EXHIBIT

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EPA

Solid Waste Disposal Facility Criteria

Technical Manual

EXHIBIT

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Depending on the type of geomembrane, several bonding systems are available for the construction of both factory and field seams. Bonding methods include solvents, heat seals, heat guns, dielectric seaming, extrusion welding, and hot wedge techniques. To ensure the integrity of the seams, a geomembrane should be seamed using the bonding system recommended by the manufacturer (U.S. EPA, 1988). EPA has developed a field seaming manual for all types of geomembranes (U.S. EPA, 1991a).

Thermal methods of seaming require cleanliness of the bonding surfaces, heat, pressure, and dwell time to produce high quality seams. The requirements for adhesive systems are the same as those for thermal systems, except that the adhesive takes the place of the heat. Sealing the geomembrane to appurtenances and penetrating structures should be performed in accordance with detailed drawings included in the design plans and approved specifications.

An anchor trench along the perimeter of the cell generally is used to secure the geomembrane during construction (to prevent sloughing or slipping down the interior side slopes). Run out calculations (Koerner, 1990) are available to determine the depth of burial at a trench necessary to hold a specified length of membrane, or combination of membrane and geofabric or geotextile. If forces larger than the tensile strength of the membrane are inadvertently developed, then the membrane could tear. For this reason, the geomembrane should be allowed to slip or give in the trench after construction to prevent such tearing. However, during construction, the geomembrane should be anchored according to the detailed drawings provided in the design plans and specifications (USEPA, 1988).

Geomembranes that are subject to damage from exposure to weather and work activities should be covered with a layer of soil as soon as possible after quality assurance activities associated with geomembrane testing are completed. Soil should be placed without driving construction vehicles directly on the geomembrane. Light ground pressure bulldozers may be used to push material out in front over the liner, but the operator must not attempt to push a large pile of soil forward in a continuous manner over the membrane. Such methods can cause localized wrinkles to develop and overturn in the direction of movement. Overturned wrinkles create sharp creases and localized stresses in the geomembrane that could lead to premature failure. Instead, the operator should continually place smaller amounts of soil or drainage material working outward over the toe of the previously placed material. Alternatively, large backhoes can be used to place soil over the geomembrane that can later be spread with a bulldozer or similar equipment. Although such methods may sound tedious and slow, in the long run they will be faster and more cost-effective than placing too much material too fast and having to remobilize the liner installer to repair damaged sections of the geomembrane. The QA activities conducted during construction also should include monitoring the contractor's activities on top of the liner to avoid damage to installed and accepted geomembranes.

Leachate Collection Systems

Leachate refers to liquid that has passed through or emerged from solid waste and contains dissolved, suspended, or immiscible materials removed from the solid waste. At MSWLF units, leachate is typically aqueous with limited, if any, immiscible fluids or dissolved solvents. The primary function of the leachate collection system is to collect and convey leachate out of the landfill unit and to control the depth of the leachate above the liner. The leachate collection system (LCS) should be designed to meet the regulatory performance standard of maintaining less than 30 cm (12 inches) depth of leachate, or "head," above the liner. The 30-cm head allowance is a design standard and the Agency recognizes that this design standard may be exceeded for relatively short periods of time during the active life of the unit. Flow of leachate through imperfections in the liner system increases with an increase in leachate head above the liner. Maintaining a low leachate level above the liner helps to improve the performance of the composite liner.

Leachate is generally collected from the landfill through sand drainage layers, synthetic drainage nets, or granular drainage layers with perforated plastic collection pipes, and is then removed through sumps or gravity drain carrier pipes. LCS's should consist of the following components (U.S. EPA, 1988):

- A low-permeability base (in this case a composite liner);
- A high-permeability drainage layer, constructed of either natural granular materials (sand and gravel) or synthetic drainage material (e.g., geonet) placed directly on the FML, or on a protective bedding layer (e.g., geofabric) directly overlying the liner;
- Perforated leachate collection pipes within the high-permeability drainage layer to collect leachate and carry it rapidly to a sump or collection header pipe;
- A protective filter layer over the high permeability drainage material, if necessary, to prevent physical clogging of the material by fine-grained material; and
- Leachate collection sumps or header pipe system where leachate can be removed.

The design, construction, and operation of the LCS should maintain a maximum height of leachate above the composite liner of 30 cm (12 in). Design guidance for calculating the maximum leachate depth over a liner for granular drainage systems materials is provided in the reference U.S. EPA (1989). The leachate head in the layer is a function of the liquid impingement rate, bottom slope, pipe spacing, and drainage layer hydraulic conductivity. The impingement rate is estimated using a complex liquid routing procedure. If the maximum leachate depth exceeds 30 cm for the system, except for short-term occurrences, the design should be modified to improve its efficiency by increasing grade, decreasing pipe spacing, or increasing the hydraulic conductivity (transmissivity) of the drainage layer (U.S. EPA, 1988).

Grading of Low-Permeability Base

The typical bottom liner slope is a minimum of two percent after allowances for settlement at all points in each system. A slope is necessary for effective gravity drainage through the entire operating and post-closure period. Settlement estimates of the foundation soils should set this two-percent grade as a post-settlement design objective (U.S. EPA, 1991b).

High-Permeability Drainage Layer

The high-permeability drainage layer is placed directly over the liner or its protective bedding layer at a slope of at least two percent (the same slope necessary for the composite liner). Often the selection of a drainage material is based on the on-site availability of natural granular materials. In some regions of the country, hauling costs may be very high for sand and gravel, or appropriate materials may be unavailable; therefore, the designer may elect to use geosynthetic drainage nets (geonets) or synthetic drainage materials as an alternative. Frequently, geonets are substituted for granular materials on steep sidewalls because maintaining sand on the slope during construction and operation of the landfill unit is more difficult (U.S. EPA, 1988).

Soil Drainage Layers

If the drainage layer of the leachate collection system is constructed of granular soil materials (e.g., sand and gravel), then it should be demonstrated that this granular drainage layer has sufficient bearing strength to support expected loads. This demonstration will be similar to that required for the foundations and soil liner (U.S. EPA, 1988).

If the landfill unit is designed on moderate-to-steep (15 percent) grades, the landfill design should include calculations demonstrating that the selected granular drainage materials will be stable on the most critical slopes (e.g., usually the steepest slope) in the design. The calculations and assumptions should be shown, especially the friction angle between the geomembrane and soil, and if possible, supported by laboratory and/or field testing (USEPA, 1988).

Generally, gravel soil with a group designation of GW or GP on the Unified Soils Classification Chart can be expected to have a hydraulic conductivity of greater than 0.01 cm/sec, while sands identified as SW or SP can be expected to have a coefficient of permeability greater than 0.001 cm/sec. The sand or gravel drains leachate that enters the drainage layer to prevent 30 cm (12 in) or more accumulation on top of the liner during the active life of the MSWLF unit LCS. The design of a LCS frequently uses a drainage material with a hydraulic conductivity of 1×10^{-2} cm/sec or higher. Drainage materials with hydraulic conductivities in this order of magnitude should be evaluated for biological and particulate clogging (USEPA, 1988). Alternatively, if a geonet is used, the design is based on the transmissivity of the geonet.

If a filter layer (soil or geosynthetic) is constructed on top of a drainage layer to protect it from clogging, and the LCS is designed and operated to avoid drastic changes in the oxidation reduction potential of the leachate (thereby avoiding formation of precipitates within the LCS), then there is no conceptual basis to anticipate that conductivity will decrease over time. Where conductivity is expected to decrease over time, the change in impingement rate also should be evaluated over the same time period because the reduced impingement rate and hydraulic conductivity may still comply with the 30 cm criterion.

Unless alternative provisions are made to control incident precipitation and resulting surface run-off, the impingement rate during the operating period of the MSWLF unit is usually at least an order of magnitude greater than the impingement rate after final closure. The critical design condition for meeting the 30 cm (12 in) criterion can therefore be expected during the operating life. The designer may evaluate the sensitivity of a design to meet the 30 cm (12 in) criterion as a result of changes in impingement rates, hydraulic conductivity, pipe spacing, and grades. Such sensitivity analysis may indicate which element of the design should be emphasized during construction quality monitoring or whether the design can be altered to comply with the 30 cm (12 in) criterion in a more cost-effective manner.

The soil material used for the drainage layer should be investigated at the borrow pit prior to use at the landfill. Typical borrow pit characterization testing would include laboratory hydraulic conductivity and grain size distribution. If grain size distribution information from the borrow pit characterization program can be correlated to the hydraulic conductivity data, then the grain size test, which can be conducted in a short time in the field, may be a useful construction quality control parameter. Compliance with this parameter would then be indicative that the hydraulic conductivity design criterion was achieved in the constructed drainage layer. This information could be incorporated into construction documents after the borrow pit has been characterized. If a correlation cannot be made between hydraulic conductivity and grain size distribution, then construction documents may rely on direct field or laboratory measurements to demonstrate that the hydraulic conductivity design criterion was met in the drainage layer.

Granular materials are generally placed using conventional earthmoving equipment, including trucks, scrapers, bulldozers, and front-end loaders. Vehicles should not be driven directly over the geosynthetic membrane when it is being covered. (U.S. EPA, 1988a).

Coarse granular drainage materials, unlike low-permeability soils, can be placed dry and do not need to be heavily compacted. Compacting granular soils tends to grind the soil particles together, which increases the fine material and reduces hydraulic conductivity. To minimize settlement following material placement, the granular material may be compacted with a vibratory roller. The final thickness of the drainage layer should be checked by optical survey measurements or by direct test pit measurements (U.S. EPA, 1988).

Geosynthetic Drainage Nets

Geosynthetic drainage nets (geonets) may be substituted for the granular layers of the LCRs on the bottom and sidewalls of the landfill cells. Geonets require less space than perforated pipe or gravel and also promote rapid transmission of liquids. They do, however, require geotextile filters above them and can experience problems with creep and intrusion. Long-term operating and performance experience of geonets is limited because the material and its application are relatively new (U.S. EPA, 1989).

If a geonet is used in place of a granular drainage layer, it must provide the same level of performance (maintaining less than 30 cm of leachate head above the liner). An explanation of the calculation used to compute the capacity of a geonet may be found in U.S. EPA (1987a). The transmissivity of a geonet can be reduced significantly by intrusion of the soil or a geotextile. A protective geotextile between the soil and geonet will help alleviate this concern. If laboratory transmissivity tests are performed, they should be done under conditions, loads, and configurations that closely replicate the actual field conditions. It is important that the transmissivity value used in the leachate collection system design calculations be selected based upon those loaded conditions (U.S. EPA, 1988). It is also important to ensure that appropriate factors of safety are used (Koerner, 1990).

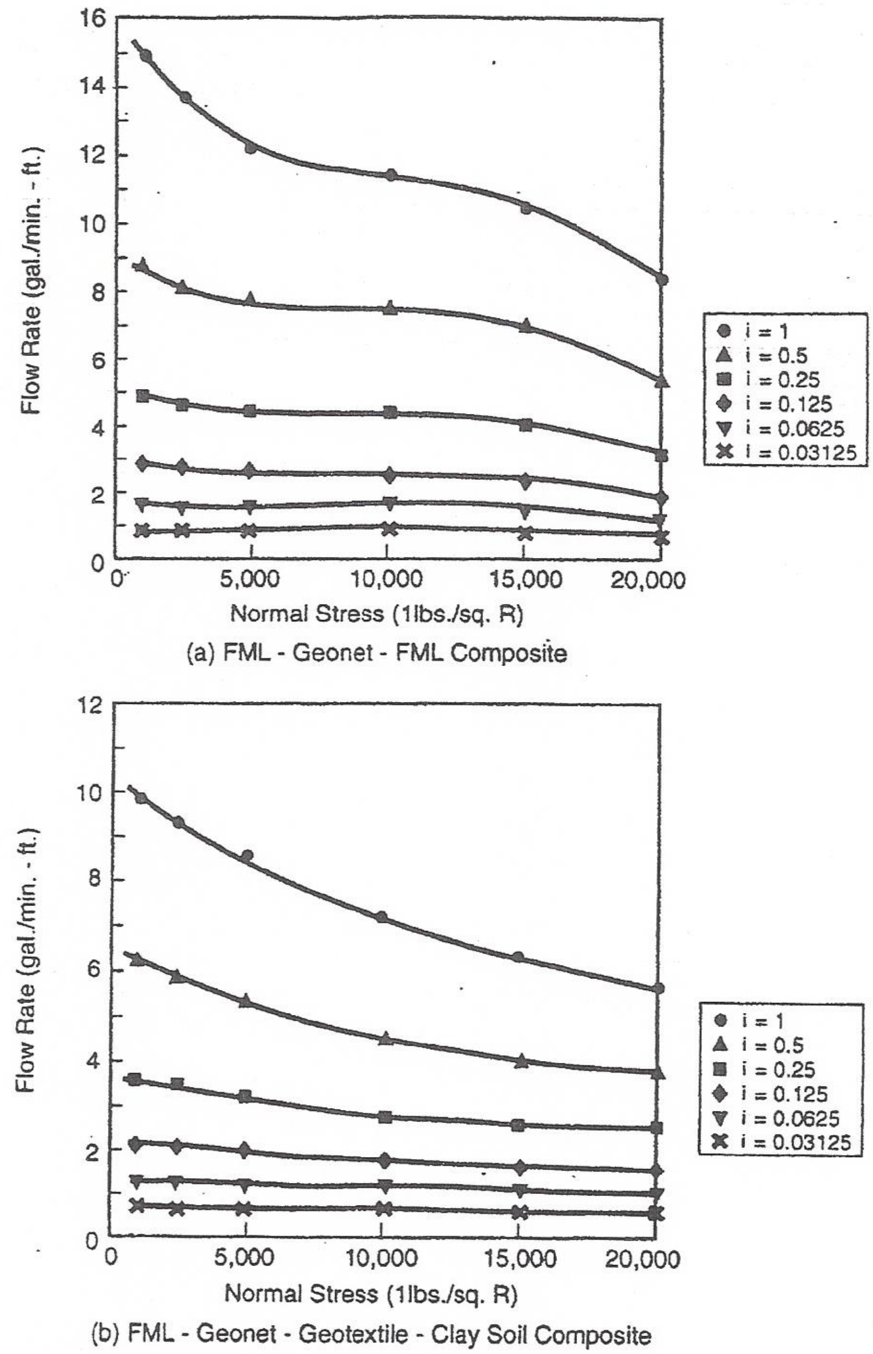
The flow rate or transmissivity of geonets may be evaluated by ASTM D-4716. This flow rate may then be compared to design-by-function equations presented in U.S. EPA (1989). In the ASTM D-4716 flow test, the proposed collector cross section should be modeled as closely as possible to actual field conditions (U.S. EPA, 1989).

Figure 4-7 shows the flow rate "signatures" of a geonet between two geomembranes (upper curves) and the same geonet between a layer of clay soil and a geomembrane (lower curves). The differences between the two sets of curves represent intrusion of the geotextile/clay into the apertures of the geonet. The curves are used to obtain a flow rate for the particular geonet being designed (U.S. EPA, 1989). Equations to determine the design flow rate or transmissivity are also presented in U.S. EPA (1989), Giroud (1982), Carroll (1987), Koerner (1990), and FHWA (1987).

Generally, geonets perform well and result in high factors of safety or performance design ratios, unless creep (elongation under constant stress) becomes a problem or adjacent materials intrude into apertures (U.S. EPA, 1989). For geonets, the most critical specification is the ability to transmit fluids under load. The specifications also should include a minimum transmissivity under expected landfill operating (dynamic) or completion (static) loads. The specifications for thickness and types of material should be identified on the drawings or in the materials section of the specifications, and should be consistent with the design calculations (U.S. EPA, 1988).

Geonets are often used on the sidewalls of landfills because of their ease of installation. They should be placed with the top ends in a secure anchor trench with the strongest longitudinal length extending down the slope. The geonets need not be seamed to each other on the slopes, only tied at the edges, butted, or overlapped. They should be placed in a loose condition, not stretched or placed in a configuration where they are bearing their own weight in tension. The construction specifications should contain appropriate installation requirements as described above or the requirements of the geonet manufacturer. All geonets need to be protected by a filter layer or geotextile to prevent clogging (U.S. EPA, 1988).

The friction factors against sliding for geotextiles, geonets, and geomembranes often can be estimated using manufacturers data because these materials do not exhibit the range of characteristics as seen in soil materials. However, it is important that the designer perform the actual tests using site materials and that the sliding stability calculations accurately represent the actual design configuration, site conditions, and the specified material characteristics (U.S. EPA, 1988).



Source: U.S. EPA. 1989.

Figure 4-7. Flow Rate Curves for Geonets in Two Composite Liner Configurations

Leachate Collection Pipes

All components of the leachate collection system must have sufficient strength to support the weight of the overlying waste, cover system, and post-closure loadings, as well as the stresses from operating equipment. The component that is most vulnerable to compressive strength failure is the drainage layer piping. Leachate collection system piping can fail by excessive deflection, which may lead to buckling or collapse (USEPA, 1988). Pipe strength calculations should include resistance to wall crushing, pipe deflection, and critical buckling pressure. Design equations and information for most pipe types can be obtained from the major pipe manufacturers. For more information regarding pipe structural strength, refer to U.S. EPA (1988).

Perforated drainage pipes can provide good long-term performance. These pipes have been shown to transmit fluids rapidly and to maintain good service lives. The depth of the drainage layer around the pipe should be deeper than the diameter of the pipe. The pipes can be placed in trenches to provide the extra depth. In addition, the trench serves as a sump (low point) for leachate collection. Pipes can be susceptible to particulate and biological clogging similar to the drainage layer material. Furthermore, pipes also can be susceptible to deflection. Proper maintenance and design of pipe systems can mitigate these effects and provide systems that function properly. Acceptable pipe deflections should be evaluated for the pipe material to be used (USEPA, 1989).

The design of perforated collection pipes should consider the following factors:

- The required flow using known percolation impingement rates and pipe spacing;
- Pipe size using required flow and maximum slope; and
- The structural strength of the pipe.

The pipe spacing may be determined by the Mound Model. In the Mound Model (see Figure 4-8), the maximum height of fluid between two parallel perforated drainage pipes is equal to (U.S. EPA, 1989):

$$h_{max} = \frac{L\sqrt{c}}{2}\left[\frac{\tan^2\alpha}{c} + 1 - \frac{\tan\alpha}{c}\sqrt{\tan^2\alpha + c}\right]$$

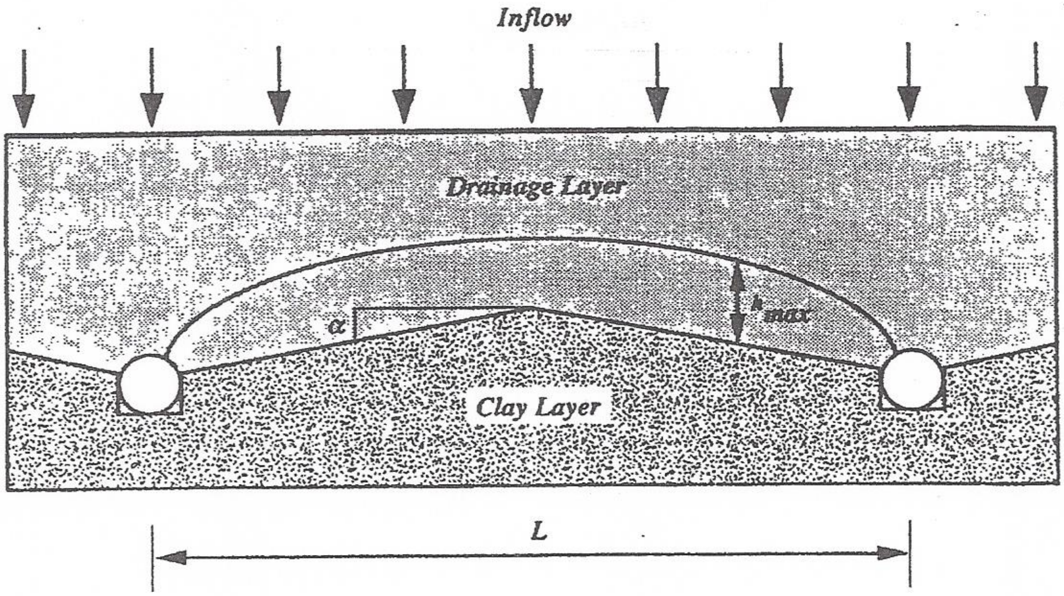
where c = q/k
k = permeability
q = inflow rate
α = slope.

The two unknowns in the equation are:

L = distance between the pipes; and
c = amount of leachate.

Using a maximum allowable head, h_{max}, of 30 cm (12 in), the equation is usually solved for "L" (U.S. EPA, 1989).

The amount of leachate, "c", can be estimated in a variety of ways including the Water Balance Method (U.S. EPA, 1989) and the computer model Hydrologic Evaluation of Landfill Performance (HELP). The HELP Model is a quasi-two-dimensional hydrologic model of water movement across, into, through, and out of landfills. The model uses climatologic, soil, and landfill design data and incorporates a solution technique that accounts for the effects of surface storage, run-off, infiltration, percolation, soil-moisture



Source: U.S. EPA, 1989

Figure 4-8. Definition of Terms for Mound Model Flow Rate Calculations

storage, evapotranspiration, and lateral drainage. The program estimates run-off drainage and leachate that are expected to result from a wide variety of landfill conditions, including open, partially open, and closed landfill cells. The model also may be used to estimate the depth of leachate above the bottom liner of the landfill unit. The results may be used to compare designs or to aid in the design of leachate collection systems (U.S. EPA, 1988).

Once the percolation and pipe spacing are known, the design flow rate can be obtained using the curve in Figure 4-9. The amount of leachate percolation at the particular site is located on the x-axis.

The required flow rate is the point at which this value intersects with the pipe spacing value determined from the Mound Model. Using this value of flow rate and the bottom slope of the site, the required diameter for the pipe can be determined (see Figure 4-10). Finally, the graphs in Figures 4-11 and 4-12 show two ways to determine whether the strength of the pipe is adequate for the landfill design. In Figure 4-11, the vertical soil pressure is located on the y-axis. The density of the backfill material around the pipe is not governed by strength, so it will deform under pressure rather than break. Ten percent is the absolute limiting deflection value for plastic pipe. Using Figure 4-11, the applied pressure on the pipe is located and traced to the trench geometry, and then the pipe deflection value is checked for its adequacy (U.S. EPA, 1989).

The LCS specifications should include (U.S. EPA, 1988):

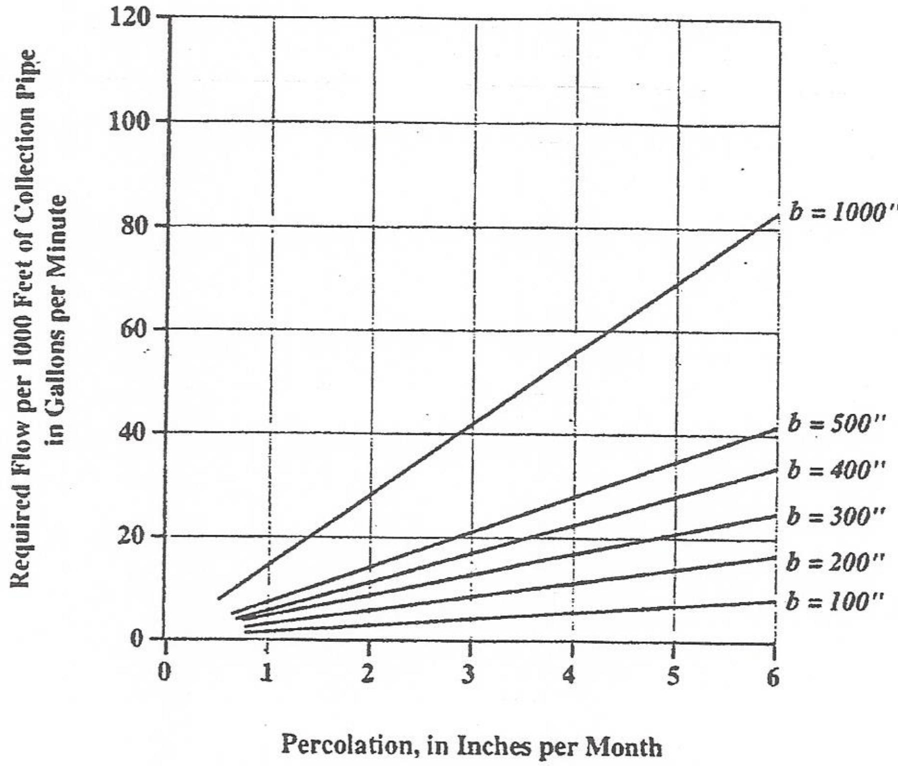
- Type of piping material;
- Diameter and wall thickness;
- Size and distribution of slots and perforations;
- Type of coatings (if any) used in the pipe manufacturing; and
- Type of pipe bedding material and required compaction used to support the pipes.

The construction drawings and specifications should clearly indicate the type of bedding to be used under the pipes and the dimensions of any trenches. The specifications should indicate how the pipe lengths are joined. The drawings should show how the pipes are placed with respect to the perforations. To maintain the lowest possible leachate head, there should be perforations near the pipe invert, but not directly at the invert. The pipe invert itself should be solid to allow for efficient pipe flow at low volumes (U.S. EPA, 1988).

When drainage pipe systems are embedded in filter and drainage layers, no unplugged ends should be allowed. The filter materials in contact with the pipes should be appropriately sized to prevent migration of the material into the pipe. The filter media, drainage layer, and pipe network should be compatible and should represent an integrated design.

Protection of Leachate Collection Pipes

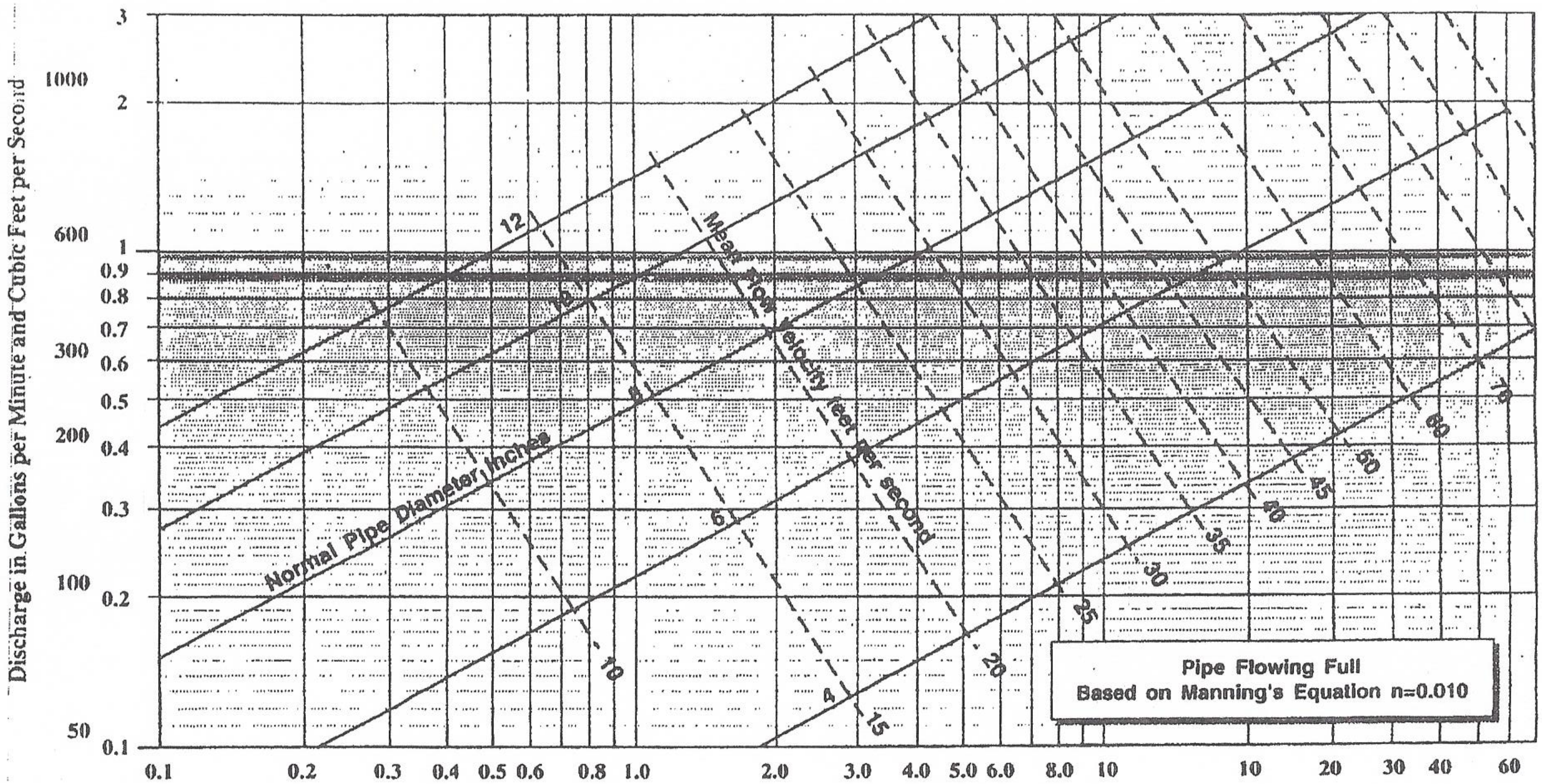
The long-term performance of the LCS depends on the design used to protect pipes from physical clogging (sedimentation) by the granular drainage materials. Use of a graded material around the pipes is most effective if accompanied by proper sizing of pipe perforations. The Army Corps of



**Where b = width of area contributing to leachate collection pipe*

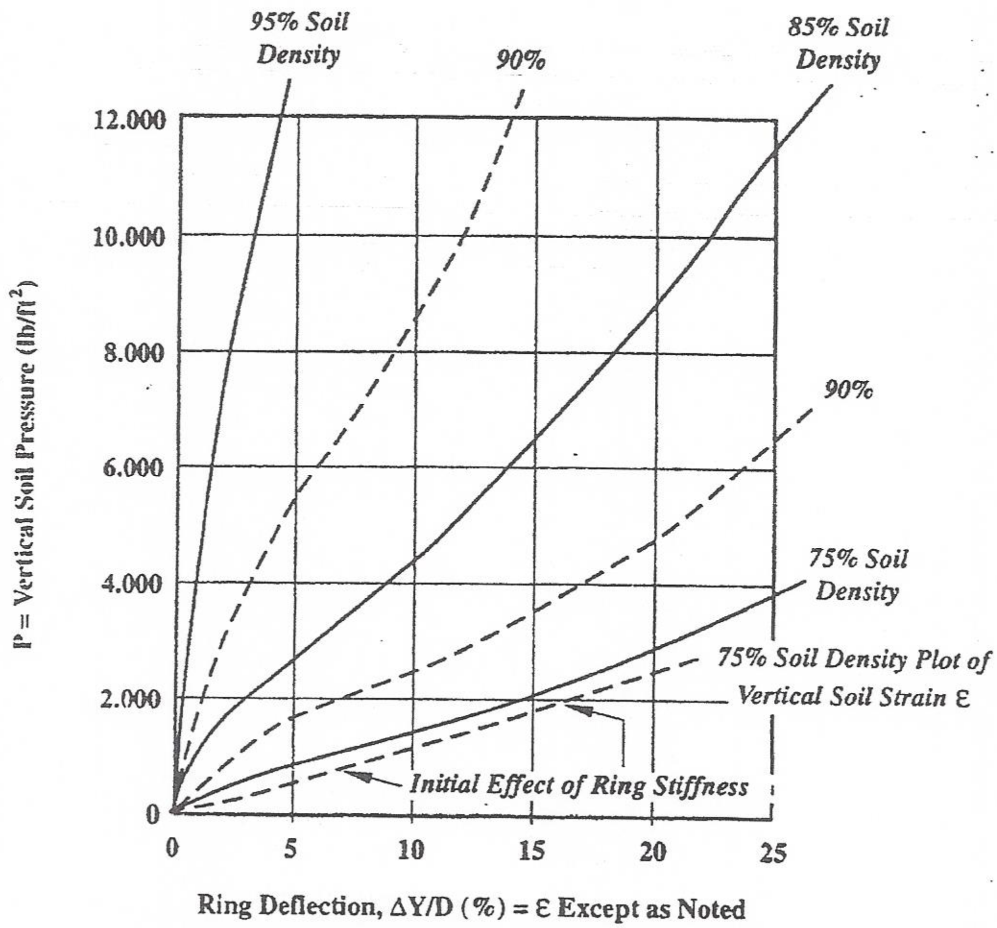
Source: U.S. EPA, 1989

Figure 4-9. Required Capacity of Leachate Collection Pipe



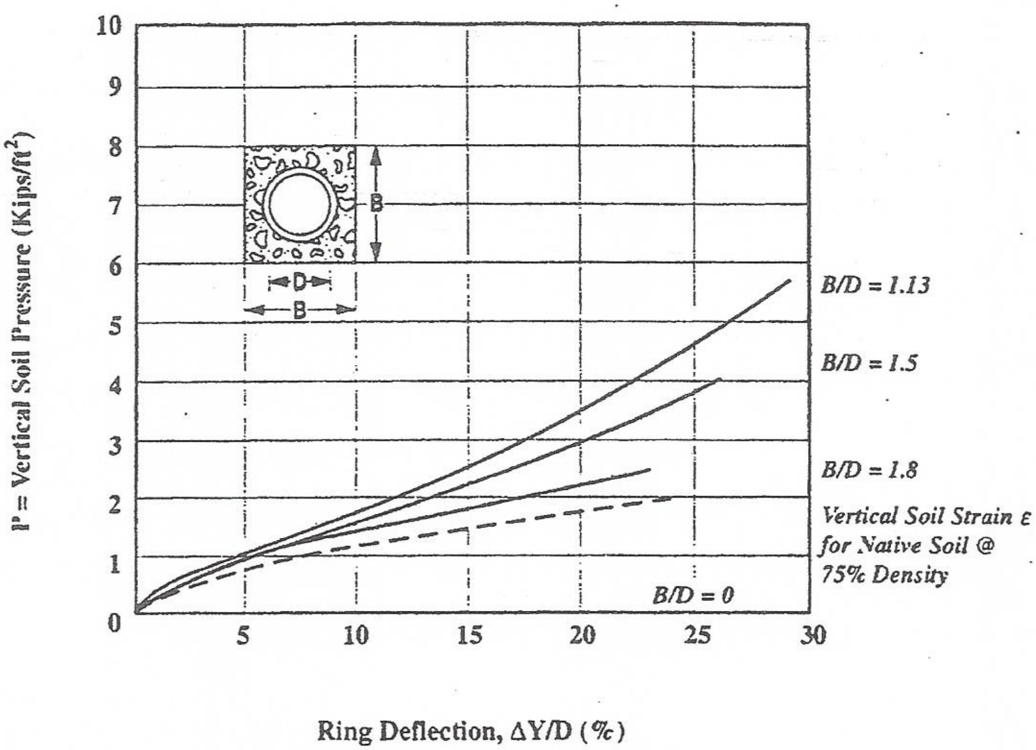
Source: U.S. EPA, 1989

Figure 4-10. Leachate Collection Pipe Sizing Chart



Source: U.S. EPA. 1989

Figure 4-11. Vertical Ring Deflection Versus Vertical Soil Pressure for 18-inch Corrugated Polyethylene in High Pressure Soil Cell



Source: U.S. EPA, 1989

Figure 4-12. Example of the Effect of Trench Geometry and Pipe Sizing on Ring Deflection

Engineers (GCA Corporation, 1983) has established design criteria using graded filters to prevent physical clogging of leachate drainage layers and piping by soil sediment deposits. When installing graded filters, caution should be taken to prevent segregation of the material (USEPA, 1991a).

Clogging of the pipes and drainage layers of the leachate collection system can occur through several other mechanisms, including chemical and biological fouling (USEPA, 1988). The LCS should be designed with a cleanout access capable of reaching all parts of the collection system with standard pipe cleaning equipment.

Chemical clogging can occur when dissolved species in the leachate precipitate in the piping. Clogging can be minimized by periodically flushing pipes or by providing a sufficiently steep slope in the system to allow for high flow velocities for self-cleansing. These velocities are dependent on the diameter of the precipitate particles and on their specific gravity. ASCE (1969) discusses these relationships. Generally, flow velocities should be in the range of one or two feet per second to allow for self-cleansing of the piping (U.S. EPA, 1988).

Biological clogging due to algae and bacterial growth can be a serious problem in MSWLF units. There are no universally effective methods of preventing such biological growth. Since organic materials will be present in the landfill unit, there will be a potential for biological clogging. The system design should include features that allow for pipe system cleanings. The components of the cleaning system should include (U.S. EPA, 1991b):

- A minimum of six-inch diameter pipes to facilitate cleaning;
- Access located at major pipe intersections or bends to allow for inspections and cleaning; and
- Valves, ports, or other appurtenances to introduce biocides and/or cleaning solutions.

In its discussion of drainage layer protection, the following section includes further information concerning protection of pipes using filter layers.

Protection of the High-Permeability Drainage Layer

The openings in drainage materials, whether holes in pipes, voids in gravel, or apertures in geonets, must be protected against clogging by accumulation of fine (silt-sized) materials. An intermediate material that has smaller openings than those of the drainage material can be used as a filter between the waste and drainage layer. Sand may be used as filter material, but has the disadvantage of taking up vertical space (USEPA, 1989). Geotextiles do not use up air space and can be used as filter materials.

Soil Filter Layers

There are three parts to an analysis of a sand filter that is placed above drainage material. The first determines whether or not the filter allows adequate flow of liquids. The second evaluates whether the void spaces are small enough to prevent solids from being lost from the upstream materials. The third estimates the long-term clogging behavior of the filter (U.S. EPA, 1989).

The particle-size distribution of the drainage system and the particle-size distribution of the invading (or upstream) soils are required in the design of granular soil (sand filter) materials. The filter material should have its large and small size particles intermediate between the two extremes. Equations for adequate flow and retention are:

- Adequate Flow:
  $d_{85f} > (3 \text{ to } 5) d_{15d.s.}$

- Adequate Retention:
  $d_{15f} < (3 \text{ to } 5) d_{85w.f.}$

Where f = required filter soil;
d.s. = drainage stone; and
w.f. = water fines.

There are no quantitative methods to assess soil filter clogging, although empirical guidelines are found in geotechnical engineering references.

The specifications for granular filter layers that surround perforated pipes and that protect the drainage layer from clogging are based on a well-defined particle size distribution. The orientation and configuration of filter layers relative to other LCS components should be shown on all drawings and should be described, with ranges of particle sizes, in the materials section of the specifications (U.S. EPA, 1988a).

Thickness is an important placement criterion for granular filter material. Generally, the granular filter materials will be placed around perforated pipes by hand, forming an "envelope." The dimensions of the envelope should be clearly stated on the drawings or in the specifications. This envelope can be placed at the same time as the granular drainage layer, but it is important that the filter envelope protect all areas of the pipe where the clogging potential exists. The plans and specifications should indicate the extent of the envelope. The construction quality control program should document that the envelope was installed according to the plans and specifications (U.S. EPA, 1988).

A granular filter layer is generally placed using the same earthmoving equipment as the granular drainage layer. The final thickness should be checked by optical survey or by direct test pit measurement (U.S. EPA, 1988).

This filter layer is the uppermost layer in the leachate collection system. A landfill design option includes a buffer layer, 12 inches thick (30 cm) or more, to protect the filter layer and drainage layer from damage due to traffic. This final layer can be general fill, as long as it is no finer than the soil used in the filter layer (U.S. EPA, 1988). However, if the layer has a low permeability, it will affect leachate recirculation attempts.

Geotextile Filter Layers

Geotextile filter fabrics are often used. The open spaces in the fabric allow liquid flow while simultaneously preventing upstream fine particles from fouling the drain. Geotextiles save vertical space, are easy to install, and have the added advantage of remaining stationary under load. Geotextiles also can be used as cushioning materials above geomembranes (USEPA, 1989). Because geotextile filters are susceptible to biological clogging, their use in areas inundated by leachate (e.g., sumps, around leachate collection pipes, and trenches) should be avoided.

Geotextile filter design parallels sand filter design with some modifications (U.S. EPA, 1989). Adequate flow is assessed by comparing the material (allowable) permittivity to the design imposed permittivity. Permittivity is measured by the ASTM D-4491 test method. The design permittivity utilizes an adapted form of Darcy's law. The resulting comparison yields a design ratio, or factor of safety, that is the focus of the design (U.S. EPA, 1989):

$$DR = ø_{allow}/ø_{reqd}$$

where:

$ø_{allow}$ = permittivity from ASTM D-4491

$ø_{reqd} = (q/a)\ (1/h_{max})$

q/a = inflow rate per unit area

h_{max} = 12 inches

The second part of the geotextile filter design is determining the opening size necessary for retaining the upstream soil or particulates in the leachate. It is well established that the 95 percent opening size is related to particles to be retained in the following type of relationship:

$$O_{95} < fct.\ (d_{50}, CU, DR)$$

where:

O_{95} = 95% opening size of geotextile;

d_{50} = 50% size of upstream particles;

CU = Uniformity of the upstream particle size; and

DR = Relative density of the upstream particles.

The O_{95} size of a geotextile in the equation is the opening size at which 5 percent of a given value should be less than the particle size characteristics of the invading materials. In the test for the O_{95} size of the geotextile, a sieve with a very coarse mesh in the bottom is used as a support. The geotextile is placed on top of the mesh and is bonded to the inside so that the glass beads used in the test cannot escape around the edges of the geotextile filter. The particle-size distribution of retained glass beads is compared to the allowable value using any of a number of existing formulas (U.S. EPA, 1989).

The third consideration in geotextile design is long-term clogging. A test method for this problem that may be adopted by ASTM is called the Gradient Ratio Test. In this test, the hydraulic gradient of 1 inch of soil plus the underlying geotextile is compared with the hydraulic gradient of 2 inches of soil. The higher the gradient ratio, the more likely that a clog will occur. The final ASTM gradient ratio test will include failure criteria. An alternative to this test method is a long-term flow test that also is performed in a laboratory. The test models a soil-to-fabric system at the anticipated hydraulic gradient. The flow rate through the system is monitored. A long-term flow rate will gradually decrease until it stops altogether (U.S. EPA, 1989).

The primary function of a geotextile is to prevent the migration of fines into the leachate pipes while allowing the passage of leachate. The most important specifications are those for hydraulic conductivity and retention. The hydraulic conductivity of the geotextile generally should be at least ten times the soil it is retaining. An evaluation of the retention ability for loose soils is based on the average particle size of the soil and the apparent opening size (AOS) of the geotextile. The maximum apparent opening size, sometimes called equivalent opening size, is determined by the size of the soil that will be retained; a geotextile is then selected to meet that specification. The material specifications should contain a range of AOS values for the geotextile, and these AOS values should match those used in the design calculations (U.S. EPA, 1988).

One of the advantages of geotextiles is their light weight and ease of placement. The geotextiles are brought to the site, unrolled, and held down with sandbags until they are covered with a protective layer. They are usually overlapped, not seamed; however, on slopes or in other configurations, they may be sewn (U.S. EPA, 1988).

As with granular filter layers, it is important that the design drawings be clear in their designation of geotextile placement so that no potential route of pipe or drainage layer clogging is left unprotected. If geotextiles are used on a slope, they should be secured in an anchor trench similar to those for geomembranes or geonets (U.S. EPA, 1988).

Leachate Removal System

Sumps, located in a recess at the low point(s) within the leachate collection drainage layer, provide one method for leachate removal from the MSWLF unit. In the past, low volume sumps have been constructed successfully from reinforced concrete pipe on a concrete footing, and supported above the geomembrane on a steel plate to protect the geomembrane from puncture. Recently, however, prefabricated polyethylene structures have become available. These structures may be suitable for replacing the concrete components of the sump and have the advantage of being lighter in weight.

These sumps typically house a submersible pump, which is positioned close to the sump floor to pump the leachate and to maintain a 30 cm (12 in) maximum leachate depth. Low-volume sumps, however, can present operational problems. Because they may run dry frequently, there is an increased probability of the submersible pumps burning out. For this reason, some landfill operators prefer to have sumps placed at depths between 1.0 and 1.5 meters. While head levels of 30 cm or less are to be maintained on the liner, higher levels are acceptable in sumps. Alternatively, the sump may be designed with level controls and with a backup pump to control initiation and shut-off of the pumping sequence and to have the capability of alternating between the two pumps. The second pump also may be used in conjunction with the primary pump during periods of high flow (e.g., following storm events) and as a backup if the primary pump fails to function. A visible alarm warning light to indicate pump failure to the operator also may be installed.

Pumps used to remove leachate from the sumps should be sized to ensure removal of leachate at the maximum rate of generation. These pumps also should have a sufficient operating head to lift the leachate to the required height from the sump to the access port. Portable vacuum pumps can be used if the required lift height is within the limit of the pump. They can be moved in sequence from one leachate sump to another. The type of pump specified and the leachate sump access pipes should be compatible and should consider performance needs under operating and closure conditions (U.S. EPA, 1988).

Alternative methods of leachate removal include internal standpipes and pipe penetrations through the geomembrane, both of which allow leachate removal by gravity flow to either a leachate pond or exterior pump station. If a leachate removal standpipe is used, it should be extended through the entire landfill from liner to cover and then through the cover itself. If a gravity drainage pipe that requires geomembrane penetration is used, a high degree of care should be exercised in both the design and construction of the penetration. The penetration should be designed and constructed in a manner that allows nondestructive quality control testing of 100 percent of the seal between the pipe and the geomembrane. If not properly constructed and fabricated, geomembrane penetrations can become a source of leakage through the geomembrane.

Other Design Considerations

The stability of the individual leachate collection system components placed on geomembrane-covered slopes should be considered. A method for calculating the factor of safety (FS) against sliding for soils placed on a sloped geomembrane surface is provided in Koerner (1990). This method considers the factors affecting the system, including the slope length, the slope angle, and the friction angle between the geomembrane and its cover soil. Generally, the slope angle is known and is specified on the design drawings. A minimum FS is then selected. From the slope angle and the FS, a minimum allowable friction angle is determined, and the various components of the liner system are selected based on this minimum friction angle. If the design evaluation results in an unacceptably low FS, then either the sidewall slope or the materials should be changed to produce an adequate design (U.S. EPA, 1988). For short slopes in a landfill unit, the FS can be as low as 1.1 to 1.2 if the slope will be unsupported (i.e., no waste will be filled against it) for only a short time, and if any failures that do occur can be repaired fairly easily. Longer slopes may require higher factors of safety due to the potential of sliding material to tear the geomembrane along the slope or near the toe of the slope.

Construction Quality Assurance and Quality Control

The following section is excerpted from U.S. EPA (1992). This section discusses quality assurance and quality control (QA/QC) objectives. For a more detailed discussion on QA/QC and specific considerations, refer to U.S. EPA (1992).

CQA/CQC Objectives

Construction quality assurance (CQA) consists of a planned series of observations and tests to ensure that the final product meets project specifications. CQA plans, specifications, observations, and tests are used to provide quantitative criteria with which to accept the final product.

On routine construction projects, CQA is normally the concern of the owner and is obtained using an independent third-party testing firm. The independence of the third-party inspection firm is important, particularly when the owner is a corporation or other legal entity that has under its corporate "umbrella" the capacity to perform the CQA activities. Although "in-house" CQA personnel may be registered professional engineers, a perception of misrepresentation may exist if CQA is not performed by an independent third party.

The CQA officer should fully disclose any activities or relationships with the owner that may impact his impartiality or objectivity. If such activities or relationships exist, the CQA officer should describe actions that have been or can be taken to avoid, mitigate, or neutralize the possibility they might affect the CQA