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Closure of unlined landfills

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CLOSURE OF UNLINED LANDFILLS

BY

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RESEARCH REPORT

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INTRODUCTION

Closure of unlined, uncontrolled solid waste disposal sites poses quite a challenge to the design engineer in addition to representing significant costs to the site owner. Often, groundwater contamination has already occurred and must be addressed as part of the closure plan. Alternative remedial measures may be taken depending on the environmental impact of the waste disposal site. Each site is unique and possesses specific characteristics which must be taken into consideration. A remedial measure which may be feasible for one site may be totally impractical for another.

The objective of this report is to identify cost-effective, environmentally acceptable methods for closure of unlined, uncontrolled solid waste disposal sites. A case study is made on a landfill which was placed on the U.S. Environmental Protection Agency's (EPA) National Priority List (NPL) of potential uncontrolled hazardous waste sites. The site history, characteristics and site specific data are presented and used to evaluate the environmental impact of various closure alternatives. Closure alternatives presented include various technologies such as stabilization, natural attenuation, leachate plume management, and surface water control. Closure technologies are evaluated based on their ability to meet established closure objectives such as environmental impact and ease of implementation.

Background

The Northwest 58th Street landfill (Landfill) is a one-square-mile site located in Dade County, Florida about five miles northwest of the Miami International Airport. Figure 1 shows the Landfill site location. The Landfill is owned by Metropolitan Dade County (County) and was the County's main disposal facility for more than thirty years. Operations at the Landfill began in 1952, with wastes placed at or below the groundwater table in shallow trenches. Until it was banned in 1960, open burning for volume reduction was practiced. Daily cover of waste material was not practiced until 1975 and fires frequently occurred in the uncovered refuse.

In 1975, daily cover was applied to the waste in response to new State of Florida regulations. By this time, approximately 70 percent of the site had been filled with solid waste, and there was little onsite soil available for cover material. Therefore, cover material had to be imported from outside sources. Materials have included: 1) calcium carbonate sludge from water treatment plants; 2) crushed limestone; and 3) spoil materials such as muck,

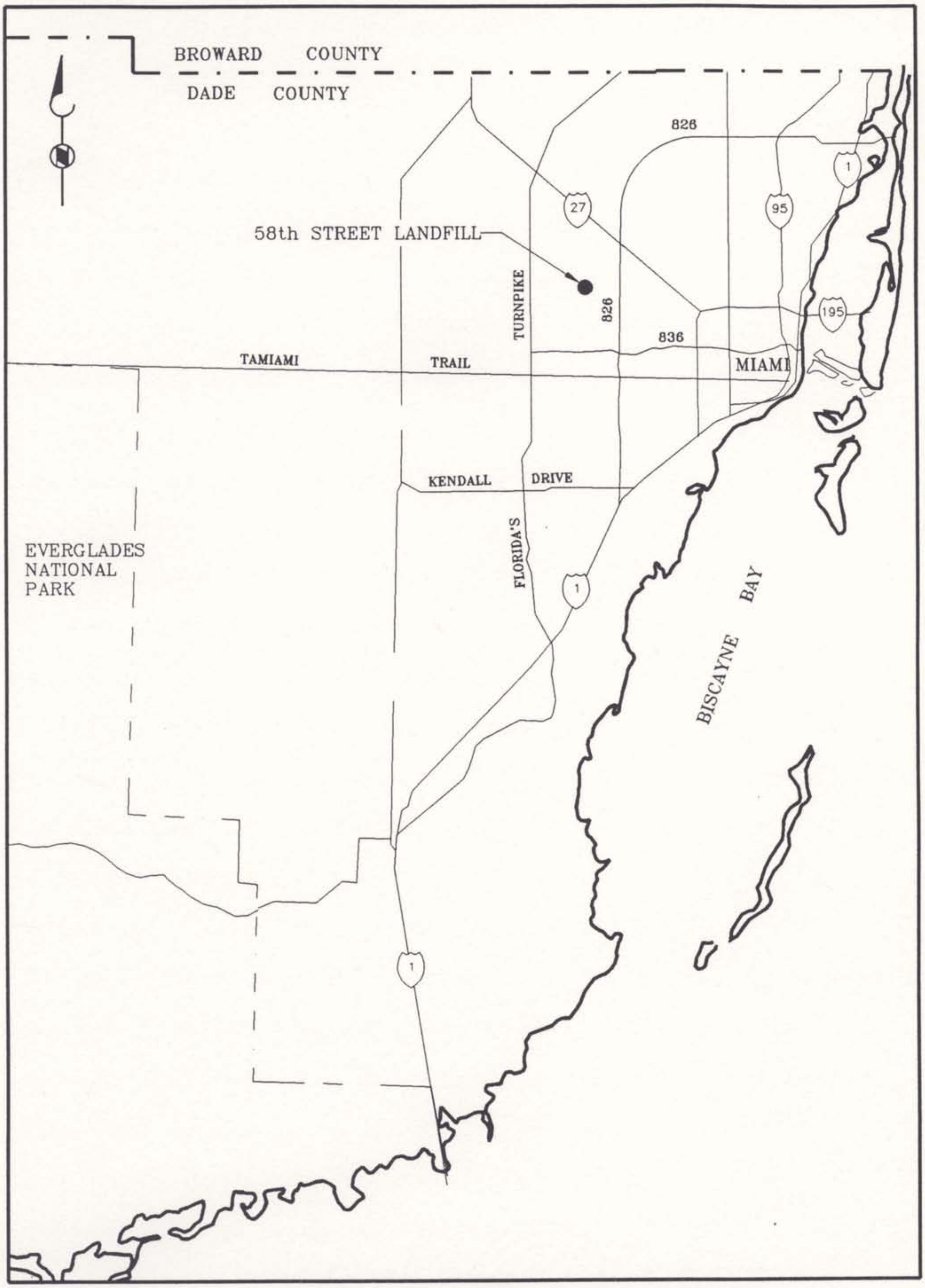


Figure 1. Landfill Site Location Map

limestone, and sand from construction sites (Brown and Caldwell March, 1986).

The type of waste at the Landfill can be described as municipal solid waste. The Landfill also accepted liquid waste from restaurant grease traps, septic tanks, and wastewater treatment plants; these wastes were disposed of with the other wastes. The Landfill was never operated or permitted as a hazardous waste facility, nor is there any evidence to suggest that hazardous materials were ever knowingly accepted.

In 1981, the EPA placed the Landfill on the NPL because of widespread low to moderate groundwater contamination in the Landfill area. Two public potable water supply wellfields downgradient of the Landfill were of particular concern. The Landfill stopped accepting wastes for disposal in October, 1982; however, a final closure plan has never been implemented. Because of the magnitude of the site and it's unique geologic setting, development of a cost-effective closure plan is a difficult task.

Data from this site are used in this report to evaluate various landfill closure alternatives. Site characteristics, such as topography, geology and leachate data, are presented in the following section. The Landfill's impact on water quality is quantified in terms of contaminant mass loading rates and the alternatives are evaluated based on landfill closure objectives.

SITE CHARACTERIZATION

Site specific information must be obtained before a landfill closure plan can be developed. Site data and characteristics should be gathered early in the closure process because conditions that preclude certain closure techniques may be revealed. This phase of the closure process is sometimes appropriately called site characterization. Data requirements include:

Topography
Soil Types
Geology and Hydrogeology
Historical Aerial Photographs
Vegetation
Climate
Waste Characteristics

Because the Landfill is on EPA's NPL, numerous investigations have been conducted at the site. In addition, site specific data were obtained in 1987 to verify and supplement the existing data base. The focus of this report will be on these most recent data. Although these data have been used to develop a closure plan in accordance with EPA's specific requirements for the Landfill closure, they will be used here in a more general sense.

Topography

Topographic maps are probably the single most important pieces of information relating to closure projects which involve cover systems. In addition to other pertinent information, the topographic map reveals surface drainage patterns, locates any structures which may be present and makes it possible to define the location of the site in relation to a specific coordinate system. The U.S. Geological Survey (USGS) publishes topographic maps which are usually readily available. These maps are useful as a basic reference; however, a site topographic map with a larger scale will always be necessary for the detailed closure plans.

The land in the vicinity of the site is relatively flat with an approximate elevation of five feet above sea level. The Landfill topography can generally be described by two distinct mounds. The larger of the two mounds is located on the eastern edge of the site, occupies approximately 90 acres, and has a height of about 70 feet. The smaller mound consists of a 61-acre area with depths of fill up to fifty feet. A 78-acre triangular-shaped area which has never received solid waste occupies the northern portion of the site. The remainder of the site consists of large areas where nonuniform filling took place. Depths of fill on the western portion of the site vary from 15 to 30 feet. The southern third of the site is relatively flatter than the other areas and has waste depths of 5 to 10 feet. Landfill topography is shown on Figure 2.

Soil Types

General information pertaining to local soils may be obtained from the U.S. Department of Agriculture (USDA). These surveys are typically performed on a countywide basis for agricultural purposes. Soil borings from onsite or nearby locations may also be available and will provide more detailed site specific information.

The existing soil cover will directly affect the quantity of leachate generated within the landfill. If the soil type can be classified in a system, such as Unified Soil Classification System (USCS) or USDA, it may be possible to estimate the permeability of the soil. If not, field testing may be required in order to obtain information necessary to perform water balance calculations. Such a field investigation was conducted at the Landfill.

The results of field investigations showed that soils within the Landfill vicinity are composed mainly of poorly drained fine sand, marl, and peat which cover an eroded limestone surface and range in thickness from 2 to 24 inches (CDM 1982). In its natural state, the Landfill was covered by a peat layer 6 to 18 inches thick.

As previously noted, the daily and intermediate cover

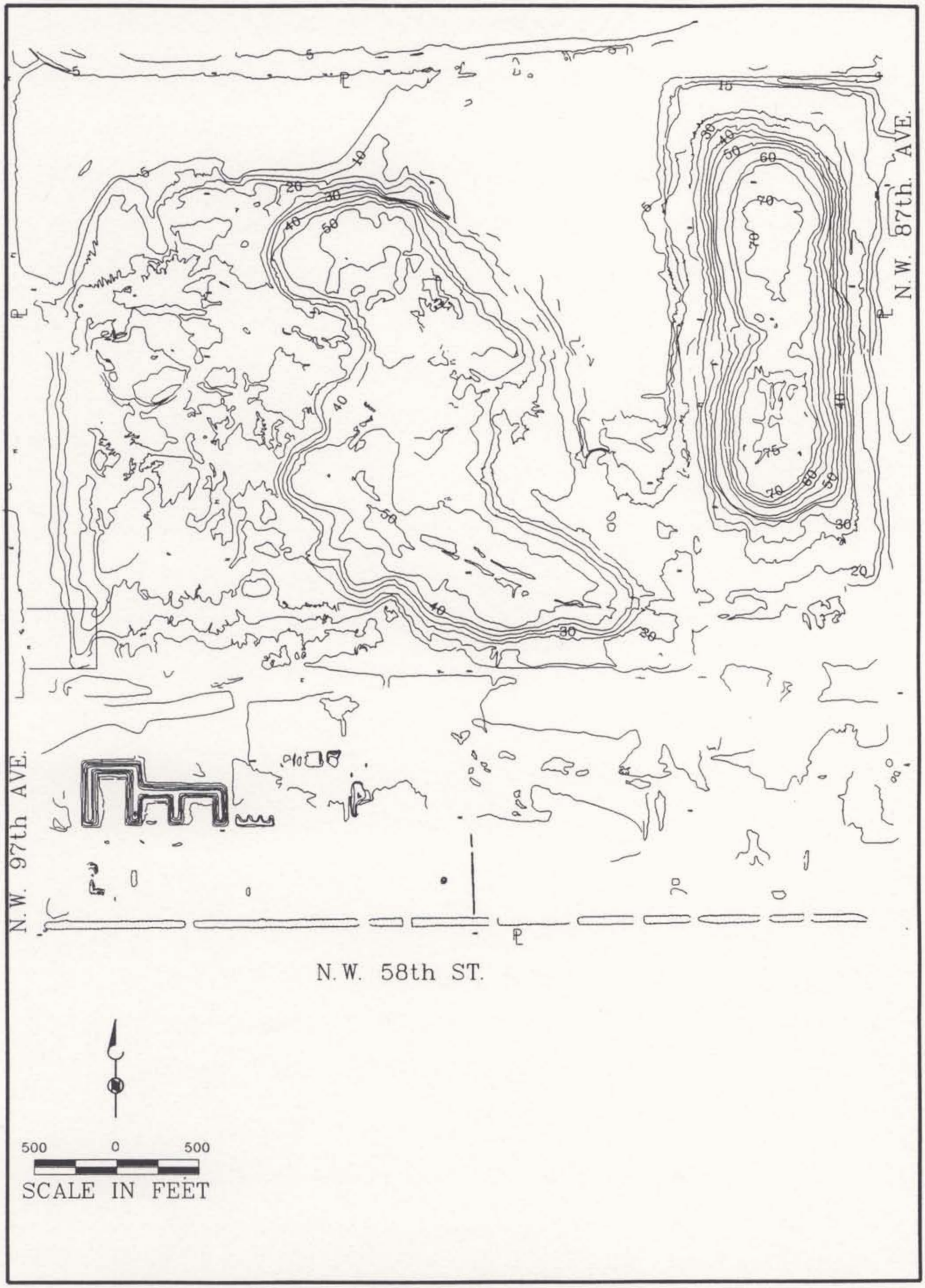


Figure 2. Landfill Topography

materials at the Landfill generally consist of calcium carbonate sludge, limerock and silty sands. The majority of the site is covered with calcium carbonate and limerock mixtures (Law Engineering October, 1987). Test pit excavations revealed that cover material thickness at the Landfill range from a few inches to four feet.

Geology and Hydrogeology

Onsite geologic information may be obtained principally from USGS maps and reports. Hydrologic and geohydrologic maps provide valuable data which include: surface drainage, well locations, groundwater quality and levels, and aquifer locations and characteristics.

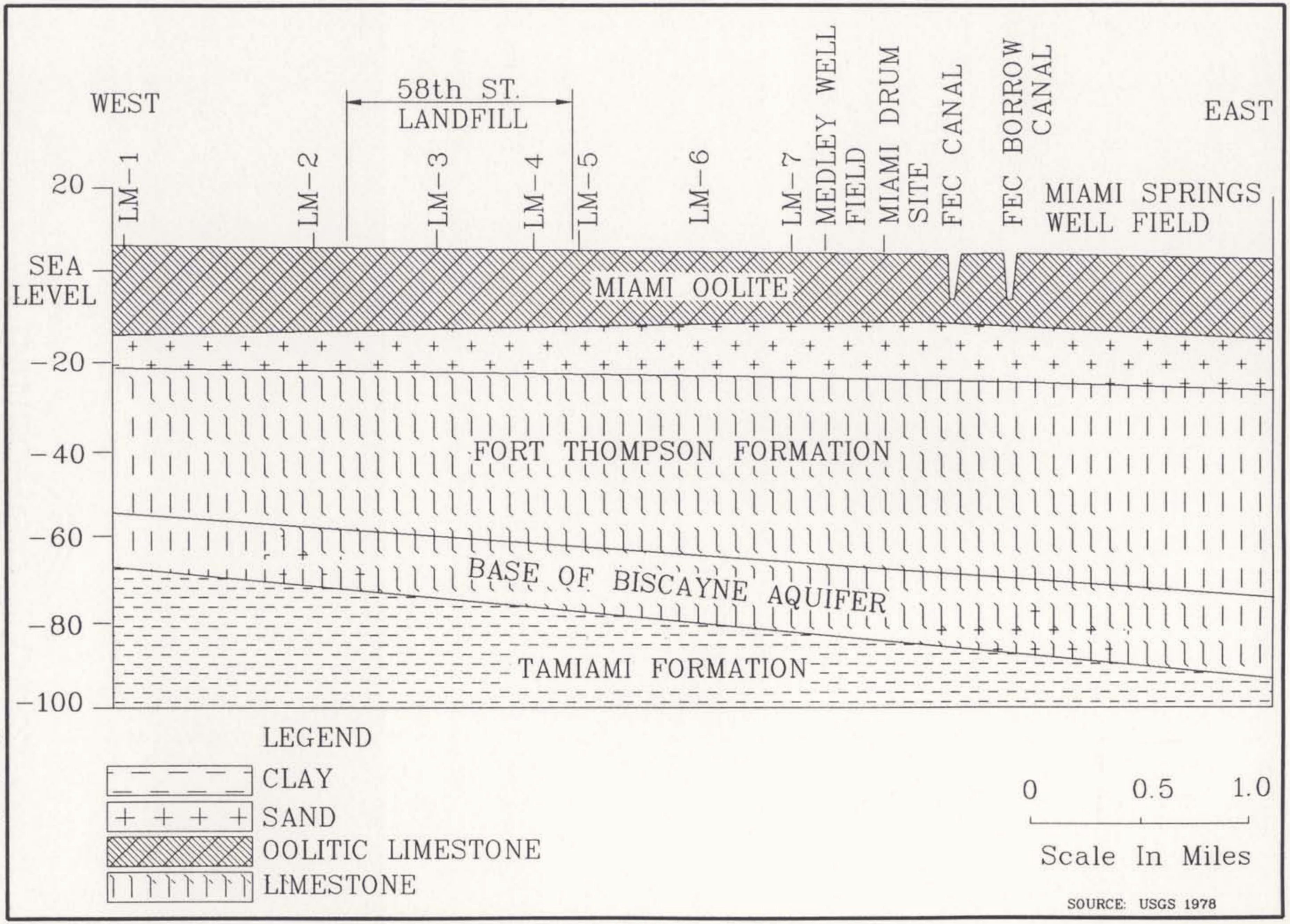
The Biscayne aquifer lies beneath the Landfill and is the sole source of potable water for Dade County. The aquifer is a wedge-shaped, unconfined body of limestone, sandstone and sand. The thickness of the aquifer varies from 80 to 150 feet along Biscayne Bay to less than 10 feet along the western edge of Dade County. Beneath the Landfill the thickness of the Biscayne ranges from 70 to 80 feet. (Brown and Caldwell March, 1986)

The upper part of the aquifer is a soft, sandy, oolitic limestone (referred to as Miami Oolite) 10-15 feet thick, which has a high horizontal and vertical hydraulic conductivity due to the numerous small solution openings in the limestone. The bottom part of this formation is a highly permeable, cavity-riddled limestone composed of bryozoans. Many of the cavities are filled with sand or silt (CDM October, 1982). A layer of fine-to-medium sand ranging in thickness from 7 to 15 feet separates this upper part of the aquifer from the lower part which is known as the Fort Thompson Formation.

The Fort Thompson Formation is composed of alternating thin layers of hard, dense limestone and thick layers of solution riddled limestone whose openings are larger than the bryozoan zone, imparting an overall very high permeability. A layer of nodular sandstone and sand of very high permeability forms the bottom part of the aquifer. Because of high yields, wells of high capacity (ranging from 1,000 to 7,000 gallons per minute) are placed in this portion of the aquifer. Underlying the Biscayne Aquifer is a relatively impermeable layer of fine sand, silt, marl and clay which make up the Tamiami and Hawthorne Formations. These formations reach depths of about 700 feet and act as an aquiclude between the unconfined Biscayne aquifer and the confined artesian Floridan Aquifer. Figure 3 shows a generalized cross-section of the Biscayne Aquifer in the Landfill vicinity.

The Biscayne aquifer is the most productive shallow, non-artesion aquifer in Florida and one of the most permeable in the world with an average transmissivity of about 5 million gallons per day per foot, an average storage

Figure 3. Generalized Geologic Section In The Study Area



SOURCE: USGS 1978

coefficient of about 0.20, and a permeability averaging between 50,000 and 70,000 gallons per day per square foot. Recharge to the Biscayne is primarily by local rainfall during the rainy season. Therefore, groundwater levels are highest during the rainy season and lowest near the end of the dry season. The average groundwater level at the Landfill is 2-feet below land surface or 3-feet above mean sea level (MSL) (USGS 1978). The prevailing groundwater flow in the Landfill area is horizontal and eastward.

Historical Aerial Photographs

Aerial photographs provide useful information which may include: vegetation, land use, cultural features, topography, and land forms. Historical aerials may also provide helpful insight pertaining to past site operations. A review of historical aerial photographs of the Landfill revealed an approximate sequence of the filling operations. The approximate sequence of fill is shown on Figure 4.

Climate

Climatic or meteorological data for a given area plays an important role in the development of site closure plans. The annual amount of precipitation directly affects the potential for leachate generation. The climate at the Landfill site can be generally described as sub-tropical, characterized by hot and humid summers and relatively

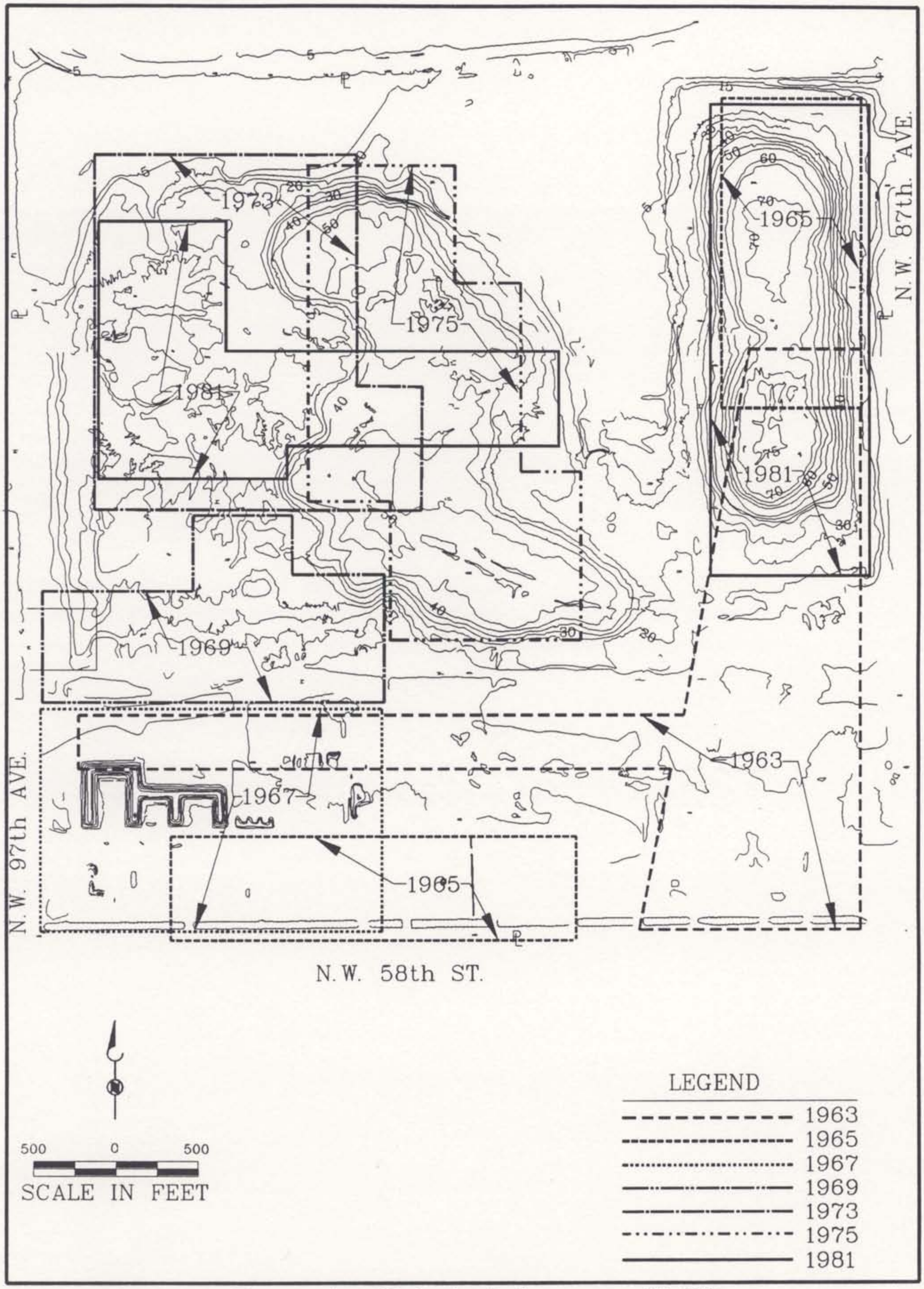


Figure 4. Historical Sequence Of Fill

cooler, dryer winters. Annual average rainfall in the Landfill area is about 60 inches and ranges from less than 40 inches to more than 80 inches (USGS 1978). As much as 80 percent of the total annual rainfall occurs during the rainy season.

Leachate Quality

Leachate data is necessary in order to predict the mass loadings of contaminants to the groundwater due to the unlined landfill. The concentrations of contaminants in the leachate entering the groundwater is directly related to the contamination which can be attributed to the site. The concentration of contaminants in leachate is a function of several factors. These factors include landfill age, waste composition, compaction, temperature, infiltration of rainfall, and moisture content. The concentration of most contaminants from a typical municipal solid waste (MSW) leachate varies with time. Most contaminants reach peak concentrations early in the leaching process and then decline thereafter (Lu, et. al. 1985).

Leachate wells were constructed in seven locations on the Landfill site in order to collect undiluted leachate samples from the Landfill. Also constructed at six of seven locations were shallow groundwater wells. Figure 5 shows typical construction details for each type of well. These wells were located throughout the site so as to obtain

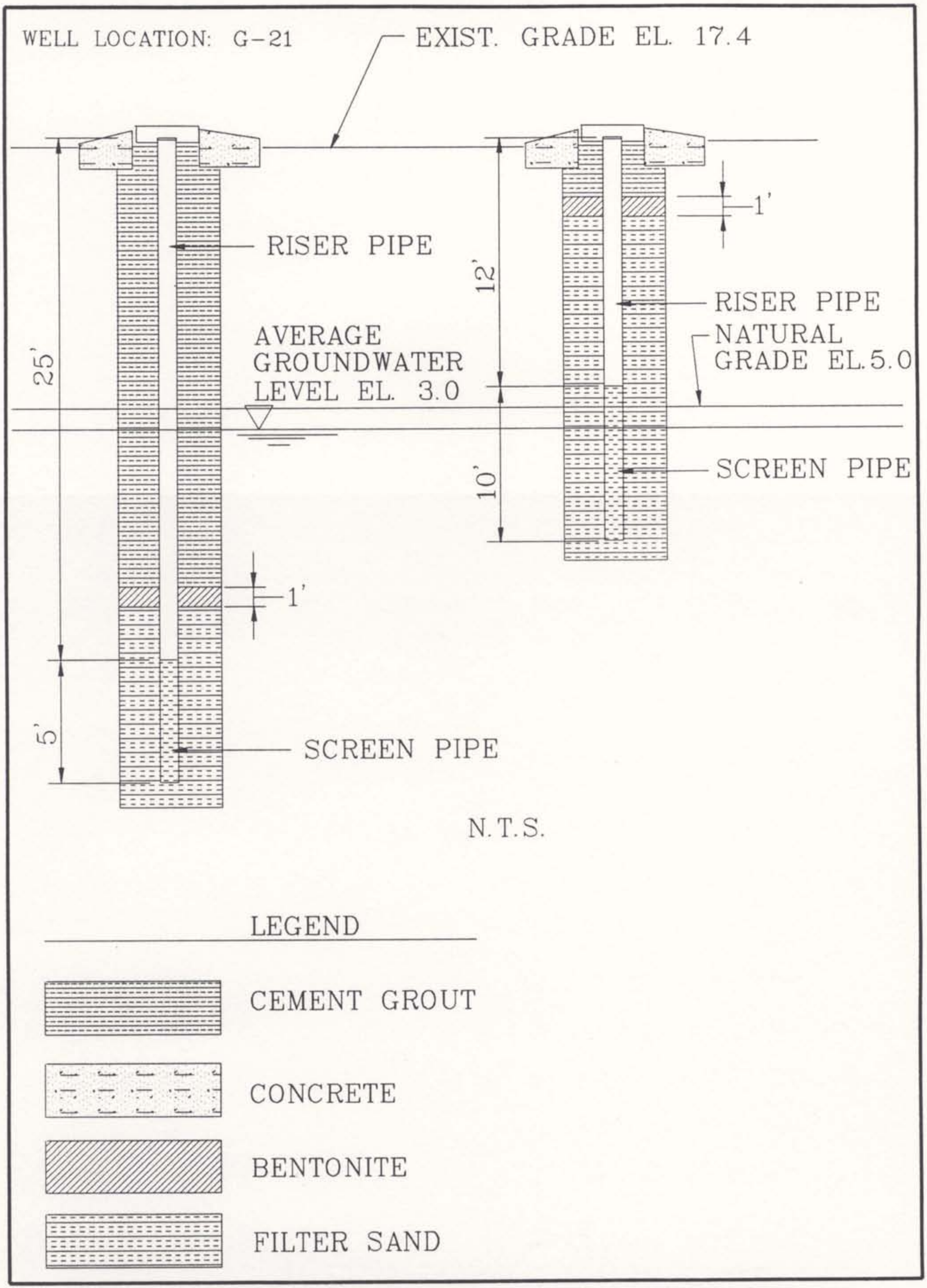


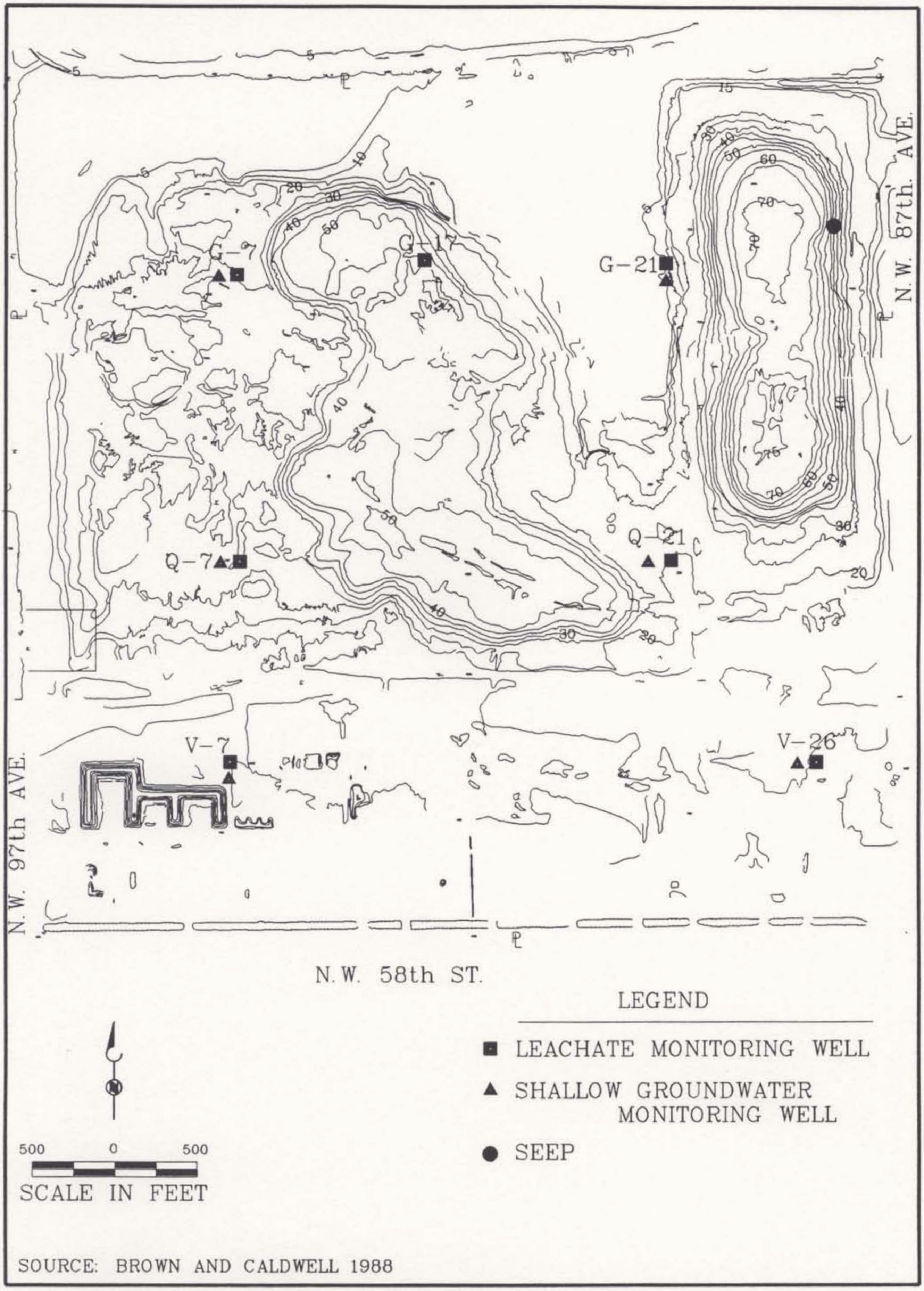
Figure 5. Typical Leachate And Shallow Groundwater Well Construction Details

leachate and shallow groundwater samples representative of the different areas within the Landfill. A sample was also obtained from a surface seep located on the east mound. The locations of these sampling sites are shown on Figure 6. Results of the sampling are presented in Table 1.

Water Quality

Based on the geological investigations previously carried out, the potential for surface and ground water contamination should be determined. If an adequate ground water monitoring well network does not exist, then steps must be taken to establish a monitoring program. Water quality data from a monitoring network should establish the background water quality as well as detect the presence of any leachate indicators.

Because the Landfill is unlined and wastes were placed at or below the groundwater table, contaminants in the Landfill leachate have a direct pathway to the aquifer and downgradient wellfields. A 1978 USGS investigation indicated that landfill leachate was migrating offsite towards public supply wellfields. According to this study, the occurrence of the leachate plume at distances greater than 0.5 miles from the Landfill was difficult to determine because dispersion and recharge diluted the contaminant (conductivity) concentrations to virtually background levels. This indicates that dilution is an important factor



SOURCE: BROWN AND CALDWELL 1988

Figure 6. Location Of Landfill Sampling Wells

TABLE 1

RESULTS OF LANDFILL LEACHATE AND SHALLOW GROUNDWATER SAMPLING

			PARAMETER, mg/L[a]								
ZONE	STATION	SAMPLE DATE	PHENOLICS	AMMONIA NITROGEN (as N)	SPECIFIC CONDUCTANCE umhos/cm	TDS	CHLORIDE	SULFATE	IRON	LEAD	ZINC
	Leachate										
1	G-21	8/20/87	0.44	990	6500	8200	1960	190	24	0.038	0.84
	Seep	8/20/87	0.45	270	7090	7140	56	360	8.5	0.01	0.28
3	G-17	8/20/87	0.07	60	1650	820	156	25	14	0.11	0.55
4	G-7	9/30/87	0.1	63	3950	1990	237	23	45	0.21	0.97
	Q-7	9/30/87	<0.05	19	880	570	56	17	61		0.65
	Q-21	8/19/87	0.15	280	330	1040	127	61	19	0.11	0.34
5	V-7	9/30/87	0.09	11	1050	830	49	170	640	3.4	4.1
	V-26	8/19/87	<0.05	48	1350	920	34	310	1200	0.07	5.4
	Shallow Groundwater										
1	G-21	8/20/87	0.19	150	3370	1610	370	54	10	0.016	0.37
4	G-7	9/30/87	<0.05	64	1450	745	113	21	2.9	0.029	0.04
	Q-7	9/30/87	<0.05	23	900	1990	58	13	4.1	0.036	0.12
	Q-21	8/19/87	0.18	120	2070	1100	154	110	44	0.12	0.41
5	V-7	9/30/87	<0.05	3.6	550	400	54	24	1.6	0.04	0.06
	V-26	9/30/87	0.06	12	780	425	1600	8	9.1	0.012	0.12
Drinking Water Standards			0.001[b]	0.5[b]	500[b]	500	250	250	0.3	0.05	5

[a] Unless otherwise noted.

[b] Dade County Department of Environmental Resources Management (DERM) Standard.

Source: Brown and Caldwell 1988

in reducing the concentration of contaminants in the leachate plume.

Additional data were collected during the period from January 1986 to 1988. This testing was extensive, with approximately 7,000 separate analyses performed. Parameters sampled included inorganic constituents, organic constituents, metals, and general water quality constituents such as COD, conductivity, pH and TDS. The results of this testing revealed that the Landfill has contributed significantly to the elevation of ammonia levels downgradient of the Landfill (Metro-Dade County 1988). The Landfill also contributed to slightly elevated levels of chloride, iron, conductivity and COD. The presence of a leachate plume was detected approximately one-mile southeast of the Landfill. No Federal primary drinking water standards were violated in the proximity of the Landfill. Organic pollutants were not significantly affected by the Landfill at the testing locations.

CLOSURE ALTERNATIVES

Once the applicable site data has been gathered, closure objectives or goals should be set and closure alternatives should be identified. Data which were gathered during site characterization can be used to evaluate alternatives. A list of feasible technologies which meet the goals for closure should be developed.

Closure Objectives

Landfill closure objectives include meeting State and Federal regulations, minimizing the site's environmental impact, maximizing the beneficial use of the site, minimizing the long term care which is required, and keeping the construction costs down. State and Federal regulations require that final cover be placed over the solid waste material when filling is completed. The cover design must meet certain guidelines which are set forth in the regulations; these will be discussed in a subsequent section.

The extent of the site's impact on the environment will depend on the physical characteristics of the site and the history of the disposal operations. A cost effective closure plan must minimize the environmental consequences while maximizing the benefits to society. The final use of the site can vary greatly; most facilities will remain as open space or green area. Some, however, have been used for parks and recreation areas for the general public, botanical gardens, residential and industrial development, parking areas, airport runways and other uses (Robinson 1986).

Long after the facility has stopped accepting waste, the owner will be required to monitor and maintain the site. This long term care should be kept as simple and as inexpensive as possible.

Regulations

Federal and State regulations require that final cover be applied at all solid waste disposal facilities. The Code of Federal Regulations (40 CFR 241.209 1989) requires no less than two feet of compacted final cover over solid waste. Florida State regulations concur with the Federal Code and further specify that a minimum of two feet of soil or a synthetic material such as PVC be used as a final cover material. Furthermore, at least six inches of soils capable of sustaining vegetative growth must make up the top portion of the cover material (Florida Administrative Code 1985).

Stabilization

Landfills have been compared to very slow anaerobic digesters, where organic stabilization takes place at extremely low rates. Landfills, as currently designed, do not optimize the biodegradation process. In fact, field observations have reported methane production rates which appear to be far below theoretical. Maintaining an adequate moisture content is one of several important factors which affect optimum microbial growth. Other factors include pH, adequate nutrients, and temperature. Controlled recirculation of leachate through the refuse mass has been shown to enhance the biodegradation process. (Legrand 1989)

Relatively low costs are associated with an anaerobic process which employs leachate recirculation. One benefit of optimizing the biodegradation process is enhanced methane production, which can be subsequently collected for it's fuel value. Little is known, however, about the positive environmental effects of speeding up the biodegradation process.

Although this technology has limitations as a means of landfill closure, it could be used in conjunction with other closure techniques. For example, collection of leachate for recirculation could be accomplished by installing an interceptor trench or a series of wells downgradient of the landfill. Leachate could then be recycled by spray irrigation, at-grade irrigation, or sub-grade irrigation

(Beck 1979). This would combine stabilization technology with a form of leachate plume management. The leachate collection system could be abandoned once a sufficient amount of stabilization has occurred and the concentrations of contaminants in monitoring wells have reached an acceptable level.

Natural Attenuation

Natural attenuation can be defined as the decrease in maximum concentration of a solute as a pulse moves through the soil. Natural attenuation can take place over time or distance (Fuller 1976). Natural attenuation of leachate pollutants takes place in soils by the following processes:

Mechanical filtration
Precipitation and coprecipitation
Sorption
Gaseous exchange
Dilution and dispersion
Microbial activity
Organic Matter

Mechanical filtration is a physical process whereby the movement of suspended contaminants is restricted by soil particles. Precipitation and co-precipitation involve the formation of insoluble compounds resulting from changes in environmental conditions such as pH and temperature as the leachate moves through the soil. Sorption includes the processes of adsorption, absorption and ion exchange where the sorbing material may be the soil, organic compounds in the soil, microbial organisms, or chemical precipitants. Gaseous exchange involves the volatilization of gaseous contaminants and decomposition products. Dilution and dispersion decreases contaminant concentrations due to intermixing with soil water. Microbial activity is the uptake and utilization of inorganic and organic contaminants by the soil microbial community (Farquhar 1976).

Obviously, the attenuation process is complex and involves many mechanisms. Certain soil characteristics play a more important role in attenuation than others (Farquhar 1976). Among these are: soil particle size distribution, free iron oxide and organic matter content of the soil, soil pH value and solution flux through the soil.

There are no economic considerations associated with attenuation processes. They occur naturally and depend on the in-situ soils. Therefore, these processes are not always reliable, and can not be used alone as a means of landfill closure. Careful evaluation on a site specific basis would be necessary to ensure that the environmental and public health risks are minimized. Natural attenuation could, however, be used in conjunction with some type of surface sealing or capping to minimize the amount of leachate production.

Leachate Plume Management

Leachate plume management or groundwater control involves manipulation of the water table in the area of the landfill to: 1) prevent the formation of leachate or further groundwater contamination, 2) contain a plume, or 3) remove a plume after measures have been taken to stop the source of contamination. Technologies for plume management usually include one or more of the following: groundwater pumping, subsurface drains or low permeability barriers (U.S. EPA October 1985).

Groundwater Pumping

Groundwater pumping involves the manipulation of groundwater to alter the direction of leachate plume movement through the use of extraction or injection wells. When a groundwater extraction well is pumped, a cone of depression is created which causes groundwater to flow towards the well. Conversely, when water is pumped into an injection well, a mound is created which causes groundwater to flow away from the well.

Well systems can be used to perform different functions, primarily groundwater level adjustment, plume containment and plume removal. Groundwater level adjustment can be used to stop plume migration or to change the speed and direction of the plume. This can be accomplished by either lowering or raising the water table through the use of extraction or injection wells, respectively. In either case, contaminated groundwater is not removed from the system for treatment.

Plume containment may use extraction wells or both extraction and injection wells in combination to effectively remove contaminated groundwater. The groundwater must then be treated and disposed of in an environmentally safe manner. Removal of a plume implies completely purging the groundwater of all contaminants. This technology is suitable when the source of contamination has been stopped. As with containment systems, groundwater must be treated (U.S. EPA October 1985).

Costs for installation of well systems vary greatly from site to site. However, operation and maintenance (O&M) costs can be greater than the initial costs. Long term O&M costs should be carefully evaluated over the life of the project. The duration of the project will greatly affect the economics of this technology.

Subsurface Drains

A subsurface drain can be defined generally as a buried conduit which is used to collect contaminated groundwater by gravity flow. A subsurface drain functions like an infinite line of extraction wells. It creates a continuous cone of influence which runs the length of the collection trench.

Subsurface drainage systems usually consist of the following: drain pipe or gravel bed, envelope, filter, backfill and manhole or wet well. Drains can be used for many of the same applications as wells, therefore, the decision to use drains or pumping is usually based on economics. Trench excavation is often the most difficult and expensive portion of drain installation. This technology may even be excluded because of the prohibitive costs.

Low Permeability Barriers

Low permeability or subsurface barriers refer to a variety of methods which employ cut-off walls or diversions below ground to contain, capture, or redirect groundwater flow at a waste site. The three major types of barriers are slurry walls, diaphragm walls and grout curtains.

The most commonly used barriers are slurry walls, particularly soil-bentonite slurry walls. A slurry wall is formed by excavating a vertical trench under a slurry which usually consists of bentonite and water to prevent the trench from collapsing. The slurry essentially acts like a drilling fluid and it also forms a filter cake on the trench walls to prevent high fluid losses to the surrounding ground. Slurry walls are classified according to the materials used to backfill the trench. Soil-bentonite slurry walls are backfilled with soil materials (the trench spoils, if suitable) mixed with bentonite slurry. Cement-bentonite walls consist of a mixture of portland cement, bentonite and water.

Diaphragm walls are barriers which consist of reinforced concrete panels (diaphragms) which are placed using slurry trench techniques. Grouting is a technique most widely used for sealing voids, fissures and solution channels in rock.

Surface Water Control

Surface water controls refer to a wide variety of methods which are designed to prevent infiltration of water into the landfill by diverting, collecting and containing surface waters. Surface water control technologies perform one or more of the following functions:

Prevention of run-on/interception of run-off
Prevention of infiltration
Control of erosion
Collection and transfer of water
Storage and discharge of water
Protection from flooding

Table 2 summarizes various surface water technologies and their primary functions. The major emphasis here will be capping, grading and surface water management.

TABLE 2

SUMMARY OF SURFACE WATER CONTROLS

TECHNOLOGY	PREVENT OR INTERCEPT RUN-ON/RUN-OFF	PREVENT OR MINIMIZE INFILTRATION	REDUCE EROSION	COLLECT AND TRANSFER WATER	PROTECTION FROM FLOODING	DISCHARGE WATER
Capping		X				
Lagoon Covers		X				
Grading	X		X			
Revegetation	X	X	X			
Dikes and Berms	X		X		X	
Channels and Waterways			X	X		
Terraces and Benches	X		X			
Chutes and Downpipes			X	X		
Seepage Basins and Ditches						X
Sedimentation Basins and Ponds	X					X
Levees and Floodwalls	X				X	

Source: U.S. EPA. 1985.

Capping

Capping involves the application of final cover materials as required by State and Federal regulations. The cover material is intended to minimize infiltration and erosion, promote drainage and function with minimum maintenance. Cover permeability is not specified; however, the regulations state that the cover must "have a permeability less than or equal to the permeability of any bottom liner system."

There are various cap designs and materials available. The design and the materials which are selected will depend on local availability and costs. In some cases synthetic materials may be used, depending on the availability of natural soils and the extent of contamination.

Typically a cover system will consist of an upper vegetative layer, a drainage layer, and a low permeability layer. The exact configuration of the cover system will depend on the site, and each system should be evaluated on an individual basis. A vegetative layer provides many desirable functions. Among these are: erosion control, percolation reduction, enhanced evapotranspiration and aesthetic appeal.

Grading

Grading involves the reshaping of a site's existing topography in order to maximize runoff, reduce erosion and promote vegetative growth. Grading operations utilize cut-and-fill earthwork techniques to establish the desired contours. Benches can also be used to shorten long slopes which, in turn, stabilizes and protects the side slopes. Contouring should be conducted to meet drainage and water removal requirements. Reduction of ponding on the landfill surface will minimize infiltration and thus leachate generation.

Surface Water Management

Surface water controls are designed to minimize the amount of surface water flowing onto a site, thereby reducing the amount of potential infiltration (Canter 1985). Capping and regrading the site will increase the amount of stormwater runoff from the landfill surface.

The prevention of run-on and the interception of runoff employ technologies that divert or intercept surface water (U.S. EPA October 1985). These technologies include: dikes, diversion channels, floodwalls, terraces, grading, and revegetation. Water which has been diverted away from the filled areas or prevented from infiltrating must then be collected and transferred to storage and discharge areas. Chutes (or flumes) and downpipes are designed to transfer water away from diversion structures such as dikes or terraces to stabilized channels. Waterways can be used to intercept or divert water, or to collect and transfer water from elsewhere. These waterways are the basis of the surface water collection system.

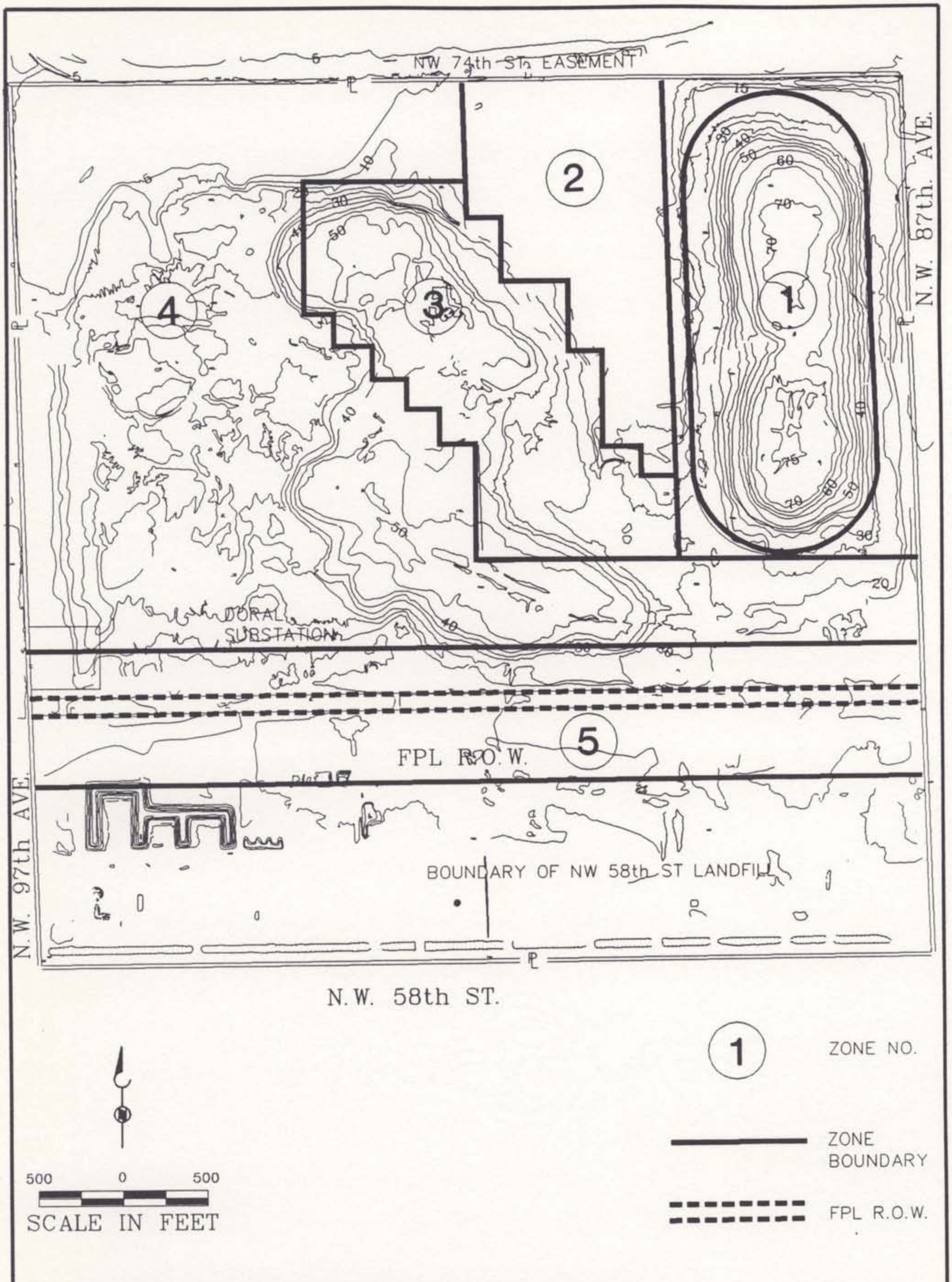
Water storage and discharge methods include seepage basins and swales, sedimentation basins, and storage ponds. If the water is not contaminated, it can be safely discharged once any suspended solids have been removed. In addition to any other criteria which may be imposed on the surface water system design, the system must be designed to convey and contain runoff from a specific storm event. This runoff must be channeled away from filled areas in order to prevent infiltration. Typically the peak flow from a 10-year return frequency design storm is used to size conveyance structures. Some state and local regulatory agencies, however, have more stringent requirements and should be consulted before beginning final design.

ALTERNATIVES EVALUATION

Alternatives will be evaluated for the following: 1) ability to meet State and Federal regulations, 2) ease of implementation, 3) environmental impact, 4) long term care which will be required, and 5) costs. A mass balance analysis will be used to evaluate the environmental impact of the closure alternatives.

Since landfilling was not accomplished uniformly over the one-square-mile site, waste depth varies from 5 to 10 feet in the southern third of the site to 70 feet in the east mound. The site is unlined and a review of historical aerials has shown that wastes were placed directly in the groundwater at various locations throughout the site. Higher concentrations of leachate contamination are expected from areas on the Landfill where waste is newer and deeper (Brown and Caldwell June 1988). Therefore, the Landfill can be divided into five separate zones based on waste depth and varying site characteristics. Figure 7 shows the five zones for Landfill alternatives evaluation.

Zone 1, a 90-acre area, consists primarily of a 70-foot high mound on the east side of the landfill and was found to have the strongest leachate concentrations. Zone 2 is a 78-acre area where waste disposal has not taken place. Zone 3



SOURCE: BROWN AND CALDWELL

Figure 7. Landfill Zones For Evaluation

is 61 acres with an older, less well-defined mound than Zone 1. Zone 3 has depths of fill up to elevation 50 feet and lower leachate concentrations than Zone 1. Zones 4 and 5 are 192 and 99 acres in size, respectively; with average fill depths of 15 to 30 feet and 5 to 10 feet, respectively. As would be expected, there are generally lower leachate concentrations in Zones 4 and 5.

Water Balance

A key step in the evaluation of alternatives is estimating the potential quantity of leachate which may be generated by the Landfill. In order to estimate this quantity, a water balance must be calculated. The currently accepted and most common method of performing a water balance uses the U.S. Army Corps of Engineer's Hydrologic Evaluation of Landfill Performance (HELP) model. Various components of the water balance may be estimated using HELP; including, but not limited to, surface water runoff, soil moisture storage, evapotranspiration and percolation. The basic water balance equation is given by:

$$PERC = P - Q - ET - \Delta S \qquad (1)$$

where

PERC = percolation, inches
P = precipitation, inches
Q = runoff, inches
ET = actual evapotranspiration, inches

This equation predicts the quantity of water that percolates through the cover into the underlying solid waste. The HELP model is described in the following section and used to estimate leachate generation under the existing conditions.

Help Model

The HELP model is a computerized program which was developed to provide a tool for rapid screening of alternative designs for hazardous waste landfills, but can also be used in other landfill applications. The model simulates daily movement of water into, through and out of a landfill. The hydrologic processes modeled are either surface or subsurface processes. The surface processes include snowmelt, interception of runoff by vegetation, runoff and surface evaporation. The subsurface processes are soil evaporation, plant transpiration, vertical unsaturated drainage, barrier-layer percolation and lateral saturated drainage. The HELP model requires data such as climatologic, soil and design data.

Climatological Data. Three options are available for entering precipitation data: 1) default precipitation, 2) manual precipitation, and 3) synthetic precipitation. Default precipitation data for 102 U.S. cities is built into the program for a period of five years (1974-1978). Caution should be exercised if this option is chosen because the period of record may be unusually wet or dry for the project location. The program allows up to 20 years of precipitation data for a specific site to be entered manually. If historical precipitation is not available, the program uses a Markov chain-gamma model to statistically generate up to 20 years of daily precipitation data for a selected location. Under the statistical or synthetic option, the user may enter monthly mean precipitation values for the project location; these monthly values are then used to adjust the synthetic precipitation data.

All three precipitation options utilize daily temperature and solar radiation data which is stochastically generated. The program generates these data for various cities depending on which precipitation option is used. The User's Guide (Volume III.) contains complete listings of the cities which may be selected under the three different precipitation options.

<u>Soil Data.</u> Either default or manual options are available for soil data. Default soil data include characteristics of the given soil type as well as a textural soil description used by USDA or USCS. Table 3 lists the 18 default soil textures and characteristics offered by the HELP model. Some basic soil properties are defined briefly below:

<u>Soil Water Content</u>- the ratio of the volume of water in a soil to the total volume occupied by the soil.

TABLE 3

HELP MODEL DEFAULT SOIL CHARACTERISTICS

SOIL TEXTURE CLASS			TOTAL POROS.	RESID. SAT.	BUBBL. PRESS. (cm)	PORE-SIZE DIST. INDEX	FIELD CAP.	WILT. PT.	SAT. HYD. COND		INF. RATE in/hr	MIN. EVAP. COEF. mm/day$^{0.5}$
HELP	USDA	USCS							cm/s	in/hr		
1	CoS	GS	0.417	0.015	6.53	0.651	0.045	0.018	1.0E-02	14.173	0.500	3.3
2	S	SW	0.437	0.020	7.26	0.592	0.062	0.024	5.8E-03	8.220	0.400	3.3
3	FS	SM	0.457	0.025	7.99	0.533	0.083	0.033	3.1E-03	4.394	0.390	3.3
4	LS	SM	0.437	0.035	8.69	0.474	0.105	0.047	1.7E-03	2.409	0.380	3.3
5	LFS	SM	0.457	0.040	9.56	0.425	0.131	0.058	1.0E-03	1.417	0.340	3.3
6	SL	SM	0.453	0.041	14.66	0.322	0.190	0.085	7.2E-04	1.020	0.300	5.1
7	FSL	SM	0.473	0.046	16.13	0.290	0.222	0.104	5.2E-04	0.737	0.250	5.1
8	L	ML	0.463	0.027	11.15	0.220	0.232	0.116	3.7E-04	0.524	0.200	3.9
9	SiL	ML	0.501	0.015	20.76	0.211	0.284	0.135	1.9E-04	0.269	0.170	5.1
10	SCL	SC	0.398	0.068	28.08	0.250	0.244	0.136	1.2E-04	0.170	0.110	5.1
11	CL	CL	0.464	0.075	25.89	0.194	0.310	0.187	6.4E-05	0.091	0.090	5.1
12	SiCL	CL	0.471	0.040	32.56	0.151	0.342	0.210	4.2E-05	0.060	0.070	5.1
13	SC	CH	0.430	0.109	29.17	0.168	0.321	0.221	3.3E-05	0.047	0.060	4.5
14	SiC	CH	0.479	0.056	34.19	0.127	0.371	0.251	2.5E-05	0.035	0.020	5.1
15	C	CH	0.475	0.090	37.30	0.131	0.378	0.265	1.7E-05	0.024	0.010	4.6
16	Barrier		0.430	0.120	45.00	0.113	0.366	0.280	1.0E-07	0.000	0.002	3.3
17	Barrier		0.400	0.140	50.00	0.096	0.356	0.290	1.0E-08	0.000	0.001	3.3
18	Mun. Waste		0.520	0.015	20.76	0.211	0.294	0.140	2.0E-04	0.283	0.230	5.1

Source: Schroeder, et. al. 1988

Porosity- the soil water content at saturation.

Field Capacity- the soil water content after a prolonged period of gravity drainage.

Wilting Point- the lowest soil water content that can be achieved by plant transpiration.

Available water capacity- the difference between the soil water contents at field capacity and wilting point.

Hydraulic conductivity- the rate at which water drains vertically through a saturated soil with no vertical pressure gradient.

Porosity, field capacity and wilting point are all dimensionless numbers between 0 and 1. If manual soil data is input, values for porosity, field capacity, wilting point, and saturated hydraulic conductivity must be entered. This option may be exercised by selecting soil texture type 19 or 20. The user must specify whether or not a soil layer is compacted; this has an effect on characteristics such as the hydraulic conductivity, the drainable porosity, and the plant available water content.

Landfill Data. The surface area of the landfill and whether or not it is active (uncovered) must be input. If the landfill is open, the percent which is allowed to runoff must be specified. The user also has the option of specifiying a runoff curve number if desired.

The number of layers in the landfill profile must also be specified. The HELP model may be used to model up to twelve layers of soil or waste in a landfill profile. Three types of layers may be selected: vertical percolation layers, lateral drainage layers and barrier soil layers. The model calculates flow through these layers in different ways. Certain rules apply to the arrangement of layers in the HELP model:

1) Vertical percolation or waste layers may not be placed directly below a lateral drainage layer.
2) A barrier soil layer may not be place above another barrier soil layer.
3) When a barrier soil layer is not place directly below the lowest drainage layer, all drainage layers in the lowest subprofile are treated as vertical percolation layers.
4) The top layer may not be a barrier soil layer.
5) The profile can contain a maximum of four barrier soil layers.

Vegetative Cover. The user must also select the type of vegetative cover and specify an evaporative zone depth. The program requires the user to select a leaf area index (LAI) for the appropriate type of vegetative cover (typical values are provided for the selected location). The LAI is a dimensionless ratio, defined by the ratio of the leaf area of actively transpiring vegetation to the nominal surface area of the soil which supports the vegetation.

The evaporative zone depth is the greatest depth at which the program allows water to be removed by evapotranspiration. The evaporative zone depth is influenced by the type of vegetative cover which is present and should extend to at least the expected root penetration depth. In the absence of vegetation, some evaporative zone depth should be specified to account for direct evaporation from the bare soil. Suggested values for evaporative zone depth vary from 18 inches for bare ground to 60 inches for excellent grass (Shroeder, et. al. 1988).

Runoff. Rainfall runoff is modeled using the Soil Conservation Service (SCS) curve-number method. The relationship between the curve number, CN, and the retention parameter, S, is given by the equation:

$$CN = 1000/(S+10) \tag{2}$$

or

$$S = 1000/CN - 10 \tag{3}$$

Runoff, Q, is related to precipitation, P, and S by the following:

$$Q = (P - 0.2S)^2/(P + 0.8S) \tag{4}$$

Based on the net rainfall (rainfall plus snowmelt) for a given day, daily runoff is calculated using equation (4). The retention parameter, S, for a given soil is varied in the following manner:

$$S = S_{mx}(1-(SM-WP)/(UL-WP)) \quad (5)$$

where

S_{mx} = maximum value of S, inches

SM = soil water content in the vegetative or evaporative zone, inches

UL = soil water storage at saturation, inches

WP = wilting point of the soil or the lowest naturally occurring soil water content, inches

Because soil moisture near the surface has greater influence on infiltration than moisture in other locations, the retention parameter is depth-weighted. The evaporative zone depth is divided into seven segments. Thicknesses for the segments are assumed; with the top segment being 1/36th of the evaporative zone depth, the second segment is 5/36th of the evaporative zone depth, and segments three through seven are each 1/6th of the evaporative zone depth. The depth weighted retention parameter is given by:

$$S = S_{mx} \; (1- \Sigma \; W_j(SM_j-WP_j)/(UL_j-WP_j)) \quad (6)$$

where

W_j = weighting factor for segment j

SM_j = soil water content of segment j, inches

UL_j = saturated capacity of segment j, inches

WP_j = wilting point of segment j, inches

The weighting factors decrease with the depth of the segment. For the assumed segment thicknesses, weighting factors of 0.111, 0.397, 0.254, 0.127, 0.063, 0.032, and 0.016 are used for segements one through seven.

The maximum moisture retention parameter, S_{mx}, is assumed to be equal to S at antecedent moisture condition I (AMC-I, which represents dry conditions) in the SCS method. The following equation relates S_{mx} to the AMC-I curve number, CN_I:

$$S_{mx} = 1000/CN_I - 10 \tag{7}$$

The HELP model requires a curve number that represents an average soil moisture condition, CN_{II}, as input. This corresponds to antecedent moisture condition II (AMC-II). The user may enter a value for CNII directly, or allow the program to compute one based on the vegetative cover type and the minimum infiltration rate of the soil.

CN_I is related to CN_{II} by the following polynomial equation:

$$\begin{aligned} CN_I = {} & 3.751*10^{-1}(CN_{II}) + 2.757*10^{-3}(CN_{II})^2 - \\ & 1.639*10^{-5}(CN_{II})^3 + 5.143*10^{-7}(CN_{II})^4 \end{aligned} \tag{8}$$

Daily runoff is calculated by the following procedure: 1) calculate CN_I and S_{mx} given CN_{II} using equations 8 and 7, 2) calculate the depth-weighted retention parameter, S, using equation 5, 3) calculate daily runoff resulting from rainfall and snowmelt using equation 4.

Infiltration. Daily infiltration into the landfill profile is calculated indirectly from a surface-water balance.

Infiltration equals the sum of rainfall and snowmelt minus runoff and surface water evaporation. This is given mathematically by:

$$IN_i = P_i - Q_i - ESS_i \tag{9}$$

where

IN_i = daily infiltration on day i, inches

ESS_i = surface water evaporation on day i, inches

Water that does not runoff or evaporate is assumed to infiltrate into the landfill; no surface storage is allowed from one day to the next.

Evapotranspiration. The evapotranspiration rate from a landfill depends on several factors: solar radiation, temperature, humidity, vegetation type and growth stage, surface wetness, soil water content and other soil characteristics.

The potential evapotranspiration is calculated by:

$$E_{oi} = (1.28A_iH_i)/((A_i+G)25.4) \tag{10}$$

where

E_{oi} = potential evapotranspiration on day i, inches

A_i = slope of saturation vapor pressure curve on day i

H_i = net solar radiation on day i, langleys

G = psychometric constant = 0.68 (assumed)

A_i and H_i are calculated from equations that (Schroeder et.al. 1988) are given in the documentation for the HELP model, the reader is referred to this documentation for a complete description of all equations. Evapotranspiration consists of three components: surface evaporation of water intercepted by vegetation or on the landfill surface, evaporation from the soil, and transpiration by vegetation. The actual evapotranspiration will be less than the potential evapotranspiration and is expressed by:

$$ET = ESS + ES + EP \qquad (11)$$

where

ESS = surface water evaporation, inches

ES = soil evaporation, inches

EP = actual plant transpiration, inches

The model first exerts evapotranspirative demand on the water available at the landfill surface. This surface moisture, ESS, may be in the form of accumulated snow or intercepted rainfall, INT. In the initial stages of a rainfall event, nearly all rainfall which strikes vegetation is intercepted. The interception storage capacity of the vegetation is a function of the leaf area index, LAI. This relationship is empirical and is given by the equation:

$$INT_{max} = 0.05(LAI/3) \qquad (11)$$

This storage capacity is reached only after considerable rainfall has reached the ground. The interception before this foliage capacity is reached is approximated by the following:

$$INT_i = INT_{max}(1-\exp^{(PREi/INTmax)}) \qquad (12)$$

When the daily temperature is above freezing, any evapotranspirative demand in excess of the available surface moisture is first exerted through soil evaporation, ES, and then through plant transpiration, EP. If the temperature is below 23 degrees F, then the program assumes no soil evaporation or plant transpiration occurs.

A vegetative growth model accounts for seasonal variation in leaf-area index, LAI, which affects the potential plant transpiration values. This growth model computes daily values of LAI based on the maximum value input by the user, daily temperature and solar radiation data, mean monthly temperatures and the length of the growing season which is temperature dependant.

Vertical Drainage. A vertical percolation layer allows movement of water either upward due to evapotranspiration or downward due to gravity drainage. The gravity drainage rate, or percolation, in a vertical percolation layer is assumed to be independant of conditions in adjacent layers. The HELP model uses Darcy's law to calculate flow through the soil and waste layers. This equation is given by:

$$q = k(dh/dl) \tag{13}$$

where

q = rate of flow (per unit time per unit area)

k = hydraulic conductivity, length/time

h = piezometric head

l = length in the direction of flow

This equation applies to unsaturated as well as saturated conditions if the hydraulic conductivity is considered to be a function of soil moisture. The model calculates unsaturated hydraulic conductivity as a function of soil moisture using a separate equation given in the HELP model documentation (Schroeder et.al. 1988).

Subsurface Water Routing. Subsurface water routing proceeds from top to bottom, one subprofile at a time. A storage routing procedure is used to route water downward from one segment to the next. Water storage is evaluated at the mid-point of a 6-hour time step. Mid-point routing smooths out abrupt changes which occur when the full amount of moisture is applied to a segment at the beginning of a time step. Utilizing mid-point routing with a small time step results in an accurate and efficient simulation of drainage processes.

Free drainage is assumed at the bottom of each segment with drainage into the top segment equaling infiltration from the surface or barrier layer percolation from the subprofile directly above. Drainage into a segment does not depend on its moisture content; therfore, a segment may receive more moisture than it can hold (the water content is greater than the total porosity). This is corrected by adding the excess water to the segment above it. The entire profile is corrected in this manner by backing up water from bottom to top. Excess water at the surface is added to the runoff for the day.

Model Limitations. The documentation of the HELP model gives complete assumptions and limitations associated with the model. Some of these limitations may affect the modeled results, especially for the existing conditions, therefore, are discussed briefly below.

Runoff is calculated is using the SCS method which does not consider surface slopes. The SCS method was developed for slopes of less than 20 percent. Most surfaces of the Landfill modeled here are 20 percent or less, however some side slopes may slightly exceed 20 percent. Runoff would be underestimated in these cases.

The model assumes that the entire landfill lies above the groundwater table. Because this is not the case at the Landfill, leachate generation may be higher due to the seasonal rising and falling of the groundwater table. The model does not account for surface water runon from other areas. Because some areas of the Landfill, particularly Zone 4, are not smoothly graded, water tends to pond on the surface after significant rainfall events. Leachate generation may be underestimated in this case.

The model does not consider flow through cracks in the soil due to roots or erosion. This type of "short circuiting" probably occurs under the existing conditions at the Landfill. Therefore, more water probably enters the Landfill than is modeled under the existing conditions.

The model uses a subroutine that models grass stands to calculate plant evapotranspiration. The existing vegetation at the Landfill consists of much more than just grass; volunteer species of palms, trees, shrubs and other varieties exist in some areas while other are relatively bare.

Existing Conditions

The existing percolation rates at the Landfill will approximate the quantity of leachate which is currently generated. The positive impact of the closure alternatives can then be quantified in terms of reduced leachate quantities. Information regarding the cover soils which was obtained during field investigations will be used to model the cover layer. This information includes: hydraulic conductivities, physical descriptions of the soils, and approximate cover thicknesses.

Hydraulic conductivity values were obtained for the cover during the data acquisition program by performing double ring infiltrometer tests at six various locations throughout the site. In groundwater hydrology, the term hydraulic conductivity is synonymous with coefficient of permeability. Permeability values ranged from 0 to $1.3*10^{-3}$ cm/sec with an average value of approximately $5.1*10^{-4}$ cm/sec. The results of the field testing are shown on Table 4.

In addition to hydraulic conductivities, a physical description of the soil was obtained at each location. Because soil data other than hydraulic conductivities are required to run the HELP model, default data for soil texture which correspond to the description of the cover materials found on site is selected for the cover layer. Soil texture number 9 from Table 3 is used for modeling the cover layer for all zones under existing conditions. Compaction is specified for the cover layer which has the effect of reducing the saturated hydraulic conductivity, the porosity and the field capacity. Therefore, the values used in the model for porosity and field capacity are lower than the values shown. The default hydraulic conductivity is overidden by manually inputting the field value. In this manner, a combination of default and manual soil characteristics are utilized for the existing cover conditions.

LAW Engineering excavated 24 test pits in August 1987 (LAW 1987). The results showed that cover thicknesses varied greatly through out the site from a few inches to over 4 feet with an average depth of about 1.2 feet. There is no way to accurately predict the average thickness of cover in each zone and the HELP model does not account for cover thickness variations, therefore, an average depth of 12-inches is used for each zone. Because the HELP model is more sensitive to hydraulic conductivities than to

TABLE 4

RESULTS[a] OF DOUBLE RING INFILTROMETER TESTING

ZONE	HYDRAULIC CONDUCTIVITY, IN/HR	PERMEABILITY, CM/SEC
1	0.9	6.4×10^{-4}
3	0.15	1.1×10^{-4}
4	1.10	7.9×10^{-4}
5	0.73	5.13×10^{-4}

[a] Six tests were run: two in Zone 1, two in Zone 3, and two in Zone 4. The values shown for Zones 1, 3, and 4 are averages of the two tests. No tests were run in Zone 5; the values shown for Zone 5 are averages of all six tests.

variations in cover thicknesses, using an average value for cover thickness will not significantly impact the results.

The existing Landfill profile consists of only two layers: a waste layer and a cover layer. Figure 8 shows this existing profile. Soil texture 18 from Table 3 (default values for MSW characteristics) is used to model the waste layer along with the appropriate thickness for each zone. Both layers are modeled as vertical percolation layers. Table 5 summarizes the soil characteristics which are used to obtain the existing conditions percolation rates.

Precipitation data for 1980 to 1989 from a rain gauge in southern Dade County (South Florida Water Management District Tidewater station) is input manually to run the existing conditions. This gives a longer period of data than the programs default data (1974-1978), and is more representative of existing conditions than the synthetic data. The average annual precipitation for these 10 years of data is approximately 46 inches, which is below the long term average of 60 inches for the Landfill area.

An evaporative zone depth of 22 inches and a crop of fair grass is selected for all zones. Although the vegetation on the Landfill actually varies from dense weeds and shrubs to bare ground, this should give a reasonable approximation of the existing conditions. Some areas may have higher evapotranspiration rates than the modeled values

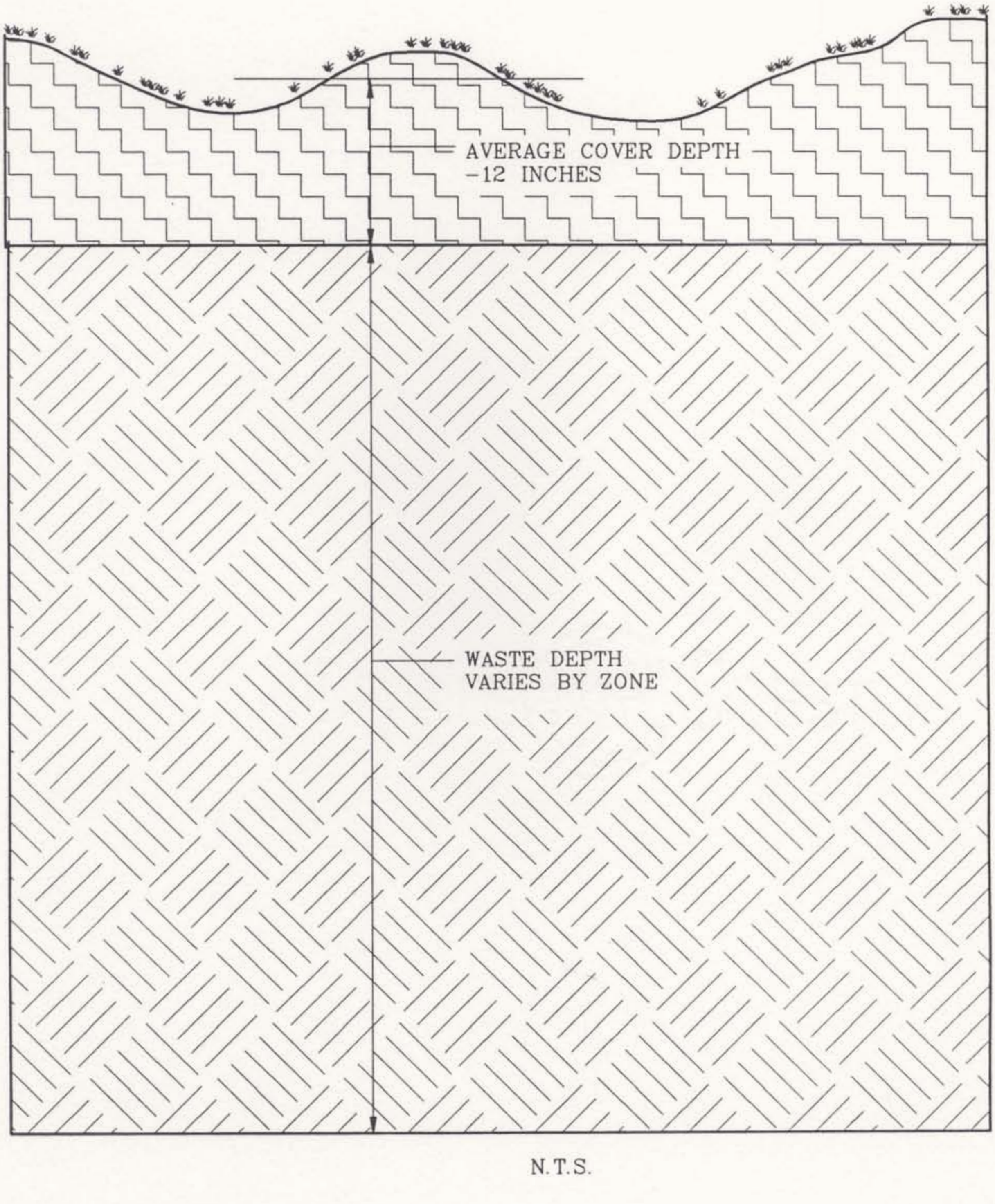


Figure 8. Existing Landfill Profile

TABLE 5

INPUT DATA FOR EXISTING CONDITIONS

SOIL CHARACTERISTICS

ZONE NO. LAYER	HELP SOIL TEXTURE	THICKNESS, INCHES	POROSITY, VOL/VOL	FIELD CAPACITY VOL/VOL	WILTING POINT VOL/VOL	INITIAL[a] SOIL WATER CONTENT, VOL/VOL	SAT.HYD. CONDUCTIVITY, CM/SEC
Zone 1							
Cover	9	12	0.4096	0.2466	0.1353	0.1461	6.4×10^{-4}
Waste	18	840	0.5200	0.2942	0.1400	0.2995	1.99×10^{-4}
Zone 3							
Cover	9	12	0.4096	0.2466	0.1353	0.1826	1.1×10^{-4}
Waste	18	600	0.5200	0.2942	0.1400	0.2967	1.99×10^{-4}
Zone 4							
Cover	9	12	0.4096	0.2466	0.1353	0.1427	7.9×10^{-4}
Waste	18	120	0.5200	0.2942	0.1400	0.3200	1.99×10^{-4}
Zone 5							
Cover	9	12	0.4096	0.2466	0.1353	0.1517	5.1×10^{-4}
Waste	18	120	0.5200	0.2942	0.1400	0.3174	1.99×10^{-4}

[a] The soil water content was initialized by the program.

and some areas may be lower. These values are conservative where trees and other vegetation with deep root zones exist.

The results of the existing conditions water balance calculations are presented in Table 6. These values are within the range of effective recharge rates due to precipitation which are reported from 2.6 to 20 inches per year (Brown and Caldwell 1988).

Mass Balance

A mass balance for existing conditions at the Landfill can be generated using percolation rates and leachate quality data. The preferred landfill leachate indicators for groundwater monitoring are chloride, bicarbonate, and sodium. Chloride will be used in this analysis because it carries a negative charge and does not form precipitates with the common cations in water (U.S. EPA 1977). Because chloride is unaffected by ambient conditions, reductions in chloride concentrations can be attributed to dispersion and diffusion.

The chloride concentrations which were obtained from the leachate sample analyses are shown in Table 7. A mass loading rate to the groundwater for the existing conditions can be obtained by multiplying the volume of water (which subsequently becomes leachate) that infiltrates each year by the chloride concentration, and converting the result to a mass loading rate (pounds per year). For example, Zone 1 is

TABLE 6

WATER BALANCE FOR EXISTING CONDITIONS:

AVERAGE ANNUAL TOTALS

ZONE	PRECIPITATION, INCHES	RUNOFF, INCHES	EVAPOTRANSPIRATION, INCHES	PERCOLATION, INCHES	CHANGE IN WATER STORAGE,[a] INCHES
1	46.45	1.55	38.93	4.53	1.44
3	46.45	3.46	39.16	3.23	0.50
4	46.45	1.44	38.81	6.48	-0.28
5	46.45	1.69	39.03	6.00	-0.27

[a] The average change in the entire soil column for the 10 year period.

TABLE 7

CHLORIDE CONCENTRATIONS FOR MASS BALANCE ANALYSIS

ZONE	CHLORIDE, mg/L
1	1010
3	156
4	140
5	42

calculated as follows:

$$\text{Mass Loading} = (1010\ \text{mg/L})(11.07*10^6\ \text{gal/yr})(3.785\ \text{L/gal})(1\ \text{lb}/454{,}000\text{mg}) = 93{,}200\ \text{lb/yr}$$

The mass loading rates to the groundwater for all contributing zones are shown in Table 8.

Stabilization

Stabilization of the landfilled wastes will occur naturally over time; however, this alternative does not meet State and Federal regulations for final cover. Therefore, the Landfill must first be capped with the required two feet of cover. Capping the Landfill will then make recirculation of leachate a difficult task. The concentrations of contaminants will decrease over time (Lu, et. al. 1985) as a result of stabilization; however, there is no real reduction in contaminant loading as a result of implementing this alternative. There are no construction or long term care costs associated with this alternative.

Natural Attenuation

Natural attenuation will depend heavily on the soils in the Landfill vicinity. Like stabilization, it will occur naturally over time; but it does not meet State and Federal regulations. There is no immediate reduction in mass

TABLE 8

MASS BALANCE FOR EXISTING CONDITIONS

ZONE	CHLORIDE, mg/L	INFILTRATION RATE MGY	MASS LOADING lb/yr
1	1010	11.07	93,200
3	156	5.51	7,200
4	140	33.78	39,400
5	42	16.13	5,600
TOTAL	--	66.49	145,400

loading due to implementation of this alternative. There are also no construction or long term care costs associated with this alternative. Because natural attenuation is dependant on the condition of the native soils, it is not always reliable.

Leachate Plume Management

Leachate plume management alone will not prevent the formation of leachate at the Landfill because infiltration can still occur through the existing cover. Therefore, the mass loading rates are the same as existing conditions. Plume management would, however, prevent further groundwater contamination from occurring. Plume management will not meet the requirements for final cover; and does not stop the source of contamination.

Because of the high transmissivity of the Biscayne aquifer combined with the magnitude of the site, groundwater removal at the Landfill site would require extensive pumping of multiple wells in order to adequately reduce the migration of a leachate plume. Treatment and disposal of the contaminated groundwater would have to be continued indefinitely because the source of contamination would still exist. The long term care costs of such a system could significantly exceed the construction costs.

A subsurface drain, because it functions by gravity flow, may work well along the eastern boundary of the

Landfill. The groundwater flow in the Landfill vicinity is generally east; therefore, a trench placed along the eastern edge of the Landfill would capture a portion of the contaminated groundwater as it leaves the Landfill site. The groundwater table is shallow at the Landfill, so construction costs will depend on the ground elevation at the eastern boundary of the site. Very little maintenance is associated with a subsurface drain, periodic cleaning is all that is really required. Again, treatment and disposal of contaminated groundwater would be continued indefinitely.

A low permeability barrier such as a slurry wall would have to be placed on at least three sides of the site, and possibly all four, in order to be effective. Because of the geology beneath the Landfill site, a subsurface barrier would have to be placed to a depth of 80-feet to the bottom of the Biscayne aquifer to prevent contaminated groundwater from flowing under or around the barrier. If a low permeability barrier were placed around the Landfill, groundwater may have to be pumped out in order to prevent a hydraulic gradient from forming. Again, the mass loading of contaminants to the groundwater is not reduced by implementing this alternative; but contaminants are contained onsite. Because construction of such a deep trench can not be done using conventional equipment, costs for excavation are very high.

Surface Water Control

Capping is the only alternative that meets the State and Federal regulations for final cover. Because of the relatively large amount of rainfall received in the Landfill vicinity, surface water controls will prevent the infiltration of water into the Landfill and the subsequent formation of leachate. Reducing the permeability of the Landfill cover will reduce the mass loading of contaminants to the groundwater.

The percent reduction in mass loading that is achieved through capping depends on the cover permeability which is applied to each zone. Theoretically, up to 100 percent reduction in mass loading of contaminants could be achieved at the Landfill if a synthetic cover system were installed over all filled areas.

Other surface water controls, such as grading to promote drainage, will also prevent the infiltration of water due to ponding, but are difficult to quantify in terms of reduction of mass loading rates.

Alternative Selection

The only alternative which meets the State and Federal regulations is surface water control (capping). Cover with surface water control is a relatively simple alternative to implement and is the only alternative that reduces the mass loading of contaminants to the groundwater. The other alternatives depend on either natural or artificial mechanisms to reduce or remove the contaminants from the groundwater subsequent to their introduction.

Relative alternative costs range from zero for natural attenuation and stabilization to high for leachate plume control and surface water control. Table 9 compares and summarizes the alternatives in terms of percent reduction in mass loading, relative costs, and their ability to meet the regulatory requirements.

Covering the Landfill and implementing surface water control will prevent water from infiltrating the wastes and forming leachate. A cover that intercepts any water percolating toward the waste is referred to as watertight (EPA 1985). A completely watertight cover would essentially eliminate the mass loading of contaminants to the groundwater due to infiltration. However, because solid waste probably lies in the groundwater, some leachate may still be generated due to the seasonal rise and fall of the groundwater table.

Cover Effectiveness Analysis

Different cover materials will produce different percolation rates and have different costs. A material such as crushed limerock, which is readily available in the Landfill area, has a permeability ranging from 10^{-5} to 10^{-6} cm/sec (Law 1984). Other locally available materials have

TABLE 9

SUMMARY OF ALTERNATIVES EVALUATION

ALTERNATIVE	PERCENT REDUCTION IN MASS LOADING	RELATIVE COST	MEETS REGULATORY REQUIREMENTS
Stabilization	0	0	No
Natural Attenuation	0	0	No
Leachate Plume Management[a]	0	Moderate to high	No
Surface Water Controls	0 - 100%[b]	Moderate to high	Yes

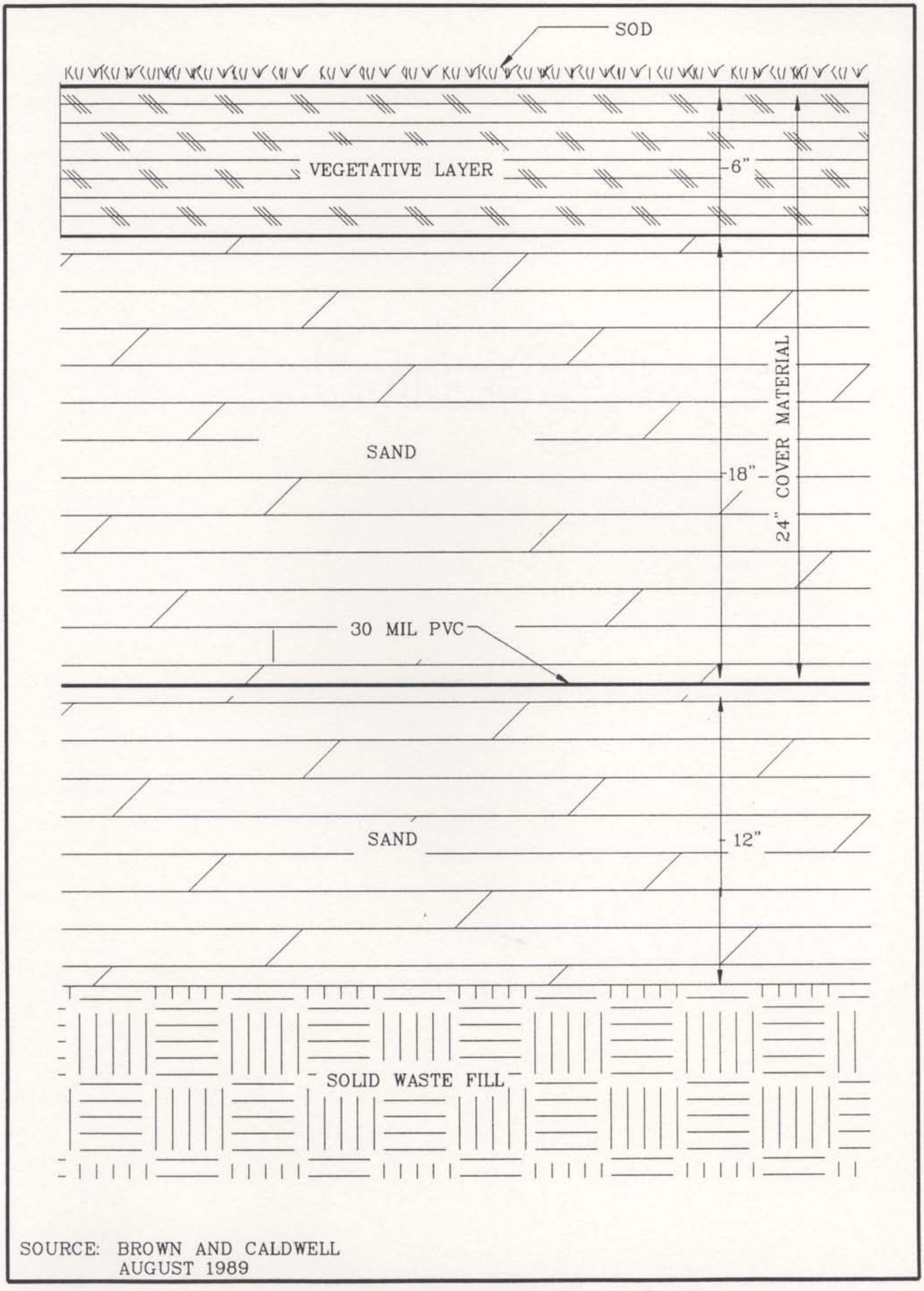
[a] This alternative will not reduce the mass loading rate of contaminants.remove contaminants contributed by the landfill; however,

[b] The percent reduction in the mass loading rate will depend on the cover system which is installed.

higher permeabilities than limerock and therefore would be unsuitable as cover materials. Calcium carbonate sludge from local water treatment plants is available at no cost, however, it is difficult to work with and erodes easily. Clay, which is commonly used as a low permeability barrier soil in landfill projects, would have to be imported and has a permeability of about 10^{-7} cm/sec. If a synthetic membrane, such as polyvinyl chloride (PVC), is utilized, a subbase consisting of a fine-grained material (sand) as well as a protective cover (also sand) will be required. A synthetic cover system consisting of a 12 inch subbase, a 30 mil PVC an eighteen inch protective layer, and a six inch vegetative cover is shown in Figure 9. A synthetic membrane theoretically eliminates the mass loading of contaminants to the groundwater due to the infiltration of precipitation.

The HELP model can be used to determine the resulting percolation rates from clay and limerock cover systems. A percolation rate of zero will be used for the synthetic cover system. To meet State and Federal requirements, a cover system must consist of a minimum of two feet of soils. Figure 10 shows a cover system which consists of two layers: 1) 18-inches of limerock or clay, and 2) 6-inches of topsoil with grass.

Table 10 shows the input conditions for the limerock and clay cover systems. A waste layer was also included in the evaluation, so the modeled landfill profile consists of



SOURCE: BROWN AND CALDWELL
AUGUST 1989

Figure 9. Synthetic Cover Systen

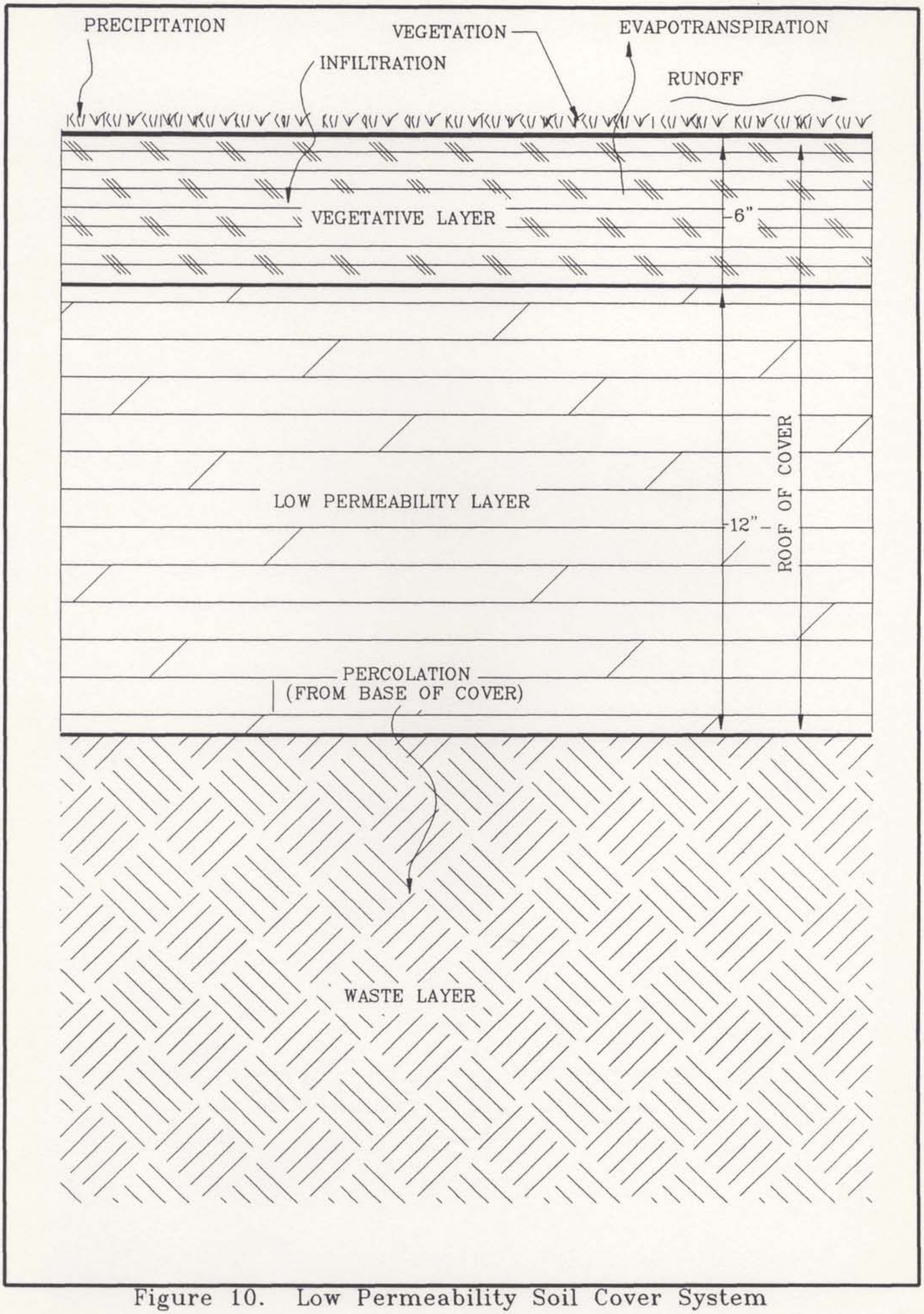


Figure 10. Low Permeability Soil Cover System

TABLE 10

INPUT DATA FOR CLOSURE CONDITIONS

LAYER	HELP SOIL TEXTURE	THICKNESS, INCHES	POROSITY, VOL/VOL	FIELD CAPACITY, VOL/VOL	WILTING POINT, VOL/VOL	INITIAL[a] WATER CONTENT, VOL/VOL	SAT.HYD. CONDUCTIVITY, CM/SEC
Vegetative Cover	3	6	0.4570	0.0831	0.0326	0.0307	9.3×10^{-3}
Limerock	9	18	0.4096	0.2466	0.1353	0.3377	9.5×10^{-6}
Clay	16	18	0.4300	0.3663	0.2802	0.4300	1.0×10^{-7}

a total of three layers. Because the waste layer has no effect on reducing percolation rates, the thickness of the waste in Zone 1 (840 inches) is used to run both the limerock and clay cover systems for all four zones. All other data which was used to run the existing conditions remains the same. The resultant water balances, by zone, are shown on Table 11.

Mass balances are calculated for the three alternative cover systems in the same manner as the existing conditions. It is assumed that the leachate concentrations will not decline initially. This assumption is reasonable, however, it should be recognized that these leachate concentrations will decline over time and will be affected by the selected cover and decreased infiltration. Tables 12, 13, and 14 show the mass balances for all three alternative cover systems.

Cost Estimate

Cost estimates are presented in this section in order to evaluate the relative cost versus the benefits of each cover system. The cost estimates developed do not include clearing, grubbing, regrading or the cost of a stormwater management system. It is assumed that these costs are constant and will not affect the relative cost versus benefit ratios. Tables 15, 16 and 17 show the costs for limerock, clay and synthetic covers, respectively. The unit

TABLE 11

WATER BALANCE FOR CLOSURE CONDITIONS:

AVERAGE ANNUAL TOTALS

COVER	PRECIPITATION, INCHES	RUNOFF, INCHES	EVAPOTRANSPIRATION, INCHES	PERCOLATION[a] INCHES	CHANGE IN WATER STORAGE INCHES
Limerock	46.45	3.19	40.29	2.81	0.16
Clay	46.45	10.92	34.97	0.94	0.38

[a] From the bottom of the landfill

TABLE 12

MASS BALANCE FOR LIMEROCK COVER

ZONE	AREA, ACRE	PERCOLATION RATE, In/Yr	INFILTRATION RATE, MGY	CHLORIDE, mg/L	MASS LOADING, Lb/Yr
1	90	2.8	6.86	1010	57,800
3	61	2.8	4.64	156	6,000
4	192	2.8	14.59	140	17,000
5	99	2.8	7.53	42	2,600
-	442	----	33.62	-----	83,400

TABLE 13

MASS BALANCE FOR CLAY COVER

ZONE	AREA, ACRE	PERCOLATION RATE, In/Yr	INFILTRATION RATE, MGY	CHLORIDE, mg/L	MASS LOADING, Lb/Yr
1	90	1.0	2.44	1010	20,500
3	61	1.0	1.66	156	2,200
4	192	1.0	5.21	140	6,100
5	99	1.0	2.69	42	900
-	442	----	12.00	----	29,700

TABLE 14

MASS BALANCE FOR SYNTHETIC COVER

ZONE	AREA, ACRE	PERCOLATION RATE, In/Yr	INFILTRATION RATE, MGY	CHLORIDE, mg/L	MASS LOADING, Lb/Yr
1	90	0[a]	0	0	0
3	61	0[a]	0	0	0
4	192	0[a]	0	0	0
5	99	0[a]	0	0	0
-	442	---	0	0	0

[a] Theoretical Rate, with no leakage

TABLE 15

LIMEROCK COVER COSTS BY ZONE

ZONE	AREA	QUANTITY[a], CY	COST, $/CY	TOTAL COST, $
1	90	326,600	7.00	$ 2,286,200
3	61	221,400	7.00	1,549,800
4	192	697,000	7.00	4,879,000
5	99	359,300	7.00	2,515,100
Total	442	1,604,300	---	$11,230,100

[a] Additional Quantities are included to account for compaction of Loose Material.

TABLE 16

CLAY COVER COSTS BY ZONE

ZONE	AREA	QUANTITY, SF	COST, $/SF	TOTAL COST, $
1	90	3,920,400	1.70	$ 6,664,700
3	61	2,657,160	1.70	4,517,200
4	192	8,363,520	1.70	14,218,000
5	99	4,312,440	1.70	7,331,200
Total	442	19,253,520	---	$32,731,100

TABLE 17

SYNTHETIC COVER COSTS BY ZONE

ZONE	AREA	QUANTITY, SF	COST, $/SF	TOTAL COST, $
1	90	3,920,400	2.00	$ 7,840,800
3	61	2,657,160	2.00	5,314,300
4	192	8,363,520	2.00	16,727,000
5	99	4,312,440	2.00	8,624,900
Total	442	19,253,520	---	$38,507,000

costs shown are based on local costs for in place materials and include: labor, equipment, overhead and profit.

Selected Alternative

Under existing conditions, the Landfill is contributing to elevated downgradient levels of ammonia, chloride, iron, conductivity and COD. There were no violations of Federal primary drinking water standards in two years of extensive groundwater testing. However, the Landfill is unlined and in direct contact with the groundwater which is the sole source of drinking water for Dade County. Therefore, the contaminant loading to the groundwater must be reduced in a cost-effective, environmentally acceptable manner.

Stabilization and natural attenuation will occur as the Landfill ages and downstream dilution takes place. However, these alternatives do not meet State and Federal requirements for final cover. Leachate plume management does not reduce the contaminant loading to the aquifer, and requires treatment and disposal of contaminated groundwater. Therefore, the only alternative that meets all of the closure objectives for Landfill closure is surface water control with capping, grading and drainage.

Three alternative cover systems were evaluated in terms of mass loading rates to the groundwater and construction costs. The reduction in mass loading rates to the groundwater under closure conditions can be calculated for all three cover systems. The percent reduction in mass loading using a limerock cover as an example is as follows:

percent reduction = (145,400 lb/yr-83,400 lb/yr)/
145,400 lb/yr*100%
= 43%

Therefore, a forty-three percent reduction in contaminant mass loadings can be achieved by installing a limerock cover over the filled areas of the Landfill. Table 18 shows the cost versus benefit for the three cover systems. The limerock cover provides the greatest unit benefit in terms of cost per percent reduction in mass loading.

TABLE 18

COST VERSUS BENEFIT

MATERIAL	REDUCTION IN MASS LOADING, PERCENT	COST, DOLLARS	UNIT BENEFIT, COST PER PERCENT REDUCTION
Limerock	43	$11,230,100	$261,200
Clay	80	$32,731,100	$409,100
Synthetic (PVC)	100[a]	$38,507,000	$385,100

[a] Theoretical value based on no leakage.

CONCLUSION

The State and Federal regulations require a minimum of two feet of soils for landfill closure. Capping with surface water controls is the only alternative which meets these regulations. The regulations do not require a specific permeability for cover materials; therefore, the most cost-effective, environmentally acceptable material should be used.

The environmental impact of the Landfill will be reduced over time as the Landfills stabilizes. The tremendous volume of flow through the Biscayne aquifer also plays an important role in dilution and attenuation of groundwater contaminants. Therefore, the most cost effective alternative utilizes a limerock cap to reduce the percolation of water through the Landfill and the subsequent generation of leachate.

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