BUREAU OF ECONOMIC GEOLOGY

Geological Circular 70-2

Geological Considerations in Disposal of Solid Municipal Wastes in Texas

By
PETER T. FLAWN, L. J. TURK, and CAROLYN H. LEACH

The University of Texas at Austin
March 1970

BUREAU OF ECONOMIC GEOLOGY

Geological Circular 70-2

Geological Considerations in Disposal of Solid Municipal Wastes in Texas

By

PETER T. FLAWN, L. J. TURK, and CAROLYN H. LEACH

The University of Texas at Austin

March 1970

CONTENTS

ILLUSTRATIONS

TABLES

GEOLOGICAL CONSIDERATIONS IN DISPOSAL OF SOLID MUNICIPAL WASTES IN TEXAS

Peter T. Flawn, L. J. Turk, and Carolyn H. Leach

INTRODUCTION

In past decades, science fiction (horror) writers used to spawn monsters from putrifying garbage dumps--usually the creature was catalyzed by a violent electrical storm acting on the rotting mass of waste. Our time has a way of making science fiction come true--the monster is there. One arm is the sheer volume of solid wastes, the other is the environmental contamination resulting from improper interment of wastes in landfills, and the third arm is the rising cost of disposal.

In the United States the average citizen produces 6 to 8 pounds of solid wastes per day--this includes his personal contribution plus his pro-rata share of industrial and agricultural wastes. A city of 200,000 to 300,000 people is faced with collecting, transporting, and disposing of about 400 tons to 500 tons of solid wastes every day. This is the amount produced by the residents and small businesses--it does not include the wastes from big industrial operations. Costs of solid waste disposal range from $10 to $30 per ton depending on local labor costs, the distance the material must be transported, and the costs of acquisition and operation of disposal sites. In Texas, cost of landfill operations alone averages $1.10 per ton (Gazda and Malina, 1969, p. 23). The practice of open burning of wastes at the disposal site has been discontinued in many areas because of air pollution control legislation. This increases the volume of material that must be buried. In some areas the volume of solid wastes is reduced by high temperature incinerators prior to ultimate disposal, in others controlled burning of wastes produces by-product steam. Currently in Texas some four municipal incinerators are in operation.

SANITARY LANDFILL

Considerable research is in progress to develop new, economic methods of collecting, transporting, and disposing of wastes. The Solid Waste Disposal Act of 1965 (Public Law 89-272, Title II) gave considerable impetus to this effort. The average city dump contains substantial quantities of metals and other potentially valuable substances that might be recovered. Wastes might be converted to a useful building material by high-temperature, high-pressure conversion to a kind of brick or block.

Purification or sterilization of wastes by atomic radiation is under investigation. Long distance transport of solid wastes to fill abandoned mines and quarries in sparsely inhabited areas is contemplated by some large cities.

However, notwithstanding the new ideas and research in progress, the most satisfactory economic means of disposing of solid municipal wastes (excluding the large volume of wastes produced by mines, smelters, and other large industries) is the sanitary landfill. Unfortunately, in Texas there are still more open dumps than sanitary landfills.

What makes the landfill "sanitary" is the practice of compacting and covering each day's accumulation of waste with a compacted layer of earth so that gases and fluids produced by chemical and biological action are restrained from escaping into the atmosphere or surface water and ground-water systems, and so that insects, rodents, and other animals are denied continued access to the wastes. The objective is to contain and isolate the fill; it should not be allowed to drain into surface or ground-water systems.

The pollution potential of a landfill depends on (1) the reactivity of the waste itself as measured in content of organic matter, soluble inorganic constituents, easily oxidized substances, etc.; (2) the physical stability of the refuse in terms of volume change (mostly shrinkage) as decomposition advances; (3) the geological and hydrological parameters of the site--the porosity and permeability of the formation in which the fill is located, topography, and whether or not the water table intersects the fill; (4) how efficiently the upper surface of the fill is protected from insects, animals (mainly rodents), and exposure to wind and rain; and (5) climate--chemical reactions are inhibited by low temperatures; in areas with little rainfall leaching of fills is slight.

The surface of the fill must be graded to insure good drainage and eliminate depressions that might trap rain. Ponded rainwater serves as a source of water to leach the fill. Subsidence within landfills is common so that an original well-graded surface may be converted to one containing small water-filled sinkholes. Periodic inspection is necessary for many years after a sanitary landfill has been properly closed and abandoned to determine if regrading is required.

The most permeable earth materials are sand, gravel, jointed and fissured rocks such as limestone and dolomite, and some vesicular lavas; least permeable are unjointed clays and shales. Wastes from incinerators where much of the original refuse has been gasified are less subject to biological action than wastes which have not been so processed, but they may contain substantial amounts of soluble constituents. Where there is an original separation of food wastes (garbage) from non-food wastes (trash or refuse) the resulting non-food accumulation is more stable than a mixture of the two. Where the landfill is located well above the water table in a relatively impermeable formation, fluids produced by leaching of the fill by rainfall do not percolate downward into the ground-water system. Where daily accumulations are compacted and protected by a well-compacted earth layer the amount of rain percolating downward is reduced and the volume of leachate is reduced. A well-compacted cover also cuts down on production of gases by oxidation and decomposition of organic matter. However, compaction alone will not protect the fill from rain if the covering material used is permeable. A compacted clayey layer is much less permeable than a compacted sandy layer. A flat-surfaced fill in England was covered by 18 inches of soil and compacted by a vibrating roller to a depth of 5 feet. Nevertheless, some 10 inches of rainfall out of a total of 25 inches penetrated the fill and produced a leachate (Hughes, 1967, p. 7). If the fill cover is impermeable, gas produced in the fill will be forced to move laterally into the surrounding formations instead of escaping into the air.

Hughes (1967) summed up investigations of the production and movement of pollutants from landfills that have been made in Great Britain, New York, California, and Illinois and presented a useful bibliography. Studies have been made of contaminants produced in ash dumps, leachates from domestic garbage landfills, the effects of refuse fills on ground water, the composition and shrinkage of refuse, the gases produced in landfills, comparisons of saturated and unsaturated fills, and the efficiency of filtering of leachates passing through natural formations and engineered gravel systems. The following discussion is condensed from Hughes (1967).

Decomposition of fills begins in contact with air and processes are aerobic; after burial anaerobic processes predominate. Rainwater or ground water moving through the fill dissolves the soluble components including CO_2 produced by decomposition. The weak acid thus produced increases the solvent power of the solution. Principal gases produced are CO_2 and methane. Gas production is at a maximum early in the deposition of the fill and decreases as the fill ages. Table 1 presents the composition of some leachates. Natural purification occurs by filtering of contaminants in sand and gravel formations and by ion exchange in clay formations. If contaminating leachates do reach the ground-water system, they may remain undetected for years because of the generally slow movement of ground water. Thus, a large reservoir of contaminated water may build up before corrective action can be initiated. Putrescent organic material that escapes from improperly designed fills is commonly a noxious brown sludge that may contain bacteria and viruses. The writers have observed such foul-smelling emissions entering streams 4 to 5 years after a fill was abandoned.

Figures 1-4 are diagrammatic illustrations of sanitary landfills in several common geologic environments; they attempt to show the effects of seasonal variations in the position of the water table. In figure 1 the fill is in a permeable formation but generally above the water table; contaminants move into the stream during periods of heavy rainfall when high

Table 1. Percentages of Materials Leached from Refuse and Ash--
based on weight of refuse as received
(from Hughes, 1967, p. 6, Table I)

	Percent leached					
Materials leached	1*	2*	3*	4*	5*	6*
Permanganate value						
30 min.	0.039					
4 hr.	0.060	0.037				
Chloride	0.105	0.127		0.11	0.087	
Ammoniacal nitrogen	0.055	0.037		0.036		
Biologic oxygen demand	0.515	0.249		1.27		
Organic carbon	0.285	0.163				
Sulfate	0.130	0.084 (as SO_4)		0.011	0.22	0.30
Sulfide	0.011					
Albuminoid nitrogen	0.005					
Alkalinity (as $CaCO_3$)				0.39	0.042	
Calcium				0.08	0.021	2.57
Magnesium				0.015	0.014	0.24
Sodium			0.260	0.075	0.078	0.29
Potassium			0.135	0.09	0.049	0.38
Total iron				0.01		
Inorganic phosphate				0.0007		
Nitrate					0.0025	
Organic nitrogen	0.0075	0.0072		0.016		

*Source of data and conditions of leaching:

1. Ministry of Housing and Local Government [Gt. Brit.], 1961, p. 117. Analyses of leachate from domestic refuse deposited in standing water.
2. Ministry of Housing and Local Government [Gt. Brit.], 1961, p. 75. Analyses of leachate from domestic refuse deposited in unsaturated environment and leached only by natural precipitation.
3. Montgomery and Pomeroy, 1949, pp. 4 and 19. Refuse from Long Beach, California. Material leached in laboratory before and after ignition.
4. Engineering-Science, Inc., 1961, p. 39. Estimate based on data reported in "Final Report on the Investigation of Leaching of a Sanitary Landfill" (Sanitary Engineering Research Laboratory, 1954). Domestic refuse in Riverside, California, leached by water in a test bin.
5. Engineering-Science, Inc., 1961, p. 73. Based on data reported in "Investigation of Leaching of Ash Dumps" (Sanitary Engineering Research Laboratory, 1952). Leaching of California incinerator ash in a test bin by water.
6. Engineering-Science, Inc., 1961, p. 73. Based on data reported in "Investigation of Leaching of Ash Dumps" (Sanitary Engineering Research Laboratory, 1952). Leaching of southern California incinerator ash in a test bin by acid.

water tables intersect the fill. In figure 2 the low permeability host prevents contaminants from moving away from the fill, and there is no ground-water contamination from a practical point of view. The fill in figure 3 above the water table in an impermeable host is secure and results in the least contamination. Figure 4 represents an environment common in Trans-Pecos Texas where the principal danger lies in cloudburst destruction of the fill's cover and consequent flushing out of accumulated contaminants.

Generally, a satisfactory site would be above the water table or zone of saturation. The permeability of earth materials should be low enough to retard movement of contaminants, and the contaminants produced either should be unable to reach any ground-water reservoir or should be removed or attenuated to acceptable levels before entering such a reservoir.

Although clays offer the best sites in terms of low permeabilities, effluents or leachates of some kinds can change the physical properties of clays. Work by the Illinois Geological Survey demonstrated that soaps, detergents, water softeners, starches, and fabric softeners changed plasticity and shrink-swell potential (White and Kyriazis, 1968). The over-all result is to affect the stability of the clay. An old landfill placed in clay that is to be used as a building site should be examined to determine whether or not the physical properties of the clays have been significantly affected by leachates from the decomposing clay. If the terrain is characterized by steep slopes, the slide potential of the filled area should be checked periodically to determine if the leachates have reduced slope stability.

The depth to the water table is more important in porous formations, such as sands and jointed limestones where ground water moves relatively rapidly, than in tight, impermeable clays. In the first case the fill should be well above the water table and the base of the fill should be separated from the aquifer or permeable zone by at least 50 feet of impermeable material. In a clay formation--even if the fill intersects the saturated zone--ground-water movement is slow and the clay acts to filter or fix the pollutants through ion exchange. If a site in impermeable materials cannot be secured within an economically attractive range of the waste-producing center, then special engineering to protect the site is necessary. Impermeable clay layers can be used to line the fill site and to cover it. Subsurface barriers to movement of leachates can be constructed, and where gases and leachates are thus impounded they can be diverted to a collection point and treated (Landon, 1969). If favorable sites are rare, it is possible to reuse proven sites by excavating old stabilized non-reactive wastes and using them as fills in more sensitive environment. Of course, this increases handling costs. Decomposition and stabilization proceed most rapidly where moisture content is high and temperatures are warm. In any case, geologic and hydrologic investigation of the site is necessary for protection of the public.

FIGURES 1 - 4

Surface waste disposal and ground-water contamination

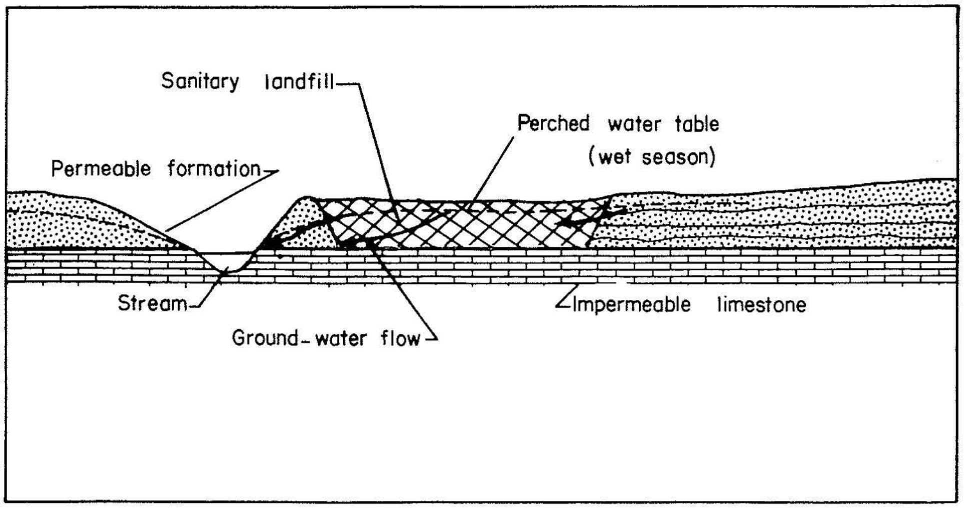

Figure 1. Perched water table, near stream. (Example: landfill in Burditt Formation, near Austin, Travis County.) Permeable sites near streams should be avoided unless special measures are taken to protect the surface water. Ground water is dynamic--always moving; the hydrologic situation at any given site is subject to seasonal and long-term variations.

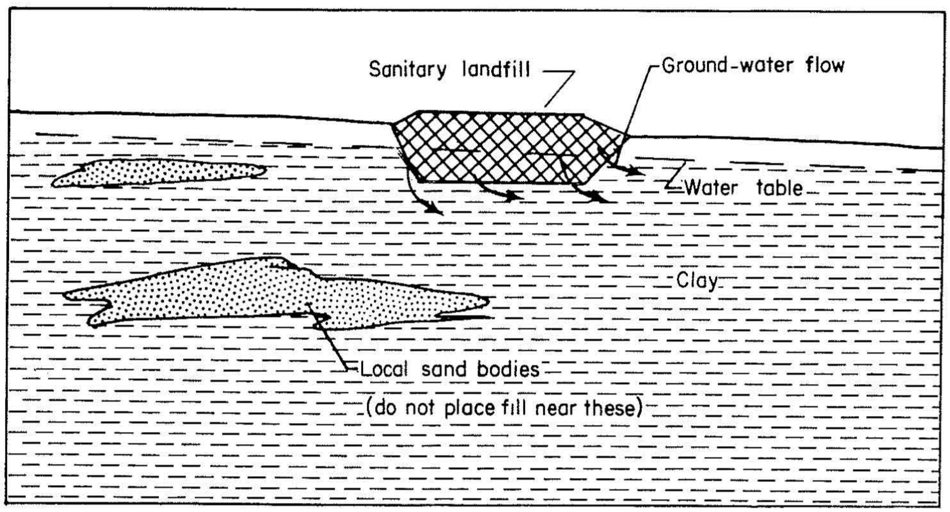

Figure 2. Low permeability host, high water table. (Example: clay in Beaumont Formation, Gulf Coast.) Fill placed below water table causes local contamination, but extremely slow movement of the ground water precludes widespread distribution of the contaminants. Typical ground-water flow rates through clayey sediments under small hydraulic gradients are 0.1 to 0.5 foot per year. Thus, in fifty years, the leachate would move only 5 to 25 feet from the fill. On-site investigation is required to locate and avoid sand bodies. Major risk of this type of fill is contamination of surface water. While active, the fill should be isolated from surface water, and before abandonment, it should be re-compacted and covered with several feet of impermeable material.

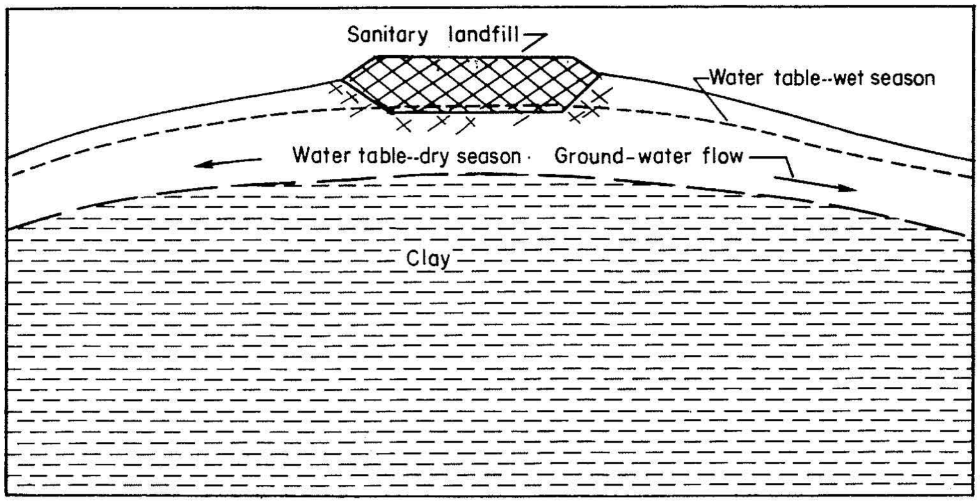

Figure 3. Low permeability host, moderate climate. (Example: clay in Taylor Formation, near Austin, Travis County.) Fill placed on a topographic rise (preferably on a broad, relatively flat area) is secure. In wet season, if water table intersects the landfill, contamination of a small area around the landfill occurs, but the low permeability of the host prevents extensive movement of the contaminants. Typical rates of ground-water movement away from the fill would be less than 1 foot per year.

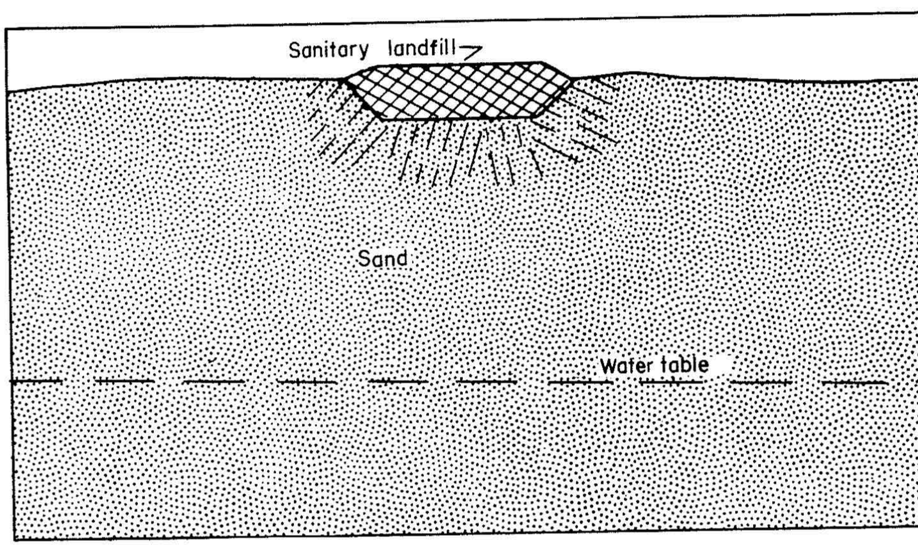

Figure 4. Dry area, fill well above water table. (Example: bolsons of West Texas.) This type of fill is secure during dry years, but a single heavy rain may flush contaminants to the water table, particularly if the host rock and cover are permeable. Security is improved considerably by lining the pit before filling, and mounding the compacted, impermeable cover of the fill before abandoning it.

TEXAS SOLID WASTES DISPOSAL ACT OF 1969

Of considerable interest to the cities of Texas is an act passed by the Legislature in 1969 that authorized the Texas State Department of Health to develop a State Municipal Solid Waste Plan and the Texas Water Development Board to develop a State Industrial Solid Waste Plan. These agencies are further authorized to promulgate rules and regulations for solid waste disposal and to establish minimum standards for performance. Open burning is already controlled under regulations of the Texas Air Control Board issued as a result of the 1967 Clear Air Act of Texas. Current landfill practices in Texas metropolitan areas have been described by Gazda and Malina (1969).

Many Texas cities will have to improve their current procedures to meet the minimum standards that will be prescribed. A logical first step for every community is a geological evaluation of landfill sites within economic haulage distance. It will be to the advantage of every community to locate geologically secure sites for sanitary landfills and acquire them now. For some communities sites with acceptable geologic parameters are scarce, and the city government should not let these sites fall to other uses through lack of planning.

Geologic maps showing the locations of various kinds of strata around Texas cities are available from the Bureau of Economic Geology of The University of Texas at Austin. A list of publications of the Bureau is available on request.

GEOLOGICAL FORMATIONS SUITABLE FOR SANITARY LANDFILLS NEAR MAJOR TEXAS CITIES

Geological formations suitable for sanitary landfills must be relatively impermeable so that the fill and its decomposition products will be contained effectively and isolated within the hydrologic environment. The following section describes such formations that occur within 25 miles of the major cities of Texas (fig. 5). Before a landfill site is chosen, however, the character of each formation must be confirmed by on-site investigations. Local variables that affect site selection include (1) topography,

Figure 5. Texas metropolitan areas.

(2) depth of soil cover, and (3) anomalous geologic features that might affect permeability, such as fracture zones, solution-collapse features, and caliche development. Fills should not be placed in swales, draws, gullies, valleys, or arroyos, unless precautions are taken to contain the produced leachate. Broad upland flats or divides away from major or tributary drainages are preferred. If the only area available is highly dissected, the heads of draws or gullies are preferable over the downstream reaches. If draws or gullies are utilized, surface drainage should be routed to prevent contamination of surface runoff by leachate from the fill. Rainwater should not be allowed to accumulate in the gully and percolate through the fill into the lower reaches of the surface drainage system. Fills should be placed below the soil zone except in special cases where deep, impermeable clay soils are developed in topographically desirable locations.

Filling abandoned sand and gravel pits or limestone quarries is in general poor practice and should be discouraged even though it is economically tempting to use existing excavations. Such sites generally contain permeable materials which permit leachates to move rapidly and for long distances. If no other site is available, however, a leaky site may be made useable by placing an impermeable liner in the pit.

Cities of the Black Prairie--Austin, Dallas, San Antonio, Waco.--Texas cities on or near the belt of Cretaceous clays and shales along the inner margin of the Gulf Coastal Plain are fortunate to have good sites for landfills. The Eagle Ford, Taylor, and Navarro Formations are composed of impermeable clays which are secure hosts for wastes. Properly designed fills located away from surface drainages will be contained effectively.

Average depth of the static water table is difficult to measure in the clay formations because the water level equilibrates slowly. Throughout the clay belt the formations appear to be saturated, commonly by capillary flow, except near the surface where they release water to the atmosphere, shrink, and develop deep cracks. Water movement is slow even in the saturated clays, and contaminants commonly are filtered or fixed close to the fill site by ion exchange. The primary concern in clay terrane is to prevent surface runoff from traversing the fill and then entering the surface drainage system.

Cities of the coastal margin--Beaumont, Brownsville, Corpus Christi, Galveston, Harlingen, Houston, Port Arthur, Texas City.--The Texas Coastal Plain is composed of clays, silts, and sands, and the water table is shallow. Fills should not be placed in these permeable sediments. The most desirable host for landfills along the Texas coast is the Beaumont Formation, which is mostly clay but also contains sands deposited in old channels. On-site geological investigations are necessary to avoid sand zones within the Beaumont Formation. Topographically the Beaumont outcrop is a nearly flat plain. Elevations range from sea level at the coast to 70 feet on the inner edge of the outcrop. Although the water table in the Beaumont Formation is generally within 10 feet of the surface, water movement in the clay is extremely slow so that escape of contaminants into the aquifer is unlikely. Around major cities where Beaumont aquifers have been pumped, the water table is as much as 100 feet below the surface. Uncontrolled movement of contaminants would be at a minimum in these areas.

Without special engineering protection (coffer dams, impervious linings), the practice of using municipal wastes to fill swamps and bays may pollute bay waters. Even separating the so-called inert wastes for use as fill may result in high concentrations of metal ions which could have long-term ecological effects.

Cities of the High Plains--Amarillo, Lubbock.--The High Plains are generally flat and featureless except for the Canadian River valley and other drainages. The water table in the Ogallala Formation ranges from 60 feet to 300 feet below the surface. Ground water flows slowly southward and eastward through the Ogallala aquifer and feeds springs in the High Plains escarpment. The Canadian River and small creeks control the surface drainage.

Most of the High Plains is covered with windblown sand and is dotted with shallow playas which have thin clay bottoms. The playas intermittently contain standing water. When the depressions are full, water escapes by lateral seepage into the more permeable cover sands. Therefore, the playas are not satisfactory sites for landfills. In the Amarillo area the Permian Quartermaster and Cloud Chief Formations contain shale and clay. These formations crop out in the Canadian River valley and along West Amarillo Creek, about 10 miles northwest of Amarillo. These rocks would be favorable hosts for landfills in relatively flat areas or on benches that can be excavated. Shale lenses of the Triassic Tecovas Formation crop out along Tecovas Creek, about 20 miles northwest of Amarillo. The 30- to 40-foot thick Tecovas shale overlying the Permian rocks would provide secure sites, as would the Tecovas along West Amarillo Creek. The Triassic Dockum shales in the Lubbock area are good hosts for wastes. The Tahoka clay at Tahoka Lake offers interesting possibilities, but it would have to be investigated thoroughly to find sites free from leakage.

Abilene.--Abilene, as well as the rest of Taylor County, lies on the red beds of the Permian Clear Fork Group. The red clays, mudstones, and shales of this group form a gently rolling to nearly level surface sloping north and south from a central plateau which in turn is underlain by remnants of Cretaceous Edwards limestone. The plateau rises 200 to 300 feet above the surrounding countryside and is bounded by steep rocky bluffs. The general surface of the plateau is level to gently rolling. Small streams provide good drainage for the county; the southern one-third drains to the south while the northern two-thirds drains mainly to the north. Most of the county uses surface water, although some ground water is drawn from the Clear Fork Group and Recent stream deposits. The water table is generally less than 100 feet below the surface.

The basal part of the Clear Fork is an excellent host for sanitary landfills. One to 5 feet of alluvial sand and gravel overburden covers most of the county. This is easily removed to uncover the Permian rocks. In the past Abilene operated a fill in the red mudstone of the Kirby Lake member of the Clear Fork. This fill, in the northeast corner of the county, is northeast of Abilene. Formations that should be avoided are the Quaternary Seymour sands, which are up to 60 feet thick; limestone gravels, up to 30 feet thick; and the residual Cretaceous soil, 5 to 10 feet thick, which flanks the outcrops and occurs in small outliers. All these units are relatively permeable.

Edinburg-McAllen-Pharr.--These neighboring cities in Hidalgo County are on a broad deltaic plain whose southern boundary is in the Rio Grande. The climate is semiarid to semitropical. Sand dunes occur in northern Hidalgo County while broad, shallow, undrained depressions are the principal surface features elsewhere in the county. The western part of the area is cut by small intermittent streams which are the easternmost tributaries of the Rio Grande. A low ridge in the southeastern part of the county, known as Mission Ridge, extends eastward from Mission to Donna. West of Mission it merges with the plain, and east of Donna it slopes down to the level of the Rio Grande Valley. Mission Ridge is bordered on the south by the Rio Grande and on the north by a broad valley which separates it from the upland plain. The small streams in western Hidalgo County provide some drainage, but Mission Ridge prevents drainage from the upland plain to the Rio Grande. Arroyo Colorado heads south of Mission Ridge, then flows northeastward, draining the eastern part of the county into Laguna Madre. Much of the rainfall flows into shallow depressions where it evaporates or seeps into the ground. Most of the water supply comes from the Rio Grande, although some is pumped from the Quaternary Beaumont clay and Lissie Formation and the Tertiary Goliad sand, as well as from Recent alluvial deposits. The water table around Edinburg, McAllen, and Pharr is near surface. Much of the area is poorly drained. Manmade drainage canals and irrigation systems are widespread.

Most of the rock exposures in Hidalgo County are obscured by Recent eolian sands and alluvium. The Beaumont Formation in this area is mostly sand and gravel. The Rio Grande flood plain in the Edinburg-McAllen-Pharr area is mostly sand. The presence of these permeable materials coupled with the high water table presents a major problem in locating a suitable and secure sanitary landfill host for the Edinburg, McAllen, and Pharr area. The shallow depressions, if they are bottomed with impermeable materials, may provide sanitary landfill sites, but lateral seepage of water into the permeable sediments may limit or preclude their use without expensive durable linings. Detailed geologic investigation is an essential prerequisite to the selection of sanitary landfill sites in this area.

El Paso.--El Paso is at the south end of the Franklin Mountains, part of a series of isolated, rugged desert ranges separated by wide valleys called bolsons. The Rio Grande drains excess runoff from the area, but most of the rainfall evaporates. Vegetation consists of sparse, thorny, desert shrubs and several varieties of cactus. Depth to the water table ranges from 5 feet along the Rio Grande to 450 feet in the bolson near the city. Ground-water movement is to the south. Sediments of the bolson comprise the primary aquifer. In some places a layer of caliche caps the bolson deposits and retards downward movement of water. Except for the Rio Grande there are no major drainage channels away from the mountains. Most of the runoff comes from steep mountain canyons, spreads out on the flanking alluvial fan, and then percolates downward into the sand and gravels of the bolson. Cloudbursts in the mountains cause flash floods and mudflows in parts of the city on the fan.

Sediments of the bolsons are unconsolidated sands, clays, and gravels. In the Hueco Bolson east of El Paso, the sediments are poorly sorted; individual layers are up to 100 feet thick but are discontinuous laterally. In La Mesa Bolson west of town, the lower part of the sequence is well-sorted, thickly bedded, moderately uniform sand overlain by alternating layers of sand and clay.

Quaternary sand and gravel veneers the caliche cap rock of the bolson deposits near El Paso. Removal of this cover yields suitable sites for landfills in the clays. Many such sites are available in the Hueco Bolson. A thick clay of the Santa Fe Group, at the base of the gravel fans southeast of the Franklin Mountains, presents possible sites for landfills. Detailed geologic investigations are essential for locating sites in the bolson sediments.

Fort Worth.--Fort Worth lies on Cretaceous limestone and marl, which provide a level to rolling, well-drained surface. The surface slopes gently eastward with a maximum relief of 600 feet in Tarrant County. The West Fork and the Clear Fork of the Trinity River drain the western half of the county, while smaller tributaries drain the rest. Depth to the water table ranges from 2 feet in the alluvium north of the West Fork near Haltom City (measured November 1953) to 683 feet in northern Fort Worth near Marine Creek (measured November 1954) (Leggat, 1957, pp. 105, 107). Water-yielding formations are the Cretaceous Travis Peak, Glen Rose, Paluxy, and Woodbine Formations, and Pleistocene and Recent alluvial deposits.

Tarrant County is divided topographically into four distinct north-trending belts. The northwestern quarter of the county, the Western Cross Timbers, is underlain by Walnut clay and Paluxy sand. The area is dissected into steep hills and deep ravines containing many waterfalls. Within this geographic area there are no good sites for sanitary landfills, because the Paluxy soils are too sandy.

The Grand Prairie covers the western two-thirds of the county except for the part encompassed by the Western Cross Timbers. This area is underlain by alternating limestones and marls which produce steplike terraced topography and black loamy soil. The Grayson Marl underlies the eastern margin of this belt, offering clays and mudstones as potential hosts for landfills. Fills within the limestones would be more expensive to excavate and develop than fills in the clays or mudstones.

The Eastern Cross Timbers area coincides with the outcrop of the Woodbine Formation. This belt is well dissected by streams and is characterized by wooded knobs formed by outliers of the basal Woodbine. There are no good landfill sites within this region.

The southeastern corner of the county, underlain by the Eagle Ford shale, is part of the Black Prairie. The poorly drained surface slopes gently eastward. Numerous good landfill sites occur in the Eagle Ford shale (see p. 10).

Laredo.--Laredo is in Webb County on the inner margin of the Gulf Coastal Plain. Principal topographic elements of the area are: (1) the Breaks of the Rio Grande--a rough strip of land dissected by the Rio Grande and its tributaries; (2) the Dentonio Plain--a flat upland between the Rio Grande and the Nueces River, more or less dissected toward the south and east; (3) the Nueces River basin--a flat-bottomed depression occupied by broad shallow valleys; (4) the Aguilares Plain--in the eastern part of the county a rolling surface, underlain by clay and shale consisting of wide valleys and narrow divides; and (5) the Bordas Escarpment--a west-facing cuesta capped by the resistant Goliad sandstone in the southeastern part of the county.

The Rio Grande and tributaries of the Nueces River are the principal drainages in the county. The climate is semiarid; vegetation consists of low trees (mostly mesquite), thorny brush, and cactus. Laredo obtains most of its water from surface supplies. Principal aquifers are the Carrizo sand, Cook Mountain Formation, Catahoula tuff, and Goliad sand. Water levels in wells range from a few feet to more than 200 feet below the surface. In some wells the potentiometric surface is as much as 10 feet above ground level.

Rocks exposed in Webb County are of Tertiary and Quaternary age. The thin permeable Quaternary gravels and alluvium are unsatisfactory sites for landfills. The upper member of the Mount Selman Formation is dominantly clay and would serve as an excellent landfill host where accessible. The upper part of the Cook Mountain Formation contains clay, but the formation is mostly sandstone in the vicinity of Laredo. Geologic investigations of this formation may disclose clay strata sufficiently thick and impermeable to serve as a host. Carbonaceous clays of the Yegua Formation offer potential suitable sites. The Jackson Formation, widely exposed east of Laredo, offers good possibilities because it contains a great deal of clay. The Frio clay would be an excellent host, but the formation probably crops out too far from Laredo to be considered.

Midland-Odessa.--The cities of Midland (Midland County) and Odessa (Ector County) are at the southern end of the High Plains in the semiarid Midland Basin. Midland County is essentially flat and featureless except for shallow playa depressions and sinkholes. The eastern part of Ector County is dominated by rolling hills, whereas the western part is broken by a prominent westward-facing escarpment, Concho Bluff, formed from erosion-resistant caliche, limestone, and sandstone. West of Concho Bluff, the remainder of the county is an alluvial plain dotted with sand hills. Dune topography is characteristic along the southwestern county boundary. Midland Draw and Monahans Draw, which drain to the southeast, carry water only after heavy rainfall. Heavy rain runs off to collect in the numerous depressions to form ponds; normal precipitation is absorbed by the loose surface materials. Shallow draws in western Ector County drain to the southwest. Depth to the water level in wells in Ector County ranges from 12.9 feet 5 miles southeast of Odessa (measured April 8, 1937) to 205.9 feet 15-1/2 miles southwest of Odessa (measured September 27, 1948) (Knowles, 1952, pp. 55, 58). In Midland County, the depth to the water level in wells ranges from 13.88 feet in the city of Midland (measured November 23, 1940) to 65.56 feet, also in the city of Midland (measured April 1, 1957) (Rayner, 1959, pp. 15-16). Aquifers in both counties are Triassic sands. Odessa also draws water from sands of the Cretaceous Trinity Group. The Tertiary Ogallala Formation and most members of the Cretaceous Fredericksburg Group are above the water table.

Rocks exposed in the two counties range in age from Cretaceous to Recent. Best sites for sanitary landfills in the Midland area are the deeper shales of the Triassic Dockum Formation. The overlying Ogallala Formation is relatively thin around Midland (20 to 30 feet), so it can be stripped to expose the Dockum shale where Cretaceous rocks are not present. Limestones of the Cretaceous Fredericksburg Group present potentially secure sites around Odessa. Sands and sandstones should be avoided in both areas. The playa depressions probably are not secure sites for landfills because the collected water may seep laterally into the permeable cover sands and into the Ogallala Formation (see p. 11). On-site geologic investigation is necessary to avoid these hazards.

San Angelo.--San Angelo lies on Permian "red beds" and the Pleistocene Leona Formation. Topographic relief within Tom Green County is about 900 feet. The northern, western, and southern parts of the county are marked by hilly remnants of the Edwards Plateau. East of San Angelo the surface becomes a plain, with river-valley flats along the Concho River and its main tributaries. The climate is semiarid to subhumid. Drainage is by the Concho River, its main tributaries, the North, Middle, and South Concho Rivers, and all their tributaries, some of which are fed by springs. San Angelo obtains its water supply from Lake Nasworthy.

The Pleistocene Leona Formation is the most important aquifer in the San Angelo area; the Bullwagon dolomite member of the Permian Vale Formation and the Cretaceous Comanche Peak limestone are also important. The depth to the water level ranges from 8.8 feet (measured December 13, 1950, 2-3/4 miles southwest of Knickerbocker) to 275.3 feet (measured May 16, 1950, 10-1/2 miles southwest of Cristoval near the southern county boundary) (Willis, 1954, pp. 76, 79).

Permian rocks are commonly covered by the Quaternary (Pleistocene) Leona Formation, which ranges from a few feet to 125 feet thick, as well as younger Quaternary alluvium. Shales and clays of the Permian Choza Formation, which occur 13-1/2 miles east of San Angelo, are potential sanitary landfill hosts, as are the clays within the San Angelo sandstone south and southwest of San Angelo.

Clays of the Cretaceous Trinity Group crop out on the lower slopes of the hills but in many places are covered with alluvium. These clays are potential landfill hosts if precautionary measures are taken to prevent contamination from runoff and slope wash. The Cretaceous Comanche Peak limestone is a possible host where it is relatively impermeable.

In this area, permeable sands, sandstones, jointed limestones, and other porous rocks occur within formations that also offer potential landfill sites. These changes in formation character over short distances suggest that careful investigation of each site is essential to avoid contamination. Quaternary alluvial deposits should be avoided.

Sherman-Denison.--The neighboring cities of Sherman and Denison are on the inner margin of the Gulf Coastal Plain in Grayson County. Maximum relief in the county is 380 feet. The surface slopes to the southeast. Tributaries of the Red River drain most of the county, although tributaries of the Trinity River drain the southeastern part. Ground water flows to the east and south; the Trinity and Woodbine sands are the principal water-bearing formations. In the northwestern part of Sherman the depth to water is up to 513 feet; 2-1/2 miles northwest of Howe the depth to water is only 0.5 foot (Baker, 1960, pp. 98, 109).

Outcrops of Cretaceous sands, clays, mudstones, and limestones in Grayson County produce four distinct topographic belts. The Western Cross Timbers, a narrow strip along the Red River in the northwestern corner of the county, occupies the Trinity sand and is characterized by sandy soils and rugged topography cut by deep, steep-walled ravines. There are no good landfill sites within this sandy area.

The Grand Prairie is a narrow belt extending the width of the county adjacent to the Red River. This is a rolling upland underlain by limestones, marls, and clays of the Washita and Fredericksburg Groups. Resistant limestones form small escarpments and ledges. Several members of the Washita Group are potential hosts for sanitary landfills, subject to geologic site investigation. These members are the Denton clay, the Weno marl, clays within the Pawpaw sand, and the Grayson marl. These units contain more mud and clay in Grayson County than in Tarrant County.

The Eastern Cross Timbers extends the entire length of the county, coinciding with the outcrop of the Woodbine sand. The area is characterized by gently rolling to rough and hilly topography. Resistant iron-rich sandstone layers cap the hills. The Templeton shale, the uppermost member of the Woodbine Formation, is a potential host for sanitary landfills.

The southeastern three-fourths of the county is on the Black Prairie, coinciding with the outcrop of the Eagle Ford shale and the Austin chalk which produce level to rolling topography and black waxy soils. Excellent landfill sites are available within the Eagle Ford shale (p. 10). The Bonham marl member of the Austin chalk is also a potential host for landfills.

Texarkana.--Texarkana (Bowie County) is on the Gulf Coastal Plain in the northeastern corner of Texas. The climate is subhumid to humid. The northern two-fifths of the county drains to the Red River, the northern boundary of Texas; the remainder is drained by Sulphur River along the southern county boundary. The Tertiary Carrizo sand and Wilcox Formation (undifferentiated) form the primary aquifer. Water levels fluctuate in response to rainfall on the outcrop and to seasonal pumping in the cities. The Quaternary alluvial sands and gravels and the Nacatoch sand of the Cretaceous Navarro Group are secondary aquifers. The Gulfward movement of ground water in the Cretaceous aquifers is locally interrupted in this area by the Luling-Mexia-Talco fault system. Quaternary floodplain deposits and low-level terraces are also significant aquifers. The water table is within 10 to 20 feet of the surface. In the dissected upland terraces, water levels are deeper, as much as 45 feet below the surface. Water from these terraces is used for irrigation.

A broad undulating ridge flanked by flat benches extends east-west across the central part of Bowie County. Flat alluvial belts occur along Sulphur River and Red River and their tributaries. Relief in the county is about 250 feet. Pimple mounds 2 to 5 feet in height are common throughout the county.

Rocks exposed in Bowie County range in age from Upper Cretaceous to Quaternary. Much of the surface is covered with Quaternary terrace deposits. Satisfactory sanitary landfill sites may be found in the Tertiary Midway Group which is mostly clay and is exposed north and west of Texarkana. On-site geologic investigation is necessary to determine specific locations for landfills. Sands of the Wilcox Group and Quaternary terrace deposits should be avoided.

Tyler.--Tyler, the largest city of the interior coastal plain, is in Smith County. Principal drainage basins are those of the Sabine and Neches Rivers, which flow eastward or southward to the Gulf. The Sabine River drains the northern part of the county; the Neches River drains the southern part. The primary aquifers are within the Carrizo and Queen City Formations. Depth to the water table ranges from 10 to 50 feet; in higher areas it may be deeper than 200 feet (Lyle, 1937, pp. 1-36).

Geologic formations in the area consist of alternating sands and clays. Although the sands of the Sparta and Queen City Formations are not secure hosts for landfills, clay and shale units within these formations would be safe wherever they are thick enough. The U. S. Department of Agriculture soil survey of Smith County (Schoenmann et al., 1917) reported that in certain areas of the county compact impermeable substrata occur beneath sandy subsoils. These layers may be suitable hosts for landfills and should be investigated.

The Weches Formation is composed of glauconite and glauconitic clays with clay interbeds. Resistant ridges of the Weches interrupt the gently rolling hills and prairies, providing local relief of up to 400 feet. East of Tyler, beds of resistant ironstone concretions, formed by weathering of the glauconite, are relatively impermeable and are possible landfill sites. Clays of the Reklaw Formation should be good hosts, especially near Troup where the formation is thick.

Wichita Falls.--Wichita Falls lies on the Carboniferous "red beds" of the Osage Plains. These red beds of fine-grained sandstone, mudstone, clay and clay shale, provide Wichita County with smooth, rolling, prairie-like topography and a maximum relief of about 300 feet. Drainage is to the east and southeast. This part of the eastward-sloping Osage Plains is dissected on the north by the broad valley of the Red River and on the south by the Wichita River valley. These rivers and their numerous small tributaries provide good drainage for the county. Most of Wichita County uses surface water rather than ground water. The ground water commonly is highly mineralized, although some potable water is pumped from Quaternary alluvial deposits. The water table is deeper under the hills than under the valleys but is generally less than 100 feet below the surface.

All of the clays, mudstones, and shales that make up the red beds are good hosts for sanitary landfills. Unfortunately, there are few good exposures of these materials because much of the county is covered by alluvial sands and gravels. The clays, mudstones, and shales of the Permian Clear Fork Group offer the best potential for landfill sites, but these strata occur only in the northwestern corner of the county, at least 25 miles from Wichita Falls. The red shales, clays, and mudstones of the Permian Wichita and Pennsylvanian Cisco Groups are also good hosts for landfills. Exposures of these rocks generally occur on the sides of broad valleys between terraces, and in upland areas. In other areas excavation of the surficial deposits, which range up to 10 feet thick and locally to 15 or 20 feet thick, may be necessary to expose suitable rocks. The sandstone of the red beds, the terrace materials, and the sandy surficial materials are not good hosts. Emplacement of fills in these materials likely would lead to contamination of surface waters.

REFERENCES

Baker, B. B., Dillard, J. W., Sonders, V. L., Peckham, R. C. (1963) Reconnaissance investigation of the ground-water resources of the Sabine River Basin, Texas: Texas Water Comm., Bull. 6307, Austin, 57 pp.

Baker, E. T., Jr. (1960) Geology and ground-water resources of Grayson County, Texas: Texas Bd. Water Engrs., Bull. 6013, Austin, 155 pp.

__________, Long, A. T., Jr., Reeves, R. D., and Wood, L. A. (1963) Reconnaissance investigation of the ground-water resources of the Red River, Sulphur River, and Cypress Creek Basins, Texas: Texas Water Comm., Bull. 6306, 127 pp.

Baker, R. C., and Dale, O. C. (1961) Ground-water resources of the lower Rio Grande Valley area, Texas: Texas Bd. Water Engrs., Bull. 6014, Austin, 81 pp.

Bergstrom, R. E. (1968) Disposal of wastes: scientific and administrative considerations: Illinois State Geol. Survey, Environmental Geol. Notes No. 20, 12 pp.

Bullard, F. M. (1931) The geology of Grayson County, Texas: Univ. Texas Bull. 3125, 72 pp.

Carter, W. T., Strike, W. W., Geib, W. V., and Templin, E. H. (1929) Soil survey of Wichita County, Texas: U. S. Dept. Agri., Washington, D. C., 52 pp.

Davis, M. E., and Leggat, E. R. (1965) Reconnaissance investigation of the ground-water resources of the upper Rio Grande basin, Texas: Texas Water Comm., Bull. 6502, 99 pp.

Dumble, E. T. (1919) The geology of East Texas: Univ. Texas Bull. 1869, 388 pp.

Evans, G. L., and Meade, G. E. (1944) Quaternary of the Texas High Plains, <u>in</u> Contributions to Geology, 1944: Univ. Texas Bull. 4401, pp. 485-507.

Gazda, F. P., and Malina, J. F., Jr. (1969) Land disposal of municipal solid wastes in selected standard metropolitan statistical areas in Texas: Univ. Texas, Environmental Health Engineering Research Lab., Pub. EHE-69-13, 114 pp.

Geologic Atlas of Texas (1965-1970) V. E. Barnes, Project Director. Maps (some with text), scale 1:250,000: Abilene, Amarillo, Beaumont, Houston, Palestine, Lubbock, Plainview, Sherman, Texarkana, Tyler, Van Horn--El Paso Sheets.

Gordon, C. H. (1913) Geology and underground water of Wichita region, North-central Texas: U. S. Geol. Survey Water-Supply Paper 317, 88 pp.

Henderson, G. G. (1928) Geology of Tom Green County [Texas]: Univ. Texas Bull. 2807, 116 pp.

Hughes, G. M. (1967) Selection of refuse disposal sites in northeastern Illinois: Illinois State Geol. Survey, Environmental Geol. Notes No. 17, 26 pp.

Knowles, D. B. (1952) Ground-water resources of Ector County, Texas: Texas Bd. Water Engrs., Bull. 5210, 112 pp.

__________, and Kennedy, R. A. (1956) Ground-water resources of the Hueco Bolson, northeast of El Paso, Texas: Texas Bd. Water Engrs., Bull. 5615, 265 pp.

Landon, R. A. (1969) Application of hydrogeology to the selection of refuse disposal sites: Groundwater, vol. 7, no. 6, pp. 9-13.

Leggat, E. R. (1957) Geology and ground-water resources of Tarrant County, Texas: Texas Bd. Water Engrs., Bull. 5709, 181 pp.

__________ (1962) Development of ground water in the El Paso district, Texas, 1955-60 Progress Report No. 8: Texas Water Comm., Bull. 6204, 56 pp.

Lonsdale, J. T., and Day, J. R. (1937) Geology and ground-water resources of Webb County, Texas: U. S. Geol. Survey Water-Supply Paper 778, 104 pp.

Lyle, W. M. (1937) Records of wells, driller's logs, water analyses, and map showing location of wells in Smith County, Texas: Texas Bd. Water Engrs., Pub. M267, 67 pp.

Rayner, F. A. (1939) Records of water-level measurements in Crane and Midland counties, Texas, 1937-1957: Texas Bd. Water Engrs., Bull. 5906, 19 pp.

Schoenmann, L. R., Smies, E. H., Rockie, W. A., Maxan, E. T., Hutton, F. Z., and Lewis, H. G. (1917) Soil survey of Smith County, Texas: U. S. Dept. Agri., Washington, D. C., 51 pp.

__________, Watkins, W. I., Carpenter, E. J., Carter, W. T., Beck, M. W., and Benton, T. H. (1921) Soil survey of Bowie County, Texas: U. S. Dept. Agri., Washington, D. C., 62 pp.

Smith, W. G., Kocher, D. E., Rogers, R. F., and Watkins, W. I. (1918) Soil survey of Taylor County, Texas: U. S. Dept. Agri., Washington, D. C., 40 pp.

White, W. A., and Kyriazis, M. K. (1968) Effects of waste effluents on the plasticity of earth materials: Illinois State Geol. Survey, Environmental Geol. Notes No. 23, 23 pp.

Willis, G. W. (1954) Ground-water resources of Tom Green County, Texas: Texas Bd. Water Engrs., Bull. 5411, 100 pp.

Winton, W. M., and Adkins, W. S. (1920) The geology of Tarrant County [Texas]: Univ. Texas Bull. 1931, 122 pp.