A HYDROGEOLOGIC STUDY OF THE LANDFILL EXPANSION IN MONTGOMERY COUNTY, NORTH CAROLINA

By

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A HYDROGEOLOGIC STUDY OF THE LANDFILL EXPANSION IN MONTGOMERY COUNTY, NORTH CAROLINA

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PREFACE

A hydrogeologic exploration of the Montgomery County, North Carolina, landfill property was conducted. Site soils were characterized in terms of hydrology, stratigraphy, engineering parameters, and general suitability for landfill liner or daily cover material. In addition, a search of available literature was made to relate regional geologic characteristics to the hydrologic regime at the site. The initial scope of this study included hydrogeologic modelling of a hypothetical contaminant plume. During the course of my research, however, the fact became apparent that insufficient information was available to conduct a meaningful analysis.

A list of references is included rather than a bibliography. I had initially intended to include a list of readings to provide a quick reference to those who might be interested in geology of the Carolinas, but who would inevitably encounter the difficult task of locating comprehensive and up-to-date sources of information. Fortunately, as this study was nearing its completion, the University of Tennessee Press published the Carolina Geological Society's Fiftieth Anniversary Volume, <u>The Geology of the Carolinas</u>. Readers are referred to this excellent text for an overview of Carolina geology and a comprehensive bibliography.

I wish to express my sincere gratitude to County Administrator Gary McCaskill and the County of Montgomery Commissioners for permission to use the information obtained for the landfill permit application as the springboard for this study. Thank you also to Westinghouse Environmental and Geotechnical Services, Inc., for the opportunity to have worked on this project.

Thank you to the School of Geology at Oklahoma State University. I appreciate the time and effort you have put into building your program, and more, the opportunity you have made available to so many of us. So, to Drs. Stewart, Pettyjohn, Hounslow, Cemen, and Kent, thanks for your help and guidance.

Thank you to Dr. Dennis Coskren, my adjunct committee member and source of sound geological advice. Critical readings of the work in progress were provided by Joe Nestor and Dr. Frank Holloway. Bruce Dickinson talked me through a lot of CAD work and Handex of the Carolinas provided computer time for figures as well as a quiet weekend haven for completing this study. My sincere gratitude to Raymond Saliba, who quietly and easily explained the essential points of the laboratory methods used in this study.

I would like to dedicate this work to the memory of Mike Groves, as fine a geologist and human being as you could meet. Thanks Mike, for the advice you so freely gave, and for the example you provided.

Finally, to my wife Rita, and my children Jason and Amy, your support, tolerance, willingness to bear the extra load, and your love, were invaluable tools in completing this task.

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CHAPTER I

INTRODUCTION

A geologic and hydrologic exploration program evaluated general subsurface conditions in the vicinity of the Montgomery County, North Carolina landfill. The purpose of the study was to characterize the hydrology of the soil and bedrock aquifers on site, and to evaluate the usefulness of site soils as landfill liner. These goals were addressed by: (1) evaluating isotropy and heterogeneity of bedrock and soil aquifers, (2) examining ground-water flow direction, (3) measuring hydraulic conductivity of in-place soils and bedrock, (4) evaluating the importance of fractures in the bedrock flow regime, and (5) evaluating site soils in regards to compactibility and remolded hydraulic conductivity.

The primary emphasis of this study was to characterize the proposed cell-expansion site and the vicinity a short distance downgradient in the ground-water flow path. Secondary emphasis was placed on characterization of the balance of the 209 acres. The study included a review of regional geology, and evaluation of its applicability to characterizing the site.

The subject property is approximately four miles southwest of Troy, Montgomery County, North Carolina (Figure 1). The landfill is southwest of State Road (SR) 1137, approximately one mile north of State Highways 24 and 27 (Figure 2). The site is surrounded by the Uwharrie National Forest, which generally includes all of the Uwharrie Mountains. Approximately 25 acres are currently or have previously been used for landfilling of solid waste; the remainder of the 209-acre site is generally wooded and undeveloped. State Road 1137, a Carolina Power and Light (CP&L) transmission line, and a Rural Electrification Administration (REA) power line traverse the northern half of the property (Figure 3).

Expansion of the landfill is proposed; the area to be occupied would be roughly triangular, bounded on one side by SR 1137 west of the intersection of SR 1137 and the CP&L transmission line, on one side by the CP&L right-of-way, and on the other side by a 300-foot buffer zone from the west property line (Figure 3). Size of the first cell is anticipated to be approximately eight acres.

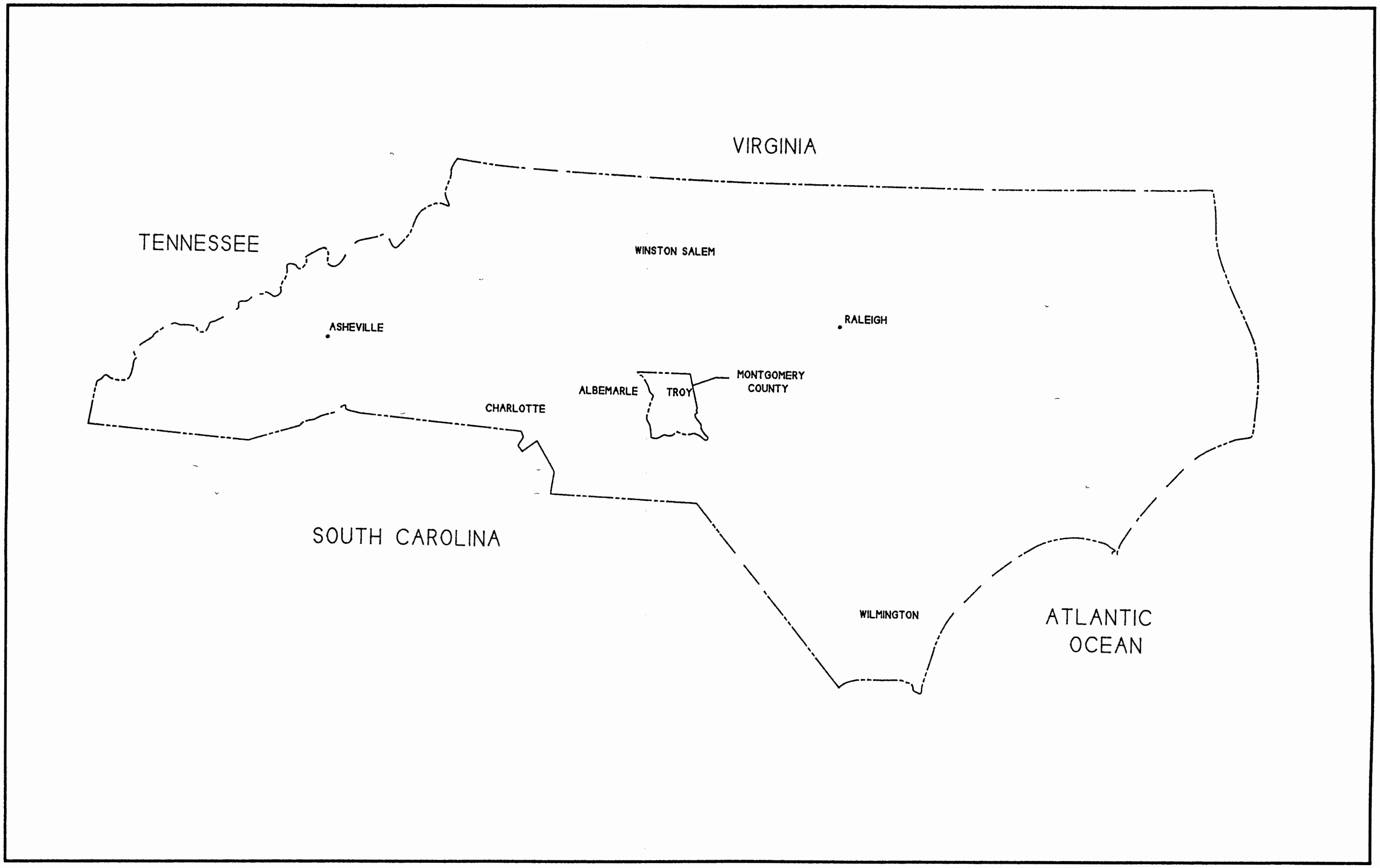


Figure 1. General location of Montgomery County Landfill, near Troy, North Carolina.

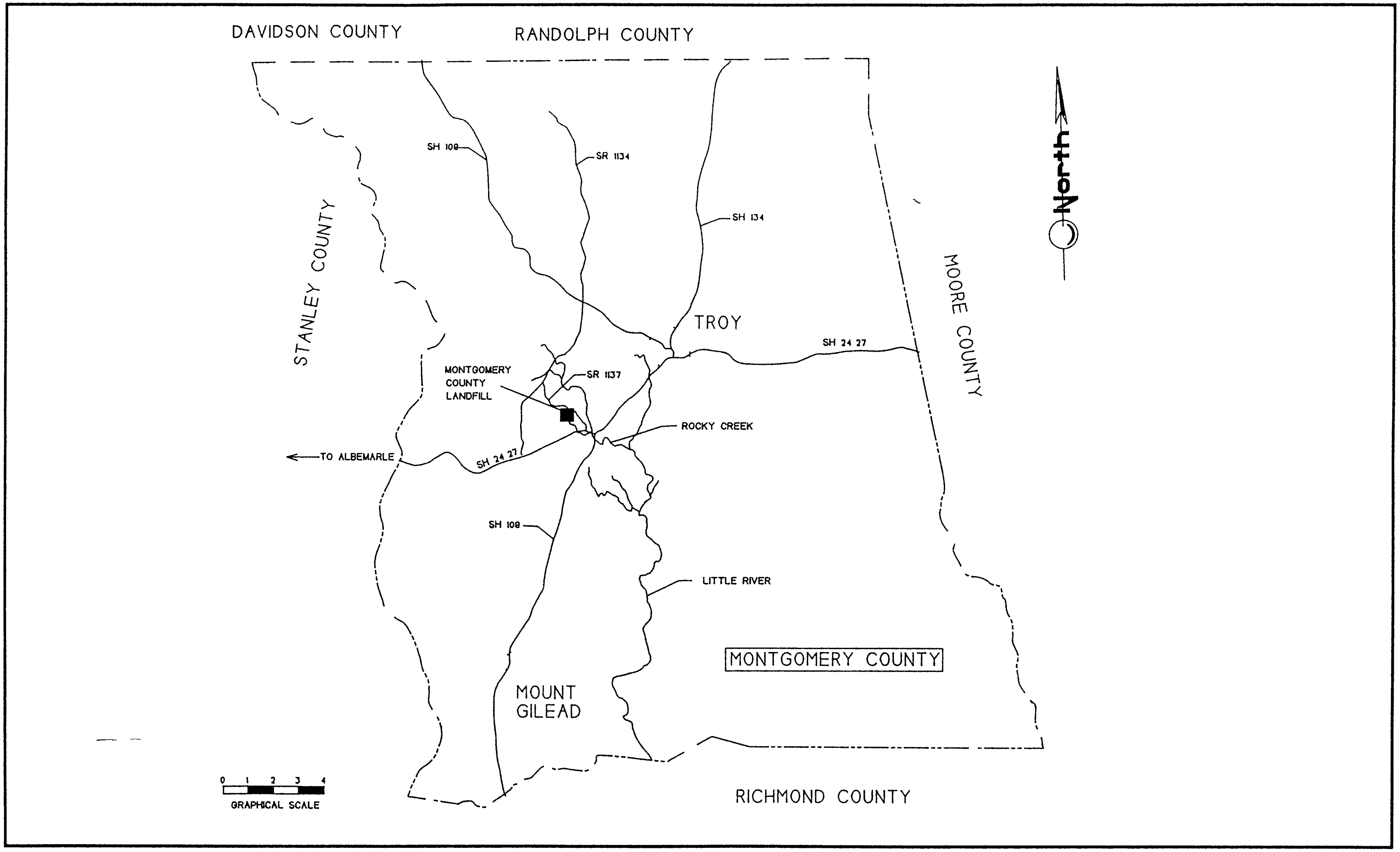


Figure 2. Location of landfill property in Montgomery County, relative to roads and Rocky Creek. Intermittent streams at the landfill flow into Rocky Creek.

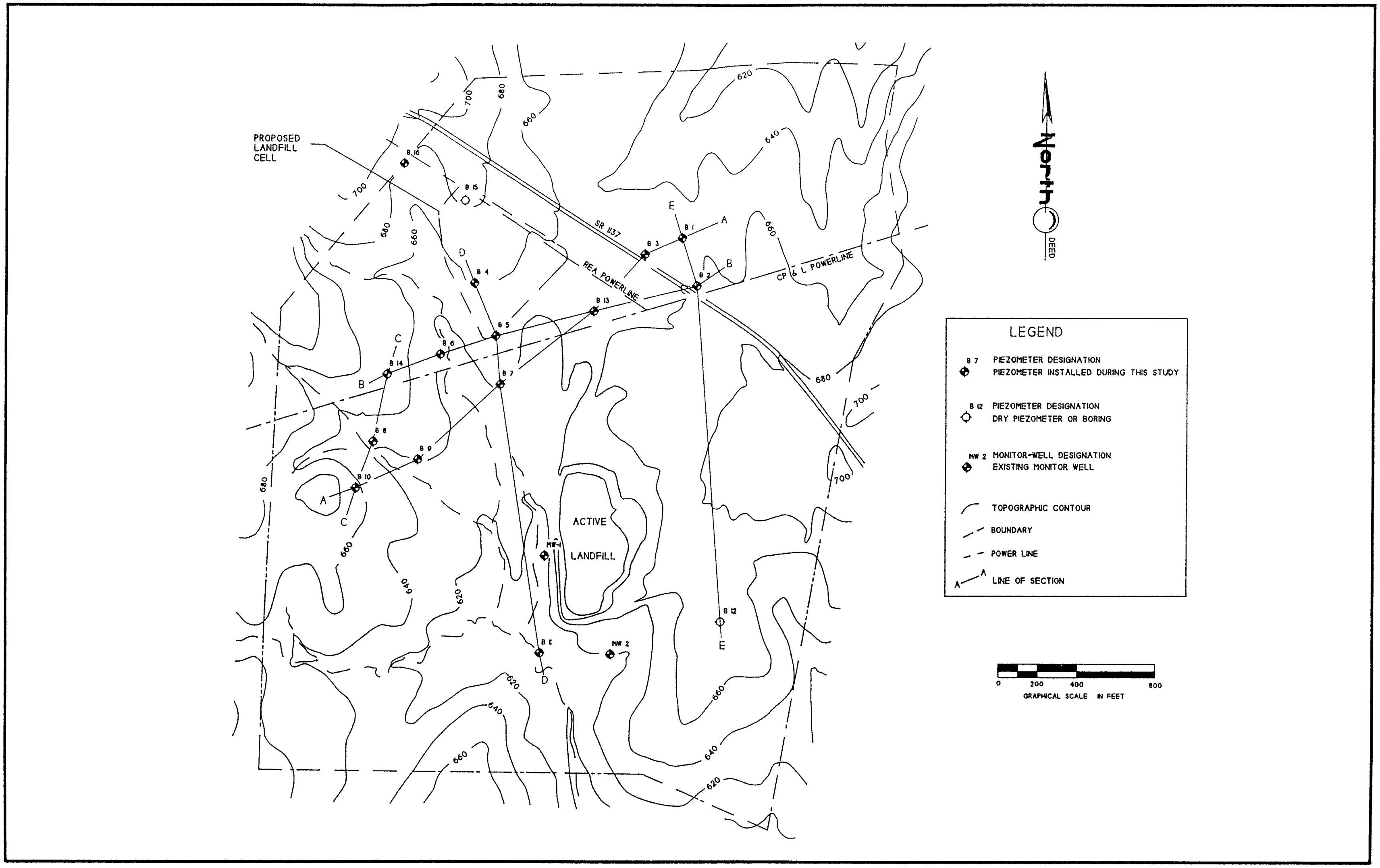


Figure 3. Site plan. Lines of cross-section are shown as Figures 8-12.

CHAPTER II

METHODS

Chapter II presents information regarding the methods in the study; significance of test results is discussed in Chapter V and Chapter VI herein. However, for the convenience of the reader, three tables were included in this chapter; one shows the type and number of tests conducted; one shows the results of laboratory tests; and the other is a qualitative description of Rock Quality Description. A description of test-method procedures is in Appendix A.

Soil-test Borings and Installation of Piezometers

Fourteen preliminary soil-test borings were conducted between December 19, 1989, and January 12, 1990, at the approximate locations shown in Figure 3. Borings were designed to document physical characteristics of soil, determine depth to auger-refusal (assumed to be depth to bedrock), and to penetrate the water table. The water table stabilized for a minimum of 24 hours after boring and before the boring was backfilled with soil cuttings. Piezometer borings were offset 5 to 10 feet from the soil-test borings.

Two additional piezometers were installed on March 2, 1990, to permit monitoring of ground-water elevations upgradient from the tract proposed for expansion of the landfill.

Borings and piezometers were located using site topography and landmarks as references. Locations and elevations of piezometer sites were surveyed and placed on a topographic base map prepared from low-level aerial photographs. Soil- and piezometer-boring locations were designated with a "B-" prefix and assigned a number between 1 and 16, without reference to a grid system or to the order in which they were drilled.

Borings were drilled by a Mobile B-57 or D-50 drill rig mounted on an all-terrain vehicle, equipped with 3.25-inch, hollow-stem, continuous-flight augers. Boreholes were advanced to auger-refusal at depths ranging between approximately 6 feet (B-11) to 44 feet (B-13) below ground surface. "Auger-refusal" is defined as the depth at which the soil-boring equipment used during this exploration could not be advanced. Borings B-1 and B-12 were extended an additional 13.5 and 9.5 feet, respectively, with a tri-cone bit, in an attempt to locate the water table.

Standard Penetration Tests were conducted at selected vertical positions during the soil-test boring, in accordance with American Society for Testing and Materials (ASTM) Designation D-1586-67 (Appendix A); data recovered provided an index for estimating soil strength and relative density. In conjunction with the penetration-testing, split-tube soil samples were recovered for classification and possible laboratory testing. Split-tube soil samples were collected at 2.5-foot intervals in the upper 10 feet, and at 5-foot intervals below 10 feet. Except for B-15 and B-16, bulk soil samples were obtained from each boring for possible evaluation of hydraulic-conductivity attributes of remolded on-site soils. Information of this kind would be useful if soils were to be used as cover material or liner material for the new part of the landfill.

Borings were advanced with 3.25-inch hollow-stem augers, and at standard intervals, soil was sampled with a standard 1.4-inch inside-diameter (I. D.), 2-inch outside-diameter (O. D.), split-tube sampler. The sampler was seated 6 inches to penetrate any loose cuttings, then driven an additional foot with blows of a 140-pound hammer that fell 30 inches. The sum of hammer blows, designated as Standard Penetration Resistance, is an index to soil strength and relative density.

Representative portions of each split-tube sample, stored in glass jars, were classified visually in the laboratory. Laboratory tests of plasticity, grain size, and specific gravity for selected samples were used to confirm visual classifications. Logs of borings, which show descriptions of soils and Standard Penetration Resistances, are in Appendix B.

Hydraulic-conductivity Testing in the Field

To evaluate in-place hydraulic conductivity and stabilized ground-water levels, piezometers were installed at all boring locations with the exception of B-12 (Figure 3). Borings B-12 and B-15 did not intersect the ground-water table at or above depths of 26.5 feet and 22.5 feet, respectively. An unslotted, 2-inch PVC pipe was installed in boring B-12 to allow monitoring for future rises in ground water; a piezometer was installed in B-15.

To obtain data on hydraulic conductivity of shallow materials, water-table piezometers were designed to have a maximal 1-foot, sand-filled "open" hole at the bottom, and the top of the screen at the water table. These design criteria were not satisfied at some localities, due to generally slow ground-water recovery rates and the resulting difficulty in determining the water-table depth while drilling. With the exception of B-15 and B-16, which were installed as soon as boring was terminated, piezometers generally were installed no sooner than 24 hours after boring was completed, so that depth to water would have stabilized. Other piezometers were placed deeper into the aquifer than water-table piezometers, in order to measure hydraulic conductivity at depth; these measurements were compared to hydraulic conductivities of materials near the water table.

The piezometers were developed utilizing an inertial pump to remove a minimum of two piezometer volumes, including the sand-packed volume. Piezometer development consisted of surging the borehole and sandpack, while pumping fluids to remove fine sediments, to enhance well efficiency. Piezometers were allowed to recover and stabilize for a minimum of 48 hours. After the stabilized water level was measured, piezometers were bailed until casing was evacuated or until ground-water recovery rate approximately equaled bailing rate. Rise in water level was measured over time, to a minimal 95 percent recovery of the stabilized ground-water level. In-place hydraulic conductivity was calculated based on procedures outlined in Cedergren (1977, p. 75, Method "e"). In-place hydraulic conductivity of soil ranged from 1.2×10^{-5} (B-2A) to 5.6×10^{-4} (B-9) cm/sec; average in-place hydraulic conductivity of soil was 9.9×10^{-5} cm/sec. Bedrock hydraulic conductivity, tested in two wells, was 7.0×10^{-4} (B-2B) and 1.1×10^{-3} (B-11); average bedrock hydraulic conductivity was 9.0×10^{-4}.

Characteristics of Soil, Measured in the Laboratory

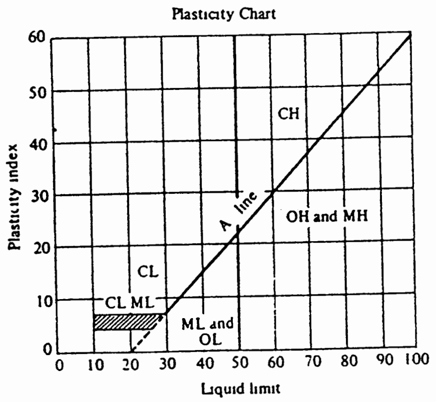
Each split-tube sample was examined visually to estimate grain-size distribution, plasticity, content of organic matter, moisture content, color, and to detect the presence of lenses or seams. Soils were classified in accordance with the Unified Soil Classification System

(USCS). USCS classification provided a visual estimate of soil compactibility. Figure 4 is a chart illustrating USCS major divisions, group symbols, typical names, and laboratory classification criteria. Soil descriptions, USCS classifications, and field results are in boring logs in Appendix B.

Representative soil samples obtained during field exploration were tested in the laboratory to determine natural moisture content, grain-size distribution, Atterberg limits, and specific gravity. These tests evaluated compaction attributes of soils, thus providing information about their suitability for use as a liner for the new cell. Laboratory test results were used to confirm visual classification of soils; in general, laboratory tests showed positive correlation with visual classification. Modification of visual classifications, where necessary, were related to plasticity or sand percentage.

In addition, Standard Proctor compaction tests and laboratory constant-head hydraulic-conductivity tests were performed on selected samples. Compaction and hydraulic-conductivity tests were conducted to measure the optimal soil conditions necessary to obtain minimal hydraulic-conductivity in the soils, using available technology. The number of tests for each method is in Table 1; laboratory test results are in Table 2.

UNIFIED SOIL CLASSIFICATION SYSTEM (ASTM D 2487)

Major Divisions			*Group Symbols*		*Typical Names*	*Laboratory Classification Criteria*		
Coarse-grained soils (More than half of material is larger than No 200 sieve size)	Gravels (More than half of coarse fraction is larger than No 4 sieve size)	Clean gravels (Little or no fines)	GW		Well-graded gravels gravel sand mixtures little or no fines	Determine percentages of sand and gravel from grain size curve Depending on percentage of fines (fraction smaller than No 200 sieve size) coarse-grained soils are classified as follows Less than 5 per cent GW GP SW SP More than 12 per cent GM GC SM SC 5 to 12 per cent *Borderline* cases requiring dual symbols[b]	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4 $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			GP		Poorly graded gravels gravel sand mixtures little or no fines		Not meeting all gradation requirements for GW	
		Gravels with fines (Appreciable amount of fines)	GM[a]	d u	Silty gravels gravel sand silt mixtures		Atterberg limits below A line or P I less than 4	Above A line with P I between 4 and 7 are *border line* cases requiring use of dual symbols
			GC		Clayey gravels gravel sand-clay mixtures		Atterberg limits below A line with P I greater than 7	
	Sands (More than half of coarse fraction is smaller than No 4 sieve size)	Clean sands (Little or no fines)	SW		Well-graded sands gravelly sands little or no fines		$C_u = \frac{D_{60}}{D_{10}}$ greater than 6 $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			SP		Poorly graded sands gravelly sands little or no fines		Not meeting all gradation requirements for SW	
		Sands with fines (Appreciable amount of fines)	SM[a]	d u	Silty sands sand silt mixtures		Atterberg limits above A line or P I less than 4	Limits plotting in hatched zone with P I between 4 and 7 are *borderline* cases requiring use of dual symbols
			SC		Clayey sands sand clay mixtures		Atterberg limits above A line with P I greater than 7	
Fine-grained soils (More than half material is smaller than No 200 sieve)	Silts and clays (Liquid limit less than 50)		ML		Inorganic silts and very fine sands rock flour silty or clayey fine sands or clayey silts with slight plasticity			
			CL		Inorganic clays of low to medium plasticity gravelly clays sandy clays silty clays lean clays			
			OL		Organic silts and organic silty clays of low plasticity			
	Silts and clays (Liquid limit greater than 50)		MH		Inorganic silts micaceous or diatomaceous fine sandy or silty soils elastic silts			
			CH		Inorganic clays of high plasticity fat clays			
			OH		Organic clays of medium to high plasticity organic silts			
	Highly organic soils		Pt		Peat and other highly organic soils			

[a] Division of GM and SM groups into subdivisions of d and u are for roads and airfields only Subdivision is based on Atterberg limits suffix d used when L L is 28 or less and the P I is 6 or less the suffix u used when L L is greater than 28

[b] Borderline classifications used for soils possessing characteristics of two groups are designated by combinations of group symbols For example GW GC well graded gravel sand mixture with clay binder

Figure 4. Unified Soil Classification System. Soil types are designated by group symbol. Plasticity index and liquid limit are used to differentiate between plastic and nonplastic silts and clays.

TABLE 1

LABORATORY TESTS CONDUCTED

Type of Test	Procedure	No. of Tests
Natural Moisture Content	ASTM D-2216-80	35
Grain-size Distribution - Hydrometer and Sieve	ASTM D-422-72	20
Atterberg Limits	ASTM D-4318-83	20
Specific Gravity	ASTM D-854-83	20
Standard Proctor Compaction	ASTM D-698	20
Constant-head Permeability	ACOE EM 1110-2-1906	10

Hydraulic Conductivity, Measured in the Laboratory

Hydraulic conductivity of remolded on-site soils was evaluated by tests on 10 bulk samples of prospective cover/liner material obtained from borings. Remolded samples, compacted 94.7 to 95.2 percent of Standard Proctor (ASTM D-698; Appendix A) maximum dry density, were tested in a permeability cell. Each remolded sample was encapsulated in a rubber membrane and placed in a triaxial-type permeability cell. An effective confining stress of 2 to 4 psi established a tight fit between membrane and sample. The sample was saturated under back-pressure of 60 to 100 psi prior to the constant-head hydraulic-conductivity test. Hydraulic-conductivity tests were performed with effective confining pressures in the range of 2 to 4 psi, and

TABLE 2

LABORATORY-TEST RESULTS

Boring No	Sample Depth (ft.)	Sample Type*	USCS Class	Natural Moisture Content %	% Finer No 200 Sieve (0 075 mm)	Atterberg Limits		Proctor Data		Specific Gravity	Constant Head Hydraulic Conductivity		
						LL	P I	Max Dry Density (pcf)	% Opt. Moisture Content		Molding Conditions		k, cm/sec
											Dry Density (pcf)	Moisture Content %	
B-2	0-5	BAG	ML	24 0	68	42	14	99 3	21 7	2 63	94 3	23 7	2 8x10^{-6}
B-3	0-5	BAG	ML	23 3	71	46	18	102 3	16 8	2 65	97 2	18 8	4 4x10^{5}
B-4	0-5	BAG	ML	22 3	67	31	10	104 8	19 0	2 64	99 8	19 9	5 1x10^{7}
B-7	0-5	BAG	ML	13 9	77	35	8	102 7	20 5	2 69	97 3	21 4	2 3x10^{6}
B-8	0-5	BAG	ML	24 1	66	30	10	108 0	17 0	2 67	103 0	17 6	1 8x10^{5}
B-9	0-5	BAG	ML	29 4	76	32	11	105 3	18 5	2 65	94 7	20 2	2 5x10^{7}
B-10	0-5	BAG	ML	29 4	83	44	16	99 9	21 0	2 64	94 9	23 0	1 3x10^{6}
B-12	0-5	BAG	MH	23 9	84	62	26	96 7	24 0	2 65	91 9	25 2	2 4x10^{6}
B-13	0-5	BAG	ML	14 4	85	40	21	98 3	21 2	2 70	93 4	22 1	4 2x10^{-6}
B-14	0-5	BAG	MH	37 2	90	54	21	94 3	24 0	2 64	89 6	26 0	2 0x10^{5}

* SS = Split Spoon, UD = Undisturbed, BAG = Bulk Sample

** NP = Not Plastic

TABLE 2 (Continued)

Boring No	Sample Depth (ft.)	Sample Type*	USCS Class	Natural Moisture Content %	% Finer No 200 Sieve (0 075 mm)	Atterberg Limits		Proctor Data		Specific Gravity	Constant Head Hydraulic Conductivity		
						LL	P I	Max Dry Density (pcf)	% Opt. Moisture Content		Molding Conditions		k, cm/sec
											Dry Density (pcf)	Moisture Content %	
B-1	8 5	SS	ML	24 4									
B-2	3 5	SS	ML	29 1		41	14						
B-2	6 0	SS	ML	16 5	63					2 64			
B-2	8 5	SS	ML	23 8									
B-3	3 5	SS	ML	25 8									
B-4	3 5	SS	ML	23 7		37	14						
B-4	6 0	SS	ML	23 7	52					2 66			
B-5	3 5	SS	ML	28 5		40	12						
B-5	6 0	SS	CL	18 9	76					2 71			
B-6A	3 5	SS	ML	19 0	79					2 60			
B-6A	6 0	SS	ML	18 3		28	10						
B-7	6 0	SS	ML	28 4									

* SS = Split Spoon, UD = Undisturbed, BAG = Bulk Sample ** NP = Not Plastic

TABLE 2 (Continued)

Boring No	Sample Depth	Sample Type*	USCS Class	Natural Moisture Content %	% Finer No. 200 Sieve (0.075 mm)	Atterberg Limits		Proctor Data		Specific Gravity	Constant Head Hydraulic Conductivity		
											Molding Conditions		k, cm/sec
						LL	PI	Max Dry Density (pcf)	Optimum Moisture Content (%)		Dry Density (pcf)	Moisture Content %	
B-9	6.0	SS	SM	25.4		28	NP**						
B-9	8.5	SS	SM	19.1	35					2.62			
B-10	13.5	SS	SM	28.3		30	NP**						
B-10	23.5	SS	SM	23.4	44					2.62			
B-12	3.5	SS	CL	21.8		45	19						
B-12	6.0	SS	ML	30.3	86					2.65			
B-12	8.5	SS	ML	21.5		28	6						
B-12	13.5	SS	ML	21.3	64					2.60			
B-13	6.0	SS	CL	24.9		41	19						
B-13	8.5	SS	ML	32.0	70					2.71			
B-14	6.0	SS	MH	32.5									
B-14	8.5	SS	ML	38.9		42	12						
B-14	13.5	SS	ML	33.8	84					2.63			

* SS = Split Spoon, UD = Undisturbed, BAG = Bulk Sample

** NP = Not Plastic

hydraulic heads in the range of 200 to 300 cm of water across samples typically 5 to 8 cm long. Inflow and outflow during each test were monitored, and hydraulic conductivity was calculated for each recorded increment. Tests continued until steady-state flow was achieved and relatively constant hydraulic-conductivity values were measured.

Hydraulic conductivity of remolded bulk samples ranged from 2.5×10^{-7} (B-9) to 4.4×10^{-5} (B-3) cm/sec; average remolded-hydraulic conductivity was 9.5×10^{-6}. Remolded-hydraulic conductivity of samples tested is shown in Table 2.

Rock Coring

Bedrock was cored in borings B-2, B-6, and B-13 (Figure 3; Appendix B) with the Mobile B-57 drill rig used in augering. Core drilling was in accordance with ASTM D-2113-70 (Appendix A). A tri-cone bit was used until rock competent enough for coring was encountered. Hard rock was cored with a NX diamond-studded bit attached to the end of a 5-foot, double-tube core barrel. Circulating water removed cuttings and cooled the core bit. Rock-core samples were protected and retained in a swivel-mounted inner tube. Upon completion of each core-run, the core was placed in boxes, in the sequence in which it was removed from the core barrel. Cores were described in terms of lithology, fracture patterns, amounts recovered, and Rock Quality Designation (RQD).

Recovery is length of core retained in the core barrel, in feet, compared to the number of feet cored. RQD is the ratio of the sum of lengths of core segments recovered, with unfractured segments 4 or more inches long, to the total length of the core run (expressed as a percentage). The RQD value applies to rock cored with bits of either an NX or NQ size. Recovery and RQD are correlated positively with rock soundness and continuity. Deere and others, denoted rock quality by RQD value (described by Bieniawski, 1989, p. 37), as shown in Table 3. Core recovery ranged from 0 to 4.75 feet; RQD ranged from 0 to 57 percent, or from less than poor rock quality to fair rock quality. Core descriptions, recovery, and RQD values are shown on the appropriate boring logs.

Soil-moisture Content

Moisture content of a given mass of soil is defined as the ratio of the weight of water in the mass to dry weight of the solid. This test was conducted in accordance with ASTM D-2216-66 (Appendix A). Natural moisture content of soils tested ranged from 13.9 (B-7) to 38.9 (B-14) percent; average natural moisture content was 25.0 percent. Results are presented in Table 2.

TABLE 3

ROCK QUALITY DESCRIPTION

RQD (%)	ROCK QUALITY
90 to 100	Excellent
75 to 90	Good
50 to 75	Fair
25 to 50	Poor

Grain-size Tests

The purpose of grain-size tests is to document particle sizes and distributions of particles in samples of soil; results of grain-sized tests were used to verify visual classification of soils. Grain-size distribution in fractions of soils coarser than a No. 200 (0.075 mm) sieve was determined by passing the sample through a set of nested sieves (ASTM D-422-72; Appendix A). Particles that passed the No. 200 sieve were suspended in solution; the grain-size distribution of this fraction of the sample was determined from the rate of settlement, calculated from specific gravity measurements by a hydrometer (ASTM D-422; Appendix A). The soil fraction passing a No. 200 sieve ranged from 35 percent (B-9) to 90 (B-14) percent; average soil fraction passing a No. 200 sieve was 71 percent. Results are in Table 2.

Soil-plasticity Tests (Atterberg Limits)

Plasticity of soil is determined by testing for Atterberg limits (ASTM D-4318-83; Appendix A). Plastic Index (PI) is representative of this characteristic; it is the difference between the Liquid Limit (LL) and the Plastic Limit (PL). Liquid Limit is the moisture content at which soil will flow as a heavy viscous fluid. Plastic Limit is the lowest moisture content at which soil can be manually rolled into 1/8-inch-diameter threads. Plastic index ranged from 6 in B-12, at 8.5 feet, to 26 in the bulk sample from B-12; average PI was 14.5. Two soil samples, B-9 at 6 feet and B-10 at 13.5 feet, were nonplastic. Test results are in Table 2.

Specific Gravity

Specific gravity is the ratio of the weight in air of a given volume of soil to the weight in air of an equal volume of water. Specific gravity was determined in accordance with ASTM D-854-58 (Appendix A). Specific gravity ranged from 2.60 (B-6A) to 2.71 (B-5); average specific gravity was 2.65. Results are summarized in Table 2.

CHAPTER III

REGIONAL GEOLOGY AND HYDROGEOLOGY

Geologic Terminology for the "Carolina Slate Belt"

Geologic regions in the Carolinas have historically been discussed in terms of geologic belts, employing the structural-lithologic-physiographic nomenclature of King (1955), as modified to emphasize metamorphic characteristics by Overstreet and Bell in 1965 (Horton and Zullo, in Horton and Zullo, 1991, p. 2). In general, terminology herein is in reference to the Geologic Map of North Carolina (Brown and Parker, 1985, 1:500,000). For an overview of the applicability of "belt terminology" in the Carolinas, the reader is referred to the introductory chapter of <u>Geology of the Carolinas</u> (Horton and Zullo, 1991, p. 1-10).

Geologic belts and major geologic features of North Carolina are subparallel to the Appalachian front; generally they trend northeastward (Figure 5). From west to east, these entities include: (1) the Blue Ridge Belt (bounded on the east by the Brevard Fault Zone in North Carolina) and the Murphy Belt, (2) the Inner Piedmont Belt, Chauga Belt,Smith River Allocthon, and Sauratown Mountains Anticlinorium, (3) the Dan River Basin, Charlotte Belt,

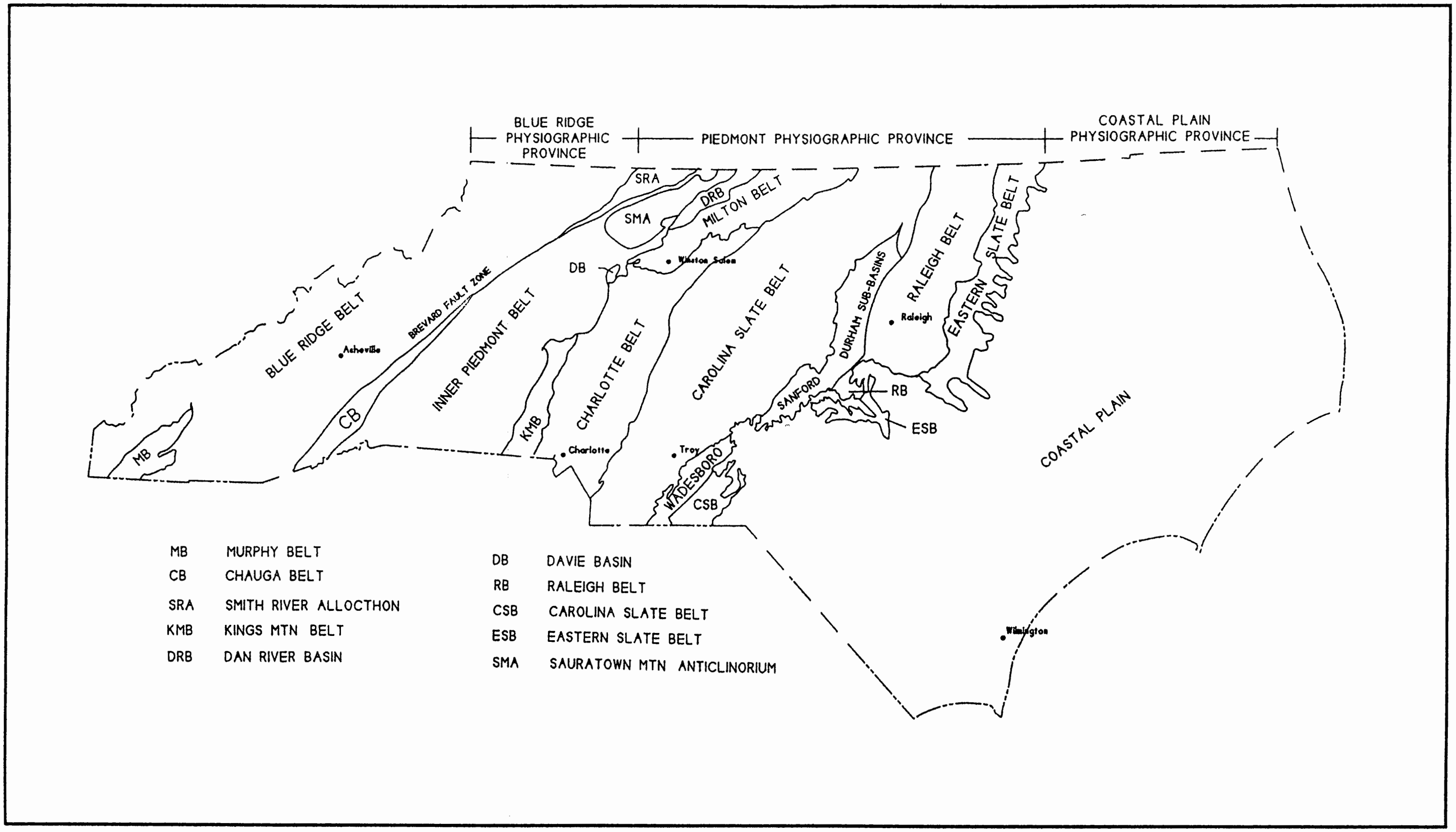


Figure 5. Geologic Features of North Carolina. The Montgomery County landfill is located near Troy, in the Carolina Slate Belt. Physiographic-province boundaries approximate geologic boundaries. (Modified after Brown and Parker, 1985.)

Kings Mountain Belt, and Milton Belt, (4) the Carolina Slate Belt, (5) the Wadesboro Basin and Sanford-Durham Sub-basins, (6) the Raleigh Belt, (7) the Eastern Slate Belt, and (8) the Coastal Plain. The age of deposition of parent rocks in metamorphic belts is considered to have been Late Proterozoic to Early Paleozoic, in the basins, Triassic, and in the Coastal Plain, Cretaceous and younger.

Geologic History of the Carolinas

Reconstruction of the geologic history of the Carolinas is complicated by a paucity of fossils, sparsity of outcrops, complex structural relationships, radioactive "clocks'" having been reset by plutonic metamorphism, and the original rock's alteration by regional metamorphism and plutonic activity. However, for the purposes of this study, a summary by Horton and Zullo (in Horton and Zullo, 1991, p. 9-10) is adequate. Their summary includes the following salient points:

- The Laurentian landmass was deformed and metamorphosed approximately 1 billion years ago, in an event named the Grenville orogeny.
- Continental rifting of Laurentia 750-700 ma (million years ago) resulted in opening of the Iapetus Ocean; rifting was marked by a transition upward from continental to shallow marine deposits. These rocks were overlain by Cambrian to Ordovician shelf deposits, mostly carbonate rock.

- Episodic closing of proto-Atlantic oceanic basins occurred during the Paleozoic Era, associated with collisions among complexes of volcanic island arcs, oceanic crust, other continental masses, and North America. These collisions resulted in accretion of various foreign terranes to Laurentia during four episodes of compression, metamorphism, and magmatism.
- Although evidence of the Late Cambrian-Early Ordovician Penobscottian orogeny is present in Virginia, no evidence of the orogeny has been documented in the Carolinas.
- Paleomagnetic data suggest that many terranes were accreted, deformed, and metamorphosed during the Ordovician Taconic orogeny (470-440 ma).
- Devonian plutonic tectonothermal events occurred in the Carolinas 380-340 ma during the Acadian orogeny; these events seem to have been younger than those associated with the Acadian orogeny in New England. How much territory was accreted to the Laurentian landmass in the Carolinas is not known.
- The Late Paleozoic Alleghanian orogeny occurred during the formation of Pangea (330-270 ma). This orogeny resulted in emplacement of mostly granitoid plutons southeast of the Brevard Fault Zone (Figure 5), amphibolite-facies metamorphism and penetrative deformation in portions of the eastern and central Piedmont, predominantly right-lateral, strike-slip

movement along major faults in the Brevard Zone and the Piedmont, and the formation of the Blue Ridge and western Piedmont through westward thrusting of a composite stack of crystalline thrust sheets.

- Late Triassic rifting associated with opening of the Atlantic Ocean resulted in deposition of rift-basin deposits correlative with the Newark Supergroup. Associated igneous activity in Early Jurassic included diabase dikes in the Piedmont, felsic dikes in the eastern Piedmont of North Carolina, and diabase sills in the Deep River Basin.
- Whether the scarcity of Upper Jurassic and Lower Cretaceous sedimentary rocks on the Carolina coast is due to erosion or nondeposition is not known.
- A Middle through Late Eocene marine transgression deposited predominantly carbonate sediments over the outer Coastal Plain.
- No other significant transgressions occurred until the Pliocene, when a thin set of fossiliferous siliciclastic and carbonate sediments was deposited.
- Marine deposits of the Pleistocene are limited to the outer Coastal Plain. Fluvial terraces associated with glacio-eustatic cycles extend inland.

Prowell and Obermeier (in Horton and Zullo, 1991, p. 318) suggested that crustal compression has occurred since Early Cretaceous. They cited evidence of (1) reverse movement along dip-slip faults, generally parallel to the northeast trend of rock fabric, (2) development of temporally separated embayments and troughs in the Coastal Plain, as indicated by the depositional record, and (3) evidence for Cenozoic uplift and erosion of sediment sources such as the Appalachian Mountains and Piedmont. They also cited studies which documented at least three liquefaction-inducing earthquakes in the last 7200 years. These earthquakes are considered to have been similar in energy and extent to the 1886 Charleston earthquake.

Geology of the Carolina Slate Belt in the Albemarle-Asheboro Area

The geology of the Carolina Slate Belt in the vicinity of Albemarle, Denton, Asheboro, and the Uwharrie Mountains (Figure 6), which generally encompasses the subject area, has been the subject of studies by Conley (1962a, 1962b), Burt (1967), and several other geologists. Because of the good quality of these studies, the low grade of regional metamorphism of rocks, and generally well preserved, relatively abundant outcrops, geology of the Albemarle-Asheboro area is as well understood as the geology of any area in the Piedmont (Butler and Secor, in Horton and Zullo, 1991, p. 67).

Conley (1962a, p. 4) divided rocks in the Albemarle Quadrangle, approximately 7 miles west of the landfill, into three sequences: (1) the Lower Volcanic sequence, consisting of primarily felsic tuffs, (2) the conformably

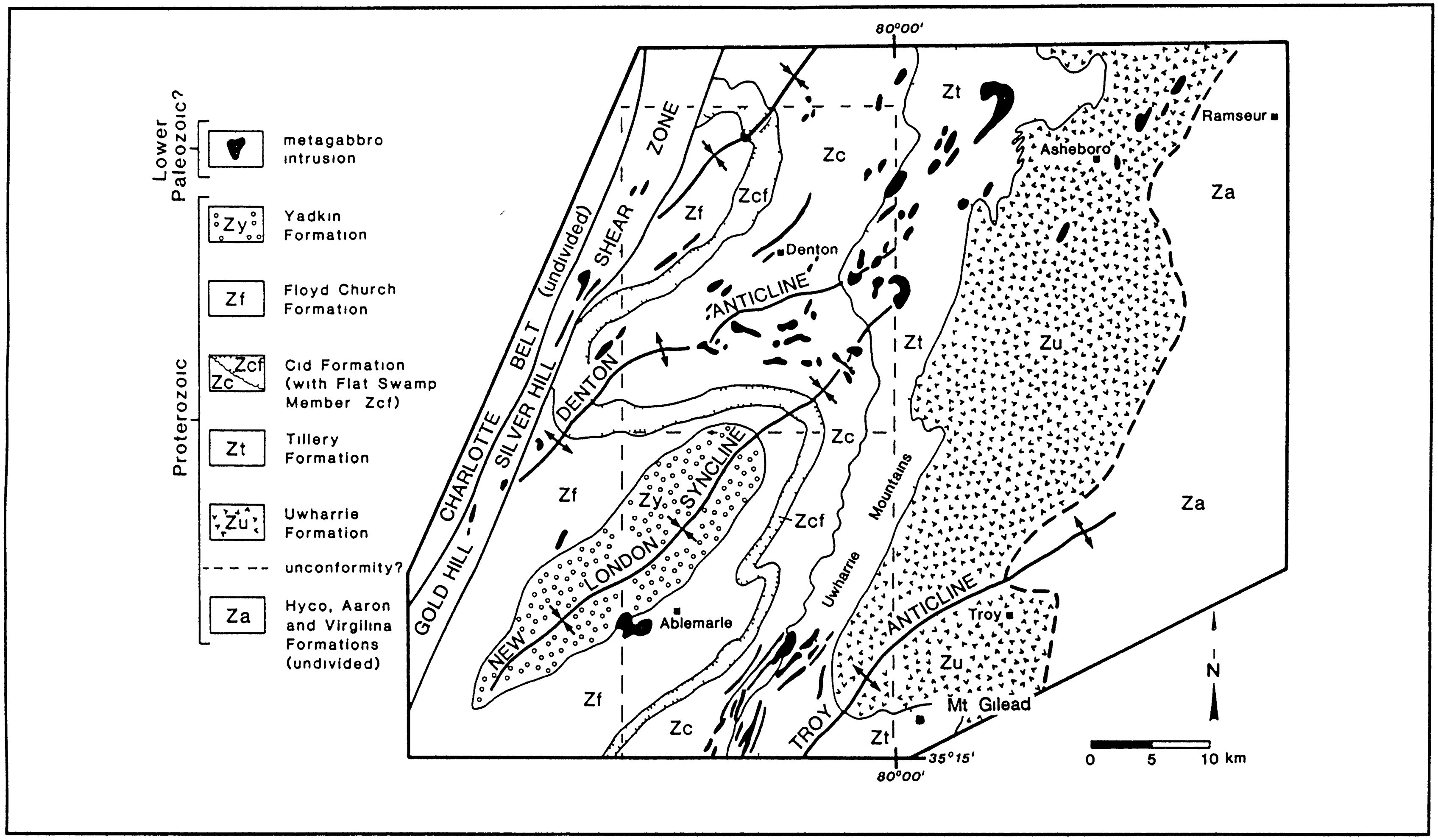


Figure 6. Generalized geologic map of the Albemarle-Asheboro area. (After Butler and Secor, in Horton and Zullo, 1991, p. 68. Reproduced with permission.)

overlying Volcanic-Sedimentary sequence, with a lower argillite unit, an intermediate tuffaceous argillite, and an upper graywacke unit, and unconformable on the graywacke, (3) an Upper Volcanic sequence, comprised of mafic and felsic volcanic rocks, ranging from andesite and basaltic tuffs to rhyolite. These sequences were named formally as the Uwharrie Formation (Lower Volcanic), the Albemarle Group (Volcanic-Sedimentary), and Tater Top Group (Upper Volcanic) by Conley and Bain (1965, p. 117-118).

Subsequent work applied this nomenclature to other areas, but eliminated the Tater Top Group (Butler and Secor, in Horton and Zullo, 1991, p. 69). Rocks formerly comprising the Tater Top Group were included in the Albemarle Group and were considered to have a conformable relationship with the underlying units. The Albemarle Group was considered to be comprised of four formations, which from oldest to youngest are: (1) laminated to thinly bedded metamudstones of the Tillery Formation, (2) the predominantly sedimentary Cid Formation, which contains volcanic members, (3) siltstones and mudstones of the Floyd Church Formation, and (4) volcanic sandstones and siltstones of the Yadkin Formation (Butler and Secor, in Horton and Zullo, 1991, p. 69-70).

In Montgomery County, intrusive rocks are diabase dikes that strike predominantly northwestward and dip almost vertically (Conley, 1962a; Ragland, in Horton and Zullo, 1991, p. 173). Diabase dikes in the Albemarle Quadrangle are 3 to 10 feet thick, are bounded by narrow baked zones with minimal alteration of country rock, and are composed of pyroxene, plagioclase, and amphibole with "... occasional olivine and magnetite." (Conley, 1962a, p. 11). Ages of these dikes were originally considered as being Triassic (Conley, 1962a, p. 11, for example), but paleomagnetic data and radioactive age dating suggested that their intrusion was Jurassic (Ragland, in Horton and Zullo, 1991, p. 171).

The main structural features in the Albemarle-Asheboro area consist of open, southwest-plunging folds, typified by the New London syncline and the Troy anticlinorium (Figure 6). Conley (1962a, p. 13) reported that the anticlinorium appears to be a series of asymmetrical, minor open folds, with wavelengths of 10 to 12 miles. The site of the Montgomery County landfill is approximately 2 miles east of the mapped axis of the Troy anticline.

Conley (1962a, p. 15) reported that two major joint systems exist in the Albemarle quadrangle; one strikes N 45° E to N 60° E with dips of about 85° NW; the other strikes N 60° W with dips of about 80° SW. Systems of minor joints strike N 10° to 20° W with almost vertical dips, and N 30° E with dips of 78° to 85° NW. Diabase dikes in the area generally strike northwestward as mapped by Conley (1962a), Burt (1981), and the Geologic Survey of North Carolina (Brown and Parker, 1985).

Councill (1954) studied the origin and characteristics of formations used as crushed stone, building stone, and flagstone in the Slate Belt. He reported that a tuffaceous argillite was quarried for building stone from two locations 2.75 miles west of Mount Gilead, in southwest Montgomery County (Councill, 1954, p. 16). As mapped (Figure 6) and by description (Councill, 1954, p. 15-16), the rocks seem to be the Tillery Formation. The primary joint system was reported to parallel the axis of folding, and trend N 30° E with a dip of about 58° SE. A secondary joint system was reported to trend N 60° W with vertical dip (Councill, 1954, p. 29). The reported strikes of these joint systems are similar to those observed to the west of the landfill property, and thus suggest that these general trends may be valid for the site. The quarry site is located approximately 12 miles southwest of the landfill.

Hydrogeology of the Piedmont

In the Piedmont, aquifers generally consist of two components, a unit of soil and weathered rock averaging 30 to 60 feet thick, and an underlying system of joints and fractures in crystalline rock (Heath, 1984, p. 46; LeGrand, 1988, p. 202). The ground-water system is recharged in topographically high areas above streams, and is discharged in floodplains through seeps and evapotranspiration, or through seeps and springs on flanks of slopes. In forested areas such as the Uwharrie Mountains, Heath (1984, p. 47) reported that "... most of the precipitation seeps into the soil zone, and most of this moves laterally through the soil in a thin, temporary, saturated zone to surface depressions or streams to discharge." The remaining precipitation seeps through the underlying soil and bedrock.

In the Piedmont, regolith is commonly referred to as residuum or saprolite, which consists mostly of sandy, silty clays, clayey, sandy silts, and silty sands. Residuum is highly weathered, generally in-place residual soil that contains none of the characteristics of the parent rock. Saprolite is a residual soil, weathered less, in which fabric and texture of the parent rock can be recognized. Residuum typically is finer grained than saprolite, and contains more clay, due to a higher degree of weathering. Residuum and saprolite are quite heterogeneous; at some localities, characteristics of the material differ significantly within a few feet or tens of feet.

In the Piedmont and Blue Ridge, porosity of regolith typically ranges from 20 to 30 percent; hydraulic conductivity ranges from 10^{-3} to 10^{-4} cm/sec (Heath, 1984, p. 46). Porosity of bedrock ranges from 0.01 to 2 percent; the range of hydraulic conductivity is similar to that of regolith. Transmissivity of aquifers ranges from 9 to 200 m^2/day and recharge rates range from 30 to 300 mm/yr.

In general, significant lateral movement of ground water is through fractures in bedrock, whereas regolith primarily is a recharge or discharge source for the bedrock aquifer (Heath, 1984, p. 46-47; LeGrand, 1988, p. 203). Bedrock can be described as being composed of two types, one with composition approximately that of granite, and one with composition approximately that of gabbro or diorite (LeGrand, 1988, p. 204). The gabbroic rocks generally produce slightly alkaline ground water, higher in total dissolved solids, primarily calcium carbonate, than the slightly acidic water from granitic rocks. Gabbroic rocks also are more susceptible to dissolution than granitic rocks; gabbroic terrain generally is of lower topographic expression. However, enhancement of fractures by dissolution appears to be limited to basic rocks, such as hornblende gneisses (LeGrand, 1988, p. 205).

CHAPTER IV

PHYSIOGRAPHY

North Carolina is divided into three physiographic provinces: the Blue Ridge, Piedmont, and Coastal Plain (Figure 5). Montgomery County is located in the eastern portion of the Piedmont physiographic province. The Piedmont is characterized by gently rolling hills, dissected by drainage systems that generally flow southeastward across the structural trend of the rocks. Streams in the vicinity of Albemarle are mature (Conley, 1962a, p. 15) whereas streams in the Uwharrie Mountains are in early maturity (Burt, 1967, p. 9).

In the eastern Piedmont, the lowest ground elevations generally range from 300 to 600 feet above mean sea level. The rolling topography of the Piedmont is interrupted, in places, by topographically high areas, such as the Uwharrie mountains. Locally referred to as monadnocks, these topographically high areas are underlain by erosion-resistant rock, such as the Uwharrie Formation.

According to the Troy topographic quadrangle map (USGS, 1982) and a 1991 benchmark survey map (1:2400) prepared in conjunction with this study, the Montgomery County landfill is near the headwaters of a drainage basin of Rocky Creek

(Figure 2). According to Conley (1962a, p. 15), a well developed trellis pattern sub-parallel to the regional structure has developed in rocks of the Uwharrie Formation. Valleys were eroded where rocks are of relatively low resistance and ridges developed upon more resistant rocks (Conley, 1962a, p. 15; Heath, 1984, p. 47).

State Road 1137 is located near a northwest-trending drainage divide that bisects the north half of the property (Figure 3). Drainage north of the road is to the northeast; drainage to the south is to the southeast. Drainage at the proposed expansion cell is southeastward. Site elevations range from 692 feet in the northwest corner of the property to 595 feet near the small creek that exits the landfill property, near the southeast boundary of the site.

CHAPTER V

STRATIGRAPHY AND HYDROGEOLOGY OF THE SITE

Stratigraphy of the Site

As indicated by soil-test borings and rock cores, subsurface materials at the site are residuum, saprolite, partially weathered rock (PWR), and bedrock. Residuum grades downward into saprolite and partially weathered rock, which generally overlies bedrock. Site stratigraphy is shown in Figures 7 through 12; lines of section are in Figure 3. Soil-boring logs, indicating general stratigraphy at each boring location, are in Appendix B.

Soils were divided into four broad categories: (1) silty to sandy clay that contains rock fragments at some localities, (2) clayey to sandy silt with relatively few rock fragments, (3) clayey to sandy silt, commonly with rock fragments, and (4) silty sand that commonly contains rock fragments at some localities. Abundance of rock fragments in silt was selected as a criterion for classification, because silts are the predominant material at depths most likely to be near the landfill bottom. Rock fragments would affect soil suitability as daily cover andliner material. For silt to be compacted by the amount necessary to obtain

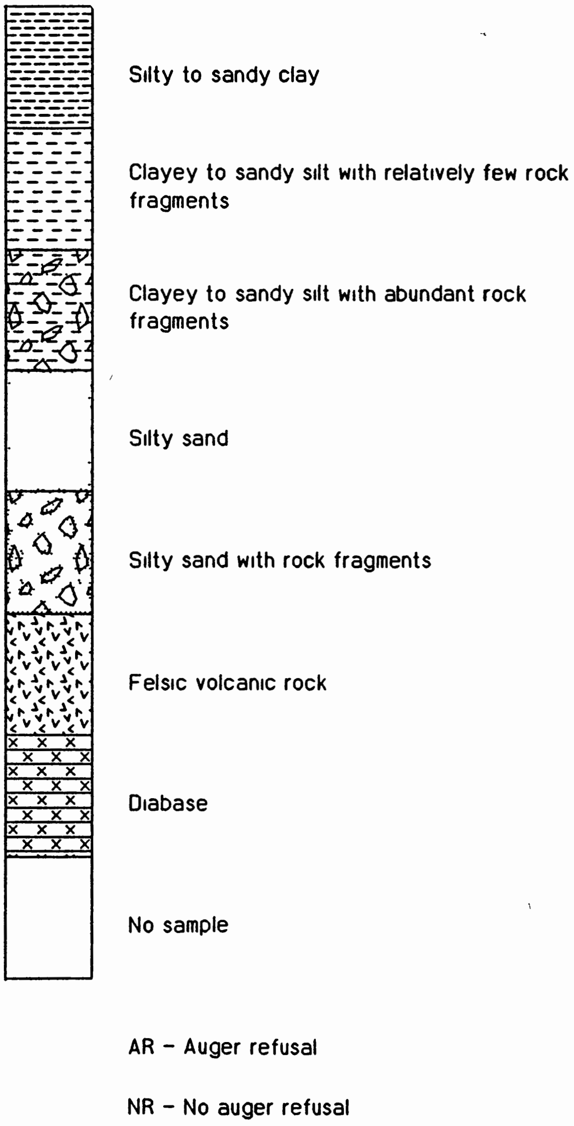


Figure 7. Lithologic symbols for Figures 8 through 12.

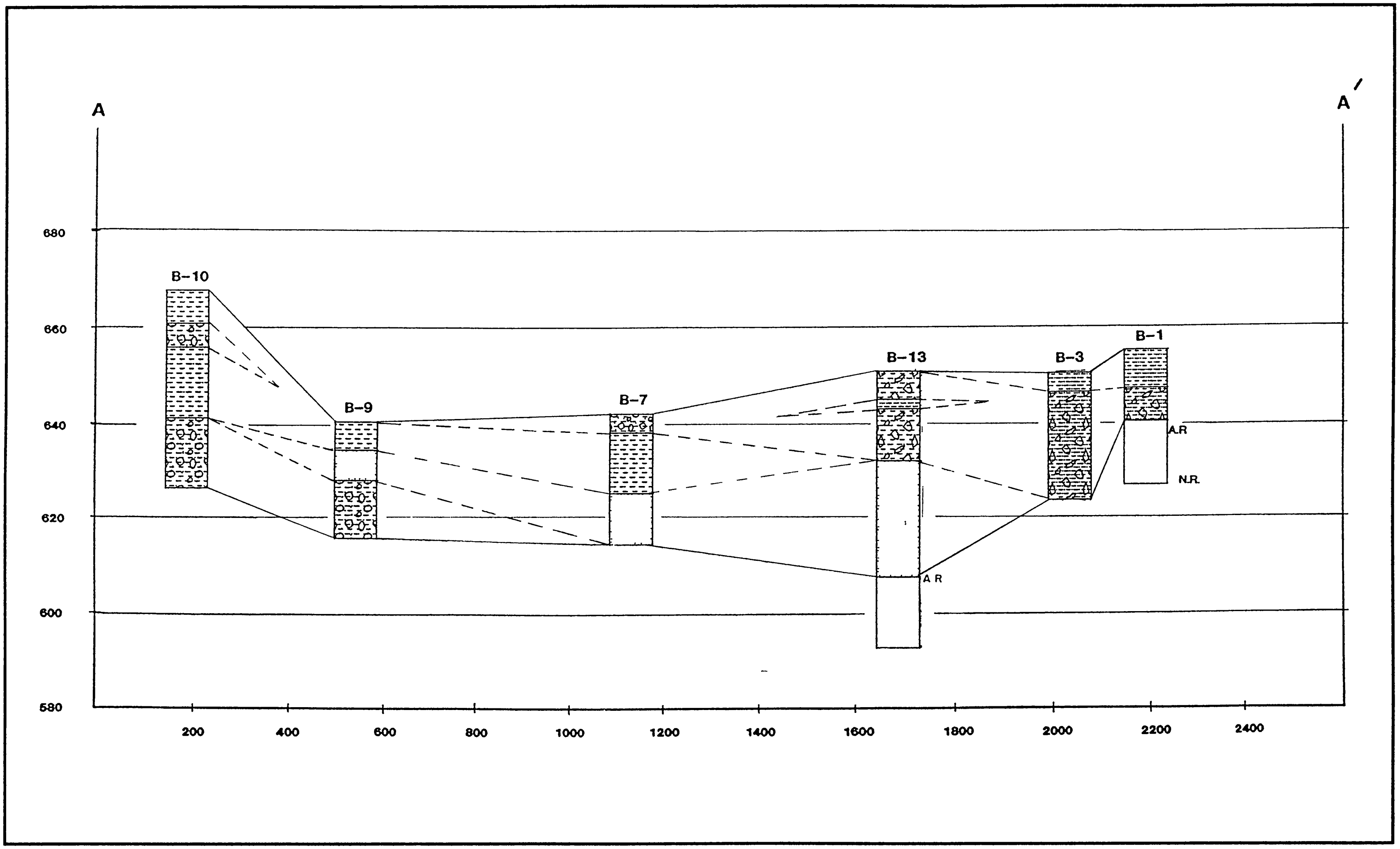


Figure 8. Cross section A-A'. (Graphic scale in feet. Vertical scale is elevation; horizontal scale is relative distance between boring locations.)

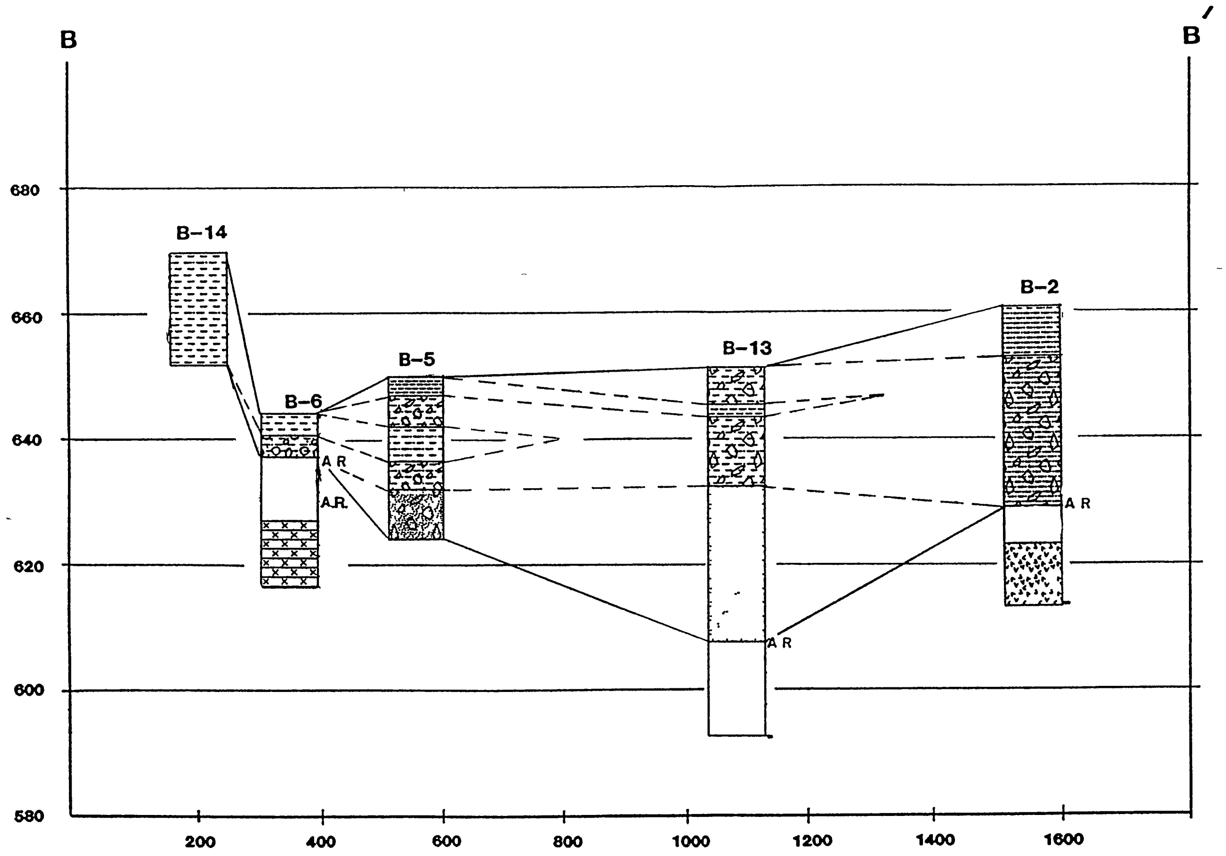


Figure 9. Cross section B-B′. (Graphic scale in feet. Vertical scale is elevation; horizontal scale is relative distance between boring locations.)

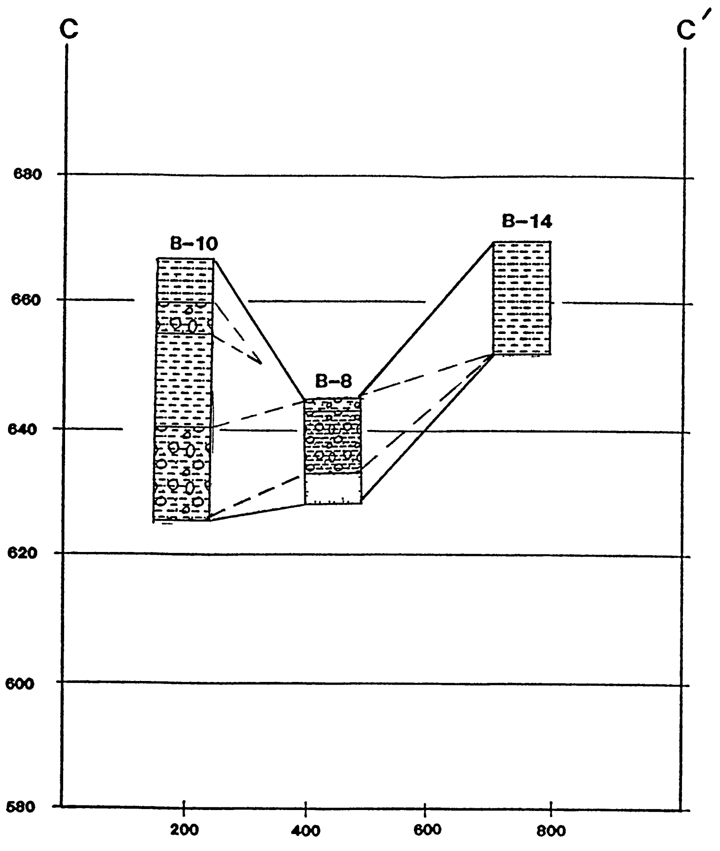


Figure 10. Cross section C-C′. (Graphic scale in feet. Vertical scale is elevation; horizontal scale is relative distance between boring locations.)

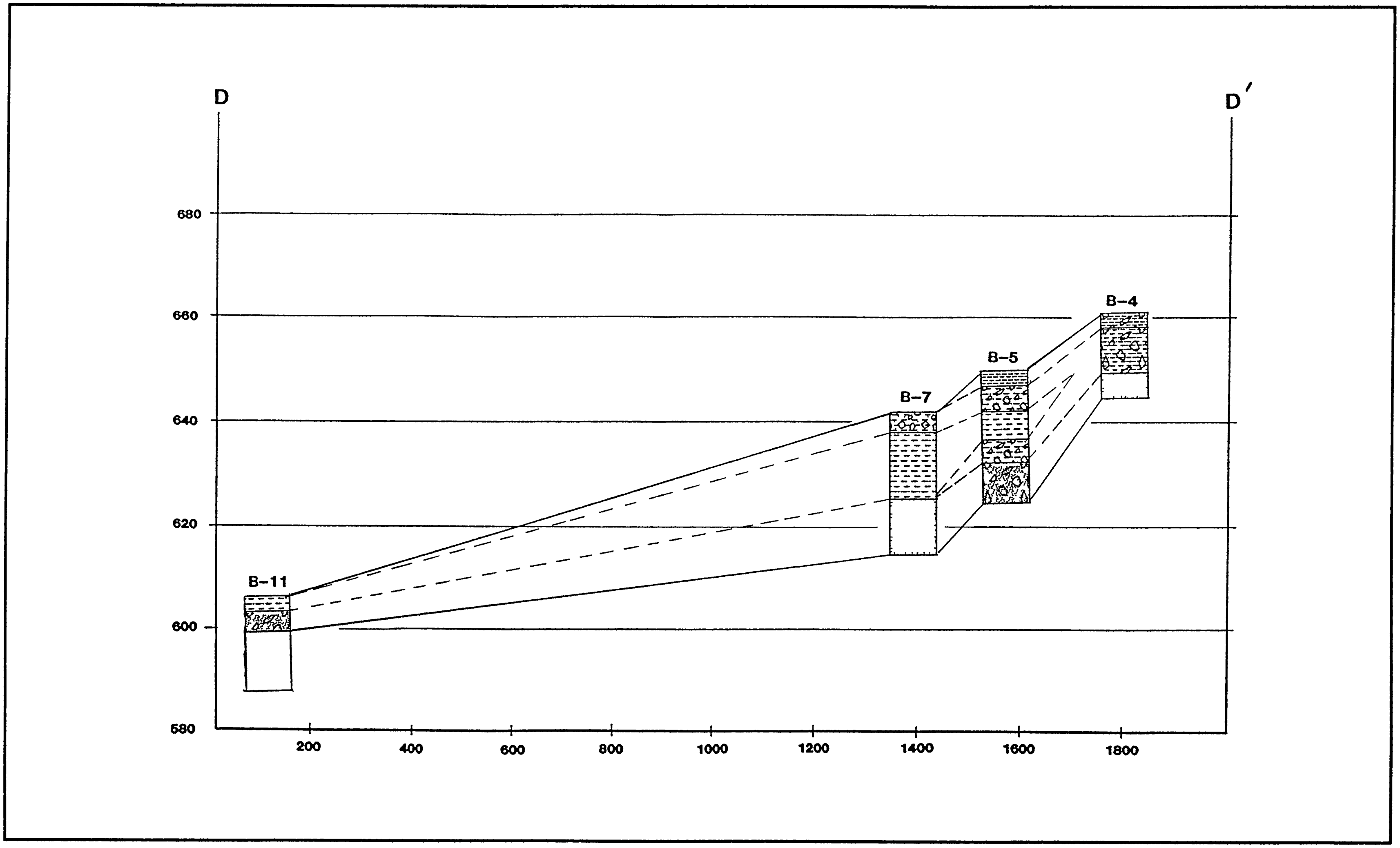


Figure 11. Cross section D-D′. (Graphic scale in feet. Vertical scale is elevation; horizontal scale is relative distance between boring locations.)

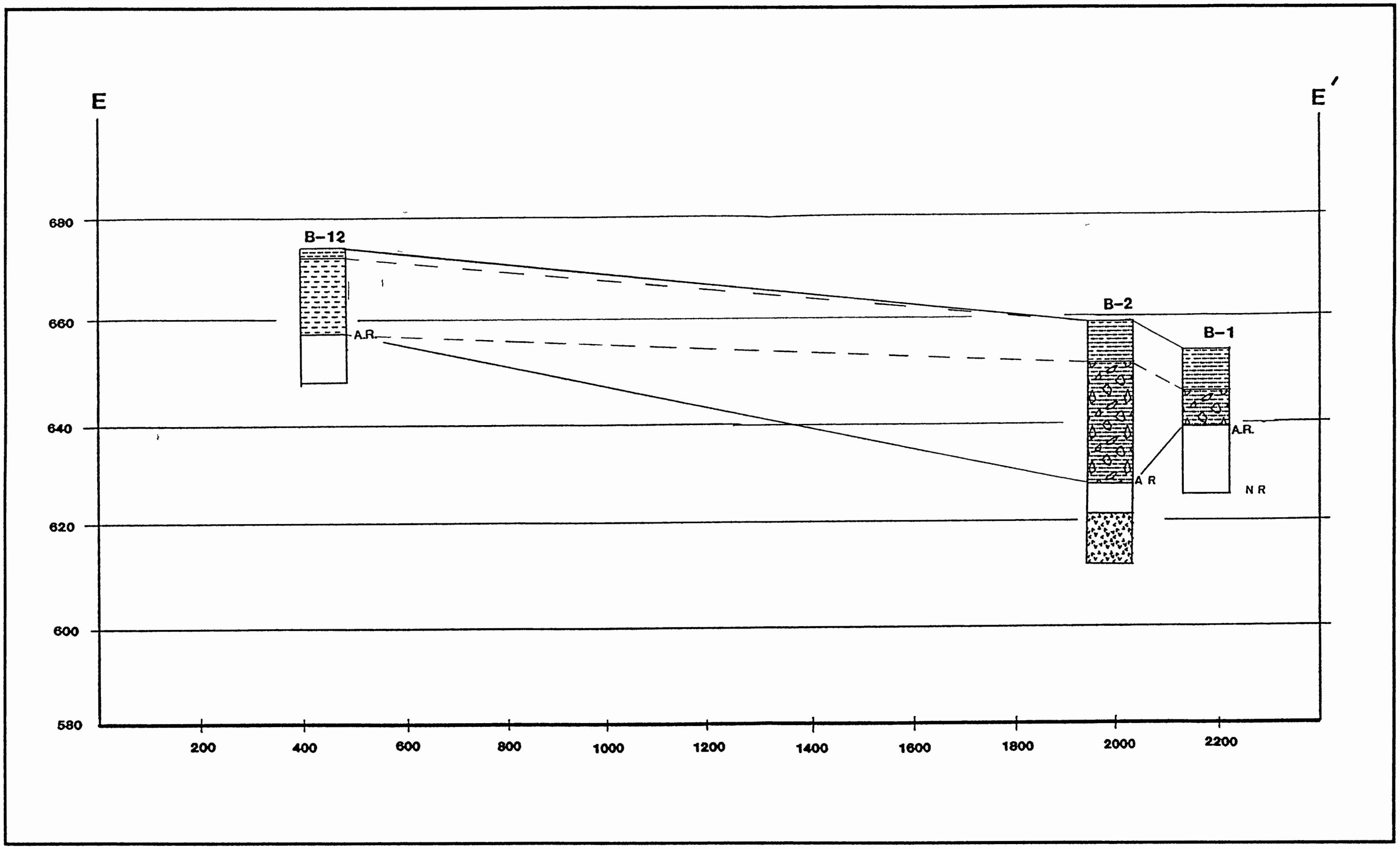


Figure 12. Cross section E-E′. (Graphic scale in feet. Vertical scale is elevation; horizontal scale is relative distance between boring locations.)

the low hydraulic conductivity required to serve as liner material, removal of rock fragments would be necessary. Thus, abundance or scarceness of rock fragments becomes an economic factor, rather than one of particular genetic significance.

Topsoil generally was not encountered within test borings, although shallow zones ranging from 0 to 2 feet deep contained rare carbonaceous materials (B-4, B-7, B-12 and B-14; Figure 3; Appendix B). Organic material consisted of solitary roots or pieces of bark. Based upon site inspection and examination of boring samples, the expectable humic topsoil with a well developed shallow root system seems to be absent.

Near-surface soils (residuum and saprolite) generally consisted of sandy to clayey silt, some of which contained rock fragments; the silts overlaid sandy, clayey silt and sandy, silty clay with abundant rock fragments that ranged from fine to medium gravel. Surficial soil of this description ranged in depth from 3 to 6 feet. Standard Penetration Resistance in the residuum and saprolite ranged from 13 to 81 blows per foot.

A thin layer of clay was at the surface in borings B-4 and B-5; the clay may extend to boring B-13, at the depth of 6 feet (Figures 9 and 11; Appendix B). Boring B-12 had a 2-foot clay layer at ground surface. Except at borings B-7, B-8, and B-13 (Figure 3), at the surface the remaining borings penetrated silt free of rock fragments. In a very broad sense, rock fragments were predominant throughout the soil section in the northeast quadrant of the landfill property (Figures 8 through 12). Soils in the northwest quadrant of the site contained abundant rock fragments, but not in the same abundance as in the northeast quadrant. In contrast, silts on topographically high areas in the south half of the site contained less rock fragments than those in the north. Based on rock-fragment fraction, the southern, topographically-high soils would be more suitable as liner material than the northern soils.

"Partially weathered rock" or "PWR" refers to saprolite that could be penetrated with the augers and drill rig used at the site, but that had a Standard Penetration Resistance of 100 blows per foot or greater. Partially weathered rock is referred to as "fifty-over" material; Standard Penetration Resistance of PWR is shown as 50 over the number of inches penetrated by the sampler (e. g., 50/2, 50/0). Where sampled, these materials typically had the appearance of fine-sandy to coarse-sandy silts or silty, fine to coarse sands. Partially weathered rock was penetrated beneath residuum and saprolite in all borings except B-12, B-14, B-15, and B-16 (Figure 3; Appendix B); PWR extended to auger refusal. Borings B-15 and B-16 were terminated prior to encountering partially weathered rock and before auger refusal. Top of PWR ranged from 3.5 feet (B-11) to 33.5 feet (B-10) below ground surface.

Silty sands were either partially weathered rock or graded into PWR. No sands were recognized in borings on higher elevations. Rather, sands appeared to be thickest on slopes near the center of the site (Figures 8 and 9). Borings that penetrated sand were insufficient to establish a recognizable pattern of rock-fragment distribution in sands. With the exception of boring B-9, sands were in contact with auger-refusal material.

Except for B-15 and B-16, auger refusal was reached at depths ranging between from 6 feet (B-11) to 44 feet (B-14). With reference to hydrology of the site, auger refusal was the depth that approximated top of bedrock, the level of change in flow regime from soil-dominated flow patterns to fracture-controlled flow paths.

As described previously, geotechnical borings were advanced to auger refusal, and piezometer borings were offset from these borings. Some borings for piezometer installation were not drilled to auger refusal, but auger refusal at five of the borings (B-1, B-2A/2B, B-6, B-11, and B-14) was significantly deeper than at the nearby geotechnical boring (Table 4); this could not be accounted for through changes in surface elevation alone. This phenomenon, in conjunction with characteristics observed in the cores, indicate that the bedrock surface is highly irregular.

Sowers (1954, p. 416-3) suggested that the thickness of saprolite, and hence bedrock-surface topography, is influenced by a medium for ground-water flow, such as open fractures in bedrock or relict fractures in soil, which allow ground water to alter bedrock chemically. The irregular bedrock topography at the site can be explained by differential weathering of bedrock along fractures.

Before installation of piezometers, coring of bedrock was attempted at three localities (B-2, B-13, and B-6; Figure 3). Highly fractured, light gray, fine grained, felsic volcanic rock was recovered at B-2; cuttings at B-13, where no core was recovered, were of similar lithology. Rocks at B-2 and B-13 seemed to be Uwharrie Formation. In contrast, the core from B-6 consisted of seemingly unmetamorphosed, dark, finely crystalline, highly fractured diabase. The diabase probably is from a previously unmapped segment of one of the Jurassic dikes known to be in the vicinity of the landfill (Burt, 1981).

TABLE 4

AUGER-REFUSAL DEPTHS - EXPLORATORY BORINGS, COMPARED TO BORINGS FOR PIEZOMETERS

Boring Location	Auger Refusal: Boring (Ft.)	Auger Refusal: Piezometer (Ft.)
B-1	15.0	25.0
B-2A/2B	32.0	35.0*
B-3	27.0	NR @ 20.0
B-4	17.0	NR @ 16.0
B-5	26.0	NR @ 15.5
B-6A/B	7.0	14.0*
B-7	28.0	NR @ 17.0
B-8	17.0	NR @ 10.0
B-9	25.0	NR @ 15.5
B-10	42.0	NR @ 28.5
B-11	7.0	6.0**
B-12	17.0	***
B-13	44.0	NR @ 26.5
B-14	18.0	NR @ 19.5
B-15	NR @ 25.0	***
B-16	NR @ 20.0	***

NR	Did not meet auger refusal.
*	Auger refusal in core hole.
**	Location offset approximately 30 feet west.
***	No offset boring.

Field and Laboratory Hydraulic Conductivity

Hydraulic conductivity of soil was calculated from field and laboratory tests. Field hydraulic-conductivity tests were performed in piezometers, utilizing a rising-head method. Results of field tests indicated that in-place hydraulic conductivities ranged from 10^{-3} to 10^{-5} cm/sec (Table 5). Field testing at B-6, where 95-percent recovery to stabilized water level was not attained in 7.5 hours, did not satisfy the criteria of the test method; hydraulic-conductivity test results at B-6 were considered invalid. Field hydraulic-conductivity tests are useful in evaluating the need for lining of a landfill (to impede leachate from easily entering underlying ground water), in evaluating soils as materials for landfill liners or daily cover, and in providing information necessary for ground-water modelling. Results of field hydraulic-conductivity tests are summarized in Table 5.

Laboratory hydraulic-conductivity testing was carried out on remolded samples of residual silts obtained from test borings and piezometer installations at depths between ground surface and 5 feet (bulk samples); low and high plasticity silts were tested. Samples were compacted in accordance with ASTM D-698 (Appendix A) at moisture contents within 2 percent of optimum (Table 2). This moisture range was judged to simulate the condition of soil likely to be required to achieve maximal compaction (minimal hydraulic conductivity) for liner construction. Samples collected were from soils near the surface, potentially low in hydraulic conductivity, and therefore considered for use as liner or top cover.

TABLE 5

FIELD HYDRAULIC-CONDUCTIVITY TEST RESULTS

Boring No.	Screen Depth (Feet) From-To	Static Water Depth* (Feet)	Ground Water Elevation (MSL)	k, (cm/sec)
B-1	23.0-28.0	16.85	640.72	1.3×10^{-4}
B-2A	17.0-22.0	18.78	644.73	1.2×10^{5}
B-2B**	43.0-48.0	16.74	646.77	7.0×10^{-4}
B-3	13.5-18.5	13.31	640.13	1.2×10^{5}
B-4	10.5-15.5	12.04	650.33	1.8×10^{5}
B-5	10.0-15.0	13.05	640.07	1.7×10^{-5}
B-6**	2.5- 7.5	7.03	638.51	-
B-7	11.5-16.5	12.60	632.45	7.0×10^{5}
B-8	4.5- 9.5	3.85	642.01	4.6×10^{5}
B-9	10.0-15.0	10.89	631.51	5.6×10^{-5}
B-10	23.5-28.5	23.66	644.94	5.3×10^{5}
B-11**	8.5-13.5	3.50	604.18	1.1×10^{3}
B-12	dry	dry	dry	dry
B-13	21.0-26.0	16.12	638.55	2.5×10^{5}
B-14	13.0-18.0	14.64	657.16	5.0×10^{5}
B-15	20.0-25.0	-	-	-
B-16	15.0-20.0	-	-	-

- No test performed or test data invalid
* Ground-water depth at time of the field hydraulic-conductivity test
** Bedrock piezometer

Following completion of the constant-head hydraulic-conductivity tests, representative samples were analyzed for specific gravity, Atterberg limits, and grain-size. Results of laboratory testing of remolded samples, including hydraulic conductivity, porosity, molding conditions, and soil type, based on the Unified Soil Classification System, are in Table 6.

The data indicated that remolded soils tested had a hydraulic conductivity in the range of 10^{-5} to 10^{-7} cm/sec, provided that in-place dry densities were at least 95 percent of the Standard Proctor maximum. North Carolina's regulations require that landfill liner material should have hydraulic conductivities of 10^{-7} cm/sec as a maximum.

TABLE 6

LABORATORY SOIL-MOLDING CONDITIONS

Boring No.	USCS* Class.	Dry Density (pcf)	Moisture Content (%)	Hydraulic Conductivity k, cm/sec	Porosity**
B-2	ML	94.3	23.7	2.8×10^{6}	39.9
B-3	ML	97.2	18.8	4.4×10^{-5}	38.1
B-4	ML	99.8	19.9	5.1×10^{-7}	36.4
B-7	ML	97.3	21.4	2.3×10^{6}	38.8
B-8	ML	103.0	17.6	1.8×10^{5}	35.2
B-9	ML	94.7	20.2	2.5×10^{-7}	36.3
B-10	ML	94.9	23.0	1.3×10^{6}	39.4
B-12	MH	91.9	25.2	2.4×10^{6}	41.5
B-13	ML	93.4	22.1	4.2×10^{6}	41.7
B-14	MH	89.6	26.0	2.0×10^{5}	42.8

* Unified Soil Classification System
** Calculated

Elevations of Ground Water

Ground-water elevations calculated from water-table measurements obtained during and after installation of the piezometers are in Table 7. Ground-water elevations calculated from water depths obtained on March 5, 1990, were used to construct a water-table map (Figure 13). Ground-water flow was assumed to be a subdued reflection of surface topography (LeGrand, 1988, p. 205). The overall direction of flow is almost certainly toward intermittent streams in the central part of the landfill property, and from there generally southeastward. On March 5, 1990, the date the highest water levels were measured, depth to water below ground surface in piezometers ranged from 2 feet to 22 feet over the landfill property; depth to water within the proposed cell expansion at that time ranged between 4 and 9 feet.

Seasonal variations in water table elevations were not examined as a part of this study, but depth to water in the Piedmont typically fluctuates with the seasons. In study of an area approximately 22 miles southwest of the landfill, near Charlotte, North Carolina (Figure 2), maximum lowering of the ground-water table happened during periods of moderate precipitation, i. e., during late summer and early fall; maximum recharge occurred during late winter and early spring, when precipitation was highest (Short, Groves, and Amar, 1990, p. 20). Decline in ground-water elevations during moderate precipitation was attributed to short-duration, high-intensity storms that generated runoff (thunderstorms), increased evapotranspiration, high soil-moisture demand, and interception of precipitation by foliage, during summer and fall. Conversely, ground-water elevations were thought to rise with high precipitation rates, where the soils were saturated, where evapotranspiration was minimal, where foliage was not abundant, and where precipitation was in the form of long duration, low-intensity events, during winter and spring.

TABLE 7

GROUND-WATER ELEVATIONS

		Observed Ground-water Elevations			
Location	TOB	24-Hours	1-22-90	3-05-90	3-21-90
B-1	Dry	ND	640.7	644.5	644.4
B-2A	Dry	646.7	644.7	647.9	649.6
B-2B	Dry	ND	647.2	646.7	650.6
B-3	Dry	641.4	640.1	645.2	645.1
B-4	Dry	652.9	650.3	654.8	653.5
B-5	Dry	643.1	640.1	644.0	642.3
B-6	Dry	ND	638.5	639.5	639.4
B-7	Dry	635.5	632.6	635.9	634.3
B-8	Dry	ND	642.1	643.0	642.4
B-9	Dry	ND	631.6	632.8	632.3
B-10	Dry	659.1	645.0	646.8	646.8
B-11	Dry	ND	604.3	604.5	604.2
B-12	Dry	Dry	Dry	Dry	Dry
B-13	Dry	ND	638.6	643.9	642.0
B-14	Dry	ND	657.7	662.2	660.6
B-15	Dry	ND	ND	Dry	Dry
B-16	671.3	ND	ND	674.8	674.3
MW-1	ND	ND	608.8	611.2	611.5
MW-2	ND	ND	616.0	613.3	614.3

ND No data recorded.

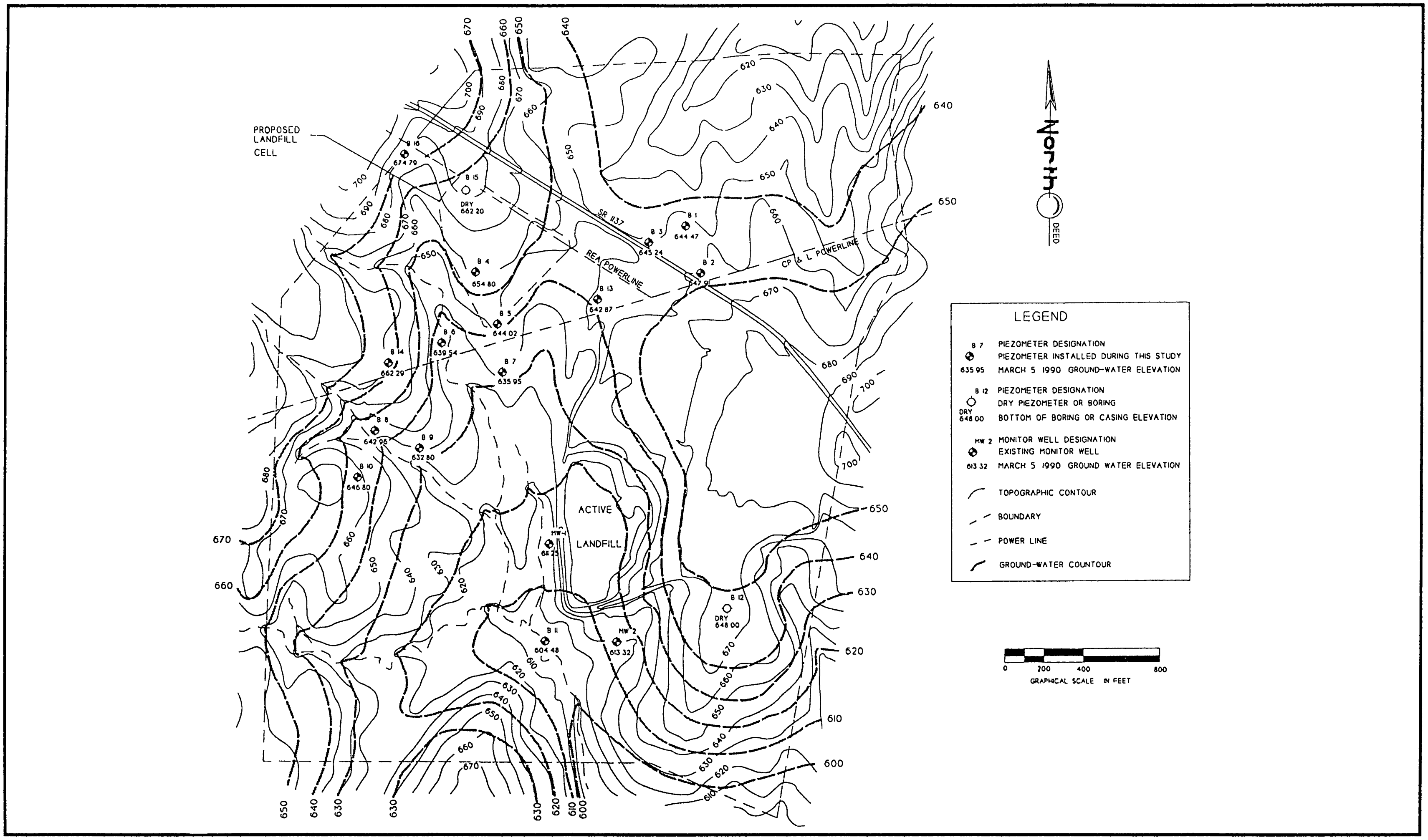


Figure 13. Map of the ground-water table, constructed from water-table measurements obtained on March 5, 1990. Ground-water flow is toward streams. Intermittent streams were flowing on date of measurements, without contribution from overland flow.

Several lines of evidence suggest that ground water is recharged on topographic highs and discharged in topographic lows: (1) No springs were observed during reconnaissance of the area, or during installation of the piezometers, (2) depths to water below ground surface were greater on topographic highs than in topographic lows, and (3) intermittent streams on-site flowed during some periods of field work, without contribution from overland flow. Because the site is near the headwaters of a drainage basin, and no surface water bodies were identified during the site reconnaissance or from aerial photographs, the source of water in the streams is ground water in or near the study area.

CHAPTER VI

SUMMARY AND CONCLUSIONS

General subsurface conditions were evaluated by a geologic and hydrologic exploration program at the 209-acre Montgomery County landfill property, with emphasis on the area of a proposed 8-acre expansion cell. The landfill is located approximately 4 miles southwest of Troy, North Carolina. The primary purpose of the study was to characterize geology and hydrology of the shallow subsurface in the vicinity of the site. Areal geology was examined to assess what impact regional conditions may have on the hydrologic regime.

Fourteen soil-test borings and sixteen piezometers were installed at the site between December 1989 and March 1990. Soil borings were advanced to auger refusal, which was considered to be penetration to bedrock. Split-tube and bulk soil samples were obtained from borings, to classify soils, and to examine their suitability for landfill daily cover or for liner material. Laboratory testing of soil samples included grain-size distribution, specific gravity, Standard Proctor compaction, plasticity, natural moisture content, and hydraulic conductivity of remolded samples.

Site soils were grouped into four broad categories: (1) silty to sandy clay that contains rock fragments at some localities, (2) clayey to sandy silt with relatively few rock fragments, (3) clayey to sandy silt, commonly with rock fragments, and (4) silty sand that contains rock fragments at some localities. This classification is primarily economic, as rock fragments inhibit the compactibility of sediments, but it also illustrates the heterogeneity of site soils. Rock fragments in silt were more common in the north half of the site.

Silt was the most common sediment in regolith; approximately 71 percent (by weight) of the soils tested were in the silt to clay grain size, but silt zones commonly contained thin layers of sand and clay. Silty sands generally overlie bedrock on flanks of ridges. A shallow, thin, sandy to silty clay layer was in three borings in the north-central portion of the site.

The soil and bedrock aquifers at the site are anisotropic with respect to ground-water flow. Flow in bedrock is along fractures; the flow direction is controlled by fracture orientation, and the extent to which fractures are interconnected. Flow in regolith is dictated by two factors, the heterogeneity of the soil and, based upon physiography and bedrock topography, relict fractures. Both criteria induce a preferred direction to ground-water flow. Ground-water flow was generally towards the southeast at the landfill property.

Fourteen piezometers were installed in regolith, and three in bedrock; one piezometer was dry. Rising-head hydraulic-conductivity tests in fourteen piezometers indicated an average in-place hydraulic conductivity of 9.9 x 10^{-5} cm/sec in the regolith, and an average hydraulic conductivity of 9.0 x 10^{-4} cm/sec in two bedrock piezometers; these values are within the range normally expected in Piedmont aquifers. Based on this limited data, bedrock hydraulic conductivity is approximately an order of magnitude greater than that of regolith. North Carolina regulations require that landfill liner material have a maximum hydraulic conductivity of 10^{-7} cm/sec. These data suggest that in-place soils are not suitable for landfill liner material.

Constant-head hydraulic-conductivity tests were performed on 10 bulk samples obtained within the top 5 feet of soil; samples were compacted 94.7 to 95.2 percent of Standard Proctor maximum dry density. Low and high plasticity soils were tested. Hydraulic conductivities of remolded soils ranged from 10^{-5} to 10^{-7} cm/sec, with an average hydraulic conductivity of 9.8 x 10^{-6} cm/sec; conductivity of only 20 percent of the samples tested was 10^{-7} cm/sec. These data suggest that some material suitable for a liner is on site, but importation of low-hydraulic-conductivity soil, or mixing of suitable materials with local soil, may be necessary to satisfy State requirements.

Additional exploration would be required to determine whether the volume of liner material on-site is sufficient.

Three rock cores were attempted to obtain bedrock samples for lithologic classification and rock quality description (RQD). The core at B-2B (Appendix B) recovered no unfractured rock in segments 4 inches long or greater; segments recovered were felsic volcanic rock of the Uwharrie Formation. Rock cuttings at B-13 (Appendix B), where no core was recovered, resembled samples of the Uwharrie Formation. Regional mapping (Figure 6) indicated the Uwharrie Formation to be the predominant rocks in the area. Bedrock is considered to be Lower Paleozoic lithic tuff.

A rock core in B-6 (Appendix B) recovered fine-grained diabase with a RQD of 57 percent, probably from a diabase dike. If this inference is correct, the orientation of the dike was not defined in this study.

The absence of unfractured rock in B-2B and B-6 in conjunction with the lack of core recovery in B-13 indicate that bedrock is highly fractured; a derivative inference is that a well developed bedrock aquifer is present. Although fractured bedrock aquifers commonly are considered to be normal in Piedmont hydrogeology (Heath, 1984, p. 46; LeGrand, 1988, p. 205), additional rock coring would be necessary to confirm the aquifer and to define its extent at the site.

As previously discussed, a higher degree of weathering occurs where a conduit, such as fractures in rock or relict fractures in soil, allows water to contact soil or bedrock. Streams and topographic lows are eroded in less resistant rocks, such as where fractures are present. Rock fragments were less common in the south half of the site than in the north (indicating a higher degree of weathering), and streams and topographic lows were predominant in the south-central portion of the site. These criteria suggest that fracturing is better developed in the southern part of the landfill.

Regional studies by Conley (1962a, p. 15) and Councill (1954, p. 15-16) suggested two major fracture trends exist in the area; one with a northwest trend and one with a northeast trend. Councill also reported that the primary fracture trend near Mount Gilead was parallel to bedding. These studies suggest that a similar fracture pattern may exist in the study area and that the fractures could serve as a first approximation of bedrock ground-water flow patterns in modelling or in designing ground-water tracer studies. Measurement of bedding or fracture planes in bedrock exposed in the on-site streams would refine these approximations.

Transmissivity and storativity, two criteria commonly used in ground-water modelling to predict contaminant flow, were not evaluated by this study. Transmissivity could be calculated over the limited intervals tested for hydraulic conductivity, but would have little significance in terms of overall aquifer behavior, due to vertical and horizontal heterogeneity of site soils. Closely spaced wells near the proposed expansion cell would be desirable to further evaluate aquifer attributes. In particular, pump tests in nested wells, screened at different and similar stratigraphic horizons to evaluate vertical and horizontal transmissivity, would be of value in predicting leachate behavior.

Based upon information obtained during this study, regolith at the landfill property is heterogeneous and anisotropic. Ground-water flow direction in regolith is generally toward the southeast. Ground-water flow direction in the bedrock aquifer is controlled, at least in part, by sets of fractures with undefined orientation; northwest- and northeast-striking fractures are suspected. However, based upon the usual correspondence between soil and bedrock aquifers in the Piedmont, ground-water flow direction in bedrock at the site is thought to be similar to that in the regolith. In-place hydraulic conductivity of soils and bedrock, and hydraulic conductivity of remolded soils tested in the laboratory, are generally greater than the 10^{-7} cm/sec of minimal hydraulic conductivity required by North Carolina regulations for landfill liners.

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APPENDIXES

APPENDIX A

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM) STANDARDS

ASTM D-422*. Method for Particle-size Analysis of Soils

Grain-size distribution of soil particles is considered to be an indicator of certain physical properties, including hydraulic conductivity, compaction characteristics, consolidation, shrink-and-swell potential, attributes of liquefaction and so forth. Soil samples are tested to determine the percentage of particles within a range of sizes. Cumulative percentages of each fraction to the total sample (by weight) are plotted against grain size, and a smooth curve is drawn through the data points.

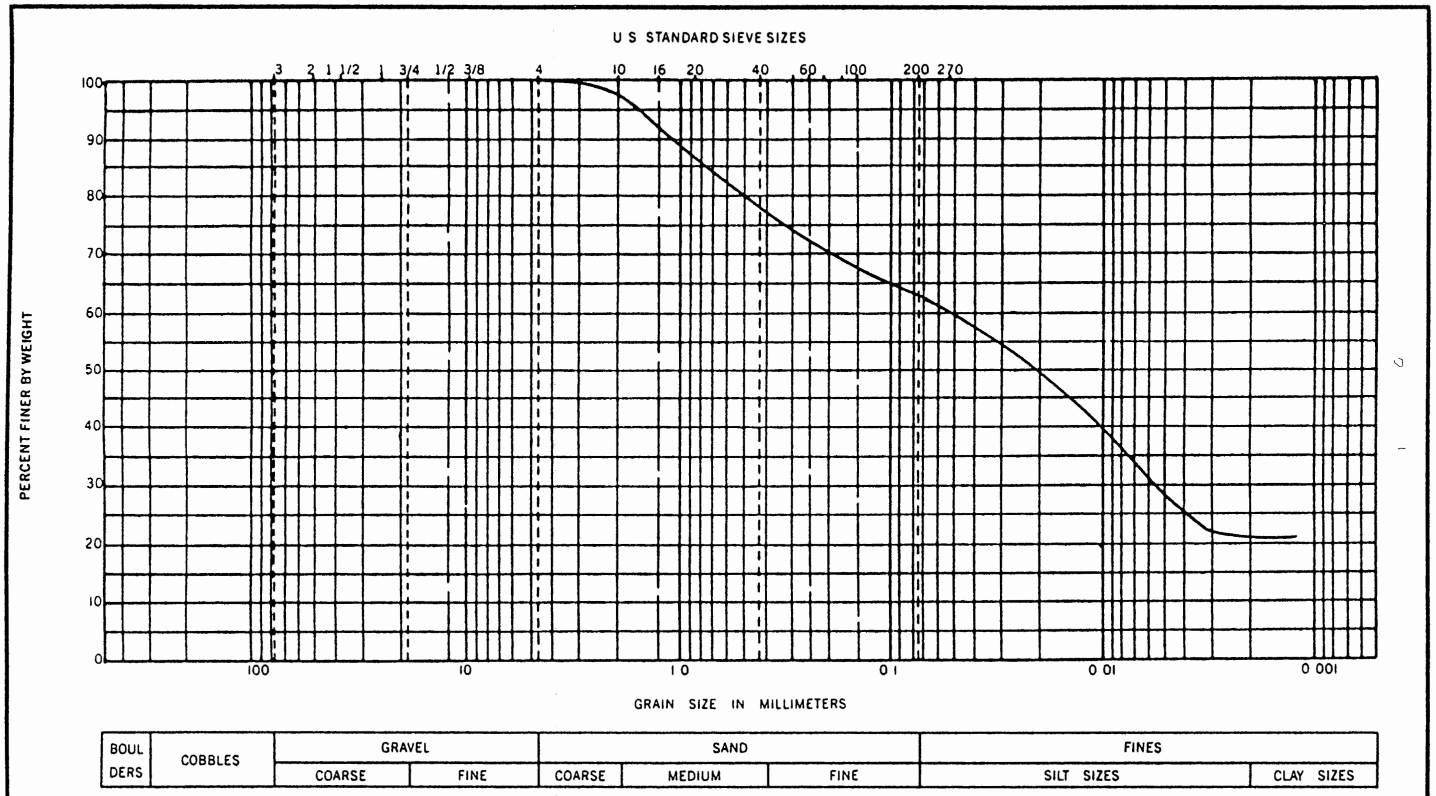
The sample was dried, weighed, and passed through a series of nested sieves, ranging from 88 mm (3-in. sieve) to 0.075 mm (No. 200 sieve) mesh. The fraction retained on each sieve was weighed, percent retained (by weight) on each sieve was calculated, and results plotted versus grain size.

The fraction passing the 0.075 mm (No. 200) sieve was suspended in a distilled water-dispersing agent (Calgon) mixture. Density of the solution was measured with a hydrometer over time; particle size and weights were computed by Stoke's Law. The percentage of each grain size (by weight) was calculated relative to the total sample (sieve and hydrometer), and plotted versus grain size (Figure 14).

ASTM D-698*. Test Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using 5.5-lb (2.49-kg) Rammer and 12-in. (305-mm) Drop

Also known as Standard Proctor Compaction test, this procedure measures the density of a soil sample at various, nonspecific moisture contents, and allows a graphical solution for prediction of maximum-obtainable compaction at specific moisture contents. The results also provide a range of moisture contents at which a level of compaction may be obtained (e. g., 95 percent compaction).

Potential liner-material samples were obtained within the top 5 feet of the ground surface. Each sample was air dried, passed through a 4.75 mm (No. 4) sieve, divided into at least four groups, and brought to different moisture contents. Each group at a particular moisture content was divided into three approximately equal volumes. The fractional volumes were placed in a 4-inch-diameter steel mold, and individually compacted with 25 blows of a 5.5 pound hammer falling 12 inches. The mold was removed and the sample was trimmed to a volume of 1/30 cubic foot. Weight and moisture content of the samples were obtained and plotted on an arithmetic scale. A smooth curve, resembling an inverted "V", was drawn through the data points. Optimum moisture content and maximum dry density were obtained from the x-y coordinates at the apex of the curve (Figure 15).



BORING NO	ELEV OR DEPTH	NAT WC	LL	PL	PI	DESCRIPTION OR CLASSIFICATION
B-2 (S-3)			-	-	-	Orange to Tan Clayey Medium to Fine Sandy SILT

GRAIN SIZE DISTRIBUTION

JOB NO 1356-90-100

Westinghouse Environmental and Geotechnical Services Inc

Figure 14. Example of plotted grain-size distribution of soil, boring B-2.

ASTM D-854*. Test Method for Specific Gravity of Soils

Samples are passed through a No. 4 (4.75 mm) sieve, oven-dried, and weighed, placed in a flask, and covered with distilled water. Entrapped air was removed by the boiling water in the flask and applying a vacuum. After allowing the flask and contents to cool to room temperature, distilled water was added until the contents comprised a known volume; flask, soil sample, and distilled water were weighed. The flask was emptied, cleaned, dried, refilled with distilled water, and weighed. Weight calculations were temperature-compensated. Specific gravity was calculated by:

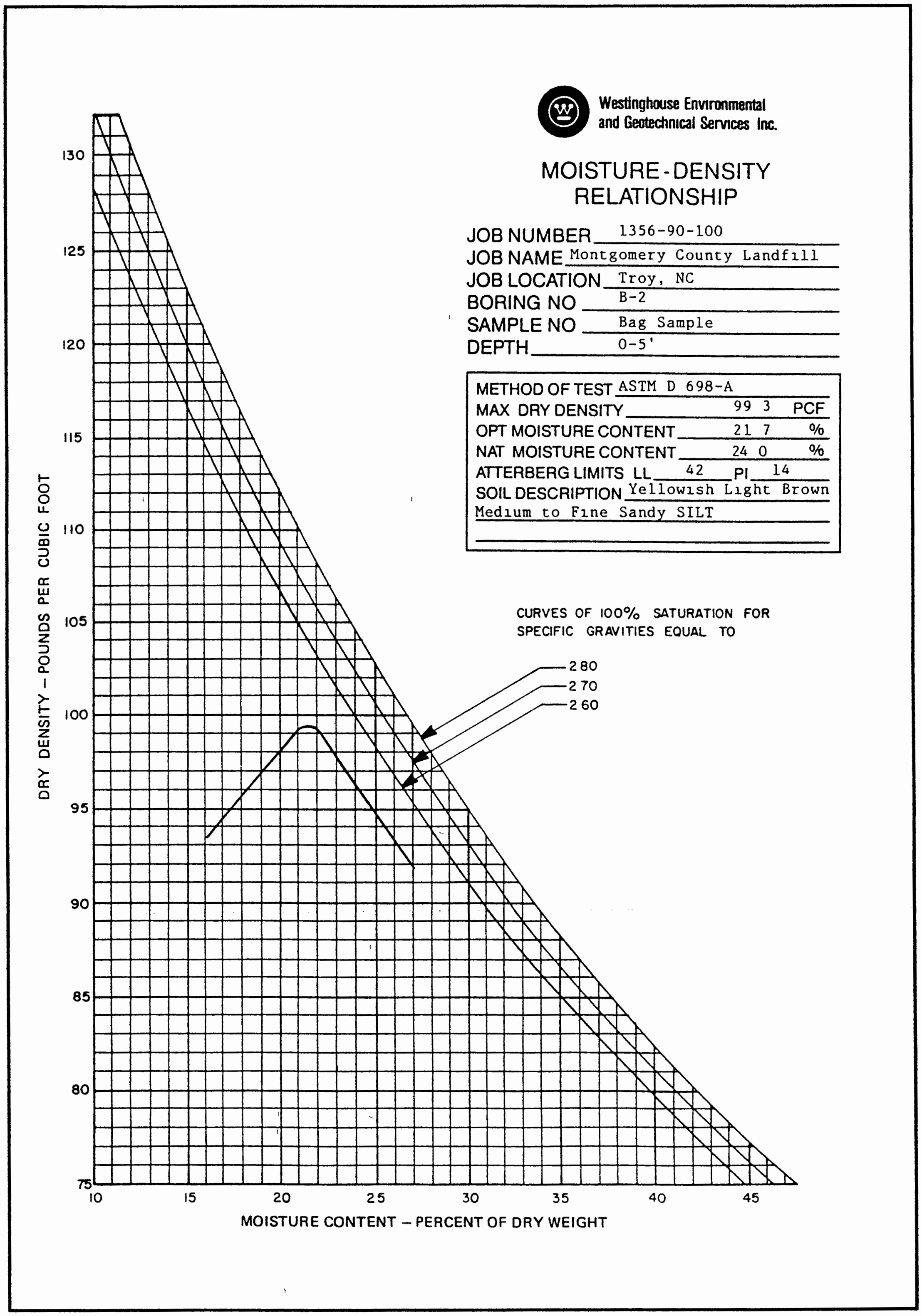
$$\frac{W_o}{W_o + (W_a - W_b)}$$

where:

W_o = Weight of oven dried sample

W_a = Weight of flask and distilled water

W_b = Weight of flask, distilled water, and sample



Westinghouse Environmental and Geotechnical Services Inc.

MOISTURE-DENSITY RELATIONSHIP

JOB NUMBER 1356-90-100
JOB NAME Montgomery County Landfill
JOB LOCATION Troy, NC
BORING NO B-2
SAMPLE NO Bag Sample
DEPTH 0-5'

METHOD OF TEST ASTM D 698-A
MAX DRY DENSITY 99 3 PCF
OPT MOISTURE CONTENT 21 7 %
NAT MOISTURE CONTENT 24 0 %
ATTERBERG LIMITS LL 42 PI 14
SOIL DESCRIPTION Yellowish Light Brown Medium to Fine Sandy SILT

Figure 15. Example of plotted moisture-density relationship, boring B-2. Optimum moisture content: 21.5%. Maximum dry density: 99.2%.

ASTM D-1586*. Method for Penetration Test and Split-barrel Sampling of Soils

Hollow-stem augers were used to advance the boring. At selected intervals, a 1.4-inch inner-diameter, 2.0-inch outer-diameter, steel, split-barrel sampler was attached to drill rods and lowered into the boring. A hammer, consisting of a 140-pound steel cylinder that slides vertically along a drill rod, was attached to the drill rods. The sampler was seated 6 inches with the hammer to penetrate loose cuttings. The sampler was then driven an additional foot by allowing the hammer to fall 30 inches repeatedly. The number of hammer blows required to drive the sampler the last foot is designated as the Standard Penetration Resistance.

ASTM D-2113*. Practice for Diamond Core Drilling for Site Investigation

Competent rock was cored with a diamond-studded bit fastened to the end of a hollow, double-tube, core barrel. The core barrel and bit were attached to hollow drill rods. The device was rotated at high speed by the drill rig; water was circulated through the drill string to remove cuttings and cool the bit. Cored rock was protected and retained in the swivel-mounted inner core barrel. At completion of each core run, the core was removed, labeled, and placed in boxes.

ASTM D-2216*. Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-aggregate Mixtures

Natural moisture content of soils was determined from samples obtained during drilling. Samples were placed in sealed jars to prevent moisture loss through evaporation. Samples were weighed and dried in an oven at approximately 110° Centigrade. Samples were dried for approximately 24 hours, and weighed. Moisture content was calculated by subtracting weight of the dried sample from weight of the moist sample and dividing by weight of the moist sample.

ASTM D-4318*. Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

Results of this procedure are often referred to as Atterberg Limits; they are a measure of soil plasticity. Plastic index (PI) is a range of moisture content over which the soil deforms plastically. Plastic index is defined as the liquid limit minus the plastic limit. Liquid limit (LL) is the moisture content at which the soil will flow as a heavy, viscous fluid; plastic limit (PL) is the lowest moisture content at which the soil can be manually rolled into threads that are 1/8 inch in diameter.

To determine plastic limit, samples were air dried, and passed through a No. 4 (4.75 mm) sieve. Small quantities of water were added to the sample until it could be manually rolled into 1/8-inch diameter threads and would break into 1/8- to 1/3-inch-long fragments if rolling continued. If the sample crumbled at a diameter larger than 1/8 inch, it was below the plastic limit; if the sample could be rolled thinner than 1/8 inch, it was above the plastic limit.

To determine liquid limit, samples were air dried, and passed through a No. 4 (4.75 mm) sieve. The sample was moistened and placed in a liquid-limit dish. A metal, V-shaped in cross section, device was used to halve the sample, with an approximate 1/4-inch separation between the halves. The dish and sample were dropped 1 cm repeatedly. Liquid limit was the moisture content at which the separation was closed along a distance of 1/2 inch with exactly 25 blow counts (drops). Liquid limit can be calculated by performing the test at multiple moisture contents, and plotting water content against the log of blow counts.

* In the text, references to ASTM methods commonly show a dash, followed by a two-digit number, after the designation shown in this appendix; the number following the dash indicates the year of adoption of the method as a standard, or the year of revision of the standard.

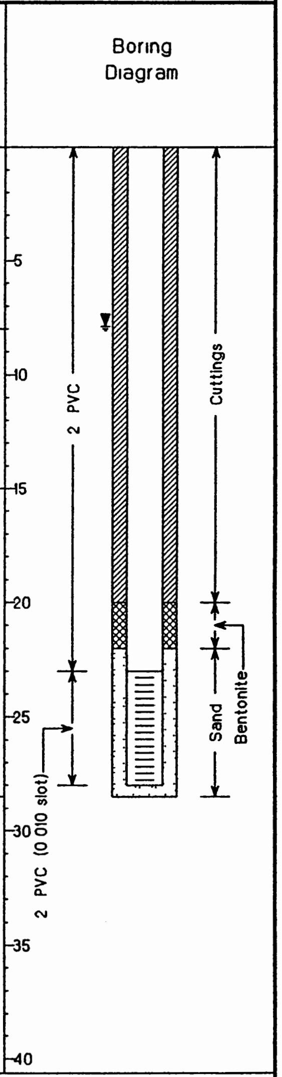
APPENDIX B

BORING LOGS

BORING LOG: B-1

	Drill Date **January 3, 1990**	Use **Piezometer**
Location **Montgomery County Landfill, NC**		
Owner **Montgomery County**	Address **Troy, North Carolina**	
Drilling Method **Hollow Stem Auger**	Hole Diameter **8 in**	Hole Depth **28.5 ft**
Sampling Method **Split-tube**	Casing Length **23 ft**	
Static Water Level **7.9 ft**	Screen Length **5 ft**	Well Depth **28 ft**

Depth	SPR (bpf)	Geologic Description
0–8	12 34 24	Brown-Orange-Gray Stiff to Hard Slightly Sandy SILT - occasional rock fragments (ML)
8–15	32 50/3	Very Hard, Sandy SILT with rock fragments (ML)
15–28		Auger refusal at 15 feet in preliminary boring No blow counts or samples with offset boring.
28–		Offset boring advanced to 25 feet without refusal



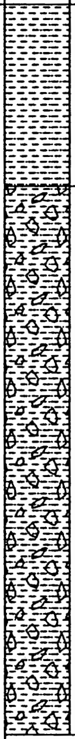
Geologist Dan Short	Driller Westinghouse (WEGS)

BORING LOG: B-2A

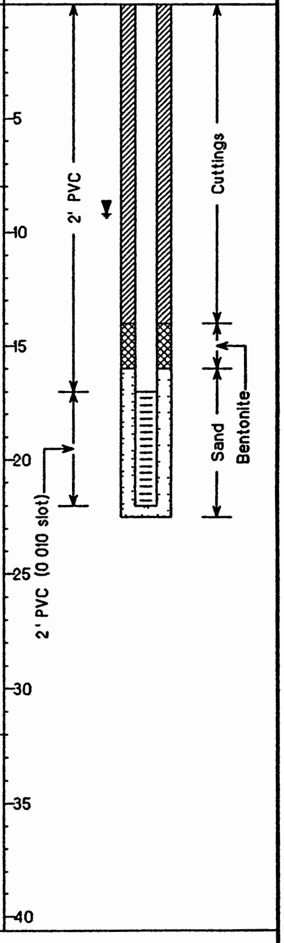
	Drill Date	Use **Piezometer**
Location **Montgomery County Landfill, NC**		
Owner **Montgomery County**	Address **Troy, North Carolina**	
Drilling Method **Hollow Stem Auger**	Hole Diameter **In**	Hole Depth **32 ft**
Sampling Method **Split-tube**	Casing Length **17 ft**	
Static Water Level **9 2 ft**	Screen Length **5 ft**	Well Depth **22 5 ft**

Depth	SPR (bpf)	Geologic Description
	7	Orange-Gray Firm to Stiff Medium to Fine Sandy SILT (ML)
5	13	
	14	
10	13	Orange-Gray, Stiff to Very Hard Medium to Fine Sandy SILT with Rock Fragments (ML)
15	35	
20	20	
25	14	
30	70/1	
	50/0	Auger refusal at 32 feet
35		
40		

Graphic Log



Well Diagram

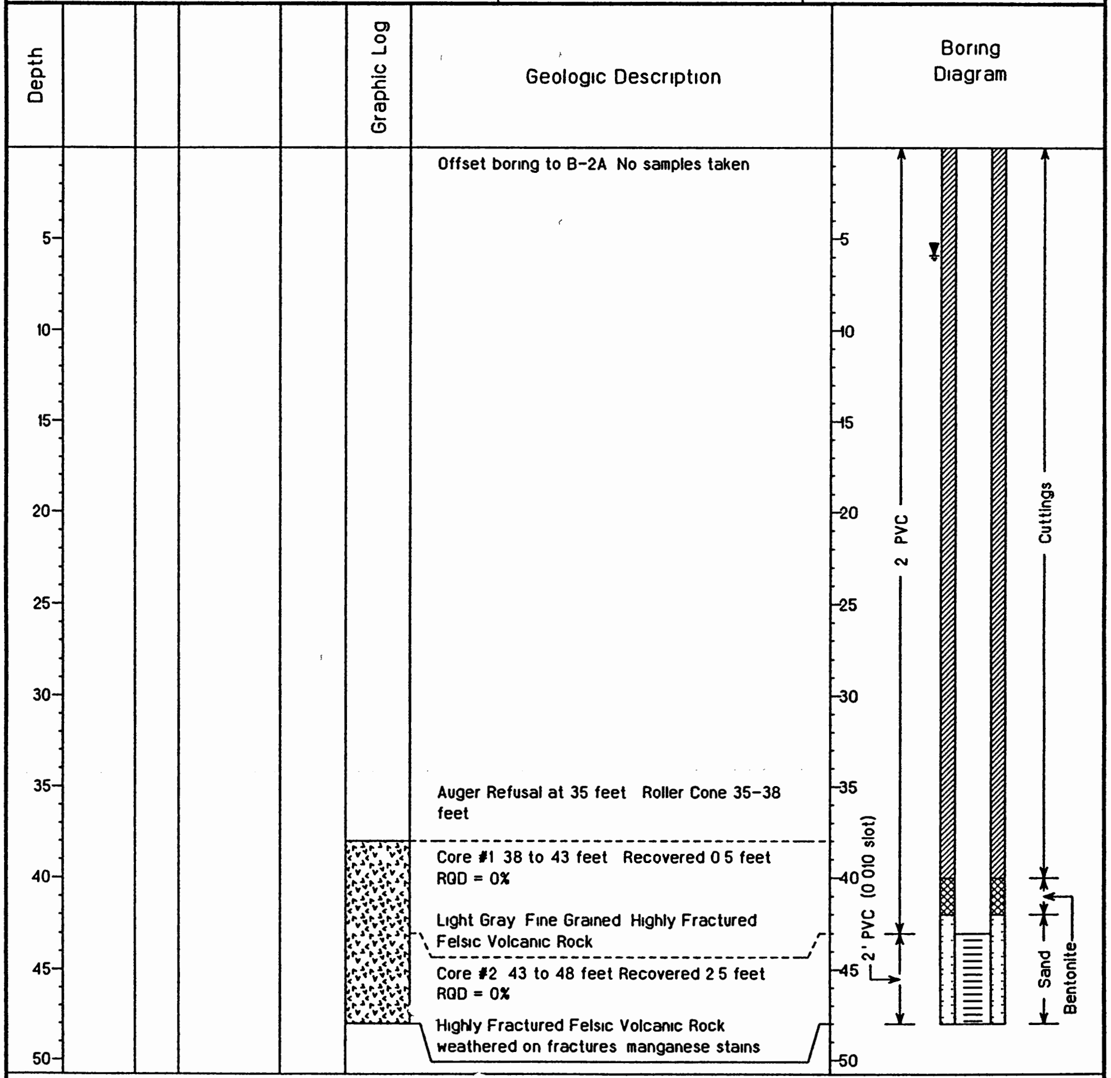


Geologist Dan Short

Driller Westinghouse (WEGS)

BORING LOG: B-2B

	Drill Date **January 1990**	Use **Piezometer**
Location **Montgomery County Landfill, NC**		
Owner **Montgomery County**	Address **Troy, North Carolina**	
Drilling Method **Hollow Stem Auger/Rotary**	Hole Diameter **6 in**	Hole Depth **48 ft**
Sampling Method **Core Barrel**	Casing Length **43 ft**	
Static Water Level **5 9 ft**	Screen Length **5 ft**	Well Depth **48 ft**



Geologic Description

Offset boring to B-2A No samples taken

Auger Refusal at 35 feet Roller Cone 35-38 feet

Core #1 38 to 43 feet Recovered 0 5 feet
RQD = 0%

Light Gray Fine Grained Highly Fractured Felsic Volcanic Rock

Core #2 43 to 48 feet Recovered 2 5 feet
RQD = 0%

Highly Fractured Felsic Volcanic Rock weathered on fractures manganese stains

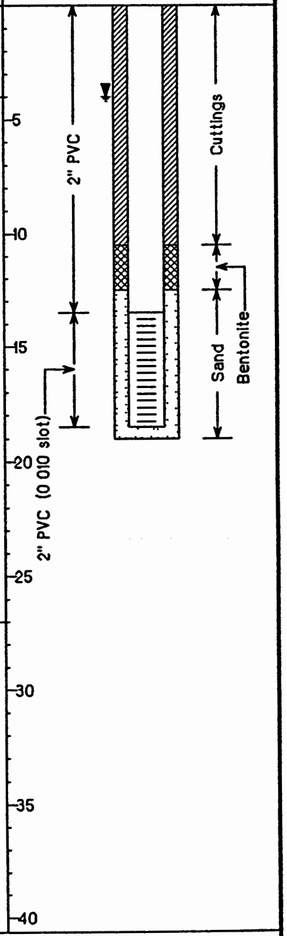
Geologist Dan Short	Driller Westinghouse (WEGS)

BORING LOG: B-3

Drill Date **January 4, 1990**
Use **Piezometer**
Location **Montgomery County Landfill, NC**
Owner **Montgomery County**
Address **Troy, North Carolina**
Drilling Method **Hollow Stem Auger**
Hole Diameter **8 in**
Hole Depth **27 ft**
Sampling Method **Split-tube**
Casing Length **13.5 ft**
Static Water Level **4.0 ft**
Screen Length **5 ft**
Well Depth **18.5 ft**

Depth	SPR (bpf)	Geologic Description
	15	Olive-Orange, Very Stiff Slightly Sandy, Clayey SILT (ML)
5	33	Orange-Gray Very Stiff to Hard Sandy Clayey SILT with rock fragments (ML)
	25	
10	26	
15	20	
		Gray Orange Very Hard Sandy SILT with medium to coarse rock fragments (ML)
20	80/9	
25	86/5	
		Auger Refusal at 27 Feet Dry at Termination of Boring
30		
35		
40		

Boring Diagram



Geologist Dan Short
Driller Westinghouse (WEGS)

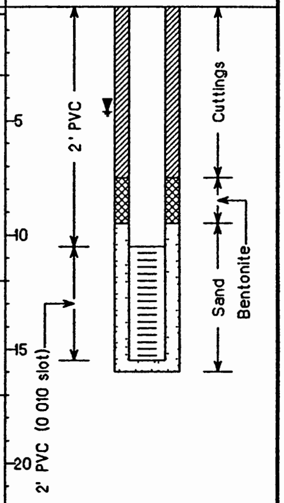
BORING LOG: B-4

	Drill Date **December 28, 1989**	Use **Piezometer**
Location **Montgomery County Landfill, NC**		
Owner **Montgomery County**	Address **Troy, North Carolina**	
Drilling Method **Hollow Stem Auger**	Hole Diameter **6 in**	Hole Depth **17 ft**
Sampling Method **Split-tube**	Casing Length **10 5 ft**	
Static Water Level **4 6 ft**	Screen Length **5 ft**	Well Depth **15 5 ft**

Depth	SPR (bpf)	Geologic Description
	18	Topsoil
		Tan-Buff Very Stiff, Silty CLAY and ROCK FRAGMENTS roots near surface (CL)
5	21	Gray Very Stiff Coarse to Fine Sandy Clayey SILT and Fine ROCK FRAGMENTS clay increases with depth (ML)
	22	
10	22	
		Light Brown Medium Dense Silty Fine SAND (SM)
15	36	
	50/0	
		Auger refusal at 17 Feet
20		Dry at Termination of Boring
25		
30		
35		
40		

Graphic Log

Boring Diagram



Geologist Dan Short

Driller Westinghouse (WEGS)

BORING LOG: B-5

Drill Date **December 28, 1989**

Use **Piezometer**

Location **Montgomery County Landfill, NC**

Owner **Montgomery County**

Address **Troy, North Carolina**

Drilling Method **Hollow Stem Auger**

Hole Diameter **6 in**

Hole Depth **26 ft**

Sampling Method **Split-tube**

Casing Length **10 ft**

Static Water Level **2 7 ft**

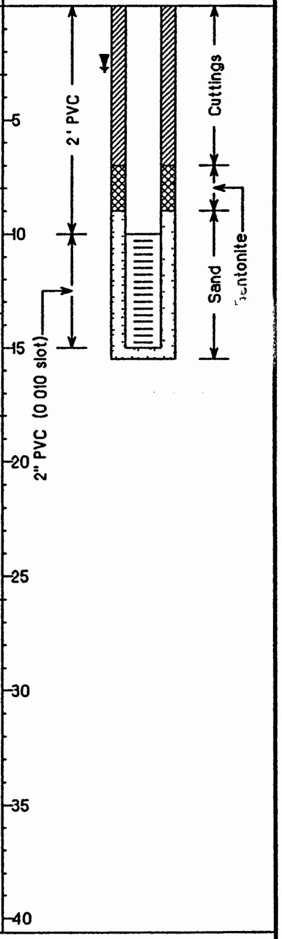
Screen Length **5 ft**

Well Depth **15 ft**

Depth	SPR (bpf)	Geologic Description
	12	Light Brown Stiff to Very Stiff, Silty, Fine Sandy CLAY (CL)
5	20 17	Mottled Tan and Brown Very Stiff, Medium Sandy SILT (ML) with Rock Fragments and Brown Very Stiff, Silty, Medium Sandy CLAY (CL)
10	14	Light Brown Stiff, Coarse to Medium Sandy SILT (ML)
15	14	Gray and Light Brown Stiff, Coarse to Medium Sandy SILT (ML) with rock fragments manganese stains
20 25	50/2 50/0	Partially Weathered Rock When Sampled Becomes White, Slightly Silty, Fine SAND and ROCK FRAGMENTS (SM)
	50/0	Auger refusal at 26 feet Dry at Termination of Boring
30		
35		
40		

Graphic Log

Boring Diagram

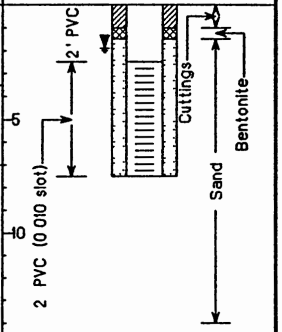


Geologist Dan Short

Driller Westinghouse (WEGS)

BORING LOG: B-6A&6B

	Drill Date **January 12, 1990**	Use **Piezometer**
Location **Montgomery County Landfill, NC**		
Owner **Montgomery County**	Address **Troy, North Carolina**	
Drilling Method **Hollow Stem Auger**	Hole Diameter **6 in**	Hole Depth **27 8 ft**
Sampling Method **Split-tube & Core Barrel**	Casing Length **2 5 ft**	
Static Water Level **1 9 ft**	Screen Length **5 ft**	Well Depth **7 5 ft.**

Depth			SPR (bpf)		Graphic Log	Geologic Description	Boring Diagram
			7			Gray to Orange Firm to Stiff Slightly Sandy, Clayey SILT (ML)	
5			34 50/3 50/0			Gray to Orange Hard, Slightly Sandy SILT with Rock Fragments (ML)	
10 15						Boring 6A Auger Refusal at 7 feet Dry at Termination of Boring. Water Level at 4 5 feet after 24 Hours Refusal in piezometer at 7 5 feet Boring 6B Auger Refusal at 14 feet. No samples taken Driller reports very hard to auger, (boulders) Roller Coned 14 to 17 feet	
20						Core #1 17 1-22 8 feet Recovered 4 75 feet RQD = 34 Fine Grained DIABASE	
25						Core #2: 22.8-27.8 feet Recovered 4 75 feet RQD = 57% DIABASE as above	
30 35 40							

Geologist Dan Short	Driller Westinghouse (WEGS)

BORING LOG: B-7

Drill Date **January 10, 1990**

Use **Piezometer**

Location **Montgomery County Landfill, NC**

Owner **Montgomery County**

Address **Troy, North Carolina**

Drilling Method **Hollow Stem Auger**

Hole Diameter **6 in**

Hole Depth **28 ft**

Sampling Method **Split-tube**

Casing Length **11 5 ft**

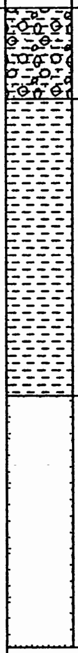
Static Water Level **4 4 ft**

Screen Length **5 ft**

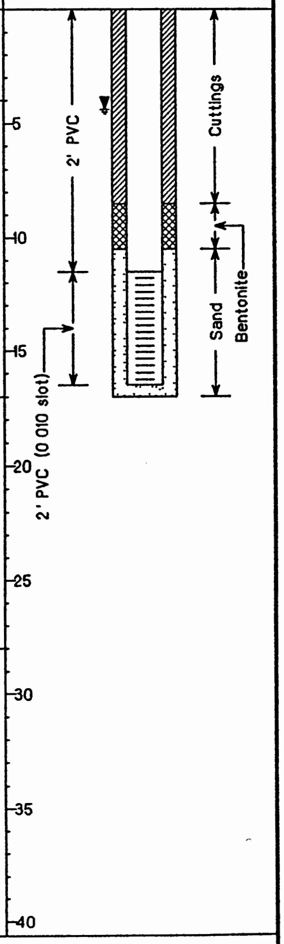
Well Depth **16 5 ft**

Depth	SPR (bpf)	Geologic Description
	12	Brown Stiff Coarse to Fine Sandy, Clayey SILT (Roots near top) with Coarse to Fine Gravel Grades to Very Stiff Brown Silt with White Clay (ML)
5	24	Light Brown to Orange, Very Stiff, Clayey Slightly Sandy SILT, Increasing Fine Sand with Depth Manganese Stains (ML)
	15	
10	14	
15	11	
		Brown, Dense, Silty SAND (SM)
20	38	
25	50/5	
	50/0	Auger refusal at 28 feet. Dry at termination of boring
30		
35		
40		

Graphic Log



Boring Diagram



Geologist Dan Short

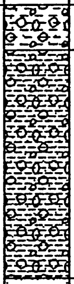
Driller Westinghouse (WEGS)

BORING LOG: B-8

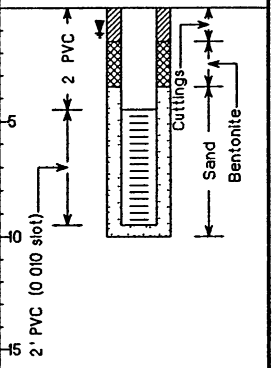
Drill Date **January 9, 1990**
Use **Piezometer**
Location **Montgomery County Landfill, NC**
Owner **Montgomery County**
Address **Troy, North Carolina**
Drilling Method **Hollow Stem Auger**
Hole Diameter **6 in**
Hole Depth **17 ft**
Sampling Method **Split-tube**
Casing Length **4 5 ft**
Static Water Level **0 1 ft**
Screen Length **5 ft.**
Well Depth **9 5 ft**

Depth	SPR (bpf)	Geologic Description
	11	Light Brown Very Stiff SILT with Roots Near Top and Abundant Rock Fragments (ML)
		White to Gray, Very Stiff to Hard Coarse to Fine Sandy SILT Silty Fine SAND and Silty Fine Sandy CLAY with Medium to Fine Gravel (ML, SM, CL)
5	14	
	11	
10	51	
		Partially Weathered Rock When Sampled Becomes Tan Dense Silty Fine to Medium SAND Abundant Manganese Stains (SM)
15	50/5	
	50/0	Auger Refusal at 17 feet Dry at Termination of Boring.
20		
25		
30		
35		
40		

Graphic Log



Boring Diagram



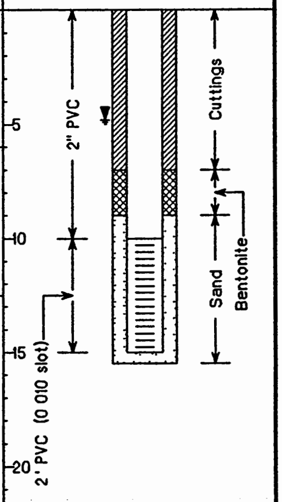
Geologist Dan Short
Driller Westinghouse (WEGS)

BORING LOG: B-9

Drill Date **January 9, 1990**
Use **Piezometer**
Location **Montgomery County Landfill, NC**
Owner **Montgomery County**
Address **Troy, North Carolina**
Drilling Method **Hollow Stem Auger**
Hole Diameter **8 in**
Hole Depth **25 ft**
Sampling Method **Split-tube**
Casing Length **10 ft**
Static Water Level **4 8 ft.**
Screen Length **5 ft**
Well Depth **15 ft**

Depth			SPR (bpf)		Graphic Log	Geologic Description
			19			Gray to Brown Stiff to Very Stiff, Coarse to Fine Sandy Clayey SILT Sand Increases with Depth (ML)
5						
			11			Silty SAND (SM)
10			9			
						Brown to Tan Very Hard Sandy SILT with Rock Fragments (ML)
15			50/4			
20			50/5			
25			50/0			Auger Refusal at 25 Feet Dry at Termination of Boring.
30						
35						
40						

Boring Diagram



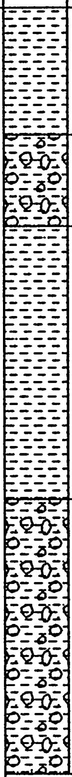
Geologist Dan Short
Driller Westinghouse (WEGS)

BORING LOG: B-10

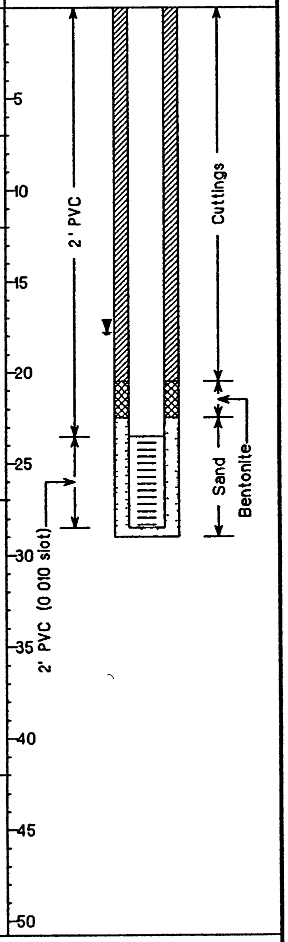
Drill Date **January 9, 1990**	Use **Piezometer**	
Location **Montgomery County Landfill, NC**		
Owner **Montgomery County**	Address **Troy, North Carolina**	
Drilling Method **Hollow Stem Auger**	Hole Diameter **6 in**	Hole Depth **42 ft**
Sampling Method **Split-tube**	Casing Length **23 5 ft**	
Static Water Level **17 8 ft**	Screen Length **5 ft**	Well Depth **28 5 ft**

Depth	SPR (bpf)	Geologic Description
	10	Brown-Orange, Stiff to Very Stiff Clayey to Sandy SILT Minor Rock Fragments (ML)
5	24	
	23	Gray-Brown Very Stiff, Slightly Sandy SILT with Rock Fragments (ML)
10	41	
		Gray-Brown Stiff to Hard Slightly Sandy to Sandy SILT (ML) and Silty SAND (SM)
15	11	
20	18	
25	42	
		Gray-Brown Very Hard Sandy SILT with Rock Fragments (ML)
30	55	
35	50/5	
40		
		Boring Terminated at 42 Feet
45		
50		

Graphic Log



Boring Diagram



Geologist Dan Short

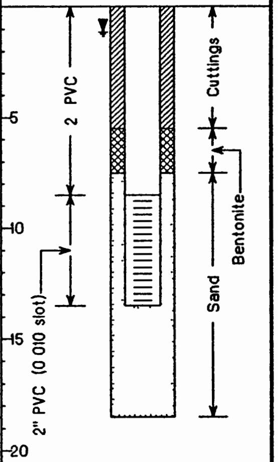
Driller Westinghouse (WEGS)

BORING LOG: B—11

Permit #	Drill Date	Use **Piezometer**
Location **Montgomery County Landfill, NC**		Handex #
Owner **Montgomery County**	Address **Troy, North Carolina**	
Drilling Method **Hollow Stem Auger**	Hole Diameter **6 in**	Hole Depth **18 5 ft**
Sampling Method **Split-tube**	Casing Length **8 5 ft**	
Static Water Level **0 2 ft**	Screen Length **5 ft**	Well Depth **13 5 ft**

Depth			SPR (bpf)		Graphic Log	Geologic Description
			16			Gray-Tan Very Stiff Clayey SILT (ML)
5			50/4			Light Gray-Cream Very Hard Silty Fine to Coarse SAND with Rock Fragments (SM)
			50/5			
						Auger Refusal at 7 Feet
10						
						Roller coned to hard rock at 18 5 feet
15						
20						
25						
30						
35						
40						

Boring Diagram

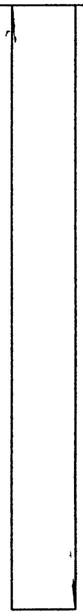


NOTES * = Sample analyzed at laboratory ☒ = Sample recovery

Geologist Dan Short	Driller Westinghouse (WEGS)

BORING LOG: B-12

Drill Date **January 10, 1990**	Use **Piezometer**	
Location **Montgomery County Landfill, NC**		
Owner **Montgomery County**	Address **Troy, North Carolina**	
Drilling Method **Hollow Stem Auger**	Hole Diameter **8 in**	Hole Depth **26 5 ft**
Sampling Method **Split-tube**	Casing Length **8 5 ft**	
Static Water Level **Dry**	Screen Length **5 ft**	Well Depth

Depth			SPR (bpf)		Graphic Log	Geologic Description	Boring Diagram
			11		▤	Red-Brown Stiff, Silty CLAY with Organic Material (CL)	
					▦	Predominantly Orange-Yellow, Stiff to Very Hard, Slightly Clayey SILT trace sand increasing with depth trace rock fragments (ML)	
5			52		▦		
			17		▦		
10			15		▦		
15			35		▦		
			50/0			Auger Refusal at 17 Feet Roller Coned 17 0 to 26 5 Feet	
20							
25							
						Boring Did Not Intersect Water Table	
30							
35							
40							

Geologist Dan Short	Driller Westinghouse (WEGS)

BORING LOG: B-13

Permit #

Drill Date **December 21, 1989**

Use **Piezometer**

Location **Montgomery County Landfill, NC**

Handex #

Owner **Montgomery County**

Address **Troy, North Carolina**

Drilling Method **Hollow Stem Auger**

Hole Diameter **6 in**

Hole Depth **59 ft**

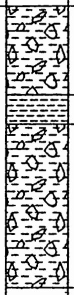
Sampling Method **Split-tube/Core Barrel**

Casing Length **21 ft**

Static Water Level **6 0 ft**

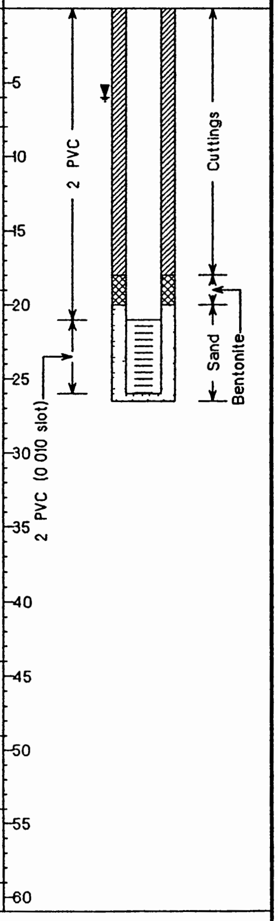
Screen Length **5 ft**

Well Depth **26 ft**



Depth	SPR (bpf)	Geologic Description
	15	Orange-Brown Very Stiff Silty Coarse to Fine Sandy Clayey SILT with Fine Gravel (ML)
5	29	
	30	Silty CLAY (CL)
10	15	Gray-Brown Very Stiff Clayey SILT with fine gravel rock fragments rock fragments increase with depth (ML)
15	16	
20	62	Partially Weathered Rock When Sampled Becomes Tan Very Hard Slightly Silty Fine to Medium SAND (SM)
25	50/5	
30	50/0	
35	50/3	
40	50/1	
	50/0	
45		Auger Refusal at 44 Feet Dry at Termination of Boring Roller coned 44 to 49 feet
50		Core #1 49 to 54 feet Recovered 0 feet
55		Core #2 54 to 59 feet Recovered 0 feet
60		Coring Terminated at 59 Feet

Boring Diagram



NOTES * = Sample analyzed at laboratory ☒ = Sample recovery

Geologist Dan Short

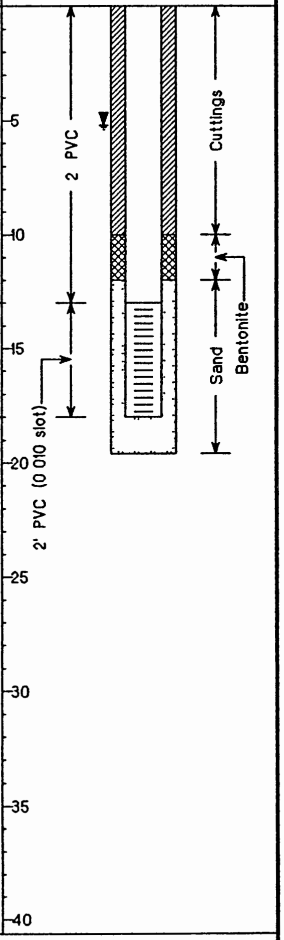
Driller Westinghouse (WEGS)

BORING LOG: B-14

	Drill Date **January 9, 1990**	Use **Piezometer**
Location **Montgomery County Landfill, NC**		
Owner **Montgomery County**	Address **Troy, North Carolina**	
Drilling Method **Hollow Stem Auger**	Hole Diameter **6 in**	Hole Depth **19 5 ft**
Sampling Method **Split-tube**	Casing Length **13 ft**	
Static Water Level **5 2 ft**	Screen Length **5 ft**	Well Depth **18 ft**

Depth			SPR (bpf)		Graphic Log	Geologic Description
			14			Gray-Orange Firm Clayey SILT Carbonaceous near top (MH)
5			20			
			13			Orange Firm Silty CLAY and Firm Clayey SILT, trace fine sand (ML-CL)
10			11			
						Cream Firm Clayey SILT trace fine sand (ML)
15			12			
						Auger Refusal at 18 feet Dry at Termination of Boring. Second boring offset 5 feet and terminated at 19 5 feet
20						
25						
30						
35						
40						

Boring Diagram



Geologist Dan Short

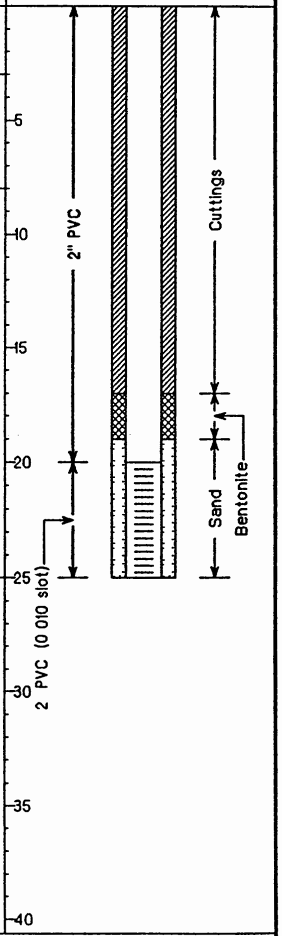
Driller Westinghouse (WEGS)

BORING LOG: B-15

	Drill Date **March 2, 1990**	Use **Piezometer**
Location **Montgomery County Landfill, NC**		
Owner **Montgomery County**	Address **Troy, North Carolina**	
Drilling Method **Hollow Stem Auger**	Hole Diameter **6 in**	Hole Depth **25 ft**
Sampling Method **Split-tube**	Casing Length **20 ft**	
Static Water Level **Dry**	Screen Length **5 ft**	Well Depth **25 ft**

Depth	SPR (bpf)	Geologic Description
	11	Red-Brown Stiff Clayey SILT (ML)
		Tan-Light Brown Very Stiff Slightly Sandy Slightly Clayey SILT Manganese Stains (ML)
5	16	
	15	
		Tan-Light Brown Hard Fine Sandy SILT Manganese Stains (ML)
10	32	
15	39	
20	32	
25	23	Boring Terminated at 25 Feet Dry at Termination of Boring.
30		
35		
40		

Boring Diagram



Geologist Dan Short

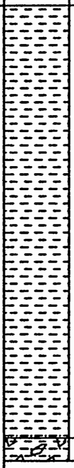
Driller Westinghouse (WEGS)

BORING LOG: B-16

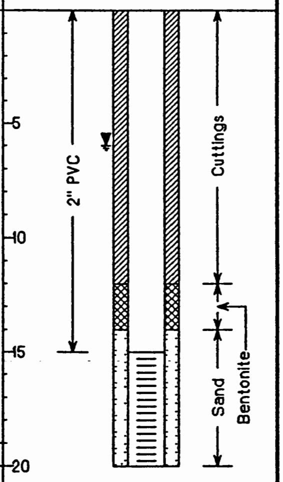
Drill Date **March 2, 1990**
Use **Piezometer**
Location **Montgomery County Landfill, NC**
Owner **Montgomery County**
Address **Troy, North Carolina**
Drilling Method **Hollow Stem Auger**
Hole Diameter **6 in**
Hole Depth **20 ft**
Sampling Method **Split-tube**
Casing Length **15 ft**
Static Water Level **6 ft**
Screen Length **5 ft**
Well Depth **20 ft**

Depth	SPR (bpf)	Geologic Description
	18	Red-Brown, Soft to Very Stiff Clayey SILT (ML)
5	24	
	19	
10	11	
15	13	
20	15	Red-Brown, Very Stiff, Clayey SILT with Rock Fragments (ML)
		Boring Terminated at 20 Feet
25		Water level at 13 5 feet at termination of boring
30		
35		
40		

Graphic Log



Boring Diagram



Geologist Dan Short
Driller Westinghouse (WEGS)

APPENDIX C

NOMENCLATURE

ACOE	Army Corps of Engineers
AR	auger refusal
ASTM	American Society of Testing and Materials
bpf	blows per foot
class	classification
k	hydraulic conductivity
LL	liquid limit
MH	plastic silt
ML	slightly plastic silt
MSL	mean sea level
NR	no (auger) refusal
opt	optimum
pcf	pounds per cubic foot
PWR	partially weathered rock
PI	plastic index
PL	plastic limit
SM	silty sand, sand-silt mixture
SPR	standard penetration resistance
TOB	termination of boring
USCS	Unified Soil Classification System

VITA

Dan Patrick Short

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Master of Science

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Professional Experience: Logging, Production, Development, and Exploration Geologist in the petroleum industry from 1974 to 1988 with companies such as Exploration Logging, Exxon, Home Petroleum, and MAPCO/CNG Producing Company; Staff Geologist, Westinghouse Environmental and Geotechnical Services, Inc., 1989 to 1991; Hydrogeologist, Handex of the Carolinas, 1991 to present.