4. ELEMENTS OF LIQUID MANAGEMENT AT WASTE CONTAINMENT SITES

Introduction

The drainage system for removing leachate or other aggressive liquids from landfills, surface impoundments, and waste piles is critically important. Even if a liner has no leaks, the phenomenon of molecular diffusion will allow some of the organics from the liquids ponded on top of the liner system to leach through the flexible membrane liner and the clay. The timely collection and removal of that leachate is at the heart of this chapter.

This chapter presents an overview of collector design and materials, followed by a discussion of the three parts of a liquid management system: the leachate collection and removal system above the primary liner, the secondary leak detection collection and removal system between the primary and secondary liners, and the surface water collection system above the closure of the completed facility. The chapter concludes with a discussion of gas collector and removal systems. The following topics will be examined:

- Overview
    - Drainage Materials
    - Filtration Materials
    - Geosynthetics
    - Design-by-function Concepts
- Primary Leachate Collection and Removal (PLCR) Systems
    - Granular Soil (Gravel) Drainage Design
    - Perforated Collector Pipe Design
    - Geonet Drainage Design
    - Granular Soil (Sand) Filter Design
    - Geotextile Filter Design
    - Leachate Removal Systems
- Leak Detection, Collection, and Removal (LDCR) Systems
    - Granular Soil (Gravel) Drainage Design
    - Geonet Drainage Design
    - Response Time
    - Leak Detection Removal Systems
- Surface Water Collection and Removal (SWCR) Systems
- Gas Collector and Removal Systems

Overview

Leachate refers to rainfall and snowmelt that combines with liquid in the waste and gravitationally moves to the bottom of a landfill facility. During the course of its migration, the liquid takes on the pollutant characteristics of the waste itself. As such, leachate is both site specific and waste specific with regard to both its quantity and quality. The first part of the collector system to intercept the leachate is the primary leachate collection and removal (PLCR) system located directly below the waste and above the primary liner. This system must be designed and constructed on a site-specific basis to remove the leachate for proper treatment and disposal.

The second part of a leachate collection system is between the primary and secondary liners. Varying with State or region, it is called by a number of names including the secondary leachate collection and removal (SLCR) system, the leak detection network, or the leak questioning system. It will be referred to here as the leak detection, collection, and removal (LDCR) system. The main purpose of this system is to determine the degree of leakage, if any, of leachate through the primary liner. Ideally, this system would collect only negligible quantities of leachate; however, it must be designed on the basis of a worst-case scenario.

The third part, called the surface water collection and removal (SWCR) system, lies above the waste system in a cap or closure above the closed facility. Its purpose is to redirect surface water coming through the cover soil from off of the flexible membrane in the cap to the outside perimeter of the system. The location of all three parts of the liquid management system is illustrated in Figure 4-1.

Drainage Materials

The drainage materials for the liquid management system must allow for unimpeded flow of liquids for the intended lifetime of the facility. In a leachate collection system, the drains may consist of pipes, soil (gravel), geonets, or geocomposites. These materials will be described in the following sections.

Perforated drainage pipes have the advantage of common usage and design, and they transmit fluids rapidly. They do, however, require considerable vertical space, and are susceptible to particulate clogging, biological clogging, and creep (deflection). Creep is of concern for both polyvinyl chloride (PVC) and high density polyethylene (HDPE) pipe materials.

According to proposed EPA regulations, the hydraulic conductivity value for soil used as the drainage component of leachate collection systems will increase over previous regulations by two orders of magnitude, from 0.01 cm/sec to 1 cm/sec, in the very near future. This regulation essentially eliminates the use of sand, and necessitates the use of gravel. Gravel that meets this regulation has particle sizes of 1/4 to 1/2 inches and must be quite clean with no fines content. While gravels of this type are durable and have high hydraulic conductivities, they require a filter soil to protect them. They also tend to move when waste is loaded onto the landfill or personnel walk on them. For the latter reason, they are practically impossible to place on side slopes.

The synthetic materials that best meet inplane flow rate regulations are called geonets. Geonets require less space than perforated pipe or gravel, promote rapid transmission of liquids, and, because of their relatively open apertures, are less likely to clog. They do, however, require geotextile filters above them and can experience problems with creep and intrusion. Geonets have the disadvantage of being relatively new and, therefore, less familiar to owners and designers than are sand and gravel drainage materials.

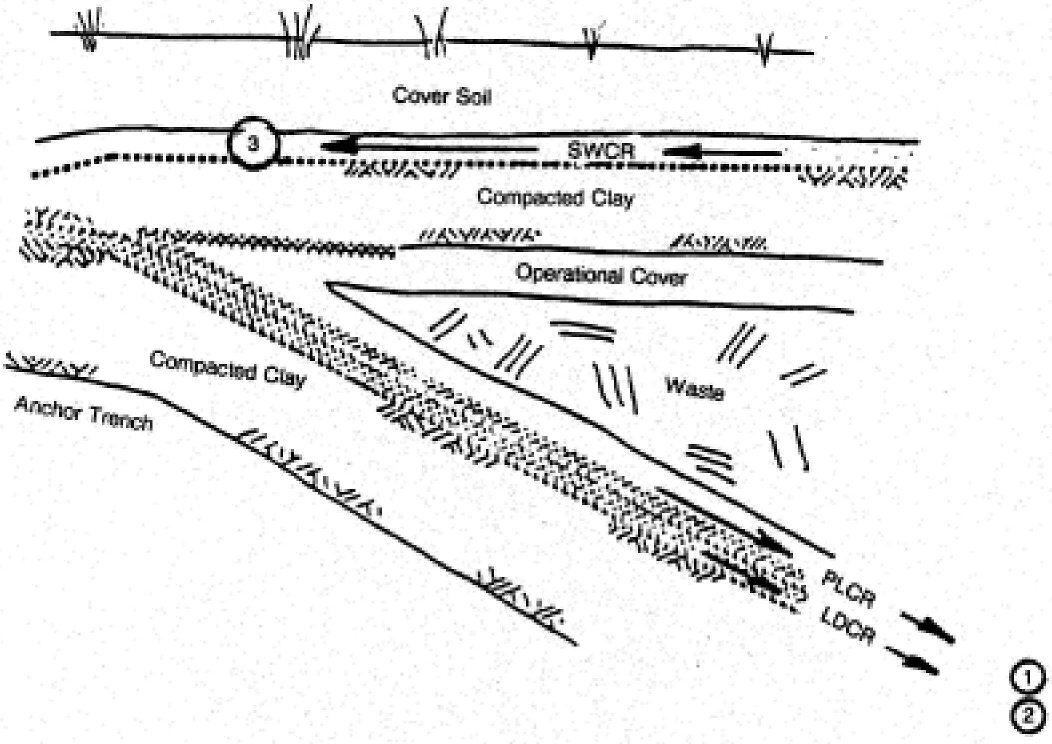


Figure 4-1. The three elements of a liquid management drainage system in a double-lined solid waste facility.

Another new synthetic material is called a drainage geocomposite, many types of which are available. Geocomposites have most of the same advantages and disadvantages of geonets. They generally are not used for primary or secondary leachate collection systems, however, because of their relatively low crush strength. The crush strength, or normal strength perpendicular to the plane, of currently available products is not sufficient to carry the weight of a large landfill. Geocomposites are useful, however, for surface water collector systems, where the applied normal stresses are quite low.

Filtration Materials

The openings in drainage materials, whether holes in pipes, voids in gravel, or apertures in geonets, must be protected against invading fine particle-sized materials. An intermediate material, having smaller openings than those of the drainage material, must be used as a filter. Commonly in a pipe or gravel drain, a medium-coarse to fine sandy soil is used as a filter. Sand, however, has the disadvantages of taking up vertical space and moving under various loading conditions.

Geotextiles used as filters avoid these problems. 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. As with sand filters, clogging can occur, and because geotextiles are a new technology much about them is not known. Geotextiles are being used more and more not only for filters, but also as cushioning materials above and/or below FMLs.

Geosynthetics

Geosynthetic materials play a key role in liquid management systems. The five major categories of geosynthetics are:

- Geotextiles
- Geogrids
- Geonets
- Geomembranes
- Geocomposites

A brief discussion of each type follows.

Geotextiles are either woven or nonwoven fabrics made from polymeric fibers. Woven geotextiles are fabrics made up of webbed fibers that run in perpendicular directions. For filtration, the spaces between the fibers are the most important element. These spaces or voids must be large enough to allow unimpeded liquid flow but be small enough to keep out invading particulates. The geotextiles also must be sufficiently strong to cover and reinforce the apertures, or openings, of the drainage materials they are meant to protect.

In nonwoven geotextiles the fibers are much thinner but far more numerous. The various types are needle-punched, resin-bond, and melt-bond. All contain a labyrinth of randomly oriented fibers that cross one another so that there is no direct line of flow. The fabric must have enough open space to allow liquid to pass through, while simultaneously retaining any upstream movement of particles. The needle-punched nonwoven type is very commonly used as a filter material.

Geogrids are very strong in transverse and longitudinal directions, making them useful as reinforcing materials for either soil or solid waste. Generally, they are used to steepen the side slopes of interior cells or exterior containment slopes of a facility. Recently they also have been used in the construction of "piggyback" landfills, i.e., landfills built on top of existing landfills, to reinforce the upper landfill against differential settlements within the lower landfill.

Geonets are formed with intersecting ribs made from a counter-rotating extruder. A typical geonet is about 1/4-inch thick from the top of the upper rib to the bottom of the lower rib, yet the flow capability is approximately equivalent to that of 12 inches of sand having a 0.01 cm/sec permeability. (The proposed regulation will increase this value to 1 cm/sec, as mentioned earlier.) The rapid transmission rate is due to clear flow paths in the geonets, as opposed to particle obstructions in a granular soil material. There are two main concerns with geonets. First, the crush strength at the rib's intersection must be capable of maintaining its structural stability without excessive deformation or creep. Second, adjacent materials must be prevented from intruding into the rib apertures, cutting off or reducing flow rates.

Foamed geonets are relatively new products made with a foaming agent that produces a thick geonet structure (up to 1/2-inch) with very high flow rates. These improved flow rates result from the thicker product, but eventually the nitrogen gas in the rib voids diffuses through the polymer structure, leaving behind a structure with reduced thickness. The result over the long term is a solid rib geonet thickness equivalent to other nonfoamed geonets.

The fourth type of geosynthetic is a geomembrane, or FML. It is the primary defense against escaping leachate and of crucial importance. FMLs are the focus of Chapter Three.

The final category of geosynthetics is drainage geocomposites. These are polymeric materials with built-up columns, nubs, cuspations, or other deformations that allow planar flow within their structure. A drainage geocomposite having 1-inch high columns can carry the flow of a 4- to 5-inch diameter pipe. Many products, however, have low crush strengths that are inadequate for deep landfills or surface impoundments. They are useful, however, for surface water collector systems above the closed facility where they only need to support approximately 4 feet of soil and construction placement equipment.

Design-by-function Concepts

Whatever parameter of a specific material one is evaluating, a required value for the material must be found using a design model and an allowable value for the material must be determined by a test method. The allowable value divided by the required value yields the design ratio (DR), or the resulting factor of safety (FS). This design-by-function concept is necessary to design and evaluate new materials that are both feasible and safe for a variety of situations.

In evaluating drainage and filtration materials, an allowable flow rate is divided by a required flow rate to obtain the design ratio or factor of safety according to the equations below:

(a) For Drainage:

$$DR = q_{allow}/q_{reqd} \quad (1)$$

or

$$DR = \Psi_{allow}/\Psi_{reqd} \quad (2)$$

where DR = design ratio
q = flow rate per unit width
Ψ = transmissivity

(b) For Filtration:

$$DR = q_{allow}/q_{reqd} \quad (3)$$

or

$$DR = \Psi_{allow}/\Psi_{reqd} \quad (4)$$

where DR = design ratio
q = flow rate per unit area
Ψ = permittivity

Transmissivity is simply the coefficient of permeability, or the hydraulic conductivity (k), within the plane of the material multiplied by the thickness (t) of the material. Because the compressibility of some polymeric materials is very high, the thickness of the material needs to be taken into account. Darcy's law, expressed by the equation $q = kiA$, is used to calculate rate of flow, with transmissivity equal to kt and i equal to the hydraulic gradient (see Figure 4-2):

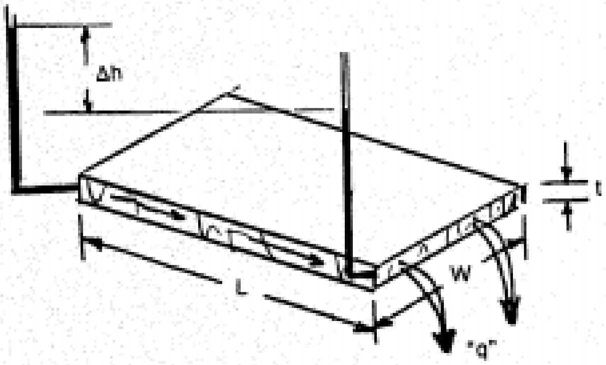


Figure 4-2. **Variables for calculating inplane flow rates (transmissivity).**

$$\begin{aligned} q &= kiA \quad (5) \\ &= k(\Delta h/L)(w \times t) \\ q/w &= (kt)(\Delta h/L) \end{aligned}$$

if $\theta = kt$

$$q/w = \theta(i)$$

where q/w = flow rate per unit width
θ = transmissivity

Note that when $i = 1.0$; $(q/w) = \theta$; otherwise it does not.

With a liquid flowing across the plane of the material, as in a geotextile filter, the permeability perpendicular to the plane can be divided by the thickness, t, to obtain a new value, permittivity (see Figure 4-3). In crossplane flow, t is in the denominator; for planar flow it is in the numerator. Crossplane flow is expressed as:

$$\begin{aligned} q &= kiA \quad (6) \\ &= k(\Delta h/t)A \\ q &= (k/t)\Delta hA \\ \Psi &= (k/t) = (q/\Delta hA) \end{aligned}$$

where Ψ = permittivity
q/A = flow rate per unit area ("flux")

Thus, both transmissivity and permittivity values allow for the thickness to be avoided in subsequent analyses.

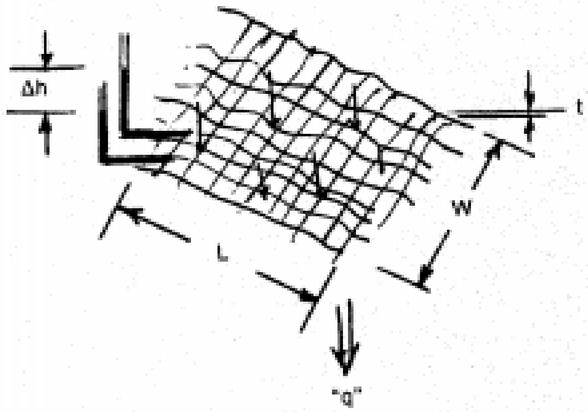


Figure 4-3. Variables for calculating crossplane flow rates (permittivity).

Table 4-1 shows some of the ASTM test methods and standards for drainage and filter materials used in primary leachate collection and leachate detection and collection systems. Test methods are determined by D18, the Soil and Rock Committee of ASTM, and by D35, the Committee on Geosynthetics.

Primary Leachate Collection and Removal (PLCR) Systems

The various design options for primary leachate collection systems are granular soil drains, perforated pipe collectors, geonet drains, sand filters, and geotextile filters. Figure 4-4 shows a cross section of a primary leachate collection system with a geonet drain on the side slope leading into a gravel drain on the bottom. This gravel drain then leads into a perforated pipe collector. A geotextile acts as a filter protecting the geonet and sand acts as a filter for the drainage gravel. Quite often the sideslope geotextile extends over the bottom sand filter as shown in Figure 4-4.

Granular Soil (Gravel) Drainage Design

Current minimum technology guidance (MTG) regulations require that granular soil drainage materials must:

- Be 30 centimeters (12 inches) thick.
- Have 0.01 cm/sec (≈ 0.02 ft/min) permeability (hydraulic conductivity).
- Have a slope greater than 2 percent.
- Include perforated pipe.
- Include a layer of filter soil.
- Cover the bottom and side walls of the landfill.

There are two ways to calculate the required flow rate, q, in granular soil drainage designs. One is based on the above MTG values; the other is based on the Mound Model (see Figure 4-5). Based on MTG values:

$$\begin{aligned} q &= kiA \qquad (7) \\ &= (0.02)(0.02)(1 \times 1) \\ &= 4 \times 10^{-4}\ \text{ft}^3/\text{min} \end{aligned}$$

Note that if MTG increases the required hydraulic conductivity of the drainage soil to 1 cm/sec, the above flow rate will be increased to 0.04 ft^3/min.

In the Mound Model, the maximum height between two perforated pipe underdrain systems is equal to:

$$h_{max} = \frac{L/c}{2}\left[\frac{\tan^2\alpha}{c} + 1 - \frac{\tan\alpha}{c}\sqrt{\tan^2\alpha + c}\right| \qquad (8)$$

where c = q/k

k = permeability

q = inflow rate

The two unknowns in the equation are L, the distance between pipes, and c, the amount of leachate coming through the system. Using a maximum allowable head, h_{max}, of 1 foot, the equations are usually solved for L.

One method of determining the value of c is using the Water Balance Method:

$$\text{PERC} = \text{P} - \text{R/0} - \text{ST} - \text{AET} \qquad (9)$$

where PERC = percolation, i.e. the liquid that permeates the solid waste (gal/acre/day).

P = precipitation for which the mean monthly values are typically used.

R/O = surface runoff.

ST = soil moisture storage, i.e., moisture retained in the soil after a given amount of accumulated potential water loss or gain has occurred.

AET = actual evapotranspiration, i.e., actual amount of water loss during a given month.

Table 4-1. Test Methods and Standards

ASTM Test Designation (or other)	Used to Determine	Material	Value Used for
D2434	Permeability	Soil	PLCR, LDCR
D2416	Strength	Underdrain pipe	PLCR, LDCR
F405, F667	General specification	HDPE pipe	PLCR, LDCR
D4716	Transmissivity	Geonet, geocomposite	PLCR, LDCR
D4491	Permittivity	Geotextile	PLCR filter
D4751	Apparent opening size	Geotextile	PLCR filter
CW-02215[a]	Gradient ratio	Geotextile	PLCR filter
GRI-GT1[b]	Long-term flow	Geotextile	PLCR filter

[a] U.S. Army Corps of Engineers Test Method.
[b] Geosynthetic Research Institute Test Method.

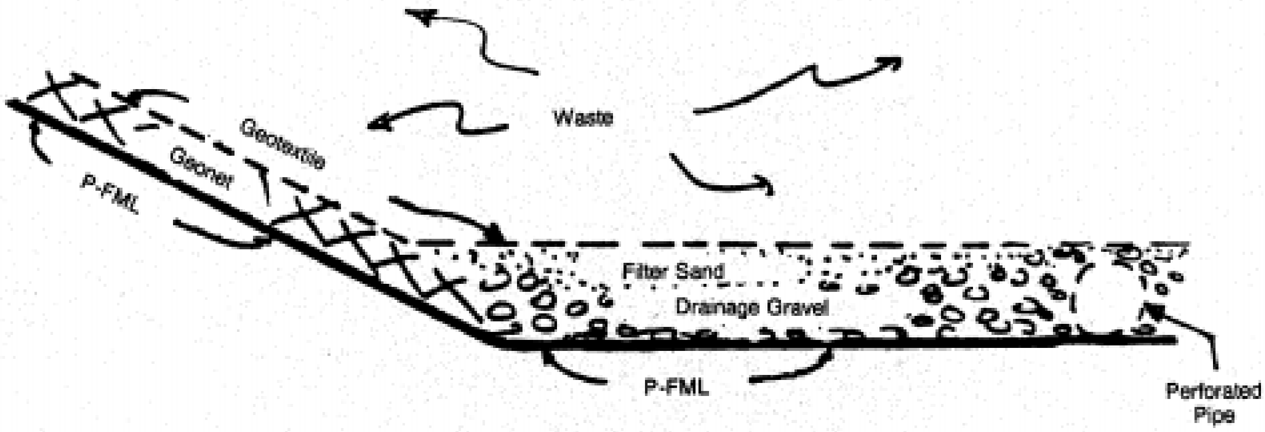


Figure 4-4. Cross section of primary leachate collection systems.

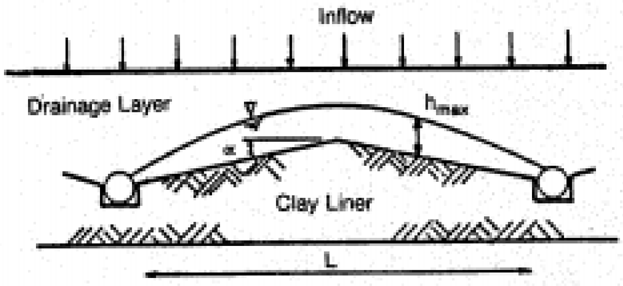


Figure 4-5. Flow rate calculations: Mound Model.

The range of percolation rates in the United States is 15 to 36 inches/year (1,100 to 2,700 gal/acre/day) (U.S. EPA, 1988).

The computer program Hydrologic Evaluation Landfill Performance Model (HELP) can also be used to calculate c. HELP was developed to assist in estimating the magnitude of water-balance components and the height of water-saturated soil above the barrier layers. HELP can be used with three types of layers: vertical percolation, lateral drainage, and barrier soil liner. By providing climatological data for 184 cities throughout the United States, HELP allows the user to incorporate extended evaluation periods without having to assemble large quantities of data (Schroeder et al, 1984).

Perforated Collector Pipe Design

The original perforated collector pipes in landfills were made of concrete like those used in highway underdrain systems. As landfills became higher, the strength of such pipes became inadequate. Today, perforated PVC pipes are commonly used, as are HDPE pipes. New regulations require that all materials be tested for chemical resistance as part of the permit-approval process.

The three steps in designing perforated collector pipes are:

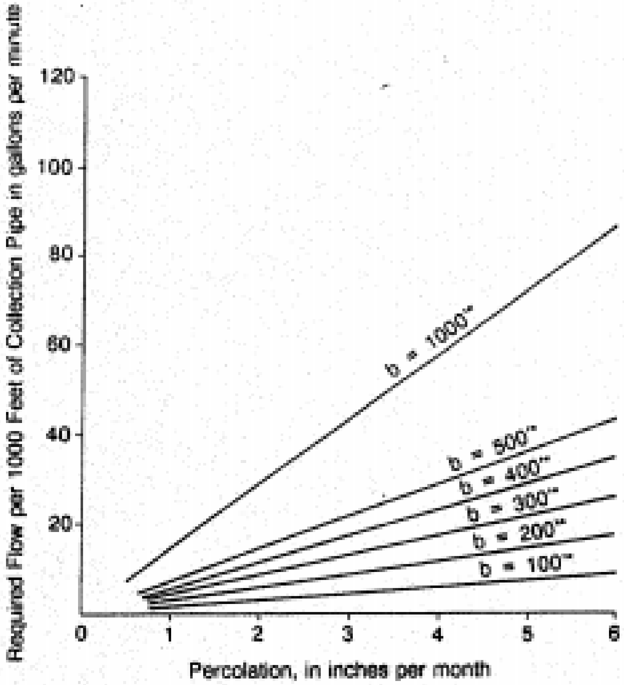
1. Obtain the required flow value using known percolation and pipe spacing.
2. Obtain the required pipe size using the required flow and the maximum slope.
3. Check the pipe strength and obtain its ring deflection to determine tolerance against crushing.

Knowing the percolation and pipe spacing from the previous calculations, the required flow can be obtained using the curve in Figure 4-6. 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, one can find the required diameter for the pipe (see Figure 4-7). Finally, the graphs in Figures 4-8 and 4-9 show two ways to determine whether or not the strength of the pipe is adequate for the landfill design. In Figure 4-8, the vertical soil pressure is located on the y-axis. The density of the backfill material around the pipe is used to determine ring deflection. Plastic pipe is not governed by strength, so it will deform under pressure rather than break. Twenty percent is often used as the limiting deflection value for plastic pipe. Using Figure 4-9 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.

Geonet Drainage Design

Table 4-2 presents a compilation of currently available geonets. The structure and properties of each are also identified. Geonets used in drainage design must be chemically resistant to the leachate, support the entire weight of the landfill, and be evaluated by the ASTM test D4716 as to allowable flow rate or transmissivity. This allowable value must then be compared to the required value in the design-by-function equation presented earlier.

In the D4716 flow test, the proposed collector cross section should be modeled as closely as possible. The candidate geonet usually will be sandwiched between a FML beneath and a geotextile above. Soil, perhaps simulating the waste, is placed above the geotextile and the load platen from the test device is placed above the soil. Applied normal stress is transmitted through the entire system. Then planar flow, at a constant hydraulic head, is initiated and the flow rate through the geonet is measured.



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

Figure 4-6. **Required capacity of leachate collection pipe (after U.S. EPA, 1983).**

Figure 4-10 shows the flow rate "signatures" of a geonet between two FMLs (upper curves) and the same geonet with the cross section described above(lower curves). The differences between the two sets of curves represent intrusion of the geotextile/clay into the apertures of the geonet. Irrespective of the comparison in behavior, the curves are necessary in obtaining an allowable flow rate for the particular geonet being designed.

The required flow rate can be calculated by three different methods: (1) directly from minimum technology guidance, (2) using an equation developed in the design manual, or (3) on the basis of surface water inflow rate. To be conservative, all three calculations should be performed and the worst-case situation (e.g., that with the highest flow rate) used for the required flow rate. The various equations to determine the required flow rate or transmissivity appear below:

1. Geonet must be equivalent to MTG regulations for natural materials:

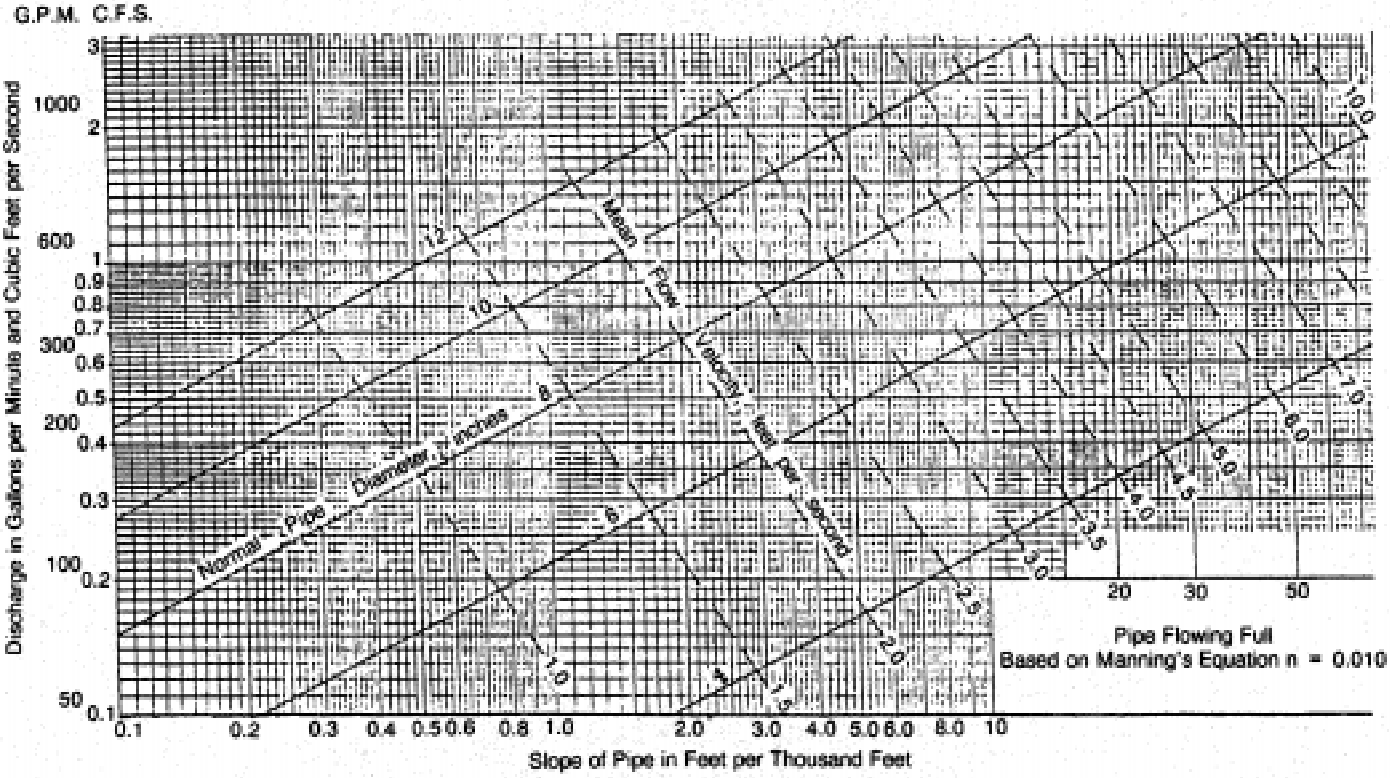


Figure 4-7. Sizing of leachate collection pipe (U.S. EPA, 1983).

$$\theta \geq 0.02\ \text{ft}^3/\text{min-ft} \qquad (10)$$

2. Based on estimated leachate inflow (Richardson and Wyant, 1987):

$$\theta_{\text{reqd}} = \frac{qL^2}{4h_{\max} + 2L\sin\alpha} \qquad (11)$$

3. Based on surface water inflow (U.S. EPA, 1986):

$$Q = CIA \qquad (12)$$

where Q = surface water inflow
C = runoff coefficient
I = average runoff intensity
A = surface area

Generally geonets result in high factors of safety or design ratios, unless creep becomes a problem or if adjacent materials intrude into the apertures.

Granular Soil (Sand) Filter Design

There are three parts to an analysis of a sand filter to be placed above drainage gravel. The first determines whether or not the filter allows adequate flow of liquids through it. The second evaluates whether the void spaces are small enough to prevent solids being lost from the upstream materials. The third part estimates the long-term clogging behavior of the filter.

Required in the design of granular soil (sand) filter materials is the particle-size distribution of the drainage system and the particle-size distribution of the invading (or upstream) soils. The filter material should have its large and small size particles intermediate between the two extremes (see Figure 4-11). Adequate flow and adequate retention are the two focused design factors, but perhaps the most important is clogging. The equations for adequate flow and adequate retention are:

- Adequate Flow: $d_{85_f} > (3 \text{ to } 5)\, d_{15_{d.s.}}$ (13)
- Adequate Retention: $d_{15_f} < (3 \text{ to } 5)\, d_{85_{u.s.}}$ (14)

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

Geotextile Filter Design

Geotextile filter design parallels sand filter design with some modifications. The three elements of