PDHonline Course C179 (3 PDH)

Surface Water and Gas Control Guidelines for HTW Sites

Instructor: John Huang, Ph.D., PE and John Poullain, PE

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5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone: 703-988-0088
www.PDHonline.com

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Advantages	Disadvantages
Drainage Ditches	
Low construction and operating cost	Requires extensive maintenance to maintain operating efficiency
Useful for intercepting landfill side seepage and runoff	Generally not suited for deep disposal sites or impoundments
Useful for collecting leachate in poorly permeable soils where subsurface drains cannot be used	May interfere with use of land
Large welted perimeter allows for high rates of flow	May introduce need for additional safety/security measures

Section III. Surface Water Controls

3-22. Surface Water Diversion.

a. Background.

(1) A major consideration at any hazardous waste site is water management. Minimizing the amount of water moving through a site reduces the spread of potentially toxic materials and the requirements to treat leachate or drainage from the area. Many sites are in low-lying areas adjacent to natural watercourses. In some instances, it has been necessary to divert drainage around a landfill or reinforce or dike streambanks to prevent the waste from being washed into the stream and contaminating the water downstream. Run-on is generally controlled using ditching, channelization, or construction of berms and dikes.

(2) Run-on diversion can be implemented at a hazardous waste site by using many of the same remedies used to control run-on at a construction site. This remedial activity is applicable when it can be demonstrated that water is entering the disposal site from adjacent slopes or that streams moving across the site are contributing water to the site or washing wastes out of the site.

(3) Where minimizing ground-water infiltration is important to prevent the water table under the site from rising, lined trenches should be considered in drainage design. Lined trenches typically are constructed of concrete, shotcrete, asphaltic concrete, metal culvert (half sections), or synthetic membrane materials (polyvinylchloride or polyethylene).

(4) The data requirements for design of drainage systems on or around a hazardous waste system are similar to those required for construction drainage, including area to be drained, type of drain proposed, grade of the proposed drainway, and maximum capacity based on rainfall and snowmelt records. Additional considerations would be the lifetime of the system. Some systems will be required only until wastes can be excavated and transported;

at other sites, the waste will remain in place, and the surface water control system will have to be maintained indefinitely.

(5) Design criteria for drainage systems at landfills are not specifically provided in regulations. The performance requirements are for most complete diversion of water possible. The Department of Agriculture and EPA guidance for sizing diversion drainage systems around a waste disposal area calls for carrying capacities equal to at least the peak run-off from a 10-year, 24-hour storm. In most cases, carrying capacities should be greater.

(6) Design procedures are typically undertaken in much the same way as those for drainage or diversion planning--from estimation of carrying capacity requirements to specific requirements as to the type of drainage and specific types of material (sod, riprap, concrete, etc.) to be employed. Models, such as Storage Treatment Overflow and Run-off Model (STORM) from the Corps* Hydrologic Engineering Center (HEC), Chemical Runoff and Erosion from Agricultural Management Systems Hydrologic Model (CREAMS) from the Department of Agriculture, and Hydrologic Evaluation of Landfill Performance (HELP) from the Corps* Waterways Experiment Station can be helpful in determining the quantity and quality of run-off from areas surrounding a waste site. Several well-established construction techniques are available for diverting and handling surface water flow in critical areas. Those methods most applicable as remedial measures at uncontrolled disposal sites are addressed below.

b. Dikes and Berms.

(1) Description and applications.

(a) Dikes and berms are well-compacted earthen ridges or ledges constructed immediately upslope from or along the perimeter of disturbed areas (e.g., disposal sites). These structures are generally designed to provide short-term protection of critical areas by intercepting storm run-off and diverting the flow to natural or man-made drainageways, to stabilized outlets, or to sediment traps. The terms "dikes" and "berms" are generally used interchangeably; however, dikes may also have applications as flood containment levees.

(b) Dikes and berms may be used to prevent excessive erosion of newly constructed slopes until more permanent drainage structures are installed or until the slope is stabilized with vegetation. Dikes and berms will help provide temporary isolation of uncapped and unvegetated disposal sites from surface run-off that may erode the cover and infiltrate the fill. These temporary structures are designed to handle relatively small amounts of runoff; they are not recommended for unsloped drainage areas larger than 5 acres.

(2) Design and construction considerations.

(a) Specific design and construction criteria for berms and dikes will depend upon desired site-specific functions of the structures. An interceptor dike/berm may be used solely to shorten the length of exposed slopes on or above a disposal site, thereby reducing erosion potential by intercepting and diverting run-off. Diversion dikes/berms may be installed at the top of the steeper side slopes of unvegetated disposal sites to provide erosion protection by diverting runoff to stabilized channels or outlets.

(b) Dikes and berms ideally are constructed of erosion-resistant, low-permeability, clayey soils. Compacted sands and gravel, however, may be suitable for interceptor dikes and berms. The general design life of these structures is on the order of one year maximum; seeding and mulching or chemical stabilization of dikes and berms may extend their life expectancy. Stone stabilization with gravel or stone riprap immediately upslope of diversion dikes will also extend performance life.

(c) All earthen dikes should be machine compacted. In addition:

n Diverted runoff should discharge directly onto stabilized areas, grassed channel, or chute/downpipe.

n Periodic inspection and maintenance should be provided.

n Diversion dikes must be seeded and mulched immediately after construction.

(3) Advantages and disadvantages. Advantages and disadvantages of dikes and berms are summarized below:

Advantages	Disadvantages
Uses standard construction techniques and equipment usually already on site	Periodic inspections and maintenance required to ensure structural integrity
Required fill dirt usually available on site	May increase seepage if installed improperly, increasing soil instability and leachate generation
Temporary control of erosion until further stabilization	Only suitable for small drainage areas (less than 2 hectares (5 acres))
Runon water reduced, and therefore leachate production	

c. Ditches. Diversions, and Waterways.

(1) Description and applications.

(a) Ditches (or swales) are excavated, temporary drainageways used above and below disturbed areas to intercept and divert runoff. They may be constructed along the upslope perimeter of disposal areas to intercept and carry storm run-off into natural drainage channels downslope of the site. Ditches may also be installed downslope of covered disposal sites to collect and transport sediment-laden flow to sediment traps or basins. Ditches should be left in-place until the disposal site is sealed and stabilized with cover vegetation.

(b) Diversions are permanent or temporary shallow drainageways excavated along the contour of graded slopes and having a support earthen ridge (dike or berm) constructed along the downhill edge of the drainageway. Essentially, a diversion is a combination of a ditch and a dike. Diversions are used primarily to provide more permanent erosion control on long slopes subject to heavy flow concentrations. They may be constructed across long slopes to divide the slope into nonerosive segments. Diversions may also be constructed at the top or at the base of long graded slopes at disposal sites to intercept and carry flow at nonerosive velocities to natural or prepared outlets. Diversions are recommended for use only in slopes of 15 percent or less.

(c) Grassed waterways (or channels) are graded drainageways that serve as outlets for diversions or berms. Waterways are stabilized with suitable vegetation and are generally designed to be wide and shallow in order to convey run-off down slopes at nonerosive velocities. Waterways may be constructed along the perimeter of disposal sites located within natural slopes, or they may be constructed as part of the final grading design for disposal areas that have been capped and revegetated.

(2) Design and construction considerations.

(a) Ditches, diversions, and waterways are generally of V-shaped, trapezoidal, or parabolic cross-section design. The specific design will be dependent on local drainage patterns, soil permeability, annual precipitation, area land use, and other pertinent characteristics of the contributing watershed. In general, such drainageways should be designed to accommodate flows resulting from rainfall events (storms) of 10- or 25-year frequency. More importantly, they should be designed and constructed to intercept and convey such flows at nonerosive velocities.

(b) Figure 3-25 depicts the effect of drainage channel shape on relative velocity of conveyed flows. In general, the wider and shallower the channel cross section, the less the velocity of contained flow and therefore the less the potential for erosion of drainageway side slopes. Where local conditions dictate the necessity of building narrower and deeper channels , or where slopes are steep and flow velocities are excessive, the channel will require stabilization through seeding and mulching or the use of stone riprap to line channel bottoms and break up flow.

(c) Table 3-6 presents maximum permissible design velocities for flow in ditches and grassed waterways, based on the channel grade and stabilizing cover material.

(d) These structures are designed for short-term application only, for upslope drainage areas of less than 2 hectares (5 acres). A minimum grade of 1 percent, draining to a stabilized outlet such as a grassed waterway or, where necessary, to a sediment basin or trap, is recommended for temporary ditches. For channel slopes greater than 5 percent, stabilization with

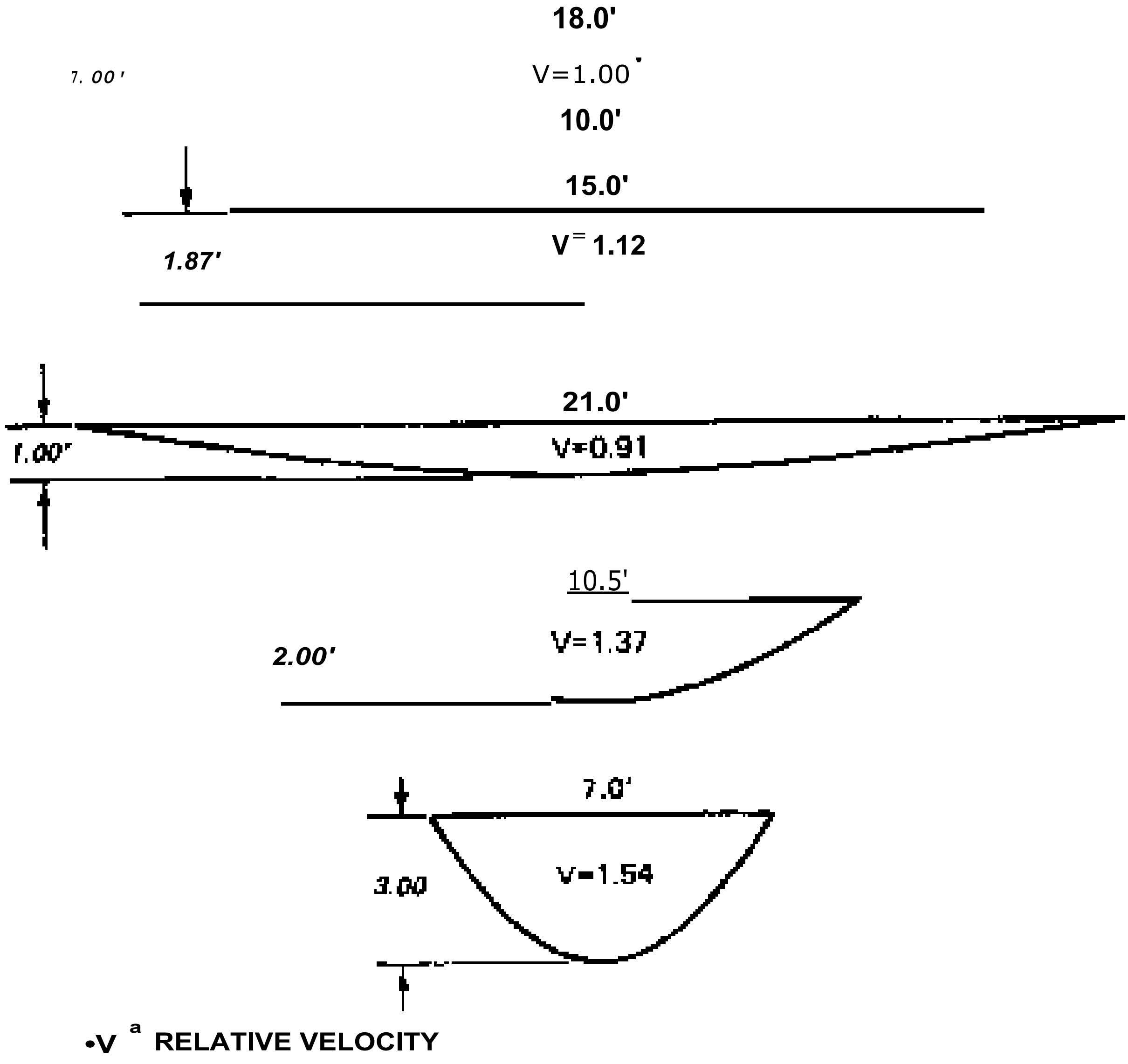


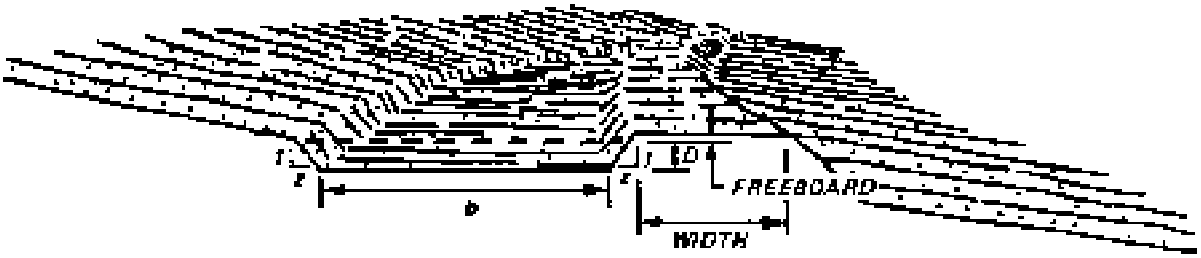
Figure 3-25. Effect of Drainage Ditch on Velocity

grasses, mulches, sod, or stone riprap will be necessary. As with all temporary structures, periodic inspection and maintenance are required to ensure structural integrity and effective performance.

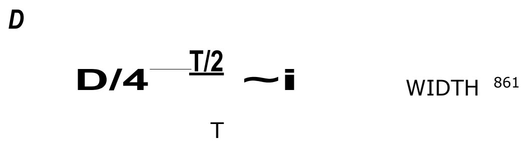
(e) Figure 3-26 presents general design features of parabolic and trapezoidal diversions. A formal design is not required for diversions used as temporary water-handling structures. General design and construction criteria for permanent diversions and waterways include the following:

Table 3-6. Permissible Design Velocities for Stabilized Diversions and Waterways

Vegetation	Channel grade (%)	Maximum design velocity (ft/sec)	(m/sec)
Bermuda grass	0-5	6	1.8
	5-10	5	1.5
	10	4	1.2
Reed canary grass	0-5	5	1.5
Tall fescue	5-10	4	1.2
Kentucky bluegrass	10	3	0.9
Grass-legume mix	0-5	4	1.2
	5-10	3	0.9
Red fescue Redtop, sericea lespedeza	0-5	2.5	0.8
Annuals; small grain (rye, oats, barley); ryegrass	0-5	2.5	0.8



TRAPEZOIDAL CROSS SECTION



PARABOLIC CROSS SECTION

Figure 3-26. General Design Features of Diversions n Diversion location will be determined on the basis of outlet conditions, topography, soil type, slope length, and grade.

n Constructed diversion will have the capacity to carry peak discharge from the 25-year design storm.

n The maximum grade of the diversion may be determined by using design velocity of the flow based on stabilization by cover type (Table 3-6).

n The diversion channel will be parabolic or trapezoidal in shape, with side slopes no steeper than 2:1.

n Each diversion will have a stable outlet such as a natural waterway, stabilized open channel, chute, or downpipe.

n For channels that carry flow during dry weather (base flow) due to ground-water discharge or delayed subsurface run-off, the bottom should be protected with a stone center for grassed waterways. Subsurface drainage with gravel/stone trenches may be required where the water table is at or near the surface of the channel bottom.

(3) Advantages and disadvantages.

(a) When they are carefully designed, constructed, and maintained, ditches, diversions, and grassed waterways will control surface erosion and infiltration at disposal sites by intercepting and safely diverting storm run-off to downslope or offsite outlets. When situated at the base of disposal site slopes, they function to protect offsite habitat from possible contamination by sediment-laden run-off. These structures are generally constructed of readily available fill, by well-established techniques.

(b) Temporary ditches and diversions, however, entail added costs because they require inspections and maintenance. Grassed waterways must be periodically mowed to prevent excessive retardation of flow and subsequent ponding of water. Also, periodic resodding, remulching, and fertilizing may be required to maintain vegetated channels.

(c) If fertilization is used, an additional disadvantage is introduced in that nitrogen and phosphorus are added to drainage wastes, which then contribute to the problem of accelerated eutrophication in receiving water bodies.

(d) It may also be necessary to install temporary straw-bale check dams, staked down at 15.2 to 30.5 m (50- to 100-foot) intervals, across ditches and waterways in order to prevent gulley erosion and to allow vegetative establishment.

(e) Permanent diversions and waterways are more cost-effective techniques than temporary structures for controlling erosion and infiltration on a long-term basis at inactive disposal sites.

d. Terraces and Benches.

(1) Description and applications.

(a) Terraces and benches are relatively flat areas constructed along the contour of very long or very steep slopes to slow run-off and direct it into ditches or diversions for offsite transport at nonerosive velocities. These structures are also known as bench terraces or drainage benches.

(b) Although benches and terraces are slope-reduction devices, they are generally constructed with reverse or natural fall to divert water to stabilized drainageways. Benches and terraces may be used to break up steeply graded slopes of covered disposal sites into less erodible segments. Upslope of disposal sites, they act to slow flow and divert storm run-off around the site. Downslope of landfill areas, they act to intercept and divert sediment-laden run-off to traps or basins. Hence, they may function to hydrologically isolate active disposal sites, to control erosion of cover materials on completed fills, or to collect contaminated sediments eroded from disposal areas. For disposal sites undergoing final grading (after capping and prior to revegetation), construction of benches or terraces may be included as part of the integrated site closure plan.

(2) Design and construction considerations.

(a) Benches and terraces generally do not require a formal design plan. Figure 3-27 presents the design for a typical drainage bench located on the slope of a covered landfill. This particular bench is designed with a natural fall. It is intended for long-term erosion protection as the associated V-shaped channel is asphalt-concrete lined. Diversions and ditches included in bench/terrace construction may be seeded and mulched, sodded, stabilized with riprap or soil additives, or stabilized by any combination of these methods. Lining the channels with concrete or grouted riprap is a more costly alternative.

(b) The width and spacing between benches and terraces will depend on slope steepness, soil type, and slope length. In general, the longer and more erodible the cover soil, the less the distance between drainage benches should be. For slopes greater than 10 percent in steepness, the maximum distance between drainage benches should be approximately 30.5 m (100 feet), i.e., a bench every 3 m (10 feet) of rise in elevation.

(c) When the slope is greater than 20 percent, benches should be placed every 20 feet of rise in elevation. Benches should be of sufficient width and height to withstand a 24-hour, 25-year storm.

(d) Bench terraces do not necessarily have to be designed with diversions or ditches to intercept flow. Reverse benches and slope benches may be constructed during final site grading on well-stabilized slopes (e.g., vegetated) to enhance erosion control by reducing slope length and steepness. At sites where an effective cap (e.g., clay or synthetic liner) has been constructed, or for sites located in arid regions, these nondrainage benches

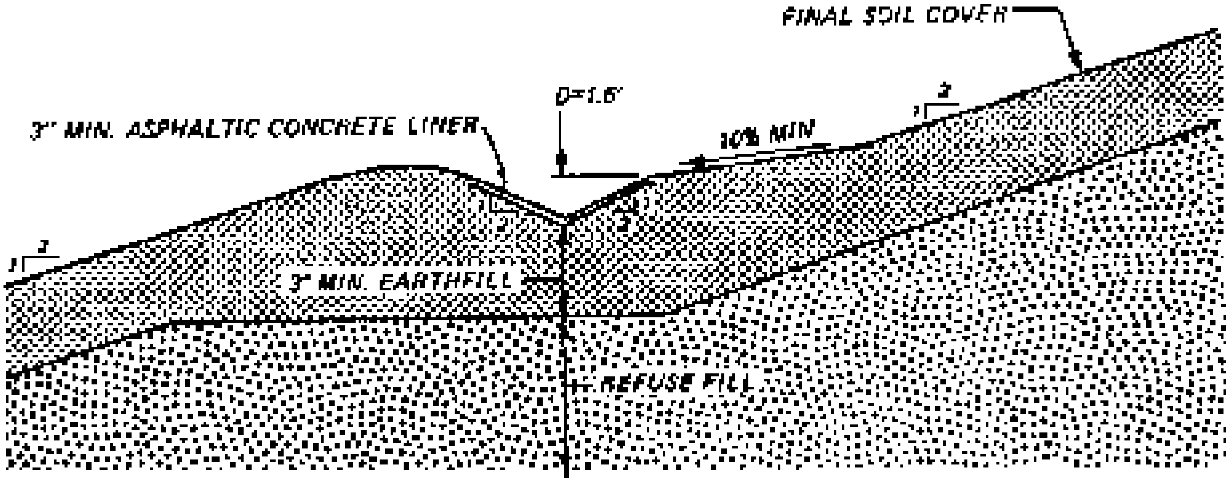


Figure 3-27. **Typical Drainage Bench**

will function to slow sheet run-off and allow greater infiltration rates, which will aid in the establishment of a suitable vegetative cover. For most disposal sites in wet climates, however, where leachate generation and cover erosion are major problems, benches and terraces should be designed in association with drainage channels that intercept and transport heavy, concentrated surface flows safely offsite.

(e) As with other earthen erosion control structures, benches and terraces should be sufficiently compacted and stabilized with appropriate cover (grasses, mulches, sod) to accommodate local topography and climate. They should be inspected during or after major storms to ensure proper functioning and structural integrity. If bench slopes become badly eroded or if their surfaces become susceptible to ponding from differential settlement, regrading and sodding may be necessary.

(3) Advantages and disadvantages.

(a) In areas of high precipitation, drainage benches and terraces are proven effective in reducing velocity of storm run-off and thereby controlling erosion. For excessively long and steep slopes above, on, or below disposal sites, these structures are cost-effective methods for slowing and diverting run-off. They may also be used to manage downslope washout of disposal site sediments that may be contaminated with hazardous waste components. Terraces and benches are easily incorporated into final grading schemes for disposal sites and do not require special equipment or materials for their construction.

(b) If improperly designed or constructed, bench terraces will not perform efficiently and may entail excessive maintenance and repair costs. It is important that these structures be stabilized with vegetation as soon as possible after grading and compaction, or they may become badly eroded and require future resodding or chemical stabilization. Benches and terraces also require periodic inspections, especially after major rainfall events.

e. Chutes and Downpipes.

(1) Description and applications.

(a) Chutes and downpipes are temporary structures used to carry concentrated flows of surface runoff from one level to a lower level without erosive damage. They generally extend downslope from earthen embankments (dikes or berms) and convey water to stabilized outlets located at the base of terraced slopes.

(b) Chutes (or flumes) are open channels, normally lined with bituminous concrete, portland cement concrete, grouted riprap, or similar nonerodible material. Temporary paved chutes are designed to handle concentrated surface flows from drainage benches located near the base of the long, steep slopes at disposal sites.

(c) Downpipes (downdrains or pipe slope drains) are temporary structures constructed of rigid piping (such as corrugated metal) or flexible tubing of heavy-duty fabric. They are installed with standard prefabricated entrance sections and are designed to handle flow from drainage areas of 5 acres or less. Like paved chutes, downpipes discharge to stabilized outlets or sediment traps. Downpipes may be used to collect and transport run-off from long, isolated outslopes or from small disposal areas located along steep slopes.

(2) Design and construction considerations.

(a) Chutes and downpipes are temporary structures that do not require formal design.

(b) Paved chute construction considerations include the following:

- The structure will be placed on undisturbed soil or well-compacted fill.

- The lining will be placed by beginning at the lower end and proceeding upslope; the lining will be well compacted, free of voids, and reasonably smooth.

- The cutoff walls at the entrance and at the end of the asphalted discharge aprons will be continuous with the lining.

- An energy dissipator (riprap bed) will be used to prevent erosion at the outlet.

(c) For downpipes, the maximum drainage area will be determined from the diameter of the piping, as follows (U.S. EPA 1976):

Pine/Tube diameter, D (inches)	(mm)	Maximum drainage area (acres)	(hectares)
12	300	0.5	0.2
18	460	1.5	0.6
21	530	2.5	1
24	610	3.5	1.4
30	760	5.0	2

(d) General construction criteria for both rigid and flexible downdrains include the following:

n The inlet pipe will have a slope of 3 percent or greater.

n For the rigid downpipe, corrugated metal pipe with watertight connecting bands will be used.

n For the flexible downdrain, the inlet pipe will be corrugated metal; the flexible tubing will be the same diameter as the inlet pipe, securely fastened to the inlet with metal strapping or watertight connecting collars.

n A riprap apron of 152 mm (6-inch-diameter) stone will be provided at the outlet.

n The soil around and under the inlet pipe and entrance sections will be hand-tamped in 102 mm (4-inch) lifts to the top of the earth dike.

n Follow-up inspection and any needed maintenance will be performed after each storm.

(3) Advantages and disadvantages. The advantages and disadvantages associated with the construction and maintenance of chutes and downpipes are summarized below:

Advantages	Disadvantages
Construction methods are inexpensive and quick; suitable for for emergency measures	Provide only temporary erosion control while slopes are stabilized with vegetative growth
No special materials or equipment are required	Entail extra cost for periodic inspections and maintenance and ultimate removal
Effective in preventing erosion on long, steep slopes	If improperly designed, may overflow and cause severe erosion in concentrated areas
Can be used to channel storm runoff to sediment traps, drainage basins, or stabilized waterways for offsite transport	

(Continued)

Advantages	Disadvantages
Can be key element in combined surface control systems	Downpipes are suitable for drainage areas 2 hectares (5 acres) in size limited applications in general

f. Levees and Floodwalls.

(1) Description and applications.

(a) Levees are earthen embankments that function as flood protection structures in areas subject to inundation from tidal flow or riverine flooding. Levees create a barrier to confine flooding waters to a floodway and to protect structures behind the barrier. They are most suitable for installation of flood fringe areas or areas subject to storm tide flooding, but not for areas directly within open floodways.

(b) Flood containment levees may be constructed as perimeter embankment surrounding disposal sites located in floodplain fringe areas, or they may be installed at the base of landfills along slope faces that are subject to periodic inundation.

(c) Levees are generally constructed of compacted impervious fill. Special drainage structures are often required to drain the area behind the embankment. Levees are normally constructed for long-term flood protection, but they require periodic inspection and maintenance to ensure proper functioning. They may be costly to build and maintain, but if properly designed on a site-specific basis, levees will reduce flooding hazards at critical waste disposal areas.

(2) Design and construction considerations.

(a) To provide adequate flood protection, levees should be constructed to a height capable of containing a design flood of 100-year magnitude. Elevation of 100-year base flood crests can be determined from floodplain analyses typically performed by state or local flood control agencies. A minimum levee elevation of 0.6 m (2 feet) above the 100-year flood level is recommended.

(b) Figure 3-28 presents design features of a typical levee constructed at the toe of a landfill slope. This design is appropriate for new or incomplete disposal sites; filled wastes may eventually be placed on the inboard slope of the levee.

(c) Ideal construction of levees is with erosion-resistant, low permeability soils, preferably clay. Most levees are homogeneous embankments; but if impermeable fill is lacking, or if seepage through and below the levee is a problem, then construction of a compacted impervious core or sheet-pile cutoff extending below the levee to bedrock (or other impervious stratum) may

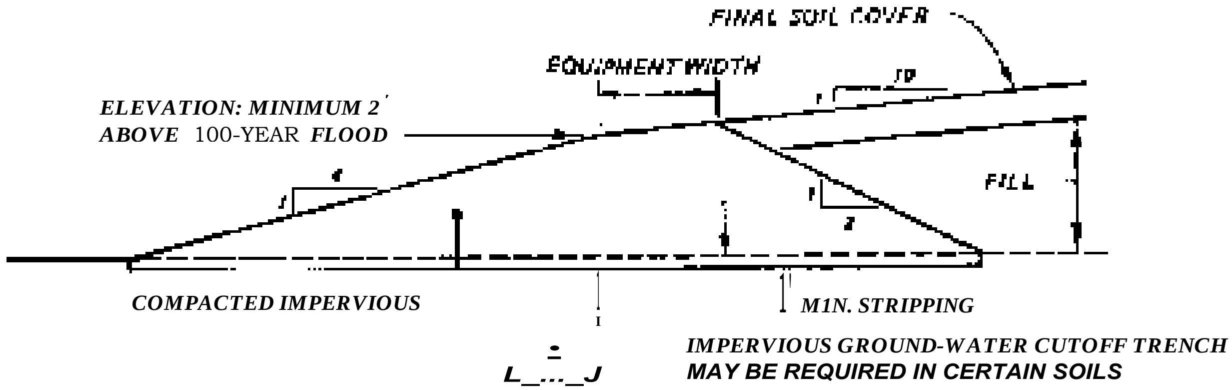


Figure 3-28. **Typical Levee at Base of Disposal Site**

be necessary. Excess seepage through the levees should be collected with gravel-filled trenches or tile drains along the interior of the levee. After draining to sumps, the seepage can be pumped out over the levee. Levee bank slopes, especially those constructed of less desirable soils (silts, sands), should be protected against erosion by sodding, planting of shrubs and trees, or use of stone riprap.

(d) Storm run-off from precipitation falling on the drainage area behind the levee may cause backwater flooding.

(e) Because of the relatively long, flat side slopes of levees, an embankment of any considerable height requires a very large base width. For locations with limited space and fill material, or excessive real estate costs, the use of concrete floodwalls is preferred as an alternative to levee construction.

(f) Floodwalls are designed to withstand the hydrostatic pressure exerted by water at the design flood level. They are subject to flood loading on one side only; consequently, they need to be well founded. Figure 3-29 presents typical floodwall sections. Like levees, floodwalls may require subsurface cutoffs and interior drainage structures to handle excessive seepage or backwater flow.

(3) Advantages and disadvantages. The advantages and disadvantages associated with flood protection levees at waste disposal sites are summarized below:

Advantages	Disadvantages
Can be built at relatively low cost from materials available at site	Flooding from storm runoff behind levee may be a problem

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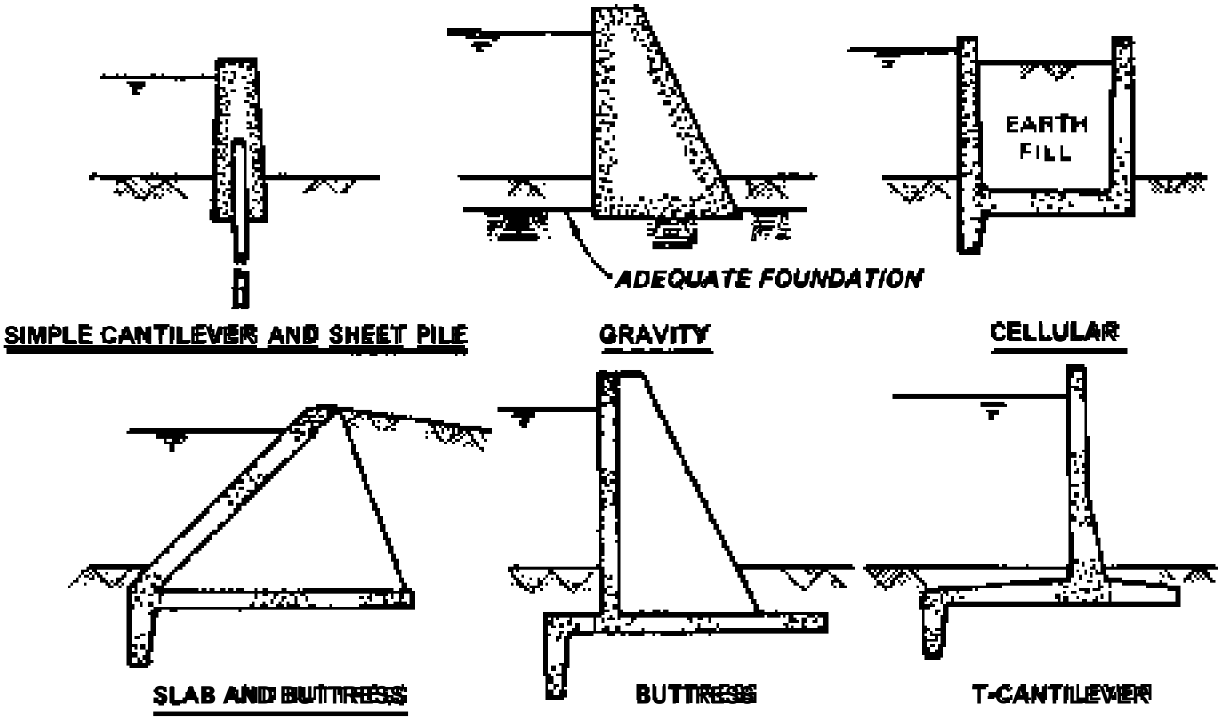


Figure 3-29. Some Typical Floodwall Sections

Advantages	Disadvantages
Will privide long-term flood protection if properly designed and constructed	Loss of flow storage capacity, with greater potential of downstream flooding
Control major erosive lossed of waste and cover material; prevent massive leachate production and subsequent contamination from riverine or tidal flooding	Levee failure during major flood will require costly emergency measures (emergency embankments; sand bags) and rebuilding of structure
	Require periodic maintenance and inspections
	Special seepage cutoffs or interior drainage structures (e.g., pressure conduits) will add to construction costs

g. Seepage Basins and Ditches.

(1) General description and applications. Seepage or recharge basins are designed to intercept run-off and recharge the water downgradient from the site so that ground-water contamination and leachate problems are avoided or minimized.

(2) Design and construction considerations.

(a) There is considerable flexibility in the design of seepage basins and ditches. Figures 3-30 and 3-31 illustrate possible design variations. Where seepage basins are used (Figure 3-30), run-off will be intercepted by a series of diversions, or the like, and passed to the basins. As illustrated, the recharge basin should consist of the actual basin, a sediment trap, a bypass for excess run-off, and an emergency overflow. A considerable amount of recharge occurs through the sidewalls of the basin, and it is preferable that these be constructed of pervious material. Gabions are frequently used to make sidewalls. An alternative design for a seepage basin is shown in Figure 3-31; it is usually used where the aquifer is shallow.

(b) Seepage ditches (Figure 3-32) distribute water over a larger area than can be achieved with basins. They can be used for all soils where permeability exceeds about 2.94×10^{-5} cm/sec (0.9 inch per day). Run-off is disposed of by a system of drains set in ditches of gravel. Depth and spacing of drains depend on soil permeability. A minimum depth of 1.2 m (48 inches) is generally recommended, and ditches are rarely less than 3 m (10 feet) apart. The ditches are backfilled with gravel, on which the distribution line is laid. Sediment is removed prior to discharging run-off into the seepage ditches by use of a sediment trap and distribution box.

(3) Advantages and disadvantages. Advantages and disadvantages of drainage systems are listed below:

Advantages	Disadvantages
Cost-effective means of intercepting run-off and allowing it to recharge	Seepage basins and ditches are susceptible to clogging
Systems can perform reliably if well maintained	Deep basins or trenches can be hazardous
	Not effective in poorly permeable soils

h. Sedimentation Basins/Ponds.

(1) General description and application. Sediment basins are used to control suspended solids entrained in surface flows. A sedimentation basin is constructed by placing an earthen dam across a waterway or natural depression, or by excavation, or by a combination of both. The purpose of installing a sedimentation basin is to impede surface run-off carrying solids, thus

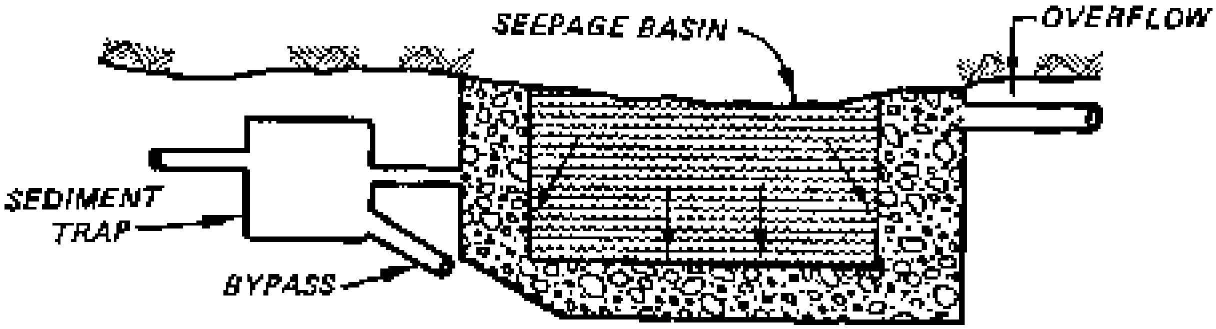


Figure 3-30. Seepage Basin; Large Volume, Deep Depth to Ground Water

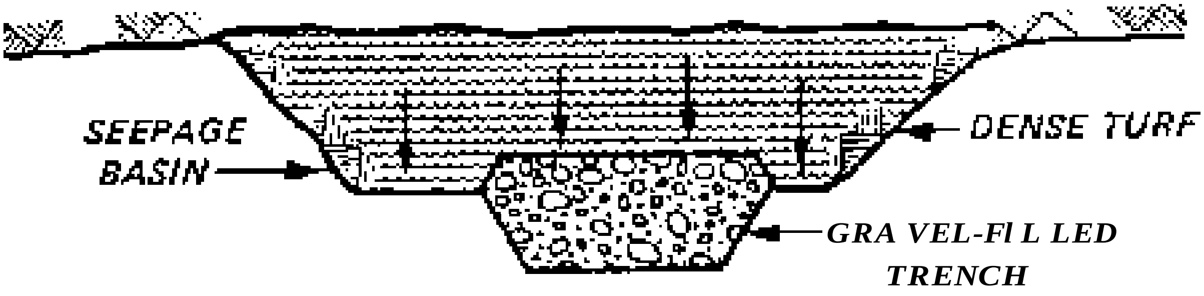


Figure 3-31. Seepage Basin: Shallow Depth to Ground Water

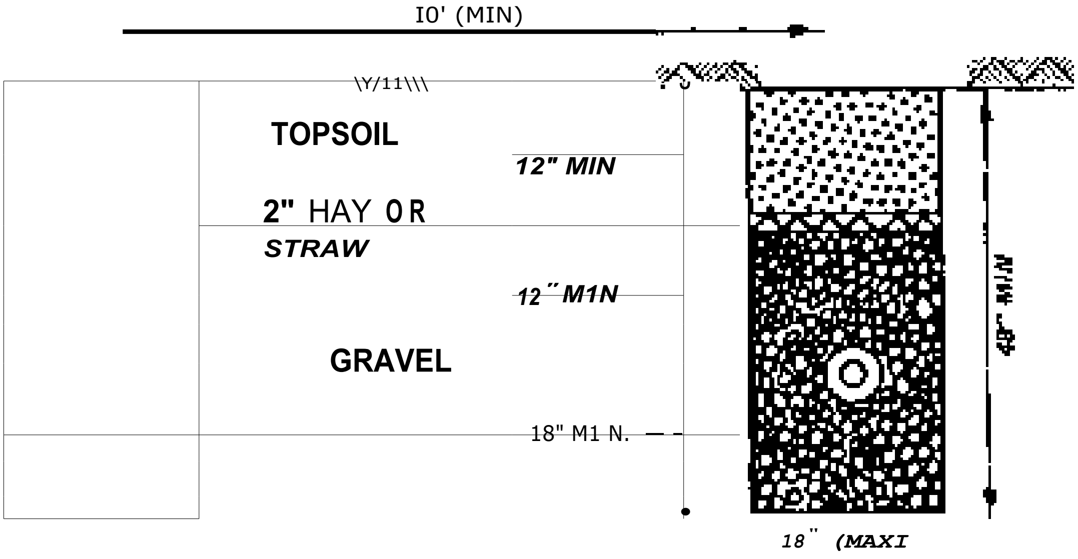


Figure 3-32. Seepage Ditch

allowing sufficient time for the particulate matter to settle. Sedimentation basins are usually the final step in control of diverted surface run-off, prior to discharge into a receiving water body. They are an essential part of any good surface flow control system and should be included in the design of remedial actions at waste disposal sites.

(2) Design and construction considerations.

(a) The removal of suspended solids from waterways is based on the concept of gravitational settling of the suspended material.

(b) The size of a sedimentation basin is determined from characteristics of flow such as the particle size distribution for suspended solids, the inflow concentration, and the volumetric flow rate. To calculate the area of the sedimentation basin pond required for effective removal of suspended solids, the following data on the flow characteristics are needed:

n The inflow concentration of suspended solids.

n The desired effluent concentration of suspended solids. The desired effluent concentration is usually regulated by local and/or Federal government authorities. For example, for coal mines, the proposed EPA "Effluent Guidelines and Standard" limits are as follows: total suspended solids concentration maximum for any one day shall not exceed 70 milligrams per liter, and average daily values for 30 consecutive days shall not exceed 35 milligrams per liter.

n The particle-size distribution for suspended solids.

n The water flow rate (Q) to the pond. For a pond receiving direct run-off, the run-off volume over a certain period of time must be determined. As an example, EPA has chosen the 10-year, 24-hour precipitation event as a design criteria for the overflow rate determination.

(g) A typical installation of a sedimentation basin embankment is illustrated in Figure 3-33. As shown, the pond consists of a dike which retains the polluted water flow. For water drawdown purposes, a principal spillway is also needed.

(h) Emergency spillways are also suggested in the design of a sediment basin. They are provided to convey large flows safely past an earth embankment, and they are usually open to channels excavated in earth, rock, or reinforced concrete.

(i) The efficiency of sedimentation ponds varies considerably as a function of the overflow rate. Sedimentation ponds perform poorly during periods of heavy rains and cannot be expected to remove the fine-grained suspended solids. If the sedimentation pond is expected to remove sediments that may have been contaminated by waste materials, consideration should be given to improving removal efficiencies by modifying basin or outlet design.

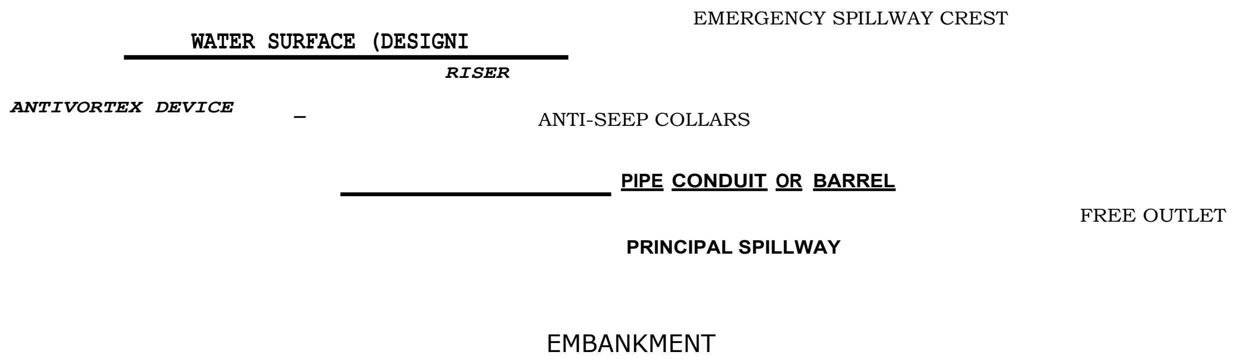


Figure 3-33. **Typical Design of** a **Sediment Basin Embankment**

(f) The quantity of material to be stored is also an important consideration in the construction of the sedimentation basin. The required storage capacity can be calculated by multiplying the total area disturbed by a constant sediment yield rate.

(3) Advantages and disadvantages. The advantages and disadvantages of the sedimentation basin in the control of water flow contaminated with suspended solids are listed below.

Advantages	Disadvantages
Easy to design and install, proven technology	Ineffective on dissolved solids
Require low operational and maintenance effort	Faulty design or structural failure may result in extensive damages
Remove suspended solids very effectively	

3-23. Surface Grading.

a. Background.

(1) Grading is the general term for techniques used to reshape the surface of covered landfills in order to manage surface water infiltration and run-off while controlling erosion. The spreading and compaction steps used in grading are techniques practiced routinely at sanitary landfills. The equipment and methods used in grading are essentially the same for all landfill surfaces, but applications of grading technology will vary by site. Grading is often performed in conjunction with surface sealing practices and revegetation as part of an integrated landfill closure plan.

(2) The major goals in surface grading of an uncontrolled waste site are to:

(a) Reduce ponding on the site and consequently minimize infiltration of water into any buried wastes.

(b) Reduce the rate of contaminant leaching from soils.

(c) Reduce erosion of cover soils that isolate any buried waste.

(3) Proper site grading is in almost all cases an advantage in the control of the potential contaminants. Since standing water in a waste site will leach contaminants from the surface materials, it is generally more likely to create a treatment problem than water collected running from the area. Ponding also creates aesthetic and trafficability problems.

(4) Finished grades at waste sites are designed on the basis of natural site topography, soil type, slope stability, rainfall intensity, size of the site, and type of final vegetative cover proposed.

b. Description and Applications.

(1) Grading techniques modify the natural topography and run-off characteristics of waste sites to control infiltration and erosion. The choice of specific grading techniques for a given waste disposal site will depend on the desired site-specific functions of a graded surface. A graded surface may reduce or enhance infiltration and detain or promote run-off. Erosion control may be considered a complicating variable in the design performance of a grading scheme.

(2) For disposal sites in wet climates (i.e., where precipitation annually exceeds evaporation and transpiration) and where subsurface hazardous leachate generation is a major problem, control of surface water infiltration is of primary importance. Manipulation of slope length and gradient is the most common grading technique used to reduce infiltration and promote surface water run-off. A slope of at least 5 percent is recommended as sufficient to promote run-off and decrease infiltration without risking excessive erosion.

(3) At landfill and dump sites where an effective surface sealing has been applied (e.g., clay cap or synthetic membrane and a topsoil layer), various grading techniques can be used to prepare the covered surface for revegetation. The grading methods- -scarification, tracking, and contour furrowing- -create a roughened and loosened soil surface that detains run-off and maximizes infiltration. Such techniques are especially important for establishing vegetation in arid regions.

c. Design and Construction Considerations.

(1) The design of graded slopes at waste disposal sites should balance infiltration and run-off control against possible decreases in slope stability and increases in erosion. The design of specific slope configurations, the choice of cover soil type, the degree of compaction, and the types of grading equipment used will all depend on local topography, climate, and future land use of the site.

(2) Improperly graded slopes may deform or fail, opening cracks, exposing waste cells, and allowing lateral seepage of leachate. Soils used to cover graded slopes should be selected on the basis of shear strength and erodibility. Soils high in silt and fine sand and low in clay and organic matter are generally most erodible. Also, the longer and steeper the slope **is**, and the sparser the vegetation cover, the more susceptible it is to erosive forces.

(3) In grading a landfill surface before construction of a seal, two important considerations apply. First, bulky and heavy waste objects should not be filled near the surface of the site because they may settle unevenly and deform or crack graded cover. Also, to provide a firm subgrade and prevent seal failure, existing cover material should be compacted to a Proctor density of 70 to 90 percent of maximum.

(4) The equipment types used to construct graded slopes consist of both standard and specialized landfill vehicles. Excavation, hauling, spreading, and compaction of cover materials are the major elements of a complete grading operation.

(5) Specialized landfill vehicles include compactors and scrapers. Steel-wheeled landfill compactors are excellent machines for spreading and compacting on flat to moderate slopes. Scrapers are effective in excavating, hauling, and spreading cover materials over relatively long distances.

d. Advantages and Disadvantages.

(1) Surface grading of covered disposal sites, when properly designed and constructed to suit individual sites, can be an economical method of controlling infiltration, diverting run-off, and minimizing erosion. A properly sealed and graded surface will aid in the reduction of subsurface leachate formation by minimizing infiltration and promoting erosion-free drainage of surface run-off. Grading can also be used to prepare a cover soil capable of supporting beneficial plant species.

(2) There may be certain disadvantages associated with grading the surface of a given site. Large quantities of a difficult-to-obtain cover soil may be required to modify existing slopes. Suitable sources of cover material may be located at great distances from the disposal site, increasing hauling costs. Also, periodic regrading and future site maintenance may be necessary to eliminate depressions formed through differential settlement and compaction, or to repair slopes that have slumped or become badly eroded.

3-24. Surface Sealing.

a. Background.

(1) Landfill covers or caps prevent water from entering a landfill, thus reducing leachate generation, and also control vapor or gas produced in the water. Landfill covers can be constructed from native soils, clays, synthetic membranes, soil cement, bituminous concrete, or asphalt/tar materials. In most cases, the cap is constructed using the same equipment

used in construction and grading. The cap should be designed to have sufficient thickness to accommodate the anticipated settlements, deformations, desiccation cracking, and constructibility. Where native soil is used for the cap, soil additives or specialized construction techniques may be necessary to obtain the required plasticity and permeability. A permeability of 10' to 10^{-8} cm/sec is considered appropriate.

(2) A cover is a useful option at sites where the major pathway for contaminant transport is percolation of infiltrating precipitation or in cases where control of gases or volatile compounds in the waste is a serious consideration. When a cap is designed for toxic or flammable gas control, gas venting and disposal systems should be considered an integral part of the capping system.

(3) Capping systems are an advantage at any site where incoming precipitation can be minimized and leach rates reduced. In areas where the wastes are buried below the water table and lateral flow of ground water is evident, capping may not be completely effective in reducing contaminant transport. In a capped landfill at Windham, CT, that was partly below the water table, a definite decrease in the degree of contamination in ground water downgradient from the site was noted. Capping is usually an economical system, and because the top of the landfill is accessible, the cap can be maintained and repaired.

b. <u>Description and Applications.</u>

(1) Clays and soils.

(a) Cover soils are spread over waste layers at most operating landfills on a daily or intermediate basis prescribed by state and local standards in order to control vectors, odors, and windblown rubbish. These soils are generally supplied from onsite excavated fill and are not selected for special qualities. Soil used for final cover on completed fills or for capping uncontrolled waste sites, however, must be relatively impermeable (low permeability coefficient, k) and erosion-resistant. Fine-grained soils such as clays and silty clays have low k values and are therefore best suited for capping purposes because they resist infiltration and percolation of water. These fine-grained soils, however, tend to be easily eroded by wind, especially in arid climates where coarse, heavy-grained gravels and sands provide more suitable cover.

(b) Blending of different soil types broadens the grain-size distribution of a soil cover and minimizes its infiltration capacity. Well-graded soils are less permeable than those with a small range of grain sizes, and mixing of local coarse and fine-grained soils is a cost-effective method of creating stronger and less porous cover soil. For example, when fine soils are not available locally, the addition of gravel or sand to fine-grained silts and clays enhances strength and reduces percolation.

(c) Similarly, additions of clay to sandy or silty cover material will lead to dramatic reductions in the k value of the soil. Blending can often be accomplished in place using a blade or harrow to turn and mix the soil to suitable depths.

(d) The Atterberg limits are a good first approximation of the mechanical behavior of a clay-type soil. The limits are defined by the water content of the soil that produces a specified consistency. In themselves the Atterberg limits mean little; however, when used as indexes to the relative properties of a clay-type soil they are very helpful.

(e) The most important soil property that will affect the performance of a cover is its permeability. Mechanical compaction is used to alter the soil properties and develop a permeability suitable for the cover being constructed. Design parameters for compaction are based on a unique density value (maximum density) and a corresponding moisture content (optimum moisture content). Generally it can be assumed that the more granular the soil (the more sandy it is), the higher the maximum density and the lower the optimum moisture content. Also the finer the soil (the more clayey it is), the less defined the maximum density is as a function of the moisture content. Typically soils used for covers will have a clay content in excess of 25-30 percent which will have a poorly defined maximum density.

(f) Density quality control in the field is very important and requires a great deal of attention and skill. When compacting a cover material on the relatively soft base of the refuse, problems in obtaining the proper compaction can result. Also, the possibility of penetrating a cap with large pieces of refuse upon compaction should be considered. For these reasons a strict field testing and quality control program should be followed during construction.

(g) When constructing the final landfill cap, normal construction techniques will apply. It is very important that the buffer layer between the refuse and barrier be thick and dense enough to provide a stable base and prevent large pieces of refuse from penetrating the barrier. The barrier layer should be covered immediately after compaction is complete to prevent drying and crack formation. The final top soil layer should not be compacted and should be seeded and mulched as soon as possible to prevent erosion.

(2) Asphalt and admixed materials.

(a) There is a variety of admixed materials that can be formed in-place to fabricate a liner and cover. These materials include asphalt, concrete, soil cement, soil asphalt, catalytically blown asphalt, asphalt emulsions, lime, and other chemical stabilizers. Many of these materials can be sprayed directly on prepared surfaces in a liquid form. This material then solidifies to form a continuous membrane.

n Hydraulic asphalt concrete is a hot mixture of asphalt cement and mineral aggregate. It is resistant to the growth of plants and weather extremes and will resist slip and creep when applied to side slopes. The material should be compacted to less than 4 percent voids to obtain the low permeability needed.

n Soil cement is a compacted mixture of portland cement, water, and selected in-place soils. The soil used should be nonorganic and well graded with less than 50 percent silt and clay. The soil should also have a maximum size of 0.75 inch and a maximum clay content of 35 percent. Soil cement has the disadvantage of cracking and shrinking upon drying.

n Soil asphalt is similar to soil cement; however, the soil used should be a low plasticity, gravelly soil with 10-25 percent silty fines. The membrane must be waterproofed with a hydrocarbon or bituminous seal.

n Catalytically blown asphalt is manufactured from asphalts with high softening points by blowing air through the molten asphalt in the presence of a catalyst such as phosphorus pentoxide or ferric chloride. The material can then be sprayed on a prepared surface regardless of cold or wet weather. As with soil asphalt the membrane must be waterproofed with a hydrocarbon or bituminous seal.

n Asphalt emulsions can also be sprayed directly on prepared surfaces at temperatures above freezing. These membranes are less tough and have lower softening points than hot air-blown asphalt. However, the toughness and dimensional stability can be increased by spraying onto supporting fabrics.

(b) A summary of spray-on chemical stabilizers for cover soils is shown in Table 3-7.

(c) Sprayed-on liners and covers require a more carefully prepared subgrade than other liner and cover membranes. If a smooth surface cannot be obtained with the subgrade, a fine sand or soil padding may be necessary. Even with a properly prepared subgrade, care must be taken in placing the material to make it pinhole free.

(d) Cover soils treated with lime, which contributes pozzolanic (cementing) properties to the resulting mixture, optimize the grain-size distribution and reduce shrink/swell behavior. Lime applied as 2 to 8 percent (by weight) calcium oxide or hydroxide is suitable for cementing clayey soils. Rotary tiller mixing followed by water addition and compaction is the general application sequence for these mixtures. Also, additions of lime are recommended for neutralizing acidic cover soils, thereby reducing the leaching potential of heavy metals. If a synthetic liner is present, liner life can be prolonged by lime addition to supporting soil.

(e) Other cover soil-chemical additives may include chemical dispersant and swell reducers. Soluble salts such as sodium chloride, tetrasodium pyrophosphate, and sodium polyphosphate are added primarily to fine-grained soils with clay minerals to deflocculate the soils, increase their density, reduce permeability, and facilitate compaction. Additives are more effective with montmorillonite clay than with kaolinite or illite. Because soils in the northeast and midwest continental United States are usually low in montmorillonite, site-specific testing should be undertaken before using additives with soils in these areas.

(3) Synthetic membranes.

Table 3-7. Summary of Chemical Stabilizers for Cover Soil

Name	Soil stabilizer	Mulch	Mulch tack	Erosion resistance		Description	Product information
				Water	Dust/wind		
Aerospray® 52	x	x		x		Water dispersible, alkyd resin emulsion; forms hard crust; nontoxic; nonphytotoxic, pH 8-9; $0.75/i (-$2.85/gal)	American Cyanamid Co., Industrial Chemicals and Plastic Div. Wayne, NJ 07970
Aerospray® 70	x	x	x	x		Water dispersible polyvinyl acetate resin emulsion; effective in sand; $0.66/D ($2.50/gal)	American Cyanamid Co., Industrial Chemicals and Plastic Div. Wayne, NJ 07970
Aquatain	x	x		x		Water dispersible, concentrate of chemicals and pectin; forms fragile crust; nontoxic; nonflammable; $0.61/a ($2.30/gal)	Larutan Corp., Anaheim, CA 02805
Curasol® AE	x	x	x		x	Water dispersible, polyvinyl acetate latex emulsion; hard crust; nontoxic; nonphytotoxic; pH 4-5; $0.69/D ($2.60/gal)	American Hoechst Corp., Bridgewater, NJ 08876

(Continued)

Table 3-7. (Concluded)

Name	Soil stabilizer	Mulch	Mulch tack	Erosion resistance		Description	Product information
				Water	Dust/wind		
Curasol® AH	x		x		x	Water dispersible; high polymer synthetic resin; flexible crust; nontoxic; nonphytotoxic; pH 4-5	American Hoechst Corp., Bridgewater, NJ 08876
DCA - 70	x	x	x		x	Water dispersible; polyvinyl acetate emulsion; can be reinforced with fiberglass filaments; nontoxic; nonphytotoxic; nonflammable; pH 4-6	Union Carbide Corp., Chemicals and Plastics New York, NY 10017
Petroset®	x	x	x	x	x	Water dispersible oil emulsion; effective in partitles below gravel size; nontoxic; nonflammable; pH 6 ± 0.5; $0.42/@ ($1.60/gal)	Phillips Petroleum Co. Chemical Dept., Bartlesville, OK 74003

(Sources: Lutton et al. 1979 and EPA 1976).

(a) The use of synthetic membrane in surface water control is new, and a wide variety of synthetic materials and compounds are being manufactured, tested, and marketed. The various membranes being produced vary not only in physical and chemical properties but also in installation procedures, costs, and chemical compatibility with waste fluids. Not only are there variations in the polymers being used but also with the compounding agents such as carbon black, pigments, plasticizers, crosslinking chemicals, antidegradients, and biocides. The sheeting is then joined or seamed together into panels as large as 30 m (100 feet) by 61 m (200 feet) depending on weight and handling limitations. The various seaming techniques include: heat seaming, dielectric seaming, adhesive seaming, and solvent welding. The four types of polymers generally considered for use in membranes are vulcanized rubbers, unvulcanized plastics such as PVC, highly crystalline plastics, and thermoplastic elastomers. The thicknesses of the polymeric membranes used in landfill applications range from 0.5 to 3 mm (20 to 120 mil), with most in the 0.5 to 1.5 mm (20- to 60-mil) range. Most membrane liners and covers are manufactured from unvulcanized polymeric (thermoplastic) compounds. The thermoplasticity allows the material to be heated for fusing or seaming without losing its original properties when cooled.

(b) One of the most important components in the installation of a synthetic membrane is the preparation of the subgrade. The subgrade must provide even support for the membrane, or the unsupported membrane could very easily fail. The in-situ soil that will be used for the subgrade should be tested for its physical, mechanical, and chemical character. These tests should determine, among other things, the shrink/swell properties of the soil and the density, strength, settlement, and permeability of the subgrade*s soil. Soils with high shrink/swell characteristics will tend to weaken earthen structures or cause void spaces which will cause membrane failure. Organic matter in the subgrade can cause membrane failure by leaving void spaces or by generating gases during the decaying process which collect under the membrane and cause a ballooning effect. Surface diversion ditches should be used to prevent the erosion of cover material on a membrane cap. Temperature extremes can make membrane placement difficult. Low temperatures can make a membrane brittle while high temperatures can cause a membrane to stretch easily.

(c) Anchoring a membrane can be accomplished in two ways. The liner can be anchored to a concrete structure, or a more economical and simpler method is the trench-and-backfill method. In this method the membrane is temporarily secured in the anchor trench while the seaming takes place, and then the trench is backfilled.

(d) Field seaming is the most critical factor in membrane installation. The membrane manufacturers have recommended sealing procedures and adhesives. If there are no recommended bonding systems, then the use of that specific material should be questioned. As with the membrane material, the integrity of the seam depends on the compatibility of the finished seam with the waste fluids with which it comes in contact. As a general rule, field seams should run vertically on side slopes where possible without decreasing panel size or increasing field seaming. Field seaming should not be done during precipitation, and the number of panels placed in one day should not exceed the number of panels seamed that day.

(4) Waste materials. Another class of available cover materials includes waste materials such as nonhazardous industrial residues, dredged sediments, and wood chips. Fly ash and lime/fly ash mixtures have also been considered for cover materials; however, the hazardous contaminants in most fly ash have discouraged its use. Furnace slag and incinerator residue are two additional waste martials of gravelly and sandy size that may be suitable for blending into soil cover for slope erosion protection. Rocky overburden from mines, quarries, and sand and gravel pits may also be locally useful as soil cover substitutes. Heavy applications of durable crushed stone, gravel, or clinkers (overcooked bricks) may be used to stabilize contaminated surface soils at landfills and dumps. Nontoxic industrial sludges such as paper mill sludge, dredged materials such as reservoir and channel silt, and composted sewage sludge are other waste materials that may be applied as substitutes or supplements to conventional cover material. Dried sludge can also provide nitrogen and organic plant nutrients in a final capping situation which will aid in establishing a vegetative cover.

c. Design and Construction Considerations.

(1) The design and implementation of a cost-effective capping strategy involves first the selection of an appropriate cover material. Site-specific cover functions- -control of water infiltration and gas migration, water and wind erosion control, crack resistance, settlement control and waste containment, side slope stability, support of vegetation, and suitability for further site use- -may be ranked in order of importance to facilitate this selection. For soils that may potentially be used in capping, laboratory and field testing of physical and chemical properties may be necessary when the choice is not clear-cut. Void ratio, porosity, water content, liquid and plastic limits, shrinkage limit, pH and nutrient levels, shear resistance, compaction, permeability, shrink/swell behavior, and grain size are some of the properties that may have to be determined for competing soil types.

(2) Where soil erosion control is a major consideration, the USDA Universal Soil Loss Equation (USLE) may be useful for comparing the predicted effectiveness of different cover soils.

(3) For information regarding soil sampling and testing, for local data on soils and climate, or for any form of technical assistance regarding selection of cover materials, regional and county Soil Conservation Service (SCS) offices should be consulted.

(4) Placement and compaction of cover materials are techniques affected by site-specific considerations such as the type of cover materials being applied and the local availability of equipment and manpower. For cover soils, compaction is generally desirable in order to increase the strength and reduce the permeability of the cap. Compactor vehicles include rubber-tired loaders and various rollers. For compaction of most solid waste covers, the conventional track-type tractor is effective. The number of passes over the surface required to achieve sufficient compaction depends on the equipment

type (size, weight, and width of compactor), the water content of the soil cover, and the base density and resilience of the covered refuse.

(5) Layering is an effective, but underutilized technique for final cover at waste disposal sites. This technique is essentially a cover system that combines several layers of different materials that serve integrated functions- -support of vegetation protection of barrier layers of membranes control of water infiltration and gas exfiltration, filtering, etc., depict examples of two-layered covered systems. A typical layered cover system may be composed of the following layers:

(a) Topsoil - usually loose, uncompacted surface layer of loams for vegetative support; may be treated with fertilizers or conditioners.

(b) Barrier layer or membrane - usually clayey soil with low k value, or a synthetic membrane; restricts passage of water or gas.

(c) Buffer layer - above and/or below barrier layer; protects clays from drying or cracking, synthetic membranes from punctures or tears; provides smooth, stable base; often a sandy soil.

(d) Water/gas drainage layer or channel - poorly graded (homogeneous) sand and gravel; channels subsurface water drainage; intercepts and laterally vents gases.

(e) Filter - intermediate grain-size layer to prevent fine particles from penetrating the coarser layer; controls settlement, stabilizes cover.

(6) A membrane and geotextile system may be used as the barrier and drainage layers under appropriate conditions. In this system a geotextile (nonwoven filter fabric) is used under a synthetic membrane to provide venting and a suitable base for membrane placement.

d. Advantages and Disadvantages.

(1) An evaluation of selected cover materials and cover systems must be made on a site-specific basis. However, certain general advantages and disadvantages of different surface-sealing techniques can be mentioned here.

(2) Fine-grained soils composed predominantly of clay are well suited for final cover in humid climates because of their low permeability. However, such soils tend to shrink and crack during dry seasons. The construction of a two-layer cover system may be useful in solving such problems.

(3) Local soils generally are much less expensive than non-native cover materials that have to be transported to the site. Where local soils are poorly graded (homogeneous grain size), blending is an effective technique for creating more suitable cover soils.

(4) Soil additives and cements have relatively high unit costs and may require special mixing and spreading methods. Also, soils modified by additions of cement, bitumen, or lime become rigid and more susceptible to

cracking due to waste settlement or freeze-thaw stresses. Patching repairs may become necessary to seal cracks that allow for escape of volatiles and allow surface water infiltration. Also, cemented soil systems may deteriorate upon extended exposure to corrosive organic and sulfurous waste products in landfill environments.

(5) Rigid barriers such as concrete and bituminous membranes are also vulnerable to cracking and chemical deterioration, but the cracks can be exposed, cleaned, and repaired (sealed with tar) with relative ease. Concrete covers may have a design life of about 50 years, except when applied to chemically severe or physically unstable landfill environments.

(6) Synthetic membranes are vulnerable to tearing, sunlight, exposure, burrowing animals, and plant roots. They also require special placement and covering procedures. Among the commercially available synthetic liners, polyethylene may be the most economical, based on both performance and cost. Locally generated waste materials such as fly ash, furnace slag, and incinerator residue may be inexpensive (or free) and, therefore, useful as cost-effective cover materials or additives. However, such materials may leach soluble trace pollutants (e.g., sulfur, heavy metals) and may actually contribute to environmental contamination.

3-25. Revegetation. The establishment of a vegetative cover may be a cost-effective method to stabilize the surface of hazardous waste disposal sites, especially when preceded by surface sealing and grading. Vegetation reduces raindrop impact, reduces run-off velocity, and strengthens the soil mass with root and leaf fibers, thereby decreasing erosion by wind and water. Revegetation will also contribute to the development of a naturally fertile and stable surface environment. Although the soil*s infiltration capacity is increased by vegetation allowing considerable water to enter the disposal site, this increased infiltration is offset at least partly by vegetative transpiration. The relative importance of these offsetting processes is a complicated question that has not been conclusively answered (Lutton et al. 1979). Revegetation can also be used to upgrade the appearance of disposal sites that are being considered for re-use options. Short-term vegetative stabilization (i.e., on a semiannual or seasonal basis) can also be used as a remedial technique for uncontrolled disposal sites.

a. Applications and Design Considerations.

(1) Revegetation may be part of a long-term site reclamation project, or it may be used on a temporary or seasonal basis to stabilize intermediate cover surfaces at waste disposal sites. Revegetation may not be feasible at disposal sites with high cover soil concentrations of phytotoxic chemicals, unless these sites are properly sealed and vented and then recovered with suitable topsoil. A systematic revegetation plan will include: (a) selection of suitable plant species, (b) seedbed preparation, (c) seeding/planting, (d) mulching and/or chemical stabilization, and (e) fertilization and maintenance.

(2) Long-term vegetative stabilization generally involves the planting of grasses, legumes, and shrubs. The establishment of short-term, seasonal

vegetative cover is limited principally to species of grasses. The selection of suitable plant species for a given disposal site depends on several site-specific variables.

(3) Grasses such as fescue and lovegrass provide a quick and lasting ground cover, with dense root systems that anchor soil and enhance infiltration. Legumes (lespedeza, vetch, clover, etc.) store nitrogen in their roots, enhancing soil fertility and assisting the growth of grasses. They are also readily established on steep slopes. Shrubs such as bristly locust and autumn olive also provide a dense surface cover, and certain species are quite tolerant of acidic soils and other possible disposal site stresses. Trees are generally planted in the later stages of site reclamation, after grasses and legumes have established a stable ground cover. They help provide long-term protective cover and build up a stable, fertile layer of decaying leaves and branches. A well-mixed cover of grasses, shrubs, and trees will ultimately restore both economic and aesthetic value to a reclaimed site, providing suitable habitat for populations of both humans and wildlife.

(4) Seedbed preparation is necessary to ensure rapid germination and growth of the planted species. Applications of lime will help neutralize highly acidic topsoils. Similarly, fertilizers should be added for cover soils low in essential plant nutrients. Optimum soil application rates for lime and fertilizers should be determined from site-specific soil tests. Where required, lime should be worked to 152 mm (6-inch) depths into the soil by discing or harrowing. For dense, impervious topsoils, loosening by tillage is recommended.

(5) Seeding should be performed as soon as possible after final grading and seedbed preparation. The most common and efficient method of seeding large areas of graded slopes is with hydroseeders. Seed, fertilizer, mulch, and lime can be sprayed from hydroseeders onto steep outslopes and other areas of difficult access. Rear-mounted blowers can be attached to lime trucks to spread seed and fertilizers over such areas. Grass or grain drills may be used to apply seed on gently rolling or level, stone-free terrain. Hand planting, a time-consuming and costly project, may be required for trees and shrubs.

(6) Mulches or chemical stabilizers may be applied to seeded soils to aid in the establishment of vegetative cover and to protect it from erosion before the plants become established. Organic mulches such as straw, hay, wood chips, sawdust, dry bark, bagasse (unprocessed sugar cane fibers), excelsior (fine wood shavings), and manure protect bare seedbed slopes from erosion prior to germination. Also, thin blankets of burlap, fiberglass, and excelsior can be stapled down or applied with asphalt tacks to form protective mulch mats for germinating seedbeds.

(a) Mulches conserve soil moisture, dissipate raindrop energy, moderate soil temperatures, prevent crusting, increase infiltration, and generally control wind and water erosion. Mulches are usually applied after seeding and fertilization, although certain mulch materials (e.g., wood fibers) may be applied as hydroseeder slurries mixed with seed, fertilizer, and lime. Mulch application rates will vary depending on local climate, soil characteristics, and slope steepness.

(b) Loose straw and hay mulches are the most common and most cost-effective temporary soil stabilizer/mulching materials available. These mulches are best applied using a mulch blower, at rates from 1120 to 8960 kg/hectare (0.5 to 4 tons) per acre. Straw/hay mulches can be anchored to the soil by asphalt, chemical binders, or jute netting.

(c) Chemical stabilizers are binders and tacks that are sprayed on bare soils or mulches to coat, penetrate, and bind together the particles. Stabilizers reduce soil water loss and enhance plant growth by temporarily stabilizing seeded soils against wind and water erosion. They can also be used to stabilize graded soils in the off-season until spring seeding. Stabilizers are used extensively in arid regions to help dry, permeable soils retain soil moisture.

(7) Chemical soil stabilizers include latex emulsions, plastic firms, oil-in-water emulsions, and resin-in-water emulsions. Table 3-7 summarizes pertinent characteristics of seven commercially available stabilizers, including cost data (where available).

(8) In field tests comparing the effectiveness of these chemical additives in controlling erodibility of several regional soil types in Virginia, none of the stabilizers tested were determined to be as cost-effective as conventional mulches of straw and asphalt-emulsions.

(9) Periodic reliming and fertilization may be necessary to maintain optimum yearly growth on seeded plots. Soils with poor buffering capacity may require frequent liming to achieve suitable pH levels; these are generally soils high in organic matter or clay content. Annual fertilization of nitrogen-, phosphorus-, or potassium-deficient soils will also aid reclamation efforts. Fertilizer application rates will vary with the nutrient content and pH level of the seeded cover soil. Twice yearly mowing and the judicious use of selective herbicides will help control undesirable weed and brush species. Grass sodding and remulching or planting new shrubs and trees are recommended for sparsely covered, erosion-prone areas.

(10) The selection of suitable plant species for purposes of revegetating a given disposal site will depend on cover soil characteristics (grain size, organic content, nutrient and pH levels, and water content), local climate, and site hydrology (slope steepness and drainage characteristics). Individual species must be chosen on the basis of their tolerance to such site-specific stresses as soil acidity and erodibility and elevated levels of landfill gases or phytotoxic waste components (e.g. , heavy metals, salts) in cover soil. Other important considerations include the species compatibility with other plants selected to be grown on the site, resistance to insect damage and diseases, and suitability for future land use.

(11) The optimum time for seeding depends on local climatic considerations and the individual species adaptations. For most perennial species in most localities, early fall seeding is recommended. Annuals are

usually best seeded in spring and early summer, although they can be planted for quick vegetation whenever soil is damp and warm. In mild climates (e.g., southeastern United States) the growth of both summer and winter grasses will extend the range of evapotranspiration and erosion resistance for cover soils.

b. Advantages and Disadvantages. A well-designed and properly implemented revegetation plan--whether for long-term reclamation or short-term remedial action--will effectively stabilize the surface of a covered disposal site, reducing erosion by wind and water, and will prepare the site for possible reuse. Evapotranspiration and interception of precipitation by vegetative cover will also control leachate generation at landfills by drying out the water near surface layers of refuse and soil. This effect, however, is more or less offset by enhanced soil infiltration capacity due to the increased detention of surface flow by the vegetation and to effects of the root systems on the cover soil (increased permeability). If subsurface liners of clay or synthetic membranes are constructed, infiltration of water into buried wastes (and subsequent leachate production) will be greatly reduced. This illustrates the importance of a layered surface sealing system and properly graded slopes, which, in combination with suitable vegetative cover, will isolate buried wastes from surface hydrologic input.

Section VI. Gas Control

3-26. Gas Generation and Migration. Uncontrolled hazardous waste sites are unusual in that they can contain a wide variety of materials that can generate toxic or explosive gases (H_25, H_2, CH_9, HCN) and many organic compounds with low vapor pressure that volatilize, forming toxic, flammable, or explosive vapors. Gas generation and migration from disposal operations can be grouped with two categories: methane generation and toxic vapor generation.

a. Gas Generation.

(1) Methane.

(a) The decomposition of any organic material in an anaerobic environment results in part in the production of methane gas. Typically, municipal solid waste (MSW) is largely degradable organic materials (50 to 80 percent). Since MSW is quite porous when placed and compacted in a landfill environment, large amounts of air (with 20 percent oxygen) are present. The result of the initial aerobic decomposition phase is the development of an anaerobic environment with a wide variety of cellulose- -glucose and organic acid breakdown products. This phase of refuse decomposition will last from a few months to a year. The methane-forming bacteria or methogens then use the organic acids as substrate to produce methane and carbon dioxide. The transition in landfill gas composition is illustrated in Figure 3-34.

(b) The methogens are slow-growing organisms and are very sensitive to environmental conditions. The aerobic decomposition phase produces a great deal of heat which will usually bring the internal temperature of a landfill within the optimum temperature range for methane production (29° to 37°C). The optimum moisture content for gas production in MSW is greater than

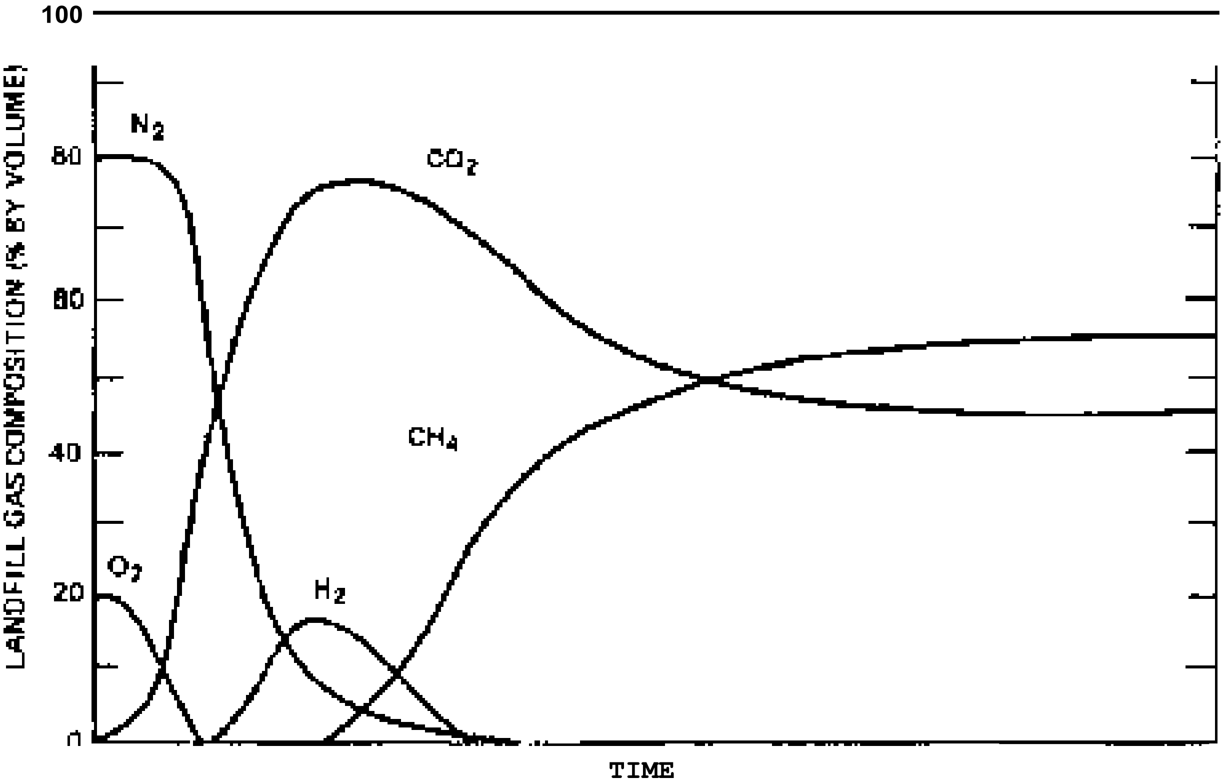


Figure 3-34. Landfill Gas Composition Transition

60 percent (on a weight basis). If the landfill is not in an arid environment, the refuse will usually become wet and the internal environment of the landfill will meet the conditions required for methane-forming bacteria.

(c) Landfills over two years old will usually contain methane in substantial concentrations in the interstitial gases. The time required for methane generation to begin in substantial quantities in a typical landfill is site specific and generally unpredictable. Environmental conditions such as temperature and precipitation and the composition of the refuse, especially the initial moisture content and density, as placed, are very important in determining when methane generation will begin. Also the mode of construction at the landfill and the type of final cover can significantly affect the time for an anaerobic environment to develop in the landfill and support methanogenic activity. The volume of gases produced in any particular landfill is very difficult to predict.

(d) On a wet-weight basis, the theoretical cubic feet of gas generated per pound of solid wastes was determined to be 6.5 for CO_2 and CH_4, and 3.3 for CH_4 alone. Studies assuming constant gas loss rates have estimated the duration of the methane-forming stage in landfill decomposition to be as short as 17 years. Other studies based the methane-generating capability on the rate at which carbon leaves the landfill, assuming that the initial amount of carbon in the refuse was "available." These studies estimated that it would take 57 years for 50 percent of the carbon to leave the landfill and 950 years for 90 percent to leave. With the uncertainties involved one should assume the active biological decomposition in a landfill to continue indefinitely.

(2) Toxic vapor.

(a) Organic compounds in hazardous industrial waste will volatilize under favorable conditions to produce toxic vapors. Waste volatilization can occur at landfills, surface impoundments, and land treatment sites. Since the volatilization and degradation processes are very slow, the emission of hazardous volatile organic compounds may persist for many years. Gas generation rates at landfills containing industrial wastes have not been studied because of the complexity and characteristic variation to be found in the wastes. While the waste composition is the most important factor affecting the rate of gas generation, other factors affecting gas generation are the surrounding climate and soil.

(b) The principal mechanisms of toxic vapor generation at disposal sites are waste volatilization, biological degradation, and chemical reaction. The toxic property of the waste will inhibit biological activities, and most toxic organic wastes such as chlorinated hydrocarbon are relatively inert. Therefore, the amount of toxic vapor production in hazardous waste landfills resulting from biological and chemical processes appears relatively small compared with volatilization. For this reason estimates of toxic vapor generation are usually based on waste volatilization or vapor loss of organic compounds and treated as a diffusion controlled process.

b. Gas Migration.

(1) Landfill-generated methane and toxic-vapor migration are the result of two processes, convection and diffusion. Convection is the movement of landfill gas and toxic vapors in response to pressure gradients developed in the landfill, while diffusion is the movement of gas and vapors from high to lower concentrations. The normal landfill construction practice of alternating layers of refuse with 152 mm (6-inch) soil layers and finishing the landfill with a compacted clay cap of 305 mm (1 foot) or more can present substantial barriers to vertical migration and can increase lateral gas migration. Gas and vapor migration is also restricted by the relative insolubility of the gas in water. The presence of a high or perched water table, which is relatively common under landfill sites, can inhibit the depth of gas migration and increase lateral gas movement.

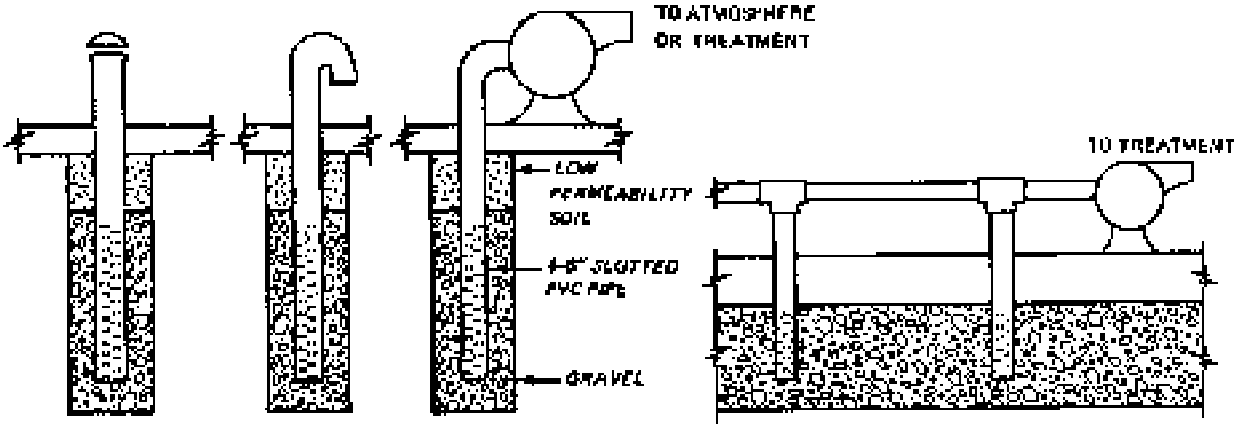
(2) Natural and man-made corridors for gas and vapor migration are quite common around landfill sites. Most landfill explosions are fueled by these corridors. Sewers, drainage culverts, and buried utility lines running near landfills can all provide corridors for gas and vapor migration. In addition, breaks in subsurface utility structures such as manholes, vaults, catch basins, or drainage culverts near landfills not only provide corridors for gas and vapor migration but also provide areas for potentially dangerous concentrations of gas to accumulate. Natural corridors for gas migration

include gravel and sand lenses and void spaces, cracks, and fissures resulting from landfill differential settlement.

3-27. Passive Gas Control Systems. Passive control systems include gravel-filled trenches, perimeter rubble vent stacks, and/or combinations of these. Passive systems will usually incorporate impermeable barriers. Passive venting systems should be deeper than the landfill to make sure they intercept all lateral gas flow. If possible the system should be tied into an impermeable zone such as the permanent water table or continuous impermeable geologic units. The systems should be backfilled with crushed rock, gravel, sand , or similar material that is graded to prevent infiltration and clogging by adjacent soil carried in by water. Passive systems without an impermeable liner can control convective gas flow; however, they are less effective in controlling diffusive gas flow.

a. Application.

(1) Vent stacks. These can be employed to control lateral and vertical migration for both methane and volatile toxics. The basic configurations in Figure 3-35 cover, or can be modified to cover, most of these applications. Atmospheric vents, both mushroom and "U" type, are used for venting methane at points where gas is collecting and building up pressure. Control of lateral migration of methane by an array of atmospheric vent stacks is believed to have little success unless vents are located very close together.



(a) ATMOSPHERIC VENT MUSHROOM TOP (b) ATMOSPHERIC VENT "U" TOP (e) FORCED VENTILATION (d) VERTICAL PIPE VENTS CONNECTED TO FORCED VENTILATION MANIFOLD SYSTEM

Figure 3-35. Design Configuration of Pipe Vents

(2) Trench vents.

(a) Trench vents are used primarily to attenuate lateral gas or vapor migration. They are most successfully applied to sites where the depth of gas migration is limited by ground water or an impervious formation. If the trench can be excavated to this depth, trench vents can offer full containment and control of gases and vapors.

(b) As with pipe vents, the applicability of different trench vent systems depends on whether methane generation is occurring or whether the problem at the site is limited to the control of toxic vapors. Passive open trenches (drawings (a) and (b) in Figure 3-36) may be applicable to the control of toxic vapors in an emergency situation where immediate relief is required. They also can be employed as a permanent control for methane migration; however, their efficiency is expected to be low. An impervious liner can be added to the outside of the trench to increase control efficiency. Open trenches are more suitable for sparsely populated areas where they will not be accidentally covered, planted over, or otherwise plugged by outsiders.

(c) Passive trench vents may be covered over by clay or other impervious materials and vented to the atmosphere. Such a system ensures adequate ventilation and prevents infiltration of rainfall into the vent. Also, an impervious clay layer can be used as an effective seal against the escape of toxic vapors.

b. Design and Construction Considerations.

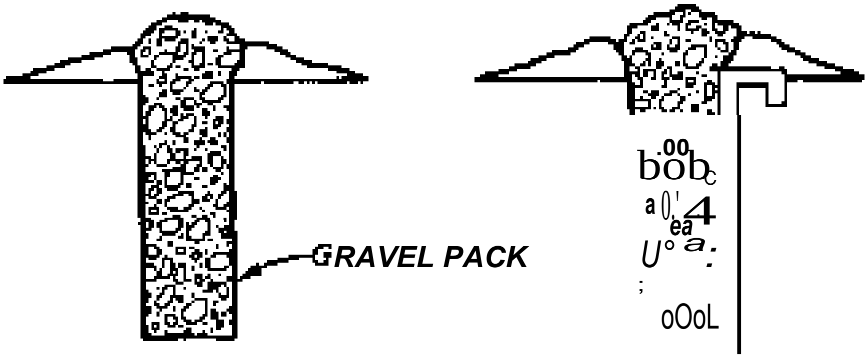
(1) Vent stacks.

(a) When designing installations of atmospheric pipe vents for methane control, proper placement of vent stacks is the chief consideration. Preliminary sampling should be conducted to determine gas collection points for proper vent placement. Methane concentrations vary widely depending on the specific landfill configuration. The highest methane concentration (70 percent is the theoretical limit) is expected in the most anaerobic section of the filled material. In many cases, this is at the bottom of the landfill. Optimum effectiveness will be obtained if vents are placed at maximum concentration and/or pressure contours. To ensure proper ventilation, vent depth should extend to the bottom of the fill material.

(b) Proper spacing of vents is important to ensure adequate ventilation of large areas where methane is concentrated. The distance between vents will depend on soil permeability; however, this distance can be estimated for a typical soil.

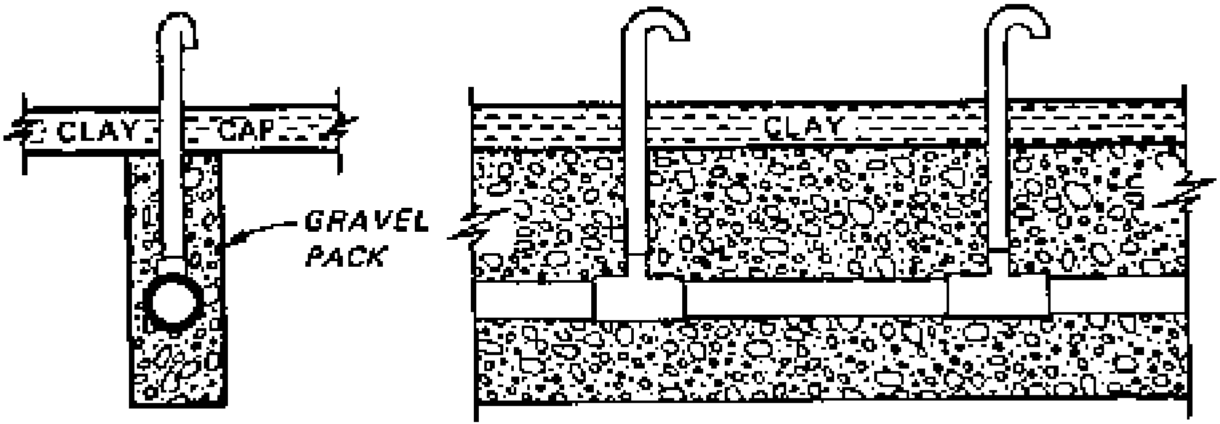
(c) A general rule to ensure adequate ventilation would be to locate wells 15.2 m (50 feet) apart. Atmospheric vent wells are not recommended for control of lateral migration of gas.

(d) Pipe wells are usually constructed of 100 to 150 mm (4- or 6-inch) PVC perforated pipe. Other material, such as galvanized iron, may be required if PVC is not compatible with the waste materials. A surrounding layer of gravel pack should be installed to prevent clogging. The pipe vent should be sealed off from the atmosphere with a cement or cement/soil grout so that excess air is not introduced into the system, and methane or volatile toxics cannot be leaked. Pipe vents may be installed through a clay cap, as shown in Figure 3-36(c and d) to prevent emission of gases or vapors to the atmosphere.



(a) OPEN TRENCH

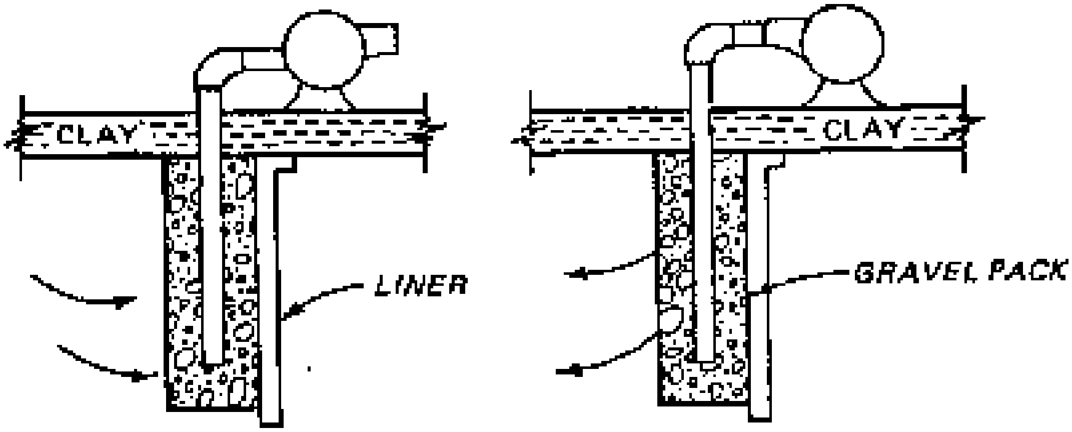
(b) OPEN TRENCH WITH LINER



SIDE VIEW

FRONT VIEW

(c) CLOSED TRENCH WITH LATERAL AND RISERS



(d) INDUCED DRAFT

(e) AIR INJECTION

Figure 3-36. Design Configuration of Trench Vents

(2) Trench vents.

(a) Open vents are subject to infiltration by rainfall run-off and could become clogged by solids. Hence, they should not be located in an area of low relief. It is advisable to construct a slope with some of the excavated soil to direct run-off away from the trench as in drawings (a) and (b) of Figure 3-36. Also, if possible, open trenches should be constructed within controlled areas to prevent any safety or vandalism problems.

(b) The gravel pack in the trench will be permeable enough, relative to the surrounding strata, to transport the gas adequately. Also, in areas of relatively high permeability or wherever safeguards are needed, a liner should be installed on the outside of the trench to prevent bypass.

(c) In passive closed trench vents, good ventilation can be ensured by proper design of laterals and risers. One successful design consisted of 300 mm (12-inch) perforated corrugated lateral pipe with 2.4 m (8-foot) corrugated risers spread at 15.2 m (50-foot) intervals.

(d) There are three types of impervious liners for containing gas flow: synthetic liners, admixed materials, and natural soil. Synthetic liners are manufactured using rubber or plastic compounds. Polyvinyl chloride liners are frequently used because they are more impermeable to methane when compared to polyethylene and are relatively inexpensive. The membranes must be put down as to avoid punctures , and usually layers of soil or sand must be placed on both sides. Admixed materials such as asphaltic concrete have the advantages of being universally available, relatively inexpensive, and can maintain their integrity under structures. However, they are more permeable than synthetic membrane liners, and they have a tendency to crack under differential settlement. Natural soil, particularly clay, can be used as a barrier to gas movement. Clay liners are inexpensive and readily available; however, the soil must be kept nearly saturated to be effective. Clay barriers like admixed materials have a tendency to crack under differential settlement and if exposed to air for prolonged periods will dry, shrink, and crack.

c. <u>Advantages and Disadvantages.</u> Passive vent stacks are an effective means of control when used in situations where gases freely migrate to a collection point and there is little or no lateral migration. Passive trench vents without a barrier are not very effective in controlling migrating gases. The addition of an impermeable liner may offer the required degree of effectiveness; however, the installation of a liner will generally be economical only if the required depth **is** 3 m (10 feet) or less. Trench vents may become plugged by soil particles with time, thereby reducing their long-term effectiveness.

3-28. <u>Active Control Systems.</u> Active gas control systems can be divided into extraction and pressure systems. Both systems will usually incorporate some type of impermeable gas barrier system. Extraction systems usually incorporate a series of gas extraction wells installed within the perimeter of the landfill. Extraction wells are similar to gas monitoring wells, only larger, and construction and materials are the same. The number and spacing needed for the extraction wells for any particular landfill are site dependent. Often a pilot system of only a few wells will be installed first to determine the radius of influence in the area of the wells. Once the wells are installed, they are connected using gas valving and condensation traps to a suction system. A centrifugal blower creates a vacuum on the manifold, drawing gas from the wells and causing the gas in the refuse and soil to flow toward each well. Depending on the location, the gas is either exhausted to the atmosphere, flared to prevent malodors, or recovered and treated. A pressure gas control system is sometimes considered when structures are built or already exist on abandoned landfills. The system uses a blower to force air under the building*s slab to flush away any gas that has collected and develop a positive pressure to prevent gas from migrating toward the structure.

a. Application.

(1) Methane migration control can be more effectively accomplished by installing forced-ventilation systems in which a vacuum pump or blower is connected to the discharge end of the vent pipe. A drawdown with a radius of influence of 45.7 m (150 feet) can be accomplished with a pumping rate of 23.6 liter/sec (50 cubic feet per minute) dependent upon soil type, compaction, and other site conditions. Such a system is applicable for controlling both vertical and lateral movement of methane in the landfill by installing vents along the perimeter of the site. The collected gas and vapor can be vented to the atmosphere, flared, or recovered and treated.

(2) In landfills containing volatile toxics, a closed forced-ventilation system is required to prevent any toxic vapors from migrating laterally or vertically through the cover material to the atmosphere. Figure 3-36, section (d), depicts a series of pipe vents installed in a trench connected to a manifold that leads to a blower and finally to gas treatment. Such a configuration can be used to prevent emission of toxics to the atmosphere across the entire area of the site. A forced-ventilation system utilizing a series of extraction wells is illustrated in Figure 3-37.

(3) Another type of forced ventilation in a trench for methane migration control is air injection; in this method, air injected into the trench by a blower forces the gas or vapor back. This system should work well in conjunction with pipe vents installed close to the landfill and inside the circumferences of the trench.

b. Design and Construction Considerations.

(1) Forced ventilation is a more effective means of controlling the lateral and vertical migration of methane or toxic vapors. The flow rate for venting should be high enough to collect all gases being generated, i.e., it should be at least equal to the gas generation rate. Also, the flow rate should be high enough to ensure a fairly large radius of influence, so as to minimize the number of wells needed to vent the area. Blowers, pumps, etc., should be explosion-proof for this type of application.

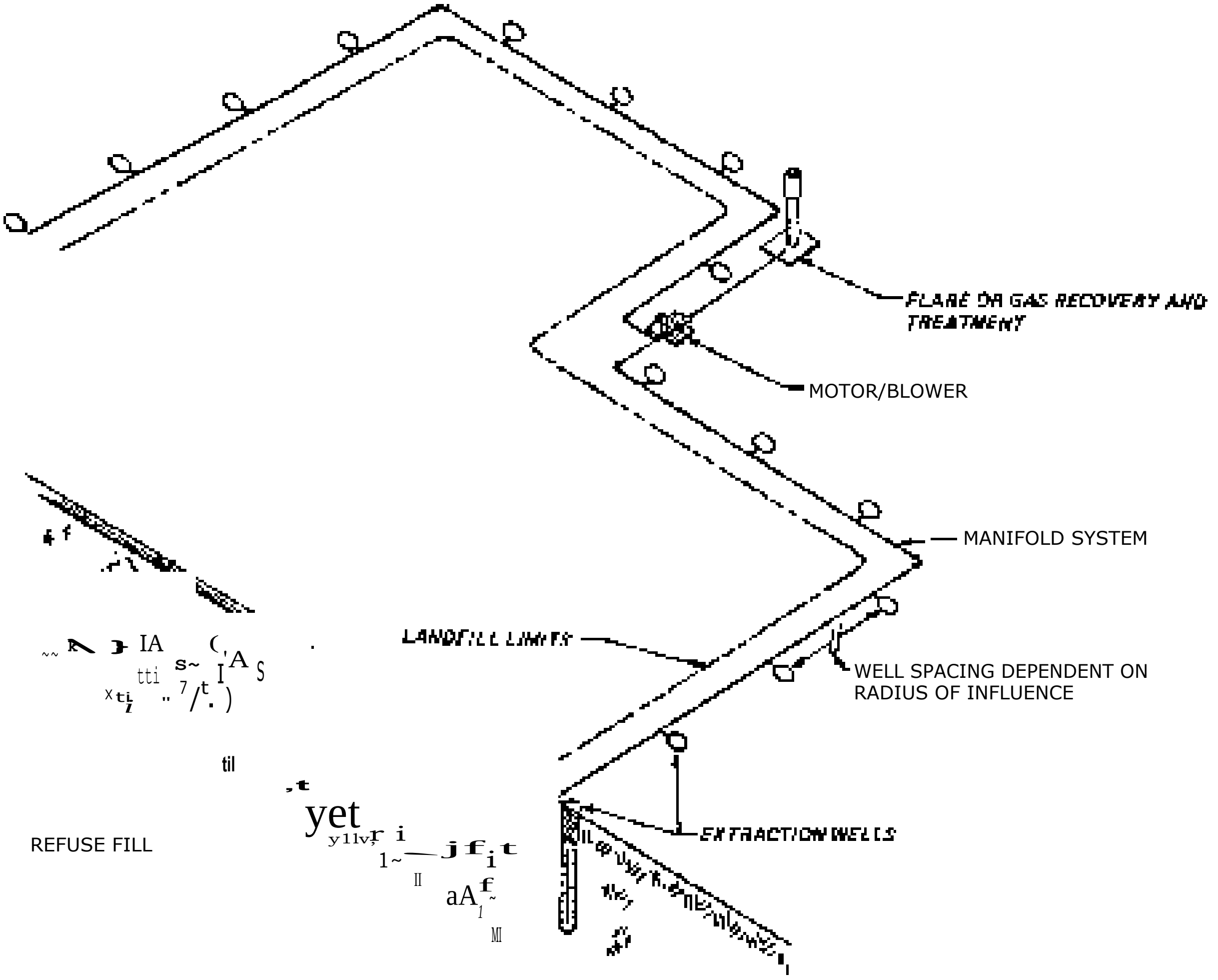


Figure 3-37. Forced-Ventilation System for Landfill Gas Control

(2) Studies at three municipal landfills in California indicated a range in gas production rates from 22 to 45 milliliters per kilograms of refuse per day. Assuming a bulk density of 250 kilograms per cubic meter for ground domestic garbage, these values convert to a range of 5.5 to 11.25 liters per cubic meter per day. If the average anaerobic layer of the fill is assumed to be 10 meters, then 55 to 113 liters of methane per day per square meter of fill area can be expected. This translates to a ventilation requirement of at least 6 to 11 cubic feet per minute per acre. In an actual demonstration for recovering methane from a municipal landfill, a steady state flow was obtained at 23.6 Pis (50 cubic feet per minute) with the radius of influence at about 39.6 m (130 feet). This translates to a ventilation rate of 128 Q/s/hectare (107 cubic feet per minute) per acre, which means a substantial portion of excess air was introduced into the system. However, it was determined that methane production was not inhibited by this amount of air, and maximum oxygen levels in the gas were only 4 percent.

(3) Diffusion rates for volatile toxics can be calculated to determine requirements for ventilation of hazardous waste landfills. However, these estimates need more field verification.

(4) When designing a forced ventilation system for a trench, pipes can probably be placed at greater distances than extraction wells since the trench fill is composed of very permeable material. If a liner is used, the spacing can be at even greater distances since the normal radial influence of the pipes will be channeled along the trench.

d. Advantages and Disadvantages. Atmospheric vents are effective means of control when used in situations where gases freely migrate to a collection point and there is little or no lateral migration. Forced ventilation is a very effective method for controlling migration of gas and toxic vapors. If forced ventilation is used, the flow rate can be increased or decreased as the gas generation or vapor flux rate increases or decreases. This offers a great deal of flexibility of control inherent in the system. At a hazardous waste site where volatile toxics are present, the mass flux rate will decrease with time as the volatiles are dissipated. Thus, ventilation rates can be reduced with time and operating costs will decrease. It is expected that gas vents from forced ventilation are more apt to clog after time, and will need to be replaced. Also, it is expected that more maintenance will be required for forced ventilation than for passive atmospheric vent systems.