SCS ENGINEERS

CONSTRUCTION OF NEW SANITARY LANDFILLS WITH COMPOSITE LINERS

Presented to:

ACUERDO DE COOPERACIÓN USAID - CCAD

Comision Centroamericana de Ambiente y Desarrollo

Presented by:

SCS ENGINEERS
12651 Briar Forest, Suite 205
Houston, Texas
(281) 397-6747

November, 2010
File No. 16210047.00

Offices Nationwide
www.scsengineers.com

PREFACE

Considering the current situation of the Central American region in environmental matters and the new commercial challenges derived from CAFTA-DR, the United States Agency for International Development (USAID), has signed with General Secretariat of the Central American System for Integration (SG-SICA) a Strategic Objective Grant Agreement for its new program in Central America and Mexico, that corresponds to the Intermediate Result called "Economic Freedom: Open diversified Expanding Economies". Since Central American Commission on Environment and Development (CCAD) is the active arm of SICA and the political reference in environmental matters, in this Agreement assume the responsibility of supporting the cooperation around the free trade agreement, for which it will coordinate and implement a series of actions in different thematic components, such as:

I. Strengthened Environmental Management Systems in CAFTA-DR countries.

II. Strengthened Capacities of the parts to comply with the environmental obligations of CAFTA-DR.

III. Compliance with improved environmental multilateral agreements.

IV. Use of increased clean production technologies.

V. Increase in inter-ministry coordination, building of capacities and communication

VI. Strengthen CCAD institutional capability and internal controls

The present Construction of new Sanitary Landfill Inspection/audit protocol is in line with Component I, Strengthened Environmental Management System in CAFTA-DR countries, which focuses in the implementation of regulatory environmental instruments that facilitate the compliance and law enforcement, technical capacity building, and analytical equipment in the laboratories; as well as the adoption of instruments of environmental incentive in each DR-CAFTA country.

TABLE OF CONTENTS

FIGURES

APPENDICES

1.0 INTRODUCTION

This document has been prepared for the Comisión Centroamericana de Ambiente y Desarrollo (CCAD) by SCS Engineers to provide guidance for constructing a sanitary landfill. This manual is designed to assist private solid waste companies and municipalities and for training environmental health inspectors on the proper techniques for the design and construction of new sanitary solid waste landfills with geomembrane liners.

This manual is intended to address municipal solid waste landfills and not hazardous or un-treated medical waste landfills. For the purposes of this manual, municipal solid waste is waste resulting from or incidental to municipal, community, commercial, institutional, agricultural, mining, and recreational activities, including garbage, rubbish, refuse, sludge from a wastewater treatment plant, water supply treatment plant, ashes, street cleanings, dead animals, abandoned automobiles, treated medical waste and other discarded material including solid, liquid, semi-solid, or contained gaseous material.

Hazardous waste includes any solid waste which, because of its quantity, concentration, or physical, chemical, or infectious characteristics may pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, or disposed of, or otherwise mismanaged. Or, that cause or contribute to an increase in mortality or an increase in irreversible or incapacitating illness. Hazardous wastes types include: ignitable hazardous waste, corrosive hazardous waste, reactive hazardous waste, and toxic hazardous waste. Hazardous wastes are further identified and listed by the administrator of the United States Environmental Protection Agency under the federal Solid Waste Disposal Act, as amended by the Resource Conservation and Recovery Act of 1976, 42 United States Code, §§6901, as amended. Additional information on hazardous waste can be found at http://www.epa.gov/osw/hazard/index.htm.

This document has been prepared to act as a general guidance document and is not intended to represent an actual sanitary landfill design. All aspects of sanitary landfill disposal soil liner, geomembrane liner, leachate collection system, landfill liners constructed below the groundwater table, groundwater monitoring wells, landfill gas monitoring probes, and other items included in this manual should be designed by a qualified engineer.

The Solid Waste Association of North American (SWANA) offers training and certifications for Manager of Landfill Operations (MOLO). This course provides a comprehensive study of efficient landfill operations, including site design, compliance with regulations, and issues to consider when planning, operating, and closing landfills. Additional information on SWANA's MOLO course can be found at http://swana.org/Education/Educate/Certification/Landfill/tabid/89/Default.aspx.

The International Solid Waste Association (ISWA) offers training and certification for International Waste Manager Program. This is designed to provide an internationally recognized certification for individual professional waste managers based on their academic achievements and their practical work experience. The certification has four levels of which three are designated as Intermediate, Advanced, and International, depending on how applicants meet the ISWA criteria. There is a fourth Preliminary level that has been established to enable those with practical experience but lacking some academic level of qualification. Additional information on the ISWA International Waste Manager Program can be found at: https://www.iswa.org/fileadmin/user_upload/IWM_001_Brochure_rev007.pdf.

1.1 Purpose

The intent of this manual is to provide reasonable technical guidance and a suggested minimum level of construction control and testing for the construction of new landfills. This includes the construction of landfill composite liners, leachate collection systems, groundwater monitoring wells, and landfill gas monitoring wells.

Figure 1: Aerial View of Sanitary Landfill with New Composite Liner Construction

New landfill disposal cells will be constructed with a composite liner and a leachate collection system. The composite liner shall consist of two components, the lower component will consist of a soil liner and the upper component will be a geomembrane. A leachate collection system and protective cover soil will be placed over the composite liner.

This manual provides materials, construction, and Quality Assurance/Quality Control criteria for various elements of the liner system, including:

- Soil liners (Chapter 2)
- Geomembrane liners (Chapter 3)
- Leachate collection layer (Chapter 4)
- Liners constructed below the seasonal high groundwater table (Chapter 5)
- Liner construction documentation and reporting (Chapter 6)
- Groundwater monitoring wells (Chapter 7)
- Landfill gas monitoring probes (Chapter 8)

1.2 General Landfill Siting Components

A new landfill should consider various physical and sociological conditions around the site. Physical conditions include natural features such as the site geology, hydrogeology, groundwater, hydrology, climate, river and streams, fault areas, seismic impact zones, unstable areas, and endangered species. These physical conditions should be considered with an environmental impact study of the proposed landfill site.

Landfills should be located outside of creeks, large drainage ways, lakes, ponds or other water bodies. Landfills should be located far enough from these features to prevent the washout of solid waste during extreme storm events.

Storm water conveyance systems (ditches, channels, ponds and pipes) should be designed and constructed to move water around the landfill to keep water from entering the landfill disposal cell and from washing out waste. Drainage systems should, at a minimum, be designed to local storm water design codes.

Storm water on the landfill should be directed around the working face to the perimeter drainage system. Storm water that falls on the landfill working face should be contained with berms and treated as contaminated water (or “leachate”).

An environmental impact study of the proposed landfill site should be conducted to determine if there are any restrictions to locating a landfill. This study should include a review of published data coupled with an actual field investigation of the site. If the review of published data and initial field investigation do not reveal any location restrictions that would preclude the siting of a landfill on the site, then a geologic/hydrogeologic boring investigation should be conducted.

Sociological conditions to consider include proximity to schools; churches; hospitals; cemeteries; ponds; lakes; commercial and residential developments; recreational areas; water supply wells; oil, gas and other mineral production wells; pipelines; utility lines; airports; archeological sites; historical sites; sites with exceptional aesthetic quality; and roadway access to the facility. These sociological conditions are typically considered with governmental and community involvement. Public involvement throughout the process allows the opportunity to determine local issues and address them early in the landfill siting and development process. The local and federal governmental agencies should be contacted at the beginning and throughout the siting process.

1.3 Landfill Disposal Cells Liner Components

New landfill disposal cells will be constructed with a composite liner and a leachate collection system. The composite liner shall consist of two components, the lower component will consist of at least a 60-cm layer of compacted soil with a hydraulic conductivity of no more than 1×10^{-7} cm/sec and the upper component will consist of a minimum 60-mil (0.152 cm) high density polyethylene (HDPE) geomembrane liner. The lower component typically consists of on-site excavated soils that are placed and compacted with heavy machinery. This soil liner is tested to verify the soil’s hydraulic conductivity, compaction and soil properties. The geomembrane liner must be installed in direct and uniform contact with the compacted soil component. Geomembrane comes with either a smooth and textured surface. The textured geomembrane has a higher friction angle than the smooth providing additional waste mass, liner, leachate collection system, drainage layer and protective cover stability. The determination of the use of textured or smooth geomembrane on the landfill floor is through a detailed mass waste stability analysis. This evaluates the stability of the waste mass at interim and final construction configurations of the landfill. Rotational (circular) and block (sliding along a defined plane) failure surfaces are assumed to occur within the waste material. These failure conditions are typically analyzed using a computer program such as STABL (http://www.ecn.purdue.edu/STABL/).

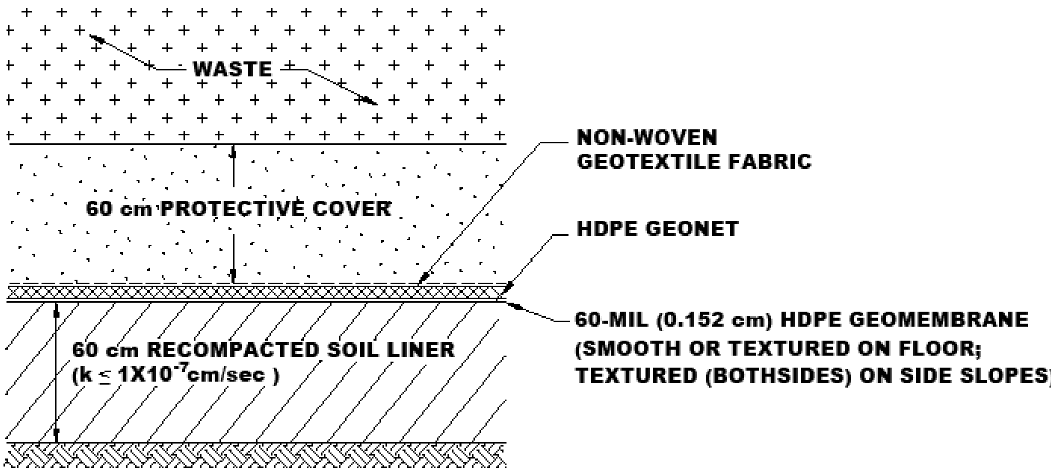


Figure 2: Standard Composite Liner with Geonet Drainage Layer Detail

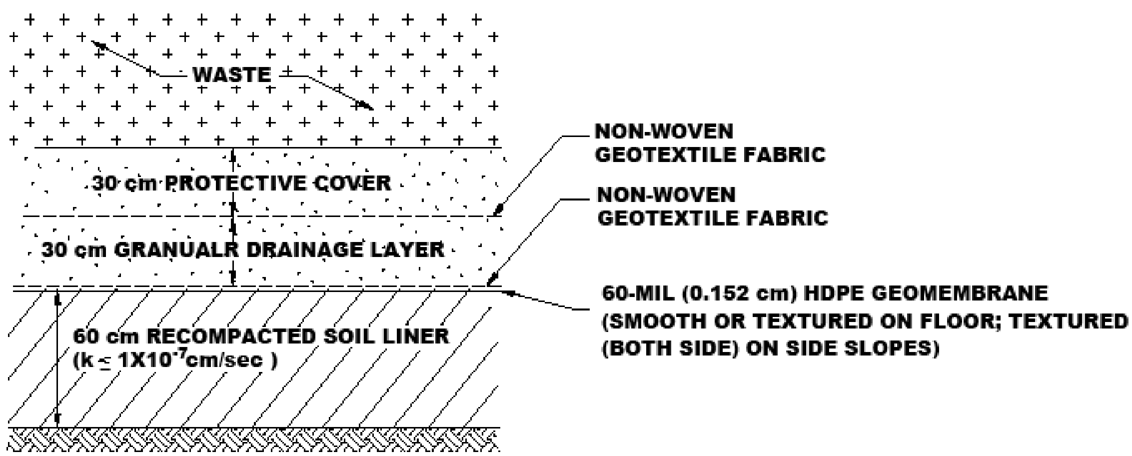


Figure 3: Standard Composite Liner with Granular Drainage Layer Detail

1.4 Leachate Collection System Components

The purpose of the leachate collection system is to control leachate head buildup within the waste during the active operations of the site and to monitor leachate levels after the disposal facility is closed. The liquid entering the landfill becomes leachate and moves to the bottom of the landfill and collects over the geomembrane liner. The liner is overlain with a leachate collection system extending over the bottom and side slopes of each landfill disposal cell. The leachate collection system is sloped to ensure leachate flows to the leachate recovery sumps. The leachate collection system is composed of 5 main components. These components include:

- Drainage Layer;
- Collection Pipes;
- Recovery Sumps;
- Pump and Riser System; and
- Recovered Leachate Handling.

Most of these components are constructed of polyvinyl chloride (PVC) or high density polyethylene (HDPE). These materials have been proven to be excellent materials for use in sanitary landfill leachate collection systems based upon their resistance to typical sanitary landfill leachate. All drainage aggregate and any granular drainage materials will have no more than 15% calcium carbonate to help prevent clogging. These materials will help ensure proper functioning of the leachate collection system throughout the active life and the post-closure period of the facility.

The leachate collection system will consist of a geosynthetic or granular drainage layer, leachate collection pipe, and a protective granular soil cover. The leachate collection system overlies the liner system that drains to the recovery sumps. Each of the leachate collection pipes convey leachate to the recovery sumps and cleanout risers.

The geosynthetic drainage layer consists of a geonet drainage layer and geotextile fabric. The geonet is typically manufactured from HDPE to form a three dimensional drainage structure that replaces a sand or gravel drainage layer. The geonet is covered with the geotextile fabric to prevent soil particles from clogging the drainage core. The separate layers of geotextile fabric and geonet could be combined through the use of a geocomposite product (i.e. a geotextile/geonet composite, or single-sided geocomposite on smooth geomembrane; a geotextile/geonet/geotextile composite, or double-sided geocomposite on textured geomembrane).

1.5 Full-Time Quality Control/Quality Assurance

The construction and testing of all elements of the landfill disposal cell liner must be in accordance with this manual. Quality assurance/quality control activities are recommended in most phases of landfill construction. Supervision of the liner construction and all quality assurance/quality control activities should be provided by an independent licensed engineer with experience in geotechnical engineering. This engineer will be referred to as the Certifying Engineer. The Certifying Engineer or his representative should be on site for all liner system construction and testing. It is recommended that the Certifying Engineer be on site at least once weekly, or as often as necessary depending on the experience of the Certifying Engineer representative, for all different construction events during liner system construction.

1.6 Landfill Gas

Landfill gas is created as solid waste decomposes in a landfill. Landfill gas is consists of about 50 percent methane (the primary component of natural gas), about 50 percent carbon dioxide (CO_2), with varying small amounts of nitrogen, oxygen, water vapor, sulfur, and other contaminants. Most of these other contaminants are non-methane organic compounds.

Landfill gas represents several concerns for landfill operators. Landfill gas serves as a significant source of odors, can represent an explosion concern because of the high methane concentrations, and represents a potent greenhouse gas source.

Landfill gas is monitored using a perimeter monitoring system around the landfill to detect underground migration of landfill gas to on-site or off-site structures. These perimeter monitoring systems are typically monitored every three months for signs of methane.

Landfill gas control measures include passive and active systems. A passive system would include vents or open wells in the landfill. These passive systems allow landfill gas to vent freely to the atmosphere, thus reducing any driving pressures in the landfill waste mass.

An active system includes wells, header pipes, flares, gas to energy generators or other landfill gas combustion systems. Landfill gas collected from an active system can be directed to a flare and destroyed. However, there are beneficial uses for landfill gas. Energy generators can be powered with landfill gas to produce electricity. Additionally, industries that use natural gas may be able to supplement their natural gas needs with landfill gas.

For additional information on landfill gas, see the USEPA Landfill Methane Outreach Program http://www.epa.gov/lmop/.

1.7 Critical Inspection Points

ITEM NO.	DESCRIPTION	WHEN	FREQUENCY
1	**Landfill Construction**		
1.1	Soil Liner Construction.	Each construction event	At least once per event
1.2	Geomembrane Liner Construction.	Each construction event	At least once per event
1.3	Leachate Collection Layer Construction.	Each construction event	At least once per event
1.4	Liner Constructed Below Seasonal High Groundwater Table.	Each construction event	At least once per event
1.5	Liner Construction Documentation and Reporting.	Each construction event	At least once per event
1.6	Groundwater Monitoring Well Construction.	Each construction event	At least once per event
1.7	Landfill Gas Monitoring Probe Construction.	Each construction event	At least once per event
1.8	Full Time Construction Quality Control On Site	Each construction event	At least once per event

2.0 SOIL LINERS

2.1 General

Soil liners may consist of 60 cm of in-situ or constructed soil. All soil liners must possess a coefficient of permeability no greater than $1x10^{-7}$ cm/sec, a liquid limit (LL) not less than 30, and a plasticity index (PI) not less than 15. The percentage of soil fines passing the 0.075mm sieve must be at least 30%. All of the soil material must pass the one-inch sieve and shall not contain rocks or stones that total more than 10% by weight. The minimum thickness for any soil liner is 60 cm for a composite liner.

The first step in the construction of a soil liner is to pre-qualify the soil materials that are selected for liner construction. Soil liner material may be in-situ soil strata or soils which have been excavated during cell construction or from a select borrow source. In-situ soils may be left in place as liner material if the material is verified and the subgrade properly prepared (see Section 2.2).

The sequence of development of the landfill must be followed so that liner coverage in a landfill is developed in a fashion that minimizes contaminant migration beyond the constructed limits during filling and maximizes the operational life of the site.

Full time construction quality assurance and quality control testing is recommended for the construction of landfill disposal cell liners.

2.1.1 Storm Water Control for Liner Construction

The control of storm water flow into or on landfill liners, both during and post construction, is very important.
Storm water conveyance systems (ditches, channels, ponds and pipes) should be designed and constructed to move storm water around the landfill liner area to keep the storm water from entering the landfill liner area.

Storm water on the landfill should be directed around the landfill liner area. Storm water that accumulates on the landfill liner should be removed as soon as practical through either gravity flow or pumps. If it is not possible to drain the landfill liner area via gravity flow, then pumps should be maintained on site during construction to allow for prompt removal of water.

Figure 4: Stormwatet Channel Along Perimeter of Landfill

2.2 In-Situ Soil Liner Material Requirements

In-situ soils may be used as liner material if they meet the general requirements for a soil liner:

- Minimum thickness of 60 cm,
- Coefficient of permeability no greater than 1×10^{-7} cm/sec,
- Liquid limit (LL) not less than 30,
- Plasticity index (PI) not less than 15, and
- The percentage of soil fines passing the 0.075mm sieve must be at least 30%. All of the soil material must pass the one-inch sieve and shall not contain rocks or stones that total more than 10% by weight.

The in-situ material verification and subgrade preparation are included in Section 2.5.3, In-situ Material Verification and Subgrade Preparation.

Table I - Standard Tests on Soils for In-Situ Soil Liners

SOIL TEST CATEGORY	TYPE OF TEST	STANDARD TEST METHOD	FREQUENCY OF TESTING
In-Situ Soil Liners	Sieve (Gradation)	ASTM D 422 or D 1140	1/5000 m^2 per 15 cm thickness of liner
	Atterberg Limits	ASTM D 4318	
	Coefficient of Permeability	ASTM D 5084 or CoE EM1110-2-1906 (laboratory) or Air-Entry Permeameter (field)	
	Thickness	Registered Surveyor	1/500 m^2

*See Appendix B for references to all standard test methods

2.3 Soil Liner Material Requirements

Representative samples of the soils to be used for liners must first be tested, in accordance with the following standards, in a geotechnical laboratory to ensure that they meet the following minimum requirements.

- Sieve Analysis - ASTM D 422 or ASTM D 1140 - At least 30% passing the 0.075mm mesh sieve.
- Atterberg Limits - ASTM D 4318 - Liquid Limit (LL) of not less than 30 and a Plasticity Index (PI) of not less than 15.
- Coefficient of Permeability - Appendix VII of the Corps of Engineers Manual EM 1110-2-1906 or ASTM D 5084 - $1x10^{-7}$cm/sec or less.

Additional initial soil testing will be required if there is a change in material or borrow source. Table II lists the required quality control testing and minimum requirements.

Table II - Standard Pre Construction Tests on Soils

SOIL TEST CATEGORY	TYPE OF TEST	STANDARD TEST METHOD	FREQUENCY OF TESTING
Quality Control Testing of Source Borrow Materials	Moisture/Density Relationship	ASTM D 698 or D 1557	Once per soil type
	Sieve (Gradation)	ASTM D 422 or D 1140	
	Atterberg Limits	ASTM D 4318	
	Coefficient of Permeability	ASTM D 5084 or CoE EM1110-2-1906	1/Moisture/Density Relationship

2.3.1 Soils for Constructed Liners

Table III lists the required quality control testing and minimum requirements for constructed soil liners.

Table III - Standard Tests on Soils for Constructed Soil Liners

SOIL TEST CATEGORY	TYPE OF TEST	STANDARD TEST METHOD	FREQUENCY OF TESTING
Constructed Soil Liners	Field Density	ASTM D 1556, D 2167, or D 2922	1/700 m^2 per 15 cm parallel lift[A]; 1/30 lineal meters per 30 cm sidewall liner (horizontal lifts)[A]
	Sieve (Gradation)	ASTM D 422 or D 1140	1/9,000 m^2 per 15 cm parallel lift[A]; 1/600 lineal m per 30 cm sidewall liner (horizontal lifts)[A]
	Atterberg Limits	ASTM D 4318	
	Coefficient of Permeability	ASTM D 5084 or CoE EM1110-2-1906 (laboratory) or Air-Entry Permeameter (field)	
	Thickness	Registered Surveyor	1/450 m^2 (parallel lifts)[A]; 15-m cross-sections (horizontal-lift sidewall liners)[A]

Notes:
A - A minimum of one of each of the designated tests must be conducted for each unit thickness of liner as indicated, regardless of liner area or length.

2.3.1.1 Moisture/Density (M/D) Testing

In addition to the minimum test requirements in Table II above, a moisture/density relationship must be determined for each soil borrow source to be used in soil liner construction. This moisture/density (M/D) compaction curve must include a zero-air-voids line based upon an estimated or measured Specific Gravity of the compacted soil. The two acceptable standard moisture/density relationship test procedures are:

- ASTM D 698 (Standard Proctor) -- 600 kN-m/m^3 [1](for light-weight equipment), or
- ASTM D 1557 (Modified Proctor) -- 2,700 kN-m/m^3 [1] (for heavy equipment)

In order to determine that the proposed soil is suitable for use as liner material, permeability tests must be conducted on samples compacted under the above-listed compactive effort test procedures. These soils shall be prepared and tested as next described.

[1] The energy values assigned to each of these two test methods are the compactive efforts used in the soils laboratory to compact each test specimen, and should be comparable to the compaction capability of the equipment used to construct the soil liner.

2.3.1.2 Coefficient of Permeability Testing

Once moisture content/density relationships have been determined for one or more compactive efforts, a soil sample should be compacted to approximately 95% of the maximum dry density at the optimum moisture content using ASTM D 698 or to approximately 90% of maximum dry density at a moisture content 1% drier than optimum using ASTM D 1557. An appropriate coefficient of permeability test should then be performed on this sample. The maximum acceptable coefficient of permeability of $1x10^{-7}$ cm/sec for any given soil sample must be demonstrated in the laboratory before the material is considered suitable for liner construction.

Once the acceptable coefficient of permeability is demonstrated through testing, the percent compaction and moisture content of the demonstration sample becomes the minimum standards for use in field control (the minimum standards, however, must not be less than 95% compaction at optimum moisture using ASTM D 698 or 90% compaction at a moisture content 1% dry of optimum using ASTM D 1557).

The permeant fluid for permeability testing must be: tap water, a 0.005N calcium sulfate solution, or captured ground water from the test boring where the soil samples are taken. Distilled or deionized water is not acceptable as a permeant and shall not be used.

Test methods and all test data calculations must be provided in the liner evaluation report. Any deviation from the methods listed below must be fully justified, explained and documented in the liner evaluation report.

The two acceptable laboratory test methods for determining the coefficient of permeability are as follows:

- Falling head -- ASTM D 5084.
- Constant head -- ASTM D 5084

2.4 Soil Liner Construction Requirements

The key elements of soil liner construction are:

Key Element of Soil Liner Construction	

Strong Quality Control	To ensure the materials and construction are provided in accordance with the construction plans, regulations and permits.
Suitable Soil Selection	Soil should meet the permeability, liquid limit, plasticity index, percentage of soil fines, and stone content specifications.
Moisture Control	Lower permeability and control desiccation cracking of highly plastic clays frequently used for liner soil.
Degree of Compaction	Assure that soil is compacted adequately to meet permeability requirements.
Type and Weight of Compaction Equipment	To achieve density, adequate bonding and clod size reduction.
Lift Thickness	Total penetration through the loose lift under compaction into the top of the previously compacted lift.
Clod Size	To reduce seepage pathways.
Lift Interface Bonding	To reduce seepage pathways.
Liner Protection from Desiccation	Desiccation causes shrinkage cracking in liner soil.
Protection from Ponded Water	Complete saturation of any portion of the liner and its protective cover compromises their structural integrity and accelerates and increases the degree of shrinkage cracking in the event of drying.
Conscientious Maintenance after Liner is Complete	To prevent desiccation, rutting, erosion and sediment build up on liner.

2.4.1 General

Liners on side slopes with greater than a 3:1 slope angle (3 horizontal to 1 vertical) should not be constructed in parallel lifts due to both the inherent lack of stability of the compaction equipment on these steep slopes as well as the compaction inefficiency. The side wall liners should be built in horizontal lifts.

Figure 5: Parallel Lifts on 3:1 Side Slope

Placement of constructed liners (clay-type material) should be in accordance with the following:

- All subgrade surface areas should be properly scarified a minimum of 5 cm and prepared to receive the liner.
- The top of each lift should be roughened to a shallow depth prior to the placement of the next lift of soil for compaction.
- No loose lift should be thicker than the pads of the compactor so that complete bonding with the top of the previous lift is achieved.
- Equipment and safety limitations prohibit finished grades with slopes greater than 3:1 if the liner is constructed parallel to the surface. For an excavated slope with steeper than 3:1 side slopes, the sidewall liner must be constructed in successive horizontal lifts.
- Horizontal lifts should be constructed wide enough to allow for the construction equipment to safely place, traverse, moisture condition, compact and grade the lift while maintaining the minimum 60 cm liner thickness perpendicular to the liner face.
- The top surface of the completed soil liner must be proof rolled with a smooth-wheel roller prior to final liner thickness surveying before placement of a geomembrane liner.
- The surface of a soil liner shall be proof rolled when construction is shut down for more than 24 hours to mitigate the effects of desiccation.

2.4.2 Constructed Soil Liners

Constructed soil liners may consist of over-excavated and recompacted in-situ soils, and/or soils from a borrow source, either on-site or off-site.

Soil liners will be constructed in an expeditious manner. Any prolonged soil liner construction schedules or delay in construction; such as larger than typical cell constructions, inclement weather delays, contractor issues, etc., will be explained in the liner evaluation report.

2.4.2.1 Liner Tie-in

When filling a landfill disposal cell towards future cells, the leading six (6) meters of the liner shall not receive waste to facilitate tie-in with the next liner segment. Continuous liners shall not be constructed by "butting" the entire thickness of a new liner segment next to the previously constructed section of liner. Liner tie-ins shall be done using one of the following methods:

$ The edge of the old section of liner is cut back on a slope so that the entire existing liner edge is tied to new construction without superimposed construction joints (Figure 6).

$ The edge of the old section of liner is cut back on off-set layers (stair-step) so that each unit thickness of the existing liner edge is tied to new construction without superimposed construction joints. The length of the tie-in area should be at least 5 meters per meter thickness of liner (Figure 6).

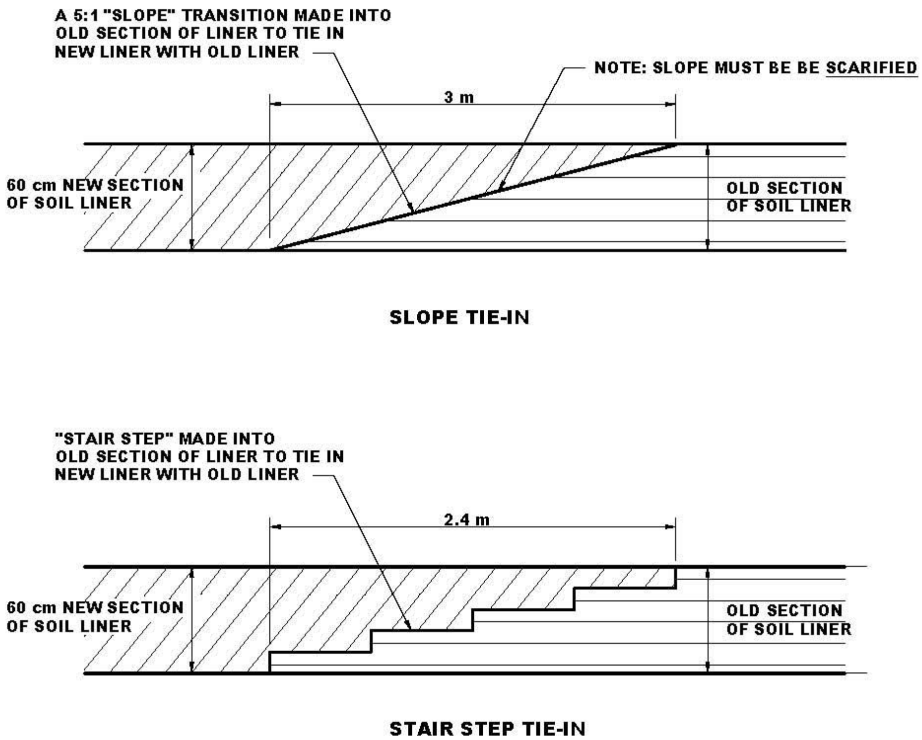


Figure 6: Soil Liner Tie In Details

2.4.2.2 Hydrating Liner Soil

The proper method of adding water to the liner soil cannot be overemphasized. Because of their cohesive nature, some clay soils are at best difficult to hydrate to the required moisture content necessary for compaction. Therefore, prior to adding water, clod size reduction should be completed through disking, pulverizing, possibly screening, etc. (It is recommended that a minimum of five passes of a disk or three passes of a pulverizer be made at alternating right angles where space permits for soil processing. Additional passes should be performed if necessary to thoroughly break up and blend the liner soil prior to compacting.) Water is added, then the soil is thoroughly mixed and stockpiled if necessary to allow adequate time (usually overnight or longer) to hydrate. The higher the plasticity of the soil, the longer this mixing and hydration process will take. Water used in hydrating liner soils must be clean and shall not have come into contact with waste or any contaminated material (see Figure 7).

Figure 7: Hydrating Soil Liner

2.4.2.3 Clod and Rock Size

Soil clods shall be reduced to the smallest size necessary to achieve the coefficient of permeability reported by the testing laboratory and to destroy any macrostructure evidence after the compaction of the clods under density-controlled conditions (see Figure 8).

Figure 8: Processing Liner Soil to Control Clod Size

The liner soil material shall contain no rocks or stones larger than 25 mm in diameter or that total more than 10% by weight. One hundred percent of the material used in the soil liner must pass the 25 mm screen. The final lift for composite liners shall not contain any rocks or any other materials that can cause damage to the geomembrane.

2.4.2.4 Compactive Effort (Soils Compaction)

All constructed soil liners must be compacted with a pad/tamping-foot (preferable) or prong-foot roller. No other type of equipment is suitable for the compaction of constructed soil liners. The lift thickness shall be controlled so that there is total penetration through the loose lift under compaction into the top of the previously compacted lift; therefore, the compacted lift thickness must not be greater than the pad or prong length. This is necessary to achieve adequate bonding between lifts and reduce seepage pathways.

Adequate cleaning devices must be in place and maintained on the compaction roller so that the prongs or pad feet do not become clogged with clay soils to the point that they cannot achieve full penetration during initial compaction. The footed roller is necessary to achieve bonding and to reduce the individual clods and achieve a blending of the soil matrix through its kneading action.

Figure 9: Compacting Soil Liner

In addition to the kneading action, weight of the compaction equipment is important. When using ASTM Test Method D 698 (Standard Proctor), the minimum weight of the compactor should be 2230 kilograms per linear meter of drum length, and a minimum of eight passes is recommended for the compaction process. Compaction equipment that develops a compactive effort equal to ASTM D 1557 (Modified Proctor) will result in greater compaction, lower coefficient of permeability due to decreased void space, and a lower optimum moisture content necessary to achieve the maximum dry density. This lower optimum moisture content may help in controlling the desiccation cracking of highly plastic clays frequently used for liner soil.

2.4.2.5 Soil Plasticity

Quality control of the soil plasticity shall be closely adhered to and maintained during material selection for liner construction. Testing of the Atterberg limits and gradation should be continually checked so that any changes in either physical property can be detected and additional appropriate laboratory testing performed. Any time the liquid limit or plasticity index changes by more than 10 points, a new compaction series should be run in the laboratory to determine the maximum dry density, optimum moisture, and the laboratory coefficient of permeability. To adequately determine the variability of the soil used for liner construction, it is strongly recommended that all liner soil borrow sources be thoroughly tested prior to use to establish their Atterberg limits and compaction parameters. This may require drilling auger holes at the borrow source to retrieve adequate samples to determine these factors.

Due to the high shrink/swell and desiccation cracking characteristic of highly plastic clays, it is suggested that, where possible, the plasticity index of clay liner soils be limited to between 15 and 30.

2.4.2.6 Liner Protection

Constructed and tested liners shall have sufficient surface-drainage controls to prevent the accumulation of both contaminated and non-contaminated water. Water from outside the lined area should be directed away from the lined area with diversion channels or dikes. Any ponded water that accumulates on newly constructed liner surfaces shall be promptly and appropriately removed. Areas where ponded water is noticed should be re-graded to assure proper drainage flow. The surface of the completed soil liner must be kept moist prior to placement of geomembrane or other overlying materials to reduce shrinkage cracking, but saturation of these soils by ponding water is not an acceptable practice. Complete saturation of any portion of the liner and its protective cover compromises their structural integrity and accelerates and increases the degree of shrinkage cracking in the event of drying.

If the soil liner is going to be uncovered by geomembrane liner long enough to cause desiccation or other damage (generally two (2) or more weeks), a 30 cm sacrificial soil layer may be applied. This sacrificial layer should be constructed with liner soils to liner construction conditions. The sacrificial layer will be removed prior to placement of the geomembrane.

2.4.2.7 Protective Cover

Protective cover overlying a leachate collection and removal system in general must have permeabilities equal to or exceeding 10^{-4} centimeters per second, or be provided with appropriate passageways for moisture, such as chimneys, in order to allow leachate to readily drain to the leachate collection system. The minimum protective cover thickness is as follows:

- There must be at a minimum 60 cm of cover material between a geomembrane and waste. Part of this separation can be provided by a suitably designed leachate collection and removal system.
- There must be at a minimum 30 cm of cover between leachate collection pipes and waste.

Figure 10: Protective Cover Soil

2.5 Quality Assurance and Testing Frequency for Soil Liners

Each constructed liner sidewall and floor area developed as a separate segment (non-monolithically) must be considered as separately evaluated areas independent of each other for the purpose of calculating dimensions to determine the required number of samples. Those sidewall and floor areas constructed or excavated as a bowl (monolithically) may be added together for the determination of their testing frequency and locations.

All holes dug or created during any sampling and/or testing shall be backfilled with a mixture of at least 20% bentonite-enriched liner soil and compacted by hand tamping or filled with an appropriate bentonite grout.

2.5.1 Constructed Soil Liners

The quality assurance testing and frequency of testing of constructed soil liners is discussed below. Table I provides an easy reference for the types of testing, standard test methods and frequency of testing. Sidewall liner evaluations for lifts constructed parallel to the surface of the excavation will be evaluated by using the same criteria and rate of testing as for the bottom.

Sidewall liner evaluations for lifts constructed horizontally may be evaluated at a frequency not to exceed 30 cm in thickness (i.e., 2 lifts). Sample locations for field density testing should not exceed 30 linear meters and should be located within the 1 meter closest to the protected wall.

The usual sampling practice for quality assurance laboratory testing of the constructed liner is to retrieve representative samples from the same sampling tube and/or conduct field permeability tests. The location of the sampling/testing is adjacent to a field density/moisture test for comparing field and laboratory results.

2.5.1.1 Field Densities and Moisture Content

All field densities and moisture contents must compare with the limits specified below and to the proper ASTM D 698 or ASTM D 1557 moisture/density curve for the corresponding soil borrow source in order to be considered passing. Passing field specifications for the ASTM D 698 moisture/density compaction relationship are at least 95% of maximum dry density and at or above the optimum moisture content. Passing specifications for the ASTM D 1557 moisture/density compaction relationship are at least 90% of maximum dry density and at or above a moisture content 1% drier than optimum. For both ASTM D 698 and D 1557, the moisture content should not exceed a maximum value that is governed by shear strength requirements and the need to minimize the possibility of rutting under construction equipment or desiccation upon drying.

Figure 11: Nuclear Density Gage

A nuclear density gage (as pictured above) cost approximately $8,000. However, manual methods are included in the referenced test methods. The equipment for these methods (drive cylinders, ovens, scales, and other items) represent costs in the $200 range, plus additional shipping and laboratory costs.

As an alternative to the above as the acceptance criteria, the "line of optimums" (described by Benson et al [1999]) may be used as the basis in field control. Under this alternate procedure, 80% of the field densities must lie on or above the line of optimums. The line of optimums as described by Benson et al is essentially a line drawn through the points corresponding to the optimum moisture content/maximum dry density on the moisture/density relationship curves for the modified proctor test, the standard proctor test, and a third compaction test using a reduced energy from the standard proctor test. (It has been shown by Benson et al that compacted soil liners that have approximately 80% or more of the field density data points above, or wet, of the line of optimums have a significantly higher probability of achieving the 1 x 10^{-7} cm/sec permeability standard than liners constructed using the conventional percent compaction basis). If this procedure is used, those field density points that do not lie above the line of optimums must not be concentrated in any specific lift or section of lift.

Sections of compacted soils liner which do not pass both the density and moisture requirements must be reworked and retested until the section in question does pass. All field density test results must be reported in the liner evaluation report, whether they indicate passing or failing values. The frequencies of testing differ for the two lift placement methods below:

- Parallel Lifts--one test for each 750 square meters of surface area per lift (but no less than 3 density tests per 15 cm lift).
- Horizontal Lifts--one for each 30 linear meters for each 30 cm of thickness.

2.5.1.2 Sieve Analysis

A minimum of one test sample should be taken within each 10000 square meters of surface area per lift, or major fraction thereof, but no less than one per 15 cm lift of parallel liner or one test per 600 linear meters per 30 cm of horizontal liner thickness.

2.5.1.3 Atterberg Limits

Use the same frequency of testing as for sieve analysis.

If either the liquid limit or the plasticity index varies by more than 10 points when compared against the appropriate moisture/density curve used for that soil borrow source, the soil is considered as a separate soil borrow source and a new test series including moisture/density, compaction relationship, sieve analysis and coefficient of permeability should be determined and these results used for field construction control.

2.5.1.4 Coefficient of Permeability

Use the same frequency of testing as for sieve analysis for either field or laboratory permeability tests.

2.5.2 Thickness Verification

Thickness of constructed soil liners will be determined by instrument survey methods only. There should be a minimum of one verification point per 500 square meters of surface area. If the area under evaluation is less than 500 square meters, a minimum of two reference points are required for verification. Reference locations will be noted on a drawing of the area evaluated. All elevation calculations necessary for thickness determination will be attached as part of the supporting documentation to the liner evaluation report including any necessary corrections for true thicknesses measured perpendicularly to sidewalls. Cross-sections at approximately 30 meter spacing showing true liner thickness for sidewall liners that are constructed in horizontal lifts should be provided if appropriate.

2.5.3 In-Situ Material Verification and Subgrade Preparation

The following section outlines the verification of in-situ materials and the preparation of the geomembrane subgrade.

After the bottom and sides of each cell are excavated to their design grades, the Quality Assurance/Quality Control professional will inspect the exposed surface on the in-situ materials to visually determine areas that will not meet the requirements for soil liner. Visual inspection will cover the entire extent of the lined areas. This inspection will include observing heavy equipment, such as loaded scrapers or trucks, proof rolling the surface at design grades. If a major fracture or fault is observed, the excavation slopes and base of the fracture or fault area will be fully mapped by a geologist under the direction of the Certifying Engineer. The presence of major structural fractures, joints, bedding planes, unsuitable materials, and other primary and/or secondary features which could adversely affect liner quality will be addressed by over-excavating the questionable area to the minimum depth of the soil liner and lined in accordance with the requirements for Constructed Soil Liners. Unsuitable materials shall include, but is not limited to, soft, yielding zones; wet, saturated material; deleterious materials; petroleum stained soils; petroleum oil; and/or organics. Unsuitable areas beneath the liner shall be excavated and replaced with suitable soil liner material and compacted to at least 95% standard proctor density. If groundwater is observed appropriate measures in Section 5.0 should be used. All visual observations will be documented by the Quality Assurance/Quality Control professional and reported in the Liner Evaluation Report.

Care will be taken by the contractor at the time of excavation not to damage the integrity of the in-situ liner material. If an area is deemed unacceptable either because of damage by the contractor, visual observation, or mapping the failing areas will be over-excavated and the subgrade or liner prepared in accordance with the requirements for constructed soil liner.

The in-situ liner areas will be tested in accordance with Table I, Standard Tests on Soils for In-Situ Soil Liners. Areas that do not pass the verification procedure will be lined with 60 cm of constructed soil liner.

Once the excavation is brought to grade, the upper 60 cm will be tested and verified in accordance with Table I. After all in-situ liner areas have been tested and passed, the upper 15 cm may be scarified and recompacted to prepare the flexible membrane liner subgrade. The quality assurance/quality control personnel will make visual observations of the upper 15 cm of in-situ material for acceptability at the time of scarification and recompaction.

All subgrade preparation will have continuous on-site inspection by the quality assurance/ quality control professional or their representative during construction. All field sampling and testing, both during construction and after completion of the subgrade preparation will be performed by the quality assurance/quality control representative. The geomembrane liner will be placed directly on the re-compacted in-situ liner subgrade. The following procedures will be utilized to prepare and re-compact the top 15 cm of in-situ liner subgrade.

1. The in-situ liner surface will be scarified to a minimum depth of 15 cm and re-compacted to a minimum of 95% of the standard Proctor for maximum dry density at a moisture content as established during preconstruction testing.
2. Areas to receive geomembrane liner shall then be smooth drum rolled to be relatively smooth and even, free of ruts, voids, rocks, desiccation cracks, and other features that may affect the integrity of the overlying geomembrane liner. The re-compacted surface will be surveyed, by a surveyor, prior to geomembrane liner installation for verification that the liner is at the correct grades and for documentation in the Liner Evaluation Report. Prior to geomembrane liner installation, the conditions and grades of the re-compacted subgrade should be deemed suitable for geomembrane liner installation by both the quality assurance/quality control professional and the geomembrane installer.

2.6 Critical Inspection Points

ITEM NO.	DESCRIPTION	WHEN	FREQUENCY
2	**Soil Liner**		
2.1	Soil liner construction has full time independent construction quality assurance and quality control monitoring.	Each construction event	At least once per event
2.2	Liner tie in to existing lined disposal cell.	During construction of tie in to existing disposal cell	2 weeks
2.3	Pre construction soil material tests.	Prior to beginning soil liner construction	Once per event
2.4	Soil meets liner material specifications.	Prior to beginning soil liner construction	Once per event
2.5	Adequate compaction equipment and effort.	First day of soil liner construction	Daily during soil liner construction
2.6	Liner soil hydrated.	First day of soil liner construction	Daily during soil liner construction

ITEM NO.	DESCRIPTION	WHEN	FREQUENCY
2.7	Clod and rock size maximum 25 mm.	First day of soil liner construction	Daily during soil liner construction
2.8	Surface drainage controls in place to keep surface water from entering the liner area.	Prior to beginning soil liner construction	Once per event
2.9	No ponded water on soil liner.	During first week of soil liner construction	After each rainfall event
2.10	Soil liner kept moist prior to placement of geomembrane to reduce shrinkage cracking.	At completion of soil liner	Every 2 weeks until geomembrane placed over soil liner
2.11	Field density and moisture content testing.	First day of soil liner construction	Daily during soil liner construction
2.12	Construction soil laboratory testing including sieve analysis, Atterberg limits, and coefficient of permeability.	First day of soil liner construction	Daily during soil liner construction
2.13	Surveyor verification of 60 cm soil liner thickness.	At completion of soil liner	Only if initial survey indicated inadequate soil liner thickness

3.0 GEOMEMBRANE LINERS

3.1 General

Geomembrane is used in a standard composite liner. The geomembrane material will be a high-density polyethylene (HDPE) flexible membrane liner. Materials, construction, and quality assurance and quality control standards for this geomembrane material shall follow minimum industry standards and the manufacturer's guidelines.

The HDPE geomembrane shall have a minimum average thickness of 60 mils (0.152 cm). The acceptable geomembrane material shall overlie and be in direct contact with an approved subgrade soil or geosynthetic liner material.

3.2 Manufacturing

Geomembrane material must be produced from virgin raw materials. Reground, reworked, or trim materials from the same lot may be acceptable but recycled or reclaimed materials must not be used in the manufacturing process. HDPE material and required welding rods shall contain between 2% and 3% carbon black and may contain no more than 1% other additives.

Geomembrane sheets must be free from pinholes, surface blemishes, scratches, or other defects (e.g., non-uniform color, streaking, roughness, agglomerates of carbon black or other additives or fillers, visibly discernible regrind or rework, etc.).

3.3 Shipping

All HDPE liner material shall be shipped in rolls. Folded or creased sections of panels are not acceptable and shall not be used unless they are a normal part of the manufacturing process.

3.4 Delivery

The Certifying Engineer or his qualified representative should inspect the delivered materials for damage and defects. Pushing, sliding or dragging of rolls or pallets can cause damage and should be avoided.

3.5 Storage

Geomembrane material must be protected from soft or wet ground and rocky or rough ground. HDPE geomembrane must not be stacked more than 5 rolls high (or as recommended by the manufacturer) to avoid crushing the cores of the rolls. A cover must be used to protect the geomembrane if stored on site more than 6 months. The rolls shall be stored in such a manner as to avoid shifting, abrasion, or other adverse movements that can damage the geomembrane.

Figure 12: Geosynthetic Rolls of HDPE Liner Stored Properly

3.6 Installation

Geomembrane installations should follow all of the manufacturer's recommendations. All geomembrane material must overlie and have intimate contact with the constructed subgrade soil or geosynthetic material.

3.6.1 Subgrade Preparation

The surface of the subgrade soil (i.e. top of clay liner) must be free of sharp stones, stones larger than 3-cm in size, sticks, or other debris in order to minimize potential damage to the overlying geomembrane. The surface of soil subgrade must be finished by rolling with a flat wheel roller until a smooth uniform surface is achieved.

The soil subgrade must be protected from desiccation and cracking, rutting, erosion, and ponding prior to and during placement of the geomembrane. If the soil liner is going to be uncovered by geomembrane liner long enough to cause desiccation or other damage to the soil liner, generally two (2) or more weeks, a 30 cm sacrificial soil layer may be applied. This sacrificial layer should be constructed with liner soils to liner construction conditions. The sacrificial layer will be removed prior to placement of the geomembrane. The condition of the subgrade must be preserved by regular watering and proof rolling or by placing a minimum of 30 cm of temporary soil cover that must be removed prior to geomembrane placement and the soil subgrade surface resurveyed.

Figure 13: Prepared Subgrade

3.6.2 Geomembrane Deployment

The deployment (including equipment used in the handling of the geomembrane) must not damage the subgrade. In cases where geomembrane material is placed over geosynthetics, construction equipment (other than ATV type vehicles) must not ride directly on the lower geosynthetic material.

Figure 14: Geomembrane Deployment

3.6.3 Weather

The geomembrane should not be placed during inclement weather such as rain or high winds.

Rainfall runoff should be directed away from the lined cell. This can be done by constructing diversion channels and dikes or by re-grading areas that drain towards the disposal cell.

Geomembrane construction and seaming will not be conducted while it is raining or the landfill is experiencing excessive moisture that would wet the liner.

Rain water will fall directly into the landfill disposal cell. This water will need to be removed as soon as practical. A storm water pump should be available at all times to pump rain water from the disposal cell. This pump should be large enough to remove ponded water from the disposal cell in one day.

During periods of high winds, the deployment should be halted and all exposed edges of the liner weighted down. This can be accomplished with soil stockpiles, rubber tired machinery, rolls of geosynthetic material, sand bags, or other heavy material that won't damage the geomembrane.

3.6.4 Equipment on Geomembrane

No vehicular traffic shall be allowed on the geomembrane prior to the placement of the leachate collection or protective cover layers. Only low-ground-pressure supporting equipment (e.g. golf carts, All Terrain Vehicles or other small rubber tired equipment with a ground pressure less than 35 kPa and a total weight less than 340 kilograms) may be allowed to traverse the geomembrane. Personnel working on the geomembrane shall not smoke, wear damaging shoes, or engage in any other activity likely to damage the geomembrane.

Figure 15: Low Ground Pressure All Terrain Vehicle on Geomembrane

3.6.5 Construction Considerations on Vertical or Near Vertical Side Slopes

Construction on vertical or near vertical side slopes should be conducted in 3 meter vertical segments. Near vertical side slopes will be those slopes that are too steep to walk or safely operate the necessary equipment. Typically this is steeper than 1 horizontal to 1 vertical side slopes.

The liner shall be secured at the top in an anchor trench designed for the weight of the liner. The liner for this segment should be seamed together. Subsequent vertical segments should be constructed similarly but providing an additional meter overlap of the lower liner segment. The bottom of this overlap does not need to be seamed. Protective cover should be added incrementally as fill progresses to assure a minimum of 60 cm protection of the liner. A sideslope stability analysis should be conducted to determine the acceptable incremental maximum protective cover height.

Vertical and near vertical sideslopes should be lined with textured (on both sides) 60 mil HDPE and a double sided geocomposite to provide protection and leachate drainage.

3.7 Seaming

Field seaming (and repairs) shall be performed in strict accordance with methods approved by the manufacturer. This is usually by fusion welding or extrusion welding when placing HDPE. Strict attention to the details of seam preparation procedures recommended by the manufacturer is crucial in order to produce consistent seams that will not allow fluid leakage and will pass the testing requirements.

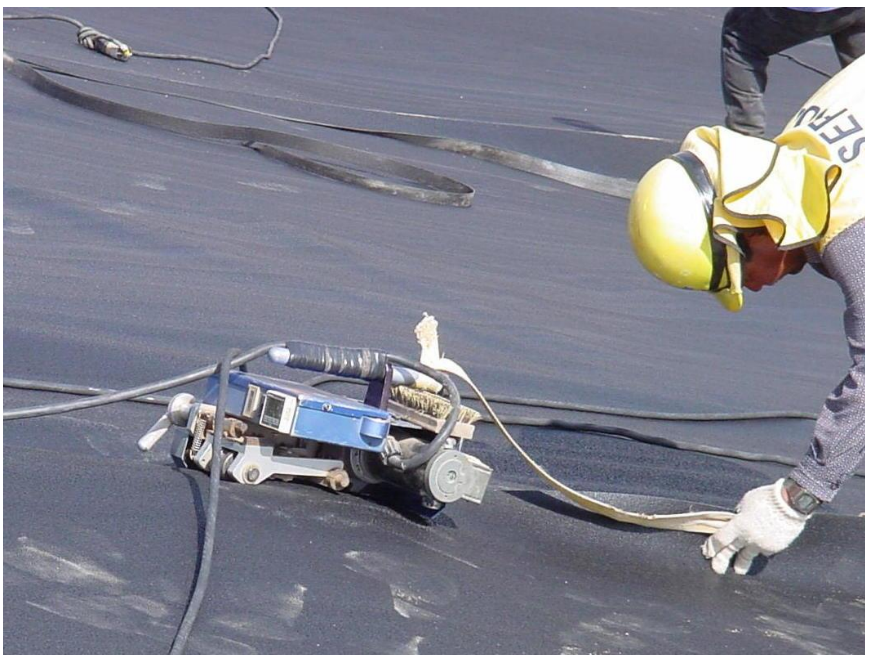


Figure 16: Fusion Welding Geomembrane

Only those geomembrane sheets that are to be placed and seamed in one day should be unrolled. Sheets should be positioned with the overlap recommended by the manufacturer, but not less than 8 cm for HDPE. The Certifying Engineer or his representative shall visually inspect the placement and overlap of the geomembrane to verify that the material is placed with sufficient overlap.

Wrinkles shall be walked-out or removed as much as possible prior to field seaming. All foreign matter (dirt, water, oil, etc.) shall be removed from the area to be bonded. No folds, large wrinkles, or fish mouths (see Appendix A Glossary) shall be allowed in the seam. Only normal factory-induced creasing from the blown film process may be acceptable. Where wrinkles or folds occur, the material shall be cut, overlapped, and welded. This process should be accomplished in such a manner that constructed seams are not required to carry significant tensile loads. During wrinkle or fold repairs, adjacent geomembrane may not necessarily be required to meet the 8 cm minimum overlap if approved by the Quality Assurance/Quality Control Professional. All completed seams shall be tightly bonded and sealed.

Figure 17: Extrusion Welding Geomembrane

Tack welds (if used) with HDPE geomembrane shall use heat only. No double-sided tape, glue, or other method will be permitted when extrusion or fusion welding is used for bonding.

Seams on sideslopes (such as slopes steeper than 6 horizontal : 1 vertical) must be oriented parallel to the sideslope direction, not across the slope. Seams that join the sideslopes and bottom sections should be located at least 1.5 meters from the sideslope and along the floor. In corners and odd-shaped geometric locations, the number of field seams should be minimized.

No seaming should be attempted above 40^0C or below 0^0C ambient air temperature unless it is demonstrated that the seams will meet the specifications outside this range. Below 0^0C ambient air temperature, special procedures such as preheating of the geomembrane material may be required.

At the end of each day or installation segment, all unseamed edges should be anchored by sand bags or other approved device. Staples, U-shaped rods, or other penetrating anchors shall not be used to secure the geomembrane.

3.8 Testing

The testing of raw materials, manufactured materials, and the installation of these materials is essential and required in order to determine their quality and suitability for geomembrane use. All geomembrane material properties must meet the manufacturer's standards and (for HDPE) the minimum values set forth in the Geosynthetic Research Institute (GRI) Standard GM13. These standards are available on line at: http://www.geosynthetic-institute.org/specifications.htm. Table III titled "Standard Tests on HDPE Geomembrane Material" addresses the applicable test methods and the frequency of testing for these geomembranes. For other types of geomembranes, manufacturer's recommendations and accepted industry practice should be followed.

Table III - Standard Tests on HDPE Geomembrane Material

TEST	TYPE OF TEST	STANDARD TEST METHOD	FREQUENCY OF TESTING
Resin	Density	ASTM D 1505	per every resin lot
	Melt Flow Index	ASTM D 1238 (90/2.16 and 190/21.6)	
Manufacturer's Quality Control	Testing per GRI Standard GM13[A]		
Conformance Testing by 3rd Party Independent Laboratory	Thickness	ASTM D 5199 (smooth HDPE) or D 5994 (textured HDPE)	per 9,000 m^2 or major fraction thereof for every resin lot
	Specific Gravity/Density	ASTM D 1505/D 792	per 9,000 m^2 or major fraction thereof for every resin lot
	Carbon Black Content	ASTM D 1603	
	Carbon Black Dispersion	ASTM D 5596	
	Tensile Properties	ASTM D 638[B] Type IV	
Destructive Seam Field Testing	Shear & Peel	ASTM D 4437	varies for field, lab, and archive
Non-destructive Seam Field Testing	Air Pressure	GRI GM6	all dual-track fusion weld seams
	Vacuum	ASTM D 5641	all non-air pressure tested seams when possible

Notes:
A - UV Resistance testing not required for HDPE that is to be immediately covered.

B - Break elongation calculated using 5 cm initial gauge length.

3.8.1 Manufacturing Quality Control (MQC)

All materials related to the manufacturing of geomembranes must be tested by the geomembrane manufacturer to determine their quality and suitability for use. The tests, methods, and frequency of testing are found in Table III.

3.8.1.1 Resin Lot

Resin used in the manufacturing of the geomembranes is purchased by the geomembrane manufacturer. HDPE geomembranes must be tested by the geomembrane manufacturer for density and melt index. The test methods and frequency of testing for these tests are found in Table III.

3.8.1.2 Geomembrane Manufacturer Testing

The geomembrane manufacturer conducts many tests throughout the manufacturing process and after the geomembrane is produced. For HDPE geomembrane the manufacturer's tests may include thickness, density, carbon black content, carbon black dispersion, tensile properties, tear resistance, puncture resistance, oxidation induction time, oven aging, stress crack resistance, and (for textured HDPE) asperity height. The types and frequencies of testing are found in Table III.

3.8.2 Conformance

Prior to acceptance of the geomembrane from the manufacturer, the Certifying Engineer should verify that it meets the required specifications. For HDPE geomembrane, the third-party independent laboratory must test thickness, density, carbon black content, carbon black dispersion, and tensile properties. The test methods and frequencies of testing for HDPE are found in Table III.

3.8.3 Seams

The Certifying Engineer or his representative should observe all test seam procedures and all seam testing. All seam testing of the geomembrane should follow all of the manufacturer's recommended testing procedures.

3.8.3.1 Trial Seam Testing

Each day, prior to commencing field seaming, test seams shall be made on fragment pieces of geomembrane to verify that seaming conditions are adequate.

Each trial test seam shall be at least 90 cm long by 30 cm wide. Four (6 when possible if using dual track fusion welding) adjoining 2.5-cm wide specimens will be die-cut from the test seam sample. Two specimens will be tested in the field for shear and 2 for peel (4 when possible if testing both inner and outer welds for dual track fusion welding).

Field testing for shear and peel is conducted using a field tensiometer. The field tensiometer is a testing device that is designed for construction site conditions for the testing of elongation, peak force, and tear force. The field tensiometer testing apparatus used for peel and shear tests must have an updated calibration certificate.

The failure criteria are the same as that for destructive seam testing described below. If one test seam fails, the trial seam will be repeated. If this trial seam also fails, then two more trial seams must be constructed and tested. This process should continue and no welding can begin for the machine or welder (if applicable) until all test seams are passing.

Additional trial seams shall be made for all of the following:

- at the beginning of each seaming period for each seaming apparatus used that day (the beginning of each seaming period is considered to be the morning, and immediately after a break);
- each occurrence of significantly different environmental conditions (such as temperature, humidity, dust, etc.);
- any time the machine is turned off for more than 30 minutes; and
- when seaming different geomembranes (e.g. tie-ins and smooth to textured).

Both the welder and the machine must be tested for each new trial seam when extrusion welding. Only the machine needs to be tested for each new trial seam when fusion welding since the machine is not as operator dependent. Each individual seamer shall make at least one test seam each day he/she actually performs seaming.

3.8.3.2 Non-Destructive Testing

Continuous, non-destructive testing shall be performed on all seams by the installer. Air-pressure testing on dual-track fusion welds and vacuum-box testing for extrusion welds are the only acceptable methods for HDPE geomembrane seams. All factory seams in addition to field seams should be non-destructively tested. All indicated leaks must be isolated and should be repaired by following the procedures described in Section 3.9 of this handbook.

3.8.3.2.1 Air-Pressure Testing

The ends of the air channel of the dual-track fusion weld must be sealed and pressured to approximately 200 kPa for HDPE. The air pump must then be shut off and the air pressure observed after 5 minutes. A loss of less than 27 kPa is acceptable if it is determined that the air channel is not blocked between the sealed ends. A loss equal to or greater than 27 kPa indicates the presence of a seam leak that must then be isolated and repaired by following the procedures described under Section 3.9. The Certifying Engineer or his representative should observe and record all pressure gauge readings.

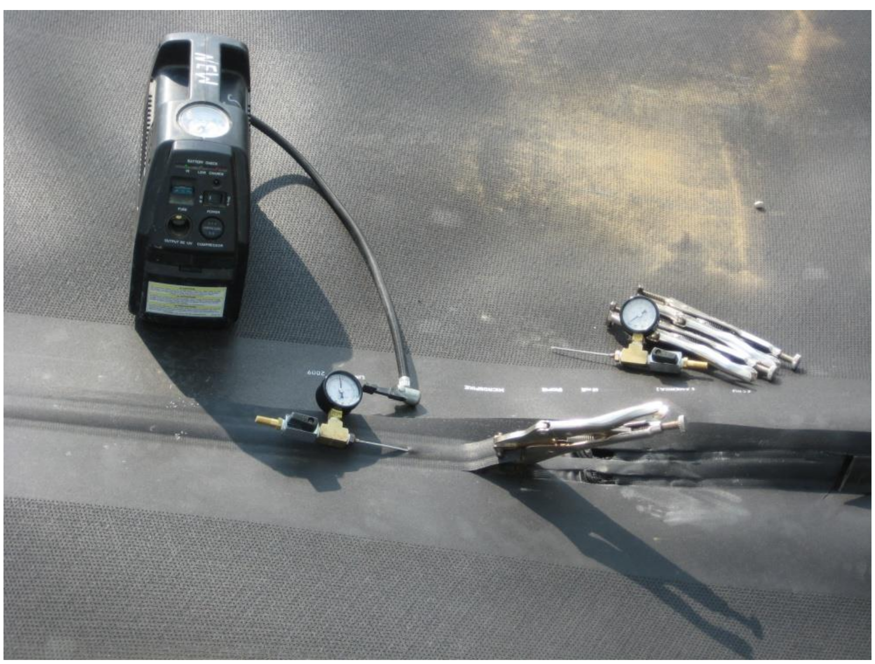


Figure 18: Air Pressure Testing of Track Welded Seam

3.8.3.2.2 Vacuum-Box Testing

A suction value of approximately 8 to 13 cm of gauge vacuum must be applied to all extrusion welded seams that can be tested in this manner. Examples of extrusion welded seams that do not easily lend themselves to vacuum testing would be around boots, appurtenances, etc. The seam must be observed for leaks for at least 10 seconds while subjected to this vacuum. The Certifying Engineer or his representative should observe 100% of this testing.

Figure 19: Vacuum Box Testing

3.8.3.3 Destructive Testing

Destructive test samples shall be taken at a minimum of one stratified location for every 150 meters of field seam or major fraction thereof. The total footage of individual repairs of leaks of more than 3 meters and individual repairs of more than 3 meters for failed seams must also be counted and destructively tested using the same frequency of testing described above. At a minimum, a destructive test must be done for each welding machine used for seaming or repairs. A sufficient amount of the seam must be removed in order to conduct field testing, independent laboratory testing, and archiving of enough material in order to retest the seam when necessary. Field testing shall include at least 2 peel test specimens (4 when possible for testing both tracks on dual-track fusion welded seams). Independent laboratory testing shall consist of 5 shear test specimens and 5 peel test specimens (10 when possible for both tracks of dual-track fusion welded seams). Destructive seam-testing locations shall be cap-stripped and the cap completely seamed by extrusion welding to the parent geomembrane. Capped sections shall be non-destructively tested. Additional destructive test samples may be taken if deemed necessary by the Certifying Engineer or his representative.

Figure 20: Destructive Testing

If a destructive test does not pass the criteria given below, additional destructive tests must be conducted at least 3 meters on both sides of the failed destructive test. If either of these destructive tests fail, the sampling and testing process must be repeated until the failed seam is bracketed by passing destructive tests. The failed seam must then be capped between the passing tests. Alternatively, all seams done by the welder/machine within the time period (between passing destructive tests or trial welds) represented by the failed destructive test must be capped.

All field-tested specimens from a destructive test location must be passing in both shear and peel for the seam to be considered as passing. Field-tested specimens are determined as passing if the specimen tested in peel fails in film tear bond and all test specimens meet the criteria listed in this subsection. Independent laboratory testing must confirm these field results.

The minimum passing criteria for independent laboratory testing are all 3 of the following:

- At least 4 of 5 specimens tested in the peel mode must fail in film tear bond.
- At least 4 of 5 specimens from each peel and shear determination must meet the minimum specified values for shear and peel:
    - The shear strength minimum requirement for HDPE is 95% of manufacturer's parent sheet strength but not less than 210 N/cm.

- The peel strength minimum requirement for HDPE is 62% of manufacturer's parent sheet strength but not less than 137 N/cm and exhibit film tear bond.

- The average value from all 5 specimens from each peel and shear determination must meet the minimum specified value.

The above criteria must be met by both tracks from each dual-track fusion welded seam before it is considered as passing.

The test methods for geomembrane are found in Table III. It should be noted that geomembrane manufacturers may have differing strength values for their geomembrane sheets and, therefore, the required specific shear and peel values are given in this SLQCP only as percentages. Consequently, the manufacturer's sheet-strength values must be provided in order to determine if the test results are passing.

If less than 4 of the 5 specimens from each destructive test location pass, or if the average calculated from all 5 specimens is less than that listed above, or if more than one specimen from the group of 5 specimens exhibits a non-film tear bond failure, the seam has failed.

3.9 Repairs and Retesting

The liner is continually visually inspected for signs of holes, punctures, tears or breaks. Any holes, punctures, tears or breaks in the liner will be repaired using patches of additional liner material, fusion welded over the damaged area. The seams for these repairs will be non-destructively tested and possibly destructively tested (refer to destructive testing criteria for repaired seams as described in Section 3.8.3.3.).

All seam leaks and destructive test locations shall be repaired for a distance of at least 15 cm on each side of the faulty spot or area detected. At a minimum, these repairs shall be non-destructively retested and possibly destructively tested (refer to destructive testing criteria for repaired seams as described in Section 3.8.3.3.)

Figure 21: Damage to HDPE Liner Flagged for Repair

3.10 Anchor Trench and Backfilling

The anchor trench should be completed around all portions of the geomembrane where the leading edge(s) of the geomembrane will not be needed for a tie-in for expansion into the next area to be lined. The excavated anchor trench shall have rounded corners in order to help protect the geomembrane. No loose soil shall be allowed to underlie the geomembrane in the anchor trench. Excavation of the anchor trench shall not be done too far in advance of geomembrane deployment.

Figure 22: Anchor Trench During Excavation

Figure 23: Anchor Trench being Backfilled with Soil

The anchor trench should be backfilled and compacted to at least 90 percent of the density as determined by the moisture/density compaction values detailed in the soils portion of this manual (see Section 2.5). Care should be used when backfilling and compacting the trench to prevent damage to the geomembrane. The anchor trench shall be backfilled at the earliest practicable time following synthetics deployment. Results of the compaction testing need not be reported.

3.11 Protective Cover and Drainage Materials

3.11.1 Deployment

All soil materials placed over a geomembrane should be placed during the coolest part of the day and deployed in "fingers" along the surface to control the amount of slack and minimize wrinkles and folds in the geomembrane. These materials must be deployed only up-slope on sideslopes so that stress imparted to the geomembrane is minimized. Material placed as protective cover must be placed with light equipment (such as dozers with less than 35 kPa contact pressure) while maintaining at least 30 cm of material between the dozer and the geomembrane. Full-time observation by the Certifying Engineer or his representative is required during deployment of these materials in direct contact with the geosynthetic materials.

Figure 24: Protective Cover Deployed in Fingers

3.11.2 Thickness and Material

At least 60 cm of protective cover (which may include a granular leachate collection layer) must be placed over the completed geomembrane to prevent damage during operation.

Protective cover placed over the surface of constructed HDPE geomembrane should contain no rock greater than 1 cm, vegetation, or other material that may damage the geomembrane. If the protective cover contains material greater than 1 cm in size, a layer of protective geotextile must be placed over the HDPE geomembrane's surface.

Figure 25: Protective Cover Placement Over Geotextile Using Traffic Cones as Thickness Indicators

Protective cover overlying a leachate collection and removal system in general must have permeabilities greater than or equal to 1 x 10^{-4} cm/sec, or chimney drains or other appropriate passageways must be constructed to allow leachate to drain to the leachate collection and removal system.

3.12 Critical Inspection Points

ITEM NO.	DESCRIPTION	WHEN	FREQUENCY
3	**Geomembrane Liner**		
3.1	Geomembrane liner construction has full time independent construction quality assurance and quality control monitoring.	Each construction event	At least once per event
3.2	0.152 mm (60 mil) High Density Polyethylene flexible membrane liner.	Each construction event	At least once per event
3.3	Geomembrane properly manufactured, shipped, delivered and stored to protect material from damage.	Each construction event	At least once per event
3.4	Subgrade compacted and rolled smooth and free of sharp stones, stones larger than 1 cm in size, and sticks or other debris.	At completion of soil liner and prior to deploying geomembrane liner	At least once per event
3.5	Geomembrane deployed to not damage subgrade.	First day of geomembrane liner construction	Daily during geomembrane liner construction
3.6	Only low ground pressure supporting equipment allowed on geomembrane (golf carts, all terrain vehicles or other small rubber tired equipment with a ground pressure less than 35kPa and a total weight less than 340 kg).	First day of geomembrane liner construction	Daily during geomembrane liner construction
3.7	All seams either fusion track welded or extrusion welded.	First day of geomembrane liner	Daily during geomembrane liner

ITEM NO.	DESCRIPTION	WHEN	FREQUENCY
		construction	construction
3.8	All fusion track welds air pressure tested.	First day of geomembrane liner construction	Daily during geomembrane liner construction
3.9	All extrusion welds vacuum box tested.	First day of geomembrane liner construction	Daily during geomembrane liner construction
3.10	No seaming above 40º C or below 1º C ambient air temperature.	First day of geomembrane liner construction	Daily during geomembrane liner construction
3.11	Control of folds, large wrinkles, and fish mouths.	First day of geomembrane liner construction	Daily during geomembrane liner construction
3.12	End of work day, all unseamed edges should be anchored.	First day of geomembrane liner construction	Daily during geomembrane liner construction
3.13	Appropriate testing of geomembrane materials.	First day of geomembrane liner construction	Daily during geomembrane liner construction
3.14	Destructive testing of seams.	First day of geomembrane liner construction	Daily during geomembrane liner construction
3.15	Anchor trench constructed and backfilled.	Prior to backfilling anchor trench	Daily during anchor trench backfilling
3.16	Protective cover or drainage layer material placed over geomembrane to control fingers and minimize wrinkles and folds in the geomembrane.	First day of protective cover or drainage layer construction	Daily during protective cover or drainage layer construction
3.17	Surveyor verification of a minimum of 60 cm of protective cover and or granular drainage layer.	At completion of protective cover or drainage layer	Only if initial survey indicated inadequate thickness
3.18	Control of rocks greater than 1 cm, vegetation or other material that may damage the geomembrane.	First day of protective cover or drainage layer construction	Daily during protective cover or drainage layer construction
3.19	Other geomembrane liner.	As required	As required

4.0 LEACHATE COLLECTION SYSTEM

The purpose of the leachate collection system is to control leachate head buildup within the waste during the active operations of the site and to monitor leachate levels after the disposal facility is closed. The leachate collection system consists of a drainage layer, collection pipes, recovery sumps, pump and riser system, and recovered leachate handling.

Full time construction quality assurance and quality control testing is recommended for the construction of landfill leachate collection systems.

4.1 Leachate Drainage Layer

The leachate drainage layer is placed above the liner to allow leachate to flow horizontally to the leachate collection pipes. The leachate drainage layer may consist of either a geonet system or granular material on the base grades, however; only a geonet drainage layer may be used on the sidewalls.

4.1.1 Materials

Soil materials used to construct leachate collection layers should consist of clean (washed if necessary) granular soil. Granular soils in leachate collection layers should have permeabilities no less than approximately 1.0×10^{-2} cm/sec. Material placed in contact with geomembrane should have a maximum particle size as indicated in Sections 3.11.2. Granular materials placed around collection pipes must have grain size larger than the size of the holes in the collection pipes.

The granular material must have less than 5% passing the 0.075 mm sieve and a minimum hydraulic conductivity of 1×10^{-2} cm/sec and may be utilized in any portion of any phase. The particle size of the granular drainage material is limited to a maximum of 1cm without a geotextile cushion (or 3 cm with a geotextile cushion) to prevent the puncture of the underlying geomembrane system.

A geonet layer is typically made of a polyethylene three-dimensional grid. It provides a planar liquid flow for conveying the accumulated leachate to the leachate collection trench. Although the geonet is much thinner than a granular drainage layer, it has a much higher hydraulic conductivity that allows for equivalent if not greater overall leachate transmission. The geonet will be overlain by a geotextile to separate cover soil from the geonet and maintain an adequate hydraulic conductivity of the system and may be used in any portion of any phase.

Figure 26: Geocomposite with Geonet and Geotextile

The base of the drainage layer is sloped to promote liquid flow toward the leachate collection pipes and ultimately to the sumps for extraction. The granular drainage layer or geonet shall provide sufficient flow capacity to effectively transmit leachate to collection trenches and sumps, thereby reducing head buildup. Leachate head buildup is estimated using the Hydrologic Evaluation of Landfill Performance (HELP) computer model. A maximum of 30 centimeters of leachate head will be maintained in all disposal areas. The sidewall liner system will utilize a double-sided geocomposite drainage layer.

4.1.2 Construction

Granular materials (washed if necessary) should be placed and spread using equipment and methods that minimize generation of fine material. Material placed over geomembrane or other geosynthetics should be placed as described in Sections 3.11.1. Granular materials should not receive any compaction other than that which is incidental to the placement and spreading process.

Geocomposite or geonet materials will be rolled out over the floor in direct contact with the geomembrane. Geocomposites or geonets will be zip tied together at a maximum spacing of 1.5 meters along side seams and 30 cm on cross seams. Geonets will be overlain with nonwoven geotextile fabric. The geotextile fabric over the geonet or the geocomposite geotextile component will be sewn.

Figure 27: Sewing Geotextile

4.1.3 Quality Assurance Testing

Quality assurance testing on granular soils conducted by the independent laboratory should consist of grain size (ASTM D 422) and permeability (ASTM D 2434) analyses conducted at a minimum frequency of 1 per 2,300 m^3 of material placed. Permeability testing requirements can be waived if it can be shown through correlation with the grain size analyses that the material easily meets the permeability criteria. All tests should be conducted on material after it has been placed to allow for any grain size reduction that may have occurred during the placement process. It is also recommended that the granular material be tested at its source for grain size (and permeability, if necessary) to pre-qualify the material prior to its use.

Granular material used in leachate collection layers must be tested for calcium carbonate content (using J&L Test Method S-105-89 or other appropriate method) by either the supplier or independent laboratory. The measured calcium carbonate content must not exceed 15%.

If chimney drains are not provided through the protective cover to the leachate collection system, permeability tests must also be conducted on the protective cover to verify permeability no less than 1 x 10^{-4} cm/sec.

The manufacturer's test results for geosynthetic materials should be checked and verified by the

Certifying Engineer to meet the minimum requirements for these materials established by the design engineer.

The thickness of granular leachate collection and protective cover layers should be verified at a frequency of one verification point per 500 m^2.

4.2 Leachate Collection Pipe

Typically, each cell should contain a leachate collection pipe. The liner floor slopes toward the collection pipe. The leachate collection pipes will typically consist of a polyvinyl chloride pipe, schedule 80, or high density polyethylene pipe, SDR 17 or lower. These collection pipes will be perforated with three rows of holes spaced at approximately 120 degrees around the perimeter. Perforation sizes shall be matched to the gradation of the surrounding drainage media using standard filter criteria, but shall be no smaller than 1 cm diameter. The collection pipes will be sloped towards the recovery sump. Pipe wall thickness should be determined through pipe crushing, wall buckling and ring deflection calculations.

Figure 28: Slotted and Perforated Leachate Collection Pipes

The leachate collection lines are placed along the floor of the landfill. In some South American countries, because of very low permeable cover soils and extremely high rainfall rates, additional layers of leachate collection lines are placed approximately every 7 vertical meters. This represents one method of keeping leachate from accumulating on cover soil above the bottom of the landfill and causing leachate seeps in the side of the landfill. Another effective means of keeping leachate from accumulating on cover soil above the bottom of the landfill is to clear windows through the daily and intermediate cover prior to the development of each day's working face. This allows for the waste to have continuous contact with the waste placed below, thus providing a flow path for leachate.

Figure 29: Leachate Collection Pipe Installation

4.3 Leachate Recovery Sumps

Leachate entering the drainage layer and/or collection pipes is subsequently discharged into recovery sumps. The recovery sumps are backfilled with a granular material with a particle size ranging from 1 cm to 8 cm and contain less than 15% calcium carbonate. The sumps are lined with an extra layer of geomembrane and also receive the protection of a geotextile between the granular material and the geomembrane. Leachate is stored in the sumps until the leachate pumps remove it. A typical sump size may be at least 3 meters, per side, square on the bottom.

The leachate is removed from the sumps by an electric or pneumatic pump lowered into the sump through a riser pipe. Leachate may then be discharged from the sump for storage and/or disposal. The leachate will be removed at a rate sufficient to keep the head on the liner outside the sump below the level of 30 cm. From the sumps the leachate will be conveyed into a force main system or directly into a storage tank or tanker trucks.

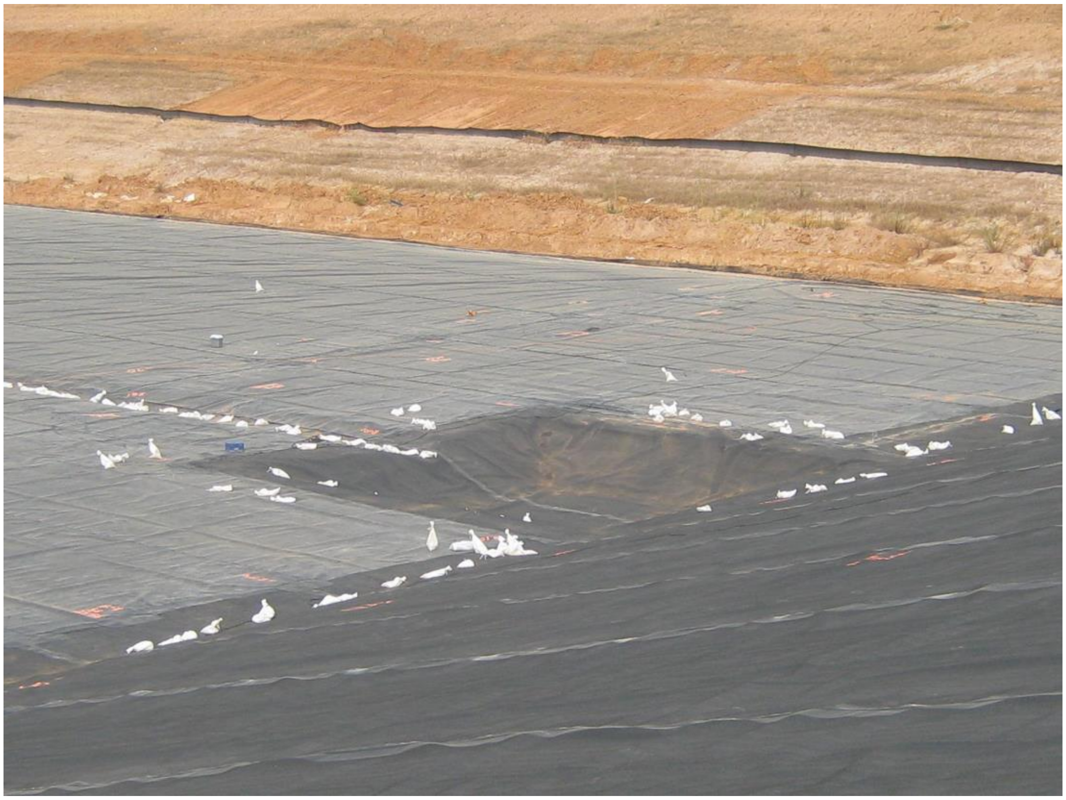


Figure 30: Leachate Collection Sump

Sump riser pipes are located along the disposal area perimeter directly up the sideslope from the sumps. The riser pipe provides a means for lowering submersible pumps down the sideslope incline to the collection sumps. The lower portion of the riser within the sump is perforated with 1 cm holes allowing the leachate to flow to the pumps. In order to prevent the perforated section of the riser pipe from clogging, a geotextile encases the sump area.

4.4 Transmission of Leachate

Leachate recovered from the recovery sumps will be pumped directly into a tanker truck, recirculated, or pumped or gravity drained through a force main system to evaporation ponds or other on-site storage or treatment facilities. Leachate pumped or gravity drained directly into tanker trucks will be disposed of off-site at an approved wastewater treatment facility. Any combination of the aforementioned transmission systems may be utilized.

A leachate force main system may be utilized for any phases at the site. The leachate force main system will convey leachate from the recovery sumps into leachate storage facilities or evaporation ponds. All force main components will be made from leachate resistant materials such as polyvinyl chloride pipe or high density polyethylene pipe. Manholes will be provided in the design to provide adequate maintenance access for the system. In the event of a force main break, the force main section can be shut off and the leachate pumped into a water or tanker truck for transportation to the storage or treatment facility.

Figure 31: Leachate Riser Pipe and Distribution System

If desired, leachate or gas condensate can be discharged directly into on-site leachate storage facilities. These facilities will consist of either future tanks or ponds. Storage tanks located outside of lined areas will have secondary containment. Storage ponds will be composite lined. Leachate from the storage facilities will either be recirculated, transferred to future on-site treatment or evaporation facilities, or hauled off-site to an approved wastewater treatment facility.

If desired, leachate or gas condensate can be discharged directly into on-site leachate evaporation ponds. The ponds will be composite lined. The ponds will store leachate and gas condensate and allow it to evaporate naturally. Leachate and gas condensate may be loaded from the pond into tanker trucks for off-site disposal or recirculation.

Leachate may also be pumped or gravity drained directly from the sumps or ponds into tank trucks for transport. If the loading hose is connected directly to the sump pump discharge, spill containment protection, such as a portable trough, will be provided at hose connection locations. All valves are required to be closed while the truck is being connected to the load-out pipe system.

Transferring leachate to a tanker truck requires a trained operator. The operator must adhere to all site safety requirements which include, at a minimum, wearing proper clothing and safety equipment and having knowledge of spill containment and reporting requirements, and the application of disposable or temporary spill pads.

Leachate shall be disposed of at an authorized facility or as authorized by an appropriate wastewater discharge permit.

4.5 Management of Recovered Leachate

There are several alternatives for the management of recovered leachate: 1) discharge to an off-site wastewater treatment facility, 2) evaporation, 3) recirculation, and 4) on-site treatment and discharge.

It is important to note that all leachate containment systems, especially ponds, should be located above and outside of any drainage features that are subject to flooding. This includes streams, rivers, ponds, lakes and drainage channels. The leachate containment systems should be designed to provide adequate freeboard for the ponds to handle extreme rain storm events without overflowing.

In the event that the landfill is located relatively close to a conventional wastewater treatment facility, it may be possible to discharge the leachate into the piping system for treatment at the plant or direct haul from the landfill to the plant. Before this is attempted the landfill should determine whether the treatment plant is capable of accommodating and treating the quantity and quality of the leachate. Pre-treatment of the leachate may be required.

If the landfill is located in an area where annual evaporation exceeds annual rainfall, then evaporation of leachate is a possibility. In this case, leachate can be discharged directly into on-site leachate evaporation ponds. The ponds will be composite lined. The ponds will store leachate and gas condensate and allow it to evaporate naturally or with the assistance of mechanical aerators. Leachate may be loaded from the pond into tanker trucks for off-site disposal or recirculation.

Leachate can be managed through recirculation into the landfill with certain constraints on where the recirculation can occur. Recirculation should only occur over those areas that are constructed with a geocomposite liner and leachate collection system as described in this manual. Recirculation will be restricted to areas with waste depths of at least 4 meters.

The recirculation will be accomplished by reintroducing the collected leachate back into the landfill waste mass. The recirculation will be accomplished in a manner that prevents ponding or significant accumulations of leachate in any one area. Typical recirculation methods include but are not limited to spray applications on the working face, saturation fields and drip irrigation.

Computer models, such as Hydrologic Evaluation of Landfill Performance (HELP) model, should be used to model the percentage of leachate that may be recirculated without exceeding 30 cm of leachate head on the liner. For more information on the HELP model, see the following: http://el.erdc.usace.army.mil/products.cfm?Topic=model&Type=landfill.

If none of the alternatives presented in the preceding paragraphs are viable, then some type of treatment will be necessary to properly manage the leachate. Just as the composition of the waste deposited in the landfill can vary substantially from municipality to municipality, the leachate produced in landfills can also have widely varying characteristics. The quality and quantity of leachate may undergo substantial variations as the climate changes. As the degradation of the contents of the landfill takes place over time, the quality of the leachate will also change.

Figure 32: Lined Aerated Lagoon for Leachate Treatment

Several types of designs have been used to treat leachate. Some of the processes include biological, physical, and chemical steps. A typical design would involve three stages of treatment: 1) pre-treatment, 2) biological treatment, and 3) physical and chemical treatment. Generally, pre-treatment involves screening, sedimentation and pH adjustment. The biological treatment is designed to remove primarily the Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and some of the nutrients. The more common methods of biological treatment include oxidation ponds, aerated lagoons, and activated sludge. The last and final stage may involve a series of processes principally designed to remove color, suspended solids, heavy metals, and any remaining COD. Processes that may be used for this stage include settling, ozone oxidation, sand filtration, flocculation, and others.

The discharge from the on-site treatment system should be in accordance with local discharge requirements.

4.6 Critical Inspection Points

ITEM NO.	DESCRIPTION	WHEN	FREQUENCY
4	**Leachate Collection System**		
4.1	Leachate collection system construction has full time independent construction quality assurance and quality control monitoring.	Each construction event	At least once per event
4.2	Granular drainage layer, geocomposite or geonet and geotextile leachate collection layer.	First day of drainage layer, geocomposite or geonet construction	Daily during drainage layer, geocomposite or geonet construction
4.3	Material meets drainage layer specifications.	Each construction event	At least once per event
4.4	Material place and deployed appropriately.	First day of drainage layer, geocomposite or geonet construction	Daily during drainage layer, geocomposite or geonet construction
4.5	Leachate collection pipe.	First day of leachate collection pipe construction	Daily during leachate collection pipe construction
4.6	Leachate recovery sump.	First day of sump construction	Daily during sump construction
4.7	Leachate handling system.	First day of leachate handling system construction	Daily during leachate handling system construction
4.8	Other leachate collection system.	As required	As required

5.0 LINERS CONSTRUCTED BELOW THE SEASONAL HIGH WATER TABLE

5.1 General

Excavations below the seasonal high water table may experience bottom or slope instability or excessive groundwater influx that may preclude liner construction. Short-term control of groundwater can be accomplished by temporarily lowering the groundwater level with mechanical dewatering systems or drains, taking advantage of favorable geology, physically cutting off the groundwater seepage, or a combination of these methods. After the liner is placed, it may experience an upward force, or uplift, due to the hydrostatic pressure of the groundwater acting on the bottom of the liner. Long-term resistance to uplift of any component of the liner system can be achieved by the weight of any overlying portions of the liner system and, if needed, by adding weight to the top of the liner system. The short term groundwater control system must function at all times until sufficient long term resistance is applied to minimize liner uplift potential.

It should be noted, in both the short and long-term conditions that without proper equipment or other facilities, maintaining the dewatering system to keep the water level down can be very difficult and lead to damage of the liner system.

5.2 Analysis, Design, and Construction

5.2.1 General

When considering the construction of liners below the seasonal high water table requires one or more years of background data to accurately access the groundwater conditions at the site. The construction of liners below the seasonal high water table requires the owner or operator to:

- Analyze the physical conditions at the site to determine if the in-situ soils and groundwater conditions do present the possibility that hydrostatic forces could cause subgrade instability or uplift of any components of the liner system;
- Design a system and corresponding procedures involving dewatering and/or employment of ballast in the form of soil or compacted solid waste that will adequately counteract the uplift forces and create a stable condition for the liner system during liner construction, landfill operation, and the closure and post-closure care periods; and
- Construct the system and complete the corresponding construction procedures with an

acceptable level of monitoring and testing, and properly document all such activities to clearly show that the integrity of the liner system has been protected at all times during liner construction and will continue to be protected during the operational life and the closure and post-closure periods of the landfill.

5.2.2 Seasonal High Water Table Determination

The initial activity in the analysis process is to determine if the liner extends below the seasonal high water table and is subject to hydrostatic uplift pressures. Site specific stratigraphic and hydrogeologic information, obtained through site specific subsurface stratigraphy studies, should be utilized to define groundwater occurrence, the groundwater flow direction, and the seasonal high water table for a specific site. These studies utilize a geologic and hydrogeologic boring program and study with continued monitoring of piezometers and groundwater monitoring wells located throughout the landfill property to determine the groundwater occurrence, flow direction, and elevation. This study is very important and should be performed before the design and construction of a liner below the seasonal high groundwater table.

Piezometers are constructed similar to groundwater monitoring wells with the sole purpose being to monitor the depth to groundwater and thus determine the elevation of the groundwater. Groundwater quality samples are not taken from piezometers. Additional information on the construction of monitoring wells is included in Section 7.

The seasonal high water table is the highest measured or calculated water level in an aquifer during investigations or monitoring at a site. Groundwater level measurements used for the determination of the seasonal high water table shall include documented monitoring events over recent years in existing monitoring wells as well as recently installed monitoring wells.

The seasonal high water table is prepared by first plotting the location of the groundwater monitoring wells and piezometers and the corresponding high groundwater elevation at each point. Groundwater elevation contour intervals are interpolated between monitoring points and then the groundwater elevation contours are connected to form groundwater contours.

This seasonal high water table map forms the basis for the design engineer’s liner and ballast design. The seasonal high water table should be re-evaluated routinely as part of each liner evaluation. Additional data that may result in the upward revision of the seasonal high water table could be obtained from water elevation readings from site groundwater monitoring wells, or from other groundwater characterization studies. The seasonal high water table should not be adjusted downward.

In the liner evaluation report for each new increment of liner construction, the engineer must provide:

- a description of the seasonal high water table;
- a summary of the groundwater data collected; and
- an analysis of the liner design or ballast requirements.

5.3 Short-Term Groundwater Control

The successful construction of the liner depends on the ability to maintain a stable excavation and to control groundwater seepage and uplift pressures during the construction period. A landfill liner shall be designed with a method for preventing uplift of the liner during construction, ensure the liner is stable during the filling of the landfill, and demonstrate that the liner foundation is stable and suitable for liner construction. All three of these requirements relate to the short-term control of groundwater from the beginning of liner construction to the completion of ballast. The most straightforward method of controlling groundwater is to lower the groundwater level by means of a dewatering system. The appropriate method of dewatering is a function of the in-situ soil properties and the soil profile, as discussed below.

5.3.1 Characterization of In-Situ Soils

The in-situ soils on the bottom and sidewalls of the excavation provide the foundation for the liner system. For the purpose of discussing groundwater control and uplift potential the in-situ soils at the landfill consist of heterogeneous layering of cohesionless and cohesive soils.

5.3.2 Dewatering Methods

Dewatering methods include the use of an underdrain along the floor of the landfill cells that shall extend up the sidewalls to 30 cm above the seasonal high water table at that area of the landfill. Underdrains may consist of geocomposite strips or blanket the cell floor and sideslopes, gravel and/or pipe filled trenches or other means of conveying water from the floor of the landfill cell to a sump area. Underdrains should direct groundwater to an underdrain sump which will be pumped at a sufficient rate to prevent uplift of the liner system, or an open excavation where water would be evacuated to prevent the water from recharging the underdrain system.

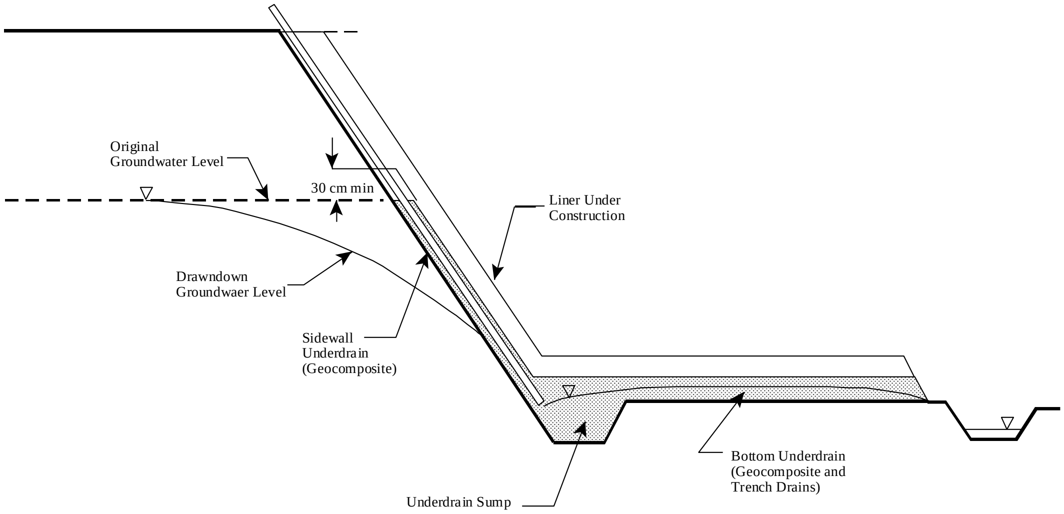


Figure 33: Dewatering Underdrain Detail

Figure 34: Dewatering Underdrain

Placing the first lift of compacted clay liner on the underdrain may not be easily accomplished. Care shall be taken to not damage the underdrain by the compactive effort.

Additionally, wellpoints or individual well dewatering systems may also be used to control uplift pressures on the liner.

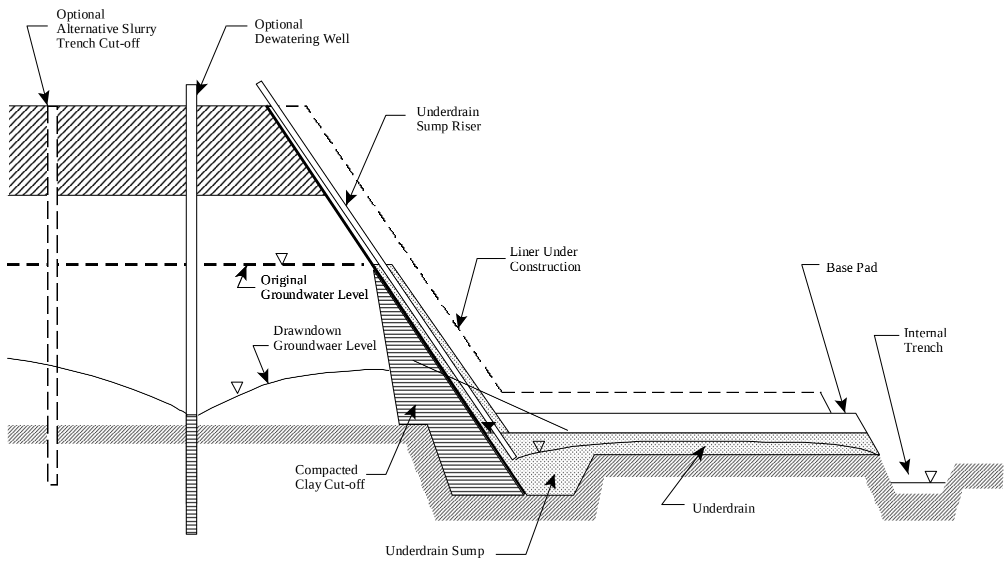


Figure 35: Dewatering Underdrain Detail with Cohesionless Sidewall and Cohesive Bottom

5.4 Dewatering Design and Performance Documentation

The dewatering system should be designed by an engineer and include estimated seepage rates into the system, and the sizing of trenches, sumps, and pumps capable of removing the seepage at the rate it is accumulated.

Dewatering/underdrain systems placed for groundwater control must be operated until the liner and ballast are placed and no longer needed. The system must be monitored on a frequent basis to ensure that the dewatering system is performing as required during the placement of ballast. After the liner is placed, the liner itself can accommodate a certain amount of uplift force, as described in the next section. The documentation of dewatering should identify this acceptable level and demonstrate that it was not exceeded.

5.5 Liner and Ballast Design for Long-Term Conditions

After construction of the liner and placement of ballast, the dewatering/underdrain system shall be terminated understanding that the groundwater will eventually rebound to the seasonal high water table. The design shall prevent liner uplift after the full hydrostatic pressure is redeveloped. The long-term uplift resistance proposed will provide sufficient weight to counteract the uplift force. This resistance will be provided by the weight of the leachate collection system components, protective cover, soil ballast if needed, waste ballast and final cover. A diagram of the hydrostatic and gravity pressures on the liner is shown on Figure 21.

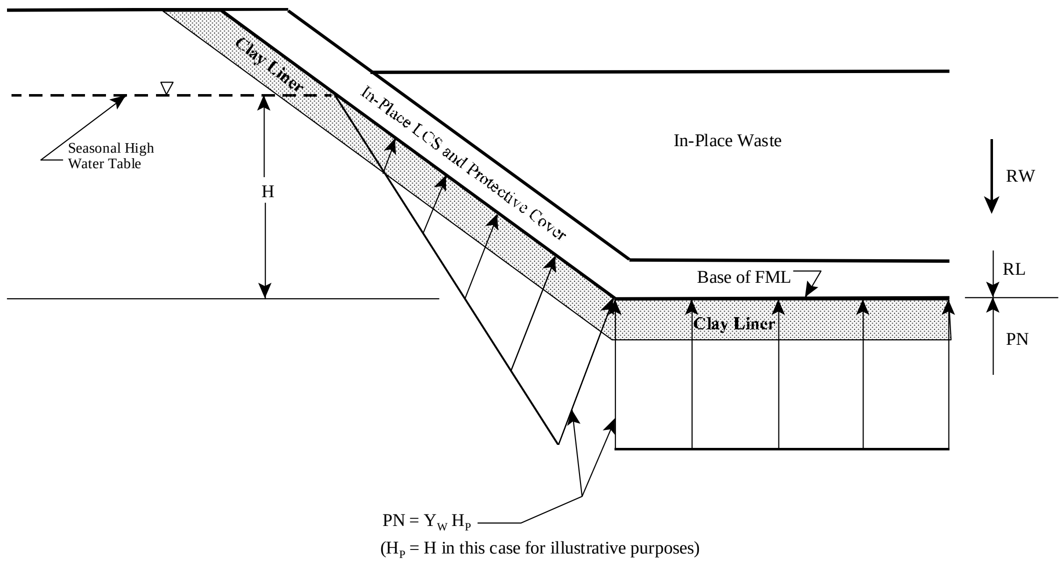


Figure 36: Long Term Uplift Resistance Detail

The hydrostatic force exerted by groundwater on the bottom surface of a landfill liner is defined by a magnitude and a direction. Since no tangential stresses can exist in a fluid, the direction of the resultant hydrostatic force is perpendicular to the liner surface (Daugherty and Franzini, 1965). At a given location, the hydrostatic uplift pressures which will act at any given point on the liner (i.e., bottom of geomembrane, etc.) can be calculated by multiplying the unit weight of water (γ_{water}) times the pressure head (H_p) at that point. The uplift pressure (PN) is therefore expressed as:

$$PN = \gamma_{water} * H_p \qquad \text{(Eq. 1)}$$

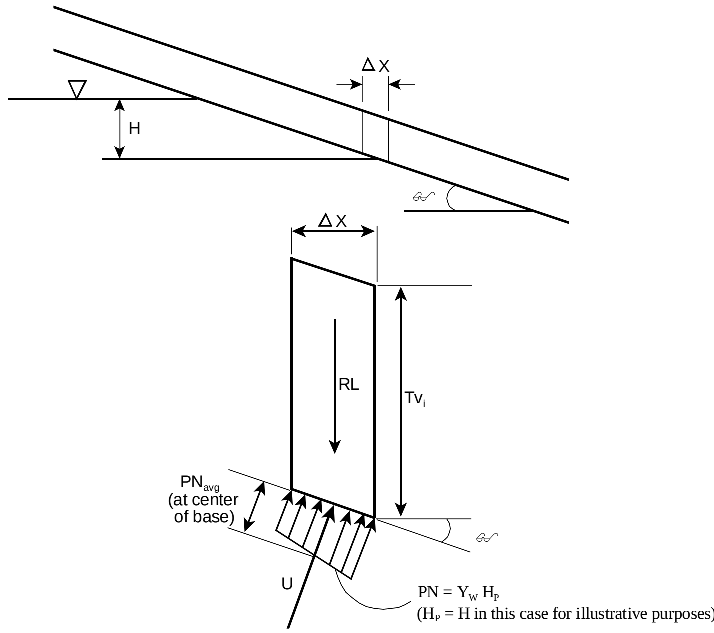


Figure 37: Uplift Stability for Liner System Element

To evaluate the uplift stability at a given point, consider an element of soil and/or waste at that point of width ΔX subject to uplift pressure PN (Figure 22) along the base of the element. (In this simplified case, the pressure head H_p is equal to the height of the groundwater surface H above the element.) The uplift force on the element (which acts normal to the bottom surface) is given by:

$$U = PN_{avg} * \Delta X / \cos \beta \qquad \text{(Eq. 2)}$$

where PN_{avg} is the uplift pressure at the center of the bottom surface of the element and β is the angle of the bottom surface with respect to horizontal or the slope angle. The resisting gravity force of the element of the liner system at the given point can be expressed as:

$$RL = \Delta X * \sum (^1/_4 * Tv_L) \text{ or } RL = \Delta X * (^1/_4 * T_{L+} \, ^1/_{PC} * T_{PC.....}) \qquad \text{(Eq. 3)}$$

where γ_i = unit weight of each component of the liner system (liner γ_L, protective cover γ_{PC}, etc.)

Tv_i = vertical thickness of each component of the liner system (liner T_L, protective cover T_{PC}, etc.)

Note that with a composite liner system consisting of a geomembrane overlying a constructed clay liner, the unit weight and vertical thickness of the clay liner component is not included and will not be considered as ballast.

When possible, the total unit weight of the liner should be determined from the standard or modified Proctors performed on the soil to be used as liner. For a clay liner compacted to a minimum 95% of maximum dry density (γd_{max}) and at a minimum water content of optimum moisture (ω_{opt}, in decimal form), the minimum total density of the liner is expressed as:

$$\gamma_L = (0.95 * \gamma d_{max}) * (1 + \omega_{opt}) \qquad \text{(Eq. 4)}$$

The total unit weight of the leachate collection system and cover soils should be measured in the field or laboratory when possible.

The following equation which balances the forces normal to the liner surface must be satisfied for the liner system element to be considered adequate to resist the normal uplift force with an adequate factor of safety (FS_U) by itself:

$$FS_U = RL * \cos\beta / U = \Sigma(\gamma_i * Tv_i) * \cos^2\beta / (\gamma_{water} * H) \geq 1.2 \qquad \text{(Eq. 5)}$$

If the above equation is satisfied at all liner locations, then no additional ballast is required for long-term uplift resistance.

If the factor of safety against uplift is less than 1.2 at any point in the liner system, then additional weight, or ballast, must be added to the top of the liner system. The additional weight may be in the form of soil or waste. If soil is used, the resisting gravity force (RS) of the soil ballast is equal to the total unit weight of the soil (γ_S) multiplied by the thickness (T_S) of the soil ballast. Sufficient soil ballast must be added to satisfy the equation:

$$(RL + RS) * \cos\beta / U \geq 1.2 \quad \text{or} \quad \Sigma(\gamma_I * Tv_i) * \cos^2\beta / (\gamma_{water} * H) \geq 1.2 \qquad \text{(Eq. 6)}$$

where γ_i and Tv_i include γ_S and T_S, respectively. If waste is used as ballast, it must meet the following requirements:

$ The first 2 meters or the total thickness of ballast, whichever is less, placed on the liner system shall be free of brush and large bulky items, which would damage the underlying parts of the liner system or which cannot be compacted to the required density.

$ The waste shall be compacted to a density of not less than 600 kg/m^3.

The resisting gravity force of waste (RW) is equal to the total unit weight of the waste (γ_{waste} = 600 kg/m^3) multiplied by the thickness of the waste (T_{waste}). Sufficient waste must be added to satisfy the equation:

$$(RL + RW) * \cos \beta / U \geq 1.5 \quad \text{or} \quad \Sigma(\gamma_i * Tv_i) * \cos^2 \beta / (\gamma_{water} * H) \geq 1.5 \qquad \text{(Eq. 7)}$$

where γ_i and Tv_i include γ_{waste} and T_{waste}, respectively.

The method outlined above is simplified and conservative, especially as the slope configuration departs from an infinite slope model as ballast is placed.

5.6 Critical Inspection Points

ITEM NO.	DESCRIPTION	WHEN	FREQUENCY
5	**Liners Constructed Below Seasonal High Water Table**		
5.1	Dewatering system and/or ballast construction has full time independent construction quality assurance and quality control monitoring.	Each construction event	At least once per event
5.2	Dewatering system constructed and operating.	Each construction event	Monthly until dewatering system no longer necessary
5.3	Other dewatering and ballast.	As required	As required

6.0 LINER CONSTRUCTION DOCUMENTATION AND REPORTING

6.1 Liner Evaluation Reports

All liner quality assurance/quality control testing must be performed in conformance with this manual. The data must be prepared as a Liner Evaluation Report.

The limits of all constructed liners, including the most recent covered by the current evaluation, must be clearly marked with the placement of red-colored markers. These markers must be readily discernible by site workers and site inspectors, and shall be maintained at all times during the active disposal operations within the area and may be removed as needed to facilitate operations upon approval of subsequent lined areas of the landfill. The liner evaluation report markers should be at least 1.8 meters high and placed a maximum of 300 meters apart. The liner evaluation report markers shall not be placed through the constructed liner.

Each liner evaluation report must include a clearly legible site map which depicts the grid coordinate system for the site, graphic scale, north arrow, sectorized fill layout plan, filled area, present active area, and area covered by the current submittal. The site map must show the areas covered by all previous liner evaluation reports. It may be a print from a master drawing which is annotated and updated with each new liner evaluation report submittal. In addition, each liner evaluation report must include all or parts of the following items as appropriate and depending on the constructed elements of the liner:

- all field and laboratory test documentation for liner soils and test and sample locations plotted on a location plan;
- all test documentation for leachate collection and protective cover layers;
- all geomembrane test documentation including manufacturer's certifications, documentation of all manufacturer's and independent testing, seaming and repair records, seam tests, and a site map showing locations of panels, repairs, and tests;
- manufacturer's certification and testing documentation for all geosynthetics; and
- a survey documentation of the thickness of the soil liner, leachate collection, protective cover layers, and location of leachate collection trenches, pipes and sump.

All field and laboratory sampling and testing of components of the liner and its construction must be under the direct supervision of a Certifying Engineer or by his qualified representative. Any completed lined area that fails to meet the minimum specified conditions of the required tests must be reworked or reconstructed to achieve the required results. Inability to achieve the required results through reworking shall be cause for rejection of the area in question. All reworked areas shall be retested to prove adequacy to meet all the applicable requirements.

A typical Liner Evaluation Report would include:

1. Narrative
    a. Construction Personnel
    b. Reference Documents
    c. Construction Quality Assurance and Quality Control Services
    d. Construction Activities
        i. Soil
        ii. Geosynthetics
        iii. Leachate Collection System
        iv. Protective Cover
    e. Other Pertinent Information
        i. Dewatering
        ii. Ballast
        iii. Other
2. Certificates of Completion
    a. Soil Liner
    b. Subgrade
    c. Geosynthetics
    d. Leachate Collection System
    e. Protective Cover
3. Preconstruction Testing
    a. Soil
        i. Liner Soil
        ii. Drainage and Protective Cover Soil
        iii. Drainage Stone
    b. Geosynthetics (from Manufacturer)
        i. Geomembrane
        ii. Geonet, Geotextile, Geocomposite
    c. Geosynthetics, Conformance (from Quality Assurance Quality Control testing)
        i. Geomembrane
        ii. Geonet, Geotextile, Geocomposite

   iii. Inventory of all Geosynthetics

4. Construction Testing
    a. Liner Soils
        i. Field Densities
        ii. Permeabilities
        iii. Soil Properties
        iv. Test Location Maps
    b. Geosynthetics
        i. Trial Weld
        ii. Panel Placement
        iii. Panel Seaming
        iv. Non-Destructive Testing
        v. Destructive Testing
        vi. Repairs
5. Resumes
    a. Surveyor
    b. Geosynthetic Installer
    c. Construction Quality Assurance and Quality Control
6. Construction Photographs
7. Record Survey Drawings
    a. Soil Liner
    b. Geomembrane Liner
    c. Leachate Collection System
    d. Protective Cover

No area may be used for the receipt of solid waste until confirmation of its acceptance by the appropriate regulatory agency.

6.2 Ballast

Liners constructed below the groundwater table require several elements of evaluation and quality assurance beyond the basic requirements of the liner evaluation report. Most of these additional documentation and evaluation activities are performed as part of the liner design before construction or during the same time as the monitoring for the clay liner construction. To avoid duplication in reporting requirements, these activities should logically be included in the liner evaluation report. The documentation and evaluation include the following:

- Summary of soil stratigraphy and properties of soils exposed on the bottom and sidewalls of the area being lined.
- Adjusted seasonal high water table, groundwater monitoring well data, or other data.
- Calculation of ballast required, and type of ballast to be used (soil or waste).
- Discussion of whether subgrade required an underdrain system or other dewatering method.
- Method of controlling uplift forces during construction (low-permeability foundation soil, dewatering, or combination).
- Monitoring of dewatering system to demonstrate that hydrostatic forces did not develop during liner construction.
- Pre-construction and top-of-liner elevations of the liner, and confirmation of liner weight. The survey elevations must be performed at the frequency required in this manual.

6.2.1 Soil as Ballast

If soil is to be used as ballast, it would be placed immediately after protective cover construction. The liner evaluation report should document the as-built density and thickness of the soil ballast. The soil ballast thickness should be surveyed at the same frequency required in this manual for the liner.

6.2.2 Waste as Ballast

If waste is used for ballast, a follow-up report in the form of a Ballast Evaluation Report should then be prepared. The ballast evaluation report would include the following documentation:

- The weight of the compactor being used to compact the waste is no less than 18,000 kg, and a certification from the owner that this compactor was utilized during the entire period of placing the waste ballast.
- Certification from the owner of the type of waste placed in the lower 1.5 meters.
- If a 18,000 kg compactor was not used, calculations to show that the in-place density of waste is not less than 600 kg/m^3. These calculations must include the following:
  - initial survey of the area to receive waste as ballast;
  - final survey and calculated volume of waste placed as ballast; and
  - weight of waste placed, based on actual measurements of truck weights at the

scalehouse.

- Survey of the top of waste to document that the thickness calculated in the liner evaluation report has been placed.
- Documentation that any dewatering system used to lower the groundwater level during liner construction was in effect throughout the completion of the ballast placement.
- Groundwater level measurements and pneumatic/vibrating wire piezometer measurements to demonstrate that hydrostatic heads did not exceed the allowable values.

A ballast evaluation report should be prepared after sufficient ballast is in place to demonstrate adequate uplift resistance against the long-term seasonal high groundwater level for a given waste cell, sector, or liner evaluation report area.

6.3 Critical Inspection Points

ITEM NO.	DESCRIPTION	WHEN	FREQUENCY
6	**Liner Construction Documentation and Reporting**		
6.1	Liner Evaluation Report.	Each construction event	At least once per event
6.2	Ballast Evaluation Report.	Each construction event	At least once per event
6.3	Other documentation and reporting.	As required	As required

7.0 GROUNDWATER MONITORING WELL CONSTRUCTION

This guidance describes the installation of a groundwater monitoring well at a sanitary landfill. The purpose of a monitoring well is to provide a water sample that represents groundwater conditions at that location. The water sample is tested by a laboratory for indications of environmental impact from the sanitary landfill.

The purpose of a landfill groundwater monitoring system is to provide water samples that are representative of in-situ groundwater conditions. Laboratory analysis of the samples is used to determine if the landfill is impacting the groundwater. After the groundwater monitoring system is installed, background samples are collected at a frequency intended to determine seasonal natural background variation in groundwater chemistry (typically, once every three months). Samples are analyzed for metals and volatile organic constituents.

A groundwater monitoring system should be installed around the perimeter of the landfill site with a sufficient number of monitoring wells, installed at appropriate locations and depths, to yield representative groundwater samples from the uppermost aquifer. This groundwater monitoring system should be designed based on a detailed hydrogeologic study of the landfill property. Groundwater monitoring wells should be placed a maximum of 250 meters apart around the down gradient perimeter of the landfill site. If the water flows through the site, an appropriate numbers of wells can be placed up-gradient from the landfill to provide a better indication of background water conditions. Up-gradient wells are typically spaced at a much larger interval than down-gradient wells. Up-gradient wells may be spaced 500 or more meters apart. Closer spacing of up-gradient wells might be warranted depending on site specific conditions.

Additional detail on the design of a groundwater monitoring system and groundwater monitoring can be found at: http://www.epa.gov/osw/nonhaz/municipal/landfill/financial/gdwmswl.htm.

After a minimum of four background samples are obtained, Detection Monitoring is conducted. Detection Monitoring compares current sampling results with historical (background) values to determine if the landfill is impacting the groundwater. If Detection Monitoring results indicate a possible landfill impact, Assessment Monitoring may be conducted at the well(s) with apparent impacts. The results of Assessment Monitoring are used to confirm whether a landfill is impacting the groundwater. Assessment Monitoring involves collecting water samples that are analyzed for an expanded range of constituents including metals, volatile organic constituents, semi-volatile organic constituents, organochlorine pesticides, polychlorinated biphenols, herbicides, and other organic parameters.

7.1 Primary Importance of Safety on Job Site

Drilling is a potentially dangerous process that can result in severe injury and death. Therefore, safety must be the top priority on the job site. A safety meeting must be held at the beginning of the job to discuss how to safely meet project objectives. Special attention must be paid to utility clearance, site-specific hazards, training, and proper equipment maintenance.

7.2 Importance of Clean Procedures

Monitoring wells at sanitary landfills are generally installed in areas that are not impacted by pollution. Therefore, the existing groundwater is “clean”, meaning free from environmental impacts of any kind. Laboratories test water samples obtained from the wells for contaminants in the parts-per-billion range. Therefore, it is critical that all well construction materials and drilling equipment are pre-cleaned prior to the installation process. Any contamination inadvertently introduced during the installation process—such as grease on the well pipe—could have long-term detrimental effects on the quality of the water samples.

Well construction materials such as sand, bentonite and PVC pipe are shipped to the job in protective wrapping. No open stockpiles of sand or other well construction materials are allowed on the job site.

7.3 Monitoring Well Design

Monitoring wells are generally constructed with PVC pipe. Individual pipe components screw together; no glue or solvents are used in the assembly and installation. The bottom section of the well pipe is screened. Well screen is PVC pipe that is slotted to allow the entry of groundwater. Monitoring well screen length is variable and dependent on the conditions at the site. Three meters is a common length for a sanitary landfill monitoring well screen.

The total depth of the well is also variable and dependent on the conditions at the site. Generally, the base of the well screen is placed to monitor near the base of the adjacent sanitary landfill excavation. One exception to this guideline is if the groundwater table is below this elevation. If the well screen is placed above the groundwater table, no water samples can be obtained. If the depth to groundwater is unknown but possibly below the base of the sanitary landfill excavation, then drilling methods and sufficient well materials must be provided to allow a field design decision regarding screen placement, using conditions encountered in the field to guide design decisions.

After the well screen and pipe are put in place, the annular space between the screen and the borehole wall is filled with sand (the “sand pack”). The sand pack stabilizes the pipe and acts as a filter through which groundwater travels from native geologic materials into the well screen.

Above the well screen sand pack, bentonite clay is placed to within ½ meter of the ground surface. The bentonite clay prevents infiltration of surface water. Finally, a concrete slab is poured at the surface (see Figure 38).

7.4 Pre-Field Activities

7.4.1 Determining Expected Geology and Groundwater Conditions

The monitoring well installation process is easier to plan and implement if reliable site-specific geology and groundwater information are obtained before field work begins. The site-specific conditions will affect the choice of drilling methods and aspects of monitoring well design such as screen elevation and total well depth.

7.4.2 Selecting Appropriate Drilling Method

The most common and most efficient drilling method for shallow monitoring well installation is hollow-stem augering. This method is appropriate for relatively shallow wells in relatively soft geologic materials such as soils, clays, or unconsolidated materials. Hollow stem augering is generally not effective in hard rock or in wells that are much deeper than 15 meters.

If hard rock and/or a deep well installation are expected, consult the drilling subcontractor regarding appropriate drilling method(s). Consulting the drilling subcontractor during the planning process will facilitate the drilling and installation process.

7.4.3 Selecting Well Materials

Well installation materials are normally procured by the drilling subcontractor, based on detailed specifications submitted by the prime contractor. Details regarding number of wells and depth of wells will allow the drilling subcontractor to procure the necessary PVC pipe, PVC screen, sand, bentonite, and concrete required for job completion.

Well screen and well pipe are most commonly 5 cm in diameter. Well screen is selected based on sand pack particle size and geologic formation conditions. Screened pipe is procured from the manufacturer with water entry slots that are machine-cut to carefully controlled dimensions. A typical groundwater monitoring well or piezometer detail follows.

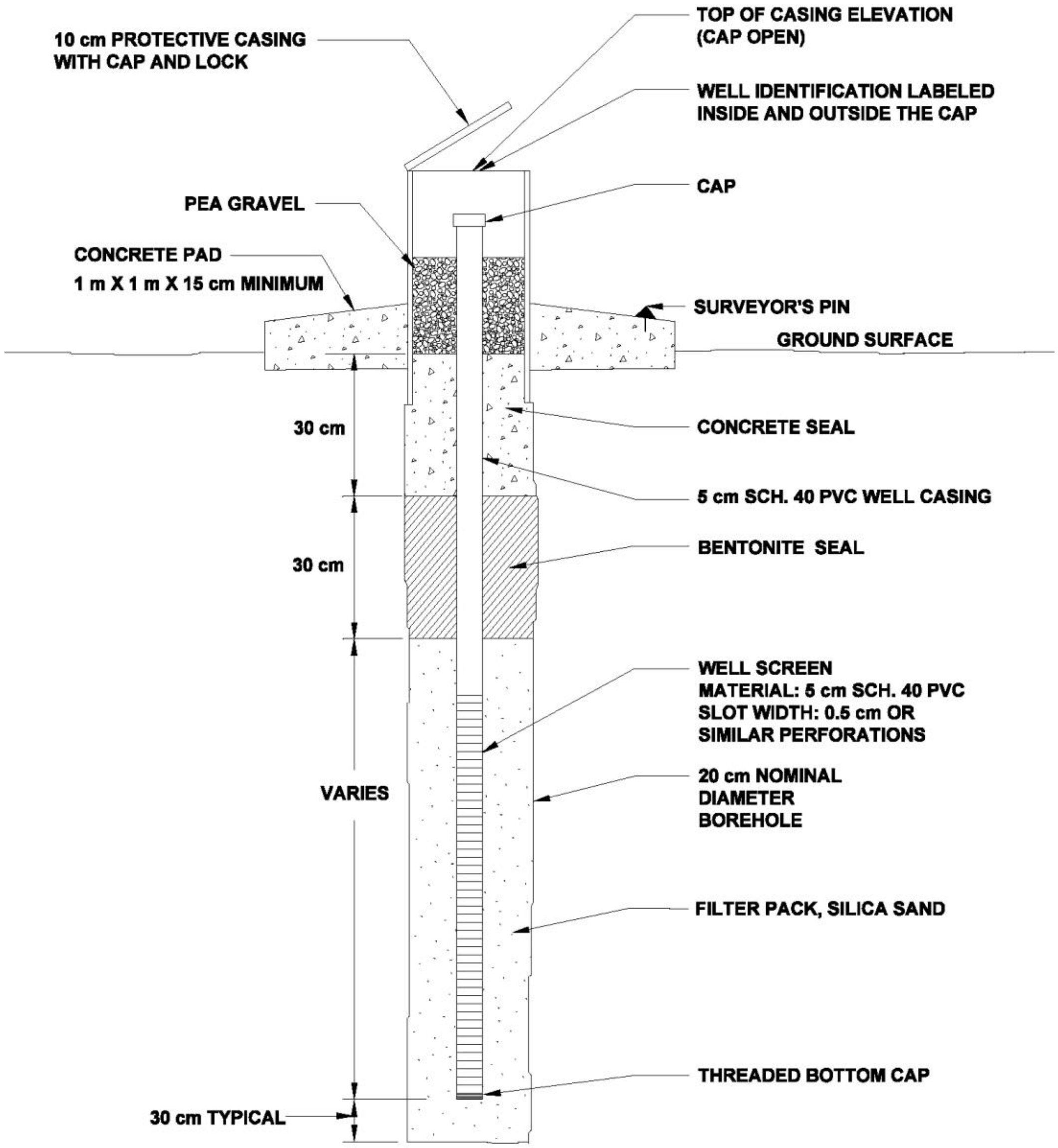


Figure 38: Typical Groundwater Monitoring Well or Piezometer Detail

7.5 Field Activities

7.5.1 Safety

Safety is the first priority on the job site. A Job Safety Analysis should be prepared for all activities at a landfill. A typical Job Safety Analysis may include:

- Review site-specific Health and Safety plan at start of job.
- Conduct daily safety meetings with job personnel.
- Assess drilling location to confirm it is clear of all utilities.
- Wear hardhat, safety vest, safety boots, safety glasses, and hearing protection.
- Stay out of the driller's work area and away from heavy machinery unless required for job.
- Keep away from potentially unstable boring.
- Work uphill or cross-grade, never downhill from heavy equipment.

A critical safety item that must be addressed at the start of the job is proper clearance from all utilities—including overhead power lines, underground water, sewer, electric, and hydrocarbon transmission pipelines. Consult site-based personnel with knowledge of local conditions and area utility companies for information that can be used to determine the proximity of utility lines. Never start a job until all uncertainties regarding safe utility clearance are resolved.

The field work is initiated with a safety/job orientation meeting to address all hazards associated with the job. Every employee who will be involved in the field work must be present at the safety meeting. Hardhats, steel-toe shoes and protective eyewear must be worn by all personnel working in the vicinity of the drilling equipment.

7.5.2 Selecting Drilling Location

Drilling locations are typically selected prior to arrival at the job site. Locations are staked by a surveyor, using coordinates provided by the prime contractor. Upon initial arrival at the job site and observation of surveyor-staked locations, final location adjustments are often necessary to avoid obstacles such as vegetation or uneven ground.

Drilling equipment requires a level area of ground at least ten meters in diameter, and a path to reach the drilling location. Drilling equipment is most commonly mounted on rubber-tired trucks that are heavy and have poor off-road mobility; therefore, a suitable road must be provided. This may require clearing and leveling by heavy equipment prior to the arrival of the drilling subcontractor. In wet/muddy conditions, it is sometimes necessary to spread gravel to form a trafficable surface both for site access and at the drilling site.

7.5.3 Monitoring Well Installation

Some drilling equipment/methods require water as a part of the drilling process. This water is sent down the hole; therefore, the water must be clean. Drillers cannot use surface water from ponds, live stock surface impoundments, etc., for drilling because it may be contaminated.

Drilling equipment must be decontaminated prior to use, and between wells. This will require specialized cleaning equipment which must be kept on site as a part of the required work equipment. The job supervisor should observe the cleaning process and/or check equipment immediately prior to use.

Once the drilling equipment is decontaminated and set up in a suitable location, drilling and well installation can proceed. The hollow stem auger drilling process proceeds quickly (assuming suitable geologic materials); a 15-meter hole can often be completed in approximately two hours.

The as-built well installation must be documented for subsequent reporting purposes. See Appendix D for an example form that can be used for field documentation, and also for formal reporting purposes.

During the drilling process, any indications of subsurface water should be documented. Indications may range from increasingly moist cuttings to saturated conditions. Noting the depth where water is encountered will guide decisions such as well screen position and drilling/completion methods.

After drilling reaches the desired depth, the well is constructed in the borehole. A ½ meter section of PVC pipe is attached to the base of the well screen to act as a sump. The purpose of the sump is to provide a place for fine materials to settle, without affecting or plugging the well screen.

The assembled sump/screen section is lowered in the borehole. Additional PVC pipe is attached as the pipe is lowered, until the bottom of the hole is reached. All pipe components are connected using screw-on connections; no glue, cement, or solvents can be used in well construction in order to avoid introducing these contaminants into water samples obtained after well installation.

Upon completion of PVC pipe assembly and placement, approximately one meter of pipe is allowed to stick above ground (this section is known as the “stick-up”). A plastic cap should be placed on the top of the pipe to prevent entry of foreign materials.

Sand is now placed in the annulus between the PVC pipe and borehole sidewall. Sand is placed until it rises ½ meter above the screen.

Above the sand, bentonite grout is pumped in the annulus using a tremie pipe. The grout should be emplaced from above the sand to within ½ meter of the ground surface.

A metal protective casing is now placed around the stick-up. The casing should have a lockable hinged lid to allow access to the PVC pipe for sampling. The metal casing is pushed into the ground approximately ½ meter, to be secured later by the concrete pad.

Figure 39: Groundwater Monitoring Well

The concrete pad is constructed using wood boards to form a pad of typical dimensions 1-meter by 1-meter by 10 cm. Steel reinforcing mesh is placed within the pad area where cement will be poured. The cement pad can be protected from damage by installing metal posts ("bollards") around the pad. These posts should be installed about 0.1 meter outside of the pad, not in the pad.

Upon completing the above steps for all wells, a surveyor is commonly employed to provide as-built measurements of final latitude, longitude, and elevation of the top of the PVC well pipe.

The well casing should be marked with the well number and the latitude, longitude and elevation of the top of the PVC well pipe.

7.5.4 Monitoring Well Development

Monitoring wells are developed after installation and before sampling. Developing is the process of removing all drilling and other foreign materials from the well. The timing of well development depends on how long it takes groundwater to enter the well. A week may be required after installation for drilling materials to settle in the well, and for groundwater to enter the well.

Developing can be conducted using a variety of tools and equipment; the driller can be consulted about the best method(s) to accomplish well development. The driller can also be contracted to provide well development services.

To accomplish development, the well is first gently surged using a plunging action within the well screen. Overly vigorous plunging can collapse the screen, ruining the well. The surging tool acts like a piston within the well screen. A rigid material that is slightly smaller in diameter that the well screen may be used. This may include a stainless steel rod or a weighted and capped piece of PVC. The surging tool should be weighted to allow it to sink in the water column. The PVC should be sand filled with threaded caps on each end. The surging tool is decontaminated then placed into the well and gently raised and lowered within the well screen, forcing water in and out of the well, while breaking up solids in the sand pack and drawing them into the well for removal. Surging helps break up undesirable materials that may be present in the sand pack, and draw the unwanted materials into the well screen where they settle in the sump area. These fine grained materials can then be removed from the sump using a bailer with a foot valve. Alternatively, an electric pump may be suitable for development. Some types of electric pumps are not designed to pump turbid water that contains some solids, so care must be used in selecting the proper equipment.

Surging and bailing is conducted in several cycles until unwanted materials are removed and the well cleans up. The water produced from the well typically progresses from turbid at the beginning to clear at the end of the process.

The well development process is documented by regularly obtaining water samples with a bailer throughout the development process. Each water sample is logged with the time the sample is obtained, amount of water removed, visual appearance, and instrument measurements including temperature, pH, and specific conductivity. As the well cleans up, the water samples will become progressively less turbid and the instrument readings should stabilize.

The time required to complete this process for one well is highly variable. Typically, four hours is the maximum amount of time expended to develop one well. However, if the well is screened in a clay-rich formation, the water may remain turbid even after many cycles of well development. If further efforts appear to produce no changes, the development effort is concluded.

After well development is complete, the well is ready for sampling. The area around the well should be cleaned up and all debris removed. The well casing should be securely locked.

Figure 40: Groundwater Monitoring Well Completion with Casing, Lock and Concrete Pad

For additional information on groundwater sampling methods and equipment, see: ASTM Guide D 4448-85a (1992), "Guide for Sampling Groundwater Monitoring Wells".

7.6 Critical Inspection Points

ITEM NO.	DESCRIPTION	WHEN	FREQUENCY
7	**Groundwater Monitoring Well**		
7.1	Metal protective casing.	After construction	Each groundwater monitoring event
7.2	Concrete pad.	After construction	Each groundwater monitoring event
7.3	Area around groundwater well and concrete pad free of debris.	After construction	Each groundwater monitoring event

ITEM NO.	DESCRIPTION	WHEN	FREQUENCY
7.4	Protective casing locked.	After construction	Each groundwater monitoring event
7.5	Monitoring well has removable cap.	After construction	Each groundwater monitoring event
7.6	Monitoring well surveyed for latitude, longitude and elevations.	After construction	Not applicable
7.7	Other groundwater monitoring well	As required	As required

8.0 LANDFILL GAS MONITORING PROBE CONSTRUCTION

Methane gas has the potential to migrate laterally from the landfill disposal cells. To monitor and detect gas that may migrate beyond the limits of the waste fill area, a monitoring system should be installed along the site's perimeter to provide coverage of the adjacent disposal areas.

The objective of a landfill gas monitoring system is to assure the concentration of methane gas does not exceed the lower explosive limit for methane at the facility property boundary. "Lower explosive limit" means the lowest percent by volume of a mixture of explosive gases in air that will propagate a flame at 25º Celcius and atmospheric pressure.

Methane is explosive when present in the range of 5% to 15% by volume in air. The lower threshold (5% for methane) is referred to as the lower explosive limit (LEL). The upper threshold (15% for methane) is referred to as the upper explosive limit (UEL).

The proposed monitoring probe locations should be selected to provide monitoring points between the waste disposal areas and nearby residences and structures (both on and off site). The gas monitoring network will be installed in phases as the sanitary landfill facility expands to provide continuous monitoring coverage between active disposal areas and the property boundary.

The general spacing for the gas probes is approximately 300 meters around the perimeter of the site. Probes are spaced along the site perimeter according to adjacent land use and proximity to structures. The gas monitoring network should be modified as needed to reflect changing on-site and off-site land use.

A landfill gas collection system is installed to remove landfill gas from the landfill. These collection systems can be "passive" or "active" systems.

A "passive" landfill gas system typically involves vents placed through the landfill cover soils. These vents may allow the landfill gas to pass through the cover into the atmosphere or may be candlestick flares that burn the gas. Passive vents constructed through the landfill final cover are typically spaced between 20 to 30 meters apart.

Vent systems may be installed as soon as the waste reaches approximately 3 meters above the liner to prevent the build up of pressure that might result in off-site gas migration or landfill cover stability issues. These vents would be extended incrementally up as the waste fill increases. These vents can be drilled in place or simply be barrels perforated with holes and backfilled with a 10 cm perforated pipe and gravel or stone. The perforations in the barrel and pipe should be smaller than the gravel or stones.

Although venting the landfill gas into the atmosphere averts potential local problems and adverse impacts, this approach contributes to the releasing of greenhouse gasses. There are several approaches that can collect the gas to burn the gas in a flare system or to use the gas in a beneficial way.

An "active" landfill gas control system includes wells; header system; and flares, electrical generators, or other landfill gas combustion systems. In an active landfill gas control system, the gas wells are typically installed from the surface to no closer than 5 meters of the underlying liner elevation (so as not to drill through the liner). These wells are typically spaced between 50 and 100 meters apart. The wells deliver the gas to the header system which in turn, delivers the gas to the flare or other end use. The flare burns the gas thus removing the primary pollutant. A gas to energy generator or other end user, also removes the primary pollutant while contributing energy or reduced dependence on natural gas.

8.1 Gas Monitoring Probe Construction

Gas probe installation at a sanitary landfill is generally similar to monitoring well installation. A drilling contractor will drill the gas monitoring probe. The driller will drill a 20 cm diameter borehole. The probe consists of a riser and a screened section, with both sections typically fabricated from 5 cm diameter PVC pipe. The riser will consist of solid pipe and extends from approximately 1 meter above ground level to a depth of approximately 1.5 meters below ground level. The screened section extends from the bottom of the solid pipe to a depth 2 meters below the water elevation or the lowest base grade elevation of the adjacent landfill cell, whichever is the higher elevation.

After drilling reaches the desired depth, the probe is constructed in the borehole. Approximately 30 cm of gravel are placed in the bottom of the borehole. The PVC pipe, solid and screened, with a cap threaded onto the bottom of the pipe, is placed in the borehole. The borehole is backfilled with gravel to 30 cm above the top of the screen. A 90 cm layer of bentonite grout is placed above the gravel. A metal, lockable, protective casing is now placed around the PVC pipe sticking up above ground. The metal casing is pushed into the ground and backfilled with pea gravel to within 15 cm of the top of the PVC pipe. The top of the PVC pipe is capped with a threaded PVC cap with a quick connect fitting installed. A concrete pad is poured around the casing.

Figure 41: Landfill Gas Probe

The concrete pad is constructed using wood boards to form a pad of typical dimensions 1-meter by 1-meter by 10 cm. Steel reinforcing mesh is placed within the pad area where concrete will be poured. The concrete pad can be protected from damage by installing metal posts ("bollards") around the pad. These posts should be installed about 0.1 meter outside of the pad, not in the pad.

Upon completing the above steps for all wells, a surveyor is commonly employed to provide as-built measurements of final latitude, longitude, and elevation of the top of the PVC well pipe.

The well casing should be marked with the well number and the latitude, longitude and elevation of the top of the PVC well pipe.

After probe construction is complete, the gas monitoring probe is ready for sampling. The area around the well should be cleaned up and all debris removed. The well casing should be securely locked.

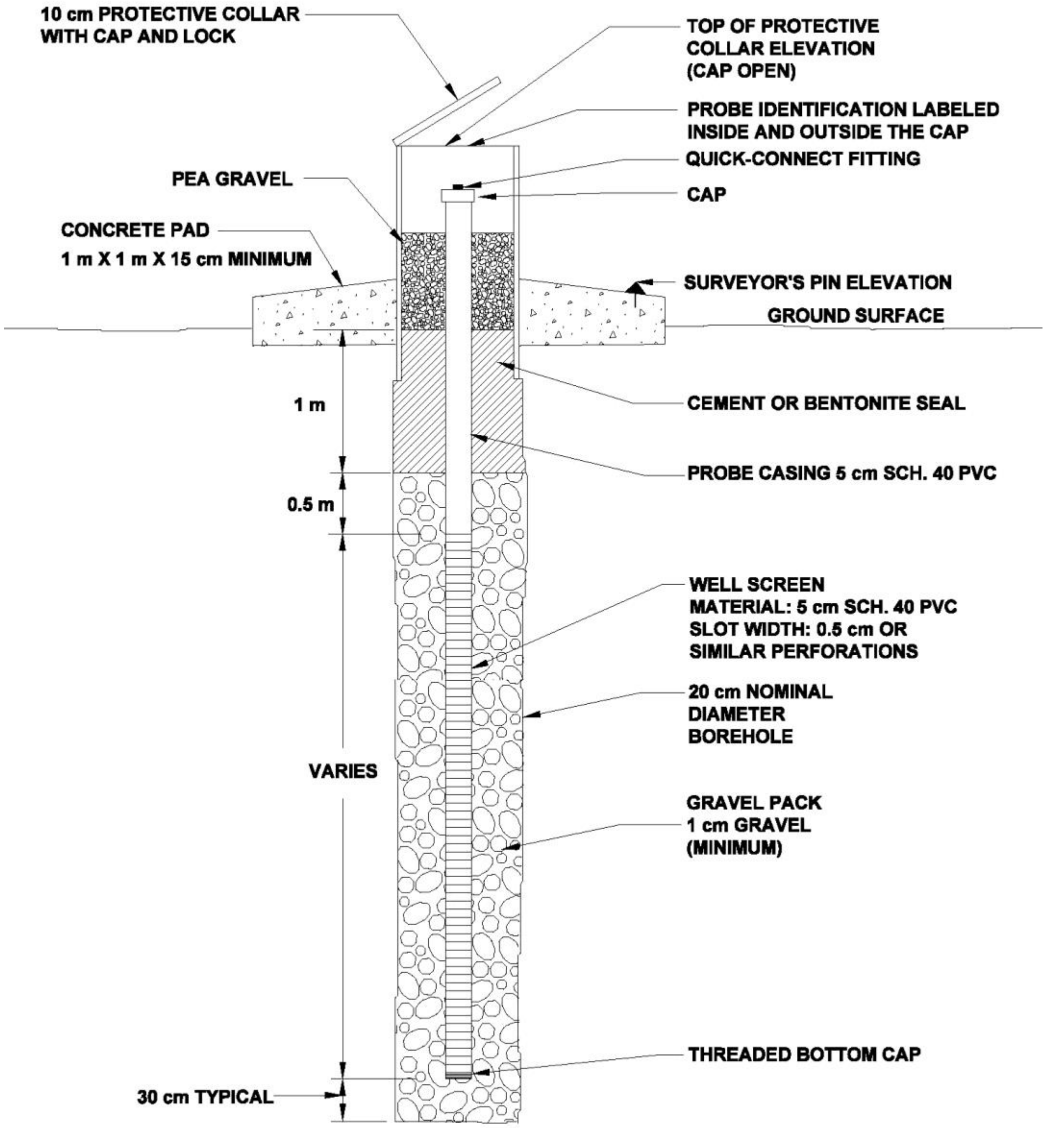


Figure 42: Typical Landfill Gas Monitoring Probe

8.2 Landfill Gas Monitoring

The landfill should monitor for the presence of landfill gas on a once every 3 month basis for the percentage methane by volume. Field personnel will conduct a visual inspection of the condition of the probe. The field technician will utilize a gas differential pressure gage, a dual-range combustible gas indicator and an electronic water level meter. The pressure in the sealed monitoring probe will be measured and the presence of methane will be determined. The probe will then be opened to allow the measurement of the depth to water.

In the event that the percentage of methane detected is greater than 5% by volume at any monitoring probe, the landfill shall immediately implement a Contingency Plan.

The Contingency Plan shall include notifying potentially affected residents or nearby businesses (those businesses within 300 meters of the affected gas monitoring probe) and conducting daily follow-up readings of the affected probe. If the follow-up readings suggest that there are methane levels exceeding 5% methane by volume at the property line, then efforts will be made to determine the extent of the methane migration away from the property line. Typical efforts to determine the extent of the gas migration may include barhole probing or drilling of additional wells to sample for methane.

If during follow up sampling it is determined that gas may have migrated into an on-site or off-site structure, that occupants of the structure will be notified immediately of the potential hazard and the building owner contacted. Corrective actions may involve installation of a methane alarm system should levels reach dangerous levels, active venting of the structure, or evacuation in order to prevent an explosion or hazard to occupants.

Monitoring of the probes and any affected structures will be continued on a weekly basis until methane readings in the probe and vicinity are less than 5%.

The facility shall prepare a Remediation Plan to remedy the landfill gas migration problem. This plan may include the construction of interceptor trenches, vent wells (either in the waste mass or in the soil in the affected area), an active gas collection system in the landfill or other similar solutions.

8.3 Critical Inspection Points

ITEM NO.	DESCRIPTION	WHEN	FREQUENCY
8	**Landfill Gas Monitoring Probe**		
8.1	Metal protective casing.	After construction	Each groundwater monitoring event
8.2	Concrete pad.	After construction	Each groundwater monitoring event
8.3	Area around gas monitoring probe and concrete pad free of debris.	After construction	Each groundwater monitoring event
8.4	Protective casing locked.	After construction	Each groundwater monitoring event

ITEM NO.	DESCRIPTION	WHEN	FREQUENCY
8.5	Gas monitoring probe has removable cap with quick connect fitting.	After construction	Each groundwater monitoring event
8.6	Gas monitoring probe surveyed for latitude, longitude and elevations.	After construction	Not applicable
8.7	Other landfill gas monitoring probe	As required	As required

APPENDICES

APPENDIX A

Glossary

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM) - One of the largest, professionally recognized voluntary standards development systems in the world.

ATTERBERG LIMITS - A series of 6 "limits of consistency" of fine-grained soils defined by Swedish soil scientist Albert Atterberg, two of which are frequently used today to establish a soil's physical boundaries dealing with its plasticity characteristics. These soil boundaries or limits used most frequently in geotechnical engineering are based upon the numerical difference of the Liquid Limit and the Plastic Limit as defined below:

Liquid Limit (LL) - The percentage of moisture in a soil, subjected to a prescribed test, that defines the upper point at which the soil's consistency changes from the plastic to the liquid state.

Plastic Limit (PL) - The percentage of moisture in a soil, subjected to a prescribed test, that defines the lower point at which the soil's consistency changes from the plastic to the semi-solid state.

Plasticity Index (PI) - The numerical difference between the LL and the PL of a fine-grained soil that denotes the soils plastic range. The larger the PI the greater a soil's plasticity range and the greater it's plasticity characteristics.

COEFFICIENT OF PERMEABILITY (a.k.a. Hydraulic Conductivity) - The amount of flow per unit of time through soil under unit hydraulic gradient at standard temperature.

COMPACTIVE EFFORT - The amount of compaction energy held constant, and usually transferred into a soil sample with a compaction hammer device, used on soil samples in various laboratory test procedures to establish a soil's density at various moisture contents.

CONSTRUCTED SOIL LINERS - Soils liners constructed from reworked in-situ soils, soils from a borrow source, or bentonite-amended soils.

CONSTRUCTION QUALITY ASSURANCE (CQA) - A planned system of activities that provides the owner and permitting agency assurance that the facility was constructed as specified in the design (U.S. EPA, 1993).

CONSTRUCTION QUALITY CONTROL (CQC) - A planned system of inspections that is used to directly monitor and control the quality of a construction project (U.S. EPA, 1993).

FIELD PERMEABILITY TEST - A field test performed on a constructed liner or in-situ soils to determine the in-place coefficient of permeability and usually performed as a Sealed Double Ring Infiltrometer Test (SDRI), or series of Boutwell field tests. This type of permeability test method is usually considered to have greater accuracy due to the area tested and the existing field conditions that may be obscured by a laboratory testing environment.

FILM TEAR BOND (FTB) - A failure in the geomembrane sheet material on either side of the seam and not within the seam itself.

FISH MOUTH - A semi-conical opening of the seam that is formed by an edge wrinkle in 1 sheet of the geomembrane.

FLEXIBLE MEMBRANE LINER (FML) or GEOMEMBRANE LINER - An essentially-impermeable geosynthetic composed of 1 or more synthetic sheets. See HDPE.

FML STRATIFIED SAMPLE - A randomly selected sample location within each 150- linear-meter interval.

GEOMEMBRANE - See FLEXIBLE MEMBRANE LINER.

GEOSYNTHETIC CLAY LINER - A factory manufactured, hydraulic barrier typically consisting of bentonite clay or other very low permeability material, supported by geotextiles and/or geomembranes that are held together by needling, stitching, or chemical adhesives.

GEOSYNTHETIC MATERIALS - Manufactured or man-made materials that include FMLs (geomembranes), geogrids, geofilters, geocomposites, geodrainage nets, and geotextiles.

GEOTECHNICAL PROFESSIONAL (GP) - A professional engineer registered in this state who possesses professional experience in geotechnical engineering and testing. Geologists may evaluate and supervise the quality control testing for constructed soil liners or in-situ soil liners only provided the have, knowledge and experience in geotechnical testing and the evaluation of the engineering properties of soils.

NOTE: All references to the Geotechnical Professional, Geotechnical Quality Control/Quality Assurance Professional, Professional of Record, etc., within the context of this handbook are interchangeable and are therefore synonymous.

GRADATION - See SIEVE ANALYSIS

GEOSYNTHETIC RESEARCH INSTITUTE (GRI) - Located at Drexel University, the GRI conducts research with geosynthetic materials and develops industry testing standards for these materials. This institute is supported by many geosynthetic manufacturers, installers, and raw materials suppliers to the industry.

HDPE (HIGH DENSITY POLYETHYLENE) - A polymer prepared by low-pressure polymerization of ethylene as the principal monomer and having the characteristics of Type III and IV polyethylene. Such polymer resins have densities greater than or equal to 0.941 g/cc.

IN-SITU LINERS - Soils liners consisting of undisturbed soils that do not exhibit primary or secondary physical features, and meet all physical and quality control testing requirements.

IN-SITU SOILS - Undisturbed soils; the term routinely used in describing an in-place soil liner.

INDEPENDENT TESTING LABORATORY - A laboratory that is independent of ownership or control by the permittee or any party to the construction of the liner or the manufacturer of the liner products used.

MANUFACTURING QUALITY ASSURANCE (MQA) - A planned system of activities that provides assurance that the raw materials were constructed (manufactured) as specified.

MANUFACTURING QUALITY CONTROL (MQC) - A planned system of inspection that is used to directly monitor and control the manufacture of a material.

MOISTURE/DENSITY (M/D) RELATIONSHIP - A test in which soil samples are compacted in a known volumetric container at various moisture contents at a constant level of compactive effort and their corresponding densities are determined. The test procedures and compactive efforts used are those normally prescribed in ASTM D 698 and D 1557. These tests are frequently designated the Standard Proctor and Modified Proctor compaction tests named after M. M. Proctor, the early developer of these test procedures for the determination of density control on compacted soil fills.

PERMEABILITY - See COEFFICIENT OF PERMEABILITY

PERMEANT FLUID - Fluid used in a laboratory coefficient of permeability test and limited to tap water or 0.005 Normal solution of $CaSO_4$. Distilled water shall not be used in these test procedures.

NOTE: 0.05 Normal as indicated in MSWR §330.56(d)(5)(B)(ii) is in error and should read 0.005 Normal.

QUALIFIED ENGINEERING TECHNICIAN - A representative of the GP who is NICET-certified in Geotechnical Engineering Technology and Geosynthetic Materials Installation Inspection at level 2 or higher, an engineering technician with a minimum of 4 years of directly-related experience, or a graduate engineer or geologist with 1 year of directly-related experience.

REPRESENTATIVE SAMPLE - A representative sample of geomembrane material consists of 1 or more specimens (commonly referred to as coupons) from the same rectangular portion of geomembrane material, oriented along a seam that is removed for field or laboratory testing purposes.

SEASONAL HIGH WATER TABLE - The highest measured or calculated water level in an aquifer during investigations for permit application and/or any groundwater characterization studies at a site.

SIEVE ANALYSIS - A laboratory soil test consisting of placing a known weight of soil sample through a series of wire mesh sieves stacked upon each other in successively smaller mesh size and used to determine the percentage size gradation of the sample.

SOIL BORROW SOURCE - Soils in which the Liquid Limit (LL) and Plasticity Index (PI) do not vary by 10 points. A soil that varies by 10 or more points from the originally- established LL or PI is considered as a separate soil source for the purpose of this handbook and requires a separate soils test series.

SOIL TEST SERIES - Tests performed to determine a soil's physical characteristics and to document its ability to satisfy the MSWR soil liner requirements. These tests include sieve analysis (gradation), Atterberg Limits, moisture/density, and coefficient of permeability.

SPECIMEN - (With respect to geomembrane destructive testing) - A specimen is the individual test strip (sometimes called coupon) from a sample location. A sample location usually consists of many specimens.

WATER TABLE - The upper surface of the zone of saturation at which water pressure is equal to atmospheric pressure, except where that surface is formed by a confining unit.

APPENDIX B

List of References

ASTM 1995, The American Society of Testing and Materials 1995 Annual Book of Standards, Section 4.- Construction, Vol.4.08 and 4.09, "Soil and Rock", Philadelphia, Pennsylvania.

Note: ASTM standards are available for purchase at:
http://www.astm.org/Standard/index.shtml?complete
Under "Search Standards" enter the ASTM number and click "Search".

ASTM D 374, "Standard Test Methods for Thickness of Solid Electrical Insulation"

ASTM D 422, "Particle-Size Analysis of Soils"

ASTM D 638, "Tensile Properties of Plastics"

ASTM D 698, "Laboratory Compaction Characteristics of Soils Using Standard Effort (12,400 ft-lbs/ft^3 (600 Kn-m/m^3))"

ASTM D 751, "Test Methods for Coated Fabrics"

ASTM D 792, "Specific Gravity and Density of Plastics by Displacement"

ASTM D 1004,"Initial Tear Resistance of Plastic Film and Sheeting"

ASTM D 1140, "Amount of Material in Soils Finer than the No. 200 (75-µm) Sieve"

ASTM D 1204, "Linear Dimensional Changes of Nonrigid Thermoplastic Sheeting or Film at Elevated Temperature"

ASTM D 1238, "Flow Rates of Thermoplastics by Extrusion Plastometer"

ASTM D 1505, "Density of Plastics by the Density-Gradient Technique"

ASTM D 1556, "Density and Unit Weight of Soil In Place by Sand-Cone Method"

ASTM D 1557, "Laboratory Compaction Characteristics of Soils Using Modified Effort (56,000 ft-lbs/ft^3 (2,700 Kn-m/m^3))"

ASTM D 1593, "Standard Specification for Nonrigid Vinyl Chloride Plastic Sheeting"

ASTM D 1603, "Carbon Black in Olefin Plastics"

ASTM D 1682, "Method of Test for Breaking Load and Elongation of Textile Fabrics"

ASTM D 2167, "Density and Unit Weight of Soil In Place by Rubber Balloon Method"

ASTM D 2434, "Permeability of Granular Soils (Constant Head)"

ASTM D 2487, "Classification of Soils for Engineering Purposes (Unified Soil Classification System)"

ASTM D 2922, "Density of Soil and Soil-Aggregate In Place by Nuclear Methods (Shallow Depth)"

ASTM D 3015, "Recommended Practice for Microscopical Examination of Pigment Dispersion in Plastic Compounds"

ASTM D 3042 – Modified, " Test Method for Determining Degradation of Landfill Drainage Materials Due to Carbonate Content" J&L Test Designation S-105-89"

ASTM D 3776, "Test Methods for Mass per Unit Area (Weight) of Fabric"

ASTM D 3895, "Test Method for Oxidative-Induction Time of Polyolefins by Differential Scanning Calorimetry"

ASTM D 4218, "Test Method for Determination of Carbon Black in Polyethylene Compounds By Muffle Furnace Technique"

ASTM D 4318, "Liquid Limit, Plastic Limit, and Plasticity Index of Soils"

ASTM D 4437, "Practice for Determining the Integrity of Field Seams Used in Joining Flexible Polymeric Sheet Geomembranes"

ASTM D 4716, "Test Method for Determining the (In-plane) Flow Rate per Unit Width and Hydraulic Transmissivity of a Geosynthetic Using a Constant Head"

ASTM D 4833, "Test Method for Index Puncture Resistane of Geotextiles, Geomembranes, and Related Products"

ASTM D 5035, "Test Method for Breaking Force and Elongation of Textile Fabrics (Strip Method)"

ASTM D 5084, "Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter"

ASTM D 5093, "Field Measurement of Infiltration Rate Using a Double-Ring Infiltrometer with a Sealed Inner Ring"

ASTM D 5199, "Measuring Nominal Thickness of Geotextiles and Geomembranes"

ASTM D 5397, "Test Method for Evaluation of Stress Crack Resistance of Polyolefin Geomembranes Using Notched Constant Tensile Load Test"

ASTM D 5596, "Test Method for Microscopic Evaluation of the Dispersion of Carbon Black in Polyolefin Geosynthetics"

ASTM D 5641, " Practice for Geomembrane Seam Evaluation by Vacuum Chamber"

ASTM D 5721, "Practice for Air-Oven Aging of Polyolefin Geomembranes"

ASTM D 5885, "Test Method for Oxidative Induction Time of Polyolefin Geosynthetics by High-Pressure Differential Scanning Calorimetry"

ASTM D 5994, "Test Method for Measuring Core Thickness of Textured Geomembrane"

ASTM D 6693, " Test Method for Determining Tensile Properties of Nonreinforced Polyethylene and Nonreinforced Flexible Polypropylene Geomembranes"

ASTM Committee D 35 on Geosynthetics (1996), Symposium on Testing and Acceptance Criteria for Geosynthetic Clay Liners, Atlanta, Georgia.

ASTM Standards, Procedures for Testing Soils, American Society for Testing Materials, 1916 Race Street, Philadelphia, PA 19103.

Benson, C.H., Daniel, D.E., and Boutwell, G.P., (1999), "Field Performance of Compacted Clay Liners," Journal of Geotechnical and Geoenvironmental Engineering, American Society of Civil Engineers, pp. 390-403.

Boardman, B.T. (1993), "The Potential Use of Geosynthetic Clay Liners as Final Covers in Arid Regions," M.S. Thesis, Univ. of Texas at Austin, 109 p.

Boutwell, G.P., and Tsai, C.N., 1992, "The Two-Stage Field Permeability Test for Clay Liners," *Geotechnical News*, Vol. 10, No. 2, pp. 32-34.

Bowders, J.J. and Daniel, D.E. (1995) "Waste for Ballast - Landfills Below the Ground-Water Table", Proceedings of the 8th Annual Municipal Solid Waste management "Options for Texas '95" Conference, Texas Natural Resources and Conservation Commission, Austin, Texas, January 25-27, 1995.

Cedergren, H.R. (1967) Seepage, Drainage, and Flow Nets, John Wiley & Sons, Inc., New York.

Cedergren, H.R. (1975) "Drainage and Dewatering" from Foundation Engineering Handbook ed. by Winterkorn, H.F. and Fang, H.Y., Van Nostrand Reinhold Co., New York, 1975.

Chamberlain, E.J., and Gow, A.J. (1979), "Effects of Freezing and Thawing on the Permeability and Structure of Soil," Engineering Geology, Vol. 13., No. 1, pp. 73-92.

Daniel, D.E. (1993), "Geosynthetic Clay Liners (GCLs) in Landfill Covers," presented at the Thirty-First Annual Solid Waste Exposition, The Solid Waste Association of North America, San Jose, California, August 2-5, 1993.

Daniel, D.E., Shan, H.Y., and Anderson, J.D. (1993), "Effects of Partial Wetting on the Performance of the Bentonite Component of a Geosynthetic Clay Liner," Geosynthetics '93, Vol. 3, Industrial Fabrics Association International, St. Paul, Minnesota, pp. 1483-1496.

Daniel, D.E., March 10 & 11, 1993, Seminar on clay liner construction and testing given to Texas Water Commission, Field Operations Municipal Solid Waste Landfill Inspectors and Central Office Personnel.

Daugherty, R.L. and Franzini, J.B. (1965) Fluid Mechanics with Engineering Applications, McGraw-Hill Book Company, New York.

Estornell, P. (1991), "Bench-Scale Hydraulic Conductivity Tests of Bentonitic Blanket Materials for Liner and Cover Systems," M.S. Thesis, Univ. of Texas at Austin, 152 p.

Estornell, P., and Daniel, D.E. (1992), "Hydraulic Conductivity of Three Geosynthetic Clay Liners," Journal of Geotechnical Engineering, Vol. 118, No. 10, pp. 1592-1606.

Eykholt, G.R. (1988), "Stability of Amended Sand Permeated with Fly Ash Leachate," M.S. Thesis, University of Texas, Austin, 55 p.

Focht, J.A. Jr. - personal communication.

Freeze, R.A. and Cherry, J.A. (1979) Groundwater, Prentice-Hall, Inc., Englewood Cliffs, N.J.

Giroud, J. P., Bonaparte, R., Beech, J. F., and Gross, B. A., "Design of Soil Layer - Geosynthetic Systems Overlying Voids", Journal of Geotextiles and Geomembranes, Vol. 9, No. 1, 1990, pp. 11-50.

Gleason, M.H. (1993), "Comparative Testing of Calcium and Sodium Smectite Clays for Geotechnical and Environmental Applications," M.S. Thesis, University of Texas at Austin, 200 p.

GRI GM6, Standard Practice for "Pressurized Air Test for Duel Seamed Geomembranes".

GRI GM 12, Asperity Measurement of Textured Geomembrane Using a Depth Gage

GRI GM 13, Test Methods, Test Properties and Testing Frequencies for High Density Polyethylene (HDPE) Smooth and Textured Geomembrane

Grim, R.E. (1948), "Some Fundamental Factors Influencing the Properties of Soil Materials," Proceedings, Second International Conference on Soil Mechanics and Foundation Engineering, Rotterdam, Vol. 3, pp. 8-12.

Grim, R.E. (1962), Applied Clay Mineralogy, McGraw Hill Book Company, New York, 442 p.

Kim, W.H., and Daniel, D.E. (1992), "Effects of Freezing on Hydraulic Conductivity of Compacted Clay," Journal of Geotechnical Engineering, Vol. 118, No. 7, pp. 1083-1097.

Koerner, R.M. (1990), Designing with Geosynthetics, Third Ed., Prentice-Hall, Englewood Cliffs, New Jersey, 783 p.

LaGatta, M.D. (1992), "Hydraulic Conductivity Tests on Geosynthetic Clay Liners Subjected to Differential Settlement," M.S. Thesis, Univ. of Texas at Austin, 120 p.

Lambe, T.N. and Whitman, R.V. (1969) Soil Mechanics, John Wiley & Sons, Inc., New York.

Lo, I.M.C. (1992), "Development and Evaluation of Clay Liner Materials for Hazardous Waste Sites," Ph.D. Dissertation, Univ. of Texas at Austin, 289 p.

Mansur, C.I. and Kaufman, R.I. (1962) "Dewatering" from Foundation Engineering ed. by Leonards, G.A., McGraw-Hill Book Co., Inc., New York.

Mesri, G., and Olson, R.E. (1970), "Shear Strength of Montmorillonite," Geotechnique, Vol. 20, No. 3, pp. 261-270.

Mesri, G., and Olson, R.E. (1971), "Mechanisms Controlling the Permeability of Clays," Clays and Clay Minerals, Vol. 19, pp. 151-158.

Mitchell, J.K. (1993), Fundamentals of Soil Behavior, Second Edition, John Wiley and Sons, New York, 437 p.

Olson, R.E. (1974), "Shearing Strengths of Kaolinite, Illite, and Montmorillonite," Journal of the Geotechnical Engineering Division, ASCE, Vol. 100, No. GT11, pp. 1215-1229.

Othman, M.A., and Benson, C.B. (1991), "Influence of Freeze-Thaw on the Hydraulic Conductivity of Compacted Clay," Proceedings, Fourteenth Annual Madison Waste Conference, University of Wisconsin at Madison, pp. 296-312.

Powers, J.P. (1981) Construction Dewatering, A Guide to Theory and Practice, John Wiley & Sons, Inc., New York.

Richardson, G. N. and R. M. Koerner, (1987). "Geosynthetic Design Guidance for Hazardous Waste Landfill Cells and Surface Impoundments," Hazardous Waste Engineering Research Laboratory, U.S. EPA Office of Research and Development, Cincinnati, Ohio; Contract No. 68-07-3338.

Reed, J. K., Allendorf, M., and Elizondo, M. (2010), “Effective Design and Construction of Subtitle D Liners Below the Groundwater Table”, 2010 Global Waste Management Symposium, San Antonio, Texas.

Savage, G. M., Diaz, L. F., Golueke, C. G., Martone, C., and Ham, R. K. (1998), Guidance for Landfilling Waste in Economically Developing Countries, U.S. EPA Contract 68-C4-0022

Schubert, W.R. (1987), "Bentonite Matting in Composite Lining System," Geotechnical Practice for Waste Disposal '87, R.D. Woods (Ed.), American Society of Civil Engineers, New York, pp. 784-796.

Shackelford, C.D., and Daniel, D.E. (1991), "Diffusion in Saturated Soil. II: Results for Compacted Clay," Journal of Geotechnical Engineering, Vol. 117, No. 3, pp. 485-506.

Shan, H.Y. (1990), "Laboratory Tests on a Bentonitic Blanket," M.S. Thesis, Univ. of Texas at Austin, 84

Shan, H.Y., and Daniel, D.E. (1991), "Results of Laboratory Tests on a Geotextile/Bentonite Liner Material," Geosynthetics '91, Vol. 2, Industrial Fabrics Association International, St. Paul, Minnesota, pp. 517-535.

Terzaghi, K. and Peck, R.B. (1967) Soil Mechanics in Engineering Practice, John Wiley & Sons, Inc., New York.

Trautwein, Stephen J. and Boutwell, Gordon P., 1993, "In-situ Hydraulic Conductivity Tests for Compacted Soil Liners and Caps," conference in San Antonio during January 1993, ASTM D-18.

U.S. Army Corps of Engineers, 1970, "Laboratory Soil Testing," Office of the Chief of Engineers, Washington, DC, Engineer Manual 1110-2-1906.

U.S. Army Corps of Engineers, (1971), "Dewatering and Groundwater Control for Deep Excavations", Department of the Army, TM 5-818-5.

U.S. EPA (1989), "Technical Guidance Document: The Fabrication of Polyethylene FML Field Seams," EPA/530/SW-89/069, U.S. EPA Office of Solid Waste and Emergency Response, Washington, DC. NTIS PB-90-119595.

U.S. EPA (1991), "Inspection Techniques for the Fabrication of Geomembrane Field Seams," EPA Technical Guidance Document, EPA/53 0/SW-91/051.

U.S. EPA (1993a), "Technical Guidance Document: Quality Assurance and Quality Control for Waste Containment Facilities," EPA/600/R-93/182, U.S. EPA Office of Research and Development, Washington DC.

U.S. EPA (1993b), "Solid Waste Disposal Facility Criteria: Technical Manual," EPA/530/R-93/017, U.S. EPA Office of Solid Waste and Emergency Response, Washington DC. NTIS PB94-100-450.

Williams, C.E. (1989) "Long Term Performance of High Rise Mat Foundation", Proceedings of the Congress on Foundation Engineering: Current Principles and Practices, American Society of Civil Engineers, Northwestern University, Volume 2, pp. 1432-1444.

Wong, L.C., and M.D. Haug (1991), "Cyclical Closed-System Freeze-Thaw Permeability Testing of Soil Liner and Cover Materials," Canadian Geotechnical Journal, Vol. 28, No. 6, pp. 784-793.

Wright, T. D., W. M. Held, J. R. Marsh, and L. R. Hovater (1987), "Manual of Procedures and Criteria for Inspecting the Installation of Flexible Membrane Liners in Hazardous Waste Facilities," EPA-6803-3247, prepared for Hazardous Waste Engineering Research Laboratory, U.S. EPA Office of Research and Development, Cincinnati, OH.

APPENDIX C

HDPE Geomembrane and Geonet Material Specifications

GEOSYNTHETIC MATERIAL SPECIFICATIONS HDPE SMOOTH GEOMEMBRANE				
Property	**Qualifier**	**Test Method**	**Specified Value 1.50 mm**	**Testing Frequency (minimum)**
Thickness * lowest individual of 10 values	Minimum average	ASTM D5199	1.50 mm -10%	Per roll
Density (geomembrane)	Minimum	ASTM D1505/D792	0.94 g/cc	90,000 kg
Tensile Properties: *(1)* 1. Yield strength 2. Break strength 3. Elongation at yield 4. Elongation at break	Minimum average (each direction)	ASTM D6693 Type IV	 22 kN/m 40 kN/m 12 % 700 %	9,000 kg
Tear strength	Minimum average	ASTM D1004	187 N	20,000 kg
Puncture resistance	Minimum average	ASTM D4833	480 N	20,000 kg
Stress Crack Resistance *(2)*		ASTM D5397 (App.)	300 hour	Per GRI GM-10
Carbon black content	Range	ASTM D1603 *(3)*	2.0 – 3.0%	9,000 kg
Carbon black dispersion	*Note 4*	ASTM D5596	*note 4*	20,000 kg
Oxidation Induction Time (OIT) *(5)* (a) Standard OIT or (b) High Pressure OIT	Minimum average	 ASTM D3895 ASTM D5885	 100 minute 400 minute	90,000 kg
Oven Aging at 85^0 *(5)*,*(6)* (a) Standard OIT - % retained after 90 days or (b) High Pressure OIT - % retained after 90 days	Minimum average	ASTM D5721 ASTM D3895 ASTM D5885	55 % 80 %	Per each formulation
UV Resistance *(7)* (a) Standard OIT or (b) High pressure OIT- % retained after 1600 hours *(9)*	Minimum average	ASTM D3895 ASTM D5885	N.R. *(8)* 50 %	Per each formulation

(1) Machine direction (MD) and cross machine direction (XMD) average values should be on the basis of 5 test specimens each direction.
Yield elongation is calculated using gage length of 33 mm.
Break elongation is calculated using a gage length of 50 mm.
(2) The yield stress used to calculate the applied load for the SP-NCTL test should be the manufacturer's mean value via MQC testing.
(3) Other methods such as D4218 (muffle furnace) or microwave methods are acceptable if an appropriate correlation to D1603 (tube furnace) can be established.
(4) Carbon black dispersion (only near spherical agglomerates) for 10 different views.
9 in Categories 1 or 2 and 1 in Category 3.
(5) The manufacturer has the option to select either one of the OIT methods listed to evaluate the antioxidant content in the geomembrane.
(6) It is also recommended to evaluate samples at 30 to 60 days to compare with the 90 day response.
(7) The condition of the test should be 20 hr. UV cycle at 75^0 C followed by 4 hr. condensation at 60^0 C.
(8) Not recommended since the high temperature of the Std. OIT test produces an unrealistic result for some of the antioxidants in the UV exposed samples.
(9) UV resistance is based on percent retained value regardless of the original HP OIT value.

HDPE TEXTURED GEOMEMBRANE				
Property	**Qualifier**	**Test Method**	**Specified Value 1.50 mm**	**Testing Frequency (minimum)**
Thickness * lowest individual for 8 out of 10 values * lowest individual of 10 values	Minimum average	ASTM D5199	1.50 mm(-5%) -10% -15%	Per roll
Asperity Height mils *(1)*	Minimum average	GM 12	0.25 mm	Every 2nd roll *(2)*
Density (geomembrane)	Minimum average	ASTM D1505/D792	0.94 g/cc	90,000 kg
Tensile Properties: *(3)* 1. Yield strength 2. Break strength 3. Elongation at yield 4. Elongation at break	Minimum average (each direction)	ASTM D6693 Type IV	 22 kN/m 16 kN/m 12 % 100 %	9,000 kg
Tear strength	Minimum average	ASTM D1004	187 N	20,000 kg
Puncture resistance	Minimum average	ASTM D4833	400 N	20,000 kg
Stress Crack Resistance *(4)*		ASTM D5397 (App.)	300 hour	Per GRI GM-10
Carbon black content	Range	ASTM D1603 *(5)*	2.0 – 3.0%	9,000 kg
Carbon black dispersion	*Note 6*	ASTM D5596	*note 6*	20,000 kg
Oxidation Induction Time (OIT)*(7)* (a) Standard OIT or (b) High Pressure OIT	Minimum average	 ASTM D3895 ASTM D5885	 100 minute 400 minute	90,000 kg
Oven Aging at 85^0 *(7),(8)* (a) Standard OIT - % retained after 90 days, or (b) High Pressure OIT - % retained after 90 days	Minimum average	 ASTM D5721 ASTM D3895 ASTM D5885	 55 % 80 %	Per each formulation
UV Resistance *(9)* (a) Standard OIT, or (b) High pressure OIT- % retained after 1600 hours *(11)*	Minimum average	 ASTM D3895 ASTM D5885	 N.R. *(10)* 50 %	Per each formulation

(1) Of 10 readings: 8 out of 10 must be ≥ 0.18 mm, and the lowest individual reading must be ≥ 0.13 mm.
(2) Alternate the measurement side for double-sided textured sheet.
(3) Machine direction (MD) and cross machine direction (XMD) average values should be on the basis of 5 test specimens each direction.
Yield elongation is calculated using gage length of 33 mm.
Break elongation is calculated using a gage length of 50 mm.
(4) P-NCTL test is not appropriate for testing geomembranes with textured or irregular rough surfaces. Test should be conducted on smooth edges of textured rolls or on smooth sheets made from the same formulation as being used for textured sheet materials.
(5) Other methods such as D4218 (muffle furnace) or microwave methods are acceptable if an appropriate correlation to D1603 (tube furnace) can be established.
(6) Carbon black dispersion (only near spherical agglomerates) for 10 different views. 9 in Categories 1 or 2 and 1 in Category 3.
(7) The manufacturer has the option to select either one of the OIT methods listed to evaluate the antioxidant content in the geomembrane.
(8) It is also recommended to evaluate samples at 30 to 60 days to compare with the 90 day response.
(9) The condition of the test should be 20 hr. UV cycle at 75^0 C followed by 4 hr. condensation at 60^0 C.
(10) Nor recommended since the high temperature of the Std. OIT test produces an unrealistic result for some of the antioxidants in the UV exposed samples.
(11) UV resistance is based on percent retained value regardless of the original HP OIT value.

GEOSYNTHETIC MATERIAL SPECIFICATIONS				
HDPE GEOMEMBRANE SEAMS				
Property	**Qualifier**	**Unit**	**Specified Value *(1)***	**Test Method**
Thickness	Minimum average	mm	1.50	NA
Bonded Seam Strength *(2)*	Minimum	N/mm	29.4	ASTM D4437*
Peel Adhesion *(3)*	Minimum	N/mm	19.4	ASTM D4437*

(1) a. All passing peel adhesion test must exhibit a Film Tear Bond (FTB)
b. At least four of five specimens from each peel and shear determination must meet the minimum specified value.
c. The average value from all five specimens from peel and shear determination must meet the minimum specified value.

(2) At least 95 percent of the specified geomembrane tensile strength at yield.

(3) At least 62 percent of the specified geomembrane tensile strength at yield.

* For shear tests, the sheet shall yield before failure of the seam. For peel adhesion, seam separation shall not extend more than 10% into the seam. For either test, testing shall be discontinued when the sample has visually yielded. Sample failure shall conform to a passing configuration as outlined in the NSF Standard.

GEOSYNTHETIC MATERIAL SPECIFICATIONS				
HDPE SOLID GEONET				
Property	**Qualifier**	**Unit**	**Value**	**Test Method**
Thickness	Minimum	mm	5.00	ASTM D5199
Mass per Unit Area	Minimum	N/m^2	0.77	ASTM D3776
Polyethylene Content	Minimum	%	95	---
Density	Minimum	g/cc	0.940	ASTM D1505
Carbon Black Content	Range	%	2.0 to 3.0	ASTM D1603 or ASTM D4218
Melt Index	Minimum	g/10 min	1.0	ASTM D1238 (Condition 190/216)
Tensile Strength (machine direction)	Minimum	N/mm	7	ASTM D1682* or ASTM D5035
Transmissivity	Minimum	m^2/sec	1×10^{-3}	ASTM D4716**

* Test method modified as follows:
1) Use 10 cm x 20 cm specimens
2) Use grip separation of 10 cm.
3) Use test rate of 20 cm/min.
4) Continue test until first strand separates completely
5) Report averages of 5 tests in machine direction.

** Gradient = 1.0; confining pressure = 723 kN/m^2 (solid geonet), 193 kN/m^2 (foamed geonet) measured between two steel plates one hour after application of confining pressure.

APPENDIX D

Monitoring Well Completion Form

Site Name: ______________________________

Location: _______________________________ Monitor Well I.D. No.:____________________

Date of Monitoring Well Installation:________ Date of Monitoring Well Development: ______

Latitude _______________________________ Longitude:_______________________________

Monitoring Well Name:______________________________________ Driller:___________________

NOTES:

- Report all depths from surface and all elevations relative to mean sea level (msl) to nearest hundredth of a meter.
- Diameter of boring should be at least 0.1 meters larger than diameter of well casing.
- Use flush screw joint casing only, 5 cm diameter or larger, with o-rings or PTFE tape in joints
- Well development should continue until water is clear, and pH and conductivity are stable.

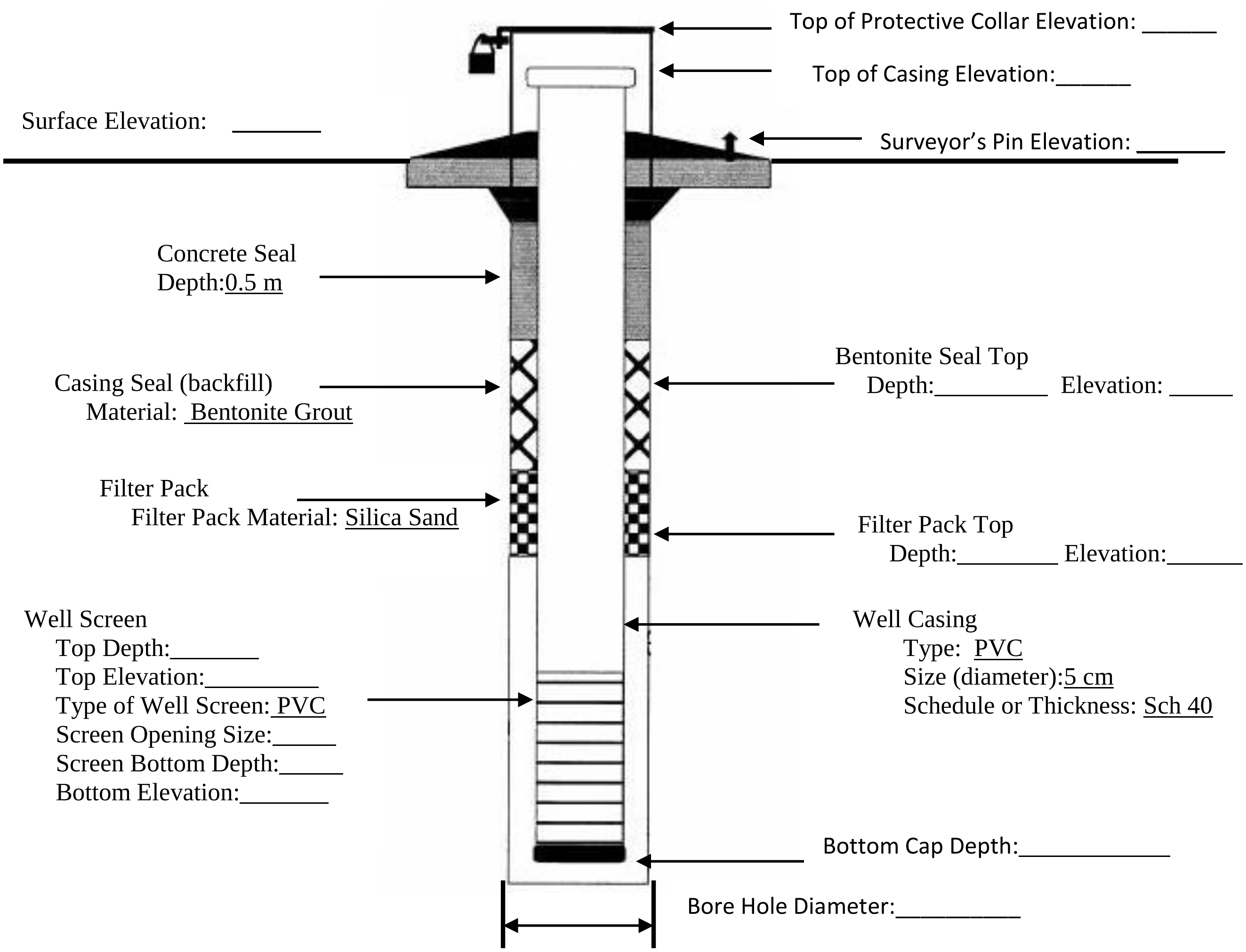
Field Staff Supervising Installation: ____

Static Water Level after Well Development:___________

Name of Geologic Formation(s) in which Well is completed: ____________________________________

Type of Locking Device: _____________ Type of Case Protection: ___________________

Concrete Surface Pad (with steel reinforcement) Dimensions: _____________



Landfill Gas Monitoring Probe Completion Form

Site Name: ______________________________

Location: _______________________________ Gas Monitoring Probe I.D. No.:_____________

Date of Monitoring Probe Installation:________

Latitude _______________________________ Longitude:_______________________________

Monitoring Probe Driller:___________________

Name:_____________________________________

NOTES:

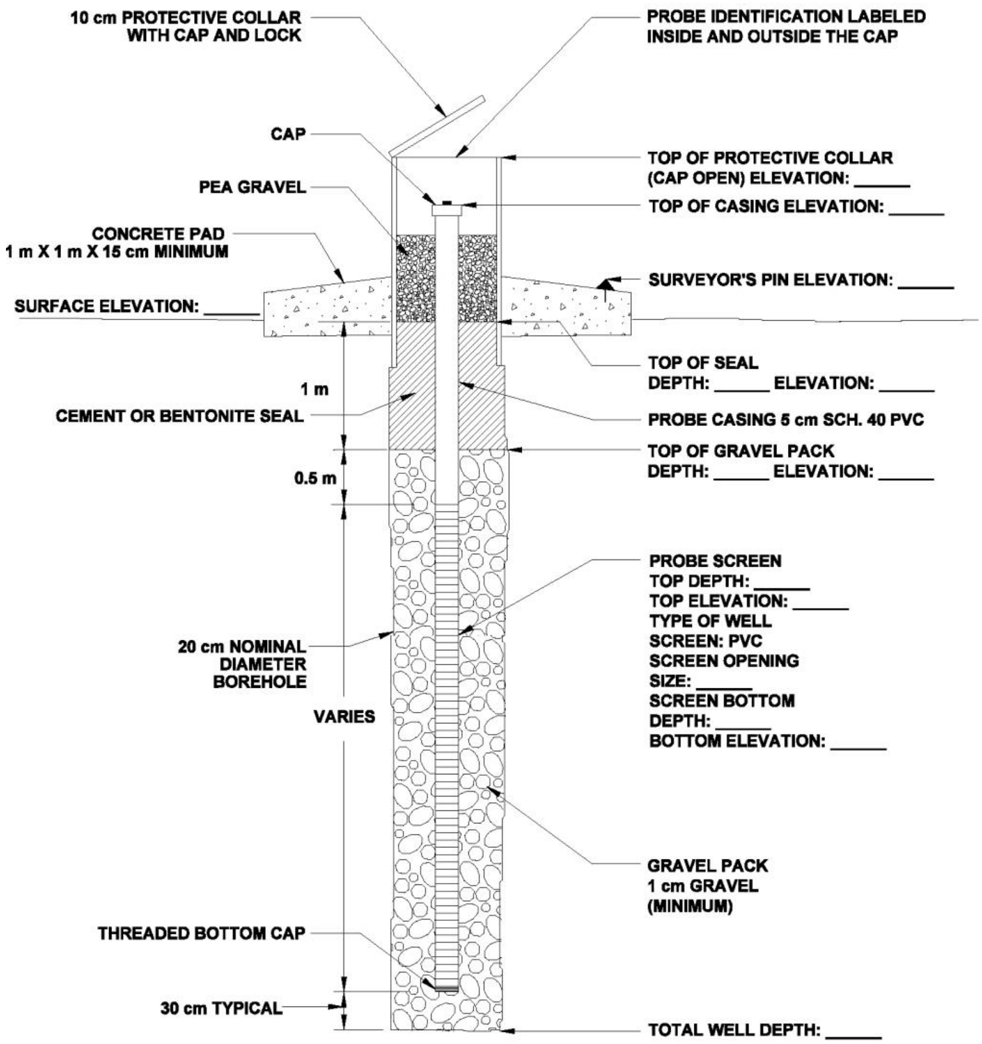
- Report all depths from surface and all elevations relative to mean sea level (msl) to nearest hundredth of a meter.
- Diameter of boring should be at least 0.1 meters larger than diameter of well casing.
- Use flush screw joint casing only, 5 cm diameter or larger, with o-rings or PTFE tape in joints

Field Staff Supervising Installation: ____

Name of Geologic Formation(s) in which Well is completed: ____________________________________

Type of Locking Device: ____________ Type of Case Protection: __________________

Concrete Surface Pad (with steel reinforcement) Dimensions: ____________


10 cm PROTECTIVE COLLAR
WITH CAP AND LOCK
PROBE IDENTIFICATION LABELED
INSIDE AND OUTSIDE THE CAP
CAP
TOP OF PROTECTIVE COLLAR
(CAP OPEN) ELEVATION: ______
PEA GRAVEL
TOP OF CASING ELEVATION: ______
CONCRETE PAD
1 m X 1 m X 15 cm MINIMUM
SURVEYOR'S PIN ELEVATION: ______
SURFACE ELEVATION: ______
TOP OF SEAL
DEPTH: ______ ELEVATION: ______
1 m
CEMENT OR BENTONITE SEAL
PROBE CASING 5 cm SCH. 40 PVC
TOP OF GRAVEL PACK
DEPTH: ______ ELEVATION: ______
0.5 m
PROBE SCREEN
TOP DEPTH: ______
TOP ELEVATION: ______
TYPE OF WELL
SCREEN: PVC
SCREEN OPENING
SIZE: ______
SCREEN BOTTOM
DEPTH: ______
BOTTOM ELEVATION: ______
20 cm NOMINAL
DIAMETER
BOREHOLE
VARIES
GRAVEL PACK
1 cm GRAVEL
(MINIMUM)
THREADED BOTTOM CAP
30 cm TYPICAL
TOTAL WELL DEPTH: ______

APPENDIX E

APPLICABLE SOLID WASTE LEGISLATION

APPENDIX F

AUDIT/INSPECTION CHECKLIST

INSPECTION AND AUDIT CHECKLIST FOR NEW SANITARY LANDFILL CONSTRUCTION

FACILITY

FACILITY NAME:____

OWNER/OPERATORS NAME:_______________________________________

LOCATION:____
_

OWNER/OPERATOR'S REPRESENTATIVE NAME:__________________________

CONTACT NUMBER:____

INSPECTION/AUDIT

DATE OF AUDIT/INSPECTION:______________________________________

INSPECTOR NAME:____

DATE OF LAST INSPECTION:_______________________________________

WEATHER CONDITIONS:____

ITEM NO.	DESCRIPTION	COMPLETED YES/NO/N.A.	DATE OF COMPLETION	COMMENTS
1	**Landfill Construction**			
1.1	Soil Liner Construction.			
1.2	Geomembrane Liner Construction.			
1.3	Leachate Collection Layer Construction.			
1.4	Liner Constructed Below Seasonal High Groundwater Table.			
1.5	Liner Construction Documentation and Reporting.			
1.6	Groundwater Monitoring Well Construction.			
1.7	Landfill Gas Monitoring Probe Construction.			
2	**Soil Liner**			
2.1	Soil liner construction has full time			

ITEM NO.	DESCRIPTION	COMPLETED YES/NO/N.A.	DATE OF COMPLETION	COMMENTS
	independent construction quality assurance and quality control monitoring.			
2.2	Liner tie in to existing lined disposal cell.			
2.3	Pre construction soil material tests.			
2.4	Soil meets liner material specifications.			
2.5	Adequate compaction equipment and effort.			
2.6	Liner soil hydrated.			
2.7	Clod and rock size maximum 25 mm.			
2.8	Surface drainage controls in place to keep surface water from entering the liner area.			
2.9	No ponded water on soil liner.			
2.10	Soil liner kept moist prior to placement of geomembrane to reduce shrinkage cracking.			
2.11	Field density and moisture content testing.			
2.12	Construction soil laboratory testing including sieve analysis, Atterberg limits, and coefficient of permeability.			
2.13	Surveyor verification of 60 cm soil liner thickness.			
2.14	Other Soil Liner.			
3	**Geomembrane Liner**			
3.1	Geomembrane liner construction has full time independent construction quality assurance and quality control monitoring.			
3.2	0.152 mm (60 mil) High Density Polyethylene flexible membrane liner.			
3.3	Geomembrane properly manufactured, shipped, delivered and stored to protect material from damage.			
3.4	Subgrade compacted and rolled smooth and free of sharp stones, stones larger than 1 cm in size, and sticks or other debris.			
3.5	Geomembrane deployed to not damage subgrade.			
3.6	Only low ground pressure supporting equipment allowed on geomembrane (golf carts, all terrain vehicles or other small rubber tired equipment with a ground pressure less than			

ITEM NO.	DESCRIPTION	COMPLETED YES/NO/N.A.	DATE OF COMPLETION	COMMENTS
	35kPa and a total weight less than 340 kg).			
3.7	All seams either fusion track welded or extrusion welded.			
3.8	All fusion track welds air pressure tested.			
3.9	All extrusion welds vacuum box tested.			
3.10	No seaming above 40º C or below 1º C ambient air temperature.			
3.11	Control of folds, large wrinkles, and fish mouths.			
3.12	End of work day, all unseamed edges should be anchored.			
3.13	Appropriate testing of geomembrane materials.			
3.14	Destructive testing of seams.			
3.15	Anchor trench constructed and backfilled.			
3.16	Protective cover or drainage layer material placed over geomembrane to control fingers and minimize wrinkles and folds in the geomembrane.			
3.17	A minimum of 60 cm of protective cover and or granular drainage layer.			
3.18	Control of rocks greater than 1 cm, vegetation or other material that may damage the geomembrane.			
3.19	Other geomembrane liner.			
4	**Leachate Collection System**			
4.1	Leachate collection system construction has full time independent construction quality assurance and quality control monitoring.			
4.2	Granular drainage layer, geocomposite or geonet and geotextile leachate collection layer.			
4.3	Material meets drainage layer specifications.			
4.4	Material place and deployed appropriately.			
4.5	Leachate collection pipe.			
4.6	Leachate recovery sump.			
4.7	Leachate handling system.			
4.8	Other leachate collection system.			
5	**Liners Constructed Below Seasonal High Water Table**			

ITEM NO.	DESCRIPTION	COMPLETED YES/NO/N.A.	DATE OF COMPLETION	COMMENTS
5.1	Dewatering system and/or ballast construction has full time independent construction quality assurance and quality control monitoring.			
5.2	Dewatering system constructed and operating.			
5.3	Other dewatering and ballast.			
6	**Liner Construction Documentation and Reporting**			
6.1	Liner Evaluation Report.			
6.2	Ballast Evaluation Report.			
6.3	Other documentation and reporting.			
7	**Groundwater Monitoring Well**			
7.1	Metal protective casing.			
7.2	Concrete pad.			
7.3	Area around groundwater well and concrete pad free of debris.			
7.4	Protective casing locked.			
7.5	Monitoring well has removable cap.			
7.6	Monitoring well surveyed for latitude, longitude and elevations.			
7.7	Other groundwater monitoring well.			
8	**Landfill Gas Monitoring Probe**			
8.1	Metal protective casing.			
8.2	Concrete pad.			
8.3	Area around gas monitoring probe and concrete pad free of debris.			
8.4	Protective casing locked.			
8.5	Gas monitoring probe has removable cap with quick connect fitting.			
8.6	Gas monitoring probe surveyed for latitude, longitude and elevations.			
8.7	Other gas monitoring probe.			

OTHER COMMENTS
