Texas Commission on Environmental Quality
Industrial Solid Waste Management
Technical Guideline No. 2
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TOPIC: Industrial Solid Waste Landfill Site Selection

Introduction

The purpose of this guideline is to assist applicants and sponsors in the selection of environmentally sound locations for landfill sites that will be used to dispose of industrial solid wastes (further classified as Hazardous, Class 1, Class 2 and Class 3). The definitions for the terms “Hazardous waste”, “Industrial solid waste”, “Class 1 waste”, “Class 2 waste” and “Class 3 waste” can be found in Title 30 Texas Administrative Code (TAC) §335.1 and 30 TAC 335 Subchapter R Waste Classification .

The Class 1 and Class 2 industrial nonhazardous wastes that are disposed of in these landfill sites must meet the waste generator criteria of Title 30 TAC §335.2(d) “No permit [is] required for the processing or disposal of nonhazardous industrial solid waste, if the waste is processed or disposed on property owned or otherwise effectively controlled by the owner or operator of the industrial plant, manufacturing plant mining operation, or agricultural operation from which the waste results is produced; the property is within 50 miles of the plant or operation; and the waste is not commingled with waste from any other source or sources (An industrial plant, manufacturing plant, mining operation or agricultural operation owned by one person shall not be considered an “other source” with respect to other plants and operations owned by the same person...”)

If no permit is needed, then in accordance with 30 TAC §335.6 Notification, the applicant should submit the details of the proposed activities to the TCEQ’s Industrial and Hazardous Waste Permits Section of the Waste Permits Division. The notification process of 30 TAC §335.6 does not incorporate any type of public participation.

If the Class 1, Class 2 or Class 3 industrial nonhazardous landfill is to accept waste from off-site sources (because it does not meet the waste generator criteria in 30 TAC §335.2(d)) then it must be permitted in accordance with Title 30 TAC §335.2 Permit Required. Public participation is incorporated by regulation into the permitting process and is discussed further in Section D Public Participation in the Permitting Process of this document.

In addition, the Texas Commission on Environmental Quality’s (“TCEQ” or “Commission”) staff use this guideline in the evaluation of sites selected by applicants. Recommendations in this Guideline can also aid in site selection for Commercial Industrial Nonhazardous Waste Landfills and hazardous waste landfills, both of which need to be permitted in accordance with applicable regulations. Specific location, design and operation requirements concerning Commercial Industrial Nonhazardous Waste Landfills are located at Title 30 TAC 335 Subchapter T. Specific siting requirements for permitted hazardous waste facilities are at Title 30 TAC §305.50, 30 TAC 335 Subchapter G, and Title 40 Code of Federal Regulations (40 CFR) §264.18.

The determination of whether a particular site is suitable should be based on a site selection analysis that is conducted by the applicant. If a permit is needed, such an analysis must take into account all applicable rules and regulations as may apply. This analysis must take into account short-term effects resulting from construction and operation of the facility and any potential long-term effects of the facility after closure.

This guideline is divided into three sections: General Siting Criteria, Technical Siting Criteria, and Other Siting Issues. General siting criteria are those necessary to complete a preliminary assessment of a potential landfill site. Technical siting criteria are those that must be addressed to fully evaluate the suitability of a site. Additional siting issues include surrounding land use and transportation, critical wildlife habitat, local jurisdiction, public participation, and technical guidelines and resources.

The considerations in site selection include effects upon the environment and effects upon the local community. The major environmental consideration is the potential for groundwater and surface water pollution due to inadequate waste containment. A combination of engineering design features and favorable hydrogeologic setting will increase the security of the waste within the facility. Engineering features such as constructed liners, leachate collection systems and perimeter dikes can overcome certain site deficiencies. However, natural settings that minimize exposure of the waste to the environment are preferable to engineering control and can substantially reduce the cost of site development.

Effects of a facility on the local community are related to the proximity of the facility and its activities to existing residences, schools, and other centers of community activity. Generally, these effects depend on the existing land use surrounding a proposed site. If the facility is compatible with existing land uses, (e.g., location within an industrial area) these effects are less significant. Public opposition is usually based on concern over increased traffic, odors, noise, possible reduced property values, and the potential for increased health risks due to operations of the facility. Facility sponsors can address these concerns through the use of buffer zones, locations that are compatible with the existing land use, appropriate facility design and operation, and early and continuing communication with local residents and landowners.

The process of siting a landfill should begin with a broad screening of a given area. The application of general siting criteria can help the applicant or sponsor to classify the various portions of the area in regards to suitability for waste management. This process can reduce the area of study to the most favorable zones for facility siting. The most favorable zones within the overall area can then be evaluated on the basis of technical siting criteria. This process will further reduce the study area to the most favorable sites. After initial field work, which may include such activities as test borings and geophysical surveying, the best site can be chosen for comprehensive hydrogeologic evaluation, impact assessment, and engineering. To ensure that a site is thoroughly evaluated, each general and technical siting criteria should be considered.

This site selection analysis allows the applicant to eliminate unacceptable sites at an early stage in the evaluation process and thereby reduce the cost of subsurface investigations and engineering plans. As applicable, the site selection analysis report may be submitted with the permit application so that it can be made part of the public hearing record if a hearing is conducted. Such a report should identify any alternative sites that were examined along with any significant environmental deficiencies found. This report must be prepared by a Texas Licensed Professional Geoscientist. The technical evaluation performed by TCEQ staff does not extend to alternative sites; a site selection analysis report would serve only to inform the public and agency staff.

I. General Siting Criteria

The general criteria are divided into two categories: recommended separation distances between the landfill and a particular entity of interest, and areas in which a landfill should not be sited unless mitigating actions are taken.

A. Separation Distances

Minimum distances should be treated in such a manner that the detailed site evaluation ultimately indicates the required separations. In addition to aiding the preliminary site selection process, the use of minimum distances will afford a design margin of protection in terms of public health and safety. The primary reasons for buffer zones include:

1. safety factors - site characteristics must accommodate control of wind-blown contaminants, possible spontaneous combustion or explosion of ignitable wastes and gases, and offensive odors. A buffer zone should provide for safe passage of emergency vehicles in the event of fires or explosions.

2. sufficient reaction time - should the monitoring system indicate that contaminants are migrating off-site, time is needed to devise and implement an appropriate mitigation method. Greater distances afford more time to develop mitigation measures.

3. adequate space for containment or corrective action measures such as slurry walls, drainage diversions or pumping systems may be required. Each measure requires a significant amount of land area.

4. adequate monitoring distance - sufficient land area must surround disposal operations so that monitoring wells can be strategically located.

5. nuisance conditions - to avoid complaints concerning noise, odors, disease vectors, and other adverse effects on adjacent land uses.

Site developers should realize that every facility will be evaluated individually and factors such as the character of adjacent land use, soil conditions, groundwater velocity, and the type and number of waste streams may require or allow deviations from the minimum distances recommended below.

In all cases, the separation distance should be sufficient to prevent adverse effects on adjacent property activities.

1. the site should include a minimum separation distance of 200 feet between landfill disposal operations and the adjacent property line.

2. a minimum separation distance of at least 500 feet should be provided between the facility boundary and public drinking water supplies, established residences, schools, hospitals, and other centers of community activity.

B. Areas of Concern

The following areas are those in which a landfill should not be established without special safeguards and/or additional governmental approvals. These items will be discussed in Section II, "Technical Siting Criteria," in more detail.

1. 100-year floodplain.

2. wetland areas.

3. coastal high hazard areas - this includes areas subject to hurricane storm surge and shoreline erosion.

4. low-lying areas with high subsidence rates or subject to shoreline erosion.

5. active fault zones

6. sole-source aquifer recharge areas - the Edwards Aquifer has been designated as a

sole-source aquifer. It is the policy of the Commission not to authorize landfills in the recharge zone of the aquifer.

7. endangered species habitat areas.

8. designated state and federal wilderness, park, and preserve areas - these areas have been designated for special purposes.

9. areas zoned for activities other than industrial use - municipal officials have established zones within city limits that restrict industrial activities in residential or commercial areas. These zoning requirements are based on a comprehensive plan that reflects the desires and goals of the municipality.

10. areas of historic or archaeologic significance - these areas include historic settlements, cemeteries, battlegrounds or Indian burial grounds.

Before the more detailed technical siting criteria are employed, it is prudent for the site sponsor to evaluate future land-use plans in terms of the general criteria. For example, proposed surface water reservoirs may be of vital importance to an area, and would be viewed as taking priority over a landfill.

C. Land Resources Map

Many studies and maps of various areas of Texas have been prepared by state agencies and private parties. These resources offer excellent area-wide guides to expected conditions in a general area.

One such map is Land Resources of Texas, published by the Texas Bureau of Economic

Geology. This is a valuable resource to assist in determining if an area is favorable for industrial solid waste disposal. The publication includes a 1:500,000 scale (approximately 8 miles per inch) map of Texas with the land areas classified according to natural suitability and recommended use considerations. Seventy land resource units are defined and grouped into the following basic land categories: areas of groundwater recharge, lands with various types of mineral resources, substrates with significant physical properties, land forms with unusual and critical configurations, areas influenced by dynamic physical processes, areas dominated by biologic habitation, lands submerged beneath coastal waters, and lands altered or created by man.

The classification of a land resource unit is based on properties that are judged to be the most significant in its potential use. The publication stresses that the evaluations are based on natural capability, which can be improved by planning and construction methods. The text indicates that derivative maps can be produced by grouping together land resources that have similar characteristics with respect to a particular activity or problem. In Table 17 of the report, each of the 70 land resource units are categorized as either good, moderate or poor for use as solid waste disposal sites. The report indicates that on-site investigation should precede location of all waste disposal facilities.
The Commission recommends that prior to extensive on-site investigation, the map and other available published information will be studied to narrow candidate land tracts to those that have a higher probability of suitability for waste disposal when fully investigated. Land areas classified by the *Land Resources of Texas* map as poorly suited for use as a solid waste disposal facility should be avoided unless detailed site specific investigation documents the suitability of the area for the proposed facility.

II. Technical Siting Criteria

Natural geologic conditions should be utilized to enhance the security of industrial solid waste in landfills. Secure landfills should be sited, designed, and constructed to provide multiple barriers to subsurface waste migration.

The primary barrier to contaminant migration, consisting of a liner or liner system and the cover system, will be established in the permit prepared for the landfill. Technical specifications and performance standards for such barriers are included in the TCEQ Industrial Solid Waste Management Technical Guideline No. 3 - Landfills. Such barriers are termed primary since they function first in order of time to prevent or minimize the migration of contaminants.

In regards to secondary containment barriers, the term “secondary” as used here does not imply that such barriers or conditions are of lesser importance than primary barriers. A secondary barrier is any physical condition that prevents or minimizes the migration of waste that penetrates the primary barrier. Secondary barriers, thus, act later in order of time than primary barriers. Ideally, the subsurface conditions should provide sufficient secondary containment so that there exists a low potential for any contaminant that penetrates the primary barrier to migrate by way of the uppermost aquifer to water supply wells, to a point of potential water well withdrawal, or to any other area of potential discharge to surface or groundwater. Ideally, a low permeability clay will underlie the entire landfill.

Determination of site suitability must be based upon a thorough assessment of the degree to which the primary barrier in combination with the secondary containment will provide assurance of effective long-term isolation of industrial solid waste. Some deficiencies in natural geologic setting can be mitigated by more stringent facility engineering design features and waste management practices. The favorable geologic or natural conditions that provide an optimal industrial solid waste landfill location are depicted in Figure 1.

A. Soils

1. Nearly Impermeable Strata

The fluid transmitting properties of the soil beneath a landfill liner system will determine to a large degree the potential for migration of waste that may have penetrated the landfill liner. Figure 2 depicts approximate ranges of hydraulic conductivity (i.e., coefficient of permeability) for a variety of unconsolidated and consolidated geologic materials. The diagram also establishes the following classification for suitability as secondary containment materials based upon hydraulic conductivity (K): Recommended, $K \leq 1E\text{-}7$ cm/sec; Marginal, $1E\text{-}5 > K > 1E\text{-}7$ cm/sec; and Not Recommended, $K \geq 1E\text{-}5$ cm/sec.

Nearly impermeable materials, such as clay and shale, greatly restrict the zone that potentially could be affected by a release from an industrial solid waste landfill when compared to more permeable soils, such as gravel, sand and silt. Clay and shale units may contain discontinuities such as fissures, joints, fractures, and desiccation cracks that can increase the unit's bulk hydraulic conductivity. However, such discontinuities must be interconnected to markedly reduce the unit's effectiveness in restricting waste migration. Homogeneous, massive, and nearly impermeable clay and shale beds that provide a large vertical separation between the base of the landfill and the uppermost aquifer are preferred locations for industrial solid waste landfills. Unfractured metamorphic and igneous rocks may also provide secure locations for disposal. For landfills sited in such locations, there is an extremely low potential that surface water or a groundwater aquifer will be adversely affected by waste migration.

Clays also can be adversely affected by certain organic chemicals. Any clay that is utilized as a barrier to waste migration should be tested for compatibility with the wastes to be disposed in the landfill.

The Commission recommends that industrial solid waste landfills not be constructed so as to intercept or to directly overlie appreciable thicknesses of permeable soils, such as gravel, sand, or silt. Seams, lenses, or thin beds of sand or silt that extend for only a short distance and are surrounded by clay will often not significantly increase the potential for waste migration. Sandy clay or clayey sand beds may exhibit a sufficiently low permeability that the rate of waste migration would be extremely slow. However, as the continuity, thickness, or permeability of a sand or silt unit increases, there is correspondingly less assurance that waste migration will be sufficiently restricted. As a result, regionally continuous beds or strata or moderately to highly permeable soils should be avoided.

Karst areas in limestone, dolomite, and caliche serve as poor hosts for industrial solid waste landfills due to their high hydraulic conductivity. Any fractured rock such as limestone, dolomite, sandstone, or igneous and metamorphic rocks will not provide a high degree of secondary containment if the fractures are interconnected. Hydraulic conductivities in limestone, dolomite, and sandstone generally are highly variable and typically are within the Marginal range. Such materials are not preferred as secondary containment materials.

The geologic maps of the *Geologic Atlas of Texas*, published by the Bureau of Economic Geology, provide the primary reference for determining the geological formation name and associated generalized stratigraphic and lithologic description. The Bureau also publishes the following references that would be helpful in a literature search of the geology of a proposed landfill location: *Bibliography and Index of Texas Geology, 1951-1960*; *Bibliography and Index of Texas Geology*, *1961-1974*; *Bibliography and Index of Texas Geology*, *1975-1980*; *Index to Areal Geologic Maps in Texas, 1961-1981*; and *Environmental Geologic Atlas of the Texas Coastal Zone*. In addition, soil surveys have been prepared for most Texas counties by the Soil Conservation Service of the U.S. Department of Agriculture.

2. Lack of Stratigraphic Complexity

It is desirable that an industrial solid waste landfill site have a simple hydrogeologic framework so that a reliable analysis of the potential for pollutant migration can be performed.

Identification and assessment of the potential pathways for pollutant migration is more difficult in areas with stratigraphic complexities, such as nonuniform beds that pinch out, vary significantly in thickness, coalesce, or grade into other units. Such areas would therefore require a significantly greater degree of subsurface investigation and groundwater monitoring than areas with horizontal beds. Consequently, subsurface investigation in these areas will require greater expenditures.

3. High Attenuation Capacity

The ability of the soil materials surrounding and underlying an industrial solid waste landfill to attenuate or reduce the concentration of dissolved constituents in leachate should be determined during the investigation phase of a site evaluation. A high attenuation capacity for those compounds or ionic species most likely to be contained within any leachate generated at a landfill is a favorable natural condition. A high attenuation capacity provides an additional natural barrier to contaminant migration, but should not be viewed as an acceptable substitute for the other favorable conditions described herein.

B. Groundwater

1. Depth to Aquifer

For a given soil type, the greater the vertical separation between the base of the landfill and the shallowest aquifer, the greater the assurance that industrial solid waste will be effectively isolated from useable groundwater resources. Geologic settings with nearly impermeable soils where the first aquifer is deep or where an aquifer is not present are ideal locations for industrial solid waste landfills. In the case where evaporation significantly exceeds precipitation and the first aquifer is deep, a more sand-rich stratigraphy may, depending on the design and operation of the landfill, provide an acceptable level of secondary containment.

It must be emphasized that the concept of a water table is not synonymous with that of an aquifer. Numerous subsurface soil investigations in the state have identified significant thicknesses of clay-rich soil that in spite of being saturated (i.e., below the water table) do not have sufficient permeability to yield appreciable quantities of groundwater. Such saturated clay and clay shale deposits have not been considered aquifers. Provided a disposal area is underlain by an impermeable, homogeneous, laterally continuous, and sufficiently thick clay or clay shale deposit, a shallow water table does not necessarily present problems that cannot be adequately compensated for in the design and operation of the landfill. Such locations can serve as environmentally adequate hosts for the land disposal of industrial solid waste.

Landfill locations that would require the placement of liners to cover appreciable thicknesses of moderately to highly permeable soils that are below the water table must be avoided. Landfill liners must be designed to withstand hydrostatic forces to which they will be exposed. However, should the landfill liner degrade or be penetrated, the industrial solid waste would be subject to more widespread dispersal by way of groundwater flow in the sand or silt unit than would be the case in either a saturated clay unit or in the unsaturated zone. A thin silt stratum of moderate hydraulic conductivity is of lesser concern in this regard than a thicker sand bed with greater hydraulic conductivity. The degree to which a sand or silt unit would affect the suitability of a site for the land disposal of industrial solid waste must be based on a thorough assessment of the unit's thickness, lateral extent, connection with other permeable units, and groundwater-yielding and transmitting capacity.

The TCEQ has published an extensive series of reports and bulletins concerning the geology, groundwater resources, records of wells, and chemical characteristics of groundwater in many areas of the State. Reports filed by water well drillers are available for review at the Commission's offices in Austin. Reports pertaining to groundwater resources and prepared by the U.S. Geological Survey and the Bureau of Economic Geology also may provide useful information for a particular landfill location.

Figures 3 - 6 are illustrations of landfills in several common geologic and hydrologic environments in Texas. They depict how sand body geometry and distribution as well as the position of the water table affect the possibility of groundwater contamination.

2. Groundwater Velocity

A slow rate of flow of groundwater in the shallowest aquifer underlying a landfill is a favorable natural condition that would serve to minimize the migration of any contaminants that penetrate the primary barrier. Average linear velocity (v) of groundwater flow is defined by the equation $v = Ki/n$ where K is the hydraulic conductivity, I is the hydraulic gradient, and n is the effective porosity. The velocity of groundwater flow is minimized under the condition where the aquifer exhibits a low hydraulic conductivity and a gentle hydraulic gradient. Figure 7 lists calculated values for average linear velocity (v) in terms of feet per year for various combinations of values for hydraulic conductivity and hydraulic gradient. For similar calculations a value for the effective porosity (n) should be selected that is representative of the aquifer materials but tends to maximize the groundwater flow rate. Figure 7 was constructed by assuming n equals 0.10. Some materials have $n=0.05$, or even less. If effective porosity has not been measured at the site, a value of $n=0.10$ may be assumed, for siting purposes.

The following classification for average linear velocity (v) of groundwater flow in the shallowest aquifer underlying a hazardous waste landfill is established: Recommended, $v < 10$ ft./yr.; Marginal, 10 ft./yr. $< v < 100$ ft./yr; and Not Recommended, $v > 100$ ft./yr. The thickness and properties of the soil materials that separate the base of the landfill from the aquifer will determine the importance that should be placed on this criterion. The aquifer flow rate would be of substantial importance if the separation distance was on the order of a few tens of feet but would be of considerably less importance if the separation distance was on the order of hundreds of feet. Groundwater flow rate can remain an important consideration for those hydrogeologic settings with a deep aquifer if the intervening materials are permeable, such as gravel, sand, silt, karst limestone, or any fractured rock.

3. Flow Path

A long path for the flow of groundwater within the uppermost aquifer prior to its discharge to a water supply well or to surface water is a desirable natural condition. There is clearly a greater risk to human health if water supply wells that produce from the uppermost aquifer are located in the immediate vicinity of the downgradient property boundary than if the wells are located several miles downgradient from the landfill. The greater separation distance provides increased assurance that the groundwater will not be used prior to the detection of contamination and also allows greater flexibility and time to implement any necessary groundwater renovation program.

4. Groundwater Quality

Poor groundwater quality in the shallowest aquifer underlying a proposed industrial solid waste landfill is a favorable natural condition. Naturally-occurring poor groundwater quality makes it less likely that the resource is or will be used for human or animal consumption and thereby reduces the risk to public health.

For many purposes, the dissolved-solids content is a major limitation on the use of water. A general classification of water based on dissolved-solids content is as follows: Fresh, less than 1,000 mg/l; Slightly Saline, 1,000 to 3,000 mg/l; Moderately Saline, 3,000 to 10,000 mg/l; Very Saline, 10,000 to 35,000 mg/l; and Brine, more than 35,000 mg/l. Where possible, industrial solid waste landfills should be located over aquifers containing groundwater with a dissolved solids content in excess of 10,000 mg/l. This recommendation is not intended to suggest that industrial solid waste landfills cannot be safely located over aquifers with fresh water or that landfills located over aquifers with poor water quality can be designed and constructed to less stringent standards.

5. Aquifer Yield and Use

The amount of groundwater that an aquifer may yield depends on its thickness and lateral extent, its porosity and hydraulic conductivity, and its pressure conditions. In general, low-yield aquifers are a favorable natural condition because there is less chance such an aquifer will be used to supply water for human or animal consumption.

However, areas overlying low-yield aquifers may not be suitable for the location of a landfill if that aquifer is the only source of water for individuals or for agricultural operations.

6. Major and Minor Aquifers

The Texas Water Development Board has identified 9 major aquifers and 20 minor aquifers in the state (Report 345, *Aquifers of Texas*, November, 1995). A major aquifer is one that can supply large quantities of water in large areas, and a minor aquifer is one that can supply large quantities of water in small areas, or small quantities of water in large areas. The proximity to a major or minor aquifer, especially in regards to its recharge area, should be considered in determining the suitability of a potential landfill site.

C. Active Geologic Processes

1. Erosion

Industrial solid waste landfills should be located in geologic settings where the potential for erosion of the final cover or disruption of the landfill on a long-term basis and the resultant exposure and release of contaminants to the environment is minimized.

Swales, draws, gullies, valleys, or arroyos should be avoided due to a concentration of runoff flow and high erosion rates. Areas of low relief (less than or equal to 5 percent) with an associated low potential for erosion, landslides, or slumping are preferred. Broad upland flats or divides away from major or tributary drainages generally provide secure landfill locations from the standpoint of erosion. Care should be taken to avoid location of a landfill in an area susceptible to erosion by one of the numerous headward-eroding streams that are cut into mud substrates along the Gulf Coast. Likewise, locations subject to erosion by fluvial processes such as meandering streams and undercut banks should be avoided.

2. Shoreline Erosion

Shoreline erosion is an active geological process that should be evaluated for an industrial solid waste landfill to be located close to the Texas coast. Monitoring of shoreline position using sequential historic maps and aerial photographs established in 1974 that erosion during the previous 74 to 132 years had subjected 46 linear miles (13 percent) of the Texas shoreline to severe erosion (greater than 10 feet per year) and 154 miles (42 percent) to moderate erosion (up to 10 feet per year). The nature of a shoreline, whether erosional, depositional, or in equilibrium, is largely a function of natural processes. Chief among these are the availability of sediment source and the intensity of wave activity. Geological evidence points to the continued landward retreat of shoreline position as the long-term trend. Land areas located too close to the shoreline to provide adequate assurance of effective long-term containment must be avoided.

3. Subsidence

Submergence of an industrial solid waste landfill below mean sea level and inundation by waters of the Gulf or of a bay is a hazard that must be avoided. Land surface subsidence affects to a varying degree a substantial part of the lower Texas coastal plain. Land subsidence both in terms of land elevation and area affected has increased significantly during the last three decades. Benchmark elevation surveys on the coastal plain indicate that in 1943 a little more than 140 square miles of land had subsided more than 1 foot with a maximum of 1.5 feet, and by 1974 that more than 3000 square miles had undergone more than 1 foot of subsidence with a maximum of 8.5 feet. Most investigators have concluded that groundwater withdrawal is the principal cause of subsidence. Since industrial solid waste landfills must provide for long-term containment of waste, protection from submergence must be provided. Publications of the Texas Bureau of Economic Geology titled Natural Hazards of the Texas Coastal Zone and Environmental Geologic Atlas of the Texas Coastal Zone contain maps depicting maximum recorded land subsidence.

4. Faults

An active fault is defined as a fault that has had movement in Holocene time, that is, since the end of the Pleistocene Era (ice age) about 10,000 years ago. The geologic maps of the Geologic Atlas of Texas, published by the Bureau of Economic Geology, depict the locations of most faults identified in the state. The maps do not distinguish active faults from inactive faults. Such determination must be based upon an evaluation of the geologic history of the area.

Industrial solid waste landfills should be offset a sufficient distance from an active fault to ensure that the liner system will not be disrupted by fault movement. The required clearance would be site specific and based on factors such as the zone of the significant surface deformation, uncertainty in locating the fault, activity of the fault, and a distance to provide a reasonable margin of safety. Active faults are relatively common along parts of the Texas coastal plain. Faults in the area are considered active if they have offset a man-made structure or if they show a clean, sharp scarp. Fault formation is attributed to natural geologic processes; however, fault activation is generally linked to the withdrawal of groundwater, oil, and gas by man. Along the Texas coastal plain in areas of documented active fault movement, industrial solid waste landfills should be offset from potentially active faults as well as active faults. Potentially active is used to describe faults that extend to the surface or offset the shallowest clear marker bed. This is necessary since the frequency and activity of fault movement is increasing in some areas. For example, early this century, faulting was not a problem in the Houston area because no active faults had been recognized. By 1980, however, Elsbury, Van Siclen and Marshall stated that in Harris County over 130 active or potentially active faults totaling over 200 miles in length have been mapped at the surface. Active faults also occur in the Trans-Pecos regions of the state.

Faults that are determined to be inactive based on geologic evidence may, depending upon the characteristics of the surrounding sediments or rocks, provide a path for rapid leachate migration to area groundwater resources. Any inactive fault should be carefully studied when determining the secondary containment suitability of a proposed landfill location.

D. Surface Water

1. Rainfall

Precipitation varies from an average annual high of 56 inches in far east Texas to a low of 8 inches in far west Texas. Net evaporation ranges from a negative value of several inches per year in the east to in excess of 100 inches per year in the west. Facilities located in east Texas receive more storm water than can be managed solely through evaporation. Significant rainfall into open landfill cells can saturate wastes and result in the production of contaminated storm water or leachate. In east Texas, precipitation of sufficient intensity and duration occurs with a frequency that requires careful consideration of storm water during the design and operation of a landfill. For this reason, sites located in east Texas require more extensive storm water management systems, often involving impoundments, dikes, ditches, and wastewater treatment facilities. As a result, additional land area may be required for this capacity, depending on the storm water management strategy and methods to be employed.

2. Floodplains

A floodplain is a land area that is normally dry, yet susceptible to being flooded. The Federal Insurance Agency has conducted extensive studies of most communities and well populated counties and has determined the extent of floodplains for the 100-year recurrence interval. Currently two levels of study have been conducted:

a. Flood Hazard Boundary Map (FHBM), and

b. Flood Insurance Rate Map (FIRM)

The FHBM is usually the first map issued for an area and is temporary. The FIRM is the floodplain map resulting from a detailed hydrologic and topographic study.

The riverine floodplain, associated with the 100-year flood, is designated as Zone A on the FIRM. There may be significant storm water velocity gradients within Zone A and this area is very poorly suited for landfills. The potential for significant long-term erosion will generally be high in Zone A due either to scouring or, in certain cases, meandering of the drainage features. In some areas, a floodway may be used to mitigate the land surface area subject to inundation. The floodway is usually defined by a series of levees used to route the flood waters.

The hazardous waste permitting regulations specify that a facility located in a 100-year floodplain must be designed, constructed, operated, and maintained to prevent the washout of any hazardous waste from the active portion of the facility by a 100-year flood. Due to the potential for scouring of the cover after closure, placement of industrial solid waste landfills within 100-year riverine floodplain areas should be avoided.

The FIRM will generally be determinative for the location of the 100-year floodplain. If a FIRM has not been completed for the proposed area, the Commission may request additional evaluation to determine the elevation of the 100-year flood.

3. Coastal Wetlands

Coastal wetlands are among the most valuable areas of the estuarine system. These areas provide essential habitat for many estuarine species and also serve other functions such as shore stabilization, flood control, and water purification. Because of these values, wetlands must be considered highly unsuitable as locations for landfills.

Wetlands are protected under Section 404 of the federal Clean Water Act. The U.S. Army Corps of Engineers (Corps) is required to exercise permitting authority over all activities in wetlands. The Corps applies a public interest review of any proposed activity that would alter wetlands. In making any permit decision, the Corps is required to consider whether the proposed activity is dependent on the wetlands resource and environment and whether feasible alternative sites are available. Any proposed landfill site in a wetland would most likely fail this review.

4. Coastal High Hazard Areas

The Texas Gulf Coast is a dynamic natural system characterized by a variety of active geological processes. These processes can present hazards to those who store, process or dispose of industrial solid waste. Hurricanes and tropical storms strike the Texas coast on an average of once every two years. Hurricane storm surges of 15 feet above mean sea level have occurred during this century; the highest level was recorded at 22 feet in restricted, shallow bays. Large, steep waves riding the crest of a storm surge erode beaches, dunes and bay shores. Flooding due to hurricane storm surges may cover hundreds of miles of coastal lowlands and is a highly significant consideration for any landfill proposed to be sited in the area. Heavy rainfall that accompanies and follows hurricane passage causes streams on the coastal plain to flood extensively. Such heavy rainfall also results in flooding of broad flat areas resulting in standing water over areas of poorly defined drainage on the coastal plain. Due to the potential for significant erosion caused by wave energy and currents, the portion of the 100-year coastal floodplain associated with either river flooding or hurricane storm surge tides should be avoided. Areas subject to such inundation are designated as Zone V (V, V1 - V30) on the Flood Insurance Rate Maps.

Landfills can be sited within Zone V only when it can be demonstrated that the disposal operation can be designed, constructed, operated, and maintained to prevent the washout of contaminants by a 100-year flood.

Factors that contribute to siting problems in the coastal zone include: (1) high rainfall and storm surge, (2) high water table conditions, (3) subsidence, (4) shoreline erosion, (5) sensitive wetland ecosystems, and (6) high population density. In consideration of these factors, siting at elevations below 15 feet mean sea level (msl) should be avoided.

The Texas Bureau of Economic Geology has published <u>Natural Hazards of the Texas Coastal Zone</u> (1974), which contains maps depicting active processes along the coast. These maps indicate areas inundated by marine waters from storm surge tides associated with both Hurricane Carla in 1961 and Hurricane Beulah in 1967. They also indicate areas of freshwater flooding by Beulah rainfall along the southwestern Texas coast and areas of potential freshwater flooding by hurricane rainfall along the northeastern Texas coast. Locations of hurricane landfalls since 1900, as well as depositional and erosional areas of the shoreline with an approximation of rates, are also depicted. Most of this information is also presented in another Bureau of Economic Geology publication titled <u>Environmental Geologic Atlas of the Texas Coastal Zone</u>.

III. Other Siting Issues

A. Surrounding Land Use and Transportation

The primary concern of the Commission is that the use of any land for an industrial solid waste disposal facility does not adversely affect public health or the environment. Therefore, it is important to locate such facilities in areas that are compatible with industrial activities. Facilities should not be located near schools, hospitals, or residential areas. The effect of a proposed facility upon a city or community will be considered in terms of its compatibility with existing land use, zoning in the area, community growth patterns, and other factors associated with the public interest. To assist the Commission in the evaluation of a proposed site, the permit application or a notification of proposed activities submitted to the TCEQ’s Waste Permits Division in accordance with Title 30 TAC §335.6 may provide the following information in map and textual formats:

1. Zoning at the site and within one mile of the site;

2. Character of the surrounding land use within one mile of the site (e.g., agricultural, industrial, commercial, residential uses);

3. Growth trends of communities within one mile of the site showing directions of major development;

4. Proximity to residences, schools, hospitals, and other institutional facilities;

5. Proximity to local emergency response units (e.g., emergency medical services, fire departments, etc.);

6. Proximity to major centers of waste generation;

7. Location of existing pipelines, underground utility lines, and municipal or private drinking water supplies within one mile of the site;

8. Availability and adequacy of access roads to the site, (e.g., paved/unpaved, weight limitations, number of roads, existing and expected volume of vehicular traffic);

9. Restrictions along transportation routes from waste generating centers to disposal site, (e.g., hazardous material routes and height and weight limits along roadways); and

10. Location of underground oil and gas storage areas in the vicinity of the site.

Site developers should recognize that land that is utilized for landfill sites will have little value for alternative uses after closure. Areas with high recreational use potential should be avoided, as should prime agricultural land, as designated by the U.S. Department of Agriculture. To avoid nuisance conditions sometimes associated with disposal operations, the TCEQ recommends that facilities locate in or adjacent to industrialized areas or areas that are sparsely populated. These locations will minimize complaints concerning litter, noise, odors and vectors because they are generally located away from incompatible uses.

B. Critical Wildlife Habitat

The critical habitat is defined as a geographical area occupied by an endangered or threatened species as listed in accordance with the Endangered Species Act (See 50 CFR Part 17). This area will contain physical or biological features essential to the conservation of the species. These features may require special management considerations or protection. When designing a waste management facility, it is essential that critical habitats be conserved. Federal RCRA requirements regarding the preservation of endangered and threatened species are listed in 40 CFR Part 257.3-2. Under these requirements, no facilities or practices shall cause or contribute to taking of any endangered or threatened species or result in the destruction or adverse modification of a critical habitat.

A series of maps depicting critical habitats in Texas is available from the U.S. Fish and Wildlife Service. The preferred location would be outside of any critical habitat. In some cases, however, it may be difficult to avoid a critical habitat. Within a critical habitat, existing developed areas should be chosen over undeveloped areas. Adequate design features should be incorporated so that the facility poses a minimal threat to the remaining critical habitat.

The bulk of the Endangered Species Act can be found in 16 U.S.C. Sections 1531-1543. The Act describes how endangered and threatened species should be protected. The Act also gives the procedure for listing a species or a critical habitat. State regulations regarding endangered or threatened species are contained in Chapters 67, 68, and 88 of the Texas Parks and Wildlife Code. The Texas Parks and Wildlife Department should be contacted to determine if any endangered species inhabit a particular area. More information may be obtained from:

U.S. Fish and Wildlife Service
Office of Endangered Species

P. O. Box 1306
Albuquerque, New Mexico 87103-1306

or

Texas Parks and Wildlife Department
4200 Smith School Road
Austin, Texas 78744

C. Local Jurisdiction

Site sponsors should recognize that municipal and county authorities may affect the siting of industrial solid waste disposal facilities. Texas counties have authority to designate land within the county as suitable for use as solid waste disposal sites [Texas Health And Safety Code §361.162]. Municipal controls that affect industrial facility siting and operation include local zoning ordinances, building codes, fire codes and health regulations. If locating a facility within the territorial limits or extraterritorial jurisdiction of a city, site sponsors should be familiar with any local requirements for industrial activities and any possible restrictions created by municipal ordinances.

Site sponsors should be aware that compliance with city and county requirements is a separate responsibility from TCEQ requirements for notification in accordance with 30 TAC 335.6 Notification or permit requirements in accordance with 30 TAC §335.2. Actions such as municipal zoning changes and load restrictions on county roads can affect the viability of a project even after a state permit is obtained. Permit applicants should therefore establish contact with local authorities early in the planning stage of siting a new industrial solid waste facility. Typical local authorities would include:

1. County judge and county commissioners
2. County engineer
3. Mayor
4. City/county health department
5. City planning department
6. Local river authorities
7. City/county environmental departments
8. Urban transportation department
9. Regional office of the State Highway Department
10. Utility companies

D. Public Participation in the Permitting Process

Due to extensive interest concerning the siting and permitting of industrial solid waste treatment, storage and disposal facilities, the applicant should initiate communication with representatives of the host community prior to submission of a permit application.

(A private landowner who is developing some part of his/her property as a waste management or waste disposal area for waste generated on-site may also find early communication with the public helpful, even though there may not be any permit requirements.) Early communication will give the public a better understanding of the issues prior to the public hearing and may reduce opposition to the proposed facility. Techniques for involving the public are addressed below.

1. Before Permit Application

Before the permit application has been filed, the applicant should conduct a public consultation program. The program should provide direct communication between the applicant and the community. It should allow for continuous feedback to citizens concerning steps taken by the site proponent to identify and resolve the concerns of the community.

This program should be designed to:

- identify and deal effectively with the local land use effects of the proposed facility;
- establish a direct relationship between the site proponent and the community, creating a method of providing accurate information on the siting proposal;
- result in good facility proposals being received that are acceptable to the community.

a. Project Announcements

Local community leaders and organizations should be contacted and briefed before the project is formally announced. This will give them time to consider the project before they are contacted by the media. Community leaders may also be useful in identifying others who should be involved, identifying some preliminary concerns with the proposed project, and establishing a public consultant program. The project proponent should keep these people informed as changes occur in the original proposal.

After community leaders and organizations have been contacted, a public announcement of the proposed project should immediately follow. A press conference is preferable to a press release since it allows the site proponent to answer directly the initial questions concerning the proposal. Press releases should also be available that respond to the concerns of the community. They should outline opportunities for the public to participate in the siting and permitting process.

b. Information Center

At the time of the press conference, an information center should be established within the community affected by the proposed facility. Someone who is familiar with the project and skilled in providing information that can be clearly understood by the public should staff the center once the project is announced. The concerns of the community resulting from the initial announcement should be handled directly and immediately. Fact sheets should be prepared as additional concerns of the community are identified and should be distributed at the information center.

c. Community Meetings

Meetings with the community should be small, informational and encourage direct interaction between community members and the site proponent. If large public meetings are necessary, a facilitator may be useful.

The purpose of the meetings should be to get information out to the public in an easily understood format so it can be discussed.

The public should have the opportunity to ask questions, voice concerns, and suggest changes in the project proposal. Public meetings are an important step in establishing the credibility of the site proponent. In addition to holding meetings and workshops, the site proponent should be willing to attend the meetings of community organizations. At these meetings, the site proponent should explain the project proposal and ask for suggestions on improving the process of involving the public, as well as solicit concerns.

d. Local Review Committee

Another method of facilitating communication is through the creation of a local review committee. This committee would review the draft facility plans and discuss the issues of local concern with the applicant so that they may be addressed before the plans are finalized and the permit application is submitted. This communication would provide for local concerns to be accommodated in the facility design or operation plan before the technical review by the Commission. The local review committee process may also serve to identify the type of facility that the community would support as well as indicate the extent of opposition to any one design prior to significant commitment of capital.

e. Public Participation Report

The applicant should describe the public participation efforts that have been conducted prior to submission of the application and present this information to the Commission when he submits his application.

2. After Permit Application

The public consultation program should be completed before the permit application is submitted to the Commission. Many of the techniques that were recommended as part of the public consultation program may also be useful during the remainder of the siting and permitting process. The work on the public consultation program will serve as the foundation for the public participation program that follows and is conducted by the Commission and the site proponent.

a. Review of Permit Application and Development of Draft Permit

When a permit application is received by the Commission, it is reviewed and evaluated for compliance with standards for design and operation. By law, a copy of the application or a summary of its contents is sent to the county judge, city mayor, city/county health department, and others designated by the TCEQ Chief Clerk. When the application satisfies the administrative requirements, it is determined to be administratively complete. When the application satisfies the technical requirements, an Executive Director's Preliminary Decision and Technical Summary and a draft permit (called a Final Draft Permit - FDP) are prepared and referred to the Chief Clerk for further action.

b. Notice and Opportunity for Public Comments, Public Meeting and Public Hearing

After the application has been determined to be administratively complete and before a technical review has started, the first of two notices are published. The first notice, called a Notice of Receipt of Application and Intent to Obtain a Permit, is published in a local newspaper of general circulation. This is an opportunity for the public to submit comments and request a public meeting and/or request a public hearing.

The applicant is advised of hearings requirements and of the scheduled hearing date. In addition to a published notice, proper notice of a hearing is given to all persons who in the judgment of the Commission may be affected. At a minimum, this notice is given to the applicant, adjacent landowners, state, county and local officials, and any other person who has expressed an interest in the application.

After an Executive Director's Preliminary Decision and Technical Summary and a draft permit have been prepared, a second notice, called the Notice of Application and Preliminary Decision, is published in a local newspaper of general circulation. The public may submit comments, request a public meeting and/or request a public hearing.

Those persons who establish a justiciable interest in the proposed facility at the hearing are designated as parties by the TCEQ or an appointed hearings examiner. In general the determination of justiciable interest is construed in favor of the persons requesting party status. Persons who cannot demonstrate a justiciable interest may still present statements at the hearing and may also solicit the assistance of the Public Interest Advocate, who may be admitted as a part to all Commission hearings. The public hearings are conducted in accordance with the rules of the TCEQ, Sections 361.079 through 361.083 of the Texas Health And Safety Code, and the requirements of the Administrative Procedure and Texas Register Act (Article 6252-13a). The decision to issue or deny a permit for the proposed facility is made by the Commission upon conclusion of the hearings and a review of the factual and legal issues presented.

E. Other Technical Guidelines

Site selection criteria and design recommendations for other types of industrial solid waste disposal facilities may be found in Technical Guidelines 3, 4, and 5 pertaining to landfills, surface impoundments, and land application facilities, respectively.

Information Sources

Maps

Acquisition of topographic maps requires the specific name of the desired sheet that may be found in index maps that are available from the U.S. Geological Survey (USGS) and local suppliers.

Topographic Maps

U.S.G.S. topographic maps 7.5-minute series, 1:24,000 contour interval varies

U.S.G.S. topographic maps 15-minute series, 1:24,000 or 1:31,680.

The maps are available from:

U.S. Geological Survey
Earth Science Information Center
Box 25286
Denver, Colorado 80225

U.S. Geological Survey
Earth Science Information Center
12201 Sunrise Valley Dr.
Mail Stop 503
Reston, Virginia 22092
703/860-6045

Other sources of information concerning maps may be obtained from:

Texas Natural Resources Information System
Texas Water Development Board
P. O. Box 13231
Austin, Texas 78711-3231
512/463-8402

and

Bureau of Economic Geology
The University of Texas at Austin
University Station, Box X
Austin, Texas 78713-8924
Attn: Publications
512/471-1534

Aerial Photos and Satellite Imagery

Air photos and satellite imagery are useful in the site selection process. These may be used to identify certain geologic features. The information required to obtain photos are typically the latitude and longitude. Air photos and/or satellite imagery are available from:

U.S. Geological Survey
User Services
EROS Data Center

Sioux Falls, South Dakota 57198
Attn: Customer Services
605/594-6511

U.S. Geological Survey
Earth Science Information Center
12201 Sunrise Valley Dr.
Mail Stop 503
Reston, Virginia 22092

Texas Natural Resources Information System
Texas Water Development Board
P. O. Box 13231
Austin, Texas 78711-3231
512/463-8402

Texas Department of Transportation
Information Systems Division
Aerial Photography Section
125 E. 11th Street
Austin, Texas 78701
512/465-5917

Soils

U. S. Department of Agriculture
Natural Resource Conservation Services
101 S. Main
Temple, Texas 76501
817/774-1221

Texas Soil and Water Conservation Board
P. O. Box 658
Temple, Texas 76503
817/773-2250

Groundwater

Texas Commission on Environmental Quality
Water Quality Division
P. O. Box 13087
Austin, Texas 78711-3087
(groundwater reports, groundwater data, and well logs)

Texas Natural Resources Information System
Texas Water Development Board
P. O. Box 13231
Austin, Texas 78711-3231

U. S. Geological Survey
Water Resources Division
8011 Cameron Rd.

Austin, Texas 78754
512/873-3000

U. S. Environmental Protection Agency
Region VI
1445 Ross Avenue
Dallas, Texas 75202-2733
214/665-6444

Floodplains and Surface Water

Federal Emergency Management Agency
Federal Insurance Administration
National Flood Insurance Program
500 C Street, SW
Washington, D. C. 20472
Attention: Public Affairs
202-646-2780

Texas Commission on Environmental Quality
P. O. Box 13087
Austin, Texas 78711-3087
(floodplain maps, rainfall maps and surface-water reports)

U. S. Army Corps of Engineers
Fort Worth District
P. O. Box 17300-0300
Fort Worth, Texas 76102

U. S. Army Corps of Engineers
Galveston District
2000 Fort Point Rd.
Galveston, Texas 77550

U. S. Army Corps of Engineers
Albuquerque District
P. O. Box 1580
Albuquerque, New Mexico
87203-1580

U. S. Army Corps of Engineers
Tulsa District
P. O. Box 61
Tulsa, Oklahoma 74121-0061
Attn: Floodplain Management

U. S. Environmental Protection Agency
Region VI
1445 Ross Avenue
Dallas, Texas 75202-2733
214/665-6444

National Climatic Data Center
151 Patton Ave., Room 120
Asheville, North Carolina 28801
704/271-4800

Geology

Bureau of Economic Geology
University of Texas at Austin
University Station, Box X
Austin, Texas 78713-8924
Environmental Geologic Atlas of the Texas Coastal Zone
Natural Hazards of the Texas Coastal Zone

U. S. Geological Survey
Department of the Interior
8011 Cameron Road
Austin, Texas 78754

Houston Geological Society
7171 Harwin, Suite 314
Houston, Texas 77036
713/785-6402
Houston Area Environmental Geology: Surface Faulting, Ground Subsidence and Hazard Liability

Endangered Species

U. S. Fish and Wildlife Service
Office of Endangered Species
P. O. Box 1306
Albuquerque, New Mexico 87103-1306

Endangered Species of Texas and Oklahoma

Texas Parks and Wildlife Department
4200 Smith School Road
Austin, Texas 78744
Attn: Endangered Resources

Public Assistance and Participation in the Permitting Process

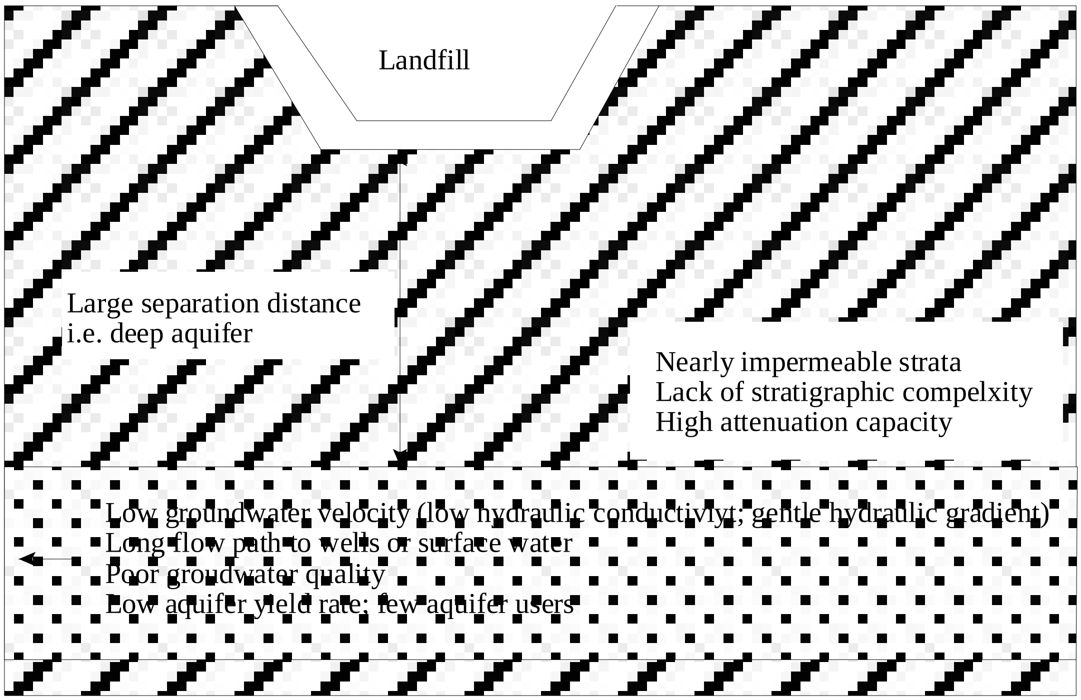
Texas Commission on Environmental Quality
Attn: Public Interest Counsel
Mail Code (MC) 103
P. O. Box 13087

Austin, Texas 78711-3087

And

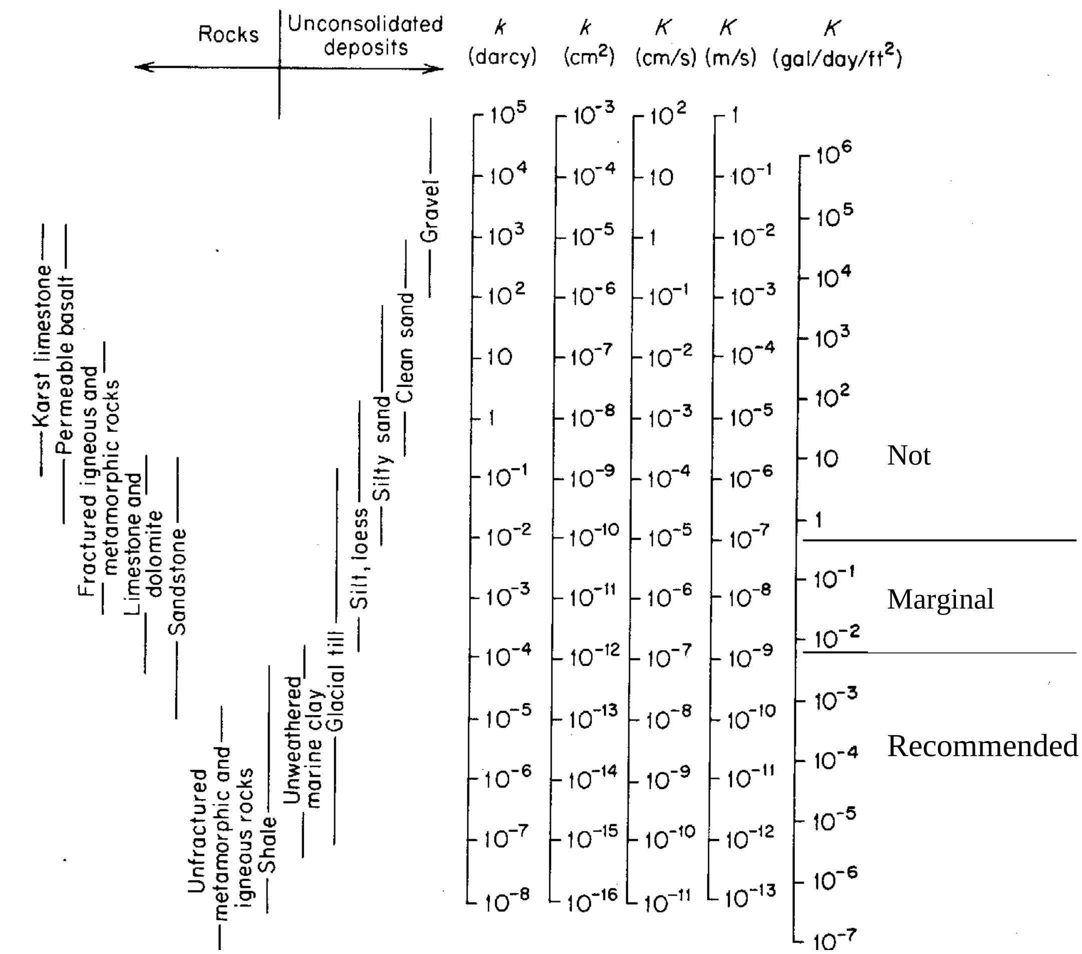
Texas Commission on Environmental Quality
Attn: Office of Public Education
Mail Code (MC) 108
P.O. Box 13087
Austin, TX 78711-3087

Figure 1 Favorable geologic or natural conditions that provide an optimal industrial waste landfill location. These natural suitability factors should be supported by favorable waste management practices and engineering features.



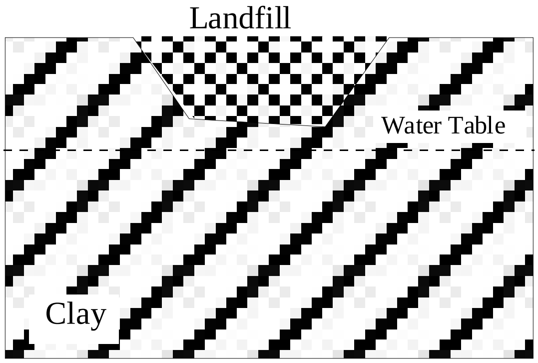
Not subject to submergence due to subsidence
Evapotranspiration exceeds rainfall
low erosion rate
Lack of active faults

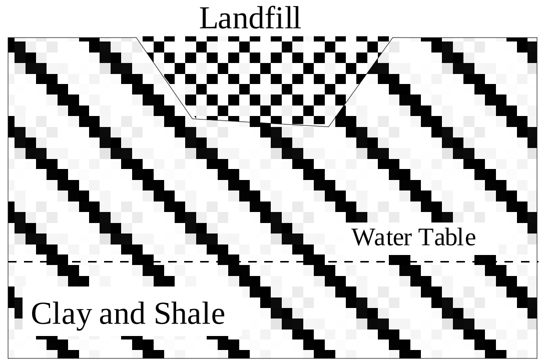
Figure 2 Suitability classification based upon range of hydraulic conductivity values for a variety of unconsolidated and consolidated geologic materials.



Modified from Groundwater by R.A. Freeze and J.A. Cherry, 1979, Table 2.2

Figure 3 Low hydraulic conductivity host, moderate climate.



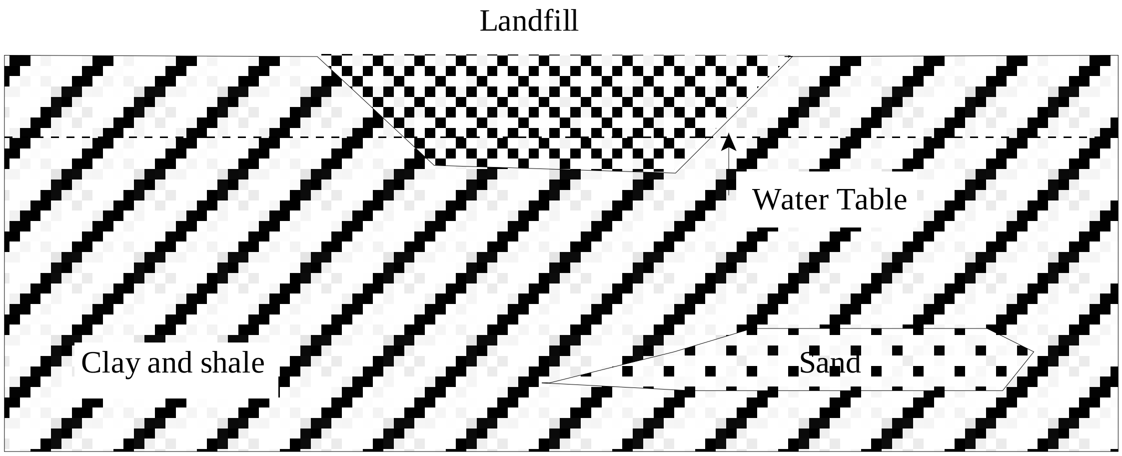


a. Clay in Taylor, Navarro, and Midway Groups; Central and North Central Texas.

b. Clay and shale in portions of Pennsylvanian and Permian age units In North Central Texas

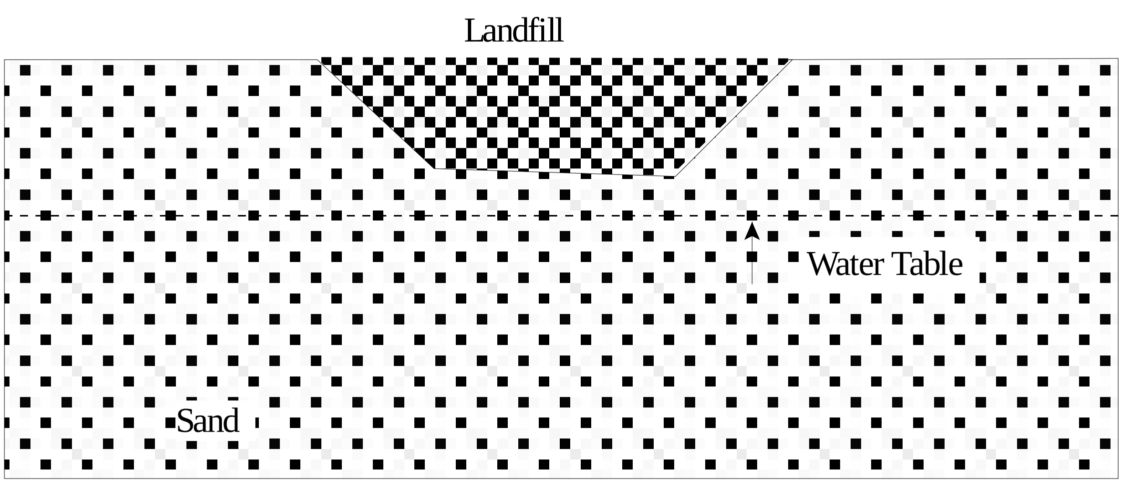
Waste placed on topographic rise (preferably on a broad, relatively flat area) is secure. If the water table intersects the landfill in the wet season, the leachate collection system should be used to withdraw any leachate formed. The low hydraulic conductivity of the host prevents extensive contamination of surrounding sediments. the shallowest aquifer is protected by a thick sequence of the low permeability clay or shale.

Figure 4 Low hydraulic conductivity host, high water table. (Example: Clay in Beaumont Formation; Gulf Coast).



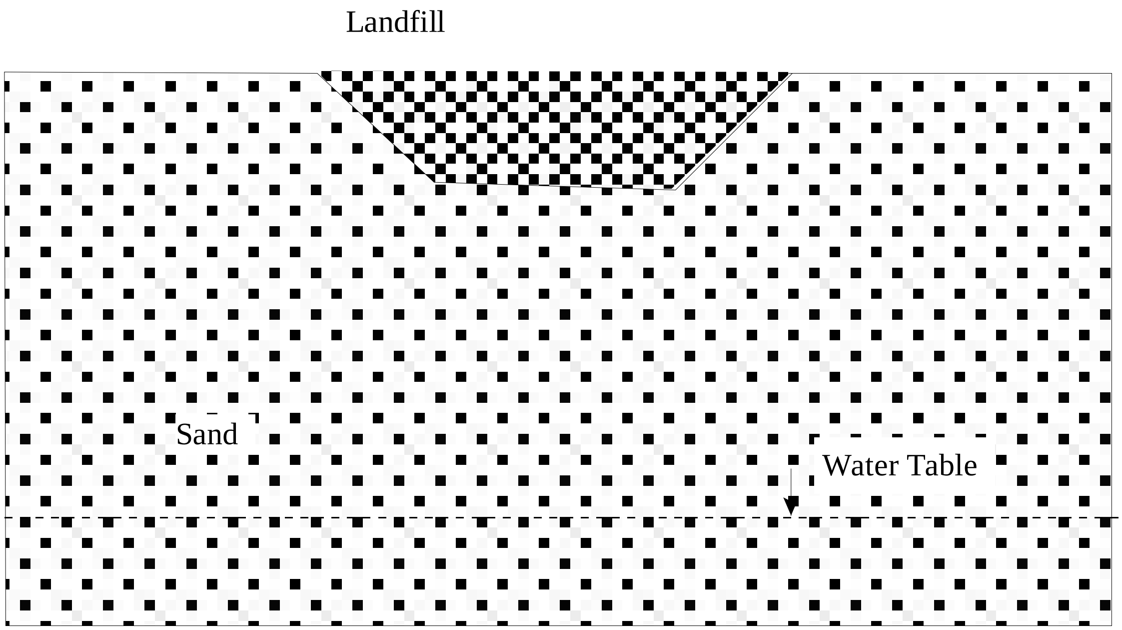
Waste placed below the water table in a uniformly-saturated clay will result in a slow flow of groundwater into the landfill. While the landfill's leachate collection system is functional, any leachate formed can be removed. Over time, however, the water table will re-establish itself through the landfill. Widespread distribution of contaminants is precluded due to the slow rate of groundwater movement through the clay. Local sand bodies should be avoided. Intersected sand layers can result in large volumes of groundwater flowing into the landfill. Also, proximate sand bodies provide pathways for potential leachate migration. The major risk of this type of fill is contamination of surface water. Careful consideration of the design, construction, and maintenance of the final cover is required.

Figure 5 High hydraulic conductivity host, high water table, moderate to high rainfall. (Examples: Recharge sand of Carrizo-Wilcox, Trinity, Queen City, Sparta and Gulf Coast Aquifers).



The permeable nature of the sediments and recharge to either a major or minor aquifer makes these sand bodies extremely poor locations for placement of industrial solid waste landfills.

Figure 6 High hydraulic conductivity host, deep water table, low rainfall and high evaporation. (Example: Bolsons of West Texas).



Due to a favorable water balance and the depth to the water table, this type of fill will be secure during most years. However, the potential exists for a single or a series of heavy rainfalls to flush available contaminants from the landfill area to the water table. Careful evaluation is required to determine whether the landfill's primary barriers (i.e., liner system and final cover) are adequate to provide long term waste containment.

Figure 7 Average linear velocity (v) in ft/yr for a variety of hydraulic gradient (i) and hydraulic conductivity values (k in cm/sec). Assume n = .10.

k \ i	0.001	0.01	0.1	1
10^{2}	3.4 E5	3.4 E6	3.4 E7	3.4 E8
10	3.4 E4	3.4 E5	3.4 E6	3.4 E7
1	3.4 E3	3.4 E4	3.4 E5	3.4 E6
10^{-1}	340	3.4 E3	3.4 E4	3.4 E5
10^{-2}	34	340	3.4 E3	3.4 E4
10^{-3}	3.4	34	340	3.4 E3
10^{-4}	0.34	3.4	34	340
10^{-5}	0.034	0.34	3.4	34
10^{-6}	3.4 E-3	0.034	0.34	3.4
10^{-7}	3.4 E-4	3.4 E-3	0.034	0.34