, propylene, and a small amount of a diene monomer that introduces double bonds onto the polymer chain. These double bonds are sites for vulcanization of the rubber and, as the unsaturation is in the side chain of the polymer molecule and not in the main chain, ozone, chemical, and aging resistance are excellent. The rubber is compatible with butyl and is often added to butyl to improve resistance of the latter to oxidation, ozone, and weathering. As it is a wholly hydrocarbon rubber like butyl, EPDM has excellent resistance to water absorption and permeation, but has relatively poor resistance to some hydrocarbons. EPDM liners are supplied in vulcanized sheeting of 20 to 125 mils thicknesses, both supported and unsupported. Special attention is required in splicing and seaming this material, as vulcanizable adhesives must be used.

Neoprene or polychloroprene

Neoprene is a synthetic rubber based primarily on chloroprene. It features good weathering and oil resistance and has been used where these properties are required. It is supplied in vulcanized sheeting of 30 to 125 mils thicknesses. As it is a vulcanized rubber, vulcanizing cements and adhesives must be used for seaming.

Polyester Elastomer

This is an experimental thermoplastic rubber which has recently been introduced as a liner material. It has excellent resistance to oils and can be heat sealed. It is supplied in relatively wide sheets of 7 to 10 mils thicknesses.

Polyvinyl Chloride (PVC)

Polymeric membranes based upon PVC are the most widely used flexible liners. They are available in wide sheets of 10 to 30 mils thicknesses; most is used as unsupported film, but fabric reinforcement can be incorporated. PVC compounds contain 30 to 50% of one or more plasticizers to make the films flexible and rubber-like. They also contain 2% of a chemical stabilizer and various amounts of fillers. There is a wide choice of plasticizers that can be used with PVC, depending upon the application and service conditions under which the PVC compound will be used. PVC polymer generally holds up well in burial tests; however, plasticized compounds of PVC films have deteriorated, presumably due to the biodegradability of the plasticizer. Also, some plasticizers are soluble to a limited extent in water. On exposure to weather with its wind, sunlight, and heat, PVC liner materials can deterioate badly due to loss of plasticizer and to polymer degradation. Consequently, they are generally covered. Plasticized PVC films are quite resistant to punsture and relatively easy to splice by solvent welding, adhesives and heat.

APPENDIX B

UNIT COST CALCULATIONS AND ASSUMPTIONS

For the purposes of developing final upgrading unit costs a calculation methodology was adopted which was similar in approach to the "Draft Environmental Impact Statement Criteria for Classification of Solid Waste Disposal Facilities." Major assumptions are as follows:

- Utilization of 10 TPD, 100 TPD, and 300 TPD sites
- Corresponding total acreages of 6 acres, 28 acres and 75 acres respectively
- Corresponding total perimeter lengths of 2,000 ft., 4,400 ft. and 7,200 ft. respectively
- 260 days operation per year
- In place refuse to soil cover ratios of 1:1, 2:1 and 3:1 respectively
- 26,000, 260,000 and 780,000 total ten year life capacity for 10 TPD, 100 TPD and 300 TPD facilities respectively

More detailed assumptions for the selected and alternative upgrading technologies are as follows:

VERTICAL IMPERMEABLE BARRIER

- 20' depth, 60 cu. ft./ft. perimeter installation
- excavation @ $0.50/cu. yd., clay material @ $3.00/cu. yd., placement @ $0.30/cu. yd.
- total unit cost $17.00/ft. ($55.76/meter)

DIKE CONSTRUCTION

- 10' depth, 567 cu. ft./ft.
- 3:1 slopes
- materials and placement @ 1.50 cu. yd.
- total unit cost $31.50/ft. ($103.32/meter)

IMPERMEABLE DAILY COVER (ON-SITE SOURCE)

- total unit cost $0.60/cu. yd. ($0.78/cu. meter)

IMPERMEABLE DAILY COVER (OFF-SITE SOURCE)

- transport @ $1.00/cu. yd., clay material @ $3.00/cu. yd. placement @ $0.30 cu. yd.
- 2 mile average transport distance
- total unit cost $4.30/cu. yd. ($5.62/cu. meter)

PONDING

- 2" 24 hr. rainfall event
- runoff storage required for twice the site landfill area
- excavation @ $0.50/cu. yd. (0.65/cu. meter) land @ $3,000/acre ($7,410/hectare)
- 10 TPD, 0.4 acres, 5' depth; 100 TPD, 1.85 acres, 5' depth; 300 TPD, 2.5 acres, 10' depth

PERIMETER GRAVEL TRENCHES

- 20' depth, 60 cu. ft/ft, perimeter installation
- excavation @ $.50/cu. yd, gravel material @ $4.00/cu. yd, placement @ $.30/cu. yd.
- total unit cost $21.00/ft. ($68.88/meter)

GAS COLLECTION

- perimeter installation
- total unit cost @ $20.00/ft for 10 TPD and 100 TPD sites, $15.00/ft for 300 TPD sites ($65.60/meter, $65.60/meter, $99.20/meter respectively
- Annual operating costs for 10 TPD, $4,000; 100 TPD, $8,800; 300 TPD, $10,800.

SYNTHETIC LINER

- total unit costs including site preparation and earth cover $3.60/sq yd. ($4.31/sq. meter)

LEACHATE RECYCLING

- 30" infiltration/year,
- 10 TPD, $6,000 piping, $2,000 pump station, $500 annual costs; 100 TPD, $13,200 piping, $4,000 pump station, $1000 annual costs; 300 TPD, $21,600 piping, $10,000 pump station, $2000 annual costs

DITCHING

- total unit cost $2.25/ft. ($7.38/meter)

FINAL IMPERMEABLE COVER (ON-SITE SOURCE)

- unit cost $0.60/cu. yd. @ 2' depth ($0.78/cu. meter)

FINAL IMPERMEABLE COVER (OFF-SITE SOURCE)

- unit cost $4.30/cu. yd. @2' depth ($6.02/cu. meter)

FINAL PERMEABLE COVER (ON-SITE SOURCE)

- unit cost $0.50/cu. yd. @ 2' depth ($0.65/cu. meter)

FINAL PERMEABLE COVER (OFF-SITE SOURCE)

- unit cost $1.75/cu. yd.@ 2' depth ($2.29/cu. meter)

REVEGETATION

- total unit cost $1000/acre ($2471/hectare)

The following table presents the development of technology unit costs in more detail:

GAS MONITORING

- 10 TPD, 4 wells; 100 TPD, 8 wells; 300 TPD, 12 wells
- wells @ $200/each, labor @ $100/day
- sampling labor for 10 TPD, 4 man-days/year; 100 TPD 8 man-days/year; 300 TPD, 12 man-days/year
- $1000 monitoring equipment

GROUNDWATER WATER QUALITY MONITORING

- 10 TPD, 3 wells; 100 TPD, 4 wells; 300 TPD, 7 wells
- quarterly sampling @ $150/sample, $1000/well
- sampling labor for 10 TPD, 3 man-days/year; 100 TPD, 4 man-days/year; 300 TPD, 7 man-days/year @ $100/day

NATURAL CLAY LINER (OFF-SITE SOURCE)

- transport @ $1.00/cu. yd., clay material @ $3.00/cu. yd., placement @ $.30/cu. yd.
- 2-foot depth clay material
- 2-mile average transport distance
- total unit cost @ $4.30/cu. yd. ($5.89/cu. meter)

LEACHATE COLLECTION FACILITIES

- 10 TPD, 3500' collector pipe; 100 TPD, 14,300' collector pipe· 300 TPD, 36,000' collector pipe
- 100' collector pipe spacing plus perimeter
- total unit cost @ $7.00/ft. ($22.96/meter)

LEACHATE MONITORING, REMOVAL AND TREATMENT

- 6" infiltration/year, 450 gal/day/acre
- 10 TPD, 2700 gal/day, 2.5¢/gal; 100 TPD, 12,600 gal/day, 1¢/gal; 300 TPD, 33,750 gal/day, 0.5¢/gal (18.7¢/cu.ft., 7.5¢/cu.ft., 3.7¢/cu.ft. respectively

PERMEABLE DAILY COVER (ON-SITE SOURCE)

- total unit cost $.50/cu. yd. ($0.65/cu. meter)

PERMEABLE DAILY COVER (OFF-SITE SOURCE)

- transport @ $.75/cu. yd, material @ $.30/cu. yd, placement @ $.50/cu. yd.
- 1-mile average transport distance
- total unit cost $1.55/cu. yd. ($2.03/cu. meter)

VERTICAL PIPE VENTS

- 2 per acre @ $2,000/vent

FIRE CONTROL

- one fire truck unit @ $1,000, $2,000, and $10,000 per site for 10 TPD, 100 TPD and 300 TPD sites respectively

ACCESS CONTROL

- perimeter installation
- total unit cost @ $12.00/ft. ($39.36/meter)

LITTER CONTROL

- litter control fencing, 130 ft., 280 ft. and 450 ft. per 10 TPD, 100 TPD and 300 TPD sites respectively @ $10.00/ft. ($32.80/meter)

COMPACTION

- one machine @ $50,000

UNIT COSTS OF CONTROL TECHNOLOGIES

Technology	Site Size	Capital Costs: Unit Costs	Capital Costs: Quantity	Capital Costs: Total	O & M Costs: Unit Cost	O & M Costs: Quantity	O & M Costs: Yearly Costs	O & M Costs: Present Worth	Total Costs/Ton (1977 dollars)
Vertical Impermeable Barrier	10 TPD	$17.00/ft.	2,000'	$ 34,000	–	–	–	–	$ 1.30
	100 TPD	"	4,400'	74,800	–	–	–	–	0.30
	300 TPD	"	7,200'	122,400	–	–	–	–	0.15
Dike Construction	10 TPD	$31.50/ft.	2,000'	$ 63,000	–	–	–	–	$ 2.40
	100 TPD	"	4,400'	138,000	–	–	–	–	0.55
	300 TPD	"	7,200'	226,800	–	–	–	–	0.30
Impermeable Daily Cover (on-site source)	10 TPD	–	–	–	$0.60/cu. yd.	5,200 cu. yd.	$ 3,120	$ 19,200	$ 0.75
	100 TPD	–	–	–	"	26,000 cu. yd.	15,600	95,800	0.35
	300 TPD	–	–	–	"	52,000 cu. yd.	31,200	191,600	0.25
Impermeable Daily Cover (off-site source)	10 TPD	–	–	–	$4.30/cu. yd.	5,200 cu. yd.	$ 22,400	$ 137,300	$ 5.30
	100 TPD	–	–	–	"	26,000 cu. yd.	111,800	686,500	2.65
	300 TPD	–	–	–	"	52,000 cu. yd.	223,600	1,372,900	1.75
Ponding	10 TPD	$ 0.50/cu. yd.	3,200 cu. yd.	$ 2,800*	–	–	–	–	$ 0.10
	100 TPD	"	15,000 cu. yd.	13,000*	–	–	–	–	0.05
	300 TPD	"	40,200 cu. yd.	27,500*	–	–	–	–	0.04
Gas Monitoring	10 TPD	$200/well	4	$ 1,800**	$100/day	4 days/year***	$ 400	$2,400	$ 0.15
	100 TPD	"	8	2,600**	"	8 days/year***	800	4,900	0.03
	300 TPD	"	12	3,400**	"	12 days/year***	1,200	7,400	0.01
Groundwater Water Quality Monitoring	10 TPD	$1,000/well	3	$ 3,000	$150/sample	3 days/year****	$2,100	$ 12,900	$ 0.60
	100 TPD	"	4	4,000	"	4 days/year****	2,800	17,200	0.10
	300 TPD	"	7	7,000	"	7 days/year****	4,900	30,100	0.05
Gas Collection Facilities	10 TPD	$ 20/ft.	2,000'	$ 40,000	–	–	$ 4,000	$ 24,600	$ 2.50
	100 TPD	"	4,400'	88,000	–	–	8,800	54,000	0.55
	300 TPD	"	7,200'	144,000	–	–	14,400	88,400	0.30

* includes land costs
** includes equipment costs at $1,000
*** 8 samples/well/year
**** 4 samples/well/year

Technology	Site Size	Capital Costs: Unit Costs	Capital Costs: Quantity	Capital Costs: Total	O & M Costs: Unit Cost	O & M Costs: Quantity	O & M Costs: Yearly Costs	O & M Costs: Present Worth	Total Costs/Ton (1977 dollars)
Natural Clay Liner	10 TPD	$4.30/cu. yd.	19,350 cu. yd.	$ 83,200	–	–	–	–	$ 3.20
	100 TPD	"	90,340 cu. yd.	388,500	–	–	–	–	1.50
	300 TPD	"	242,000 cu. yd.	1,040,600	–	–	–	–	1.35
Leachate Collection	10 TPD	$7.00/ft.	3,500'	$ 24,500	–	–	–	–	$ 0.95
	100 TPD	"	14,300'	100,100	–	–	–	–	0.40
	300 TPD	"	36,000'	252,000	–	–	–	–	0.30
Leachate Treatment	10 TPD	–	–	–	2.5¢/gal.	2,700 gal/day	$24,600*	$151,300	$ 5.80
	100 TPD	–	–	–	1.0¢/gal.	12,600 gal/day	46,000*	282,400	1.10
	300 TPD	–	–	–	0.5¢/gal.	33,750 gal/day	61,600*	378,200	0.50
Permeable Daily Cover (on-site source)	10 TPD	–	–	–	$0.50/cu. yd.	5,200 cu. yd.	$ 2,600	$ 16,000	$ 0.60
	100 TPD	–	–	–	"	26,000 cu. yd.	13,000	79,800	0.30
	300 TPD	–	–	–	"	52,000 cu. yd.	26,000	159,600	0.20
Permeable Daily Cover (off-site source)	10 TPD	–	–	–	$1.55/cu. yd.	5,200 cu. yd.	$ 8,100	$ 49,500	$ 1.90
	100 TPD	–	–	–	"	26,000 cu. yd.	40,300	247,400	0.95
	300 TPD	–	–	–	"	52,000 cu. yd.	80,600	494,900	0.65
Vertical Pipe Vents	10 TPD	$2000 per	12	$ 24,000	–	–	–	–	$ 0.90
	100 TPD	"	56	112,000	–	–	–	–	0.45
	300 TPD	"	150	300,000	–	–	–	–	0.40
Perimeter Gravel Trenches	10 TPD	$21.00/ft.	2,000'	$ 42,000	–	–	–	–	$ 1.60
	100 TPD	"	4,400'	92,400	–	–	–	–	0.35
	300 TPD	"	7,200'	151,200	–	–	–	–	0.20

* treatment 7 days/week

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