Topic: Landfills

The TCEQ recognizes that waste management is expensive and requires careful planning to avoid threats to human health and the environment. The preferred alternative is to eliminate or reduce the generation of a waste in the first place. By modifying processes and selecting process materials, Texas industries have made notable progress in waste reduction. If a waste-like material results from an industrial process, it may be suitable to reuse the generated waste in the original process as a substitute for feed materials, or for recycling elsewhere on site. If a material can not be used at the site, another facility may be able to recycle the material or use it as feedstock. Wastes that can not be used, recycled, or reclaimed should be treated to reduce their toxicity and/or volume. Appropriate liquid wastes can be injected into authorized deep disposal wells. The least preferable of the responsible industrial waste management options is land disposal. This technical guideline presents TCEQ recommendations that can minimize the risks of landfilling.

Waste disposal planning should begin with identification and characterization of the expected wastes and a determination of optimal management methods, such as incineration, land treatment, deep well injection, or landfilling, which can best treat or dispose of those wastes. Site selection should be directed to finding a location that has the best features for the particular facility components to be constructed. TCEQ Technical Guideline No. 2, "Industrial Solid Waste Landfill Site Selection," contains specific recommendations on landfill site selection. That guideline is intended primarily to identify environmentally sound locations for onsite Class 1 industrial nonhazardous waste landfills (hereafter referred to as Class 1 landfills), but the Technical Siting Criteria (Section 2 of Technical Guideline No. 2) also should be consulted when evaluating a proposed Class 2 industrial nonhazardous waste landfill (hereafter referred to as Class 2 landfill) location.

A landfill design should provide for efficiency, safety, and environmental protection during active operation, and also should specify interim and final landfill closure procedures that will assure long-term waste containment with minimum post-closure maintenance. Planning closure before starting construction makes the eventual closure easier, more effective, and less costly. For example, separating and stockpiling adequate clay from soils that are excavated from a landfill can eliminate the need, years later, of buying clay to cover and close the landfill. Plans for post-closure care should include such activities as ground-water monitoring, removing leachate from a leachate collection system, and maintaining the cover by periodic regrading, reseeding, irrigation, fertilizing, and mowing. Closure and post-closure planning is a necessary component of landfill designs.

Both hazardous and commercial nonhazardous waste landfills are subject to many requirements that are not discussed in this guideline. Specific requirements for industrial hazardous waste landfills can be found at 30 Texas Administrative Code (TAC) Chapter 335, Subchapter F. Specific requirements for commercial industrial nonhazardous waste landfills can be found at 30 TAC Chapter 335, Subchapter T. In addition, most hazardous wastes are restricted or prohibited from land disposal unless they first are treated to meet Land Disposal Restriction standards as required by 30 TAC Chapter 335, Subchapter O.

General Considerations

The pollution potential of a landfill depends on a number of factors such as: (1) the stability and mobility of the waste as measured by content of organic matter, soluble inorganic constituents, octanol-water partition coefficient, etc.; (2) the physical stability of the waste material in terms of volume change as decomposition and consolidation take place; (3) the geologic and hydrologic parameters of the site including the thickness, porosity, and permeability of the formation in which the landfill is located, topography of the site area, and proximity of the water table to the base of the landfill; (4) the protection of the upper surface of the landfill from infiltration of storm water and from erosion and other disruptions; (5) the effectiveness of the liner and leachate collection system in preventing the release of leachate; and (6) climate, including temperature, annual precipitation, intensity of rainfall, and net evapotranspiration.

Waste Characterization and Classification

The wastes to be disposed of must be characterized and classified. An explanation of waste categories is may be found in TCEQ Publication RG-22, "Guidelines for the Classification & Coding of Industrial Wastes and Hazardous Wastes." In addition, TCEQ recommends that the effect of Class 1 or 2 wastes on the soils or lining materials to be used as waste containment barriers be determined by testing. One method available for determining the effects of waste leachate on a soil or geosynthetic liner is EPA Method 9090. This testing will determine if the fluid constituents or the water extractable constituents of the wastes have any detrimental effect (causing dissolution, shrinkage, increase in permeability, etc.) on the soils or liner materials that are used. Wastes that have a significant detrimental effect on materials being used as permanent barriers for waste containment should not be landfilled unless the wastes can be treated to eliminate the detrimental effects. Wastes should be evaluated for compatibility with other wastes. These wastes should be segregated in storage and disposal operations as well as in the landfill.

Physical Stability of the Waste

While the possibility does exist of volume changes due to either expansion or contraction, subsidence or settlement of landfill areas will be the most commonly encountered situation. Subsidence of landfills normally is due to decomposition, dewatering, and differential compaction of the waste materials. Landfilling of empty, uncrushed containers should be avoided. The total amount of settlement that will occur at any given landfill will be a function of the total depth of the waste, the initial degree of compaction, and the composition of the waste. Most of the settlement occurs within the first few years of the landfill operation. The amount of settlement can vary greatly, but settlement upto 0 percent has occurred in Class 1 waste landfills.

Appreciable settlement in a landfill can result in a depression on the landfill surface could cause rainwater to pool and may affect or damage the liner system. Settlement also can produce cracks in the final cover that, in combination with ponded water, will result in greatly increased infiltration. Any water that filters into the landfill can leach pollutants from the deposited wastes, increasing the potential for contaminants to be carried down to groundwater.

Waste Isolation

The Texas solid waste secure landfilling strategy relies on establishment of stable landfills that provide long term isolation of waste with a minimum necessity for maintenance. When a landfill is closed, a transition or post-closure period is specified, normally 30 years for permitted landfills. The post-closure period is provided for the removal of residual leachate, to monitor ground water that may have been affected by landfill operations, to maintain and repair the landfill, and to establish a perennial vegetative cover.

Landfill Liner

This section provides guidance with regard to the engineering design, including construction and material specifications, of liners for the base and sides of the landfill. TCEQ recommends that the liner for each landfill be designed individually, but that the recompacted or constructed liner of soil materials and the synthetic membrane components that are used should meet at least the following minimum recommendations. More stringent facility design features may be warranted if the standard recommended barrier, in combination with the natural geologic setting, do not provide assurance of effective long-term isolation of industrial solid waste. The permitting regulations for hazardous waste landfills require a synthetic membrane liner in addition to a composite membrane/constructed soil liner, leachate collection and detection systems, and additional design features.

A quality assurance/quality control program, such as is described in U.S. EPA Publication EPA/600/R-93/182, "Quality Assurance and Quality Control for Waste Containment Facilities", should be followed for installation of hazardous, Class 1 or Class 2 waste landfill liners.

Soil Component of Liner

The basis of an effective landfill liner is properly compacted soil material, which either is the liner or is a component of a composite liner. The liner for a landfill that receives only Class 3 waste could consist of the native soil, recompacted to a depth of two feet. Soil material for all other kinds of landfill liners should contain a significant quantity of clay. The liner soil should have a liquid limit of 30% or greater, a plasticity index of 10% or greater, more than 30% by weight passing a number 200 sieve, gravel content less than 30%, and no particles larger than 2 inches. The hydraulic conductivity of the compacted soil should be $1x10^{-7}$ cm/sec or less. If a soil meeting these specifications is not available, a common practice is to mix bentonite with the local soil.

The compacted clay component of the liner should be at least three feet thick, both for Class 1 and Class 2 waste. A geosynthetic clay liner (GCL) could replace the upper portion of the compacted clay, provided that at least two feet of compacted clay at a Class 1 landfill, or one foot of compacted clay at a Class 2 landfill, are in place immediately beneath the GCL. The compacted clay beneath the GCL will serve as a backup barrier in case the thin GCL is breached during construction or landfill operation. Recommended compacted soil liner thickness should not be reduced even if soil materials are less permeable than $1x10^{-7}$ cm/sec.

Soil material to be compacted for a liner should be placed in lifts not less than six inches nor greater than nine inches in compacted thickness. The soil should be compacted by kneading with a pad foot roller. The roller-foot length should be approximately equal to lift thickness. Selection of an appropriate molding moisture content and density will depend on the results of permeability tests and should be sufficient to allow clods to be completely broken down during compaction. The recommended procedure is:

1. Determine compaction curves for the soil using Proctor (ASTM Standard MethodD-698), Reduced Proctor (using 15 blows instead of 25), and Modified Proctor (ASTM D-1557) compactive efforts.

2. Determine hydraulic conductivity of compacted specimens.

3. Plot the compaction curves on a single chart, with a distinctive symbol for

specimens with hydraulic conductivities ≤ $1x10^{-7}$ cm/sec.

4. Set specifications for molding water content and density to include only acceptable hydraulic conductivities and that meet other site engineering considerations.

In most cases, water content will be somewhat above optimum water content, by ASTM D-698, but in dry climates a water content at optimum with greater mechanical compactive effort may reduce shrink-swell effects.

Hydraulic Conductivity Testing

A test that is particularly well suited to predicting the hydraulic performance of a landfill liner is the Sealed Double-ring Infiltrometer test (ASTM D-5093). Because the SDRI test measures infiltration through a six-foot-square block of soil, results represent field conditions much better than the typical small-diameter laboratory hydraulic conductivity test. The TCEQ recommends that prior to construction of a hazardous of Class 1 landfill, the SDRI test be performed on a test fill that has been constructed under the same conditions and design as proposed for the landfill. If the SDRI test shows a hydraulic conductivity of $1x10^{-7}$ cm/sec or less, and good quality control is applied during construction, the liner clay layer can be completed and covered without waiting for results from laboratory permeability tests. In lieu of SDRI test, alternative test methods for hydraulic conductivity testing may be used with the TCEQ approval. In addition to field tests, laboratory hydraulic conductivity tests can be useful for quality control.

The hydraulic conductivity test report should include a description of the test apparatus (flexible wall, double ring, etc.), number of pore volumes passed, the hydraulic gradient during the test, soil sample preparation (compaction method, density, compacted in the tube or trimmed, etc.), and if a flexible.wall permeameter is used, the maximum and minimum stress and the back pressure.

Membrane Component of Liner

At Class 1 and Class 2 landfills, the TCEQ recommends the use of a composite liner composed of compacted clay immediately beneath a synthetic membrane liner (high density polyethylene, polyvinyl chloride, chlorinated polyethylene, butyl rubbers, etc.). However, a monofill that contains only certain specific, consistent, well-characterized wastes that have been found to have low migration potential in a landfill normally would not require a membrane in the liner. The wastes that have been found to be suitable for placement in clay-lined monofills are asbestos, coal bottom ash, coal fly ash, coal FGD residue, and stabilized steel mill scale.

Special precautions should be taken to seal and test all seams, inspect and test the membrane, and ensure that its integrity will be maintained. The TCEQ recommends that synthetic membrane material be thick enough for reliable seaming and for puncture resistance, be installed on a properly prepared clay-rich soil underlining, and be protected by a sufficiently thick soil cover. High density polyethylene (HDPE) should be at least 40 mils thick, and TCEQ recommends that HDPE should be at least 60 mils thick for liners.

Additional waste isolation could be provided for Class 1 waste by installing a second membrane liner above the composite liner. If used, a double liner system should have a secondary leak detection and removal system installed between the two liners. The uppermost liner is designated the primary liner because it is the first liner to intercept leachate.

Leachate Collection Systems

The TCEQ recommends that a leachate collection system should be installed over the membrane liner of a hazardous waste, Class 1 waste, or Class 2 waste landfill to limit leachate depth to 30 centimeters (one foot) or less. By limiting the depth of leachate over the liner, standing liquid is kept out of the waste and leakage through the liner is minimized. To calculate of maximum leachate head, use the following formula which can be found in EPA publications *SW-869* and in *CERI-88-33*:

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

Where

h_{max} is the maximum leachate height;
L is the distance between collector drain pipes;
α is the slope angle of the drainage layer; and
c is rainfall inflow rate divided by drainage hydraulic conductivity.

The results of the leachate depth calculations depend upon what rainfall inflow rate is used. The design inflow rate should ignore any retardation or absorption of liquids by waste or cover material, other than that which is implicitly included in the following inflow rate assumptions. For the active life, the design calculations should assume an inflow rate into the primary leachate collection system equal to the average precipitation rate during the 5-year, 7-day rainfall, spread out over 7 days. The secondary leachate detection/collection system, if one is used, should be designed assuming a daily inflow rate equal to the mean annual rainfall divided by 365 days.

For the leachate collection layer, TCEQ recommends at least one foot of sand or gravel with a hydraulic conductivity of at least 0.01 cm/sec, overlain by a fabric or granular filter layer, to prevent clogging. High Density Polyethylene (HDPE) drainage net, which also is called geonet, could be substituted, provided that maximum leachate mounding is kept within the thickness of the geonet. Leachate mounding usually can be kept within the geonet on sidewalls of both primary and secondary systems and in the entire secondary leak detection and removal system of facilities that are in arid regions of Texas. The sand and gravel portion of the primary leachate collection system should be designed so that after closure it is capable of removing the leachate without relying on any of the capacity of pipes in the system, other than the riser, assuming a daily inflow rate equal to the mean annual rainfall divided by 365 days.

If a design is found to allow excessive mounding, mounding can be reduced by design changes such as moving collector drain pipes nearer together, increasing the bottom slope of the liner, having multiple layers of geonet, or increasing the hydraulic conductivity of the granular drainage layer.

Hydrologic Considerations

Whenever possible, the base of the landfill area should be well above the seasonally high ground-water level. Significant hydraulic connection (surface and subsurface) between the site and standing or flowing surface water should be absent. Each disposal site will be evaluated individually, but as a rule, the minimum recommendations in Table I should be met.

Table I

Landfill Hydrologic Recommendations

Parameter	Nonhazardous Waste Classification 1	Nonhazardous Waste Classification 2	Nonhazardous Waste Classification 3
Ground water monitoring	Yes	Yes	-
Depth to expect high water level below base of landfill waste containment barrier	5’	5’	-
Separation distance between base of landfill and uppermost permeable (hydraulic conductivity greater than 1x10-5 cm/sec) saturated unit	5’	5’	-
Flood protection if site is below 100-year floodwater elevation	X^1,Y^2	Z^3	Y^2
Flood protection If site is above 100-year floodwater elevation	Z^3	Z^3	Y^2

X^1 = operator should provide ample surface water diversion dikes with a minimum height equal to two (2) feet above the 100-year floodwater elevation around the perimeter of the disposal site. Facilities in areas subject to flooding by the 100-year hurricane storm surge will need additional freeboard to prevent overtopping by wave action.

Y^2 = avoid washout of waste.

Z^3 = operator should provide diversion structures capable of diverting all of the surface water runoff and run-on from a 24-hour, 100-year storm.

* Recommendations for design of subsurface monitoring systems are contained in TCEQ Technical Guideline No. 6, "Monitoring Systems". Monitoring should continue for 30 years after closure at Class 1 and Class 2 waste facilities.

** The suggested values for the depth to the expected high water level set forth above may not be appropriate for all variations in landfill design and hydrogeologic setting. Saturated clay and clay shale deposits with shallow ground-water tables such as occur along the Texas Gulf Coast may, if they are sufficiently impermeable, homogeneous, massive and laterally extensive, serve as environmentally acceptable locations with regard to seepage control from landfills.

Storm Water Management

Landfills located on broad upland flats or divides away from major or tributary drainages are likely to have fewer problems with storm water than landfills placed in swales, draws, gullies, valleys, or arroyos. Whenever possible, it is wise to take advantage of natural favorable grade to direct storm-water runoff around the landfill area. In many instances it will be necessary to build dikes, ditches, or other structures to divert runoff around the landfill area. Such diversion structures should be capable of handling at least a maximum 24-hour/100-year rainfall. The only water that should enter the landfill area is that rainwater that falls directly onto the landfill.

Landfill Cover

The cover or cap, which is the component of the landfill that overlies waste, serves to minimize water infiltration, promote good surface drainage, maximize runoff, and to separate wastes from animals, plant roots, and surface exposure. The cover also restricts or controls gas migration. From the completion of closure, continued safe containment of the waste primarily depends on the integrity of the cover system. During the post-closure care period, the landfill will be dewatered using the leachate collection system. By preventing infiltration of water, the cover preserves the leachate-free condition of the landfill after the post-closure period. The cover and the rest of the landfill need to remain intact and function to isolate waste for as long as the waste retains its characteristics that require isolation. Wherever possible, the lifetimes of the specific wastes in a landfill should be considered. The cover should be designed and constructed to minimize the need for maintenance.

By applying an interim cover over waste as each section is filled, the active area is minimized, contaminated storm water and leachate production are decreased, and liability for closure costs is reduced. When waste settlement and consolidation have stabilized and the area with interim cover is large enough to allow effective and efficient construction, the interim cover should be incorporated into or replaced by the final cover. Hazardous waste and commercial nonhazardous waste landfills have additional final cover requirements beyond the recommendations that are given here.

Where necessary to prevent air pollution problems, public health hazards (particulates, odors, vectors, etc.), and excessive leachate production, intermediate cover should be applied to deposited waste. Operators of landfills accepting putrescible, rapidly biodegradable, soluble, foul-smelling, volatile, or easily wind blown wastes should cover these wastes daily with a minimum of six (6) inches of soil. Landfills accepting large volumes of "trash" such as paper, wood, plastics, and metal cans that are readily compactable, should have a minimum of six (6) inches of soil applied for every five (5) feet of compacted waste. At a minimum, this type of waste should be covered once a week. Some wastes that pose no problem from short-term open exposure would not require intermediate cover.

Cover material should consist of a well-graded, fine-grained, clay-rich soil having low cracking potential and good workability and compaction characteristics. TCEQ recommends a soil containing at least 20 percent of material passing a No. 200 sieve, having a plasticity index between 10 percent and 35 percent, having less than 10 percent gravel, and that includes no rocks larger than 2 inches in diameter. The compacted soil should have a hydraulic conductivity of $1x10^{-7}$ cm/sec or less. If a suitable soil is not available on the site, it will be necessary to import the appropriate cover material or modify on-site material. The cover should be constructed and maintained to avoid ponding and erosion.

The minimum recommended compacted soil thickness of a clay final cover is four feet for Class 1 waste or three feet for Class 2 waste. A composite cover system should have at least two feet of clay underlying the membrane. An alternative cover system could include a Geosynthetic Clay Liner (GCL) layer. The GCL should be placed over at least two feet of compacted clay, if overlying Class 1 waste, or be placed over at least 12 inches of compacted clay at a landfill for Class 2 waste. Compacted clay beneath a GCL will provide a barrier if the thin GCL is damaged. In addition, a cap should be at least as impermeable as the liner; that is, if the liner includes a membrane, the cap also should have a membrane.

The relationship between moisture content, compacted density, and hydraulic conductivity should be determined for clay cover material, using the procedures that were described in this Guideline for the liner soil component. Clay cover material should be placed in lifts not less than six inches nor greater than nine inches, compacted with a fully-penetrating footed roller to appropriate density and water content, and scarified to a minimum depth of two inches prior to placement of the following lift. The final cover should be graded to have a crown with slopes between 3% and 5%.

The entire surface of the landfill should be covered with a minimum of 18 inches of uncompacted, fertile topsoil that is stabilized with self-sustaining vegetative cover or other acceptable material to minimize erosion. The cover soil thickness should be greater than frost penetration depth. Vegetation is recommended because of its capacity to extract infiltrating water by evapotranspiration. Plants for a vegetative cover should be selected for the site climatic conditions. With the possible exception of dry climates, the depth of the root zone should be relatively shallow to minimize disruption of the cover. The TCEQ recommends a drainage layer beneath the topsoil, both to reduce infiltration through the cover and to increase slope stability.

An unvegetated rock or gravel surface is resistant to erosion, but it greatly increases net infiltration of storm water. Rock or gravel should be considered only at very arid sites. A concrete surface typically has a hydraulic conductivity of $1x10^{-5}$ to $1x10^{-6}$ cm./sec., which increases as it cracks and spalls over time. Asphalt paving becomes brittle and cracks if it is not reworked by traffic. The TCEQ does not recommend such materials as permanent cover surfaces in most locations, although they may have utility in temporary covers to facilitate industrial operations.

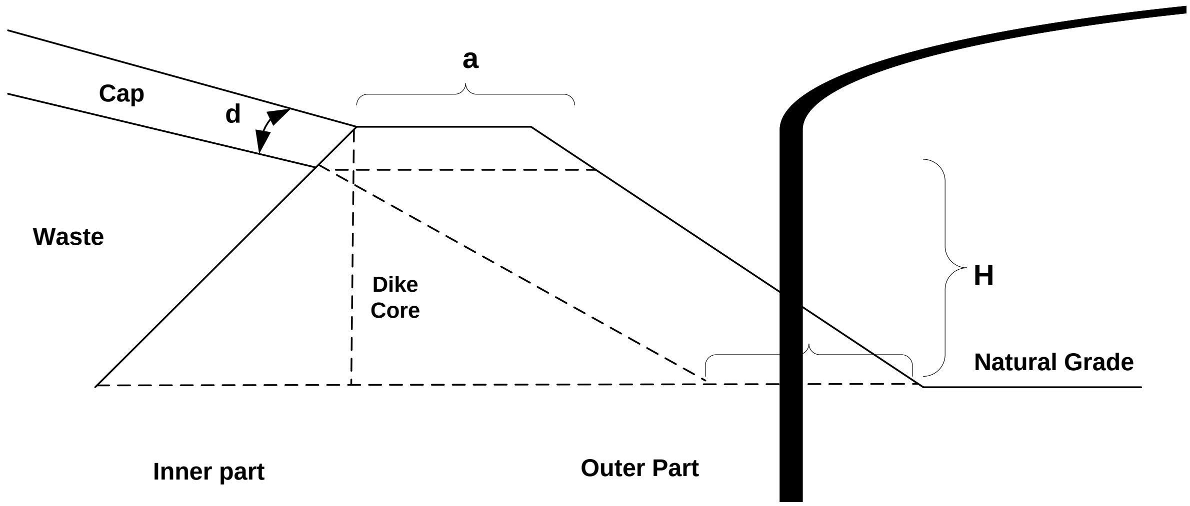
Perimeter Containment Dike

Maximum recommended waste elevations are considered in relation to a design topographic surface that is termed the design grade. The design grade is either the natural ground surface elevation or the crest elevation of a massive containment dike that effectively raises the ground surface around the landfill. The containment dike should be constructed with an exterior slope no steeper than 4:1 (horizontal:vertical) for Class 1 waste or 3:1 for Class 2 waste, and with a minimum crest width of eight feet.

The overall performance objectives for the dike are:

1. Prevent washout, release, or exposure of waste.
2. Physical stability against slope failure, with a safety factor of 1.5 for Class 1 waste and 1.3 for Class 2 waste.
3. Hydrostatic and hydrodynamic stability against storms and floods.
4. Prevent storm water from reaching the waste to contribute to leachate.
5. Minimize the release of leachate.
6. Minimize long-term maintenance.

Generally a dike is constructed of compacted clay-rich soil, but functionally equivalent materials that meet the following minimum standards would be acceptable for non-hazardous waste landfills. The outer part of the dike, which underlies the crest and outer slope of the dike, acts primarily to facilitate runoff and provide protection against erosion. It may be necessary to use lined conveyance structures to route runoff to the natural grade elevation. The portion of the outer part that is most critical in preventing erosion is depicted in Figure 1.



The base width of the erosion-critical portion may be calculated for a Class 1 landfill as $b = 6\sqrt{H}$, and for a Class 2 landfill as $b = 5\sqrt{H}$, where b is the base width and H is the height to the top of the cap over the dike. The erosion-critical portion should be constructed of clean soils that will support vegetation and that will resist erosion. If available, a soil with a lower erosivity than clay should be used with this design.

The core portion of the outer part, which is further inward than the erosion-critical portion, also is illustrated in Figure 1. The core portion routinely may consist of any clean soil or Class 3 waste that has suitable physical strength. Also, some uniform, inorganic, pozzolanic Class 2 wastes that have low potential for generating harmful leachate, such as pozzolanic coal ash or stabilized steel mill scale, could be suitable for the core of a dike. At a minimum, the leachate from the TCEQ leaching procedure performed on such a waste should not exceed any allowable daily composite concentration specified in Title 30 Texas Administrative Code Section 319.22.

The inner part of the dike, shown in Figure 1, includes part of the liner that is equivalent to the bottom liner. The liner, and the leachate collection system should extend continuously from the bottom liner up the sides to a level above the wastes at the edge, and should isolate the waste from the outer part of the dike. Any portion of the inner part of the dike that is outside of the liner should meet the standards of the core portion. Any material within the inner part of the dike must have sufficient strength to produce a stable inner slope. The design should not put an undue stress on any liner component.

Maximum Recommended Waste Elevations

Recommendations for the maximum elevation of waste relative to design grade are based on the nature of the waste and the consequences if the waste were exposed.

Class 1 Waste

The TCEQ prefers that Class 1 waste and hazardous waste remain below design grade, which is below the potential base line of gully erosion. In any case, TCEQ recommends that Class 1 waste and hazardous waste should not be placed above grade in a part of a landfill that could be exposed by gullying. Wastes should be placed no higher than three feet below the design grade elevation at the outer edge of the waste but could slope up at a maximum slope of 3% toward the center of the landfill.

If a landfill is to be placed over an existing landfill, the predicted effect of this additional weight on the existing liners and leachate collection system due to consolidation should be determined.

Class 2 Waste

All Class 2 wastes should be at least two feet below the design grade elevation at the outer edge of the waste, but could slope up to the center of the landfill, provided that the cover is maintained at an adequate thickness with a 3% to 5% surface slope. Cover specifications are the same for below-grade and above-grade facilities.

Class 3 Waste

The design should provide means for maintaining placement of the waste and minimizing runoff from and run-on into the facility. Design should be based on site-specific conditions.

Erosion Control at Above-grade Landfills

If Class 1 industrial waste or hazardous waste is to be placed above the design grade, the cover design should avoid storm water concentration that could promote serious erosion in the long term. Soil loss predictions based on the Universal Soil Loss Equation (USLE), the Water Erosion Prediction Project (WEPP), and the Wind Erosion Equation (WEQ) are primarily useful in active-management situations, such as agriculture or active landfilling operations, where periodic regrading evens out soil loss from sheet and rill erosion and prevents the establishment of gullies. During and after the post-closure care period, although sheet, rill, and wind erosion should be kept at low levels, gully erosion will be of the greatest concern. Even if overall areal soil loss is not excessive, deep gullies could reach down to expose deep cover components and the waste.

Whether a vulnerable slope actually develops gullies depends on the amount of time between rainstorms, geological origin of the soil, and many factors other than the layout of the slope. Both the USLE and WEPP are incapable of predicting gullying. However, if a slope is designed to restrict water flow velocities on all parts of a slope overlying above-grade Class 1 waste or hazardous waste to those velocities where gullying is unlikely to occur, other risk factors may be disregarded. TCEQ recommends that long slopes should be designed with terraces, protected waterways, and other structures to prevent excessive runoff velocities during storms.

A procedure that TCEQ recommends for calculating storm water velocity down a slope is based on field data (Gilley et al., T. ASAE 33(6):1900-1906, 1990) that was used to develop WEPP.

1. Conduct a hydrologic study, using site-appropriate rainfall data and assuming conditions that maximize runoff rate, to determine the maximum downslope flow rate for various parts of the slope.

2. Considering that typical rill spacing is about 1 rill per meter of field width, use the flow rate per meter of slope width as the flow rate in a rill.

3. Calculate the rill width as

Width (meters) = 1.13*($Qe^{.303}$)

Where Qe is the discharge rate in a rill in cubic meters per second.

4. Assuming a rectangular channel, use Manning's equation or Chezy's equation to compute flow velocity in the rill.

The cover should be designed to limit storm water flow velocity on all parts of the slope, including in rills, to no more than 1.5 ft./sec. (0.46 m./sec.) over sand, silt, sandy loam, or silty loam, to no more than 2.0 ft./sec. (0.61 m./sec.) over silty clay loam or sandy clay loam, and to no more than 2.5 ft./sec. (0.76 m./sec.) over clay. If the site has dispersive clays, which are much more prone to erode, please contact the TCEQ for additional site-specific guidance. The design should limit velocities, even if the vegetation were to receive no care after post closure. The lack of care could shift the mix of plant species and probably would develop some bare spots. A gully that begins in a bare spot can undercut and advance uphill into vegetated areas. The slope design should include a safety factor of at least 1.5 for Class 1 or hazardous waste landfills.

Slope Stability

Slopes of the liner, cover, and lateral containment dike should be evaluated for stability against mass movements. Calculations should use actual measured shear strengths of the slope materials and of the interfaces between slope materials as they will occur at the landfill, rather than using general figures from a manufacturer or from other sites. Of particular concern is the interface between a geomembrane and (saturated) soil or between a geomembrane and another manufactured product. The analysis should consider seepage forces, especially if the cap does not have a drainage layer. The design should have a safety factor under representative or typical conditions of at least 1.5 for Class 1 or hazardous waste landfills and a safety factor of at least 1.3 for Class 2 landfills. The safety factor for other potential conditions, including development of residual strength, should be at least 1.0.

Climate

If a landfill is located in an area of recurring storms (coastal high hazard areas) its design should provide adequate protection from storm surge, tropical storm rainfall, and wave action during flooding.

Any facility within the 100-year floodplain should be designed so that it does not significantly restrict flood flow, reduce the temporary water storage capacity of the floodplain, or allow washout of waste.

Where annual rainfall is high, especially where it exceeds gross evapotranspiration, the leaching potential of a landfill could be high. A calculation of water-balance and infiltration is recommended to show if the cover design and leachate collection system design are adequate.

Operating Methods/Considerations

A clean, safe, orderly, environmentally sound operation requires constant and competent supervision and experienced or adequately trained personnel to operate the landfill.

For continuing evaluation and future planning, detailed records should be kept of all incoming material: volume, waste analysis and characterization, and source or origin. It is also important to record accurately the location of final disposal of all Class 1 wastes buried at the site.

The on-site roads to the unloading area should be of all-weather construction. These roads should be maintained in full operating condition at all times and routinely inspected for spills.

Treatment or Stabilization of Free Liquids

Wastes that contain free liquids should not be placed in a landfill without adequate treatment. Wastes that are liquid or semisolid should be mixed with clay-rich soil, cement, boiler fly ash, cement kiln flue dust, or other effective sorbent prior to their placement in landfills. Granular soil materials are not recommended as sorbents due to the potential for waste mobilization by infiltrating fluids. Sorbents for Class 1 wastes should not be subject to future decomposition or to the release of liquids after compaction. Hazardous waste liquids that have been stabilized with only sorbents are prohibited from land disposal, by the Land Disposal Restrictions (LDR's).

Working Face

The size of the working face of the landfill is determined somewhat by the rate of unloading of incoming vehicles. The working face should be as narrow as possible to minimize the exposed area and reduce contaminated storm water runoff, but not so small as to interfere with the unloading operations and the movement of landfill equipment.

Wet Weather Operation

Wet weather can seriously hamper the operations of a landfill by making the soil too soft, mucky, or slippery for equipment operation. Wet weather can also seriously interfere with trenching, covering, and general traffic flow to and from the working face. For these reasons, all-weather roads and adequate drainage should be provided. In many cases, it is desirable to provide a temporary wet weather landfill area adjacent to the all-weather road. Such sites are used only during the wet weather periods when the normal working area is not accessible. Free-standing liquids should be removed from the landfill prior to deposition of additional waste materials.

Maintenance

Routine maintenance of all facilities (roads, dikes, ditches, fences, spill control, safety, emergency, and operating equipment, etc.) at the landfill site is essential to maintain a clean, orderly, safe, and environmentally acceptable operation. All components should be inspected frequently and kept in good condition.