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PERMIT MODIFICATION

FOR PHASE III OF THE

WHITE STREET MUNICIPAL SOLID WASTE LANDFILL

FEBRUARY 2000
(Revised July 2000)

PREPARED FOR:

CITY OF GREENSBORO

APPROVED
DIVISION OF WASTE MANAGEMENT
SOLID WASTE SECTION
DATE 10-6-2000 BY RS (GL)
Permit # 41-12

JUL 2000
Received
Solid Waste
Section

PREPARED BY:

HDR

HDR ENGINEERING, INC. OF THE CAROLINAS
128 SOUTH TRYON STREET, SUITE 1400
CHARLOTTE, NORTH CAROLINA 28202-5001

July 19, 2000

Mr. Jim Coffey
Environmental Engineer Supervisor
Solid Waste Section
Division of Solid Waste Management
Department of Environment and Natural Resources
401 Oberlin Road, Suite 150
P.O. Box 27687
Raleigh, NC 27611

Re: Greensboro White Street Landfill, Permit No. 41-12
Permit Modification Application
HDR Project No. 06770-029-018

Dear Mr. Coffey:

Enclosed are five copies of the revised Permit Modification Application for Phase III of the Greensboro White Street Landfill, Permit No. 41-12. This application is a resubmittal, on behalf of the City of Greensboro, of the original report sent to you under cover letter dated February 8, 2000. This application has been revised to address comments transmitted by Mr. Lutfy under cover letter dated June 5, 2000, subsequent meetings, and telephone conversations.

This application addresses four proposed modifications to the Greensboro White Street Landfill, Permit No. 41-12:

- Alternate Liner Demonstration for Cells 2 and 3 of Phase III.
- Adjustment to the Cell 2 northwest boundary.
- Adjustment to the proposed subgrade of Cell 2.
- Revision to the proposed final grades in Cell 2 area.

It is our expectation that this submittal will resolve all issues raised by section staff. Should you have any questions regarding this submittal, please contact me or Eric Wright at (704) 338-6700.

Sincerely,

HDR Engineering, Inc. of the Carolinas

Joseph C. Readling, PE
Senior Project Manager

JCR/jvw

Enclosures

cc: Frank Coggins (1 copy of enclosure)

**HDR Engineering, Inc.
of the Carolinas**

Employee Owned

128 S. Tryon Street
Suite 1400
Charlotte, North Carolina
28202-5001

Telephone
704 338-6700
Fax
704 338-6760

JCR 7-19-00 Lutfy - ALD Resubmittal

June 12, 2000

HDR

Mr. Bobby Lutfy
North Carolina Department of Environment
and Natural Resources
Solid Waste Section
401 Oberlin Road, Suite 150
Raleigh, NC 27605

OFFICE COPY

Re: Subsurface Hydrogeologic Characterization within 250 feet of Critical Area of Concern for Phase III Permit Modification
White Street Municipal Solid Waste Landfill (Permit No. 41-12)
HDR Project No. 06770-033-018

Dear Mr. Lutfy:

HDR Engineering, Inc. of the Carolinas (HDR), on behalf of the City of Greensboro (the City), has prepared the following work scope to collect supplemental hydrogeologic information from the above-referenced facility for the preparation of site-specific conceptual hydrogeologic models (i.e., cross sections) in the vicinity of the critical area of concern as presented in our document entitled "Permit Modification for Phase III of the White Street Municipal Solid Waste Landfill", dated February 2000. This scope of work was prepared in response to your review of the subject document (letter dated June 5, 2000) and to address the Sections' issues raised during the June 7, 2000 meeting with the hydrogeologists of the Solid Waste Section of the North Carolina Department of Environment and Natural Resources (NCDENER).

Project Understanding

HDR understands that the primary concern the Section has with the current alternate liner demonstration is that the existing hydrogeologic data along the critical path from the area of concern (the sump within Cell II of the Phase III expansion area) suggests that the predominant uppermost ground-water flow regime is fracture controlled and that dilution of released constituents during contaminant movement through this regime is presumed to be low. Based on our discussion with the Section during the recent meeting, it is our understanding that additional hydrogeologic data is warranted in the vicinity of this region of Cell 2 to better "model" or represent actual site hydrogeologic conditions. With this additional site-specific data, a more representative dilution/attenuation factor (DAF) will be calculated for the site in the event this study indicates that there is adequate porous media ground-water movement downgradient of the area of concern. If sufficient porous-media flow is not present, then HDR understands that additional fractured rock data (i.e., pumping test) may be warranted.

Project Intent

It is the intent of this work scope to provide additional data regarding saprolite characteristics (e.g., composition, thickness in the saturated and unsaturated state, and ground-water potentiometric and flow direction) as well as data regarding the depth to the upper-most limits of fractured bedrock along the critical path. With this additional data, conceptual hydrogeologic cross sections will be developed to characterize (model) the subsurface conditions along the critical path.

Project Scope

As depicted in the enclosed Site Map, HDR proposes to install up to 10 exploratory soil borings in the vicinity of the northwestern corner of Cell 2 near the proposed sump location. Three cross-sectional transects are proposed for the collection of hydrogeologic data. Each transect will originate from the sump area and will proceed along the potential flow paths anticipated for this portion of the site. Based on existing site-specific ground-water flow data presented in the Permit Application, the primary ground-water flow path from the sump is to the northwest with minor components of ground-water flow potentially to the two nearby surface drainage features located west and north-northeast of the sump. An initial soil boring will be installed in the vicinity of the proposed sump. At a spacing of approximately 100 feet, additional soil borings will be installed along these transects with the last boring of each section installed at a distance no greater than 250 feet from the point of compliance.

Each boring will be installed using a track-mounted drill rig utilizing hollow stem augers. Split-spoon samples will be collected every five feet starting from surface grade to the depth of auger refusal for determination of saprolite consistency and composition. Upon reaching auger refusal, a temporary piezometer will be installed in those soil boring locations in which ground water was encountered prior to reaching auger refusal. A five-foot well screen section would be installed and a filter sand pack installed around the annulus surrounding the well screen. A one-foot thick bentonite seal will be placed above the sand pack and the remaining annulus will be backfilled with the cuttings from the borehole. Each piezometer will be fitted with a water-tight locking cap and locked. A weep hole will be installed at the top of each piezometer casing just below the cap to allow the release of pressure during fluctuations in the water table. Each piezometer will stick up above the surrounding grade approximately 2.5 feet.

Collection of Hydrogeologic Data

Once each piezometer has stabilized at least 24 hours, static water level measurements will be obtained using an electronic water level indicator. These level measurements will be transformed into a water table elevation based on surveyed top-of-casing elevations which will be determined for each piezometer location.

Preparation of Conceptual Hydrogeologic Models

With existing and newly acquired geologic and hydrogeologic data from this work scope, three conceptual site hydrogeologic cross sections will be prepared depicting subsurface conditions along each transect.

Anticipated Schedule

HDR plans to begin implementing the above-referenced scope on Wednesday, June 14, 2000 with the completion of field data collection within three days of initiation. The preparation of the three conceptual site models. The resubmittal of DAF calculations will be completed within one week from the collection of the field data if the study indicates sufficient thickness of saturated porous zone is present downgradient of the sump. If it is determined that additional data from these piezometers are not warranted, all piezometers will be properly abandoned in accordance with North Carolina Well Abandonment Standards within thirty (30) days from the collection of the hydrogeologic data.

If you have any questions or comments regarding this work plan, please feel free to contact me at (704) 338-6832.

Sincerely,

HDR Engineering, Inc. of the Carolinas

John R. Isham, PG
Senior Hydrogeologist

JRI/jvw

Enclosure

cc: Mr. Frank Coggins, City of Greensboro
Mr. Jack Amar, S&ME, Inc.

NORTH CAROLINA DEPARTMENT OF ENVIRONMENT AND NATURAL RESOURCES
DIVISION OF WASTE MANAGEMENT

NCDENR

JAMES B. HUNT JR.
GOVERNOR

BILL HOLMAN
SECRETARY

WILLIAM L. MEYER
DIRECTOR

RECEIVED
JUN 7 2000
HDR ENGINEERING, INC.
OF THE CAROLINAS

June 5, 2000

Ms. Jeryl Covington, P.E.
Environmental Services Director
City of Greensboro
P.O. Box 3136
Greensboro, N.C. 27402-3136

RE: Permit Modification For Phase III Of The Greensboro White Street Municipal Solid Waste Landfill
Permit Number 41-12

Dear Ms. Covington,

This letter provides comments from the hydrogeologic review of the Permit Modification for Phase III Cell 2 of the Greensboro White Street MSW Landfill. There was somewhat limited data available in the immediate new sump area to support the "Adjustment to the proposed subgrade of Cell 2". What data is available appears to indicate that the new subgrade elevations are probably generally satisfactory. However there are definitely some problems with the "Alternate Liner Demonstration", which is not sufficient to demonstrate compliance.

An "Alternate Liner Demonstration for Cells 2 and 3 of Phase III" of the Greensboro Landfill has been submitted to the Solid Waste Section. A MULTIMED ground-water model was used to demonstrate compliance.

The alternative liner proposed is one of two alternative liners in Rule .1624 subparts (b)(1)(A)(ii) and (iii) that have defined design and construction requirements. A model demonstration of this rule requires the proposed design will ensure the maximum concentration levels for the 15A NCAC 2L Groundwater Standards will not be exceeded in the aquifer at the relevant point of compliance.

The City of Greensboro and HDR Engineering need to consider and respond to the following questions and comments regarding the "Alternate Liner Demonstration" before the Solid Waste Section can continue with our review:

NC SCHOOLS FIRST IN AMERICA 2010

1646 MAIL SERVICE CENTER, RALEIGH, NORTH CAROLINA 27699-1646
401 OBERLIN ROAD, SUITE 150, RALEIGH, NC 27605
PHONE 919-733-4996 FAX 919-715-3605

The most critical problem identified is that the MULTIMED model used in the demonstration does not appear to be appropriate for the hydrogeologic conditions at the site. MULTIMED can only be used when there is a significant porous media aquifer such as occurs in unconsolidated soil sediments. For most of the Cell 2 area, including the critical area at the lower end of the cell where the new sump is located, the uppermost aquifer occurs in the fractured bedrock under normal water table conditions. There is very little support documentation provided for the input values to the model. However, it appears that seasonal high water table conditions were used to estimate the aquifer thickness (of less than one meter) that was used in the model. An evaluation of the average water table conditions for the Cell 2 area indicates the uppermost aquifer is in the fractured bedrock (except for the very upper part of the cell). Therefore, under normal water table conditions, there is no ground water in the unconsolidated sediments. When the liner is constructed and ground-water recharge is cut off for this area, it is likely that the water table will become even lower.

There is very little documentation for the input values used in the model. This documentation needs to be provided to ensure that data representative of site-specific hydrogeologic conditions is being used to model.

It is not necessary to compare the standard Composite Liner with the proposed Alternative Liner. The intent of the alternative liner demonstration is to show the alternative liner is protective of the ground water in a specific hydrogeologic setting. The EPA Subtitle D requirements and subsequently approved Solid Waste Management Rules are written in such a way that the Solid Waste Section can not consider data used to compare the Standard Composite Liner to the Alternative Liner as part of the alternative liner demonstration required in Rule .1624. Approval must be granted based upon the merits of an accurate and appropriate model for the site-specific hydrogeologic setting that demonstrates compliance with the 15A NCAC 2L Groundwater Standards at the relevant point of compliance.

Modeling should encompass the most susceptible area for a potential plume of contamination. Ground-water flow patterns and other hydrogeologic data needs to be considered in delineating the critical ground-water flow paths. In the vicinity of the new sump, there are two drainage features that influence ground-water flow in this area. Mafic dikes and other geologic features could also influence ground-water flow.

The MULTIMED model, and many other ground-water models, assume fairly homogeneous aquifer conditions. The Phase III Landfill has rather varied geologic conditions that could affect ground-water flow, especially in the bedrock. The demonstration report will need to address the varied hydrogeologic conditions at the site.

The demonstration report should make it clear that the initial model is run with input flow rates as determined in the SWANA "White Paper". These values are very conservative and presume a constant 30 cm head on the liner and eight small holes in the liner per acre. The leakage rate for the GCL alternative composite liner is 0.53 gal/acre/day. (This information may be used as a comparison with leakage rates developed by the HELP model.)

In summary, the MULTIMED model used to demonstrate compliance for the alternative liner is not appropriate for the hydrogeologic conditions at the site. Therefore it appears that the City of Greensboro has three options:

- Since you are on a tight schedule to begin construction of Cell 2, you may wish to consider using the Standard Composite Liner for this cell.

- If you wish to make a successful demonstration for an alternative liner as required by Rule .1624, then another means of ground-water modeling must be used. Due to the somewhat complex fractured bedrock environment present at the site, additional hydrogeologic investigation may be necessary to provide representative model input data. Since there is little contaminant attenuation in fractured bedrock and also relatively little dilution, it may be more difficult to demonstrate compliance under these conditions.

- For the two standard Alternate Liner designs, Rule .1624 also allows that "the Division may waive the site-specific modeling requirement if it can be demonstrated that a previous site for which a model was approved had similar hydrogeologic characteristics, climatic factors, and volume and physical and chemical leachate characteristics". Presently only a few sites have been approved where portions of the uppermost aquifer system are in fractured bedrock. I do not know if any of these sites "had similar hydrogeologic characteristics..." to the Greensboro Phase III Cell 2 site. It will probably be necessary to provide additional hydrogeologic investigation in order to demonstrate that the Greensboro site has "similar hydrogeologic characteristics" to a site previously modeled.

A revised Permit Modification report needs to be provided before the Solid Waste Section can complete the review and issue a Permit. If the City of Greensboro chooses one of the latter two options outlined above, then your consultant will need to meet with the Solid Waste Section to discuss possible ways to proceed with one of the demonstrations. (Either of these latter two options will probably require additional hydrogeologic investigation to provide data necessary for making a competent technical decision.)

If you or your consultants have any questions regarding this letter or would like to schedule a meeting, you may contact me at (919) 733-0692, extension 258.

Sincerely,

Bobby Lutfy
Hydrogeologist
Solid Waste Section

cc: Jim Coffey, Solid Waste Section
Bill Sessoms, Solid Waste Section
Hugh Jernigan, SWS Winston-Salem Office
Frank Coggins, City of Greensboro
Eric Wright, HDR Engineering, Inc.

CITY OF GREENSBORO

NORTH CAROLINA

P.O. BOX 3136
GREENSBORO, NC 27402-3136

February 8, 2000

Mr. Jim Coffey
Division of Solid Waste Management DENR
P.O. Box 27687
Raleigh, NC 27611

Dear Mr. Coffey:

Enclosed are two copies of the Permit Modification Application. This application addresses four proposed modifications to the Greensboro White Street Landfill, Permit No. 41-12:

- Alternate Liner Demonstration for Cells 2 and 3 of Phase III.
- Adjustment to the Cell 2 northwest boundary.
- Adjustment to the proposed subgrade of Cell 2.
- Revision to the proposed final grades in Cell 2 area.

It is our intent to proceed with bidding the project in March and receive construction bids in April.

These documents were prepared with the assistance of HDR Engineering, Inc. of the Carolinas, and questions or inquiries should be directed to:

Mr. Eric Wright, P.E.
HDR Engineering, Inc. of the Carolinas
128 South Tryon Street, Suite 1400
Charlotte, NC 28202
704-338-1800

Your attention and assistance is greatly appreciated.

Sincerely,

Jeryl W. Covington

Jeryl Covington, P.E.
Environmental Services Director (acting)

JC/jvw

Enclosure: Permit Modification Application (2)

PERMIT MODIFICATION

FOR PHASE III OF THE

WHITE STREET MUNICIPAL SOLID WASTE LANDFILL

FEBRUARY 2000
(Revised July 2000)

PREPARED FOR:

CITY OF GREENSBORO

PREPARED BY:

HDR ENGINEERING, INC. OF THE CAROLINAS
128 SOUTH TRYON STREET, SUITE 1400
CHARLOTTE, NORTH CAROLINA 28202-5001

EXECUTIVE SUMMARY

This application addresses four proposed modifications to the Greensboro White Street landfill, Permit No. 41-12:

- Alternate Liner Demonstration for Cells 2 and 3 of Phase III in accordance with Rule .1624,
- Adjustment to the Cell 2 northwest boundary,
- Adjustment to the proposed subgrade of Cell 2,
- Revision to the proposed final grades in the Cell 2 area.

Alternate Liner System

An alternate composite liner system is proposed for the White Street Municipal Solid Waste Landfill (Landfill) in Greensboro, North Carolina. The proposed alternative liner system consists of the following components from the top down:

- 60-mil HDPE geomembrane.
- Geosynthetic clay liner (GCL).
- 18 inches of 1E-5 cm/sec compacted soil liner.

This application is intended to satisfy the Point of Compliance (POC) demonstration required by Subtitle D, 40 CFR 258.40(a)(1), and the North Carolina Department of Environment and Natural Resources (NCDENR) Division of Waste Management Rule 15A NCAC 13B .1624. The proposed alternative liner system, was examined for the following factors:

- The rate of leakage through the alternate liner system.
- Contaminant concentration levels.

A POC analysis was performed to demonstrate that the alternate composite liner system would prevent ground-water contamination levels at the POC from exceeding the specified Maximum Contaminant Levels (MCLs). The Dilution Attenuation Factor (DAF) for the worst-case condition modeled is 135. These results satisfy the DAF minimum of 100 per EPA. Therefore, the proposed alternate liner system satisfies the demonstration required by 40 CFR 258.40(a)(1) and NCDENR Rule 15A NCAC 13B .1624.

Cell 2 Boundary Adjustment

A Duke Power substation is located within Landfill property adjacent to Phase III. At the time of original permitting, Duke Power owned the property and the Phase III boundary was established to maintain the minimum 300-foot buffer off the substation property. The impact of this separation requirement on the Phase III footprint was a reduction in potential lined area of approximately 0.9 acres. This area was discussed during the permitting process with NCDENR and the decision was made to apply for this modification after the City of Greensboro (City) acquired the substation property. To expedite the permitting process, this area was deleted from the original MSWLF unit design drawings, however, all other aspects of the permit were handled as if this would become part of the unit.

The City obtained title to the substation on December 10, 1997. Revised drawings are included in this application that depict the additional 0.9 acre lined area afforded by the City owning the substation property. The design adjustments comply with all NCDENR buffer requirements.

Cell 2 Subgrade Adjustment

This modification incorporates the expanded footprint into the subgrade design of Cell 2. The required separation between groundwater has been maintained. Improved bedrock surface information was obtained during preliminary preparation of the subgrade. The attached Bedrock Surface Map has been modified based on this information. This resulted in raising grades in some locations and lowering them in others. The proposed revision maintains the required 4-foot separation between the bedrock surface and liner system.

Final Grade Revision

The final grading plan is revised to reflect the liner boundary change in Cell 2. The net result of these changes increases the gross operating capacity of the facility by slightly more than 1%.

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APPENDICES

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1.0 PURPOSE

The purpose of this application is to gain approval for four proposed landfill modifications, they include:

- Alternate Liner Demonstration for Cells 2 and 3 of Phase III in accordance with Rule .1624,
- Adjustment to the Cell 2 northwest boundary,
- Adjustment to the proposed subgrade of Cell 2,
- Revision to the proposed final grades in the Cell 2 area.

2.0 BACKGROUND

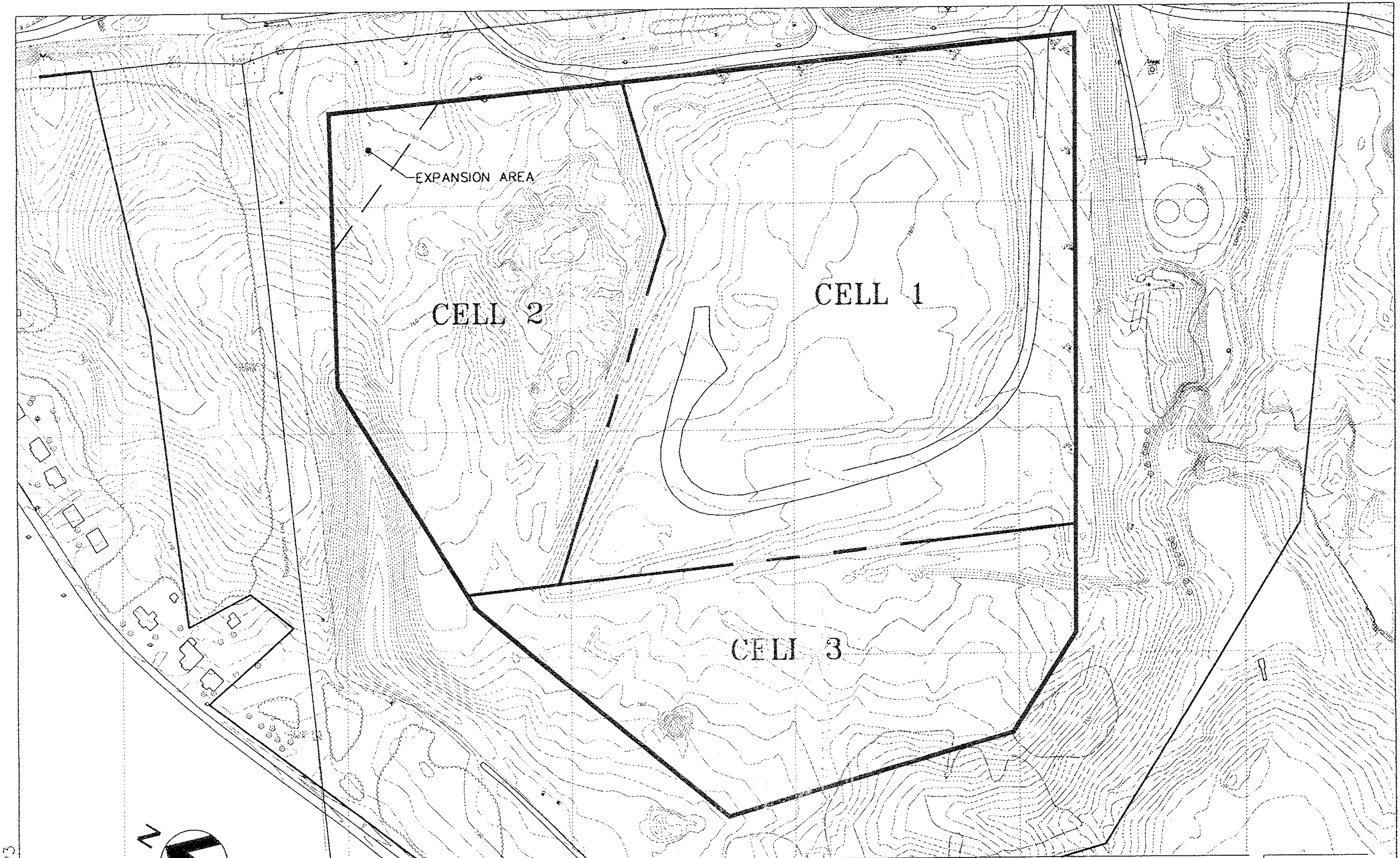
2.1 General History

The Landfill is operated by the City as a municipal solid waste landfill under NCDENR permit 41-12. The Landfill is located east of US Highway 29, at the east end of White Street.

Waste disposal activities in the area now known as the White Street Sanitary Landfill began in 1943. The current Landfill property covers an area of approximately 767 acres. As constructed, the Landfill is divided into three Phases. Phase I is an 85-acre site that stopped receiving waste prior to 1978. Phase II consists of approximately 135 acres, which received municipal solid waste until the end of 1997. Phase III is the first area to be lined and consists of three cells totaling approximately 51 acres. Waste placement began in Cell 1 (approximately 25.5 acres) in December 1997.

2.2 Landfill Configuration

Cell 2 is located to the west of Cell 1, and Cell 3 is located South of Cells 1 and 2 (see to Figure 1). The proposed subgrade ranges between 2 to 6 percent slope. Cells 2 and 3 consist of approximately 14 and 12 lined acres respectively. Based on information submitted with the Construction Permit Application, ground water generally flows in a north-northeast direction. The long axis of Cell 2 is roughly parallel to ground water flow. A minimum separation of 4 feet is required (by regulation) between the bottom of the liner and the estimated long-term seasonal high water table. A separation between the liner system and the long term



HDR
HDR Engineering, Inc.
of the Carolinas
Suite 1400
128 S. Tryon Street
Charlotte, NC 28202-5001
(704) 338-1800

WHITE STREET SANITARY LANDFILL
PHASE III
PHASING MAP

Date
7/00

Figure
1

P:\GBORO\FIG1-P3

seasonal high groundwater table of 5 feet was estimated based on data from boring B-1, as reported in the Design Hydrogeologic Report. Boring B-1 is centrally located within Cell 2. This boring was chosen for modeling purposes to best represent the actual site conditions.

The proposed alternate liner system varies from the standard Subtitle D design by replacing the 2-foot thick 1E-7 cm/sec compacted clay liner with a geosynthetic clay (bentonite) liner (GCL) and 18 inches of 1E-5 cm/sec soil. The liner systems are illustrated in Figure 2.

3.0 ALTERNATE LINER DEMONSTRATION

3.1 Purpose

HDR Engineering, Inc. of the Carolinas (HDR) was retained by the City to prepare an alternate liner demonstration for Cells 2 and 3 of the Phase III Landfill expansion at the Landfill in Greensboro, North Carolina. This section summarizes the approach and methods used to collect additional geologic and hydrogeologic data at the landfill to characterize the uppermost aquifer in the vicinity of the path of critical flow. This data was then used to calculate the necessary aquifer parameters for the determination of a DAF based on actual site conditions.

3.2 Methods

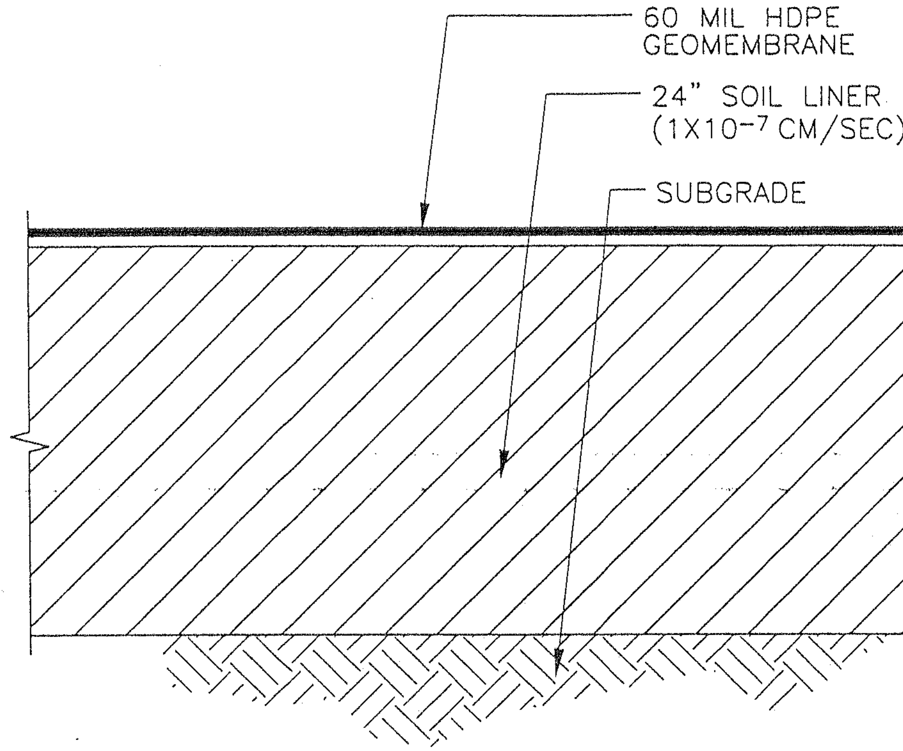
The performance of this demonstration was executed in four phases which consisted of the following:

1. Installation of seven (7) soil borings (converted to temporary piezometers) to auger refusal to determine the presence or absence of ground-water flow in the saprolite in the vicinity of the path of critical flow.

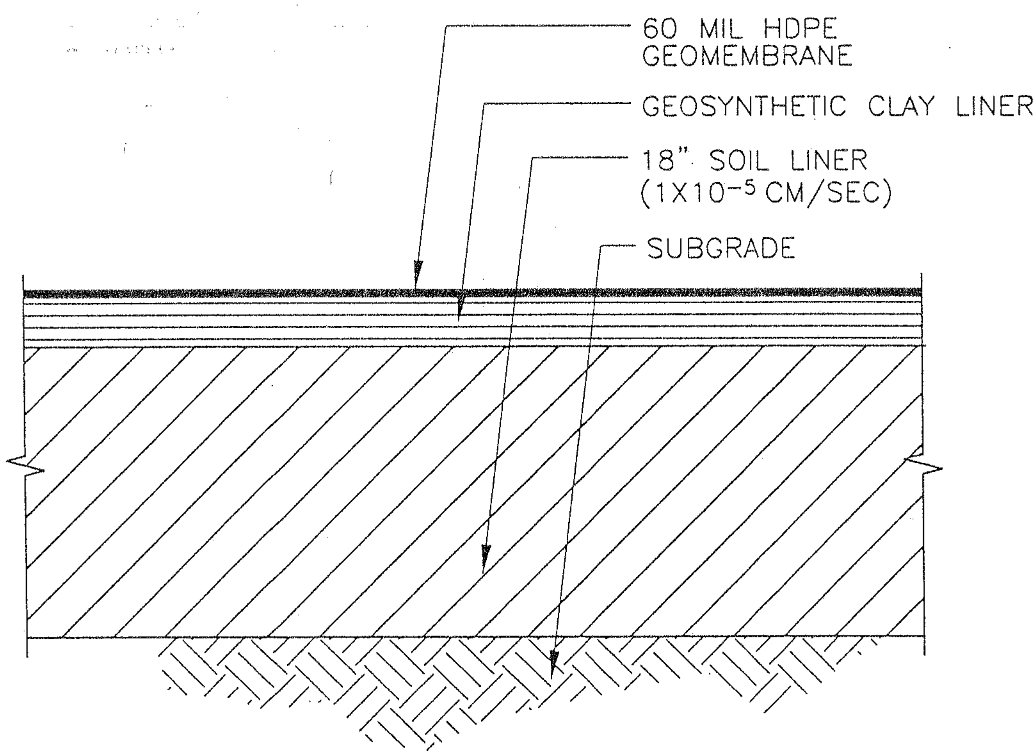
2. Installation of five (5) piezometers completed into bedrock for the collection of rock core, water level, and pumping test data from the sump region of Cell 2.

3. Calculations of aquifer hydraulic conductivity based on steady state pump test data, rising head analysis, and previous slug test data.

4. Calculation of a DAF using mass balance calculations based on site-specific aquifer parameters (e.g., hydraulic conductivity, hydraulic gradient, etc.) and landfill design (e.g., liner leakage rate, leachate flux rate, etc.).



STANDARD COMPOSITE LINER



PROPOSED ALTERNATE LINER

HDR
HDR Engineering, Inc. of the Carolinas
Suite 1400
128 S. Tryon Street
Charlotte, NC 28202-5001
(704) 338-1800

WHITE STREET SANITARY LANDFILL PHASE III

CITY OF GREENSBORO NORTH CAROLINA

Date 12/99

Figure 2

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3.3 Data Collection

The following section briefly describes the procedures executed during the above-referenced phases of work.

3.3.1 <u>Temporary Soil Boring/Piezometer Installations</u>

HDR prepared a work plan (dated June 12, 2000) entitled "Subsurface Hydrogeologic Characterization within 250 feet of Critical Area of Concern for Phase III Permit Modification which proposed the installation of up to 10 soil borings (PZ-1 through PZ-10) to determine the presence or absence of aquifer flow within the porous saprolitic soils. The plan consisted of installing soil borings at 100-foot intervals starting from the approximate center of the sump of Cell 2 and advancing downgradient along three potential ground-water flow paths based on existing potentiometric data from the Design Hydrogeologic Report (HDR, January 1997). The primary flow path is to the northwest with secondary paths to the surface water with drainage features to the west and north-northeast. The attached site plan shows the location of these soil borings. This plan was verbally approved by the Section prior to implementation.

Between June 14 and 15, 2000, seven soil borings (PZ-2 through PZ-6, PZ-8 and PZ-9) were installed using 3.25-inch inside diameter conventional hollow stem augers by S&ME, Inc. of Charlotte, North Carolina under the oversight of an HDR geologist. Proposed soil borings PZ-1, PZ-7, and PZ-10 were not installed due to utility location conflicts and drill rig access constraints. In addition, these borings were not deemed necessary since the data from the first seven soil borings installed did not appear to warrant their installation. Split-spoon samples were collected at 5-foot intervals starting from 3.5 feet below land surface until auger refusal was encountered. The soils were classified according to grain size (visual) and a log of each soil boring was prepared from the field evaluation of the split-spoon samples. Soil boring logs are included in Appendix A.

Once auger refusal was encountered, each soil boring location was converted to a temporary piezometer using standard 2-inch diameter polyvinyl chloride (PVC) well materials. Each location was fitted with a 5-foot screen flush-threaded to solid riser pipe which was allowed to stick up above grade. A washed silica sand pack was installed around each screen from the bottom of the screen to at least 1 foot above the top of the screen. A bentonite seal was installed immediately above the sand pack to an average thickness of 1 foot. The bentonite was hydrated with potable water overnight and the remaining annulus from the bentonite to ground surface was backfilled and compacted in place with the formation cuttings generated during auger drilling. A water-tight locking well cap was installed on each piezometer and the appropriate peizometer identification was marked on the outside of each casing stickup. The depth to ground water (if encountered) was measured at the time of boring and within 24 hours of piezometer completion. These piezometers were monitored periodically during the performance of this investigation for static depth to ground water. Upon completion of this investigation, each piezometer will be overdrilled and the remaining borehole will be tremie-grouted to surface grade using Portland Type I cement in accordance with North Carolina Well Construction and Abandonment Regulations, NCAC Title 15A, Subchapter 2C, Section .0100 (1992). Appendix A contains piezometer construction details for each temporary piezometer.

3.3.2 Rock Coring/Piezometer Installation

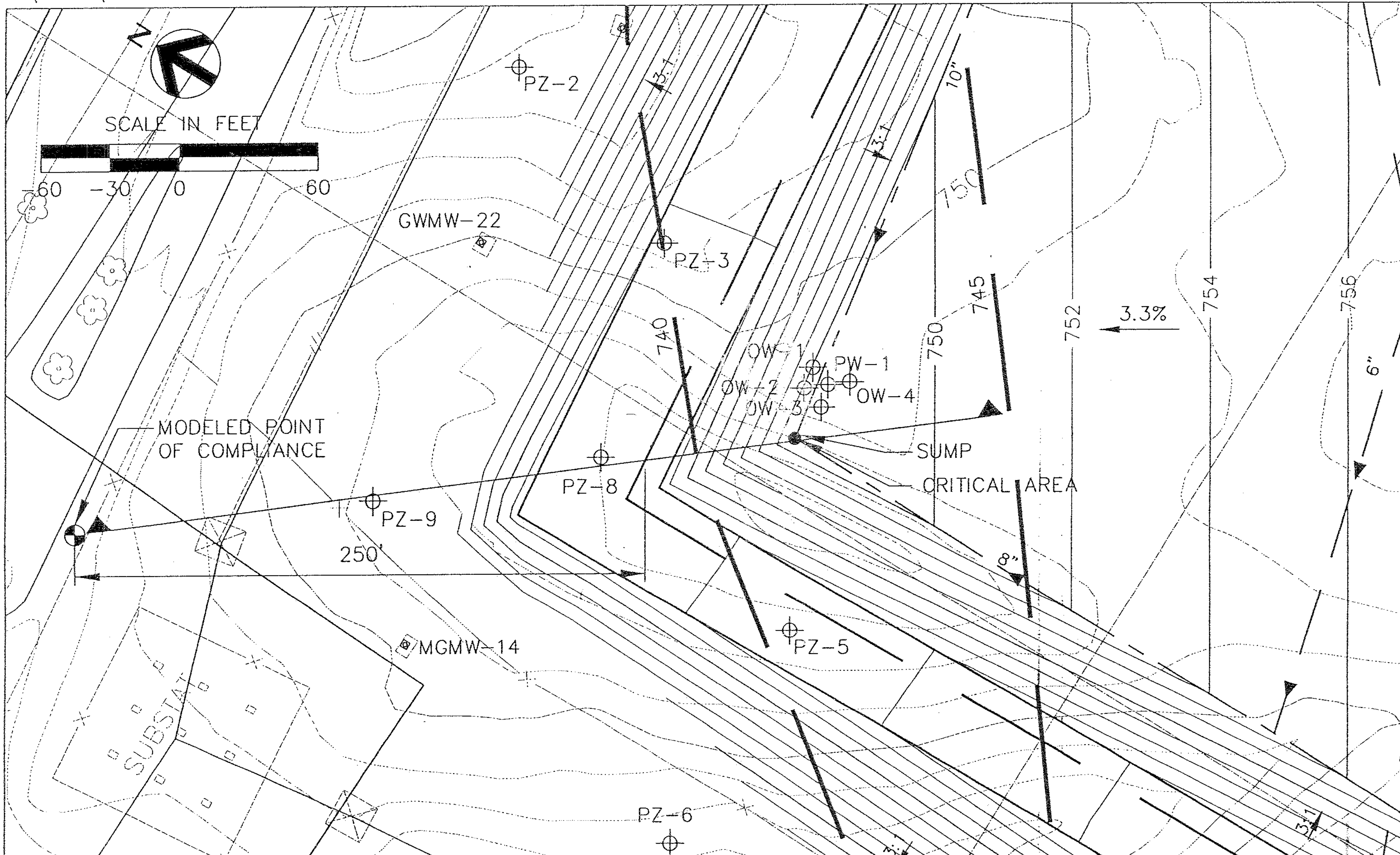
A decision was made in the field to change drilling methods to be able to advance deeper into the subsurface into the underlying bedrock. On June 15, 2000, rock coring commenced with the installation of shallow bedrock piezometers for water level and pumping test data collection. Five piezometers were installed in the vicinity of the sump of Cell 2. In order to obtain adequate data during pump testing regarding the spatial distribution of drawdown around the pumping well, four rock piezometers (OW-1 through OW-4) were installed at a distance of approximately 10 feet from a pumping well (PW-1) positioned within the approximate location of the sump. The attached illustrations (see Figure 3 and Drawing C-6) shows the location of these pumping/observation piezometers.

Drilling activities commenced on June 15, 2000, and were completed on June 20, 2000. Each location was initiated by advancing 4-inch diameter steel core barrel casing fitted with a diamond-impregnated carbide cutting head through the saprolite until the top of bedrock was encountered. The casing was advanced (using potable water) until the casing was firmly seated within the top of bedrock. A 10-foot long NQ core barrel was inserted through the casing and was rotated at a high speed with water introduced to keep the barrel cool. Due to the need to maintain an adequate supply of water during coring, a 3,500-gallon potable water truck was positioned near the drill site to supply water during coring efforts.

A typical subsurface hydrogeologic investigation performed during the permitting of a municipal solid waste Subtitle D Landfill in the Piedmont of North Carolina requires that the upper 10 feet of bedrock (minimum) be characterized. It was decided that an additional 10 feet of rock would be investigated as part of this work scope. Core recovery was logged in the field and the rock quality designation (RQD) was calculated for each core run. Depending upon penetration rates and rock competency, core runs ranged in length from 1.5 feet to 11 feet. The core recovered was boxed and taken back to HDR for detailed evaluation and logging. Features such as mineral composition, rock competency, fracture depth and attitude, secondary porosity conditions, and degree of weathering were recorded on logs which are attached to this document.

Once each coring event was completed to approximately 20 feet below the top of bedrock (15.5 feet in the case of OW-1), a piezometer was installed at each location using standard 2-inch PVC well materials. Each piezometer was constructed with a 20-foot screen to bracket the entire length of rock penetrated. On the average, each piezometer was installed to approximately 30 feet below land surface, with the exception of OW-1 which was terminated at approximately 27.5 feet below land surface. Solid riser pipe was flush-threaded to each screen and was allowed to stick up above ground surface. Due to the small diameter of the cored interval (slightly over 3 inches), a thin veneer of washed silica sand was placed between the well screen and the side wall of the cored interval to a depth of at least 1 foot above the top of the screen. A bentonite seal was placed immediately above the sand pack to an average thickness of 1 foot. The remaining annulus was backfilled and compacted in place with the formation cuttings. Upon completion of this investigation, each piezometer will be overdrilled to the top of bedrock and the remaining borehole will be tremie-grouted to surface grade using Portland Type I cement in accordance with North Carolina Well Construction and Abandonment Regulations, NCAC Title 15A, Subchapter 2C, Section .0100 (1992). Geologist logs for each core location are included in Appendix A. The construction specifications for the temporary piezometers are also shown on the logs.

P:\GBORO\FIG3-4



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WHITE STREET SANITARY LANDFILL
PERMIT MODIFICATION
BORING AND PUMP TEST LOCATION

Date 7/00

Figure 3

3.3.3 Soil Boring/Piezometer Survey

Each soil boring/piezometer was surveyed on June 20, 2000, by landfill personnel assisted by HDR. A northing and easting were determined for each piezometer as well as the elevation relative to mean sea level (msl) at ground surface and at the top edge of the PVC pipe. The coordinates were used to show the actual location of the piezometers on the attached site plan. Table 1 summarizes the survey data for the newly installed soil borings and piezometers.

TABLE 1
SUMMARY OF SURVEY DATA

Location	Northing	Easting	Ground	Casing
OW-1	858670.81	1783553.27	749.20	750.78
OW-2	858669.37	1783543.78	750.09	750.74
OW-3	858658.71	1783540.65	750.71	752.42
OW-4	858653.85	1783556.65	749.25	750.96
PW-1	858661.35	1783550.53	749.79	750.64
PZ-2	858849.69	1783596.38	741.92	744.70
PZ-3	858755.10	1783565.02	747.09	748.47
PZ-5	858619.30	1783451.52	754.10	756.39
PZ-6	858614.74	1783344.99	744.90	747.23
PZ-8	858729.57	1783471.37	755.28	757.69
PZ-9	858804.47	1783403.26	751.51	754.00

Ground and casing elevations are in feet relative to mean sea level (msl).
Northings and eastings are based on the state plane coordinate system.

3.3.4 Aquifer Testing

Beginning on June 20 and ending on June 23, 2000, a two-phased aquifer test was performed utilizing pumping well PW-1 and observation piezometers OW-1 through OW-4. In order to evaluate potential aquifer yield, a specific capacity (or step-drawdown) test was initially performed for approximately 8 hours. A Redi-Flow electric submersible pump was installed at PW-1 and was pumped at variable rates while adjacent observation wells were monitored for drawdown influence at specified intervals. The rate of pumping (Q) was measured using a stop watch and a graduated container.

The amount of drawdown in the pumping well and the observations wells was measured using an electronic water level indicator capable of measuring differences in water level up to 0.01 feet. The test was ended when the observed drawdowns in adjacent observations wells appeared to stabilize and the pumping rate had been adjusted to approximately 1 gallon per minute (gpm).

A second (long-term) aquifer test was performed for the collection of drawdown and pumping rate data under steady-state conditions. For the second test, the pump was placed in observation well OW-3 to provide at least two observation points at different distances from the pumping well for drawdown monitoring. This test was initiated with a pumping rate of 1 gpm. Early in the test, the stabilized (potential) flow rate was reduced based on the rate of drawdown occurring at the pumping well. A stabilized flow rate of approximately 0.2 gpm was achieved shortly after testing began and was maintained throughout the duration of the test approximately 26 hours. Water level measurements were frequently obtained from the pumping well and adjacent observation piezometers as well as periodically from ground-water monitoring wells MW-13, MW-22R, and MW-23 near the test site. The pumping rate was also checked during water level monitoring period to verify flow rate consistency. The total duration of the long-term pumping test was approximately 30 hours. The measured drawdown at the pumping wells (PW-1 for initial test and OW-3 for long-term test), the observations wells (OW-1, OW-2, and OW-4), and the measured pumping rate curve for each pumping test are illustrated in Appendix B. The field data obtained during each respective test is presented in spreadsheet form in Appendix B.

In addition to the collection of aquifer data during pump testing, two rising head tests were performed at the completion of each pumping period. The water level recovery (rise) from the initial capacity test at PW-1 and the long-term pumping test at OW-3 was monitored to provide an alternate method for calculating an estimated aquifer hydraulic conductivity. An electronic water level indicator was used to record recovery data with readings collected at specified intervals.

3.4 Data Evaluation

3.4.1 <u>Core Data</u>

The core recovered at each piezometer location was evaluated (visually) for rock type, competency, level of weathering, predominant mineralogy, nature, and degree of secondary porosity types (i.e., fractures and vugular), relationships between host rock and intrusions features (e.g., dikes), and overall evidence of water movement. In addition, the level of recovery for each core run was also calculated along with RQD for each run. A core log for each piezometer was prepared and are included in Appendix A.

3.4.2 <u>Aquifer Test Data</u>

The drawdown readings over time and the pumping rate data were entered into an Excel spreadsheet and a graph of drawdown over time for the pumping and observation wells was prepared to visually show drawdown trends over time for determination of when steady-state conditions were achieved. Pumping rates were also graphed in order to verify the steady-state pumping rate for aquifer calculations (see Appendix B).

An aquifer hydraulic conductivity (in feet per day) was calculated using pumping test data (long-term) and from the rising head tests conducted at the completion of pump testing. Since steady-state conditions were achieved during pumping, the following equation was used to represent steady-state conditions (Source: Applied Hydrogeology, Fetter, 1980). This equation was developed by C. E. Jacob from an equivalent expression first used by Thiem in 1906.

$$K = \frac{Q \ln(r_2 \div r_1)}{\pi(h_2^2 - h_1^2)}$$

Where: K = hydraulic conductivity (feet per day)
Q = steady-state pumping rate (cubic feet per minute)
h_1 = head potential at distance r_1 from pumping well (feet)
h_2 = head potential at distance r_2 from pumping well (feet)
r_1 = distance from pumping well at h_1 (feet)
r_2 = distance from pumping well at h_2 (feet)

The above-referenced parameters were entered into an Excel spreadsheet and hydraulic conductivity values were calculated for three separate cases where the distance between r_1 and r_2 varied. The attached calculation sheet in Appendix C shows the calculation of hydraulic conductivity for each steady-state case.

Rising head calculations were based on the equation by Bouwer, 1989. A graph of drawdown (change in head) was graphed against time on a semi-log scale. The slope of the data was derived from the data curve and the equation was solved using specific input parameters for each test well. The attached calculation sheets in Appendix C reference the equation used and the results of the calculations.

3.5 Findings

3.5.1 Saprolite Geology

Based on the split-spoon samples collected from the installation of soil borings/piezometers PZ-2, PZ-3, PZ-4, PZ-5, PZ-6, PZ-8, and PZ-9 in the vicinity of the sump, the subsurface saprolitic soils are predominantly composed of a sand with an interstitial matrix varying in grain size from a silt (sm) to a gravel (sp) derived from the inplace weathering of the underlying bedrock formation. Less dominant soil types consisted of clayey and sandy silts (ml). The thickness of this unit is relatively uniform across the study area ranging from approximately 11 feet at PZ-4/OW-3 to 17.5 feet at PZ-9, averaging 14.2 feet for the study area. Relict foliation, evidence of mafic xenoliths, and healed hairline fractures were preserved in the soil texture. Soil penetration resistance values (N-values) ranged from 20 blows per foot to over 100 blows per foot. On the average, most of the material encountered resulted in blow counts of 50 blows per foot or greater. 100 blows per foot indicate partially weathered rock. Auger refusal depths corresponded well to the depth at which competent rock was encountered during the seating of the outer core barrel casing. All soil samples were dry upon inspection, however, evidence of water was noted as some zones (clayey regions) were moist and sticky upon examination.

3.5.2 Bedrock Geology

Based on the core samples obtained during the installation of the five piezometers at the sump region, the dominant bedrock lithology across all piezometer locations was a white to light gray, non-foliated to slightly foliated (flow banding) granite. Similar in mineralogic composition but with a preferred mineral alignment (i.e., foliation), gneiss was also encountered at piezometer OW-2. Several intrusions were also encountered within the study area. The dominant intrusion appeared to be an altered (slightly metamorphosed) basalt (referred to as a greenstone). This can be seen in the logs for OW-1 and OW-2. A similar intrusion of like mineralogic composition but coarser grained (phaneritic) was encountered at OW-3 was identified as a meta-gabbro. A single occurrence of an aplite/pegmatite dike (late-stage residual granitic fluids) was noted at PW-1. Further details concerning the bedrock type and characteristics at each of the piezometer locations can be found on the attached core logs in Appendix A. The following is a generalization of the overall findings from the rock core evaluation.

In general, the upper 20 feet of bedrock at the study area is highly fractured and shows varying degrees of weathering due to ground-water interaction. Also, the degree of weathering is dependent upon the type of rock present, granite/gneiss being more resistant to physical and chemical weathering than the mafic intrusions (basalt/gabbro intrusions). The RQD ranged from as low as 19% (predominantly mafic compositions) up to 100% (granitic compositions). Primary porosity throughout the section was essentially absent; however, secondary porosity was relatively high due to the abundance of open fractures and vugular porosity resulting from the loss of mafic minerals (biotite) and dissolution along healed fractures. Open fractures were present throughout the 20-foot section with a higher percentage occurring within the upper limits of the formation and immediately adjacent to intrusions. In general, fractures appeared to strongly parallel foliation (when present) and were cross-cutting near contacts with intrusions. Fracture angles ranged from subhorizontal (related to stress relief) to nearly vertical (80 degrees). There appeared to be a strong preference for fracture angles to be either between 40 to 45 degrees or 60 to 70 degrees. Overall, fracture planes were smooth with the occasional evidence of secondary mineralization (formation of chlorite) due to low-grade contact metamorphism during fracture movement. However, fractures within a thin quartzite unit (OW-1) were jagged with marginal fractures occurring at nearly 45 degree angles to the primary fracture orientation due to the interlocking nature of the quartz grains during recrystallization). Fractures with evidence of geochemical reaction to ground-water movement showed a thin veneer or coating of either iron or manganese oxide resulting from the oxidation of mafic minerals. In addition to the core logs from the newly installed pumping/observation piezometers, Appendix A contains copies of core logs from previous ground-water study piezometers B-1d, B-9d, B-17d, B-22d, B-25d, B-34d, MW-13, and MW-22R installed as part of the Design Hydrogeologic Report of the Permit Application for Phase III. The location of these additional data point locations are shown on Figure 3 and Drawing C-6.

3.5.3 Saprolite Hydrogeology

Based on the periodic monitoring of the temporary piezometers installed in the soil borings near the sump region of Cell 2, ground water was not present within the unconsolidated saprolitic soils from the location of the sump to approximately 250 feet downgradient of the point of compliance at six of the seven piezometer locations. A trace of ground water (less than 1 foot) was observed in piezometer PZ-3 within 24-hours of completion. After a significant rain event (5 inches in 2.5 hours) on June 19, 2000, approximately 3 feet of water was measured at this location within several hours after the storm event. This is suggestive that the shallow bedrock aquifer beneath the study area is readily recharged during the infiltration of precipitation through the sandy soil. None of the other piezometers detected the presence of ground water during this investigation. This indicates that the depth to ground water is below the screened interval at these well locations (i.e., below the top of bedrock).

3.5.4 Bedrock Hydrogeology

Based on the water level and pumping test data collected from the five piezometers installed in the vicinity of the sump, the uppermost aquifer (to a depth of at least 20 feet below the top of bedrock) consists of an unconfined aquifer residing in a highly fractured bedrock environment. On the average, the depth to ground water is approximately 0.6 to 1.8 feet below the top of competent bedrock, with the exception of piezometer location OW-1. At OW-1, ground water prior to pump testing was approximately 2.9 feet above the top of competent rock at this location. Ground-water levels during seasonal high periods (or even after significant storm events) may rise by as much as 1 to 3 feet putting the water table periodically above the bedrock interface within the overlying saprolitic unit. Ground-water movement occurs along fractures created by stress relief and post-cooling deformational events (regional tectonic stresses and localized dike intrusions). Based on observations made during pump testing, the movement of ground water through the bedrock formation appears to be controlled more by fracture density and interconnectivity rather than actual rock type. Primary porosity in crystalline rock is essentially nonexistent. Therefore, rock type (i.e., mineralogic composition) is not typically the primary controlling factor for ground-water movement. However, mineralogic composition can play a part in the formation of secondary porosity (i.e., by physical/chemical weathering). Mafic-rich mineralogic compositions tend to weather more readily than granitic compositions under low-temperature geochemical environments. There was no evidence in the rock record from any of the cored locations to suggest preferential weathering between rock types. In general, those rock types near the saprolite/bedrock interface showed a higher degree of weathering than did similar rock types at depth.

3.5.5 Aquifer Testing

The results from the aquifer tests showed that the response to pumping on the water table aquifer within the fractured bedrock formation was similar to the response expected for an aquifer dominated by flow through a porous media. The evaluation of the drawdown data over time from the adjacent observation wells during pump testing showed that each location experienced very similar drawdown responses regardless of the well's relationship to the pumping well (e.g., upgradient, downgradient, sidegradient). Response to pumping was observed almost immediately after pumping began (within 3 minutes) in all directions and the point in time at which stabilized drawdown occurred was also very similar. The level of drawdown in PW-1 and OW-4 were essentially the same indicating a high degree of connectivity between the two piezometer locations. This is also supported by the occurrence of artesian conditions induced at PW-1 and OW-4 by the introduction of potable water during the coring of OW-3.

The primary goal of the long-term pumping test was to achieve a steady-state pumping condition on the aquifer and monitor the response to the aquifer (i.e., drawdown in pumping and observation points) over a sufficient duration of time until drawdown in the pumping and/or adjacent observation points stagnates. Based on the raw data presented in Appendix B, a stabilized pumping rate (0.2 gpm average) was achieved approximately 35 hours into the test and was maintained for approximately 26 additional hours thereafter. Drawdown response in the observation wells achieved steady-state conditions (stabilization of drawdown) within approximately 4 hours of the start of the test. The drawdown over time for the observation wells are shown on the attached figure in Appendix B. Likewise, the measured pumping rate over time for the same period is also shown in Appendix B.

3.5.6 Determination of Site-Specific Hydraulic Conductivity

In order to determine the appropriate site-specific hydraulic conductivity for the determination of a DAF, HDR not only evaluated the hydraulic conductivity values calculated from pumping test data but the conductivity values previously reported from slug testing of similar piezometers over the entire footprint as part of the Design Hydrogeologic Investigation phase of permitting. Table 2 is a summary of the hydraulic conductivity values compiled and evaluated as part of this determination.

TABLE 2
SUMMARY OF HYDRAULIC CONDUCTIVITY VALUES

Location	Rock Type	Depth	Test Method	Conductivity ft/day
OW-1/OW-2	Gr./Gneiss	Shallow	Pumping Test	0.14
PW-1/OW-2	Granite	Shallow	Pumping Test	0.02
PW-1/OW-1	Granite	Shallow	Pumping Test	0.06
PW-1	Granite	Shallow	Rising Head	0.14
OW-3	Granite	Shallow	Rising Head	0.03
B-17d	Gneiss	Deep	Falling Head	0.45
B-22d	Granite	Shallow	Falling Head	0.09
B-25d	Granite	Shallow	Falling Head	0.16
			Geometric Mean	0.091

Depths are relative to the screen position below the top of competent rock.
Shallow completions are screened less than 25 feet below the top of rock.
Deep completions screened greater than 25 feet below top of rock.
Rock type is the dominant rock type encountered
Gr. – granite

Based on the hydraulic conductivity (K) values calculated from the pumping test data, these values are well within the expected range for a fractured bedrock aquifer. In addition, the pumping test resulted in hydraulic conductivity values consistent with the existing hydraulic conductivity values obtained from rising and falling head tests conducted during previous hydrogeologic investigations conducted at the site. Furthermore, the rising head tests conducted at the conclusion of the pumping test also yielded hydraulic conductivity values consistent with the pump test results. When averaging K values, it is a generally accepted practice to use the geometric mean. A geometric mean is approximate for data that typically varies by orders of magnitude as is the case with K values from various aquifer evaluation methods. The geometric mean is calculated by taking the "n^{th}" root of the product of "n" terms. This method, when applied to all of the hydraulic conductivity values obtained for the landfill, results in a geometric mean hydraulic conductivity value for the aquifer of 0.091 feet per day. This value was selected as the most representative for DAF determination.

3.6 Calculation of Dilution-Attenuation Factor

The calculation of a DAF can be divided into three primary components; 1) the determination of the rate of leachate leakage from the liner system, 2) the rate or volume of available ground water for dilution of the leachate released, and 3) determination of the leachate concentration at the point of compliance. The following sections describe the steps and the site-specific input parameters utilized in determining each of the above-referenced results.

3.6.1 Liner System Leakage Rate

Since not all of the lined areas of Cells 2 and 3 would equally contribute leachate leakage to the point of compliance (based on particle vector analysis from flow path determinations along the critical path), the critical area of the liner system (i.e., the area most capable of contributing leachate along the critical path) must first be identified. Based on the evaluation of Drawing C-6, the critical area of liner has been determined to be 8 acres. This represents the total area anticipated to contribute leachate at the greatest concentration to the point of compliance.

Once the area of contribution is identified, the total anticipated leakage rate can be calculated based on the assumed unit leakage rate of 0.53 gallons/acre as stated in the NCDENR guidance document and NC SWANA's 1997 "white paper" (see Appendix H). Based on the conditions presented, the total anticipated leakage rate (defined as Q_L) of the critical area of the landfill liner would be:

$$Q_L = 0.53 \text{ gallons/acre/day} \times 8 \text{ acres} = 4.24 \text{ gallons/day}$$

As indicated in subsequent text, the leakage rate (Q_L = 4.24 gallons/day) is assumed to be evenly distributed over a 630 foot wide segment of the aquifer at the point of compliance.

3.6.2 Ground-Water Flux Rate

The amount or rate (defined as Q_W) of ground-water movement through the area of critical concern can be calculated using the following relationship developed by Darcy:

$$Q = KiA$$

Where: K = hydraulic conductivity of the aquifer (feet per day)
i = average site hydraulic gradient across the critical area (feet per foot)
A = cross sectional area of the aquifer (square feet)

The hydraulic conductivity (K) of the aquifer was previously calculated in Section 3.5.6 as 0.091 feet per day. The following sections document the determination of the remaining input parameters; hydraulic gradient and the cross sectional area of the aquifer.

Hydraulic Gradient

The average hydraulic gradient of the water table through the critical area of Cell 2 of the sump was determined to be 0.033 feet per foot (3.3%) based on the evaluation of water table elevation data presented in the Design Hydrogeologic Investigation Report, dated January 1997. Several ground-water flow paths were evaluated within Cells 2 and 3 in order to determine the maximum and minimum gradients for Phase III. Gradients ranged from 2% (0.02 feet per foot) to 10% (0.10 feet per foot). The 0.033 feet per foot is representative of the gradient across the critical area and is conservative in the fact that this falls near the low end of the gradients calculated for Cells 2 and 3 of Phase III. Figure 4 depicts the conceptual hydrogeologic cross section along the critical path to the point of compliance.

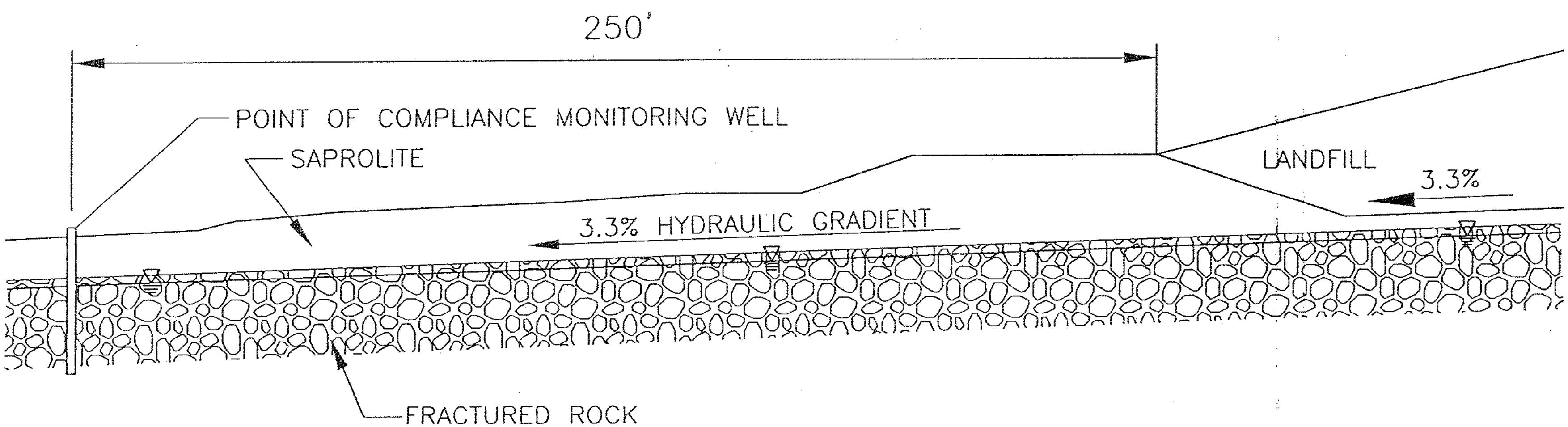
Cross Sectional Area of Aquifer

The calculation of the cross sectional area of the aquifer requires two separate inputs to be determined, 1) width of the aquifer across the critical path and 2) the aquifer's thickness.

Based on the water table potentiometric contours represented in Drawing C-6, the area of critical path was chosen based on the flow net evaluation of all components of ground-water flow originating from Cells 2 and 3. This area is represented by the northwestern portion of Cell 2 which not only has the longest particle flow path of either Cell but is also the location of a sump near the downgradient edge of Cell 2. Considering the flow vectors passing through this point of the landfill, the width of the critical area is equivalent to the width of the water table potentiometric contour contributing to the predominant flow across this area. This calculates to a width of 630 feet. This relationship can be seen in Drawing C-6.

The second parameter needed to calculate the cross sectional area is aquifer thickness (b). This parameter is to be taken as the true thickness of the aquifer as represented by a fully penetrating well. Since the uppermost aquifer at the site is unconfined and there is no true confining unit marking its lower boundary, the thickness of the aquifer corresponds to the depth at which there is the lack of appreciable ground-water movement (lack of or closure of fractures). This depth is not known at the Landfill. Cressler and Others (1983) discovered that significant yields within fractured rock are available at depths between 400 to 600 feet below land surface from horizontal openings (stress-relief fractures) that formed as a result of erosional unloading. According to the Geology and Ground Water in the Greensboro Area, the average depth of a well completed in granite is 175 feet and the average depth of a well completed in a gneiss is 123 feet. All wells completed into fractured bedrock in Guilford County (County) average 158 feet. Furthermore, a deep monitoring well (MW-11) has been previously installed approximately 300 feet downgradient of the critical area to a depth of 101.5 feet below land surface. Rock core data indicates that fractures are present throughout the bedrock section to a depth greater than 90 feet below land surface. Based on the static ground-water measurement at this well after 24-hours, the depth to ground water at this well location is approximately 18.41 feet below land surface (approximately 1.1 feet above the top of bedrock). This equates to a water column of 82 feet. Since igneous/metamorphic environments are not prone to having identifiable, regional aquitards or aquicludes, the actual bottom of the fractured bedrock aquifer beneath the landfill is unknown. This well represents the deepest drilling event near Phase III. Private and commercial water wells in the Greensboro area are typically completed to greater depths and are still

P:\GBORO\FIG3-4



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WHITE STREET SANITARY LANDFILL
PERMIT MODIFICATION
CONCEPTUAL HYDROGEOLOGIC CROSS SECTION

Date	7/00
Figure	4

producing ground water from the uppermost aquifer. Based on the available onsite data and literature, HDR believes that the 82-foot water column in MW-11 is a conservative approximation to use as an aquifer thickness for DAF calculation. The drilling log for monitoring well MW-11 is included in Appendix A. Through discussion with the NCDENR Solid Waste Section, it was agreed that an even more conservative aquifer thickness of 40 feet would be used.

Relating back to the ground-water flux equation by Darcy, the following calculations can be performed for the available ground-water movement across the critical area.

$$Q_W = 0.091 \text{ feet/day} \times 0.033 \text{ ft/ft} \times (40 \text{ feet} \times 630 \text{ feet})$$
$$= 75.68 \text{ cubic feet/day} \times 7.481 \text{ gallons/cubic foot}$$
$$= 566.2 \text{ gallons/day (from the aquifer)}$$

3.6.3 <u>Initial Leachate Concentration</u>

The initial leachate concentration (C_L) of 1 milligrams per liter (mg/l) was taken from the North Carolina Department of Environment and Natural Resources 1998 Permitting Guidance Document.

3.6.4 <u>Leachate Concentration at Point of Compliance</u>

The concentration of leachate at the point of compliance can be calculated by means of the following mass balance equation (H. Peavy, 1985).

$$C_{poc} = \frac{C_L Q_L}{Q_L + Q_W}$$

Given the previous relationship, the concentration at the point of compliance (poc) calculates as follows.

$$C_{poc} = \frac{1 \text{ mg/l} \times 4.24 \text{ gallons/day}}{(4.24 \text{ gallons/day} + 566.2 \text{ gallons/day})}$$
$$= 7.43 \times 10^{-3} \text{ mg/liter}$$

3.7 Calculation of DAF

The DAF describes the decrease in contaminant concentration between the bottom of the landfill disposal unit (point of leakage) and the POC. A unit concentration of 1 mg/l is used in the model for the convenience of calculating the DAF. The DAF is defined as the initial leachate concentration divided by the predicted concentration at the POC. The design would, according to the USEPA, be acceptable if the DAF is 100 or greater, due to the maximum expected concentration of contaminants. Typical leachate contaminant concentrations found in municipal solid waste landfills are approximately 100 times greater than the MCL for each constituent [Ref. 9]. MCL standards are shown on Table 3.

The DAF calculation is based on the following relationship presented in the 1997 SWANA white paper.

$$DAF = \frac{C_L}{C_{poc}}$$

$$= \frac{1 \text{ mg/liter}}{7.43 \times 10^{-3} \text{ mg/liter}}$$

$$DAF = 135$$

Since the resulting DAF is greater than the required 100, the alternate liner demonstration is successful.

TABLE 3 PERFORMANCE STANDARDS (15A NCAC 13B.1624)	
Chemical	**NCDENR Maximum Contaminant Level (mg/l)**
Arsenic	0.05
Barium	1.0
Benzene	0.005
Cadmium	0.001
Carbon tetrachloride	0.005
Chromium (hexavalent)	0.05
2,4-Dichlorophenoxy acetic acid	0.1
1,4-Dichlorobenzene	0.075
1,2-Dichloroethane	0.005
1,1-Dichloroethylene	0.007
Endrin	0.0002
Fluoride	4
Lindane	0.004
Lead	0.05
Mercury	0.002
Methoxychlor	0.1
Nitrate	10.0
Selenium	0.01
Silver	0.05
Toxaphene	0.005
1,1,1-Trichloroethane	0.2
Trichloroethylene	0.005
2.4,5-Trichlorophenoxy acetic acid	0.01
Vinyl Chloride	0.002

3.8 Construction Implications

A copy of the CQA Plan and drafts of the associated specifications for the Soil Liner System (02276), Geosynthetic Liner (02775), and Geosynthetic Clay Liner (GCL) (02800) are included in the Appendices.

4.0 CELL 2 BOUNDARY ADJUSTMENT

A Duke Power substation is located within Landfill property adjacent to Phase III. At the time of original permitting, Duke Power owned the property, and the Phase III boundary was established to maintain the minimum 300-foot buffer off the substation property. The impact of this separation requirement on the Phase III footprint is a reduction in lined area of approximately 0.9 acres. This area was discussed during the permitting process with NCDENR and the decision was made to apply for this modification after the City acquired the substation property. To expedite the permitting process this area was deleted from the original Landfill unit design drawings, however, all other aspects of the permit were handled as if this would become part of the unit. The City obtained title to the substation on December 10, 1997. Revised drawings are included in this application that depict the additional 0.9 acre area afforded by the City owning the substation property. The design adjustments comply with all NCDENR buffer requirements.

5.0 SUBGRADE REVISION

This modification incorporates the expanded footprint into the subgrade design of Cell 2. Before modifying the subgrade, the ground-water and rock data acquired since the Construction Permit Application was evaluated. Groundwater elevations collected from recent monitoring events around Cell 2 (see Table 4) were plotted with the seasonal high groundwater elevations determined from the original piezometers. None of the recent events exceeded the seasonal high water table. Drawing C-4 is included to illustrate the long term seasonal high ground-water elevations in the vicinity of the expanded footprint, (see ground-water contours 740 and 745). The required separation between ground-water and base grades is maintained as illustrated in drawing C-1. The Vertical Separation Criteria Table (11-1), from the Construction Permit Application is updated below as Table 5. A column for the revised base grade elevation was added. The bedrock and water table separation columns include the original and revised distances. The base grades for Cell 2 are generally limited by groundwater.

During excavation, for the construction of Cell 1 in 1997, incidental rock was encountered between boring locations. The City obtained NCDENR approval to blast. The area was resurveyed at the completion of excavation to improve the mapping of the area. Survey shots were gathered from the rock exposed during excavation. These shots were used to adjust the estimated bedrock contours. Monitor well logs for MW-11, 13, 22, and 23 indicated the presence of rock at depth. Based on this information, we modified contours 745 through 760 in Cell 2 shown on the attached Bedrock Surface

Map, drawing C-5. The original locations of the bedrock contour lines are shown as dashes.

TABLE 4 GROUND-WATER ELEVATION DATA SUMMARY PHASE III - WHITE STREET LANDFILL GREENSBORO, NORTH CAROLINA										
Elevation (Feet)										
Well No.	**9/17/97**	**12/16/97**	**1/14/98**	**2/13/98**	**3/6/98**	**3/20/98**	**5/6/98**	**5/19/98**	**October 14 & 15, 1998**	**3/25/99**
MW-13	720.93						723.41		718.93	722.43
MW-21		737.72	738.48	740.77	740.10				734.96	739.66
MW-22					736.27	737.35	735.93	736.05	731.62	736.42
MW-23		734.20	735.15	737.69	734.90				728.45	735.20
MW-24		751.14	749.56	749.93	749.65				745.95	749.27
MW-25		733.97	732.49	733.80	733.69				734.07	733.42

Part of the base grade revision includes a second sump, which is a more conservative design than originally proposed for the Phase III unit. The revision results in raising grades in the northeast corner of Cell 2 and lowering them along the ridge and at the new sump. The proposed revision maintains the required four-foot separation between the bedrock surface and liner system. Drawing C-2 illustrates the proposed top of liner grades and revised leachate collection layout for Cell 2.

6.0 FINAL GRADE REVISION

The final grading plan has been revised to address the expanded Cell 2 footprint. The revised final grades increase the total capacity of Phase III by slightly more than 1%.

7.0 CONCLUSION

The results of the alternate liner modeling yielded a minimum DAF of 135for a 12-inch head. The proposed design is, according to EPA guidance, acceptable because the DAF is greater than the EPA recommendation of 100.

The adjustment of the Cell 2 boundary complies with the required buffers based on the City's purchase of the substation property. The subgrade revisions comply with the required long term seasonal high ground-water and bedrock separations. The final grade revision is consistent with the concept of the original final grades.

TABLE 5 VERTICAL SEPARATION CRITERIA							
Boring (a)	Ground Elevation (b)	Permitted Base Grade Elevation (c)	Revised Base Grade Elevation (f)	Top of Bedrock (d)	Bedrock Separation (Permitted/ Revised)	Seasonal High Water Table Elevation[e]	Water Table Separation (Permitted/ Revised)
B-1	760.80	757.40	755.8	747.80	9.60/8.0	750.31	7.09 / 5.5
B-7	773.09	762.60		748.59	14.01	756.91	5.69
B-10	778.09	772.00		745.59	26.41	757.12	14.88
B-11	769.20	764.80		752.70	12.10	756.97	7.83
B-12	776.06	779.20		765.06	14.14	773.54	5.66
B-16	782.71	772.40	771.2	746.71	25.69/24.5	766.40	6.00/4.8
B-17	787.71	782.60		773.71	8.89	778.55	4.05
B-18	771.60	767.40		758.60	8.80	760.00	7.40
B-19	775.78	770.00	769.3	764.78	5.22/4.5	764.90	5.10/4.4
B-20	770.68	759.60		754.68	4.92	748.45	11.15
B-22	754.92	755.80		723.92	31.88	748.65	7.15
B-23	765.26	757.40		734.26	23.14	751.51	5.89
B-24	750.08	758.00		738.08	19.92	744.25	13.75
B-25	744.54	749.20		706.04	43.16	743.57	5.63
B-26	739.20	755.84		732.70	23.14	740.00	15.84
B-28	739.33	744.64		738.83	5.81	740.54	4.10
B-29A	743.61	751.54		735.61	15.93	742.30	9.24
B-31	747.10	752.00		722.10	29.90	747.90	4.10
B-33	757.22	758.74		742.22	16.52	754.47	4.27

Notes:
- (a) Borings located within the proposed Landfill footprint (cell limits).
- (b) Ground elevation at time of boring installation.
- (c) See Figure C-2 of the Construction Permit Application.
- (d) See Figure D-3 of the Construction Permit Application.
- (e) Adjusted January 29, 1996, water level readings.
- (e) See Figure C-1 of the Permit Modification.

8.0 REFERENCES AND RELATED BIBLIOGRAPHY

(1) Daniel, D.E., and R.M. Koerner, (1993), *Quality Assurance and Quality Control for Waste Containment Systems*, United States Environmental Protection Agency, Office of Research and Development, Technical Guidance Document, EPA/600/R-93/182, September 1993.

(2) Fetter, C. W. Jr., "Applied Hydrogeology," Charles E. Merrill Publishing Co., Columbus, Ohio, ©1980.

(3) Giroud, J.P., et. al., "New Developments in Landfill Liner Leakage Evaluation," 1998 Sixth International Conference on Geosynthetics, March 1998.

(4) HDR Engineering, Inc. of the Carolinas, "Subsurface Hydrogeologic Characterization within 250 feet of Critical Area of Concern for Phase III Permit Modification," White Street Municipal Solid Waste Landfill, Greensboro, North Carolina, June 2000.

(5) HDR Engineering, Inc. of the Carolinas, "Design Hydrogeologic Report," in Construction Permit Application, White Street Sanitary Landfill, Greensboro, North Carolina, revised November 1996.

(6) McEnroe, Bruce M., "Maximum Saturated Depth over Landfill Liner," Journal of Environmental Engineering, ASCE, Vol. 119, No. 2. pp. 262-270. March/April 1993.

(7) North Carolina Department of Environment, Health, and Natural Resources, "Well Construction Standards – Criteria and Standards Applicable to Water Supply and Certain Other Wells," NCAC Title 15A, Subchapter 2C, Section .0100, December 1992.

(8) Schroeder, P.R., et. al., (1994, *The Hydrologic Evaluation of Landfill Performance (HELP) Model – User's Guide for Version 3,* United States Environmental Agency, Office of Research and Development, Cincinnati, OH, EPA/600/R-94/168a, September, 1994.

(9) Sharp-Hansen, et. al., (1990), *A Subtitle D Landfill Application Manual for the Multimedia Exposure Assessment Model (MULTIMED),* United States Environmental Agency, Environmental Research Laboratory, Athens, GA.

Appendix A

SOIL BORING LOGS, CORE DESCRIPTIONS

AND PIEZOMETER CONSTRUCTION DIAGRAMS

PROJECT: WHITE STREET LANDFILL (PHASE III)				PROJECT NO: 06770-021-018	
LOCATION: GREENSBORO, N.C.				BORING NUMBER: B-1d	PAGE: 1 OF 1
CORE LOG					DATE: 12/17/94
NUMBER	DEPTH	REC	RQD	DESCRIPTION (ROCK)	FRACTURES (W/ANGLE)
	14'			AUGER REFUSAL	SAPROLITE
FIRST CORE RUN	18' 22'	90%	78% GOOD	BASALT: FINE-GRAINED, DARK GRAY TO BLACK, CONTAINS PYRITE, HEALED FRACTURES CONTAINING PLAGIOCLASE (?) OR CHLORITE (?), PYRITE AND MANGANESE OXIDE STAINING, TWO HORIZONTAL FRACTURES WITH IRON OXIDE STAINING VERTICAL CONTACT BETWEEN BASALT AND GABBRO	HORIZONTAL HORIZONTAL
SECOND CORE RUN	26' 30'	91%	83% GOOD	GABBRO: COARSE-GRAINED, DARK GRAY TO BLACK, SMALL PHENOCRYSTS OF PLAGLOCLASE, FEWER HEALED FRACTURES, SOME IRON OXIDE STAINING ALONG FRACTURES	HORIZONTAL HORIZONTAL HORIZONTAL HORIZONTAL
	34' 38'			TD = 31.0'	

COREHOLE COMPLETION: 31' BELOW LAND SURFACE

WATER DEPTH: 755.27 DATE: 12/27/94

DRILLING METHOD: NX CORE (15 FT.)

LOGGED BY: CURT M. WELTY, PG

KEY:
REC–RECOVERY
RQD–ROCK QUALITY DESIGNATION
NA–NOT APPLICABLE

HDR

PROJECT: WHITE STREET LANDFILL (PHASE III) PROJECT NO: 06770-021-018

LOCATION: GREENSBORO, N.C. BORING NUMBER: B-9d PAGE: 1 OF

CORE LOG

DATE: 12/20/94

NUMBER	DEPTH	REC	RQD	DESCRIPTION (ROCK)	FRACTURES (W/ANGLE)
				AUGER REFUSAL	SAPROLITE
FIRST CORE RUN	54' – 58'	81%	30% POOR	GREENSTONE: ALTERED BASALT DIKE, FINE-GRAINED, FOLIATED, CHLORITE-RICH, METAMORPHOSED, NUMEROUS, CLOSELY-SPACED (<1") VERTICAL FRACTURES THAT PARALLEL FOLIATION, FRACTURES COATED WITH IRON AND MANGANESE OXIDE, VERTICAL CONTACT WITH GRANITE AT 58'.	FRACTURE ZONE
SECOND CORE RUN	62' – 66'	93%	99% EXCELLENT	GRANITE: CONTAINS QUARTZ, FELDSPAR, BIOTITE AND MINOR EPIDOTE, COARSE-GRAINED, MASSIVE, FRACTURES FROM ≈20° TO 75° FROM HORIZONTAL, ABOUT ONE FRACTURE EVERY 6", IRON OXIDE COATING ON FRACTURE SURFACES	65° 65° 50°
	70'			TD = 67.0'	

COREHOLE COMPLETION: 67' BELOW LAND SURFACE

WATER DEPTH: 753.82 DATE: 12/27/94

DRILLING METHOD: NX CORE (15 FT.)

LOGGED BY: CURT M. WELTY, PG

KEY:
REC–RECOVERY
RQD–ROCK QUALITY DESIGNA
NA–NOT APPLICA

HDR

PROJECT: WHITE STREET LANDFILL (PHASE III) PROJECT NO: 06770-021-018

LOCATION: GREENSBORO, N.C. BORING NUMBER: B-17d PAGE: 1 OF 1

CORE LOG DATE: 12/28/94

NUMBER	DEPTH	REC	RQD	DESCRIPTION (ROCK)	FRACTURES (W/ANGLE)
	4' 8' 12'			AUGER REFUSAL	SAPROLITE
FIRST CORE RUN	16' 20'	100%	83% GOOD	GNEISS: FOLIATED, WHITE, GRAY AND BLACK, FINE TO MEDIUM GRAINED, SLIGHTLY BROKEN TO MASSIVE, HARD TO VERY HARD, CONTAINS QUARTZ, FELDSPAR, BIOTITE MICA, MINOR PYRITE, FOLIATION NEARLY VERTICAL TO 70° FROM HORIZONTAL, OPEN FRACTURES NEARLY HORIZONTAL TO 55°, FELDSPAR HEALED FRACTURES (70–80°) TO NEARLY HORIZONTAL	30° 55° 35°
SECOND CORE RUN	24' 28'	78%	71% FAIR	GNEISS: LESS DISTINCT FOLIATION, FOLIATION AT 55° FROM HORIZONTAL, FRACTURES (60°) SLIGHTLY CONCOIDAL, HARD TO VERY HARD, MASSIVE	60°
	32' 36' 40'			TD = 28.0'	

COREHOLE COMPLETION: 28' BELOW LAND SURFACE

WATER DEPTH: 753.62 DATE: 12/29/94

DRILLING METHOD: NX CORE (14.5 FT.)

LOGGED BY: JOHN R. ISHAM

KEY:
REC–RECOVERY
RQD–ROCK QUALITY DESIGNATION
NA–NOT APPLICABLE

HDR

PROJECT: WHITE STREET LANDFILL (PHASE III) PROJECT NO: 06770-021-018

LOCATION: GREENSBORO, N.C. BORING NUMBER: B-25d PAGE: 1 OF

CORE LOG

DATE: 12/29/94

NUMBER	DEPTH	REC	RQD	DESCRIPTION (ROCK)	FRACTURES (W/ANGLE)
	34'			AUGER REFUSAL	SAPROLITE
FIRST CORE RUN	38' 42'	88%	27% POOR	GRANITE:WHITE TO CREAM, SOFT TO MEDIUM HARD, BROKEN TO SLIGHTLY BROKEN, WEATHERED, HIGHLY FRACTURED (45°-70°) WITH CONJUGATE SETS AT 90°, COARSE-GRAINED QUARTZ, FELDSPAR PARTIALLY WEATHERED TO KAOLINITE (EARTHY), PATCHY IRON OXIDE STAINING, DENDRITIC MANGANESE OXIDE COATINGS	FRACTURE ZONE 45° 70° FRACTURE ZONE
SECOND CORE RUN	46' 50'	79%	25% POOR/ V. POOR	GRANITE: SLIGHTLY BROKEN AND HARD FROM 40-45', WHITE TO CREAM, ABUNDANT CONVEX FRACTURES (45-90°), ABUNDANT HEALED FRACTURES (45-90°), CONTAINS GRAY QUARTZ, WEATHERED FELDSPAR, BIOTITE MICA, DENDRITIC MANGANESE OXIDE STAINING, MINOR VUGULAR POROSITY NEAR FRACTURE SURFACES, MINOR INTERGRANULAR POROSITY	45° FRACTURE ZONE 50°
	54'			TD = 52.0'	

COREHOLE COMPLETION: 52' BELOW LAND SURFACE

WATER DEPTH: 737.69 DATE: 1/25/95

DRILLING METHOD: NX CORE (15 FT.)

LOGGED BY: JOHN R. ISHAM

KEY:
REC-RECOVERY
RQD-ROCK QUALITY DESIGNAT
NA-NOT APPLICABLE

HDR

PROJECT: WHITE STREET LANDFILL (PHASE III) PROJECT NO: 06770-021-018

LOCATION: GREENSBORO, N.C. BORING NUMBER: B-34d PAGE: 1 OF 1

CORE LOG

DATE: 12/29/94

NUMBER	DEPTH	REC	RQD	DESCRIPTION (ROCK)	FRACTURES (W/ANGLE)
	4'			AUGER REFUSAL	SAPROLITE
FIRST CORE RUN	8' 12'	79%	50% FAIR-POOR	DIORITE: METAMORPHOSED, FOLIATED TO NON-FOLIATED DARK GREEN, MEDIUM-GRAINED, PHANERITIC, 7-9' IS SLIGHTLY BROKEN AND HARD TO VERY HARD, FRACTURED (RIGHT ANGLE BREAK), IRON OXIDE AND MANGANESE OXIDE STAINING; 9.0-15.25' IS SLIGHTLY BROKEN TO MASSIVE, HARD TO VERY HARD, FRACTURES SCARCE (35-45°), HEALED FRACTURES WITH FELDSPAR, MINOR CHLORITE ON FRACTURE SURFACES.	FRACTURE ZONE 30°
SECOND CORE RUN	16' 20'	100%	94% GOOD	DIORITE: SLIGHTLY METAMORPHOSED, MINOR FOLIATION, HARD TO VERY HARD, MINOR FRACTURES (HORIZONTAL TO 35°), CHLORITIZED ZONES, HEALED FRACTURES WITH FELDSPAR, NO IRON OXIDATION ON FRACTURES.	35°
	24' 28'			TD = 22.0'	

COREHOLE COMPLETION: 22' BELOW LAND SURFACE

WATER DEPTH: 742.73 DATE: 12/29/94

DRILLING METHOD: NX CORE (15 FT.)

LOGGED BY: JOHN R. ISHAM

KEY:
REC-RECOVERY
RQD-ROCK QUALITY DESIGNATION
NA-NOT APPLICAL

HDR

PROJECT: WHITE STREET LANDFILL (PHASE III) PROJECT NO: 06770-021-018

LOCATION: GREENSBORO, N.C. BORING NUMBER: MW-13 PAGE: 2 OF

CORE LOG

DATE: 1/6/93

NUMBER	DEPTH	REC	RQD	DESCRIPTION (ROCK)	FRACTURES (W/ANGLE)
	14'			PARTIALLY WEATHERED ROCK	
FIRST CORE RUN	18' 22' 26'	92%	79% GOOD	GNEISS: FOLIATED, SLIGHTLY BROKEN TO MASSIVE, HARD TO VERY HARD, CONTAINS QUARTZ, FELDSPAR, BIOTITE MICA, FOLIATION NEARLY VERTICAL TO 70° FROM HORIZONTAL; HEALED FRACTURES WITH SERPENTINE, FINE TO MEDIUM-GRAINED, PYRITE-BEARING FRACTURES	FRACTURE ZONE 60° 65° 50° 50°
SECOND CORE RUN	30'	44%	88% GOOD	GNEISS: FOLIATED, MASSIVE, HARD TO VERY HARD, MOTTLED BLACK, WHITE AND GRAY, CONTAINS QUARTZ, FELDSPAR, BIOTITE MICA, FOLIATION NEARLY VERTICAL TO 70° FROM HORIZONTAL, FRACTURES AT 35° FROM HORIZONTAL, MINIMAL IRON OXIDE STAINING OF FRACTURES	35° 35° 35° 35°
	34' 38'			TD = 34.0'	

COREHOLE COMPLETION: 34' BELOW LAND SURFACE

WATER DEPTH: 718.5 DATE: 12/27/94

DRILLING METHOD: NX CORE (16 FT.)

LOGGED BY: JOHN R. ISHAM

KEY:
REC-RECOVERY
RQD-ROCK QUALITY DESIGNAT
NA-NOT APPLICAE

HDR

PROJECT: WHITE STREET LANDFILL (PHASE III) PROJECT NO: 06770-021-018

LOCATION: GREENSBORO, N.C. BORING NUMBER: B-22d PAGE: 1 OF 1

CORE LOG

DATE: 12/29/94

NUMBER	DEPTH	REC	RQD	DESCRIPTION (ROCK)	FRACTURES (W/ANGLE)
	24' 28'			AUGER REFUSAL	SAPROLITE
FIRST CORE RUN	32' 36'	81%	46% POOR	GRANITE: BROKEN TO SLIGHTLY BROKEN TO 30.5',MED. HARD, BROKEN FROM 30.5' TO 33', FRACTURED (HORZ. TO 25°), COARSE-GRAINED, QUARTZ, FELDSPAR, BIOTITE MICA, MINOR INTERGRANULAR POROSITY, MORE WEATHERED AND BROKEN 30.5-33.0', IRON OXIDE AND MANGANESE OXIDE STAINING, BECOMES BROKEN TO SLIGHTLY BROKEN 33.0-35.5', HEALED FRACTURES; 35.5-39.5' IS BROKEN, MEDIUM HARD, WHITE TO BUFF GRANITE,HIGHLY FRACTURED, WEDGE-SHAPED PIECES FROM FRACTURE SETS AT 45-50°,SOME VERTICAL FRACTURES WITH RIGHT ANGLE BREAKS, IRON OXIDE AND MANGANESE OXIDE STAINING; 39.5-44.5', SLIGHTLY BROKEN TO MASSIVE, MEDIUM HARD, FRACTURES AT 45° TO HORIZONTAL, HEALED FRACTURES.	FRACTURE ZONE 25° 45° 40°
SECOND CORE RUN	40' 44'	88%	56% FAIR		FRACTURE 45° 55° 45° 45°
	48'			TD = 47.5'	

COREHOLE COMPLETION: 44.5' BELOW LAND SURFACE

WATER DEPTH: 740.26 DATE: 12/29/94

DRILLING METHOD: NX CORE (15 FT.)

LOGGED BY: JOHN R. ISHAM

KEY:
REC-RECOVERY
RQD-ROCK QUALITY DESIGNATION
NA-NOT APPLICA'

HDR

DRILLING LOG	DIVISION Earth Science	INSTALLATION	SHEET 1 OF 2 SHEETS

1. PROJECT Greensboro Landfill	10. SIZE AND TYPE OF BIT 2.0" (NQ)
2. LOCATION (Coordinates or Station) Guilford County, NC	11. DATUM FOR ELEVATION SHOWN (TBM or MSL) TBM
3. DRILLING AGENCY Engineering Tectonics, P.A.	12. MANUFACTURER'S DESIGNATION OF DRILL Mobil B-57
4. HOLE NO. (As shown on drawing title and file number) MW-11 (CORE LOG)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED 4 — UNDISTURBED --
5. NAME OF DRILLER David Barron	14. TOTAL NUMBER CORE BOXES 9
6. DIRECTION OF HOLE [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER
	16. DATE HOLE — STARTED 4-11-89 — COMPLETED 4-13-89
7. THICKNESS OF OVERBURDEN 19.5'	17. ELEVATION TOP OF HOLE 797.80
8. DEPTH DRILLED INTO ROCK 81.0'	18. TOTAL CORE RECOVERY FOR BORING 100 %
9. TOTAL DEPTH OF HOLE 100.5'	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	RQD	DRILL RATE	FRAC. FREQ.	FRAC ANGLE	WATER RETURN
	0–19.5	4" PVC Pit Casing	Overburden (See Boring Log)						
	19.5–55		White and black, hard to v/hard, slight to freshly weathered, foliated to massive, granoblastic, fine to med. grained gneiss with an occasional ½" quartz vein, fractures iron stain, some fractures green and schistose, occasional rehealed hairline fractures	100%	60%	4"/min	11/5ft	0-30°	100%/0
				100%	95%	3"/min	5/10ft	30-60°	95%
			Foliation/Preferred orientation 75 to 85 degrees from horizontal, all fractures discolored pale green and slightly schistose.	100%	95%	3.5"/min	13/10ft	15-65°	95%
			NOTE: Increase in mafic mineral content 50-80%, significantly less fracturing.	100%	100%	3"/min	2/10ft	60-85°	95%
	55–		White and black, v. hard, freshly weathered, foliated to massive, granoblastic, fine to medium grained gneiss, fractures green and slightly schistose, foliated at 60 to 80 degrees from horizontal.	100%	96%	2.5"/min	8/10ft	30-80°	95%

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT Greensboro Landfill — HOLE NO. 11

DRILLING LOG	DIVISION	INSTALLATION	SHEET 2 OF 2 SHEETS

1. PROJECT Greensboro Landfill	10. SIZE AND TYPE OF BIT
2. LOCATION (Coordinates or Station)	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number) MW-11	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED — UNDISTURBED
5. NAME OF DRILLER	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER
	16. DATE HOLE — STARTED — COMPLETED
7. THICKNESS OF OVERBURDEN	17. ELEVATION TOP OF HOLE
8. DEPTH DRILLED INTO ROCK	18. TOTAL CORE RECOVERY FOR BORING %
9. TOTAL DEPTH OF HOLE	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	RQD	DRILL RATE	FRAC. FREQ.	FRAC ANGLE	WATER RETURN
	70		Occasional 2-8 mm pheno cryst between 65 to 67.5 feet.	100%	97%	1.5"/min	6/10ft	30-60°	95%
	75–80		Mafic and felsic mineral content approx. 50/50. NOTE: Occasional rehealed hairline fractures at 20 to 80 degrees.	100%	100%	3"min	4/10ft	20-70°	95%
	85–90		NOTE: Increase in fracture frequency.	100%	92%	4"/min	11/10ft	20-70°	95%
	95		NOTE: Abundant rehealed fractures from 95 to 97 ft., major fractures oriented at 60 to 80 degrees.	100%	95%	5"/min	3/5ft	20-80°	95%
	100								
	105		Coring Terminated at 100.5'.						

PROJECT | HOLE NO.

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE.

(TRANSLUCENT)

Project No: 06770-033-018

Project: Alternate Liner Demonstration

Client: City of Greensboro

Location: White Street Landfill

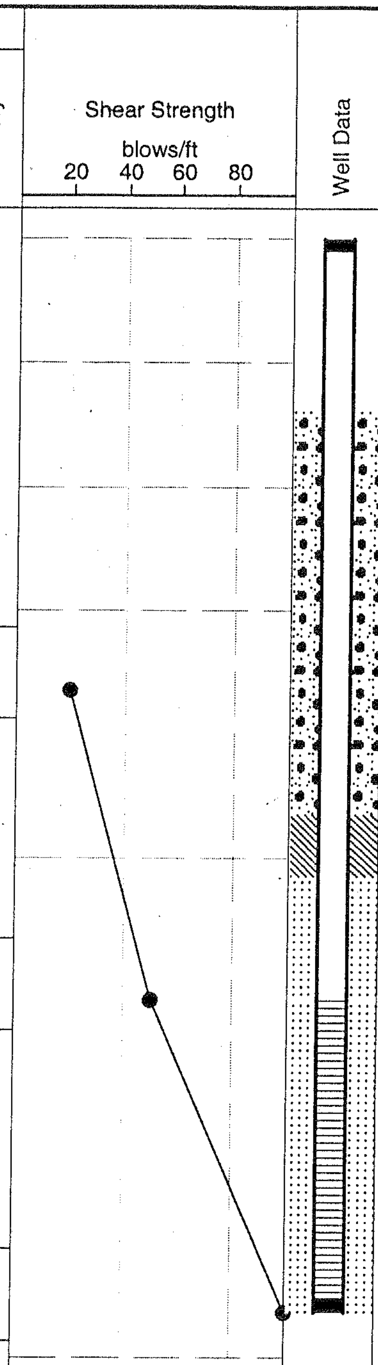
Geologist Log PZ-2

Ground Elevation: 741.92' MSL

Geologist: John R. Isham, PG.

HDR

Depth	Description (Subsurface Profile)	Depth/Elev.	Sample Number	Type	Blows/ft	Recovery	Remarks
-2 to 0	Ground Surface	2.78 / 744.7					
0 – 6.5	***CLAYEY SILT (ml)*** Orange-brown to tan, minor very fine-grained sand mixed, weak mineral alignment (flow banding), feldspar fragments, manganese oxide stained fractures/veins, dry.		1		20		Backfilled Cuttings
6.5 – 12	***SILTY SAND (sm)*** Reddish-brown to tan and white, medium to fine grained, brittle, manganese oxide mottling, iron oxide staining around mafic grains, weak mineral alignment (flow banding), mafic xenoliths, slightly kaolinitic, dry.	6.5 / 735.4	2		50		3/8-inch Bentonite Chips; #2 Silica Sand
12 – 14.75	***SILTY SAND (sm)*** Reddish-brown to tan, fine grained, manganese oxide mottling, fragments of kaolinite, no visible mineral alignment, dry.	12 / 729.9	3		100		2-inch Diameter SCH 40 PVC 0.010-inch Slots
14.75	End of Borehole	14.75 / 727.2					Auger Refusal



Drilled by: S&ME, Inc.

Drill Method: 3.25-inch ID HSA

Drill Date: June 15, 2000

HDR Engineering, Inc. of the Carolinas
128 S. Tryon Street
Suite 1400
Charlotte, NC. 28202

Hole Size: 6 inches

Top-of-Casing: 744.70' MSL

Sheet: 1 of 1

Project No: 06770-033-018

Project: Alternate Liner Demonstration

Client: City of Greensboro

Location: White Street Landfill

Geologist Log PZ-3

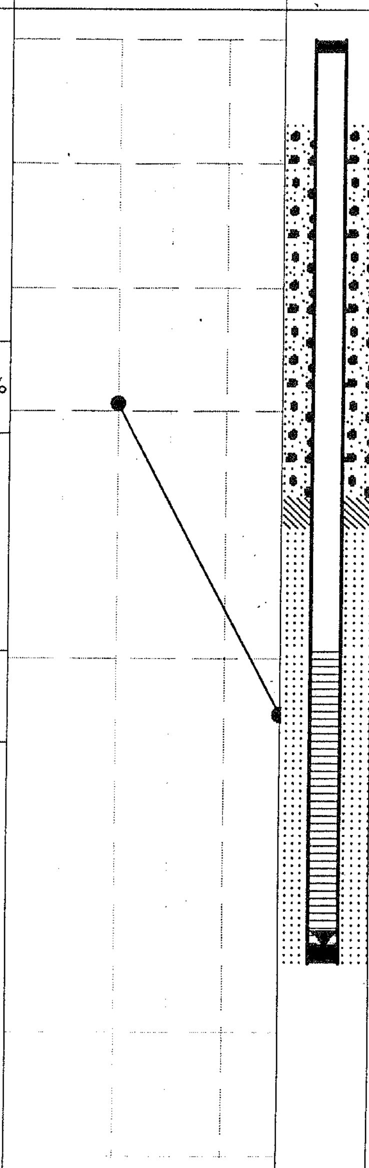
Ground Elevation: 747.09' MSL

Geologist: John R. Isham, PG.

HDR

SUBSURFACE PROFILE				SAMPLE			
Depth	Symbol	Description	Depth/Elev.	Number	Type	Blows/ft	Recovery
-1			1.38 / 748.5				
0		Ground Surface					
0–6.5		***SANDY SILT (ml)*** Reddish-brown to orange-brown, relict vertical foliation, manganese oxide stained, relict healed hairline fractures, dry (mafic intrusive ?).					
4				1		40	100%
6.5–13.5		***SILTY SAND (sm)*** Reddish-brown, mottled black, fine to very fine grained, brittle, relict vertical foliation, manganese oxide staining along foliation, dry (mafic intrusive ?), PWR.	6.5 / 740.6				
9				2		100	50%
13.5		End of Borehole	13.5 / 733.6				

Shear Strength (blows/ft): 20 40 60 80



Well Data Remarks	
Backfilled Cuttings	
3/8-inch Bentonite Chips	
#2 Silica Sand	
2-inch Diameter SCH 40 PVC 0.010-inch Slots	
Auger Refusal	

Drilled by: S&ME, Inc.

Drill Method: 3.25-inch ID HSA

Drill Date: June 15, 2000

HDR Engineering, Inc. of the Carolinas
128 S. Tryon Street
Suite 1400
Charlotte, NC. 28202

Hole Size: 6 inches

Top-of-Casing: 748.47' MSL

Sheet: 1 of 1

Project No: 06770-033-018

Project: Alternate Liner Demonstration

Client: City of Greensboro

Location: White Street Landfill

Geologist Log PZ-5

Ground Elevation: 754.10' MSL

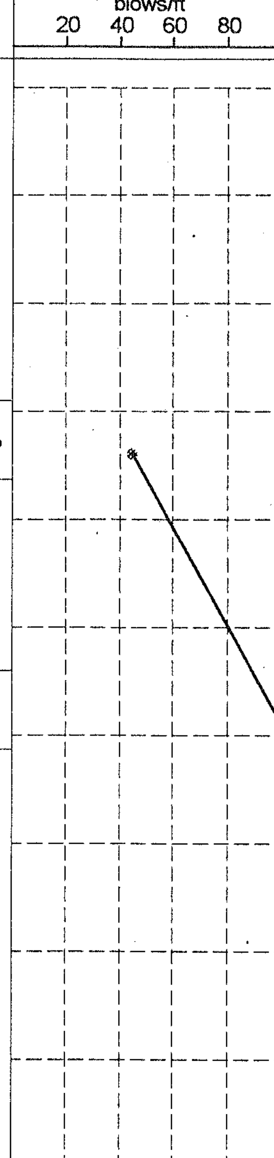
Geologist: John R. Isham, PG.

HDR

Depth	Description	Depth/Elev.	Sample Number	Type	Blows/ft	Recovery	Remarks
-2		2.29 / 756.4					
0	Ground Surface						
0–7.5	***GRAVELLY SAND (SP)*** Tan, white and yellow-brown, coarse to very coarse grained, brittle, quartz (angular) and feldspar grains abundant, iron oxide staining, no relict foliation or structures, dry.						Backfilled Cuttings
4			1		45	60%	
5							3/8-inch Bentonite Chips
7							#2 Silica Sand
7.5–13.5	***GRAVELLY SAND (SP)*** Same as above, hard, PWR, dry.	7.5 / 746.6					
9			2		100	0%	
11							2-inch Diameter SCH 40 PVC 0.010-inch Slots
13.5	End of Borehole	13.5 / 740.6					Auger Refusal

Shear Strength

blows/ft



Well Data

Drilled by: S&ME, Inc.

Drill Method: 3.25-inch ID HSA

Drill Date: June 14, 2000

HDR Engineering, Inc. of the Carolinas
128 S. Tryon Street
Suite 1400
Charlotte, NC. 28202

Hole Size: 6 inches

Top-of-Casing: 756.39' MSL

Project No: 06770-033-018

Project: Alternate Liner Demonstration

Client: City of Greensboro

Location: White Street Landfill

Geologist Log PZ-6

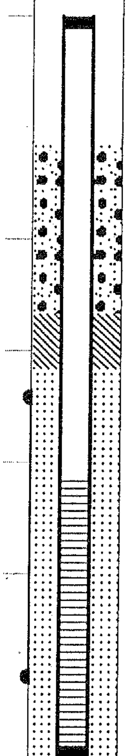
Ground Elevation: 744.90' MSL

Geologist: John R. Isham, PG.

HDR

SUBSURFACE PROFILE				SAMPLE						
Depth	Symbol	Description	Depth/Elev.	Number	Type	Blows/ft	Recovery	Shear Strength blows/ft 20 40 60 80	Well Data	Remarks
			2.33 / 747.2							
0		Ground Surface								
0–7.5		***SANDY SILT (ml)*** Yellow-brown to orange and white, fine to very fine grained, brittle, kaolinitic, weak relict foliation (gneissic banding), manganese oxide staining, dry.								Backfilled Cuttings; 3/8-inch Bentonite Chips
~4				1		100				#2 Silica Sand
7.5		***SILTY SAND (sm)*** Yellow-brown to tan and white, slightly micaceous, fine grained, mixed with PWR fragments of kaolinite (wéathered feldspar), weak to moderate relict foliation (gneissic banding), iron oxide and manganese oxide stained relict fractures and mottling, dry.	7.5 / 737.4							2-inch Diameter SCH 40 PVC 0.010-inch Slots
~9				2		100				
11.5		End of Borehole	11.5 / 733.4							Auger Refusal

Depth scale: -2, -1, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17



Drilled by: S&ME, Inc.

Drill Method: 3.25-inch ID HSA

Drill Date: June 15, 2000

HDR Engineering, Inc. of the Carolinas
128 S. Tryon Street
Suite 1400
Charlotte, NC. 28202

Hole Size: 6 inches

Top-of-Casing: 474.23' MSL

Sheet: 1 of 1

Project No: 06770-033-018

Project: Alternate Liner Demonstration

Client: City of Greensboro

Location: White Street Landfill

Geologist Log PZ-8

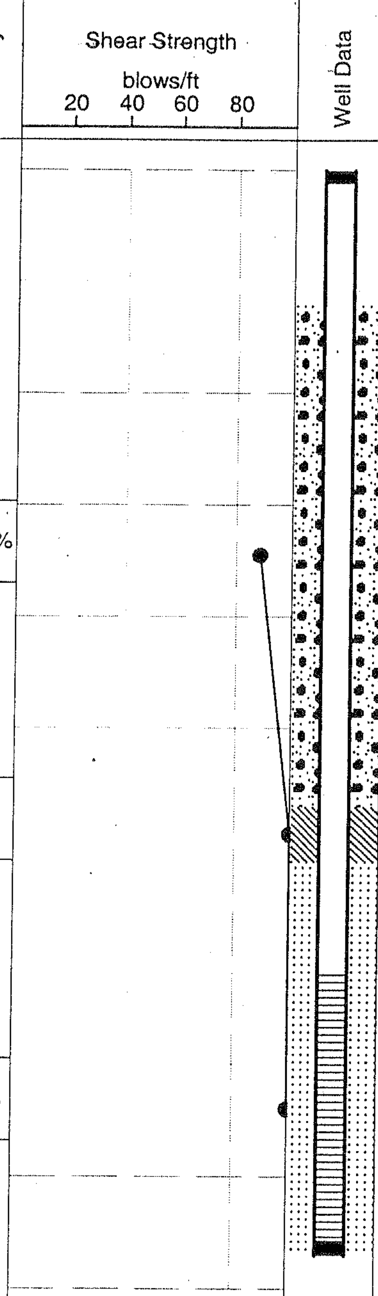
Ground Elevation: 755.28' MSL

Geologist: John R. Isham, PG.

HDR

SUBSURFACE PROFILE / SAMPLE

Depth	Description	Depth/Elev.	Number	Type	Blows/ft	Recovery	Remarks
-2 to 0		2.41 / 757.7					
0	Ground Surface						
0 – 9	***SILTY SAND (sm)*** Light brown to tan, medium to coarse grained, feldspar grains abundant, weak relict foliation (gneissic banding), iron oxide staining, manganese oxide healed hairline fractures, dry.		1		89	100%	Backfilled Cuttings
9 – 12.5	***SILTY SAND (sm)*** Same as above, finer grained, brittle, quartz and feldspar grains abundant, hard, dry.	9 / 746.3	2		100	5%	3/8-inch Bentonite Chips; #2 Silica Sand
12.5 – 17.3	***SILTY SAND (sm)*** Light tan to brown, medium to coarse grained, abundant mafic minerals, manganese oxide staining, slightly loose, dry.	12.5 / 742.8	3		100	40%	2-inch Diameter SCH 40 PVC 0.010-inch Slots
17.3	End of Borehole	17.3 / 738					Auger Refusal



Drilled by: S&ME, Inc.

Drill Method: 3.25-inch ID HSA

Drill Date: June 14, 2000

HDR Engineering, Inc. of the Carolinas
128 S. Tryon Street
Suite 1400
Charlotte, NC. 28202

Hole Size: 6 inches

Top-of-Casing: 757.69' MSL

Sheet: 1 of 1

Project No: 06770-033-018

Project: Alternate Liner Demonstration

Client: City of Greensboro

Location: White Street Landfill

Geologist Log PZ-9

Ground Elevation: 751.51' MSL

Geologist: John R. Isham, PG.

HDR

SUBSURFACE PROFILE

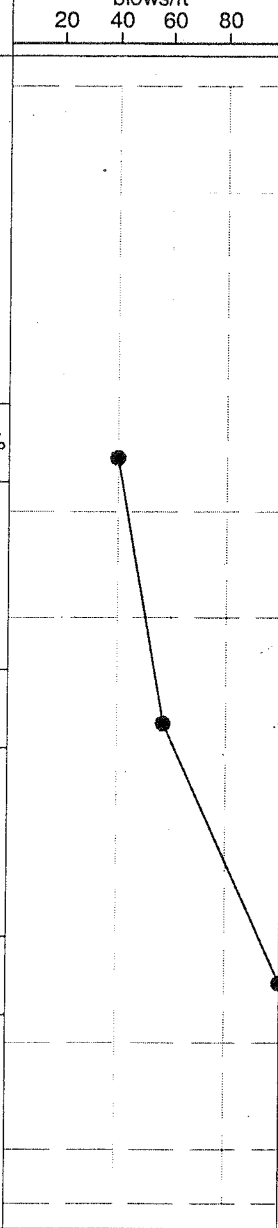
Depth	Description	Depth/Elev.
		2.49 / 754
0	Ground Surface	
0–7	*SILT (ml)* Yellow-orange and yellow-brown, dense, uniform texture, no relict foliation or structure, manganese oxide stained, dry (mafic intrusive ?).	
7–12.5	*SILT (ml)* Same as above, uniform, no relict foliation or structure, manganese oxide stained, dry (mafic intrusive ?).	7 / 744.5
12.5–17.5	*SILT (ml)* Yellow-orange to yellow-brown, harder than above (mixed with PWR fragments), manganese oxide stained, no relict foliation or structure, dry.	12.5 / 739
17.5	End of Borehole	17.5 / 734

SAMPLE

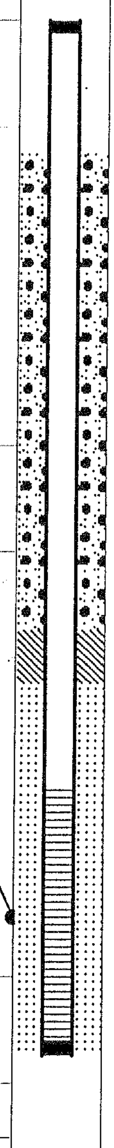
Number	Type	Blows/ft	Recovery
1		40	100%
2		57	20%
3		100	5%

Shear Strength

blows/ft



Well Data



Remarks

- Backfilled Cuttings
- 3/8-inch Bentonite Chips
- #2 Silica Sand
- 2-inch Diameter SCH 40 PVC 0.010-inch Slots
- Auger Refusal

Drilled by: S&ME, Inc.

Drill Method: 3.25-inch ID HSA

Drill Date: June 14, 2000

HDR Engineering, Inc. of the Carolinas
128 S. Tryon Street
Suite 1400
Charlotte, NC. 28202

Hole Size: 6 inches

Top-of-Casing: 754.00' MSL

Sheet: 1 of 1

Project No: 06770-033-018

Project: Alternate Liner Demonstration

Client: City of Greensboro

Location: White Street Landfill

Geologist Log OW-1

Ground Elevation: 749.20' MSL

Geologist: John R. Isham, PG.

HDR

SUBSURFACE PROFILE				SAMPLE				Shear Strength blows/ft 20 40 60 80	Well Data	Remarks
Depth	Symbol	Description	Depth/Elev.	Number	Type	Blows/ft	Recovery			
			1.58 750.8							
-1										
0		Ground Surface								
1										
2										
3										
4										Backfilled Cuttings
5										
6		***SAPROLITE*** Interval not sampled, see adjacent soil boring logs for temporary piezometers for details.								
7										3/8-inch Bentonite Chips
8										
9										#2 Silica Sand
10										

Drilled by: S&ME, Inc.

Drill Method: 3.25-inch ID HSA/NQ Core

Drill Date: June 17-20, 2000

HDR Engineering, Inc. of the Carolinas
128 S. Tryon Street
Suite 1400
Charlotte, NC. 28202

Hole Size: 6 inches/3 inches

Top-of-Casing: 750.78' MSL

Project No: 06770-033-018

Project: Alternate Liner Demonstration

Client: City of Greensboro

Location: White Street Landfill

Geologist Log OW-1

Ground Elevation: 749.20' MSL

Geologist: John R. Isham, PG.

HDR

Depth	Description	Depth/Elev.	Number	Type	Blows/ft	Recovery	Shear Strength blows/ft (20 40 60 80)	Well Data	Remarks
10–12									
12–15	***GRANITE*** White to tan, composed of quartz, feldspar, biotite, very highly weathered section, abundant secondary porosity as fractures and vugular, iron oxide staining around biotite grains, feldspars altered to kaolinite, brittle, friable, chalky appearance, subhorizontal to nearly vertical healed hairline fractures.	12 / 737.2	01			67%			Auger Refusal 25 Degree F 55 Degree F Hor. Frac. 70 Degree F Zone 25 Degree F
15–18	***GREENSTONE*** Dark green to black, foliated, fine grained (altered basalt dike), chlorite-rich, numerous healed hairline fractures parallel to foliation (nearly vertical), heavy iron oxide staining (as limonite) along fractures.	15 / 734.2							25 Degree F Subhor. Zone to 16' Subhor. Frac 70 Degree F Hor. Frac. Zone Subhor. Frac.
18–21+	***GRANITE*** White to light gray, composed of quartz, feldspar, biotite, competent section, little weathering, biotite grains slightly altered to chlorite, no preferred mineral alignment or foliation visible, iron oxide staining along fracture planes, abundant healed hairline fractures from subhorizontal to 70 degrees.	18 / 731.2							60 Degree F 30 Degree F 30 Degree F 20 Degree F 35 Degree F 35 Degree F

Drilled by: S&ME, Inc.

Drill Method: 3.25-inch ID HSA/NQ Core

Drill Date: June 17-20, 2000

HDR Engineering, Inc. of the Carolinas
128 S. Tryon Street
Suite 1400
Charlotte, NC. 28202

Hole Size: 6 inches/3 inches

Top-of-Casing: 750.78' MSL

Project No: 06770-033-018

Project: Alternate Liner Demonstration

Client: City of Greensboro

Location: White Street Landfill

Geologist Log OW-1

Ground Elevation: 749.20' MSL

Geologist: John R. Isham, PG.

HDR

SUBSURFACE PROFILE				SAMPLE						
Depth	Symbol	Description	Depth/Elev.	Number	Type	Blows/ft	Recovery	Shear Strength blows/ft 20 40 60 80	Well Data	Remarks
22			22.1							45 Degree F 45 Degree F 40 Degree F 40 Degree F
23–25		***QUARTZITE*** Light blue-gray to gray, very hard, dense (uniform quartz), massive, healed hairline fractures with feldspar, minor iron oxide staining along fractures, weak flow banding as base near contact with host rock (contact metamorphism during intrusion), fracture planes are angular/rough.	727.1 25.1	02			100%			20 Degree F 25 Degree F Subhor. Frac. 25 Degree F
26–28		***GRANITE*** White to light-gray, composed of quartz, feldspar, biotite, alteration of biotite grains to chlorite, no preferred mineral alignment or relict foliation visible, iron oxide staining along fractures, abundant healed hairline fractures from subhorizontal to 70 degrees.	724.1 27.5 721.7	03			80%			60 Degree F 45 Degree F Zone
29–33		End of Borehole								2-inch Diameter SCH 40 PVC 0.010-inch Slots Run 1 RQD=19% Run 2 RQD=91% Run 3 RQD=69%

Drilled by: S&ME, Inc.

Drill Method: 3.25-inch ID HSA/NQ Core

Drill Date: June 17-20, 2000

HDR Engineering, Inc. of the Carolinas
128 S. Tryon Street
Suite 1400
Charlotte, NC. 28202

Hole Size: 6 inches/3 inches

Top-of-Casing: 750.78' MSL

Project No: 06770-033-018

Project: Alternate Liner Demonstration

Client: City of Greensboro

Location: White Street Landfill

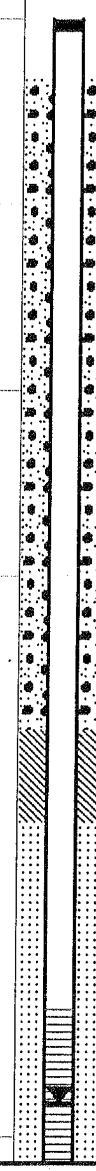
Geologist Log OW-2

Ground Elevation: 750.09' MSL

Geologist: John R. Isham, PG.

HDR

SUBSURFACE PROFILE				SAMPLE						
Depth	Symbol	Description	Depth/Elev.	Number	Type	Blows/ft	Recovery	Shear Strength blows/ft 20 40 60 80	Well Data	Remarks
			0.65 750.7							
0		Ground Surface								
0–10		***SAPROLITE*** Interval not sampled, see adjacent soil boring logs for temporary piezometers for details.								Backfilled Cuttings 3/8-inch Bentonite Chips #2 Silica Sand
10–11			10 740.1							Auger Refusal Frac Zone Sub Hor to 70 10' to 12.4'



Drilled by: S&ME, Inc.

Drill Method: 3.25-inch ID HSA/NQ Core

Drill Date: June 15-16, 2000

HDR Engineering, Inc. of the Carolinas
128 S. Tryon Street
Suite 1400
Charlotte, NC. 28202

Hole Size: 6 inches/3 inches

Top-of-Casing: 750.74' MSL

Sheet: 1 of 3

Project No: 06770-033-018

Project: Alternate Liner Demonstration

Client: City of Greensboro

Location: White Street Landfill

Geologist Log OW-2

Ground Elevation: 750.09' MSL

Geologist: John R. Isham, PG.

HDR

Depth	Symbol	Description	Depth/Elev.	Number	Type	Blows/ft	Recovery	Shear Strength blows/ft 20 40 60 80	Well Data	Remarks
12		***GREENSTONE*** Light brown to tan, extremely weathered, brittle, mafic minerals highly altered (heavy iron oxide), entire unit earthy in appearance, foliated (nearly vertical to 80 degrees), high secondary porosity from vugular porosity, fractures, and weathering along foliation, manganese oxide staining along fracture planes, chlorite evident, appears to be an altered basalt dike, highly weathered due to periodic contact with ground water.	12.4 737.7							70 Degree Contact 70 Degree F 70 Degree F 25 Degree F Sub Hor F Zone 80 Degree F Zone 20 Degree F
13–16		***GRANITE*** White to tan, composed of quartz, feldspar, biotite, weathered, highly fractured below dike, mafic xenoliths present, chlorite along fractures, abundant secondary porosity from fractures and vugular, healed hairline fractures throughout section, weak flow banding (alignment of mafic minerals)	19.8 730.3							Sub Hor F Zone Sub Hor F Zone to 18' 25 Degree F 40 Degree F 30 Degree F 40 Degree F 40 Degree F 40 Degree F 25 Degree F
20–22		***GNEISS*** Light blue-gray to gray, weakly foliated at top, abundant healed hairline fractues with feldspar, very fine grained, iron oxide staining around mafic minerals and along fracture planes.	23 727.1							Sub Hor F 30 Degree F Sub Hor F Zone to 30 20 Degree F 25 Degree F Sub Hor F Sub Hor F 35 Degree F
23										50 Degree F

Drilled by: S&ME, Inc.

Drill Method: 3.25-inch ID HSA/NQ Core

Drill Date: June 15-16, 2000

HDR Engineering, Inc. of the Carolinas
128 S. Tryon Street
Suite 1400
Charlotte, NC. 28202

Hole Size: 6 inches/3 inches

Top-of-Casing: 750.74' MSL

Project No: 06770-033-018

Project: Alternate Liner Demonstration

Client: City of Greensboro

Location: White Street Landfill

Geologist Log OW-2

Ground Elevation: 750.09' MSL

Geologist: John R. Isham, PG.

HDR

SUBSURFACE PROFILE				SAMPLE						
Depth	Symbol	Description	Depth/Elev.	Number	Type	Blows/ft	Recovery	Shear Strength blows/ft 20 40 60 80	Well Data	Remarks
24		***GRANITE*** White, pink, and light gray, composed of quartz, feldspar, biotite, no visible foliation, manganese oxide staining along fractures, abundant healed hairline fractures, competent, hard, slightly massive.	24.3 / 725.8							40 Degree F
25										
26		***GNEISS*** Dark gray to black, mottled white (feldspar), slightly migmatitic, minor epidote present, healed hairline fractures with serpentine, fine to medium grained, contains phenocrysts of feldspar, minor pyrite along fracture planes.								2-inch Diameter SCH 40 PVC 0.010-inch Slots
27										
28										
29										45 Degree F
30										40 Degree F
										25 Degree F Zone to 30.5'
31		End of Borehole	31 / 719.1							
32										
33										Run 1 RQD=84% Run 2 RQD=80%
34										
35										

Drilled by: S&ME, Inc.

Drill Method: 3.25-inch ID HSA/NQ Core

Drill Date: June 15-16, 2000

HDR Engineering, Inc. of the Carolinas
128 S. Tryon Street
Suite 1400
Charlotte, NC. 28202

Hole Size: 6 inches/3 inches

Top-of-Casing: 750.74' MSL

Project No: 06770-033-018

Project: Alternate Liner Demonstration

Client: City of Greensboro

Location: White Street Landfill

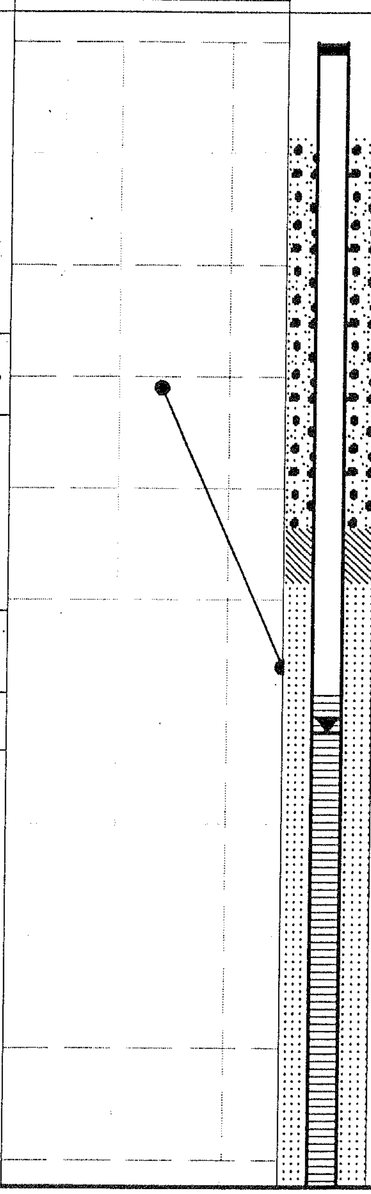
Geologist Log PZ-4/OW-3

Ground Elevation: 750.71' MSL

Geologist: John R. Isham, PG.

HDR

SUBSURFACE PROFILE				SAMPLE						
Depth	Symbol	Description	Depth/Elev.	Number	Type	Blows/ft	Recovery	Shear Strength blows/ft 20 40 60 80	Well Data	Remarks
			1.71 / 752.4							
0		Ground Surface								
0–6.5		***GRAVELLY SAND (sp)*** White to tan and brown, slightly clayey, medium to fine grained sand, kaolinitic, iron oxide stained, dry.								Backfilled Cuttings
4				1		56	80%			
6.5–11		***GRAVELLY SAND (sp)*** Same as above, weak relict foliation (flow banding), medium to coarse grained, dry.	6.5 / 744.2							3/8-inch Bentonite Chips
9				2		100	10%			#2 Silica Sand
11–18		***GRANITE*** White to light gray, composed of quartz, feldspar, biotite, iron oxide halos around biotite grains, vugular porosity from weathered mafic minerals, no preferred mineral alignment or foliation visible, slightly weathered throughout, biotite grains altered to actinolite (?), kaolinitic.	11 / 739.7				83%			Auger Refusal; 40 Degree F; 2-inch Diameter SCH 40 PVC 0.010-inch Slots; Hor. Fracture Zone; 20 Degree F
18			18 / 732.7							



Drilled by: S&ME, Inc.

Drill Method: 3.25-inch ID HSA/NQ Core

Drill Date: June 15 & 20, 2000

HDR Engineering, Inc. of the Carolinas
128 S. Tryon Street
Suite 1400
Charlotte, NC. 28202

Hole Size: 6 inches/3 inches

Top-of-Casing: 752.42' MSL

Sheet: 1 of 2

Project No: 06770-033-018

Project: Alternate Liner Demonstration

Client: City of Greensboro

Location: White Street Landfill

Geologist Log PZ-4/OW-3

Ground Elevation: 750.71' MSL

Geologist: John R. Isham, PG.

HDR

Depth	Symbol	Description (SUBSURFACE PROFILE)	Depth/Elev.	Number (SAMPLE)	Type	Blows/ft	Recovery	Shear Strength blows/ft 20 40 60 80	Well Data	Remarks
19–21		***GRANITE*** White to light gray, more competent than above, less weathering, biotite altered to actinolite (?), green tint throughout section.	21 / 729.7	01			83%			Hor. Fracture
21–26.6		***GRANITE*** White to light gray, composed of quartz, felspar, biotite, no preferred mineral alignment or foliation visible, minor healed hairline fractures, secondary porosity as vugular (biotite weathering).	26.6 / 724.1	02			88%			2-inch Diameter SCH 40 PVC 0.010-inch Slots; Sub. Hor. F; 60 Degree F; 60 Degree Contact; 80 Degree F Zone
26.6–31		***META-GABBRO*** Dark greenish-gray, less competent than granite, highly fractured, finely phaneritic, no foliation or preferred mineral alignment visible, altered to chlorite (schistose) along fracture planes (mafic intrusive).	31 / 719.7							60 Degree F; 60 Degree F Zone; 45 Degree F Set; 40 Degree F; 45 Degree F; 60 Degree F
31–38		End of Borehole								Run 1 RQD=95%; Run 2 RQD=84%

Drilled by: S&ME, Inc.

Drill Method: 3.25-inch ID HSA/NQ Core

Drill Date: June 15 & 20, 2000

HDR Engineering, Inc. of the Carolinas
128 S. Tryon Street
Suite 1400
Charlotte, NC. 28202

Hole Size: 6 inches/3 inches

Top-of-Casing: 752.42' MSL

Project No: 06770-033-018

Project: Alternate Liner Demonstration

Client: City of Greensboro

Location: White Street Landfill

Geologist Log OW-4

Ground Elevation: 749.25' MSL

Geologist: John R. Isham, PG.

HDR

SUBSURFACE PROFILE				SAMPLE				Shear Strength blows/ft 20 40 60 80	Well Data	Remarks
Depth	Symbol	Description	Depth/Elev.	Number	Type	Blows/ft	Recovery			
-1			1.71 / 751							
0		Ground Surface								
0–9		***SAPROLITE*** See descriptions for adjacent piezometers for general soil descriptions.								Backfilled Cuttings; 3/8-inch Bentonite Chips; #2 Silica Sand; Auger Refusal
9–10			9 / 740.2							

Drilled by: S&ME, Inc.

Drill Method: 3.25-inch ID HSA/NQ Core

Drill Date: June 15-16, 2000

HDR Engineering, Inc. of the Carolinas
128 S. Tryon Street
Suite 1400
Charlotte, NC. 28202

Hole Size: 4 inches/3 inches

Top-of-Casing: 750.96' MSL

Sheet: 1 of 3

Project No: 06770-033-018

Project: Alternate Liner Demonstration

Client: City of Greensboro

Location: White Street Landfill

Geologist Log OW-4

Ground Elevation: 749.25' MSL

Geologist: John R. Isham, PG.

SUBSURFACE PROFILE				SAMPLE						
Depth	Symbol	Description	Depth/Elev.	Number	Type	Blows/ft	Recovery	Shear Strength blows/ft 20 40 60 80	Well Data	Remarks
11–15		***GRANITE*** White, composed of quartz, feldspar, biotite (abundant), iron oxide halos around biotite grains, minor secondary porosity as vugular, nearly vertical to 60 degree healed hairline fractures, heavy iron oxidation along open fractures, no preferred mineral alignment or foliation visible, minor manganese oxide staining, increased fracture density at base of run.	15	01			95%			60 Degree F; 30 Degree F; 30 Degree F; 30 Degree F
15–18		***GRANITE*** White to light gray, composed of quartz, feldspar, biotite, more competent than above, less vugular porosity, no preferred mineral alignment or foliation visible, minor healed hairline fractures, iron oxide staining along open fractures.	734.2 / 18	02			100%			30 Degree F
18–22		***GRANITE*** White to light gray, very competent with very little weathering, little secondary porosity as vuggular, scattered xenoliths of mafic rock (phaneritic), little evidence of oxidation along open fractures.	731.2				99%			Hor. Fracture 20 Degree F

Drilled by: S&ME, Inc.

Drill Method: 3.25-inch ID HSA/NQ Core

Drill Date: June 15-16, 2000

HDR Engineering, Inc. of the Carolinas
128 S. Tryon Street
Suite 1400
Charlotte, NC. 28202

Hole Size: 4 inches/3 inches

Top-of-Casing: 750.96' MSL

Project No: 06770-033-018

Project: Alternate Liner Demonstration

Client: City of Greensboro

Location: White Street Landfill

Geologist Log OW-4

Ground Elevation: 749.25' MSL

Geologist: John R. Isham, PG.

HDR

SUBSURFACE PROFILE				SAMPLE				Shear Strength blows/ft 20 40 60 80	Well Data	Remarks
Depth	Symbol	Description	Depth/Elev.	Number	Type	Blows/ft	Recovery			
23			23.5	03			99%			2-inch Diameter SCH 40 PVC 0.010-inch Slots
24–29		***GRANITE*** White to light gray, competent, uniform, no preferred mineral alignment or foliation visible, chlorite (?) along fracture planes, kaolinitic along healed hairline fractures, minor iron oxide staining.	725.8 / 29	04			98%			60 Degree F 45 Degree F 60 Degree F 60 Degree F
29–34		End of Borehole	720.2							Run 1 RQD=90% Run 2 RQD=92% Run 3 RQD=92% Run 4 RQD=100%

Drilled by: S&ME, Inc.

Drill Method: 3.25-inch ID HSA/NQ Core

Drill Date: June 15-16, 2000

HDR Engineering, Inc. of the Carolinas
128 S. Tryon Street
Suite 1400
Charlotte, NC. 28202

Hole Size: 4 inches/3 inches

Top-of-Casing: 750.96' MSL

Project No: 06770-033-018

Project: Alternate Liner Demonstration

Client: City of Greensboro

Location: White Street Landfill

Geologist Log PW-1

Ground Elevation: 749.79' MSL

Geologist: John R. Isham, PG.

HDR

SUBSURFACE PROFILE				SAMPLE				Shear Strength blows/ft (20 40 60 80)	Well Data	Remarks
Depth	Symbol	Description	Depth/Elev.	Number	Type	Blows/ft	Recovery			
			0.85 / 750.6							
0		Ground Surface								
0–10		***SAPROLITE*** See descriptions for adjacent piezometers for general soil descriptions.	10							Backfilled Cuttings; 3/8-inch Bentonite Chips; #2 Silica Sand
10		***GRANITE*** White with black mottle, composed of quartz, feldspar, biotite, weathered, kaolinitc (chalky), highly fractured, abundant vugular porosity, iron oxide staining around biotite grains and along fracture planes, no preferred mineral alignment or foliation visible,	739.8; 11.1 / 738.7; 13.1 / 736.7							Auger Refusal; 50 Degree F; 30 Degree F Zone; 35 Degree Zone; 45 Degree F Zone; Sub Hor. F; Sub Hor. F; Sub Hor. F; Sub Hor. F.
15.5		***Aplite/Pegmatite Dike*** White to cream, fine grained outer margins, pegmatitic veins along contact, minor vugular porosity, large quartz, biotite/muscovite, healed fractures, iron oxide staining, mafic minerals altered to chlorite or	16 / 733.8				95%			Sub. Hor. Frac. Zone; Sub. Hor. F; Sub. Hor. F Zone; 50 Degree F

Drilled by: S&ME, Inc.

Drill Method: 3.25-inch ID HSA/NQ Core

Drill Date: June 15, 2000

HDR Engineering, Inc. of the Carolinas
128 S. Tryon Street
Suite 1400
Charlotte, NC. 28202

Hole Size: 4 inches/3 inches

Top-of-Casing: 750.64' MSL

Project No: 06770-033-018

Project: Alternate Liner Demonstration

Client: City of Greensboro

Location: White Street Landfill

Geologist Log PW-1

Ground Elevation: 749.79' MSL

Geologist: John R. Isham, PG.

HDR

SUBSURFACE PROFILE				SAMPLE				Shear Strength	Well Data	Remarks
Depth	Symbol	Description	Depth/Elev.	Number	Type	Blows/ft	Recovery	blows/ft 20 40 60 80		
20			21	01			95%			
21–30		***GRANITE*** White to light green-gray, composed of quartz, feldspar, and biotite, no preferred mineral alignment or foliation visible, healed hairline fractures, few mafic xenoliths, competent, not much weathering between fractures until base of run, iron oxide halos around mafic minerals.	728.8	02			100%			2-inch Diameter SCH 40 PVC 0.010-inch Slots
			30							45 Degree F 30 Degree F Fracture Set @ 45 to 70 Deg
30–39		End of Borehole	719.8							Run 1 RQD=86% Run 2 RQD=95%

Drilled by: S&ME, Inc.

Drill Method: 3.25-inch ID HSA/NQ Core

Drill Date: June 15, 2000

HDR Engineering, Inc. of the Carolinas
128 S. Tryon Street
Suite 1400
Charlotte, NC. 28202

Hole Size: 4 inches/3 inches

Top-of-Casing: 750.64' MSL

Sheet: 2 of 2

Appendix B

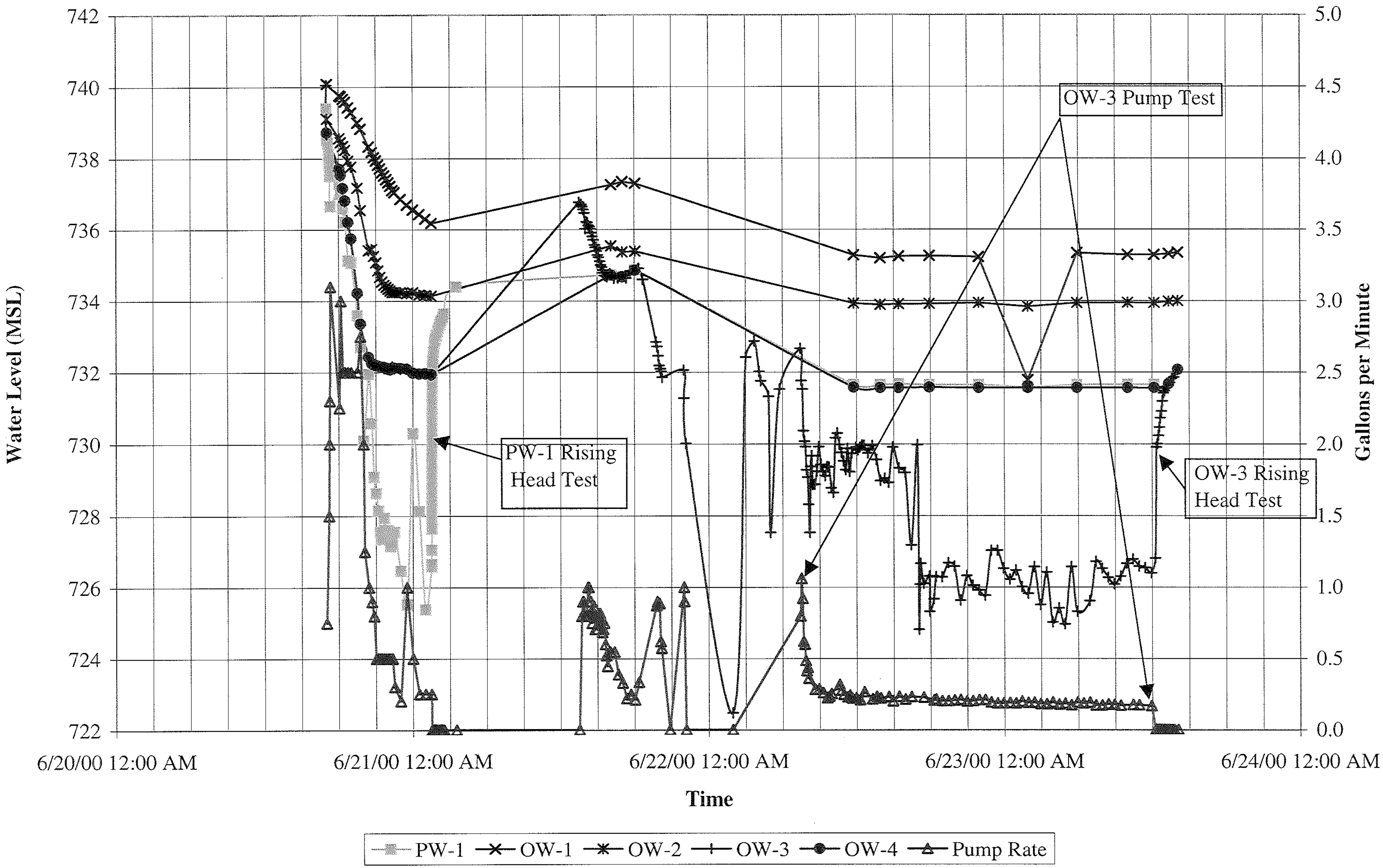
PUMPING TEST DATA

	Test Time (minutes)	gpm Pump Rate	OW-3 below TOC	OW-3 drawdown	PW-1 below TOC	PW-1 drawdown	TOC elev 752.42 OW-3 H_2O Level	TOC elev 750.64 PW-1 H_2O Level	TOC elev 750.78 OW-1 below TOC	OW-1 H_2O Level	TOC elev 750.74 OW-2 below TOC	OW-2 H_2O Level	TOC elev 750.96 OW-4 below TOC	OW-4 Water Level	Comments
6/20/00 5:00 PM	0	0.8	12.37	0	11.25	0.00	740.05	739.39							Begin Pumping on PW-1
6/20/00 5:02 PM	3		13.74	1.37	12.11	0.86	738.68	738.53	10.70	740.08	11.64	739.1	12.24	738.7	
6/20/00 5:08 PM	8				12.22	0.97		738.42							
6/20/00 5:12 PM	12	1.5			12.53	1.28		738.11							
6/20/00 5:14 PM	14	2.0			12.82	1.57		737.82							
6/20/00 5:16 PM	17	2.3			13.13	1.88		737.51							
6/20/00 5:18 PM	19	3.1			13.98	2.73		736.66							
6/20/00 6:02 PM	63	2.3	14.75	2.38	13.35	2.10	737.67	737.29	11.02	739.76	12.18	738.56	13.25	737.7	
6/20/00 6:10 PM	70	3.0	14.89	2.52	13.64	2.39	737.53	737	11.05	739.73	12.29	738.45	13.42	737.5	
6/20/00 6:20 PM	80	2.5	15.26	2.89	14.05	2.80	737.16	736.59	11.12	739.66	12.40	738.34	13.79	737.2	
6/20/00 6:30 PM	90	2.5	15.62	3.25	14.42	3.17	736.8	736.22	11.20	739.58	12.50	738.24	14.14	736.8	
6/20/00 6:45 PM	105	2.5	16.24	3.87	15.51	4.26	736.18	735.13	11.36	739.42	12.81	737.93	14.75	736.2	
6/20/00 7:00 PM	120	2.5	16.71	4.34	15.57	4.32	735.71	735.07	11.50	739.28	12.97	737.77	15.21	735.8	
6/20/00 7:30 PM	150	2.5	18.24	5.87	17.05	5.80	734.18	733.59	11.79	738.99	13.56	737.18	16.74	734.2	
6/20/00 7:45 PM	165	2.8	19.09	6.72	17.93	6.68	733.33	732.71	11.96	738.82	14.19	736.55	17.60	733.4	
6/20/00 8:00 PM	180	2.0			20.55	9.30		730.09							
6/20/00 8:05 PM	185	1.3													
6/20/00 8:25 PM	205	1.0	20.02	7.65	18.69	7.44	732.4	731.95	12.45	738.33	15.32	735.42	18.53	732.4	
6/20/00 8:40 PM	220	0.9	20.17	7.8	20.07	8.82	732.25	730.57	12.61	738.17	15.29	735.45	18.70	732.3	
6/20/00 8:50 PM	230	0.8	20.21	7.84	21.56	10.31	732.21	729.08	12.75	738.03	15.48	735.26	18.74	732.2	
6/20/00 9:00 PM	240	0.5	20.23	7.86	22.02	10.77	732.19	728.62	12.84	737.94	15.66	735.08	18.75	732.2	
6/20/00 9:10 PM	250	0.5	20.23	7.86	22.50	11.25	732.19	728.14	12.96	737.82	15.89	734.85	18.77	732.2	
6/20/00 9:20 PM	260	0.5	20.27	7.9	23.10	11.85	732.15	727.54	13.06	737.72	16.07	734.67	18.79	732.2	
6/20/00 9:30 PM	270	0.5	20.27	7.9	23.30	12.05	732.15	727.34	13.17	737.61	16.20	734.54	18.81	732.2	
6/20/00 9:40 PM	280	0.5	20.30	7.93	22.70	11.45	732.12	727.94	13.26	737.52	16.29	734.45	18.81	732.2	
6/20/00 9:50 PM	290	0.5	20.30	7.93	23.05	11.80	732.12	727.59	13.36	737.42	16.35	734.39	18.83	732.1	
6/20/00 10:00 PM	300	0.5	20.33	7.96	23.05	11.80	732.09	727.59	13.45	737.33	16.40	734.34	18.86	732.1	
6/20/00 10:10 PM	310	0.5	20.35	7.98	23.50	12.25	732.07	727.14	13.55	737.23	16.45	734.29	18.88	732.1	
6/20/00 10:20 PM	320	0.5	20.26	7.89	23.30	12.05	732.16	727.34	13.67	737.11	16.50	734.24	18.83	732.1	
6/20/00 10:30 PM	330	0.3	20.31	7.94	23.10	11.85	732.11	727.54	13.73	737.05	16.50	734.24	18.83	732.1	
6/20/00 11:00 PM	360	0.2	20.32	7.95	24.18	12.93	732.1	726.46	13.92	736.86	16.50	734.24	18.84	732.1	
6/20/00 11:30 PM	390	1.0	20.32	7.95	25.12	13.87	732.1	725.52	14.08	736.7	16.53	734.21	18.86	732.1	
6/21/00 12:00 AM	420	0.5	20.45	8.08	20.35	9.10	731.97	730.29	14.22	736.56	16.50	734.24	18.97	732	
6/21/00 12:30 AM	450	0.3	20.46	8.09	22.52	11.27	731.96	728.12	14.35	736.43	16.57	734.17	19.00	732	
6/21/00 1:00 AM	480	0.3	20.46	8.09	25.26	14.01	731.96	725.38	14.48	736.3	16.58	734.16	18.99	732	
6/21/00 1:30 AM	510	0.3	20.49	8.12	24.05	12.80	731.93	726.59	14.60	736.18	16.60	734.14	19.02	731.9	End pumping on PW-1
6/21/00 1:31 AM	0	0.0			24.00	12.75		726.64							Begin Recovery of PW-1
6/21/00 1:31 AM	0.08	0.0			23.60	12.35		726.64							
6/21/00 1:31 AM	0.17	0.0			23.00	11.75		727.04							
6/21/00 1:31 AM	0.25	0.0			22.80	11.55		727.64							
6/21/00 1:31 AM	0.33	0.0			22.50	11.25		727.84							
6/21/00 1:31 AM	0.42	0.0			22.30	11.05		728.14							
6/21/00 1:31 AM	0.50	0.0			22.00	10.75		728.34							
6/21/00 1:31 AM	0.58	0.0			21.80	10.55		728.64							
6/21/00 1:31 AM	0.67	0.0			21.60	10.35		728.84							
6/21/00 1:31 AM	0.75	0.0			21.40	10.15		729.04							
6/21/00 1:31 AM	0.83	0.0			21.20	9.95		729.24							
6/21/00 1:31 AM	0.92	0.0			21.00	9.75		729.44							
6/21/00 1:32 AM	1.00	0.0			20.80	9.55		729.64							
6/21/00 1:32 AM	1.17	0.0			20.60	9.35		729.84							
6/21/00 1:32 AM	1.33	0.0			20.40	9.15		730.04							
6/21/00 1:32 AM	1.50	0.0			20.20	8.95		730.24							
6/21/00 1:32 AM	1.67	0.0			20.00	8.75		730.44							
6/21/00 1:32 AM	1.83	0.0			19.80	8.55		730.64							
6/21/00 1:33 AM	2.00	0.0			19.60	8.35		730.84							
6/21/00 1:33 AM	2.17	0.0			19.30	8.05		731.04							
6/21/00 1:33 AM	2.33	0.0			19.10	7.85		731.34							
6/21/00 1:33 AM	2.50	0.0			18.80	7.55		731.54							
6/21/00 1:33 AM	2.67	0.0			18.65	7.40		731.84							
6/21/00 1:33 AM	2.83	0.0			18.60	7.35		732.04							
6/21/00 1:34 AM	3.00	0.0			18.58	7.33		732.06							
6/21/00 1:34 AM	3.50	0.0			18.55	7.30		732.09							
6/21/00 1:35 AM	4.00	0.0			18.53	7.28		732.11							
6/21/00 1:35 AM	4.50	0.0			18.46	7.21		732.18							
6/21/00 1:36 AM	5	0.0			18.42	7.17		732.22							
6/21/00 1:37 AM	6	0.0			18.38	7.13		732.26							
6/21/00 1:38 AM	7	0.0			18.31	7.06		732.33							
6/21/00 1:39 AM	8	0.0			18.25	7.00		732.39							
6/21/00 1:40 AM	9	0.0			18.19	6.94		732.45							
6/21/00 1:41 AM	10	0.0			18.08	6.83		732.56							
6/21/00 1:43 AM	12	0.0			17.93	6.68		732.71							
6/21/00 1:45 AM	14	0.0			17.84	6.59		732.8							
6/21/00 1:47 AM	16	0.0			17.75	6.50		732.89							
6/21/00 1:49 AM	18	0.0			17.74	6.49		732.9							
6/21/00 1:51 AM	20	0.0			17.70	6.45		732.94							
6/21/00 1:56 AM	25	0.0			17.60	6.35		733.04							
6/21/00 2:01 AM	30	0.0			17.49	6.24		733.15							
6/21/00 2:06 AM	35	0.0			17.39	6.14		733.25							
6/21/00 2:11 AM	40	0.0			17.30	6.05		733.34							
6/21/00 2:16 AM	45	0.0			17.21	5.96		733.43							
6/21/00 2:21 AM	50	0.0			17.18	5.93		733.46							
6/21/00 2:26 AM	55	0.0			17.09	5.84		733.55							
6/21/00 2:31 AM	60	0.0			17.00	5.75		733.64							
6/21/00 3:31 AM	120	0.0			16.25	5.00		734.39							End Recovery of PW-1
6/21/00 1:31 PM	720	0.0													
6/21/00 1:31 PM	6		15.65	3.28			736.77								Begin Pumping at OW-3
6/21/00 1:42 PM	11	0.8	15.71	3.34			736.71								

	Test Time (minutes)	gpm Pump Rate	OW-3 below TOC	OW-3 drawdown	PW-1 below TOC	PW-1 drawdown	TOC elev 752.42 OW-3 H_2O Level	TOC elev 750.64 PW-1 H_2O Level	TOC elev 750.78 OW-1 below TOC	OW-1 H_2O Level	TOC elev 750.74 OW-2 below TOC	OW-2 H_2O Level	TOC elev 750.96 OW-4 below TOC	OW-4 Water Level	Comments
6/21/00 1:47 PM	16	0.9	15.77	3.4			736.65								
6/21/00 1:52 PM	21	0.9	15.85	3.48			736.57								
6/21/00 1:57 PM	26	0.8	15.95	3.58			736.47								
6/21/00 2:02 PM	31	0.8	16.40	4.03			736.02								
6/21/00 2:07 PM	36	0.8	16.20	3.83			736.22								
6/21/00 2:12 PM	41	1.0	16.22	3.85			736.2								
6/21/00 2:17 PM	46	1.0	16.30	3.93			736.12								
6/21/00 2:22 PM	51	0.9	16.33	3.96			736.09								
6/21/00 2:27 PM	56	0.9	16.40	4.03			736.02								End Measuring Flow on a 1 min / X gal basis
6/21/00 2:32 PM	61	0.8	16.51	4.14			735.91								Begin Measuring Flow on Larger volume
6/21/00 2:37 PM	66	0.8	16.61	4.24			735.81								
6/21/00 2:42 PM	71	0.9	16.71	4.34			735.71								
6/21/00 2:47 PM	76	0.7	16.85	4.48			735.57								
6/21/00 2:52 PM	81	0.8	16.92	4.55			735.5								
6/21/00 2:57 PM	86	0.7	17.02	4.65			735.4								
6/21/00 3:02 PM	91	0.8	17.13	4.76			735.29								
6/21/00 3:07 PM	96	0.8	17.20	4.83			735.22								
6/21/00 3:12 PM	101	0.8	17.31	4.94			735.11								
6/21/00 3:17 PM	106	0.8	17.41	5.04			735.01								
6/21/00 3:22 PM	111	0.7	17.47	5.1			734.95								
6/21/00 3:27 PM	116	0.7	17.56	5.19			734.86								
6/21/00 3:32 PM	121	0.8	17.63	5.26			734.79								
6/21/00 3:37 PM	126	0.6	17.71	5.34			734.71								
6/21/00 3:42 PM	131	0.5	17.72	5.35			734.7								
6/21/00 3:47 PM	136	0.4	17.75	5.38			734.67								
6/21/00 4:01 PM	150	0.5	17.65	5.28			734.77								
6/21/00 4:07 PM	156				15.92	4.67		734.72	13.52	737.26	15.20	735.54	16.24	734.7	
6/21/00 4:21 PM	170	0.5	17.79	5.42			734.63								
6/21/00 4:41 PM	190	0.4	17.78	5.41			734.64								
6/21/00 5:01 PM	210	0.3	17.75	5.38	15.96	4.71	734.67	734.68	13.43	737.35	15.37	735.37	16.28	734.7	
6/21/00 5:21 PM	230	0.2	17.78	5.41			734.64								
6/21/00 5:41 PM	250	0.2	17.59	5.22			734.83								
6/21/00 6:01 PM	270	0.2	17.57	5.2			734.85								
6/21/00 6:04 PM	273				15.77	4.52		734.87	13.48	737.3	15.35	735.39	16.10	734.9	
6/21/00 6:21 PM	290	0.3	17.51	5.14			734.91								
6/21/00 6:41 PM	310		17.82	5.45			734.6								
6/21/00 7:46 PM	375	0.9	19.57	7.2			732.85								
6/21/00 7:51 PM	380	0.9	19.70	7.33			732.72								
6/21/00 7:56 PM	385	0.9	19.96	7.59			732.46								
6/21/00 8:01 PM	390	0.9	20.23	7.86			732.19								
6/21/00 8:06 PM	395	0.6	20.32	7.95			732.1								
6/21/00 8:11 PM	400	0.6	20.40	8.03			732.02								
6/21/00 8:16 PM	405		20.56	8.19			731.86								
6/21/00 8:51 PM	440	0.0													Pump stopped "Ground Fault Error"
6/21/00 10:00 PM	509	1.0	20.36	7.99			732.06								Initiate Flow @ 1 gpm
6/21/00 10:01 PM	1	0.9	21.15	8.78			731.27								Begin Readings
6/21/00 10:10 PM	10	0.0	22.41	10.04			730.01								Pump malfunction, zero flow
6/22/00 1:56 AM	745	0.0	29.95	17.58			722.47								OW-3 Dry, Pumping Stopped
6/22/00 3:01 AM	810		20.00	7.63			732.42								Pump malfunction, working on system
6/22/00 3:42 AM	851		19.55	7.18			732.87								
6/22/00 4:06 AM	875		20.40	8.03			732.02								
6/22/00 4:14 AM	883		20.67	8.3			731.75								
6/22/00 4:51 AM	920		21.10	8.73			731.32								
6/22/00 5:01 AM	930		24.90	12.53			727.52								
6/22/00 5:45 AM	974		20.90	8.53			731.52								
6/22/00 7:26 AM	1,075	0.8	19.76	7.39			732.66								Started Time Over, restart Pump OW-3
6/22/00 7:31 AM	1,080	1.1	20.66	8.29			731.76								
6/22/00 7:36 AM	1,085	0.9	20.90	8.53			731.52								
6/22/00 7:41 AM	1,090	0.6	22.06	9.69			730.36								
6/22/00 7:46 AM	1,095	0.6	22.35	9.98			730.07								
6/22/00 7:51 AM	1,100	0.5	22.50	10.13			729.92								
6/22/00 7:56 AM	1,105	0.4	23.15	10.78			729.27								
6/22/00 8:01 AM	1,110	0.4	23.35	10.98			729.07								
6/22/00 8:06 AM	1,115	0.4	24.11	11.74			728.31								
6/22/00 8:11 AM	1,120		24.90	12.53			727.52								
6/22/00 8:16 AM	1,125		23.05	10.68			729.37								
6/22/00 8:21 AM	1,130		22.75	10.38			729.67								
6/22/00 8:26 AM	1,135		23.56	11.19			728.86								
6/22/00 8:36 AM	1,145	0.3	23.55	11.18			728.87								
6/22/00 8:46 AM	1,155		23.19	10.82			729.23								
6/22/00 8:56 AM	1,165	0.3	22.50	10.13			729.92								
6/22/00 9:06 AM	1,175		23.00	10.63			729.42								
6/22/00 9:16 AM	1,185	0.3	23.20	10.83			729.22								
6/22/00 9:26 AM	1,195		23.31	10.94			729.11								
6/22/00 9:36 AM	1,205	0.2	23.06	10.69			729.36								
6/22/00 9:46 AM	1,215	0.2	23.07	10.7			729.35								
6/22/00 9:56 AM	1,225	0.3	23.65	11.28			728.77								
6/22/00 10:06 AM	1,235		23.78	11.41			728.64								
6/22/00 10:16 AM	1,245		22.25	9.88			730.17								
6/22/00 10:26 AM	1,255		22.12	9.75			730.3								
6/22/00 10:36 AM	1,265	0.3	22.44	10.07			729.98								
6/22/00 10:46 AM	1,275	0.3	22.66	10.29			729.76								
6/22/00 10:56 AM	1,285	0.2	22.90	10.53			729.52								
6/22/00 11:06 AM	1,295		23.15	10.78			729.27								
6/22/00 11:16 AM	1,305	0.2	22.55	10.18			729.87								
6/22/00 11:26 AM	1,315	0.2	23.20	10.83			729.22								
6/22/00 11:36 AM	1,325	0.2	22.69	10.32			729.73								

	Test Time (minutes)	gpm Pump Rate	OW-3 below TOC	OW-3 drawdown	PW-1 below TOC	PW-1 drawdown	TOC elev 752.42 OW-3 H_2O Level	TOC elev 750.64 PW-1 H_2O Level	TOC elev 750.78 OW-1 below TOC	OW-1 H_2O Level	TOC elev 750.74 OW-2 below TOC	OW-2 H_2O Level	TOC elev 750.96 OW-4 below TOC	OW-4 Water Level	Comments
6/22/00 11:46 AM	1,335				19.00	7.75		731.64	15.50	735.28	16.81	733.93	19.39	731.6	
6/22/00 11:56 AM	1,345	0.2	22.51	10.14			729.91								
6/22/00 12:06 PM	1,355		22.59	10.22			729.83								
6/22/00 12:16 PM	1,365	0.2	22.52	10.15			729.9								
6/22/00 12:26 PM	1,375		22.46	10.09			729.96								
6/22/00 12:36 PM	1,385	0.3	22.46	10.09			729.96								
6/22/00 12:56 PM	1,405		22.68	10.31			729.74								
6/22/00 1:16 PM	1,425	0.2	22.47	10.1			729.95								
6/22/00 1:36 PM	1,445	0.2	22.86	10.49			729.56								
6/22/00 1:56 PM	1,465	0.2	23.45	11.08	19.00	7.75	728.97	731.64	15.58	735.2	16.85	733.89	19.40	731.6	
6/22/00 2:16 PM	1,485		23.38	11.01			729.04								
6/22/00 2:36 PM	1,505	0.2	23.50	11.13			728.92								
6/22/00 2:56 PM	1,525	0.2	22.51	10.14			729.91								
6/22/00 3:26 PM	1,555	0.2	23.10	10.73	18.98	7.73	729.32	731.66	15.53	735.25	16.83	733.91	19.40	731.6	
6/22/00 3:56 PM	1,585	0.2	23.22	10.85			729.2								
6/22/00 4:26 PM	1,615	0.2	25.25	12.88			727.17								
6/22/00 4:56 PM	1,645		22.45	10.08			729.97								
6/22/00 5:03 PM	1,652		27.60	15.23			724.82								
6/22/00 5:08 PM	1,657		26.34	13.97			726.08								
6/22/00 5:11 PM	1,660		25.76	13.39			726.66								
6/22/00 5:26 PM	1,675	0.2	26.32	13.95			726.1								
6/22/00 5:54 PM	1,703		26.11	13.74			726.31								
6/22/00 5:56 PM	1,705		27.10	14.73	19.00	7.75	725.32	731.64	15.52	735.26	16.82	733.92	19.39	731.6	
6/22/00 6:16 PM	1,725	0.2	26.75	14.38			725.67								
6/22/00 6:26 PM	1,735	0.2	26.13	13.76			726.29								
6/22/00 6:56 PM	1,765	0.2	26.14	13.77			726.28								
6/22/00 7:26 PM	1,795	0.2	25.74	13.37			726.68								
6/22/00 7:56 PM	1,825	0.2	25.84	13.47			726.58								
6/22/00 8:26 PM	1,855	0.2	26.79	14.42			725.63								
6/22/00 8:56 PM	1,885	0.2	26.10	13.73			726.32								
6/22/00 9:26 PM	1,915	0.2	26.37	14			726.05								
6/22/00 9:56 PM	1,945	0.2	26.50	14.13	19.00	7.75	725.92	731.64	15.55	735.23	16.80	733.94	19.40	731.6	
6/22/00 10:26 PM	1,975	0.2	26.65	14.28			725.77								
6/22/00 10:56 PM	2,005	0.2	25.40	13.03			727.02								
6/22/00 11:26 PM	2,035	0.2	25.40	13.03			727.02								
6/22/00 11:56 PM	2,065	0.2	25.90	13.53			726.52								
6/23/00 12:26 AM	2,095	0.2	26.20	13.83			726.22								
6/23/00 12:56 AM	2,125	0.2	25.95	13.58			726.47								
6/23/00 1:26 AM	2,155	0.2	26.41	14.04			726.01								
6/23/00 1:56 AM	2,185	0.2	26.60	14.23	19.05	7.80	725.82	731.59	19.00	731.78	16.90	733.84	19.40	731.6	
6/23/00 2:26 AM	2,215	0.2	25.85	13.48			726.57								
6/23/00 2:56 AM	2,245	0.2	26.91	14.54			725.51								
6/23/00 3:26 AM	2,275	0.2	26.00	13.63			726.42								
6/23/00 3:56 AM	2,305	0.2	27.40	15.03			725.02								
6/23/00 4:26 AM	2,335	0.2	27.00	14.63			725.42								
6/23/00 4:56 AM	2,365	0.2	27.45	15.08			724.97								
6/23/00 5:26 AM	2,395	0.2	25.85	13.48			726.57								
6/23/00 5:56 AM	2,425	0.2	27.10	14.73	19.00	7.75	725.32	731.64	15.44	735.34	16.80	733.94	19.40	731.6	
6/23/00 6:26 AM	2,455	0.2													
6/23/00 6:56 AM	2,485	0.2	26.80	14.43			725.62								
6/23/00 7:26 AM	2,515	0.2	25.70	13.33			726.72								
6/23/00 7:56 AM	2,545	0.2	25.90	13.53			726.52								
6/23/00 8:26 AM	2,575	0.2	26.15	13.78			726.27								
6/23/00 8:56 AM	2,605	0.2	26.34	13.97			726.08								
6/23/00 9:26 AM	2,635	0.2	26.12	13.75			726.3								
6/23/00 9:56 AM	2,665		25.76	13.39			726.66								
6/23/00 10:02 AM	2,671				18.99	7.74		731.65	15.49	735.29	16.79	733.95	19.40	731.6	
6/23/00 10:26 AM	2,695	0.2	25.64	13.27			726.78								
6/23/00 10:56 AM	2,725	0.2	25.84	13.47			726.58								
6/23/00 11:26 AM	2,755		25.88	13.51			726.54								
6/23/00 11:56 AM	2,785	0.2	26.03	13.66			726.39								
6/23/00 12:11 PM	2,800				18.99	7.74		731.65	15.49	735.29	16.80	733.94	19.40	731.6	Data set for K calc
6/23/00 12:16 PM	2,805	0.0	25.61	13.24			726.81								End Pumping on OW-3
6/23/00 12:21 PM	2,810	0.0	22.51	10.14			729.91								Begin Recovery of OW-3
6/23/00 12:26 PM	2,815	0.0	22.42	10.05			730								
6/23/00 12:31 PM	2,820	0.0	22.19	9.82			730.23								
6/23/00 12:36 PM	2,825	0.0	21.96	9.59			730.46								
6/23/00 12:41 PM	2,830	0.0	21.70	9.33			730.72								
6/23/00 12:46 PM	2,835	0.0	21.51	9.14			730.91								
6/23/00 12:51 PM	2,840	0.0	21.23	8.86			731.19								
6/23/00 12:56 PM	2,845	0.0	21.01	8.64			731.41								
6/23/00 1:01 PM	2,850	0.0	20.95	8.58			731.47								
6/23/00 1:06 PM	2,855	0.0	20.88	8.51			731.54								
6/23/00 1:11 PM	2,860	0.0	20.85	8.48			731.57								
6/23/00 1:16 PM	2,865	0.0	20.84	8.47			731.58								
6/23/00 1:21 PM	2,870	0.0	20.79	8.42	18.98		731.63		15.46	735.32	16.76	733.98	19.29	731.7	
6/23/00 1:26 PM	2,875	0.0	20.72	8.35			731.7								
6/23/00 1:36 PM	2,885	0.0	20.61	8.24			731.81								
6/23/00 1:46 PM	2,895	0.0	20.56	8.19			731.86								
6/23/00 2:06 PM	2,915	0.0	20.36	7.99	18.57		732.06		15.43	735.35	16.74	734	18.89	732.1	End Recovery of OW-3

Figure 5
Pump Test Data
Greensboro Landfill



Appendix C

HYDRAULIC CONDUCTIVITY CALCULATIONS

DETERMINATION OF HYDRAULIC CONDUCTIVITY (K) UNDER STEADY-STATE CONDITIONS

Greensboro White Street Landfill

Computation Date: 7/12/00

K = $Q*\ln(r_2/r_1)/\pi/(h_2^2-h_1^2)$ Source: Applied Hydrogeology, Fetter, 1980

Q= 0.02673611 (in cubic feet per minute under steady-state condition)

Base El.= 719.7 (reference elevation at base of pumping well)

		h_1	h_2	r_1	r_2	$\ln r_2/r_1$	$h_2^2 - h_1^2$	ft/min	ft/day
Case 1:	**OW-3/OW-2**	14.3		11.11					
	OW-3/OW-1		15.65		17.48	0.45	40.43	9.54E-05	0.14
Case 2:	**OW-3/PW-1**	11.95		10.23					
	OW-3/OW-2		14.24		11.11	0.08	59.98	1.17E-05	0.02
Case 3:	**OW-3/PW-1**	11.95		10.23					
	OW-3/OW-1		15.65		17.48	0.54	102.12	4.46E-05	0.06

Notes:

h_1 head potential at distance r_1 from pumping well in feet.

h_2 head potential at distance r_2 from pumping well in feet.

r_1 Distance from pumping well to observation well with head h_1 in feet

r_2 Distance from pumping well to observation well with head h_2 in feet.

OW-3 is the pumping well during testing.

OW-1, OW-2, OW-4, and PW-1 are observation wells.

HDR Engineering, Inc. of the Carolinas

Client: City of Greensboro, NC.

Project: Rising Head Tests
White Street Landfill

Project No.: 06770-033-018
Sheet: 1/1
Date: 6/28/00
Well: OW-3
Reference: Bouwer, 1989

Hydraulic Conductivity, K = ((Req^2)ln(Re/Rw)/2Le)*(1/T)*ln(Yo/Yt)

Where: **Req = [(1-n)(Rc^2) + n(Rw^2)]exp^1/2 (Correction for sand pack)**

ln(Re/Rw)=[1.1/ln(Lw/Rw)+(A+Bln[(H-Lw)/Rw])/Le/Rw]exp^-1

Lw = Ht. of Water Column in Well =	19.79	(water in
Le = Screen Interval Open to Aquifer =	20	casing)
Rw = Radius of Well Including Sand Pack =	0.26	
Rc = Radius of Casing =	0.083	
H = Aquifer Thickness to First Aquitard =	30	
Yo = Relative Ht. of Water at Time Zero =	13.24	
Yt = Relative Ht. of Water at Time t =	7	
n = Porosity =	0.05	
T = Time (in minutes) =	23.33	

A & B are Constants to be Determined

Correction for Sand Pack
Req = 0.099622 (not necessary)

Evaluation of A & B
Le/Rw = 76.923077

from attached graph of A & B

A =	
B =	

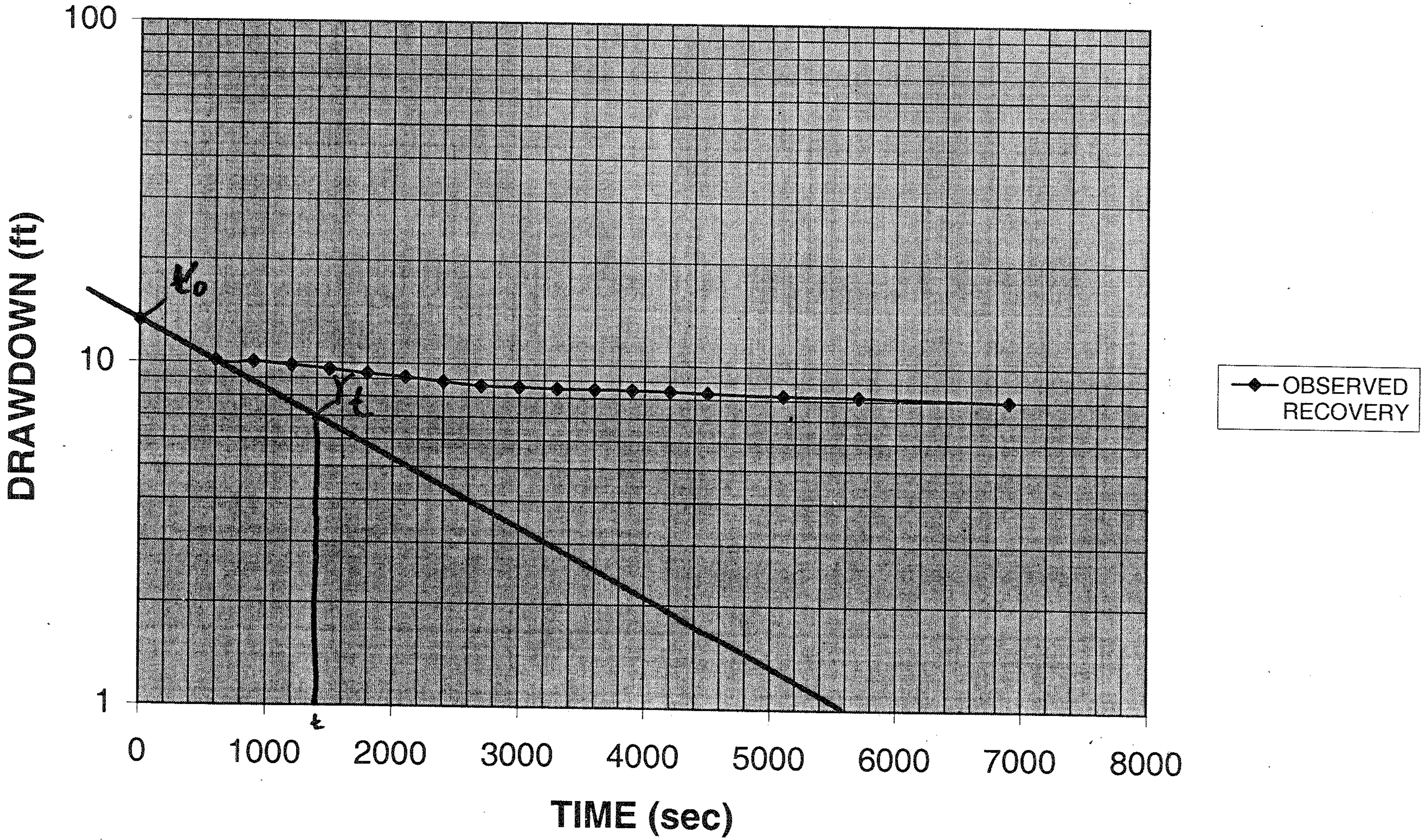
Determination of ln Term

ln Re/Rw = 3.9384095

Determination of Hydraulic Conductivity

K = 1.853E-05 feet/min
0.03 feet/day
9.41E-06 cm/sec

RISING HEAD TEST AT OW-3



HDR Engineering, Inc. of the Carolinas

Client: City of Greensboro, NC.

Project: Rising Head Tests
White Street Landfill

Project No.: 06770-033-018
Sheet: 1/1
Date: 6/27/00
Well: PW-1
Reference: Bouwer, 1989

Hydraulic Conductivity, K = ((Req^2)ln(Re/Rw)/2Le)*(1/T)*ln(Yo/Yt)

Where: **Req = [(1-n)(Rc^2) + n(Rw^2)]exp^1/2 (Correction for sand pack)**

ln(Re/Rw)=[1.1/ln(Lw/Rw)+(A+Bln[(H-Lw)/Rw])/Le/Rw]exp^-1

Lw = Ht. of Water Column in Well =	19.78	(water in
Le = Screen Interval Open to Aquifer =	20	casing)
Rw = Radius of Well Including Sand Pack =	0.26	
Rc = Radius of Casing =	0.083	
H = Aquifer Thickness to First Aquitard =	29.5	
Yo = Relative Ht. of Water at Time Zero =	13	
Yt = Relative Ht. of Water at Time t =	5	
n = Porosity =	0.05	
T = Time (in minutes) =	6.66	

A & B are Constants to be Determined

Correction for Sand Pack
Req = 0.099622 (not necessary)

Evaluation of A & B
Le/Rw = 76.923077

from attached graph of A & B

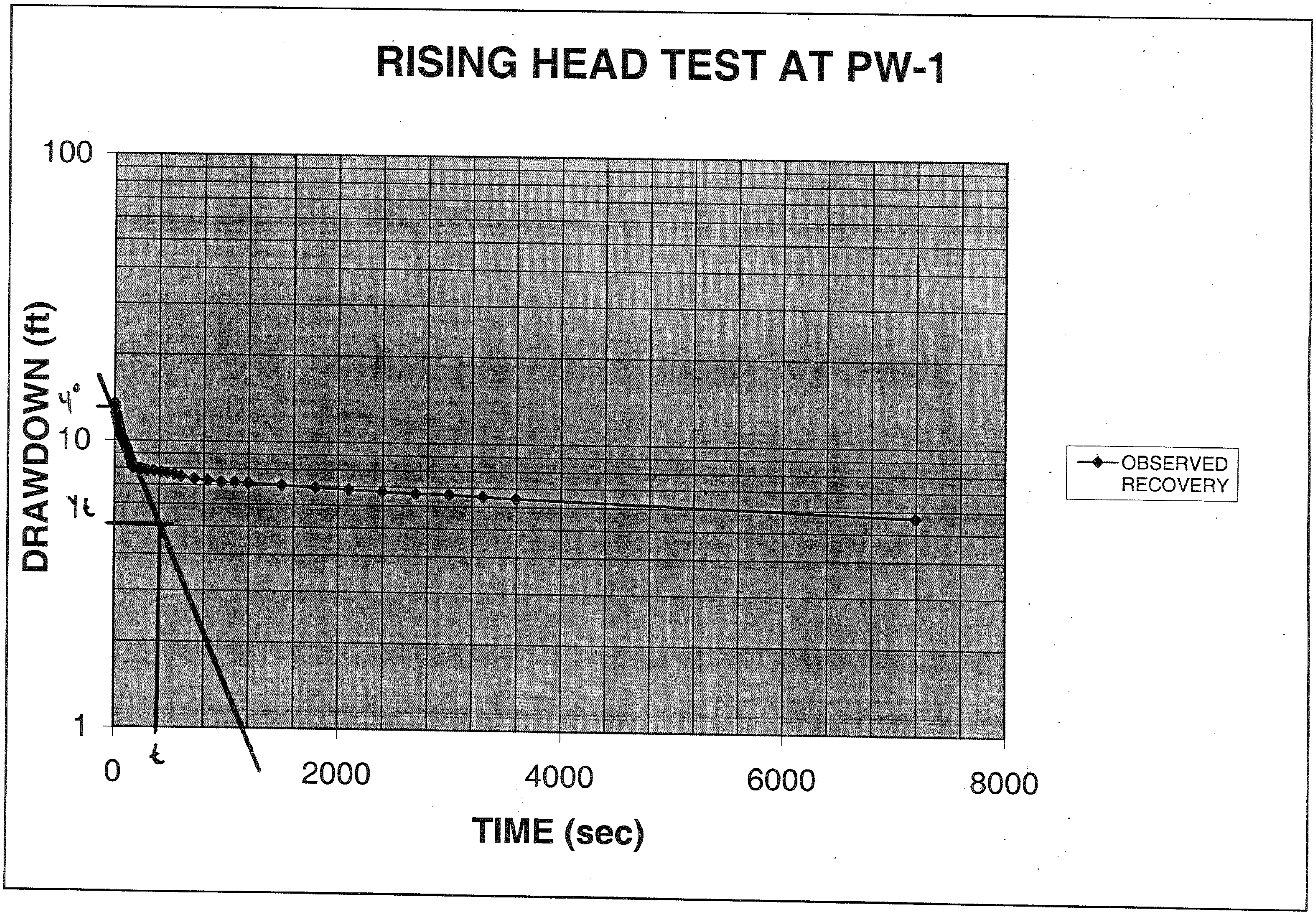
A =	
B =	

Determination of ln Term

ln Re/Rw = 3.93795

Determination of Hydraulic Conductivity

K = 9.73E-05 feet/min
0.140 feet/day
4.94E-05 cm/sec


RISING HEAD TEST AT PW-1
100
10
1
DRAWDOWN (ft)
0
2000
4000
6000
8000
TIME (sec)
OBSERVED RECOVERY

HDR Engineering, Inc.

Client:	White Street Landfill	Project No.	06770-021-018
		Sheet	1/1
Project:	Falling Head Tests	Date:	11/27/95
		Well	B-17d
		Reference:	Bouwer, 1989

Hydraulic Conductivity, K = ((Req^2)ln(Re/Rw)/2Le)*(1/T)*ln(Yo/Yt)

Where: **Req = [(Rc^2) + n(Rw^2 - Rc^2)]exp^1/2 (Correction for sand pack)**

ln(Re/Rw)=[1.1/ln(Lw/Rw)+(A+Bln[(H-Lw)/Rw])/Le/Rw]exp^-1

Lw = Ht. of Water Column in Well =	27.96	(water in
Le = Screen Interval Open to Aquifer =	5	casing)
Rw = Radius of Well Including Sand Pack =	0.375	
Rc = Radius of Casing =	0.083	
H = Aquifer Thickness to First Aquitard =	53	
Yo = Relative Ht. of Water at Time Zero =	1.76	
Yt = Relative Ht. of Water at Time t =	0.8	
n = Porosity =	0.35	
T = Time (in minutes) =	3.33	

A & B are Constants to be Determined

Correction for Sand Pack (not necessary in this case)

Req = 0.083

Evaluation of A & B

Le/Rw = 13.33333

from attached graph of A & B

A =	1.9
B =	0.38

Determination of ln Term

ln Re/Rw = 1.93288

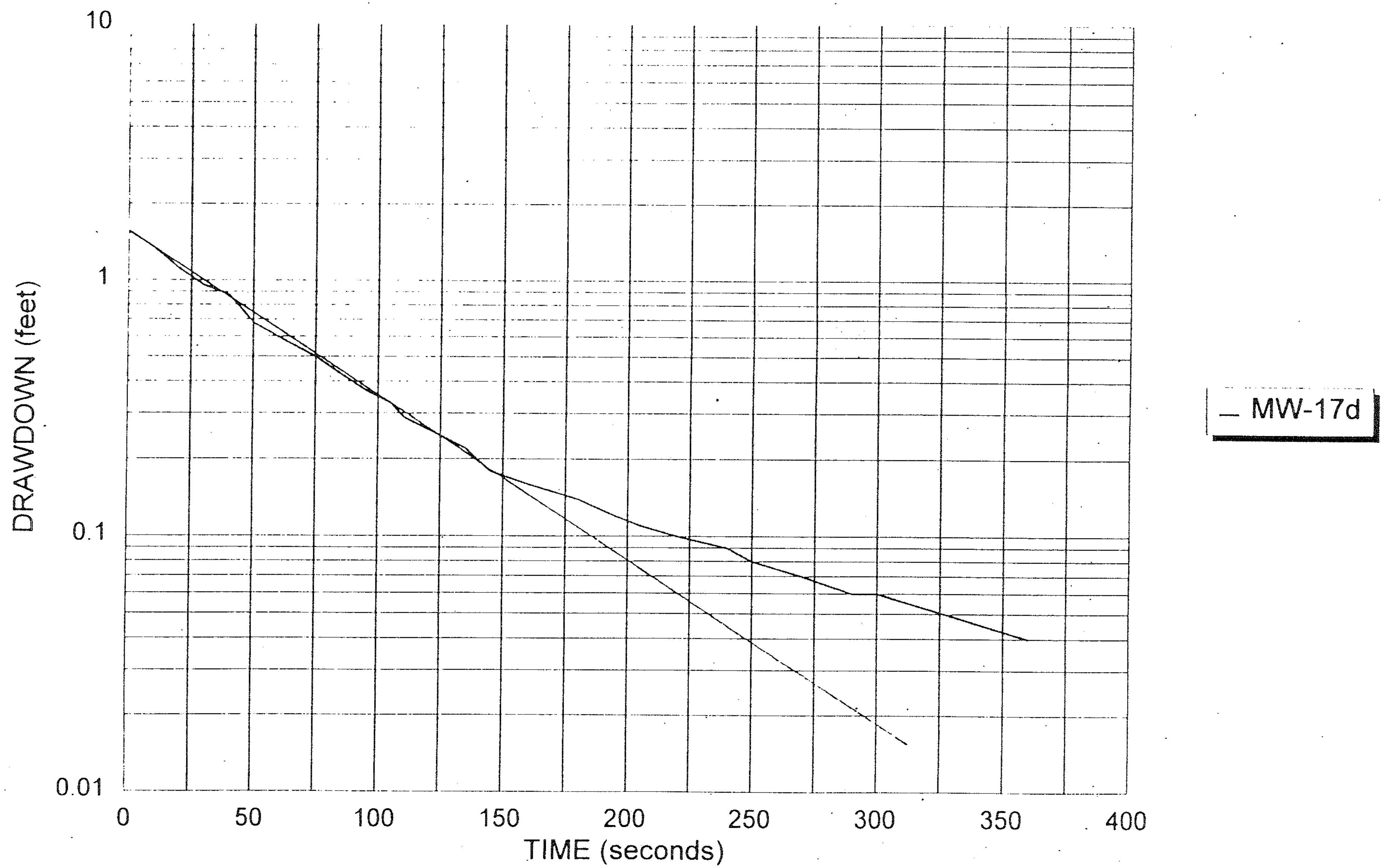
Determination of Hydraulic Conductivity

K = 0.000315 feet/min.

0.454002 feet/day = 1.60×10^{-4} cm/sec

FALLING HEAD TEST: MW-17d

Greensboro White Street Landfill



HDR Engineering, Inc.

Client:	White Street Landfill	Project No.	06770-021-018
		Sheet	1/1
Project:	Falling Head Tests	Date:	11/27/95
		Well	B-22d
		Reference:	Bouwer, 1989

Hydraulic Conductivity, K = ((Req^2)ln(Re/Rw)/2Le)*(1/T)*ln(Yo/Yt)

Where: **Req = [(Rc^2) + n(Rw^2 - Rc^2)]exp^1/2 (Correction for sand pack)**

ln(Re/Rw)=[1.1/ln(Lw/Rw)+(A+Bln[(H-Lw)/Rw])/Le/Rw]exp^-1

Lw = Ht. of Water Column in Well =	36.53	(water in
Le = Screen Interval Open to Aquifer =	5	casing)
Rw = Radius of Well Including Sand Pack =	0.375	
Rc = Radius of Casing =	0.083	
H = Aquifer Thickness to First Aquitard =	46	
Yo = Relative Ht. of Water at Time Zero =	2.07	
Yt = Relative Ht. of Water at Time t =	2	
n = Porosity =	0.35	
T = Time (in minutes) =	0.83	

A & B are Constants to be Determined

Correction for Sand Pack (not necessary in this case)

Req = 0.083

Evaluation of A & B

Le/Rw = 13.33333

from attached graph of A & B

A =	1.9
B =	0.38

Determination of ln Term

ln Re/Rw = 2.106352

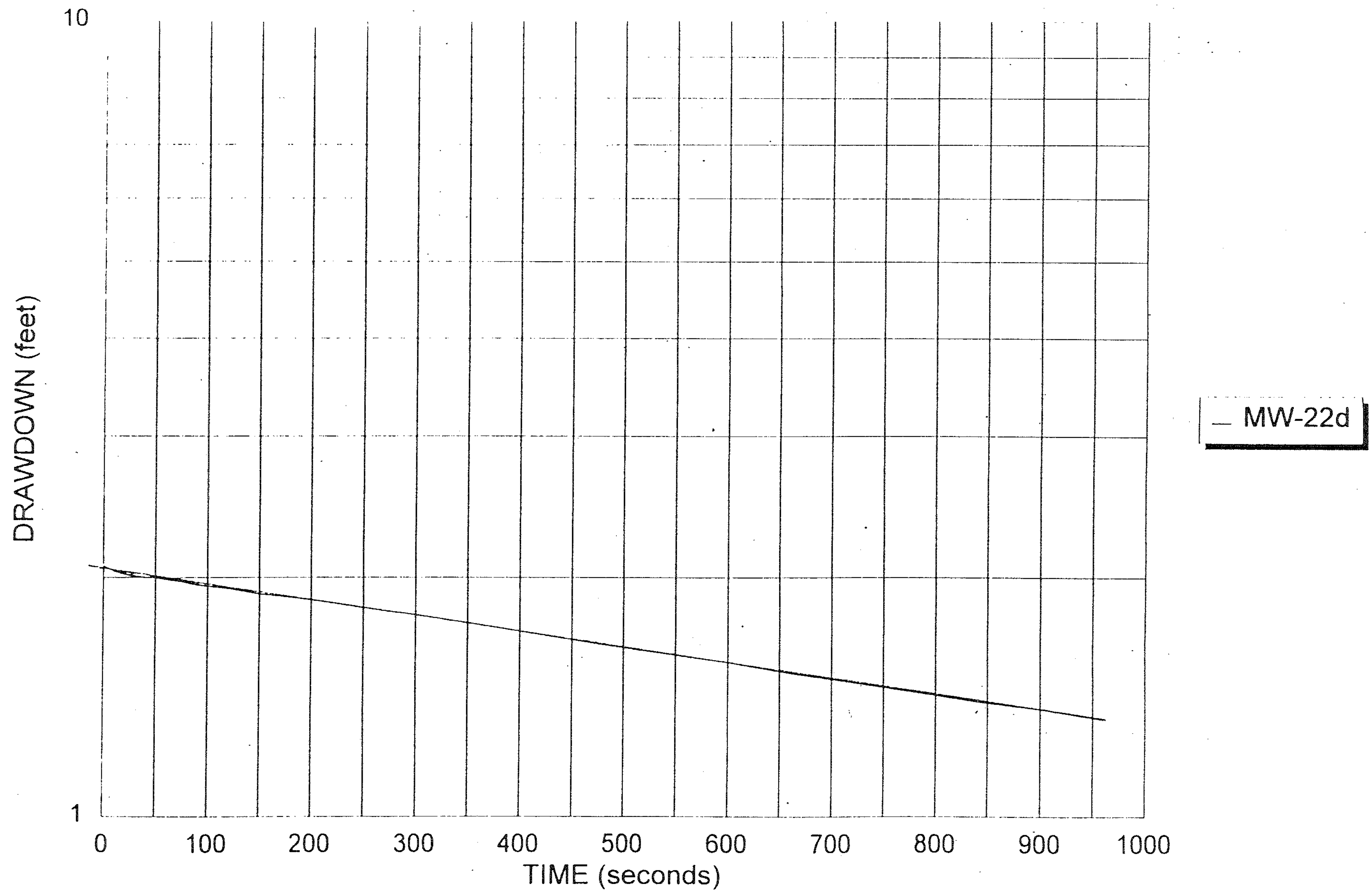
Determination of Hydraulic Conductivity

K = 0.00006 feet/min.

0.086606 feet/day = 3.06×10^{-5} cm/sec

FALLING HEAD TEST: MW-B22d

Greensboro White Street Landfill



HDR Engineering, Inc.

Client:	White Street Landfill	Project No.	06770-021-018
Project:	Falling Head Tests	Sheet	1/1
		Date:	11/27/95
		Well	B-25d
		Reference:	Bouwer, 1989

Hydraulic Conductivity, K = ((Req^2)ln(Re/Rw)/2Le)*(1/T)*ln(Yo/Yt)

Where: Req = [(Rc^2) + n(Rw^2 - Rc^2)]exp^1/2 (Correction for sand pack)

ln(Re/Rw)=[1.1/ln(Lw/Rw)+(A+Bln[(H-Lw)/Rw])/Le/Rw]exp^-1

Lw = Ht. of Water Column in Well =	42.05	(water in casing)
Le = Screen Interval Open to Aquifer =	5	
Rw = Radius of Well Including Sand Pack =	0.375	
Rc = Radius of Casing =	0.083	
H = Aquifer Thickness to First Aquitard =	52	
Yo = Relative Ht. of Water at Time Zero =	1.9	
Yt = Relative Ht. of Water at Time t =	0.9	
n = Porosity =	0.35	
T = Time (in minutes) =	10	

A & B are Constants to be Determined

Correction for Sand Pack (not necessary in this case)

Req = 0.083

Evaluation of A & B

Le/Rw = 13.33333

from attached graph of A & B

A =	1.9
B =	0.38

Determination of ln Term

ln Re/Rw = 2.132193

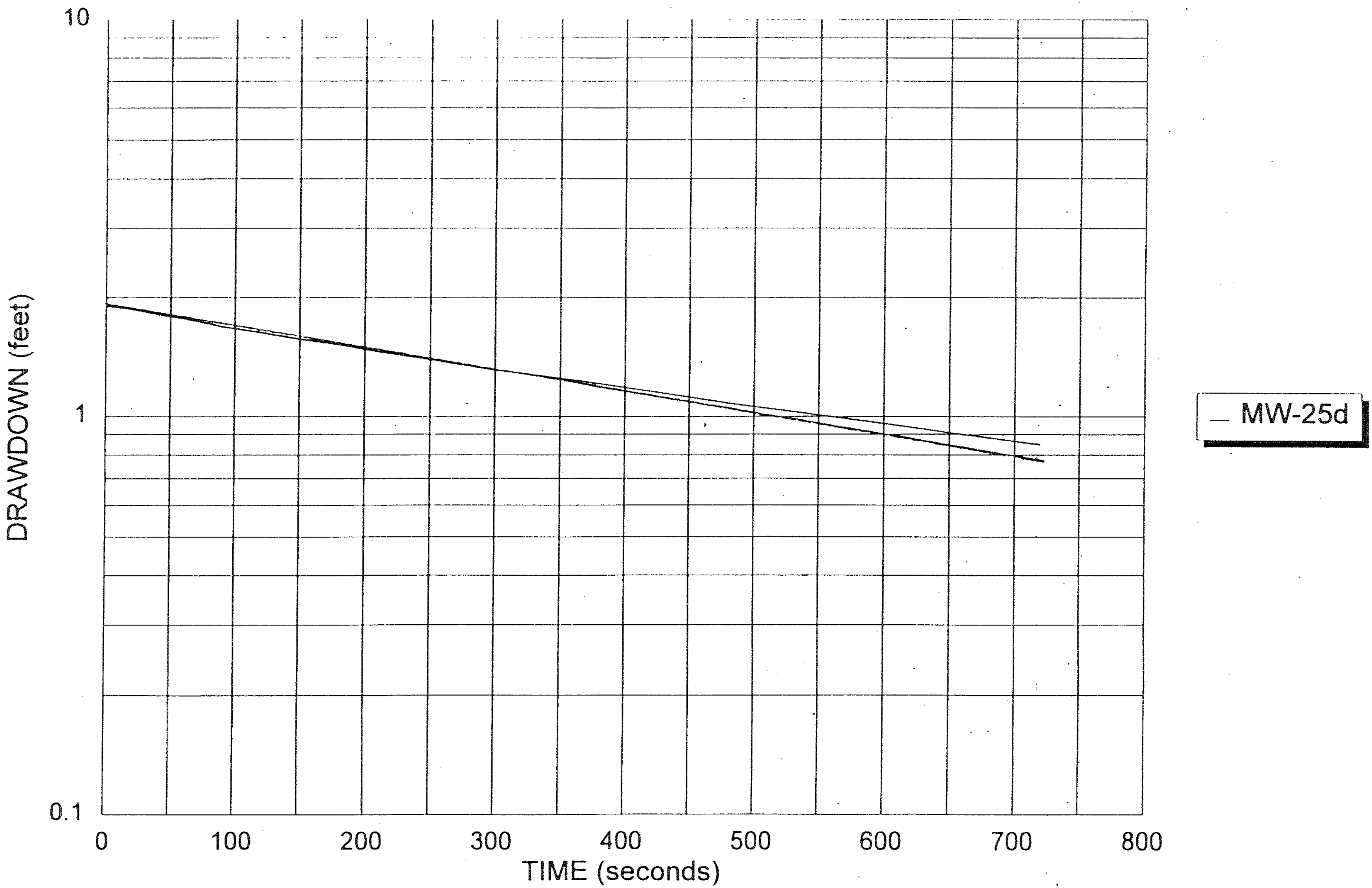
Determination of Hydraulic Conductivity

K = 0.00011 feet/min.

0.158049 feet/day = 5.58×10^{-6} cm/sec

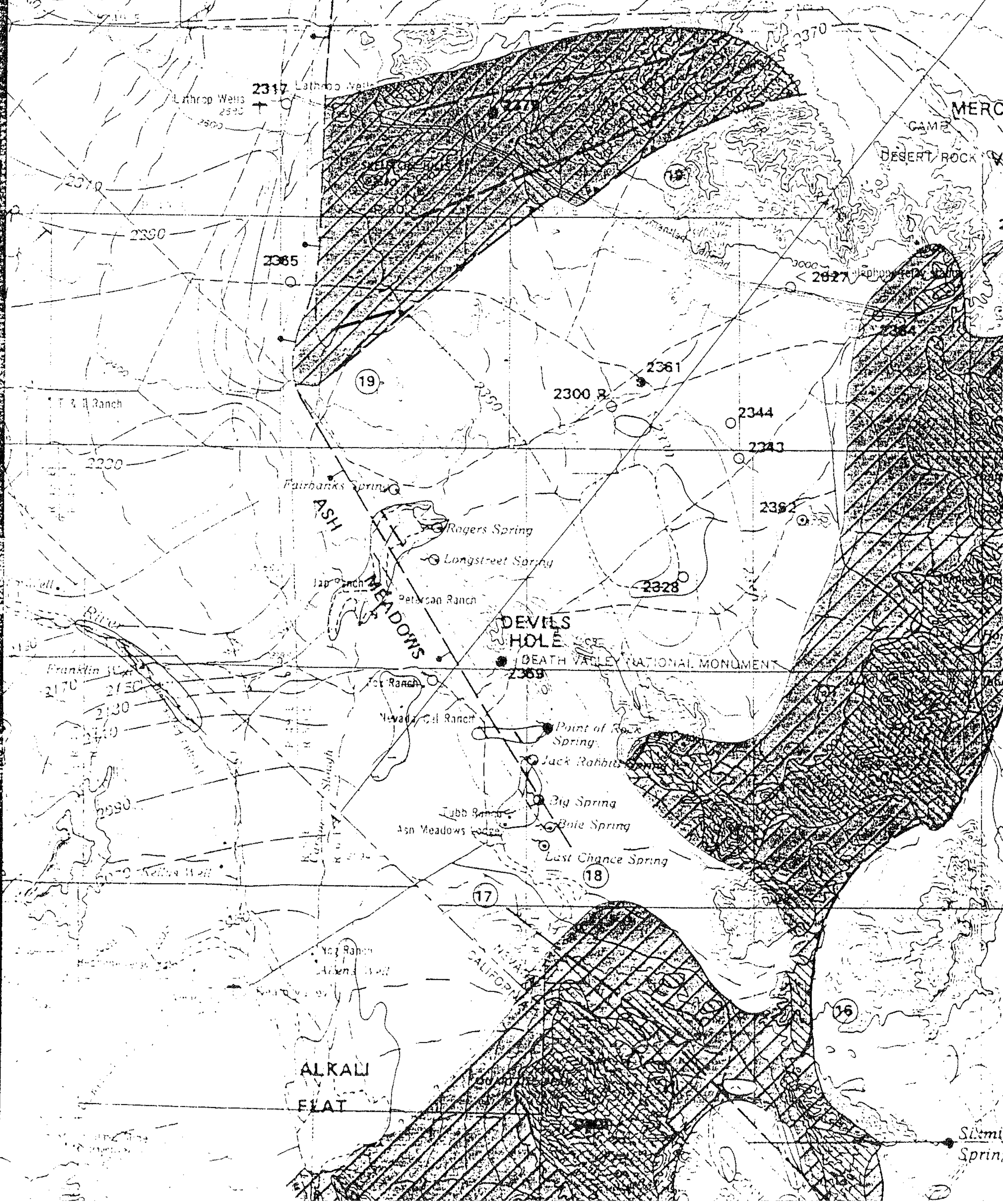
FALLING HEAD TEST: MW-25d

Greensboro White Street Landfill



C.W. Fetter, Jr.

APPLIED HYDROGEOLOGY



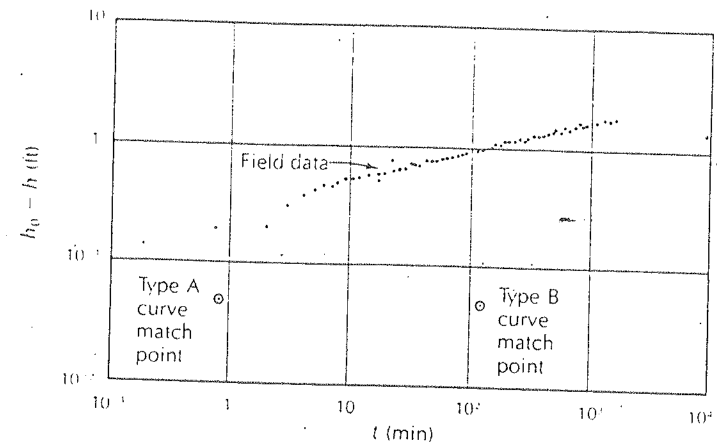


FIGURE 8.19. Field data for example problem of analysis of aquifer test for an unconfined aquifer.

8.7 STEADY-STATE RADIAL FLOW

Prior to the development of the Theis nonequilibrium formula, people doing well analysis assumed a condition of steady flow. That is, the drawdown rate in the pumped well was assumed to be so low as to be essentially zero. This assumption is valid for both nonleaky artesian and water-table aquifers if a long period of time has elapsed since the start of pumping (41). For nonleaky artesian aquifers, the appropriate equation is

$$T = \frac{Q}{2\pi(h_2 - h_1)} \ln(r_2/r_1) \tag{8-55}$$

where

Q is the pumping rate

h_1 is the head at distance r_1 from the pumping well

h_2 is the head at distance r_2 from the pumping well

For an unconfined aquifer,

$$K = \frac{Q}{\pi(h_2^2 - h_1^2)} \ln(r_2/r_1) \tag{8-56}$$

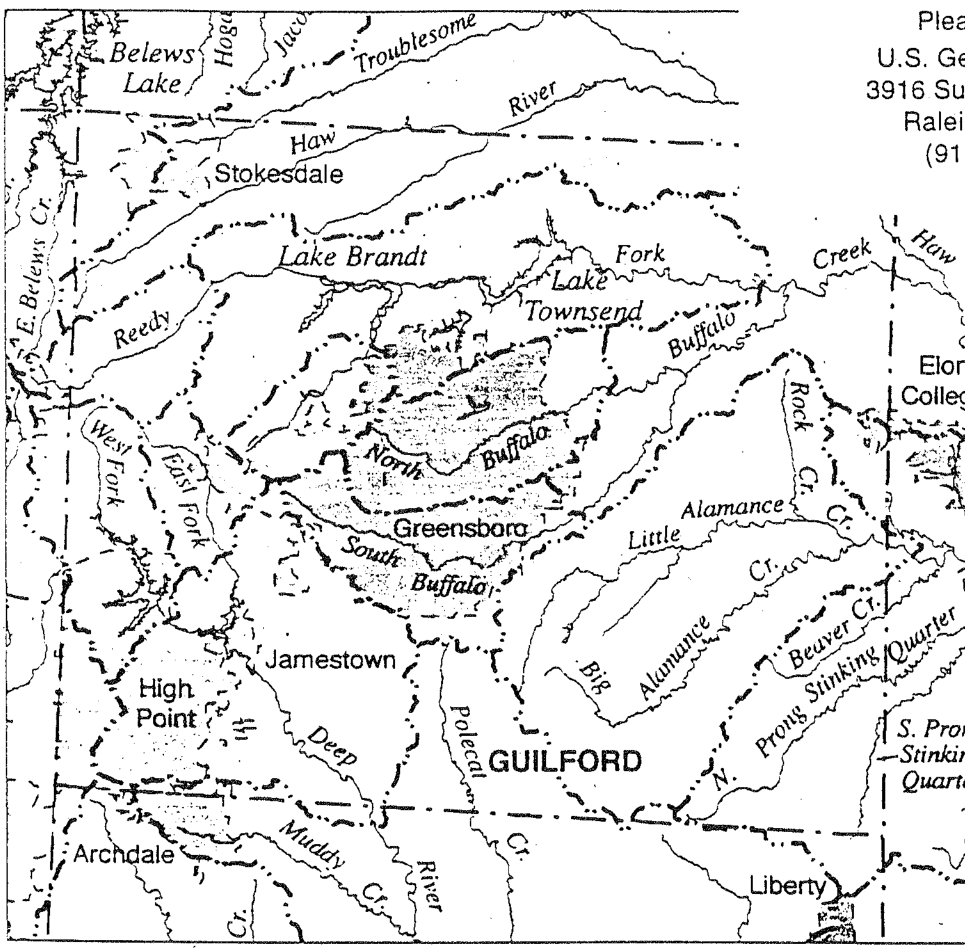
To find values of T or K from steady-state equations, there must be at least two observation wells at different distances from the pumping well. The well must be pumped long enough for the drawdown to approach a steady-state condition.

The usefulness of steady-state analysis is limited, as values of storativity or specific yield are not obtained. However, transmissivity or hydrau-

USGS
science for a changing world

GROUND-WATER RECHARGE TO AND STORAGE IN THE REGOLITH-FRACTURED CRYSTALLINE ROCK AQUIFER SYSTEM, GUILFORD COUNTY, NORTH CAROLINA

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 97-4140



Prepared in cooperation with
Guilford County Health Department and
Guilford Soil and Water Conservation District

U.S. Department of the Interior

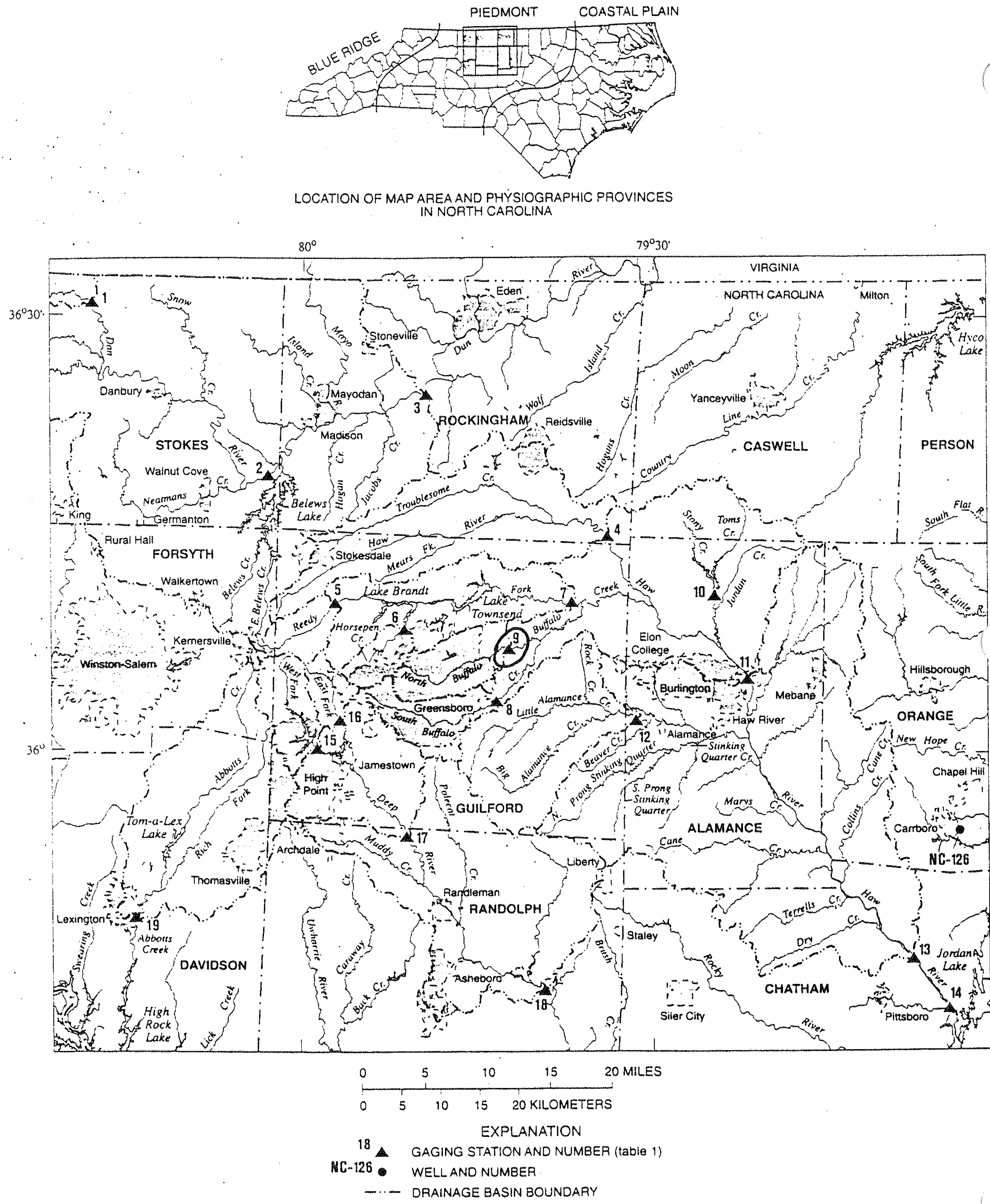
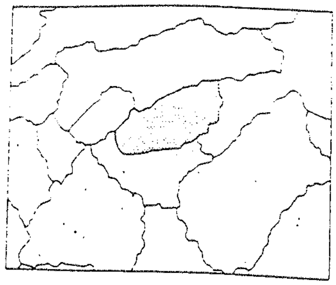


Figure 1. Regional setting of the Guilford County study area in the Piedmont physiographic province of North Carolina, selected drainage basins, and locations of gaging stations used in the ground-water recharge analysis.

North Buffalo Creek Basin



The North Buffalo Creek Basin is the 37.1-mi^2 area that lies upstream from gaging station 02095500 (site 9, fig. 1) near Greensboro, N.C. North Buffalo Creek originates in central Guilford County within the city of Greensboro, N.C., and flows in a northeasterly direction until it is joined by South Buffalo Creek to form Buffalo Creek. Buffalo Creek continues into northeastern Guilford County where it joins Reedy Fork. The area within the North Buffalo Creek Basin upstream from station 02095500 is 6 percent of the land area of the county.

Discharge records for gaging station 02095500 were analyzed by hydrograph separation to produce daily estimates of recharge for the 62-year period between 1929 and 1990. Station 02095500 was discontinued in 1990 (table 1). Wastewater was discharged into North Buffalo Creek upstream of the gaging station during this period and contributed to total streamflow; however, records of wastewater discharge are unavailable and no adjustment has been made to the recharge estimates. Thus, the estimates of recharge are probably somewhat higher than would have been obtained for natural conditions. The daily estimates of recharge were further analyzed to produce the results presented in tables 18 and 19 and figure 14. Annually, estimated mean recharge in the North Buffalo Creek Basin is 9.69 in., or 723 (gal/d)/acre. The median recharge is 681 (gal/d)/acre. Monthly mean recharge varies seasonally as shown in table 18 and figure 14.

Table 18. Statistical summary of recharge estimates for the North Buffalo Creek Basin upstream from station 02095500 near Greensboro, N.C.

A. Annual recharge, in inches per year

Number of years	Mean	Standard deviation	Minimum	Maximum	Percent of total runoff
62	9.69	2.60	4.62	14.68	47.2

B. Monthly recharge, in gallons per day per acre

Month	Number of months	Mean	Minimum	Maximum
October	62	536	133	1,140
November	62	604	174	1,140
December	62	740	227	1,440
January	62	902	325	1,530
February	62	1,020	385	1,880
March	62	1,020	519	1,750
April	62	899	399	1,540
May	62	707	310	1,570
June	62	609	190	1,280
July	62	561	171	1,200
August	62	556	136	1,130
September	62	522	174	1,070
All months	744	723	133	1,880

Table 19. Ground-water recharge duration statistics for the North Buffalo Creek Basin upstream from station 02095500 near Greensboro, N.C.

Recharge, in gallons per day per acre, that was equaled or exceeded for indicated percentage of time

Percent of time	Recharge (gal/d)/acre	Percent of time	Recharge (gal/d)/acre	Percent of time	Recharge (gal/d)/acre	Percent of time	Recharge (gal/d)/acre
0	4,760						
1	1,880	26	871	51	674	76	486
2	1,620	27	861	52	666	77	472
3	1,480	28	848	53	657	78	463
4	1,390	29	844	54	653	79	451
5	1,330	30	830	55	650	80	437
6	1,280	31	817	56	640	81	436
7	1,230	32	817	57	632	82	420
8	1,200	33	803	58	626	83	408
9	1,170	34	790	59	623	84	399
10	1,140	35	789	60	612	85	382
11	1,110	36	778	61	602	86	379
12	1,090	37	768	62	599	87	363
13	1,060	38	762	63	594	88	354
14	1,050	39	755	64	585	89	341
15	1,030	40	746	65	575	90	328
16	1,010	41	735	66	572	91	318
17	988	42	734	67	564	92	303
18	974	43	725	68	555	93	295
19	956	44	716	69	545	94	276
20	946	45	708	70	544	95	262
21	929	46	708	71	532	96	239
22	920	47	700	72	522	97	219
23	903	48	690	73	517	98	198
24	893	49	681	74	504	99	169
25	880	50	681	75	490	100	92.6

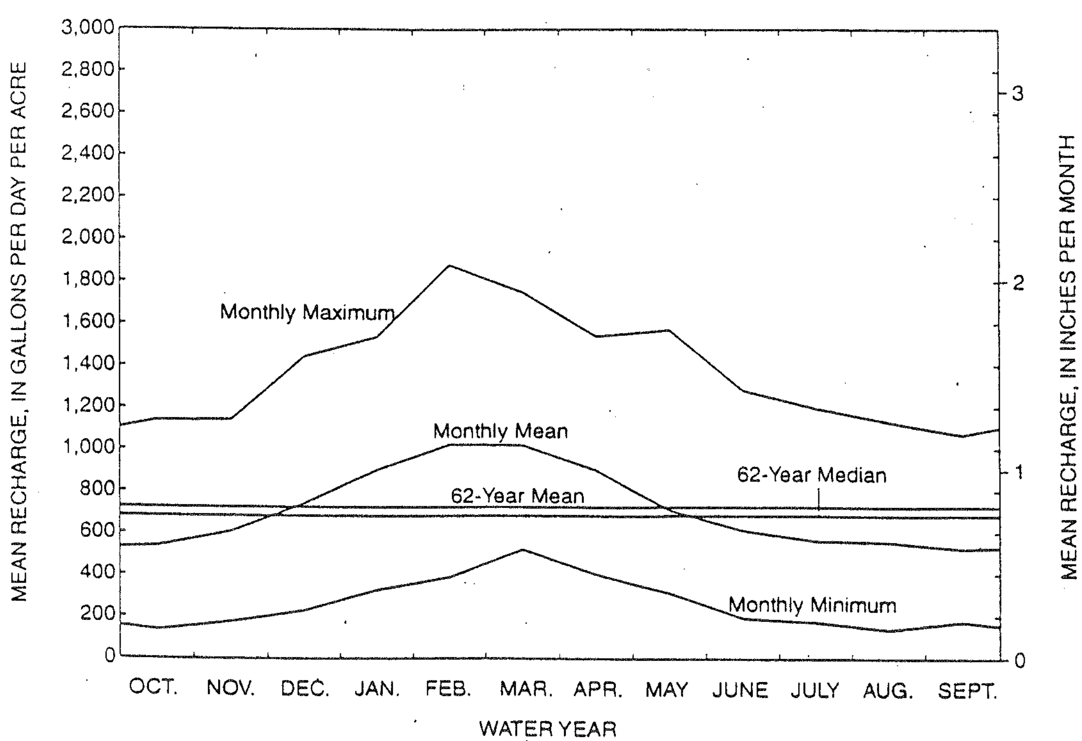


Figure 14. Variation of monthly mean ground-water recharge in the North Buffalo Creek Basin upstream from station 02095500 near Greensboro, N.C.

Comparison of Basins

Ground-water recharge in 15 Guilford County drainage basins and subbasins is compared in figure 22. The box plots summarize the recharge duration characteristics of the 15 basins and subbasins. Recharge rates that will be equaled or exceeded 90-, 75-, 50-, 25-, and 10-percent of the time are shown. The mean ground-water recharge also is shown for comparison to the duration characteristics.

Mean ground-water recharge in the 15 drainage basins and subbasins ranges from 4.03 in/yr

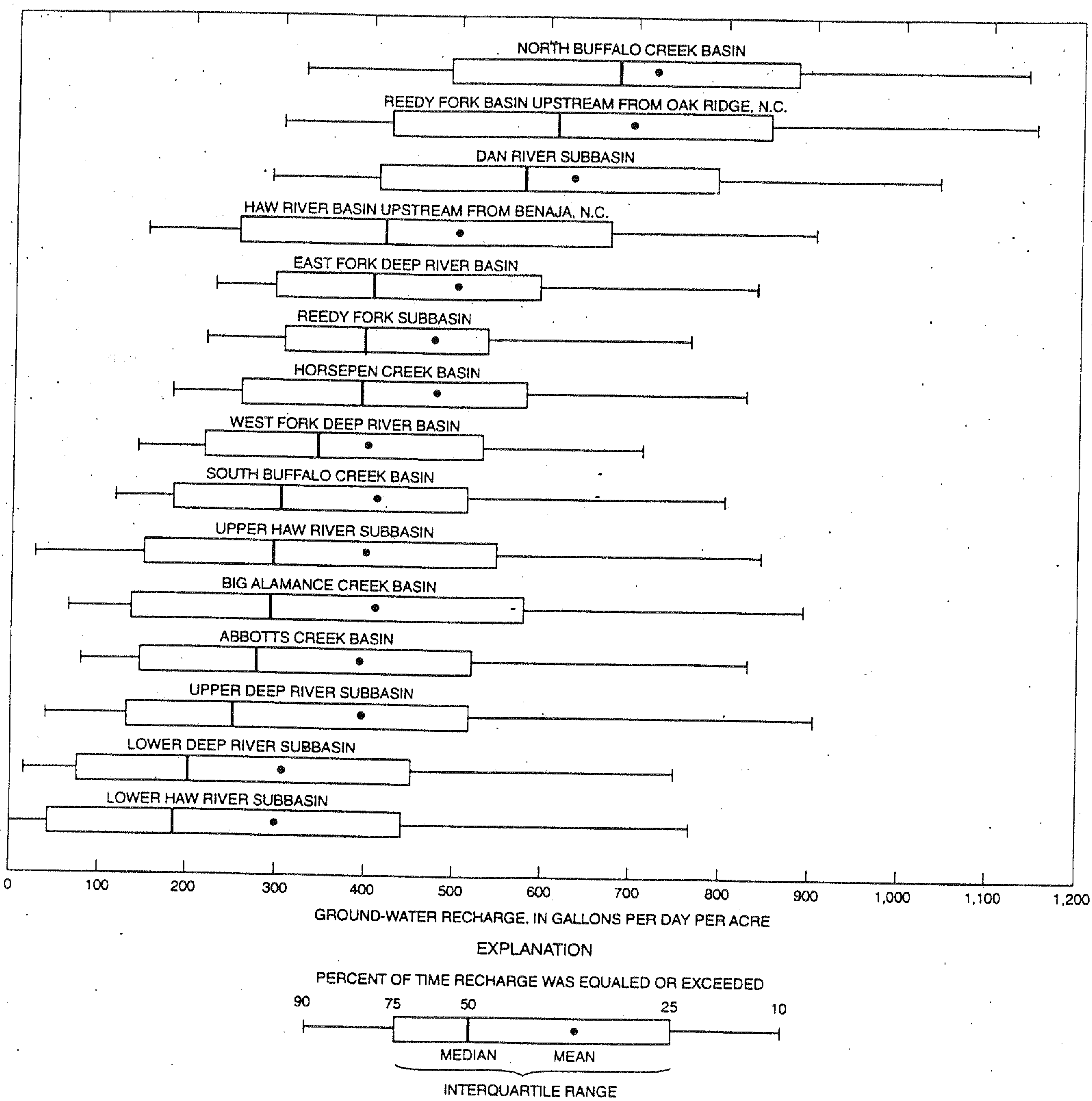


Figure 22. Box plots showing selected ground-water recharge duration characteristics and mean recharge in 15 basins and subbasins in Guilford County, N.C.

(302 (gal/d)/acre) in the lower Haw River subbasin to 9.69 in/yr (723 (gal/d)/acre) in the North Buffalo Creek Basin. The mean recharge for the 15 basins is 6.28 in/yr (469 (gal/d)/acre). In general, recharge rates are highest for basins in the northern and northwestern parts of the county and lowest in the southern and southeastern parts of the county.

Median ground-water recharge (recharge that will be equaled or exceeded 50-percent of the time) in the 15 drainage basins and subbasins ranges from 2.47 in/yr (184 (gal/d)/acre) in the lower Haw River subbasin to 9.15 in/yr (681 (gal/d)/acre) in the North Buffalo Creek Basin. The median recharge for the 15 basins is 4.65 in/yr (346 (gal/d)/acre).

The distribution of recharge rates in the county suggests a correlation between recharge rates and hydrogeologic units (and derived regolith). Although none of the 15 basins and subbasins that were studied are sufficiently small to characterize recharge rates according to individual hydrogeologic units, several basins are underlain predominantly by one hydrogeologic unit and some basins are underlain by no more than two. Recharge rates also depend on other factors which vary from basin to basin. An important factor is the infiltration capacity of the soil which depends not only on soil properties derived from weathering of the bedrock, but on land use and land cover. When land use and land cover are considered independent of other factors, the highest recharge rates and infiltration capacities are in forested areas; the lowest are in urban areas. Agricultural land uses typically are intermediate. Topography is also important, because gentle slopes reduce runoff rates and allow more time for infiltration.

Nearly all of Guilford County is underlain by hydrogeologic units consisting of igneous and metaigneous rocks of several types. MIF (metaigneous, felsic), MII (metaigneous, intermediate), and IFI (igneous, felsic intrusive) predominate (fig. 4; table 2). More than half (63 percent) of the county is underlain by metaigneous rocks which have similar weathering properties, and more than a fifth (22 percent) of the county is underlain by intrusive igneous rocks of felsic composition. The remainder of the county (15 percent) is underlain by metasedimentary and metavolcanic rocks of various types. The occurrence of IFI is limited exclusively to a single large plutonic body that underlies much of the northwestern third of the county; nearly all of the metaigneous rocks occur southeast of this pluton (fig. 4).

Recharge estimates for the North Buffalo Creek Basin, Reedy Fork basin upstream from Oak Ridge, and Dan River subbasin, are higher than any other basin or subbasin in Guilford County. Ground water also constitutes a higher percentage of total streamflow in Reedy Fork upstream from Oak Ridge (60.7 percent), and the Dan River subbasin (59.7 percent), than in any other streams in the county. Four other basins, Haw River upstream from Benaja, East Fork Deep River, Reedy Fork subbasin, and Horsepen Creek, have similarly high recharge estimates. Six of these seven basins and subbasins generally lie to the north and northwest of an imaginary line that extends from the northeast corner of Guilford County to the southeast corner of Forsyth County. The seventh basin, North Buffalo Creek, is crossed by this imaginary line, but generally lies southeast of the line. The presence of large areas of regolith derived from the IFI (igneous, felsic intrusive) hydrogeologic unit may explain the high recharge estimates (base-flow rates) in the six basins and subbasins northwest of this line. This unit tends to weather deeply and produce a deep, sandy, porous regolith with high infiltration capacity. The soil and saprolite resulting from the weathering of IFI is typically light colored and sandy, and is classified in the Cecil-Madison soil association (U.S. Department of Agriculture, 1977). However, most of the North Buffalo Creek Basin is underlain by MIF (metaigneous, felsic) and the remainder is underlain by MII (metaigneous, intermediate); none of the basin is underlain by IFI. The high recharge estimate for the North Buffalo Creek Basin may be due to reported, but unaccounted for, wastewater discharges upstream of station 02095500 (U.S. Geological Survey, 1929–90).

North Buffalo Creek and South Buffalo Creek are in adjacent basins and both are underlain by MIF and MII, yet the estimated annual recharge in the North Buffalo Creek Basin is 4.18 in/yr higher than the annual recharge in South Buffalo Creek Basin (5.51 in/yr). The 4.18 in/yr difference is equivalent to 11.4 ft^3/s. It is possible that this is due to the contribution of wastewater discharges to total streamflow. Although the rate of wastewater discharges to North Buffalo Creek is unknown, some indication of the amount of water used in Greensboro can be had from the reported diversions of water from reservoirs on Reedy Fork. Beginning in 1935, annual diversions from Lake Brandt were reported to be 8.1 ft^3/s; by 1990, the last year of discharge measurements at station 0209550, total annual diversions from Lake Brandt and Lake Townsend (diversions from Lake Townsend began in 1970) had increased to 51.7 ft^3/s (U.S. Geological Survey). For the period between 1929 and 1990 (the 62-year period of streamflow records used for recharge estimates), the average diversion from reservoirs on Reedy Fork for water supply was 24.0 ft^3/s. If only half of this water was returned as treated wastewater to North Buffalo Creek, the high recharge estimate could be explained. On the other

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DETERMINING THE PERMEABILITY OF WATER-TABLE AQUIFERS

By C. E. Jacob

ABSTRACT

If the Theis graphical method is used for determining the hydraulic constants of an aquifer under water-table conditions, the observed drawdowns should be corrected for the decrease in saturated thickness. This is especially true if the drawdown is a large fraction of the original saturated thickness, for then the computed coefficient of permeability is highly inaccurate if based on observed, rather than corrected, water levels.

Wenzel's limiting formula, a modification of the Theis graphical method, is useful where $u=r^2S/4Tt$ is less than about 0.01. However, a shorter procedure for determination of the coefficient of transmissibility, as well as the coefficient of storage, consists of plotting the values of the corrected drawdowns against the values of the logarithm of r.

Wenzel (1942) suggested that observation wells be situated on lines that extend upgradient and downgradient from the pumped well. However, a detailed analysis of aquifer-test results indicates that such a restriction is unnecessary.

The gradient method for determining permeability should yield the same results as the Thiem method. The former, when applied for a distance within the range of applicability of the latter, is merely a duplication of effort or, at best, a crude check. Because of the limitations of accuracy in plotting, the gradient method is much less satisfactory. That Wenzel (1942) obtained identical results from the two methods is regarded as a coincidence.

Failure to take into consideration the fact that the pumped well does not tap the full thickness of the aquifer leads to an apparent coefficient of permeability that is much too low, especially if the aquifer consists of stratified sediments. The average coefficient of permeability computed from uncorrected drawdowns may be only a little more than half of the true value.

THE THEORY OF PERMEABILITY

Formulas for the steady radial flow of water toward a well that taps the full thickness of an unconfined sand are based upon the premise, originally set forth by Dupuit (1863), that for low water-table gradients the average of the horizontal, or radial, velocity in a vertical section is proportional to the slope of the water table $(\partial h/\partial r)$—that is

$$v=-k(\partial h/\partial r).$$

The horizontal component of velocity at the water table actually is equal to $-k(\partial h/\partial r)/[1+(\partial h/\partial r)^2]$ but, for slopes that are very small in comparison to unity, the $(\partial h/\partial r)^2$ in the denominator becomes insignificant. If the small vertical components are neglected, all flow lines in a given vertical plane through the well can be assumed to be both parallel and horizontal; consequently, the distribution of vertical pressure is hydrostatic or, in other words, the head in a vertical section is uniform. Therefore, the horizontal component of the velocity in a vertical section is also uniform and equals the horizontal component at the free surface, or water table. The time rate of flow per unit width normal to the flow is then $-kh(\partial h/\partial r)$.

In the immediate vicinity of a pumped well that taps the full thickness of an unconfined aquifer, the slope of the water table is steep and the foregoing relations obviously do not pertain. At distances where the flow toward the well has not yet become steady, the water table is declining at radially differential rates—that is, the slope of the water table is changing with time—and again the above relations do not pertain. When applying the theory of Dupuit, these limiting distances should be approximated.

Between the two limits, Dupuit's assumption is valid. Inasmuch as the flow is steady, the inward flow of water through a cylindrical surface concentric with the well equals the discharge of the well, or

$$Q=2\pi krh(\partial h/\partial r). \tag{1}$$

Separating the variables and integrating between r_1 and r_2, which are both within the limiting distances,

$$h_2^2-h_1^2=(Q/\pi k)\log_e(r_2/r_1) \tag{2}$$

If one integration limit is considered to be fixed and the other moving, this equation defines, to a sufficient approximation, the lowered water table in the annular area, concentric with the well, over which Dupuit's assumption is valid.

Solving equation 2 for k gives

$$k=\frac{Q\log_e(r_2/r_1)}{\pi(h_2^2-h_1^2)}. \tag{3}$$

An equivalent expression was first used by Thiem about 1906 to determine the permeability of an aquifer from drawdowns in two observation wells near a pumped well (Wenzel, 1936). Principally through the work of Wenzel, this equation has had widespread application in this country. To minimize errors of observation as well as errors arising from inhomogeneities of structure, Wenzel has advocated using many observation wells spaced systematically on lines radiating from the pumped well, preferably in upgradient and downgradient directions; then from a modification of Thiem's equation known as the limiting formula, an effective average permeability is determined graphically from drawdowns observed at several points on the two opposing radii. The same result might be obtained more directly, however, by plotting values of h^2 against $\log_{10}r$. If the equation is a valid engineering approximation, the graph should yield a straight line and the value of k can be determined from the slope of the straight line and Q.

Often the results of an aquifer test are desired in terms of the coefficient of transmissibility (T) of the water-bearing material. The coefficient of transmissibility is the product of k, which can be determined graphically from Thiem's relation or from Wenzel's limiting formula and the original saturated thickness, m, which is assumed to be uniform when the water table is in its undisturbed position. A graph of the values of the drawdown, corrected as indicated in the following pages, plotted against corresponding values of $\log_{10}r$ gives T directly, again by the straight-line method. A graph of this kind permits visualization of the distribution of drawdown and of the approximate limits of usefulness of the related linear mathematical expression. Moreover, it is useful in comparing methods involving steady-state drawdowns with those involving nonsteady-state drawdowns and in justifying application of the theory of nonsteady flow in a confined aquifer of uniform transmissibility to water-table aquifers wherein the thickness of saturated material diminishes appreciably. In fact, as will be seen in the following pages, only after such corrections have been made can the graphical procedure of Theis reasonably be applied to nonsteady-state drawdowns.

THEIS GRAPHICAL SOLUTION USING CORRECTED DRAWDOWNS

From equation 3 above,

$$T=\frac{Q\log_e(r_2/r_1)}{2\pi(h_2^2-h_1^2)/2m}=\frac{2.30\,Q\log_{10}(r_2/r_1)}{2\pi\left[\left(\frac{h_2^2}{2m}+\frac{m}{2}\right)-\left(\frac{h_1^2}{2m}+\frac{m}{2}\right)\right]}.$$

Substituting $s=m-h$ in this relation gives

$$T=\frac{2.30\,Q\log_{10}(r_2/r_1)}{2\pi[(h_2+s_2^2/2m)-(h_1^2+s_1^2/2m)]},$$

or

$$T=\frac{2.30\,Q\log_{10}(r_2/r_1)}{2\pi[(s_1-s_1^2/2m)-(s_2-s_2^2/2m)]},\qquad(4)$$

where $s-s^2/2m$ is the corrected drawdown.

If the corrected drawdown is replaced by

$$s' = s - (s^2/2m) = m - (h + s^2/2m), \tag{5}$$

where
s' is the drawdown that would occur in an equivalent confined aquifer, then

$$T = \frac{2.30\ Q \log_{10}(r_2/r_1)}{2\pi(s_1' - s_2')}. \tag{6}$$

Equation 6 is an expression in terms of the drawdown, s', for the coefficient of transmissibility of a confined aquifer of uniform thickness. To solve equation 6, and hence equation 4, graphically, plot values of s' against corresponding values of $\log_{10} r$ and find the slope of the straight-line plot. If $\Delta s' = s_1' - s_2'$ is taken as the change in drawdown over one log cycle, then $\log_{10}(r_2/r_1) = 1$. and

$$T = \frac{2.30\ Q}{2\pi \Delta s'}. \tag{7}$$

The nonsteady flow of water toward a well that taps the full saturated thickness and that discharges at a constant rate from an extensive aquifer of constant transmissibility obeys the relation

$$Q = 2\pi r T(\partial s/\partial r) + \int_0^r S(\partial s/\partial t)\, 2\pi r dr, \tag{8}$$

where S is in the coefficient of storage (Jacob, 1940, p. 579). When the time rate of change of drawdown $(\partial s/\partial t)$ becomes small in relation to its rate of change with distance, equation 8 reduces to equation 1, which applies to steady radial flow. The integration of equation 8 yields

$$s = \frac{Q}{4\pi T} W(u)$$

$$= \frac{Q}{4\pi T}\left(-0.5772 - \log_e u + u - \frac{u^2}{2\cdot 2!} + \cdots\right), \tag{9}$$

where

$$u = \frac{r^2 S}{4Tt}.$$

For small values of u (that is, when r is small or t is large), equation 9 can be approximated by

$$s = \frac{Q}{4\pi T}\left(\log_e \frac{4Tt}{r^2 S} - 0.5772\right). \tag{10}$$

When t is constant, this is the equation for the straight line (on semi-logarithmic coordinates) in equation 6. After T is determined from the slope of the straight line, S can be determined from the intercept, r_e, on the r-axis (or the log r-axis). At that point $s=0$; hence

$$\frac{r_e^2 S}{4Tt}=e^{-0.5772}=0.562,$$

from which

$$S=4 \cdot 0.562\,\frac{Tt}{r_e^2}. \tag{11}$$

Wenzel designated equation 9 as the nonequilibrium formula. It is a particular solution of the general second-order differential equation and is but one of a great many particular solutions for different limiting conditions. The given limiting conditions are that the discharge of the well is constant, that the initial drawdown (referred to the undisturbed piezometric surface) is everywhere zero, and that the flow across the upper and lower bounding planes of the aquifer is everywhere negligible.

Equation 9 is a valid engineering approximation of the actual flow only where T is virtually constant. This condition is satisfied in a confined homogeneous bed of approximately uniform thickness or in an unconfined homogeneous bed wherein the drawdowns are small compared to the initial thickness of saturated material. The nonequilibrium method, or graphical procedure of solving the exponential-integral relation for T and S from observations of the variation of s with t or with r, was devised by Theis (Jacob, 1940, p. 582).

When the drawdown is a large fraction of the initial saturated thickness, the need for correcting the drawdown before applying the nonequilibrium method can be demonstrated by using data from an aquifer test conducted by S. W. Lohman near Wichita, Kans. (Wenzel, 1942, p. 142). Both the observed and corresponding corrected drawdowns in 6 wells after 18 days of continuous pumping at 1,000 gpm, or 1,440,000 gpd, are given in table 1, and both are plotted against r in figure 72 and against r^2 in figure 73. The average of the 18-day observed drawdowns in the corresponding observation wells along the north and south lines gives $T=120{,}000$ gpd per foot and $S=0.47$ by both the straight-line method (fig. 72) and the Theis graphical method (fig. 73), whereas the average of the 18-day corrected drawdowns in the same observation wells gives $T=154{,}000$ gpd per ft and $S=0.35$ by the same two methods. The average thickness of saturated material at the test site at the beginning of the test was 26.8 feet and after the 18-day period of pumping was 22.3 feet.

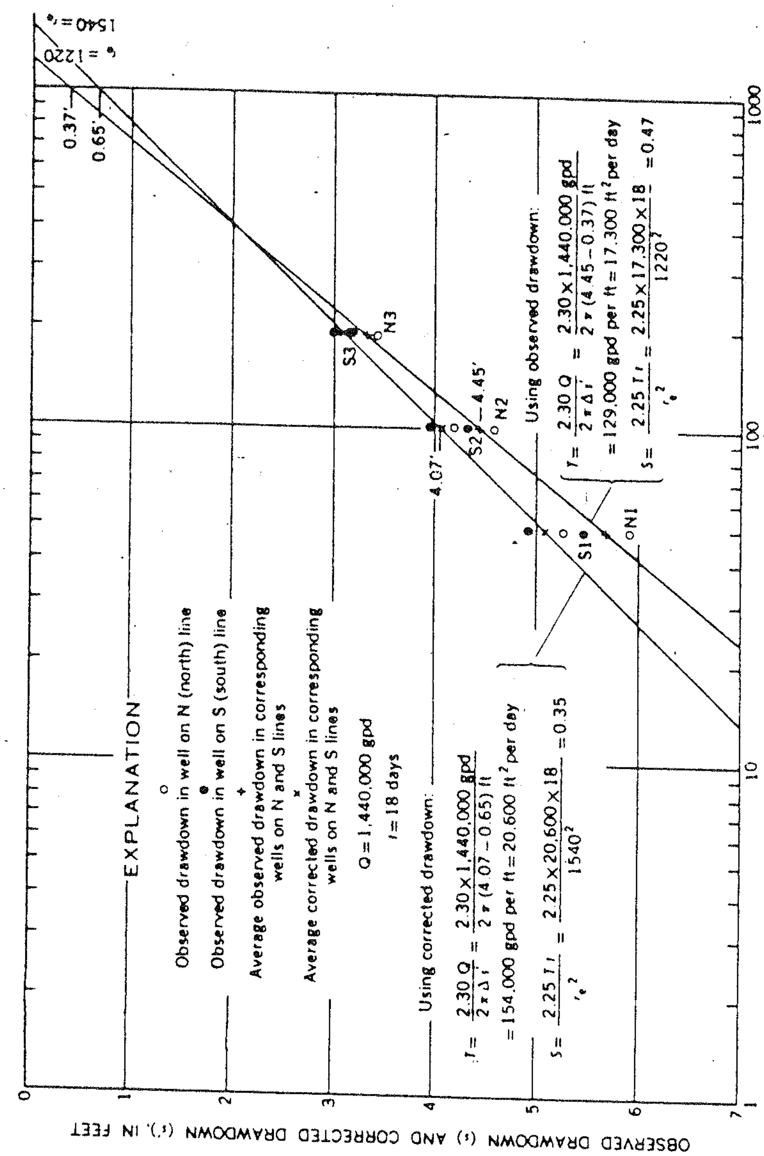

FIGURE 72.—Semilog graph of water-level drawdown during aquifer test near Wichita, Kans.

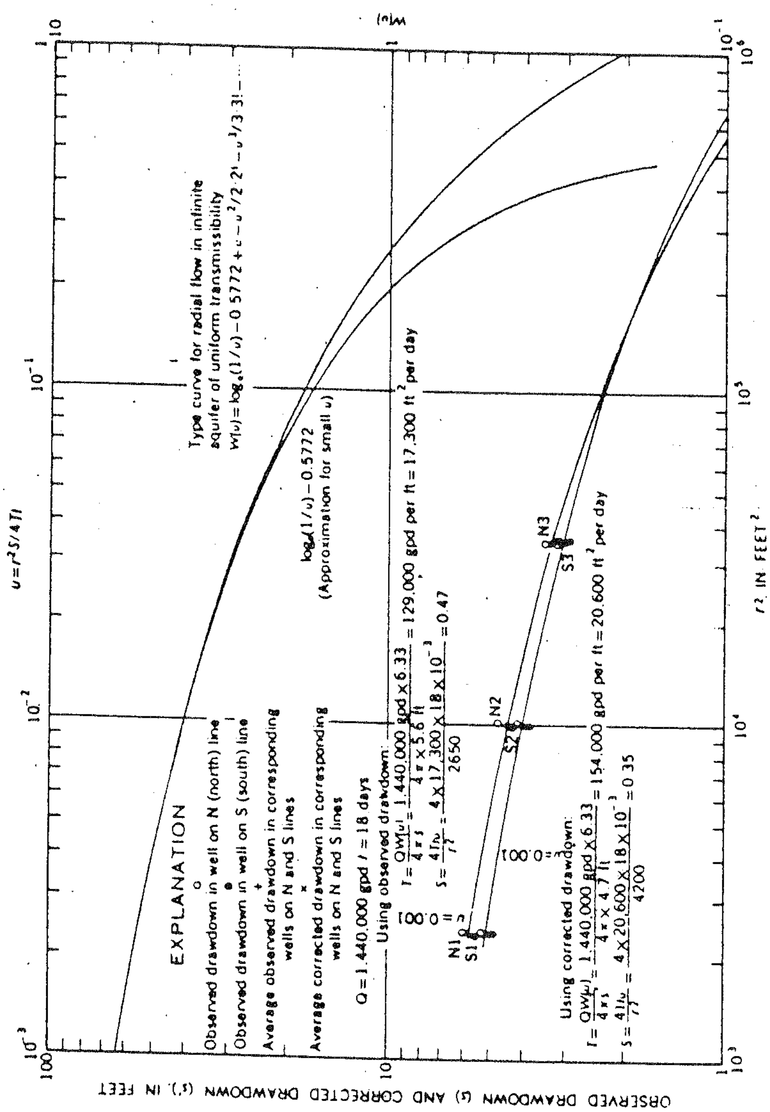

FIGURE 72.—Log graph of water-level drawdown during aquifer test near Wichita, Kans.

TABLE 1.—*Data for aquifer test near Wichita, Kans., giving drawdowns after 18 days of continuous pumping at 1,000 gpm*

Well	Distance from pumped well, r (ft)	r^2 (ft²)	Observed drawdown, s (ft)	$s^2/2m$ (ft)	Corrected drawdown, s' (ft)	Ratio of observed to corrected drawdown
Line extending north from pumped well						
1	49. 2	2, 420	5. 91	0. 65	5. 26	1. 12
2	100. 7	10, 140	4. 58	. 39	4. 19	1. 09
3	189. 4	35, 900	3. 42	. 22	3. 20	1. 07
Line extending south from pumped well						
1	49. 0	2, 400	5. 48	0. 56	4. 92	1. 11
2	100. 4	10, 080	4. 31	. 35	3. 96	1. 09
3	190. 0	36, 100	3. 19	. 19	3. 00	1. 06

That the two procedures (the straight-line method and the Theis graphical method) should give identical results for the test near Wichita is clear from figure 73. The approximation for u, upon which the straight-line plotting is based, does not differ by any significant amount from the type curve within the range of values of u that is involved. In this and similar instances, the nonequilibrium method becomes an equilibrium method and the two procedures should check each other within the limits of accuracy of plotting. Therefore, in the analysis of aquifer-test data, the straight-line method should be used to determine whether the flow is steady or nonsteady over the range of the distances involved. If the flow is found to be steady, the straight-line method suffices for determination of the hydraulic constants, but if the flow is found to be nonsteady, the Theis graphical method needs to be applied.

Dividing the value of T obtained from the corrected drawdowns by the initial thickness of saturated material, $m=26.8$ feet, gives $k=5{,}750$ gpd per sq ft, which agrees reasonably with Wenzel's $P=5{,}787$ gpd per sq ft. The value $S=0.47$, which was determined from the uncorrected drawdowns, is believed to be about 0.18 too high because the value $S=0.35$, obtained from the corrected drawdowns, is only an approximation and becomes even smaller when corrected further for the reduction in saturated thickness. The corrected drawdowns used in determining $S=0.35$ were those that would have occurred in a confined aquifer having similar hydrologic properties and a thickness equal to the initial thickness of saturated material in the water-table aquifer. In order to determine the average coefficient of storage more closely, the above determined value may be multiplied by the average ratio of the final to the initial saturated thickness. The theoretical justification of this procedure follows.

The second-order differential equation governing the radial flow of water in an unconfined aquifer is

$$kh[(\partial^2 h/\partial r^2)+(1/r)(\partial h/\partial r)]=S(\partial h/\partial t). \quad (11a)$$

Substituting $(m-s)$ for h gives

$$k(m-s)[(\partial^2 s/\partial r^2)+(1/r)(\partial s/\partial r)]=S(\partial s/\partial t), \quad (11b)$$

which can be expressed in terms of the corrected drawdown, s' rather than the actual drawdown, s, by determining the relationships between their respective differential coefficients. From

$$s'=s-(s^2/2m),$$
$$\partial s'/\partial r=[(m-s)/m](\partial s/\partial r) \quad (11c)$$

and

$$\partial^2 s'/\partial r^2=[(m-s)/m](\partial^2 s/\partial r^2)-(1/m)(\partial s/\partial r)^2. \quad (11d)$$

For low water-table gradient—values of $(\partial s/\partial r)^2$ small in comparison with $m(\partial^2 s/\partial r^2)$—the last term of equation 11d can be omitted and the equation becomes

$$\partial^2 s'/\partial r^2=[(m-s)/m](\partial^2 s/\partial r^2). \quad (11e)$$

The third relation required is

$$\partial s'/\partial t=[(m-s)/m](\partial s/\partial t). \quad (11f)$$

Making the substitutions indicated by equations 11c, 11e, and 11f in equation 11b gives

$$km[(\partial^2 s'/\partial r^2)+(1/r)(\partial s'/\partial r)]=[m/(m-s)]S(\partial s'/\partial t), \quad (11g)$$

which can be rewritten

$$T[(\partial^2 s'/\partial r^2)+(1/r)(\partial s'/\partial r)]=S'(\partial s'/\partial t), \quad (11h)$$

where

$$T=km$$

is the initial transmissibility and

$$S'=[m/(m-s)]S$$

is the apparent coefficient of storage.

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If the variation of s is small in comparison with m, S' may be considered essentially constant, and the integration of equation 11h gives equation 9, in which s is replaced by s' and S by S' as one solution. By application of the graphical method of Theis to the corrected drawdowns (s'), the values of T and S' can be determined; the approximate average coefficient of storage is then

$$S = [(m - s)/m]S'. \tag{11i}$$

In the test near Wichita, the initial saturated thickness was 26.8 feet; the drawdown averaged over the logarithm of the distance 50 to 200 feet—that is, the drawdown at the geometric mean distance, 100 feet—was 4.5 feet; and hence S' was found to be 0.35. Therefore,

$$S = [(26.8 - 4.5)/26.8]0.35 = 0.3$$

instead of 0.47, as determined from the observed drawdowns. This is only an approximate spatial average (at a fixed time) of a coefficient of storage that varies not only with distance from the pumped well but also with time. Even if the coefficient of storage were invariable, its true value could not be determined precisely by this application, to an unconfined aquifer, of the theory of nonsteady flow in an aquifer of uniform transmissibility.

WENZEL'S LIMITING FORMULA

For the aquifer test near Wichita, Kans., Wenzel's limiting formula gives $P_f = 5{,}805$ gpd per sq ft, which does not differ significantly from the value obtained by the corrected drawdown methods in figures 72 and 73. The steps involved in the application of Wenzel's limiting formula and in the straight-line method are described below.

Wenzel's limiting formula:

1. Tabulate well numbers, distances, and observed drawdowns.
2. Plot the water-level data on graph paper having rectangular coordinates, and draw smooth curves through the points.
3. Determine values of drawdown from these curves for equal but opposite radii, preferably upgradient and downgradient from the well, and tabulate, for several different pairs of radii, values of B (half the difference in the averages of the upgradient and downgradient drawdowns).
4. Determine the average thickness of saturated material upgradient and downgradient between the same pairs of radii, and divide the logarithm of the corresponding ratios of outer to inner radii by these values. The resulting quotients are values of A.
5. Plot each value of A against the corresponding value of B, draw a straight line through the plotted points and the origin, and from the slope of that line determine P_f (or k).

Appendix D

SPECIFICATIONS

SECTION 02276
SOIL LINER SYSTEM

PART 1 - GENERAL

1.1 SUMMARY

A. Section Includes:
   1. Soil used in the containment system.

B. Related Sections include but are not necessarily limited to:
   1. Section 02110 - Site Clearing.
   2. Section 02220 - Earthwork.
   3. Section 02775 – HDPE Geomembrane Liner Systems.
   4. Section 02800 - Geosynthetic Clay Liner.
   5. Construction Quality Assurance Plan.

1.2 QUALITY STANDARDS

A. Reference Standards:
   1. ASTM - American Society for Testing and Materials:
      a. ASTM D-422 - Particle Size Analysis.
      b. ASTM D-698 - Standard Proctor.
      c. ASTM D-854 - Specific Gravity.
      d. ASTM D-1140 - Fines Content in Soils.
      e. ASTM D-1556 - In-situ Density Measurement Using the Sand Cone.
      f. ASTM D-1557 - Modified Proctor.
      g. ASTM D-2166 - Unconfined Compressive Strength.
      h. ASTM D-2216 - Moisture Content Using Over-Dry Method.
      i. ASTM D-2487 - Soils Classification.
      j. ASTM D-2573 - Field Vane Shear Test.
      k. ASTM D-2922 - In-situ Density Using Nuclear Methods.
      l. ASTM D-3017 - In-situ Moisture Content Using Nuclear Methods.
      m. ASTM D-4318 - Atterberg Limits.
      n. ASTM D-5084 - Flexible Wall permeameter.
   2. USEPA - United States Environmental Protection Agency
      a. EPA/600/R-93/182 -"Quality Assurance and Quality Control for Waste Containment Facilities," September, 1993.
   3. ASCE – American Society of Civil Engineers.
      a. ASCE Paper No. 25333 – Water Content – Density Criteria for Compacted Soil Liners (Daniel et at, 1998).
      b. ASCE Paper No. 23827 – In-Site Hydraulic Conductivity for Compacted Clay (Daniel et at, 1989).
   4. Construction Quality Assurance (CQA) Plan.

1.3 SUBMITTALS

A. See Section 01300 - Submittals.

B. Refer to the CQA Plan.

1.4 JOB CONDITIONS

A. Verify conditions of subgrade prior to commencing work.

1.5 TOLERANCES

A. The soil liner system must meet the following tolerances:
   1. The saturated hydraulic permeability of the soil liner must be equal to or less than 1.0×10^{-5} cm/sec, as determined by ASTM D5084.
   2. The thickness of the soil liner must be equal to or greater than 18 inches. Any excess shall be on the bottom of the layer.
   3. The work should be constructed to lines, grades, and control points indicated on the Drawings, and shall be controlled and documented with survey methods. Laser based survey systems are preferred for grading.
   4. Finished grade tolerance; plus 0.1 FT from required elevation.

PART 2 - PRODUCTS

2.1 MATERIALS

A. Low Permeability Soil - General:
   1. Contractor shall provide natural, fine-grained soil or bentonite amended soil that is capable of being worked to produce a soil layer of thickness shown on the Drawings that meets the hydraulic conductivity requirements.
   2. In accordance with these Specifications, the Contractor is responsible for conducting a borrow soil characterization study (BSCS).
   3. Contractor shall provide the CQA Consultant and Owner access to information about the borrow source of the low permeability soil and certify that it is not contaminated with hazardous materials or hazardous wastes.
   4. The soil shall be relatively homogeneous in color and texture and shall be free from roots, stones, foreign objects, and other deleterious materials.
   5. Some soils not meeting the requirements of B.1. and B.4. below, may be acceptable for use in the Work at the sole discretion of the Engineer. The contractor may submit data on soils for the Engineer's review. For the Engineer to approve the materials, the submittal should contain: a statement signed by a qualified professional Engineer that the proposed soils will meet the hydraulic conductivity requirement and are otherwise suitable for use in the Work; and, supporting geotechnical test results and data.
   6. All soils must be approved for use by the Engineer prior to use in the Work.

B. Natural Fine-Grained Soil
   1. Classification: Natural fine-grained soil shall have a classification of CH, CL, MH, or ML as determined by ASTM D2488.
   2. Grain sizes shall be within the following gradation:

Sieve Size	Percent Passing by Weight
3/4 IN	100
No. 4	> 90
No. 200	> 30

   3. Hydraulic Conductivity: The saturated hydraulic conductivity of the natural fine-grained soil shall meet the stated tolerances, when compacted in accordance with requirements established by the CQC Consultant and Contractor on the basis of the soil liner test strip as specified herein.
   4. Other Soil Liner Properties:
      a. The liquid limit shall be at least 25 as measured by ASTM D4318.
      b. The plasticity index shall be at least 10 and less than 30 as measured by ASTM D4318.

C. Bentonite Amended Soil (where applicable):

1. Hydraulic conductivity of constructed bentonite amended soil shall meet the tolerances when compacted in accordance with requirements established by the CQC Consultant on the basis of test results from the soil liner test strip and the borrow soil characterization study.
2. Soil used in the bentonite amended soil shall be free from roots, organic matter, debris, particles larger than 3/4 IN, and other deleterious material. All soil used in the bentonite amended soil shall be taken from a borrow area approved by the CQC Consultant and Engineer.
3. Unless approved otherwise by the CQC Consultant, the soil used in the bentonite amended soil shall meet the following washed sieve gradation:

Sieve Size	Percent Passing by Weight
¾ IN	100
No. 4	55-100
No. 20	45-75
No. 200	10-40

4. Bentonite:
   a. Bentonite shall be free-flowing, powdered, high-swelling, sodium montmorillonite clay (bentonite) free of additives.
   b. Acceptable bentonite manufacturers are:
      1) American Colloid, Co., (800) 637-6654.
      2) Bentonite Corp., (303) 291-2940.
      3) CETCO, (813) 527-0605.
      4) Federal Industrial, (800) 231-3565.
      5) WYO-BEN, (800) 548-7055.
   c. The Contractor may propose a bentonite supplier other than those listed above if it is demonstrated that its use in the amended soil satisfies the requirements of these Specifications.

D. Permeability Test
1. Laboratory permeability tests (ASTM D-5084) shall be conducted in constant head, triaxial type permeameters. The specimens shall be consolidated under an isotropic effective consolidation stress not to exceed 10 psi. The inflow to and outflow from the specimens shall be monitored with time and the coefficient of permeability calculated for each recorded flow increment. The test shall continue until steady state flow is achieved and relatively constant values of coefficient of permeability are measured.

E. Interface Friction Tests.
1. Test materials using ASTM D 5321. Section 01060. Special Conditions, paragraph 1.13, outlines the conditions under which this material shall be tested.
2. This material is part of a system. The system shall meet the requirements before the component material can be deemed acceptable.
3. The costs associated with this testing shall be included in the Bid price for each material. Any retesting or other additional testing required to meet the Specifications shall be at no additional cost to the Owner.

2.2 SOIL LINER MATERIAL ACCEPTANCE

A. General: All imported, on-site, and processed materials specified in this Section are subject to the following requirements:
1. All tests necessary for the Contractor to locate and define acceptable sources of materials shall be made by the CQC Consultant. Certification that the material conforms to the Specification requirements along with copies of the test results from a qualified commercial testing laboratory shall be submitted to the CQA Consultant for approval at least 10 days before the material is required for use. All material samples shall be furnished by the Contractor at the Contractor's sole expense.

2. All samples required in this Section shall be representative and be clearly marked to show the source of the material and the intended use on the project. Sampling of the material source shall be done by the CQC Consultant in accordance with ASTM D75.
3. Notify the CQA Consultant at least 24 hours prior to sampling so that they may observe the sampling procedures.
4. Tentative acceptance of the material source shall be based on an inspection of the source by the CQA Consultant and the certified test results of the Borrow Source Characterization Study (BSCS) as submitted by the Contractor to the CQA Consultant. No imported materials shall be delivered to the site until the proposed source and materials tests have been accepted in writing by the CQA Consultant.
5. Final acceptance of any material will be based on results of tests made on material samples taken from the completed soil liner test strip, combined with the results of the BSCS. If tests conducted by the CQC Consultant or the CQA Consultant indicate that the material does not meet Specification requirements, material placement will be terminated until corrective measures are taken. Material which does not conform to the Specification requirements and is placed in the work shall be removed and replaced at the Contractor's sole expense.
6. Contractor shall be solely responsible for obtaining all permits required to obtain acceptable sources of materials for use in the work.

B. Sampling and testing required herein shall be done at the Contractor's sole expense.

C. Borrow Source Characterization Study:
1. The Contractor will be responsible for all processing and screening of the soil liner material at his own cost to meet the requirements of the Specifications. The Contractor will be responsible for the erosion protection of the stockpile and borrow area during his operation. The Contractor shall coordinate all aspects of this operation with the CQC Consultant, CQA Consultant, and Project Manager.
2. CQC Consultant shall complete a BSCS of natural fine-grained soils or of soil that will be used in bentonite amended soils.
3. Contractor shall conduct tests, including particle size, Atterberg limits, moisture-density, and hydraulic conductivity tests, as necessary to locate an acceptable source of material.
4. Once a potential source of material has been located, the CQC Consultant shall develop and undertake a testing program to demonstrate the acceptability of the proposed material. Certified results of all tests shall be submitted to the CQA Consultant upon completion of tests. Tentative acceptance of the borrow source by the CQA Consultant will be based upon the results of the study. The testing program shall include the following elements, at a minimum:
   a. An excavation plan for the borrow source indicating proposed surface mining limits and depths of samples to be taken for testing.
   b. Test pits for borrow source sampling shall be appropriately spaced to reflect site geomorphology and sampled at depth intervals appropriate to the proposed excavation methods.
   c. A minimum of 12 samples shall be collected and tested for the parameters required as described in the following paragraphs.
5. Test Parameters and Reporting for Natural Fine-Grained Soils: All samples collected from the proposed borrow area for natural fine-grained soils shall be tested for the following parameters:

Parameter	Test Method
Particle Size (sieve plus hydrometer)	ASTM D422
Atterberg Limits	ASTM D4318
Standard Proctor	ASTM D698
Hydraulic Conductivity(1)	ASTM D5084

1. Dewatering of soil liner borrow excavations, if required, shall be solely at the Contractor's expense.
2. Drying, blending, or wetting required to maintain the soil liner soil at a suitable moisture content shall be solely at the Contractor's expense.

2.3 EQUIPMENT

A. Compaction Equipment:
1. The compaction equipment shall be of a suitable type, adequate to obtain the permeability specified, that provides a kneading action, such as a wobble-wheeled roller or a sheepsfoot roller having tines as long as the maximum loose lift thickness to ensure proper lift interface compaction free of voids.
2. The CQC Consultant shall confirm compaction equipment adequacy, and recommend changes if required, based on the soil liner test strip. Such additional equipment will be provided by Contractor at no additional cost.
3. The compaction equipment shall be maintained and operated in a condition that will deliver manufacturer's rated compactive effort.
4. Hand-operated equipment shall be capable of achieving specified soil densities.
5. The finished surface of the final lift shall be rolled with a smooth steel drum roller or rubber-tired roller to eliminate tine or roller marks and provide a smooth, dense surface for geomembrane placement.

B. Moisture Control Equipment:
1. Equipment for applying water shall be of a type and quality adequate for the work, shall not leak, and shall be equipped with a distributor bar or other approved device to assure uniform application.
2. Equipment for mixing and drying out material shall consist of blades, discs, or other equipment defined by the CQC Consultant as approved by the CQA Consultant.
3. Mixing of natural fine-grained soils may also be required to get even distribution of moisture.
4. Soil liner material must not be compacted within 24 hours of the adjustment of water content by the addition of water.

C. Bentonite Amended Soil Mixing Equipment (where applicable):
1. Contractor shall mix, process, and condition the bentonite amended soil in a pugmill prior to placing and compacting the mixture.
2. The pugmill shall have the capability to break up soil clumps and mix material to form a homogeneous blend. The pugmill shall have controls that allow a variable rate of discharge from it, to control the degree of mixing. The pugmill shall have automated controls to control the rate of feed of each material to within an accuracy of 2 percent by weight.
3. The pugmill discharge shall be equipped with a batching bin having a drop outlet for loading hauling vehicles directly from the pugmill. Pugmill shall be positioned to allow direct discharge to hauling vehicles.
4. Contractor shall not store amended soil in a manner or for a length of time that will cause any degradation of the project or amended soil.

PART 3 - EXECUTION

3.1 SOIL LINER TEST STRIP

A. Test Strip Installation:
1. Prior to actual soil liner installation, a soil liner test strip of a dimension no less than 100 FT long by 30 FT wide by 1.5 FT thick shall be constructed by the Contractor over a compacted subgrade within the liner construction site.

2. The soil liner test strip shall be constructed in 6 IN lifts. The final compacted thickness of each lift shall be a maximum of 6 IN. Prior to placement of successive lifts, the surface of the lift in place shall be scarified or otherwise conditioned to eliminate lift interfaces.
3. The soil liner test strip shall be constructed using the same equipment and construction procedures that are anticipated for use during actual liner installation.
4. During test strip installation, the Contractor in coordination with his CQC Consultant and the CQA Consultant shall determine the field procedures that are best suited for his construction equipment to achieve the requirements specified herein.
5. If the test strip fails to achieve the desired results, the soil material of the strip shall be completely removed, and additional test strip(s) shall be constructed until the requirements are met.
6. The CQC Consultant shall document that the subgrade of the test strip liner is properly compacted to at least 95 percent of the maximum dry density, as determined using the Standard Proctor test (ASTM D-698). Field density tests on the subgrade shall be performed by the CQC Consultant and documented at a minimum of three test locations within the test strip area.
7. At least five field density measurements shall be performed by the CQC Consultant on each lift of the liner test strip. The field density tests shall be conducted using a nuclear gauge (ASTM D-2922) or other method, as approved by the CQA Consultant. Corresponding tests for moisture content to determine dry density shall likewise be performed by using a nuclear gauge (ASTM D-3017), or other approved method. On the test pad, the density measurement if performed by a nuclear gauge shall be verified through performance of one sand cone test (ASTM D-1556) or drive tube test (ASTM D-2937) at a location selected by the CQA Consultant. The moisture content measurement, if performed by a nuclear gauge shall be verified by recovering at least five samples for oven-dry testing (ASTM D-2216) from the test location.
8. A composite sample will be taken from each lift for recompacted lab permeability (ASTM D-5084).
9. Upon completion of the soil liner test strip, the CQC Consultant, as observed by the CQA Consultant, shall measure the thickness of the test strip at a minimum of five random locations.
10. A minimum of five random samples of the liner construction materials delivered to the site during test strip installation shall be tested by the CQC Consultant for moisture content (ASTM D-2216), sieve analyses (ASTM D-421, D-422) and Atterberg limits (ASTM D-4318).
11. The CQC Consultant shall conduct at least one standard Proctor (ASTM D-698) and one modified Proctor (ASTM D-1557) compaction test on bag samples of the test strip material to determine the moisture-density relationships.
12. A minimum of one undisturbed sample shall be taken from each lift of the test strip by the CQC Consultant for laboratory hydraulic conductivity testing. The samples shall be taken within a 2 FT radius of the in-situ density and moisture tests. The CQA Consultant will also conduct at least one confirmatory in-situ hydraulic conductivity testing.
13. The data gathered from the test strip sampling (i.e., field density, moisture, undisturbed samples, and in-situ hydraulic conductivity) shall be used along with the Proctor curve for the soil to develop a range of acceptable moisture and density test values which are likely to be consistent with the required maximum permeability. This range of moisture/density values will be established by the CQC Consultant and the CQA Consultant and will be utilized as a means to establish Pass/Fail Criteria for the area to be lined by the subject material.
14. The test strip will be considered acceptable if the measured hydraulic conductivity of the test strip as determined by ASTM D-5084 meets the requirements of the Specifications.

15. If field and laboratory test data indicate that the installed test strip meets the requirements of this Specification, it may be used as part of the liner provided that it is adequately protected by the Installer from drying and equipment damage after installation. The Installer shall scarify the liner material along the edge of the test strip. A minimum 2 FT overlap per lift is required for mixing and compaction between the test strip and the liner.
16. If the test strip fails to meet Specifications, additional mix designs (if bentonite amended) and/or test strips will be constructed until a test strip meets the requirements. No soil liner may be placed until a test strip has been accepted by the CQA Consultant.
17. Upon receipt of the test data from the CQA Consultant, the Project Manager shall inform the Contractor if the test strip can remain in-place as part of the liner.

3.2 INSTALLATION

A. The subgrade to be lined shall be smooth and free of vegetation, sticks, roots, foreign objects, and debris. It shall be the responsibility of the Contractor to keep the receiving surfaces in the accepted condition until complete installation of the liner is accomplished.

B. The subgrade shall be proofrolled with a pneumatic tired vehicle of at least 20 tons GVW, making passes across the area as directed by the CQC and/or CQA Consultants. The soil liner shall not be placed over areas deemed unacceptable by either the CQC or CQA Consultants based on proofroll observations or inadequate test results.

C. The soil liner shall be installed in 6 IN compacted lifts. The material shall be placed consistent with criteria developed from construction of a satisfactory test strip.

D. When particles exceeding ¾ IN are observed at the final lift surface, they shall be removed by the Contractor prior to final rolling of the surface.

E. Equipment shall be used such that bonding of the lifts will occur. Equipment shall have cleats or other protrusions of such length necessary to completely penetrate into the loose lift. Compaction shall be performed using appropriately heavy, properly ballasted, penetrating foot compactor making a minimum number of passes as approved by the CQC Consultant and CQA Consultant based on the soil liner test strip.

F. If desiccation and crusting of the lift surface occurs prior to placement of the next lift, this area shall be scarified to a minimum depth of 2 IN or until sufficiently moist materials are encountered, whichever is greater. After scarification, the superficial material should be reworked to obtain a moisture content at least 2 percent above optimum moisture content. Alternately, the drier superficial soil may be stripped and mixed with additional moist soil to achieve a moisture content satisfying the project requirements.

G. No frozen material shall be placed.

H. Material shall not be placed on a previous lift which is frozen. Frozen in-place material shall be removed prior to placement of additional soil material.

I. Material which has been subjected to a freeze/thaw cycle(s) shall be disked and recompacted prior to placement of subsequent lifts.

J. During construction, exposed finished lifts of the soil liner material should be sprinkled with water to minimize desiccation, as necessary. The Contractor is responsible to protect the soil liner from rain, drying, desiccation, erosion and freezing. All defective areas shall be repaired by the Contractor to the satisfaction of the CQC Consultant at no extra compensation.

K. At the end of each day's construction activities, completed lifts or sections of the compacted soil liner should be sealed. Common sealing methods include rolling with a rubber tired or smooth-drum roller, backdragging with a bulldozer, or placement of temporary cover soil over the compacted soil liner. The compacted soil liner should be sprinkled with water, as needed.

L. If testing shows that a lift is significantly thicker than 6 IN, the top of the lift will be shaved off so that the lift is approximately 6 IN thick.

3.3 FIELD QUALITY CONTROL AND QUALITY ASSURANCE

A. Refer to the CQA Plan.

B. The following field and laboratory quality control tests shall be performed by the CQC Consultant at no additional expense to the Owner during soil liner construction:

Test	Method	Minimum Frequency	Acceptable Criteria
1. Field Density	ASTM D2937	1/10,000 SF/lift	≥ 95%
	or		
	ASTM D2937	1/5 D3017 tests	≥ 95%
	ASTM D3017	1/10,000 SF/lift	≥ 95%
2. Thickness	Surveyor	8 locations/acre	≥18 IN
3. Atterberg Limits	ASTM D4318	1/acre/lift	BSCS Criteria
4. Fines Content	ASTM D1140	1/acre/lift	BSCS Criteria
5. Hydraulic Conductivity	ASTM D5084	1/acre/lift	$\leq 1\text{x}10^{-5}$ cm/sec
6. Laboratory Moisture Density Relationship	ASTM D698	1/5,000 CY of placed liner material	NA

C. Test methods shall also conform to criteria set forth in Paragraph 3.1, Soil Liner Test Strip.

D. Test frequencies may be modified by the CQA Consultant. If there are indications of declining or failing test results, frequencies may be increased. If hydraulic conductivity test results are well above acceptable, the frequency for Atterberg limit and fine content testing may be waived by the Engineer.

E. The acceptable criteria may be modified by the CQA Consultant if supported by the test strip results and approved by the Engineer.

F. Holes in the compacted soil liner created as a result of destructive testing (eg., thin-walled Shelby tube sampling and nuclear gauge, field density determinations) shall be backfilled and tamped by rod uniformly in 2 IN thick lifts. The backfill material shall be the same liner construction material or hydrated bentonite powder, if approved by the CQA Consultant. On the surface, the backfill material shall extend slightly beyond the holes to make sure that a good tie-in with the surrounding liner is achieved. Repaired areas shall be observed and documented by the CQC Consultant.

G. Give minimum of 24 HR advance notice to CQA Consultant when ready for soil testing and inspection in completed area of the soil liner.

H. For areas not meeting field and laboratory testing criteria, the Contractor shall scarify the full depth of the lift or replace the material as needed. The material shall be reshaped, rewetted as needed, rehomogenized and recompacted to the specified density. Areas not meeting the thickness requirements shall be augmented with additional materials. The added materials shall be reworked with the soil layer to ensure homogeneity and proper bonding. This may be done by scarification of the surface prior to addition of new material. The repaired area shall be properly documented, and field and laboratory quality control testing shall be performed to ensure the repaired liner section meets the requirements specified herein.

I. The Contractor shall pay for all costs associated with corrective work and retesting resulting from failing tests. The CQA Consultant shall be informed immediately of all failing tests.

END OF SECTION

SECTION 02775
HDPE GEOMEMBRANE LINER SYSTEM

PART 1 - GENERAL

1.01 SUMMARY

A. Section Includes:
1. Furnish all labor, materials, tools, and equipment, and perform all work and services necessary for or incidental to the furnishing and installation, complete, of an impermeable, HDPE geomembrane liner as shown on Drawings and specified in accordance with provisions of the Contract Documents.
2. Completely coordinate work with that of all other trades.
3. Work items in project include, but are not necessarily limited to, the liner for the landfill lateral expansion.
4. Although such work is not specifically shown or specified, all supplementary or miscellaneous items, appurtenances, and devices incidental to or necessary for a sound, secure, complete, and compatible installation shall be furnished and installed as part of this work.
5. Furnish CQC Consultant to monitor work of Geomembrane Installer and to perform CQC testing in accordance with provisions of the Contract Documents.
6. The Contractor, Geomembrane Installer, and CQC Consultant are required to attend the CQA/CQC Resolution Meeting and the CQA/CQC Preconstruction Meeting, Section 01200.

B. Related Sections include but are not necessarily limited to:
1. Section 02220 - Earthwork.
2. Section 02221 - Trenching, Backfilling, and Compacting.
3. Section 02240 - Operational Cover and Leachate Collection Layer.
4. Section 02276 - Soil Liner System.
5. Construction Quality Assurance Plan.

1.2 QUALITY STANDARDS

A. Referenced Standards:
1. American Society for Testing and Materials (ASTM).
    a. D638, Standard Test Method for Tensile Properties of Plastics.
    b. D792, Standard Test Method for Density and Specific Gravity (Relative Density) of Plastics by Displacement.
    c. D1004, Standard Test Method for Initial Tear Resistance of Plastic Film and Sheeting.
    d. D1238 Standard Test Method for Flow Rates of Thermoplastics by Extrusion Plastometer.
    e. D1603 Standard Test Method for Carbon Black in Olefin Plastics.
    f. D3015 Standard Practice for Microscopic Examination of Pigment Dispersion in Plastic Compounds. Refer to Subpart 2.2 for property to be tested.
    g. D3895 Test Method for Oxidative Induction Time of Polyolefins by Thermal Analysis.
    h. D4218 Test Method for Determination of Carbon Black Content in Polyethylene Compounds by the Muffle-Furnace Technique.
    i. D4833 Test Method for Index Puncture Resistance of Geotextiles, Geomembranes, and Related Products.
    j. D5199 Test Method for Measuring Nominal Thickness of Geotextiles and Geomembranes.
    k. D5397 Procedure to Perform a Single Point Notched Constant Tensile Load – Appendix (SP-NCTL) Test.

l. D5596 Test Method for Microscopic Evaluation of the Dispersion of Carbon Black in Polyolefin Geosynthetics.
m. D5721 Practice for Air-Oven Aging of Polyolefin Geomembranes.
n. D520 Pressured Air Channel Evaluation of Dual Seamed Geomembranes
o. D5885 Test Method for Oxidative Induction Time of Polyolefin Geosynthetics by High Pressure Differential Scanning Calorimetry.
p. D5994 Test Method for Measuring the Core Thickness of Textured Geomembranes.

2. The Geosynthetic Research Institute (GRI).
   a. GM6 Pressurized Air Channel Test for Dual Seam Geomembranes.
   b. GM10 Specification for the Stress Crack Resistance of Geomembrane Sheet.
   c. GM11 Accelerated Weathering of Geomembranes Using a Fluorescent UVA-Condensation Exposure Device.
   d. GM12 Measurement of the Asperity Height of Textured Geomembranes Using a Depth Gauge.
   e. GM13 Standard Specification for Test Properties, Testing Frequency, and Recommended Warranty for High Density Polyethylene (HDPE) Smooth and Textured Geomembrane.

B. Qualifications:
1. Each geomembrane manufacturing or installation firm shall demonstrate 5 years continuous experience, including a minimum of 10,000,000 SF of HDPE geomembrane manufacture or installation.
2. Geomembrane Installer Personnel Qualifications:
   a. Installation Superintendent shall have worked in a similar capacity on at least five HDPE geomembrane liner jobs similar in size and complexity to the project described in the Contract Documents.
   b. The Master Welder shall have completed a minimum of 5,000,000 sf of HDPE geomembrane seaming work using the type of seaming apparatus proposed for use on this Project.
   c. Other welders shall have seamed a minimum of 1,000,000 sf of HDPE geomembrane.
3. The CQC Consultant shall meet the qualification requirements of Section 01410 of these Specifications.

C. CQA Plan Implementation: Construction Quality Assurance for the HDPE geomembrane installation will be performed for the Owner by the CQA Consultant in accordance with the CQA Plan prepared for this project. The work performed under the CQA Plan is paid for by the Owner and is not a part of this contract. The Contractor, CQC Consultant, and Geomembrane Installer, however, should familiarize themselves with the CQA Plan and are responsible for providing reasonable notice of and access to work elements that the CQA Consultant is required by the CQA Plan to overview.

1.3 SUBMITTALS

A. Submit for Engineer's approval prior to placement of geomembrane liner, including:
1. Manufacturer's Submittals.
   a. Manufacturer's Quality Control (MQC) Program: Submit for review a complete description of the geosynthetic manufacturer's formal quality control program for manufacturing HDPE geomembrane. The MQC program shall at a minimum conform to GRI GM13 standards. The manufacturer shall reject resin and geomembrane that does not conform with the requirements of the approved MQC program.
   b. Manufacturer's Field Installation Procedures Manual: Submit complete geomembrane manufacturer's specifications, descriptive drawings, and literature for the recommended installation of the HDPE geomembrane liner system, including recommended methods for handling and storage of all materials prior to installation, and field installation guidelines that the manufacturer feels are relevant and important to the success of this project. The manual clearly identifies any exceptions taken by the manufacturer in the

specified execution of the Work. Unless excepted and approved by the Engineer, the procedures herein shall be considered part of the manual.

c. Manufacturer's Material Data: Submit statement of planned production date(s) for the geosynthetics to be provided for this Project. Prior to shipment of geomembrane, submit quality control certificates for each roll demonstrating conformance with the requirements of these Specifications. Submit statement of production dates for the resin and the HDPE geomembrane for this work.

d. Manufacturer's written acceptance of Geomembrane Installer's qualifications for installation of the HDPE geomembrane.

e. Warranty: Submit a warranty signed by the manufacturer regarding the material supplied.

2. Geomembrane Installer's Submittals.

a. The Geomembrane Installer will submit written documentation that their personnel satisfy the qualifications of 1.2 B.

b. Geomembrane Installer's Construction Quality Control Program: Submit for review a complete description of the Geomembrane Installer's formal construction quality control programs to include, but not be limited to, product acceptance testing, installation testing, including both nondestructive and destructive quality control field testing of the sheets and seams during installation of the geomembrane, proposed methods of testing geosynthetic joints and connections at appurtenances for continuity, documentation and changes, alterations, repairs, retests, and acceptance.

c. Geomembrane Installer's Installation Procedures Manual: Submit for approval the Installer's installation manual to include: ambient temperature at which the seams are made, control of panel lift up by wind, acceptable condition of the subsurface beneath the geomembrane, quality and consistency of the welding material, proper preparation of the liner surfaces to be joined, cleanliness of the seam interface (e.g., the amount of airborne dust and debris present), and proposed details for connecting the HDPE liner to appurtenances, i.e. penetrations of the containment facilities. The document shall include a complete description of seaming by extrusion welding and hot-wedge welding. The Geomembrane Installer's Installation Manual will by reference include requirements of the Manufacturer's Installation Manual unless exceptions are noted and approved by the Engineer. After this manual has been approved by the Engineer, the Geomembrane Installer shall not deviate from the procedures included in the manual.

d. Geomembrane panel layout with proposed size, number, position, and sequencing of panels and showing the location and direction of all field joints. Joints shall be perpendicular to flow direction where possible, unless approved otherwise.

e. Warranty: The Geomembrane Installer shall agree in writing to warranty the geomembrane system.

3. CQC Consultants Submittals:

a. CQC Consultant shall submit written documentation that their personnel satisfy the qualifications of Section 01400.

b. CQC Consultants CQC Geomembrane Manual: Submit CQC Consultant's written program for meeting the geomembrane material conformance and CQC requirements of these Specifications.

4. Provide all submittals in a single coordinated transmittal. Partial submittals will not be accepted. All submittals must be submitted prior to the Geomembrane Preconstruction Meeting, Section 01200.

B. Submittals for Engineer's Approval Required for Final Acceptance of HDPE Geomembrane Liner System:

1. Geomembrane Installer's Submittals.

a. Warranty: Submit a warranty signed by the Geomembrane Installer that the installed geomembrane liner, attachments, and appurtenances are free of defects in material, manufacturing, and workmanship.

b. Record Drawings: Submit reproducible drawings of record showing changes from the approved installation drawings. The record drawings shall include the identity and location of each repair, cap strip, penetration, boot, and sample taken from the installed geosynthetic for testing. The record drawings shall show locations of each type of material anchor trenches and the construction baseline.

c. Welder Certification: Submit certification for each welder and performance records that include linear feet of weld completed, number of samples tested, and test failure rate for each welder. Submit field notes with daily equipment reports.

2. CQC Consultant's Submittals.

a. Certification: Submit written certification that the geomembrane liner was installed in accordance with this Specification and with the approved shop drawings.

b. CQC Records: Submit copies of all material and seam test results. Each test shall be identified by date of sample, date of test, sample location, name of individual who performed the test, and standard test method used.

c. CQC Weld Test Summary Report: The CQC Consultant shall submit a report showing normal distribution of all CQC seam test results, identifying the high, low, and average of the five coupon samples in each test.

3. Provide all submittals in a single coordinated transmittal. Partial submittals will not be accepted.

1.4 PROJECT CONDITIONS

A. When the weather is of such a nature as to endanger the integrity and quality of the installation, whether this is due to rain, high winds, cold temperatures, or other weather elements, the installation of the geomembrane shall be halted at the direction of, or with the concurrence of, the Owner until the weather conditions are satisfactory.

B. The Contractor shall ensure that adequate dust control methods are in effect to prevent the unnecessary accumulation of dust and dirt on geosynthetic surfaces which hamper the efficient field seaming of geosynthetic panels.

C. The Contractor shall maintain natural surface water drainage diversions around the work area and provide for the disposal of water which may collect in the work area directly from precipitation falling within the area or from inadequate diversion structures or practices.

D. The Contractor shall be responsible to coordinate the installation of the leachate collection system which shall be in accordance with Geomembrane Installer's Installation Manual and as specified in these Specifications and shown on the Contract Drawings.

E. Vehicles will not be allowed on the liner area unless at least 24 inches of cover has been placed over the liner except as noted in these Specifications.

F. Vehicles larger than one and one-half ton pickup trucks are prohibited on the exterior berms. Contractor shall repair any damage to exterior berms prior to final payment.

1.5 DEFINITIONS AND RESPONSIBILITIES

A. Geomembrane Manufacturer: Manufacturer of geomembranes producing geomembrane sheets from resin and additives. The manufacturer is responsible for producing geomembrane sheet which complies with these Specifications. These responsibilities include but are not limited to:

1. Acceptance of the resin and additives from chemical formulators. Testing of the raw resin and additives to ensure compliance with the manufacturer's specifications and with this Specification.
2. Formulation of the resin and additives into geomembrane sheeting using mixing and extrusion equipment.
3. Testing of the geomembrane sheet to ensure compliance with manufacturer's specification and this Specification.
4. Shipping of the geomembrane sheet to installer designated facilities.

5. Certification of the raw materials and finished geomembrane sheet to comply with this Specification.
6. Certification of installer's training, experience, and methods for welding and inspection of geomembrane installations in compliance with manufacturer's standards.

B. Geomembrane Installer. Installer of geomembranes are responsible for handling, fitting, welding, and testing of geomembrane sheets or blankets in the field. These responsibilities include but are not limited to:
1. Acceptance (in writing) of the geomembrane from the manufacturer.
2. Acceptance (in writing) of the CSL surface which will serve as a base for the geomembrane. This acceptance shall precede installation of the geomembrane, and shall state that the installer has inspected the surface, and reviewed the Specifications for material and placement, and finds all conditions acceptable for placement of geomembrane liners. The written acceptance shall explicitly state any and all exceptions to acceptance.
3. Handling, welding, testing, and repair geomembrane liners in compliance with this Specification and the Geomembrane Installer's Installation Procedures Manual.
4. Performance of QA/QC testing and record keeping as required by the approved Geomembrane Installer's Field Installation Procedures Manual.
5. Repair or replacement of defects in the geomembrane as required by the CQC Consultant or the CQA Consultant.

C. Engineer: Responsible for approval of submittals from the Contractor.

D. CQC Consultant: Responsible for observing field installation of the geomembrane and performance of material conformance and CQC testing to provide the Contractor with verbal and written documentation of the compliance of the installation with these Specifications. The CQC Consultant reports to the Contractor and is part of this contract.

E. CQA Consultant: Responsible for implementing CQA Plan including overviewing material conformance testing, field installation of the geomembrane, and CQC activities, and to perform limited CQA conformance testing to provide Owner with verbal and written documentation of the compliance of the installation with these Specifications. The CQA Consultant will use the written results of the CQC program and the CQA program in the preparation of the facility Certification Document. The CQA Consultant reports to the Owner and is not part of this contract.

F. Refer to the accompanying CQA Plan for additional definitions.

1.6 WARRANTIES

A. The Manufacturer's warranty shall be against manufacturing defects and workmanship and against deterioration due to ozone, ultra- violet, and other exposure to the elements, for a period of 20 years on a pro rata basis. The warranty shall be limited to replacement of material, and shall not cover installation of replacement geomembrane.

B. The geomembrane supplied shall be capable of preventing the leachate produced by the solid waste (refuse) from reaching the underlying soil. The material supplied including factory and field seams shall have a manufacturer's warranty that it will remain impermeable when exposed over twenty (20) years to a raw landfill leachate having the following range of values*:

LEACHATE QUALITY

Component	Range of Values**	
pH	3.6	8.5
Hardness (Carbonate)	35	8,120
Alkalinity (Carbonate)	310	9,500
Calcium	240	2,570
Magnesium	64	410
Sodium	85	3,800

Iron (Total)	6	1,640
Chloride	96	2,350
Sulfate	40	1,220
Organic Nitrogen	2.4	550
Ammonia Nitrogen	0.2	845
Conductivity	100	1,200
BOD	7,050	32,400
COD	800	50,700
Suspended Solids	13	26,500

* Gewsein, Allen J., USEPA: EPA/530/SE-137, March 1975

** Values are in milligrams per liter except pH (pH units) and conductivity (Micromhos per cubic centimeter).

C. The Installer's warranty shall be against defects in the system installed for a period of two years from the date of final acceptance of the Work by the Owner.

PART 2 - PRODUCTS

2.1 ACCEPTABLE MANUFACTURERS AND/OR GEOMEMBRANE INSTALLERS

A. Subject to compliance with the Contract Documents, the following manufacturers and installers are acceptable:
   1. HDPE Geomembrane liners manufacturers::
      a. GSE, Inc., 19103 Gundle Road, Houston, Texas 77073.
      b. Serrot International, Inc. 271 Highway 74 North, Suite 4, Peachtree City, Georgia 30269.
      c. Poly-Flex Inc., 2000 W. Marshall Drive, Grand Prairie, TX 75051.
      d. Agru/America, Inc., 500 Garrison Road, Georgetown, SC 29440.
   2. HDPE Geomembrane Liner Installers:
      a. Authorized installers of approved manufacturers.
      b. Other installers may qualify by providing references for a minimum of 10,000,000 SF of liner installations.

B. Submit requests for substitution in accordance with Specification Section 01640.

2.2 MATERIALS

A. HDPE Geomembrane Liners:
   1. Geomembrane liners shall consist of unsupported polyethylene in thickness as shown on Drawings and manufactured from virgin, first quality resin designed and formulated specifically for liquid containment in hydraulic structures. Reclaimed polymer shall not be added to the resin; except use of polymer recycled during the manufacturing process shall be allowed provided that recycled polymer shall be clean and shall not exceed 2 percent by weight.
   2. The geomembrane liner shall be manufactured to be free of holes, blisters, undispersed raw materials, or any sign of contamination by foreign matter. Any such defects shall be cause for rejection of the defective geomembrane material. Minor defects may be repaired in accordance with manufacturer's recommendations if this repair is approved by the Engineer.
   3. The geomembrane liner shall be manufactured as seamless rolls or as prefabricated panels with a minimum width of 22 FT as delivered to the site. All factory seams shall be inspected and tested for strength and continuity prior to delivery to the site.
   4. No additives or fillers may be added to the resin prior to or during manufacture of the geomembrane.

5. Prior to shipment, the geomembrane manufacturer will provide the Project Manager and the CQC Consultant with a quality control certificate for each roll of geomembrane provided. The quality control certificate will be signed by a responsible party employed by the geomembrane manufacturer and will include:
   a. Roll numbers and identification; and
   b. The results of quality control tests performed under the MQC program.
6. The CQC Consultant will verify that a control certificate has been received for each roll and that the certified roll properties meet the requirements of these Specifications.
7. Textured HDPE sheet (both sides) shall be used on all lined slopes of 25 percent or greater. Smooth HDPE shall be used in all other lined areas.
8. The geomembrane liner material shall consist of **60 MIL NOMINAL HDPE** and meet or exceed GRI GM13 and the following requirements:

PROPERTY	TEST METHOD	TEST VALUE TEXTURED HDPE	TEST VALUE SMOOTH HDPE
a. Sheet Thickness, Mils	ASTM D5994 or D5199 (for smooth)		
• Minimum Average		nominal ± 5%	Nominal ± 5%
• Lowest Individual 8 of 10		nominal ± 10%	Nominal ± 5%
• Lowest Individual 10 of 10		nominal ± 15%	Nominal ± 10%
b. Sheet Density (g/cc)	ASTM D792 or D1505	0.940	0.940
c. Minimum Tensile Properties	ASTM D638, Type IV, Dumb-bell at 2 imp. (each direction)		
• Yield Stress		140 ppi	140 ppi
• Break Stress		90 ppi	240 ppi
• Elongation at Yield		13%	13%
• Elongation at Break (2-inch gage length)		150%	700%
d. Min. Tear Resistance Initiation	ASTM D1004, Die C	45 lbs	45 lbs
e. Carbon Black	ASTM D1603 or ASTM D4218	2.0-3.0%	2.0-3.0%
f. Carbon Black Dispersion	ASTM D5596	Category	Category
• 8 of 10		1 or 2	1 or 2
• 10 of 10		1, 2, or 3	1, 2, or 3
g. Puncture Resistance, Minimum Average	ASTM D4833	90 lbs	90 lbs
h. Oxidative Induction Time, Minimum Average	ASTM D3895 or ASTM D5885	100 min. 400 min.	100 min. 400 min.
i. Asperity Height, Minimum Average	GRI GM12	7 mil	NA

B. Extrusion rod shall be manufactured from identical resin to that used in geomembrane manufacture. Manufactured extrusion rod shall be tested for carbon black content and dispersion, specific gravity, and melt index at a frequency of not less than one test per batch.

2.3 INTERFACE FRICTION TESTS

A. Interface Friction Tests.

1. Test both materials using ASTM D 5321. Section 01060-Special Conditions, paragraph 1.13, outlines the conditions under which this material shall be tested.
2. This material is part of a system. The system shall meet the requirements before the component material can be deemed acceptable.
3. The costs associated with this testing shall be included in the bid price for each material. Any retesting or other additional testing required to meet the Specification shall be at no additional cost to the Owner.

2.4 EQUIPMENT

A. Welding Equipment: Extrusion welding equipment shall be provided with thermocouples and temperature readout devices which continuously monitor the temperature of the extrudate. Radiant wedge welding equipment shall be provided with thermocouples and temperature readout devices which continuously monitor the temperature of the wedge. Equipment shall be maintained in adequate number to avoid delaying work, and shall be supplied by a power source capable of providing constant voltage under a combined-line load. Use a rub sheet, sand bags, or other method approved by the CQA Consultant to separate the electric generators from the geomembrane.

B. Field Tensiometer: The Geomembrane Installer shall provide a tensiometer for on-site shear and peel testing of geomembrane seams. The tensiometer shall be in good working order, built to ASTM D638 (Type IV, 2 ipm) specifications, and accompanied by evidence of recent calibration. The tensiometer shall be motor driven and be equipped with a gauge that measures the force in unit pounds exerted between the jaws as displayed on a digital readout.

C. Vacuum Box: The Geomembrane Installer shall provide a minimum of 2 vacuum box assemblies consisting of a rigid housing, a transparent viewing window, a soft closed cell neoprene gasket attached to the bottom, a port hole or valve assembly, a vacuum gauge, a vacuum pump assembly equipped with a pressure control, a rubber pressure/vacuum hose with fittings and connections, and a soapy solution and an applicator. The equipment shall be capable of inducing and holding a minimum vacuum of 5 psi.

D. Air Pressure Test: The Geomembrane Installer shall provide the necessary air pump and fittings required to perform the GRI GM6 air pressure test on dual seams.

E. Roll Handling Equipment: The Geomembrane Installer shall provide handling equipment that is adequate and does not pose a risk to the geomembrane rolls. The CQC Consultant shall inspect the equipment and confirm its adequacy.

PART 3 - EXECUTION

3.1 LINER SYSTEM CONSTRUCTION

A. Compacted Soil Liner (CSL) Component:
   1. The CSL component shall be constructed in accordance with Section 02276 and the Contractor shall protect the CSL from freezing, desiccation, flooding with water, and freezing.
   2. Prior to placement of the geomembrane, the CSL must be prepared as follows:
      a. Lines and grade must be verified by a Licensed Land Surveyor.
      b. The surface must be proofrolled to verify the supporting soil condition.
      c. The surface must be inspected for rocks larger than 0.75 IN.
      d. Steel drum rolled in preparation for the geomembrane.
   3. CSL acceptance: Geomembrane liner materials shall not be placed until the required CSL preparation has been completed and the CSL has been accepted and certified in writing by the Geomembrane Installer and approved by the CQA Engineer.

B. Geomembrane Liner:

1. The geomembrane liner shall be manufactured in accordance with the approved MQC program. The manufacturer shall not deviate from the program without written approval of the Engineer.
2. Transportation and handling of the geomembrane shall meet the following requirements:
   a. Transportation of the geomembrane is the responsibility of the Geomembrane Installer, Contractor, or other party as agreed upon.
   b. All handling on site is the responsibility of the Geomembrane Installer.
   c. The CQC Consultant will verify that the handling equipment used on the site is adequate and will not damage the geomembrane.
   d. Upon delivery to the site, the Geomembrane Installer and the CQC Consultant will conduct a surface examination of all rolls for defects or damage. This inspection will be conducted without unrolling rolls. The CQC Consultant will ensure that defective rolls are rejected and removed from the site.
   e. The Geomembrane Installer will be responsible for the storage of the geomembrane on site. The Project Manager will provide a storage location on site. The Geomembrane Installer shall ensure that the storage space is adequate to protect the geomembrane from theft, vandalism, vehicular damage, etc.
3. Field Panel Identification: The CQC Consultant will document that the Geomembrane Installer labels each field panel with an "identification code" consistent with the approved panel layout plan. The location of the label and the color of marker used must be as agreed to in the QA/QC Preconstruction Meeting.
4. Geomembrane Installation: Geomembrane liner shall be installed in accordance with the approved Geomembrane Installer's Field Installation Procedure Manual and panel layout drawing. The Geomembrane Installer shall maintain a weekly updated as-built drawing showing the location of all field panels.
   a. Geomembrane shall not be placed upon standing water or other conditions which will result in deterioration of the soil liner.
   b. The Geomembrane Installer shall remove any materials placed to protect the soil liner prior to placement of the geomembrane liner.
   c. Geomembrane liner shall be handled and placed in a manner which minimizes wrinkles, scratches, and crimps.
   d. Test seams shall be made upon each start of work for each seaming crew, upon every four hours of continuous seaming, every time seaming equipment is changed, or if significant changes in geomembrane temperature and weather conditions are observed. These test welds shall be tested using daily record that summarizes panels deployed, seams completed, seam testing, seam repair, personnel on site, and equipment on site using field tensiometer and, at a minimum, exhibit the required seam strength.
   e. Surfaces to be welded shall be clean and dry at the time of welding. Geomembrane shall not be welded when ambient temperatures are below 40 Deg F (5 Deg C) or above 104 Deg F (40 Deg C) unless the Geomembrane Installer can demonstrate that the seam quality is not compromised.
   f. Geomembrane liners shall be welded continuously without fishmouths or breaks in the weld. Where fishmouths are unavoidable, the geomembrane sheet shall be slit to a point such that the sheet lies flat and with no remaining wrinkle. The two edges of the slit shall be welded together provided that the overlap for this weld shall be a minimum of 3 IN. Areas of the slit which do not achieve an overlap of 3 IN, including the terminus of the slit, shall be provided with a patch as discussed below.
   g. Defects in and damage to geomembrane sheets shall be repaired by welding a patch over the defect using extrusion welding equipment. The patch material shall consist of an undamaged piece of geomembrane cut to provide a minimum of 3 IN of overlap in all directions from the defect. Torn or permanently twisted geomembrane shall be replaced at no expense to the Owner.
   h. Personnel walking on the geosynthetic shall not engage in activities or wear types of shoes, that could damage the geosynthetic. Smoking shall not be permitted while working on the geomembrane.

i. Vehicular traffic directly on the geosynthetic shall not be permitted. Equipment shall not damage the geosynthetic materials by handling, trafficking, leakage of hydrocarbons, or any other means. The unprotected geomembrane surface shall not be used as a work area, for preparing patches, storing tools and supplies, or other uses.

5. Geomembrane Testing (Nondestructive): The Geomembrane Installer shall test and document all seam welds continuously using one of the following nondestructive seam tests:
   a. Vacuum testing shall conform to the following procedure: Brush soapy solution on geomembrane. Place vacuum box over the wetted seam area. Ensure that a leak-tight seal is created. Apply a pressure of approximately five (5) psi. Examine the geomembrane through the viewing window for the presence of soap bubbles for not less than 15 seconds. All areas where soap bubbles appear shall be marked and repaired as described in this Section.
   b. Air Pressure Testing (for double seam with an enclosed space) shall conform to GRI GM6 requirements.
6. Destructive Testing: The Geomembrane Installer shall field test seams destructively at a minimum frequency of one test per 500 LF of weld. Destructive testing of these samples shall also be performed by the CQC Consultant using the CQC Geosynthetics Laboratory. The CQC Consultant shall determine the location of destructive test samples. Conformance testing will be performed by the CQA Consultant in accordance with the project CQA Plan.
   a. The destructive sample shall be 16 IN wide by 42 IN long with the seam centered lengthwise. The sample shall be cut into three (3) equal parts for distribution to the geomembrane installer, the Owner, and the CQC Consultant.
   b. All tests shall exhibit a Film Tearing Bond type of separation in which the geomembrane material tears before the weld. At least 5 coupons shall be tested by each test method. Five of five coupons shall meet minimum requirements, as specified below:

Description	Test Method	Value (lbs/in width)
HDPE Peel	ASTM D4437	90
HDPE Shear	ASTM D4437	120

7. Documentation: The following documentation must be maintained at the project site for review by the Project Manager or CQA Consultant:
   a. Geomembrane Installer's Documentation:
      1) Daily Log: daily record that summarizes panels deployed, seams completed, seam testing, seam repair, personnel on site, and equipment on site.
      2) Panel Log: provides geomembrane roll number used and subgrade acceptance for each panel deployed.
      3) Seam Testing Log: provides a complete record of all nondestructive and destructive seam tests performed as part of the Geomembrane Installer's QC program.
      4) Seam/Panel Repair Log: provides a complete record of all repairs and vacuum box testing of repairs made to defective seams or panels.
      5) As-Built Drawing: maintain an as-built drawing updated on a weekly basis.
   b. CQC Consultant's Documentation:
      1) Daily Log: daily record that summarizes panels deployed, seams completed, CQC seam testing, seam repair, personnel on site, equipment on site, weather conditions, etc.
      2) CQC Testing Log: record of all seam destructive tests and material conformance tests performed by the CQC Geosynthetics Laboratory.
      3) Material Conformance: maintain original conformance certificate(s) from geomembrane manufacturer.

4) Subgrade Acceptance Log: maintained originals of subgrade acceptance forms for each panel and signed by the Geomembrane Installer.

3.2 GEOMEMBRANE ACCEPTANCE

A. The Geomembrane Installer shall retain all Ownership and responsibility for the geomembrane liner system until final acceptance by the Owner. Owner will accept the geosynthetic installation when the installation is finished and all required submittals from the Geomembrane Installer and CQC Consultant have been received and approved, and CQA verification of the adequacy of all field seams and repairs, including associated testing, is complete.

END OF SECTION

SECTION 02800

GEOSYNTHETIC CLAY LINER (GCL)

PART 1 - GENERAL

1.1 SUMMARY

A. Section Includes:
   1. Furnish all labor, material, and equipment to complete installation of the GCL in accordance with the Contract Drawings and these Specifications.
   2. Completely coordinate work with that of other trades.
   3. Although such work is not specifically shown or specified, all supplementary or miscellaneous items, appurtenances, and devices incidental to or necessary for a sound, secure, complete, and compatible installation shall be furnished and installed as part of this work.
   4. Furnish CQC Consultant to monitor the work of GCL Installer and to perform CQC testing in accordance with provisions of the Contract Documents.

B. Related Sections include but are not necessarily limited to:
   1. Section 02220 - Earthwork.
   2. Section 02775 - HDPE Geomembrane Liner.

1.2 QUALITY STANDARDS

A. Referenced Standards:
   1. American Society for Testing and Materials (ASTM).
      a. ASTM D4632, Test Method for Grab Breaking Load and Elongation of Geotextile.
      b. ASTM D4643, Determination of Water Content of Soil by Microwave Oven Method.
      c. ASTM D4833, Test Method for Index Puncture Resistance of Geotextiles, Geomembranes, and Related Products.
      d. ASTM D5084, Test Method for Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter.
      e. ASTM D5261, Measuring Mass Per Unit Area of Geotextiles.
      f. ASTM D5321, Test Method for Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method.
      g. ASTM D5887, Measurement of Index Flux through Saturated GCL Specimens Using a Flexible Wall Permeameter.
      h. ASTM D5888, Storage and Handling of GCL.
      i. ASTM D5889, Quality Control of GCL.
      j. ASTM D5890, Swell Index Measurement of Clay Mineral Component of GCL.
      k. ASTM D5891, Fluid Loss of Clay Mineral Component of GCL.
      l. ASTM D5993, Measuring Mass Per Unit Area of GCL.
      m. ASTM D6072, Installation of GCL.
   2. Geosynthetic Research Institute (GRI):
      a. GCL-2, Permeability of Geosynthetic Clay Liners.

B. Qualifications:
   1. Manufacturer: The GCL shall be furnished by a manufacturer that has previously produced a minimum of 1,000,000 SF of the material for use in similar projects.

C. CQA Plan Implementation: Construction Quality Assurance documentation for the GCL installation will be performed for the Owner by the CQA Consultant in accordance with the CQA Plan prepared for this project. The work performed under the CQA Plan is paid for by the Owner and is not a part of this contract. The Contractor, CQC Consultant, and GCL Installer, however, should familiarize themselves with the CQA Plan and are responsible for providing reasonable notice of and access to work elements that the CQA Consultant is required by the CQA Plan to overview.

1.3 DEFINITIONS

A. Manufacturer: Manufacturer produces geosynthetic clay liner panels from first quality geotextiles and sodium bentonite. The manufacturer is responsible for producing panels which comply with this Specification. These responsibilities include but are not limited to:
   1. Acceptance of the geotextiles, bentonite, and additives from suppliers/manufacturers and testing of these materials to ensure compliance with the manufacturer's specifications and with this Specification.
   2. Fabrication of the geotextiles and bentonite into GCL panels using mixing and extrusion equipment.
   3. Testing of the GCL to ensure compliance with manufacturer's specification and this Specification.
   4. Shipping of the GCL to fabricator/installer designated facilities.
   5. Certification of the raw materials and finished GCL to comply with this Specification.
   6. Certification of fabricator's and installer's training, experience, and methods for seaming and inspecting GCL installations in compliance with manufacturer's standards and with Quality Assurance requirements of this Specification (Article 1.2).

B. Installer: Installers of GCLs are responsible for storing, handling, fitting, seaming, and testing of GCL panels in the field. These responsibilities include but are not limited to:
   1. Acceptance (in writing) of the GCL rolls from the transporter.
   2. Acceptance (in writing) of the soil material which will serve as a base for the GCL. This acceptance shall precede installation of the GCL, and shall state that the installer has inspected the surface, and reviewed the Specifications for material and placement, and finds all conditions acceptable for placement of GCL liners. The written acceptance shall explicitly state any and all exceptions to acceptance.
   3. Handling, seaming, testing, and repair of GCL liners in compliance with this Specification and with written procedure manuals prepared by the installer or the manufacturer.
   4. Repair or replacement of defects in the GCL as required by the Inspector or the Owner.
   5. Installer and manufacturer may be the same firm.

C. Inspector: Inspectors of GCL liner are responsible for observing field installation of the GCL and providing the manufacturer, installer, and Owner with verbal and written documentation of the compliance of the installation with this Specification and with written procedures manuals prepared by the manufacturer. Inspector's responsibilities include, but are not limited to:
   1. Inspection of material, handling, and field installation of the GCL liner. Inspection of all seams, repair, and test results.
   2. All exceptions to material or installation shall be documented to the Engineer in writing within 48 hours of discovery.

D. Engineer: The Engineer is responsible for design of the geosynthetic liner system.

E. Owner: Owner designates the party responsible for constructing and operating the lined containment system.

1.4 SUBMITTALS

A. Pre-Installation: The Contractor shall submit the following information and material to the CQA Consultant prior to installation of the GCL.
   1. Product Data and Factory Test Results: Published product properties and specifications for the proposed GCL, as well as factory test results of materials certified by the GCL manufacturer, shall be submitted showing conformance with the requirements of these Specifications. In addition, the Contractor shall submit the manufacturer's certification stating that the material is similar to and of the same formulation as that for which test results are submitted, and by which actual usage has been demonstrated to be satisfactory for the intended application.

2. Samples: Samples of the GCL sheeting shall be provided to the CQA Consultant. Samples shall have a width of 6 IN, and a length of 8 IN.
3. Delivery, Storage, and Handling Instructions: The manufacturer's recommendations for delivery, storage, and handling shall be submitted to the CQA Consultant for review.
4. Delivery Date: The CQA Consultant shall be notified of the scheduled delivery date for the materials.
5. Installation Drawings, Procedures, and Schedules: Installation drawings, procedures, and a schedule for carrying out the work shall be provided by the Contractor to the CQA Consultant for review. Procedures addressed by the Contractor shall include but not be limited to material unloading, storage, installation, repair, and protection to be provided in the event of rain. A schedule showing the order of placement, location of panels, seams, and penetrations shall be submitted for the CQA Consultant's review. Submit drawings showing the panel layout, seams, and associated details including pipe penetrations. Following review, these drawings will be used for installation of the GCL. Any deviations from these drawings must be approved by the CQA Consultant.

B. Post-Installation: Upon completion of GCL installation, the Contractor shall submit the following to the CQA Consultant:
1. A certificate stating that the GCL has been installed in accordance with the Plans, Specifications, and the manufacturer's recommendations.
2. Manufacturer's Warranty: The material warranty shall be for defects or failures related to manufacture on a non-prorata basis for five (5) years after date of shipment.
3. GCL Installer's Warranty: The GCL Installer's warranty shall warrant their workmanship to be free of defects on a non-prorata basis for five (5) years after the final acceptance of the Work. This warranty shall include but not be limited to overlapped seams, anchor trenches, attachments to appurtenances, and penetration seals.
4. Record Drawing Information: Record drawings including but not limited to drawings showing the location of all seams, panels, repairs, patches, anchor trenches, pipe penetrations, and other appurtenances, including measurements and dimensions, shall be prepared by the Contractor and submitted to the CQA Consultant following completion of the project.

1.5 PROJECT CONDITIONS

A. The GCL shall not be placed in standing water, high humidity, or while raining. Any material that becomes partially or completely hydrated in the opinion of the CQA Consultant shall be removed and replaced at Contractor's expense.

B. Take necessary precautions to protect underlying soil and geomembrane liners from damage due to any construction activity. Damage to liners shall be repaired at Contractor's expense.

C. The Contractor shall ensure that adequate dust control methods are in effect to prevent the unnecessary accumulation of dust and dirt on geosynthetic surfaces, which hampers the efficient field seaming of geosynthetic panels.

D. The Contractor shall maintain natural surface water drainage diversions around the work area. The Contractor shall provide for the disposal of water that may collect in the work area, from precipitation falling on the work or from inadequate diversion structures.

PART 2 - PRODUCTS

2.1 MATERIALS

A. General:
1. The GCL shall consist of bentonite encased, front and back, with geotextile. GCL consisting of bentonite backed with geomembrane can be used only if approved by the Project

Manager and Engineer. The materials supplied under these Specifications shall be first quality products designed and manufactured specifically for the purposes of this work.

2. The GCL shall be supplied in rolls which have a minimum width of 12 FT. The roll length shall be maximized to provide the largest manageable sheet for the fewest overlaps. Labels on the roll shall identify the sheet number, date of fabrication, proper direction of unrolling, and minimum recommended overlap. A quality control certificate shall be supplied with each roll.
3. **The GCL shall be reinforced on slopes of 25% or greater and unreinforced on slopes less than 25%.**
4. The bentonite shall be continuously adhered to both geotextiles to ensure that the bentonite will not be displaced during handling, transportation, storage and installation, including cutting, patching, and fitting around penetrations. The bentonite sealing compound or bentonite granules used to seal penetrations and make repairs shall be made of the same natural sodium bentonite as the GCL and shall be as recommended by the GCL manufacturer. The permeability of the GCL overlap seams shall be equal to or less than the permeability of the body of the GCL sheet.

B. Physical Properties: Physical properties of GCL shall be as shown in Table 1 of this Section. The manufacturer shall certify that materials provided meet these criteria according to ASTM D5889 as modified by this Specification.

TABLE 1: REQUIRED GCL PROPERTIES

GCL PROPERTY	TEST METHOD	VALUE	
		REINFORCED	NONREINFORCED
Maximum Hydraulic Conductivity	ASTM D5084 (@ 30 psi effective stress)	$5x10^{-9}$ cm/s	$5x10^{-9}$ cm/s
Minimum Bentonite Content	ASTM D5993 (@ 0% moisture)	0.75 lb/sf	0.75 lb/sf
Minimum Grab Tensile Strength	ASTM D4632	90 lbs	75 lbs
Minimum Puncture Resistance	ASTM D4833	80 lbs	NA
Average Minimum Shear Strength	ASTM D5321	500 psf (when hydrated)	50 psf
Minimum Free Swell	ASTM D5890	24 mL	24 mL
Maximum Fluid Loss	ASTM D5891	18 mL	18 mL
Maximum Moisture Content (per roll)	ASTM D4643	100%	100%

C. Interface Friction Tests.

1. Test this and adjacent materials using ASTM D 5321. Section 01060 Special Conditions paragraph 1.13 outlines the conditions under which this material shall be tested.
2. This material is part of a system. The system shall meet the requirements before the component material can be deemed acceptable.

3. The costs associated with this testing shall be included in the Bid price for each material. Any retesting or other additional testing required to meet the specification shall be at no additional cost to the Owner.

PART 3 - EXECUTION

3.1 CONSTRUCTION

A. Shipping, Handling, and Storage:
  1. During periods of shipment and storage, all GCL shall be protected from direct sunlight, water, mud, dirt, dust, and debris. To the extent possible, the GCL shall be maintained wrapped in heavy-duty protective covering until use. GCL delivered to the project site without protective wrapping shall be rejected.
  2. The Engineer shall approve the shipping and delivery schedule prior to shipment. The Engineer shall approve the on-site storage area for the GCL. Unloading and storage of GCL shall be the responsibility of the Contractor.
  3. GCL that is damaged during shipping, handling, or storage shall be rejected and replaced at Contractor's expense.

B. Installation of GCL:
  1. GCL shall be placed to the lines and grades shown on the Contract Drawings. At the time of installation, GCL shall be rejected by the CQA Consultant if it has defects, rips, holes, flaws, evidence of deterioration, or other damage.
  2. The surface receiving the GCL shall be prepared to a relatively smooth condition, free of obstructions, excessive depressions, debris, and very soft or loose pockets of soil. This surface shall be approved by the CQA Consultant prior to GCL placement.
  3. The GCL shall be placed smooth and free of excessive wrinkles.
  4. The GCL shall be installed on sideslopes with vertical seams only.
  5. When GCL is placed with upslope and downslope portions, the upslope portion shall be lapped such that it is the upper or exposed surface.
  6. The GCL shall not be placed in standing water or while raining. Any material that becomes partially/totally hydrated shall be removed and replaced.
  7. The GCL seams shall be laid with a minimum overlap equal to 6 IN or the manufacturer's recommendation, whichever is greater. Bentonite powder shall be placed at all GCL seams.
  8. GCL shall be temporarily secured in a manner approved by the CQA Consultant prior to placement of overlying materials.
  9. Any GCL that is torn or punctured shall be repaired or replaced as directed by the CQA Consultant, by the Contractor at no additional cost to the Owner. The repair shall consist of a patch of GCL placed over the failed areas and shall overlap the existing GCL a minimum of 12 IN from any point of the rupture.
  10. If in-place GCL is not otherwise protected from hydration due to rainfall, the GCL shall be covered with a minimum of 12 IN of the overlying design material within 12 hours of GCL placement.

3.2 FIELD QUALITY CONTROL

A. The CQA Consultant shall monitor and document the installation of GCL to ensure that the installation and necessary repairs are made in accordance with these Specifications.

3.3 GCL ACCEPTANCE

A. The GCL Installer shall retain all ownership and responsibility for the GCL until final acceptance by the Owner. The Owner will accept the GCL installation when the installation is finished, all required submittals have been received and approved, and CQC/CQA verification of the adequacy of all field seams and repairs, including associated testing, is complete.

END OF SECTION

Appendix E

CQA PLAN

City of Greensboro
Greensboro, North Carolina

White Street Landfill – Phase III/Cell 2 Expansion

Construction Quality Assurance Plan

HDR Project No: 06770-029-018

HDR

HDR Engineering, Inc. of the Carolinas
128 S. Tryon Street, Suite 1400
Charlotte, North Carolina 28202

CONSTRUCTION QUALITY ASSURANCE PLAN

TABLE OF CONTENTS

SECTION 1.0
GENERAL

1.1 INTRODUCTION

This Construction Quality Assurance (CQA) Plan has been prepared to provide the Owner, Engineer, and CQA Consultant the means to govern the construction quality and to satisfy landfill certification requirements under current solid waste management regulations.

More specifically, this CQA Plan addresses the soils and geosynthetics components of the liner and leachate collection/removal (LCR) systems. The liner system, as referenced herein, generally consists of a soil subgrade and a composite liner (consisting of a compacted soil liner, a Geosynthetic Clay Liner and an overlying HDPE geomembrane liner). The LCR system consists of a granular drainage material with perforated collection piping, manholes, and fittings. General references in this Plan to the various components as the "liner or LCR system(s)" are intended to be as described herein.

The CQA Plan is divided into the following sections:

- Section 1.0 General
- Section 2.0 Soil Liner Construction Quality Assurance
- Section 3.0 Geomembrane Liner Construction Quality Assurance
- Section 4.0 LCR Construction Quality Assurance
- Section 5.0 Geotextile Construction Quality Assurance
- Section 6.0 High Density Polyethylene Pipe, Manholes, and Fittings Construction Quality Assurance
- Section 7.0 Geonet Construction Quality Assurance
- Section 8.0 GCL Construction Quality Assurance
- Section 9.0 Surveying Construction Quality Control
- Section 10.0 Construction Quality Assurance Documentation

1.2 DEFINITIONS RELATING TO CONSTRUCTION QUALITY

1.2.1 Construction Quality Assurance (CQA)

In the context of this Plan, construction quality assurance is defined as a planned and systematic program employed by the Owner to assure conformity of the liner systems, LCR systems, and protective cover system installation with Contract Drawings, and the project specifications. CQA is provided by the CQA Consultant as a representative of the Owner and is independent from the Contractor and all manufacturers. The CQA program is designed to provide adequate confidence that items or services meet contractual and regulatory requirements and will perform satisfactorily in service.

1.2.2 Construction Quality Control (CQC)

Construction Quality Control refers to actions taken by manufacturers, fabricators, installers, or the Contractor to ensure that the materials and the workmanship meet the requirements of this CQA Plan and the project specifications. In the case of the liner and LCR systems, CQC is provided by the Contractor's CQC Consultant. In the case of geosynthetic components, material quality control (QC) is provided by the manufacturer's certification and the CQC for the installation of the various geosynthetics is provided by the Contractor's CQC Consultant. The manufacturer's specifications and quality control (QC) requirements are included in this CQA Plan by reference only. A complete updated version of each geosynthetic component manufacturer's QC Plan will be incorporated as part of the Contractor's CQC Plan.

1.2.3 CQC/CQA Certification Document

At the completion of construction and prior to placement of waste in the landfill, a certification document will be prepared by the CQA Consultant and be submitted to State Solid Waste Regulators. The certification report will include all QC testing performed by the Geosynthetics Manufacturers, all CQC testing performed by the CQC Consultant, or Geosynthetic Installers, and all CQA conformance testing performed by the CQA Consultant.

1.2.4 Discrepancies Between Documents

The CQA Plan is intended to be a supporting document to improve the overall documentation of the Work. The CQA Plan is less specific from the project specifications, and conflicts may exist between the documents. The Contractor is instructed to bring discrepancies to the attention of the Engineer or CQA Consultant for resolution. The Engineer has the sole authority to determine resolution of discrepancies existing within the Contract Documents. Unless otherwise determined by the Engineer, the more stringent requirement shall be the controlling resolution. Reference is made to the project specifications, Section 00700 - General Conditions.

1.3 PARTIES TO CONSTRUCTION QUALITY ASSURANCE

1.3.1 Description of the Parties

The parties to Construction Quality Assurance and Quality Control include the Owner, Project Manager, Engineer, Contractor, Geosynthetics Manufacturer, Geosynthetics Installer, CQA Consultant, Geosynthetics CQA Laboratory, Soils CQA Laboratory, CQC Consultant, Geosynthetics CQC Laboratory, and Soils CQC Laboratory. The lines of authority and communications between each of the parties involved in the CQA and CQC are illustrated in Figure 1 (Page 4).

1.3.1.1 Owner

The Owner is the City of Greensboro, who owns and/or is responsible for the facility.

1.3.1.2 Project Manager

The Project Manager is the official representative of the Owner. The Project Manager serves as communications coordinator for the project, initiating the resolution, preconstruction, and construction meetings outlined in Section 1.7. The Project Manager shall also be responsible for proper resolution of all quality issues that arise during construction. The Project Manager is HDR Engineering, Inc. of the Carolinas, of Charlotte, NC.

1.3.1.3 Engineer

The Engineer is responsible for the engineering design, drawings, plans and project specifications for the liner system and protective cover system. The Engineer is HDR Engineering, Inc. of the Carolinas, of Charlotte, NC.

1.3.1.4 Contractor

The Contractor is responsible for the construction of the subgrade, construction of the subbase (as applicable), soil liner berms, soil and geosynthetic liners, anchor trench excavation and backfill, and for placement of the LCR system. The Contractor is responsible for submittal coordination and the overall CQC on the project.

1.3.1.5 Geosynthetics Manufacturer

The Geosynthetics Manufacturer(s) is(are) responsible for the production of geomembranes, geosynthetic clay liners, geonets, and geotextiles. The manufacturers are responsible for Quality Control (QC) during manufacture of the geosynthetic components, certification of the properties of the geosynthetic components, and field installation criteria.

1.3.1.6 Geosynthetics Installer

The Geosynthetics Installer(s) is(are) a subcontractor of the Contractor and is(are) responsible for field handling, storing, placing, seaming, protection of (against wind, etc.), and other aspects of the geosynthetics installations, including the geomembranes, geosynthetic clay liners and geotextiles. The Installer may also be responsible for transportation of these materials to the site, and for the preparation and completion of anchor trenches.

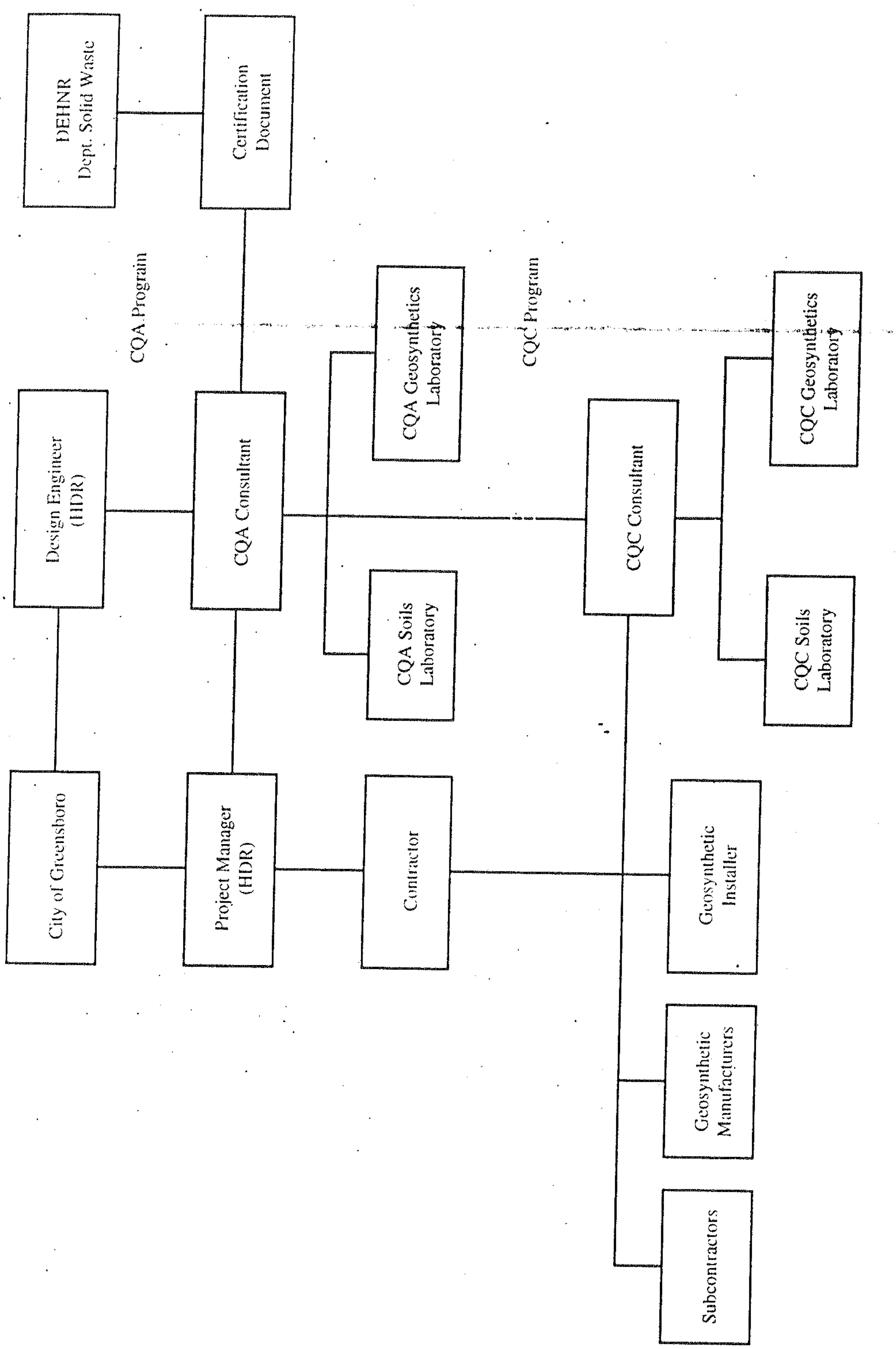

Figure 1 - CQA/CQC Lines of Authority and Communication

1.3.1.7 Construction Quality Assurance Consultant

The CQA Consultant is a representative of the Owner and is responsible for observing, testing, and documenting activities related to the CQC/CQA of the earthworks at the site, and the installation of the geosynthetic components of the liner and leachate collection/removal systems. The CQA Consultant is also responsible for issuing a facility certification report, sealed by a Professional Engineer registered in North Carolina.

1.3.1.8 Geosynthetics Construction Quality Assurance Laboratory

The Geosynthetics CQA Laboratory is a party, independent from the Owner, that is responsible for conducting tests on conformance samples of geosynthetics used in the liner and LCR systems. The Geosynthetics CQA Laboratory service cannot be provided by any party involved with the manufacture, fabrication, or installation of any of the geosynthetic components.

1.3.1.9 Soils Construction Quality Assurance Laboratory

The Soils Construction Quality Assurance Laboratory is a party, independent from the Owner, that is responsible for conducting geotechnical tests on conformance samples of soils used in the liner system. The Soils CQA Laboratory service cannot be provided by any party involved with the Contractor.

1.3.1.10 Construction Quality Control Consultant

The CQC Consultant is a representative of the Contractor and is responsible for the earthwork and soil liner quality control sampling and testing. The term CQC Consultant shall be used to designate the Engineer in charge of the quality control work. The personnel of the CQC Consultant also includes Quality Control Monitors who are also located at the site for construction observation and monitoring. The CQC Consultant is responsible for the timely conveyance of CQC testing results to the CQA Consultant.

1.3.1.11 Geosynthetics Construction Quality Control Laboratory

The Geosynthetics CQC Laboratory is a party, independent from the Contractor, that is responsible for conducting tests on conformance samples of geosynthetics used in the liner and LCR systems.

1.3.1.12 Soils Construction Quality Control Laboratory

The Soils Construction Quality Control Laboratory is a party, independent from the Contractor, that is responsible for conducting geotechnical tests on conformance samples of soils used in the liner system.

1.3.2 Qualifications of the Parties

The following qualifications are required of all parties involved with the manufacture, fabrication, ~~installation, transportation, and CQC/CQA of all materials for the~~ liner and LCR systems. Where applicable, these qualifications must be submitted by the Contractor to the Project Manager for review and approval.

1.3.2.1 Contractor

Qualifications of the Contractor are specific to the construction contract and independent of this CQA Plan.

1.3.2.2 Geosynthetics Manufacturers

Each Geosynthetics Manufacturer must satisfy the qualifications presented in the project specifications and must be prequalified and approved by the Project Manager.

The physical properties of each geosynthetic product must be certified by the geosynthetics manufacturer. The properties certified must include, at a minimum, those identified in the project specifications. Manufacturers certification must be approved by the CQA Consultant before the product is used.

1.3.2.3 Geosynthetic Installer(s)

The Geosynthetic Installer(s) will be trained and qualified to install the geosynthetics components of the liner system. Each Geosynthetics Installer must meet the requirements of the project specifications and be approved by the Project Manager. The Geomembrane Installer must be approved by the Geomembrane Manufacturer.

1.3.2.4 Construction Quality Assurance Consultant

The CQA Consultant will act as the Owner's CQA Representative and will report to the Project Manager. The CQA Consultant will perform conformance testing to satisfy the requirements of this CQA Plan, will observe the CQC work performed by the CQC Consultant, and will prepare the certification document incorporating both CQA and CQC test data. The CQA Consultant will have experience in the CQC/CQA aspects of landfill liner system construction and soils testing, and be familiar with ASTM and other related industry standards. The activities of the CQA Consultant will be performed under the supervision of a Registered Professional Engineer.

1.3.2.5 Construction Quality Control Consultant

The CQC Consultant will be a party, independent from the Contractor. The CQC Consultant will be experienced with soils, including soil liners, and geosynthetics, including geomembranes, geosynthetic clay liner, geonets, and geotextiles. The CQC Consultant will satisfy the requirements of the project specifications and be approved by the Project Manager. ~~The activities of the CQC Consultant will be performed~~ under the supervision of a Registered Professional Engineer.

1.3.2.6 Geosynthetics Construction Quality Control Laboratory

The Geosynthetics CQC Laboratory is a subcontractor of the CQC Consultant and will have experience in testing geosynthetics and be familiar with ASTM, GRI, and other applicable test standards. The Geosynthetics CQC Laboratory will be capable of providing test results within 24 hours or a reasonable time after, as agreed to at the outset of the project, receipt of samples, and will maintain that standard throughout the installation.

1.4 SCOPE OF CONSTRUCTION QUALITY ASSURANCE PLAN

The scope of this CQA Plan includes the CQA of the soils and geosynthetic components of the liner and LCR systems for the subject facility. The CQA for the selection, evaluation, and placement of the soils is included in the scope. This document is intended to be used in concert with the CQC requirements presented in the project specifications.

1.5 UNITS

In this CQA Plan, all properties and dimensions are expressed in U.S. units.

1.6 REFERENCES

The CQA Plan includes references to the most recent version of the test procedures of the American Society of Testing and Materials (ASTM), the Federal Test Method Standards (FTMS), and the "Geosynthetic Research Institute" (GRI).

1.7 SITE AND PROJECT CONTROL

To guarantee a high degree of quality during installation, clear, open channels of communication are essential. To that end, meetings are critical.

1.7.1 CQA/CQC Resolution Meeting

Prior to field mobilization by the Contractor, a Resolution Meeting will be held. This meeting will include all parties then involved, including the Project Manager, the CQA Consultant, the Engineer, the Contractor, and the CQC Consultant.

The purpose of this meeting is to begin planning for coordination of tasks, anticipate any problems which might cause difficulties and delays in construction, and, above all, review the CQA and CQC Plans to all of the parties involved. It is very important that the rules regarding testing, repair, etc., be known and accepted by all.

This meeting should include all of the following activities:

- communicate to all parties any relevant documents;
- review critical design details of the project;
- review the seam layout drawing provided by the Geomembrane/Geosynthetic Installer.
- review the site-specific CQA and CQC Plans;
- make any appropriate modifications to the CQA and CQC Plans to ensure that they specify all testing activities that are necessary;
- reach a consensus on the CQA/CQC quality control procedures, especially on methods for determining acceptability of the soils and geosynthetics;
- review the proposed liner system and protective cover system;
- decide the number of spare seaming units for geomembranes to be maintained on site by the Geomembrane/Geosynthetic Installer (this number depends on the number of seaming crews and on the type of seaming equipment);
- select testing equipment and review protocols for testing and placement of general earthwork materials;
- confirm methods for the soil liner material selection testing, acceptable zone determinations, and test strip installation;
- confirm the methods for documenting and reporting, and for distributing documents and reports; and

- confirm the lines of authority and communication.

The meeting will be documented by the Project Manager and minutes will be transmitted to all parties.

1.7.2 CQA/CQC Preconstruction Meeting

A Preconstruction Meeting will be held at the site prior to placement of the geosynthetic liner system. At a minimum, the meeting will be attended by the Project Manager, Engineer, ~~the CQA Consultant, the Contractor, the CQC Consultant~~, and the Geosynthetic/Geomembrane Installation Superintendent.

Specific topics considered for this meeting include:

- make any appropriate modifications to the CQA and CQC Plans;
- review the responsibilities of each party;
- review lines of authority and communication;
- review methods for documenting and reporting, and for distributing documents and reports;
- establish protocols for testing;
- establish protocols for handling deficiencies, repairs, and retesting;
- review the time schedule for all operations;
- establish rules for writing on the geomembrane, i.e., who is authorized to write, what can be written, and in which color;
- outline procedures for packaging and storing archive samples;
- review panel layout and numbering systems for panels and seams;
- establish procedures for use of the extrusion seaming apparatus, if applicable;
- establish procedures for use of the fusion seaming apparatus, if applicable;
- finalize field cutout sample sizes;

- review seam testing procedures;
- review repair procedures; and
- establish soil stockpiling locations (if any).

The meeting will be documented by the Project Manager and minutes will be transmitted to all parties. The Resolution Meeting and the Preconstruction Meeting may be held as one meeting or separate meetings, depending on the direction of the Project Manager.

1.7.3 Daily and Weekly CQA/CQC Progress Meetings

A weekly progress meeting will be held between the Project Manager, the CQA Consultant, the Contractor, the CQC Consultant, the Geosynthetic/Geomembrane Installation Superintendent, and representatives from any other involved parties. This meeting will discuss current progress, planned activities for the next week, and any new business or revisions to the work. The CQA Consultant will log any problems, decisions, or questions arising at this meeting in his daily report. Any matter requiring action which is raised in this meeting will be reported to the appropriate parties.

A daily meeting will be held between the CQA Consultant, the CQC Consultant, the Geosynthetic/ Geomembrane Installation Superintendent, and representatives from any other involved parties. This meeting will discuss current progress, planned activities for the next shift, and any new business or revisions to the work. The CQA Consultant will log any problems, decisions, or questions arising at this meeting in his daily report. Any matter requiring action which is raised in this meeting will be reported to the appropriated parties.

Meeting frequency will depend on the schedule of the project and the mutual agreement of all parties involved.

1.7.4 Problem or Work Deficiency Meetings

A special meeting will be held when and if a problem or deficiency is present or likely to occur. At a minimum, the meeting will be attended by all interested parties, the Contractor, the Project Manager, and the CQA Consultant. If the problem requires a design modification, the Engineer should also be present. The purpose of the meeting is to define and resolve the problem or work deficiency as follows:

- define and discuss the problem or deficiency;
- review alternative solutions; and

- implement an action plan to resolve the problem or deficiency.

The meeting will be documented by the Project Manager and minutes will be transmitted to affected parties.

SECTION 2.0
SOIL LINER CONSTRUCTION QUALITY ASSURANCE

2.1 INTRODUCTION

This section of the CQA Plan addresses the soil components of the liner system, and outlines the soils CQA program to be implemented with regard to materials confirmation, laboratory and field confirmation test requirements, overview and interfacing with the Contractor's CQC Program, and resolution of problems.

2.2 EARTHWORK CONSTRUCTION

2.2.1 Subgrade

The subgrade material below the controlled fill will be prepared by the Contractor prior to the placement of fill. The CQC Consultant will provide density testing of the pre-fill subgrade at the frequency specified in the project specifications. The CQA Consultant will observe the proofroll by the Contractor, review the density test data provided by the CQC Consultant, and provide verification that the pre-fill subgrade is acceptable. The CQA Consultant may conduct confirmation density testing as deemed appropriate.

2.2.2 Structural/Controlled Fill

The Contractor shall place fill in accordance with the project specifications. The CQC Consultant shall provide testing of the controlled fill material in accordance with the project specifications. The CQA Consultant will provide confirmation testing of the controlled fill as deemed appropriate.

2.3 SOIL LINER SYSTEM

2.3.1 Soil Liner Subgrade

Testing will be conducted by the CQC Consultant as observed by the CQA Consultant. The subgrade material below the subbase is composed of controlled fill and in situ soils. The surface of the subgrade will be prepared prior to the construction of the subbase. The CQA Consultant will visually examine the surface of the subgrade to verify that any potentially deleterious materials have been removed.

2.3.2 Soil Liner Material

The soil liner material shall be placed and compacted in accordance with the project specifications. The CQC Consultant shall conduct field density and moisture tests at the frequency presented in the project specifications. The CQA Consultant shall provide conformance tests at a frequency of approximately 10 percent of the required CQC tests. Additional CQA conformance testing may be performed at the discretion of the CQA Consultant.

Hydraulic ~~Conductivity, Atterberg Limits, and Percent Fines~~ testing of the soil liner material shall be performed by the CQC Consultant in accordance with the project specifications. Additional CQA conformance testing may be performed at the discretion of the CQA Consultant.

Thickness measurement shall be conducted in accordance with the project specifications by the CQC Consultant and observed by the CQA Consultant.

2.4 SOILS TESTING

2.4.1 Test Methods

All testing used to evaluate the suitability or conformance of soils materials will be carried out in accordance with the project specifications.

2.4.2 Soils Testing Requirements

The soil CQC testing must comply with the minimum frequencies presented in the project specifications. The frequency of CQA testing required will be determined by the CQA Consultant in light of the potential variability of materials and the acceptance/failure rate of the CQC testing.

2.5 SOILS CONSTRUCTION QUALITY ASSURANCE

CQA will be performed on all soil components of the liner construction. CQA evaluation will consist of: (1) monitoring the work and observing the CQC testing; and (2) performing laboratory and field conformance tests. Laboratory CQA conformance tests will be conducted on samples taken at the borrow source, stockpile, and during the course of the work prior to construction. Field CQA conformance tests will be conducted during the course of the work.

2.5.1 Monitoring

The CQA Consultant shall monitor and document the construction of all soil components. Monitoring the construction work for the subbase soil, and the soil component of the liner system, includes the following:

- observing CQC testing to determine the water content and other physical properties of the subbase and soil component of the liner system during compaction and compilation of the data;
- monitoring the loose thickness of lifts as placed;
- monitoring the action of the compaction and/or heavy hauling equipment on the construction surface (i.e., penetration, pumping, cracking. etc.); and
- monitoring the number of passes used to compact each lift.

2.5.2 Construction Quality Assurance Judgmental Testing

During construction, the frequency of conformance testing may be increased at the discretion of the CQA Consultant when visual observations of construction performance indicate a potential problem. Additional testing for suspected areas will be considered when:

- the rollers slip during rolling operation;
- the lift thickness is greater than specified;
- the fill material is at an improper moisture content;
- fewer than the specified number of roller passes are made;
- dirt-clogged rollers are used to compact the material;
- the rollers may not have used optimum ballast;
- the fill materials differ substantially from those specified; or
- the degree of compaction is doubtful.

2.5.3 Perforations in Soil Liner

Perforations that must be filled will include, but not be limited to, the following:

- nuclear density test probe locations;
- permeability sampling locations; and/or
- thickness checks.

Unless otherwise noted, or as directed by the Project Manager, all perforations of the subbase by probes or sample tubes will be backfilled in accordance with project specifications. The CQA Consultant will observe and confirm that adequate procedures are being employed.

2.5.4 Deficiencies

If a defect is discovered in the earthwork product, the CQC Consultant will immediately determine the extent and nature of the defect. If the defect is indicated by an unsatisfactory test result, the CQC Consultant will determine the extent of the deficient area by additional tests, observations, a review of records, or other appropriate means. If the defect is related to adverse site conditions, such as overly wet soils or surface desiccation, the CQC Consultant will define the limits and nature of the defect.

2.5.5.1 Notification

After determining the extent and nature of a defect, the CQC Consultant will notify the Project Manager, the CQA Consultant, and Contractor and schedule appropriate retests when the work deficiency is corrected. The CQA Consultant shall observe all retests on defects.

2.5.5.2 Repairs and Retesting

The Contractor will correct the deficiency to the satisfaction of the CQA Consultant. If a project specification criterion cannot be met, or unusual weather conditions hinder work, then the CQC Consultant will develop and present to the Project Manager and CQA Consultant suggested solutions for approval.

All retests recommended by the CQC Consultant must verify that the defect has been corrected before any additional work is performed by the Contractor in the area of the deficiency. The CQA Consultant will verify that all installation requirements are met and that all submittals are provided.

2.5.5.3 Penalties

Refer to Specification Section 02775.

3.1.1.2 Geomembrane Manufacturing

Prior to the installation, the Geomembrane Manufacturer will provide the Contractor and the CQA Consultant with the following:

- a properties sheet including, at a minimum, all specified properties, measured using test methods indicated in the project technical specifications, or equivalent;
- the sampling procedure and results of testing; and
- a certification that property values given in the properties sheet are minimum average roll values and are guaranteed by the Geomembrane Manufacturer.

The CQA Consultant will review these documents and verify that:

- the reported property values certified by the Geomembrane Manufacturer meet all of the project technical specifications;
- the measurements of properties by the Geomembrane Manufacturer are properly documented and that the test methods used are acceptable; and
- Report any discrepancies with the above requirements to the Project Manager.

3.1.1.3 Rolls and Sheets

Prior to shipment, the Geomembrane Manufacturer will provide the CQA Consultant and the CQC Consultant with a quality control certificate for each roll (HDPE geomembrane) or sheet (non-HDPE geomembrane) of geomembrane provided. The quality control certificate will be signed by a responsible party employed by the Geomembrane Manufacturer, such as the Production Manager. The quality control certificate will include:

- roll numbers and identification; and
- sampling procedures and results of quality control tests -- as a minimum, results will be given for thickness, tensile characteristics and tear resistance, evaluated in accordance with the methods indicated in the project specifications or equivalent methods approved by the Engineer.

The quality control certificate will be bound and included as part of the report required in Section 3.1.1.1.

The CQA Consultant will:

- verify that the quality control certificates have been provided at the specified frequency and that each certificate identified the rolls or sheets related to it;

- review the quality control certificates and verify that the certified roll or sheet properties meet the project technical specifications; and

- report any discrepancies with the above requirements to the Project Manager.

3.2 GEOMEMBRANE INSTALLATION

3.2.1 Transportation, Handling, and Storage

3.2.1.1 Transportation and Handling

The CQA Consultant will verify that:

- handling equipment used on the site is adequate, meets manufacturer's recommendations, and does not pose any risk of damage to the geomembrane; and

- the Geomembrane Installer's personnel handle the geomembranes with care.

Upon delivery at the site, the CQA Consultant will conduct a surface observation of all rolls and sheets for defects and damage. This examination will be conducted without unrolling rolls or unfolding sheets unless defects or damages are found or suspected. The CQA Consultant will indicate to the Project Manager:

- any rolls or sheets, or portions thereof, that should be rejected and removed from the site because they have severe flaws; and

- any rolls or sheets that have minor repairable flaws.

Refer to ASTM D4873 for detailed methods.

3.2.1.2 Storage

The CQA Consultant will document that the Contractor's storage of the geomembrane provides adequate protection against moisture, dirt, shock, and other sources of damage or contamination.

3.2.2 Earthwork

3.2.2.1 Surface Preparation

The CQC Consultant and the Geomembrane Installer will certify in writing that the surface on which the geomembrane will be installed meets line and grade, and the surface preparation requirements of the project specifications. The certificate of acceptance will be given by the CQC Consultant to the CQA Consultant prior to commencement of geomembrane installation in the area under consideration. The CQA Consultant will give a copy of this certificate to the Project Manager.

To ensure a timely covering of the soil liner surface, the Project Manager may allow subgrade acceptance in areas as small as one acre. After the supporting soil has been accepted by the Geomembrane Installer, it will be the Geomembrane Installer's responsibility to indicate to the Project Manager of any change in the supporting soil condition that may require repair work. If the CQA Consultant concurs with the Geomembrane Installer, then the Project Manager will ensure that the supporting soil is repaired.

3.2.2.2 Anchorage System

The CQA Consultant will verify that anchor trenches have been constructed and backfilled according to project specifications and design drawings.

3.2.3 Geomembrane Placement

3.2.3.1 Field Panel Identification

The CQA Consultant will document that the Geomembrane Installer labels each field panel with an "identification code" (number or letter-number consistent with the layout plan) agreed upon by the CQC Consultant, Geomembrane Installer, and CQA Consultant at the CQA/CQC Preconstruction Meeting, Section 1.7.2.

The Geomembrane Installer will establish a table or chart showing correspondence between roll numbers and field panel identification codes. This documentation shall be submitted to the CQC Consultant and CQA Consultant weekly for review and verification. The field panel identification code will be used for all quality control and quality assurance records.

3.2.3.2 Field Panel Placement

3.2.3.2.1 Location

The CQA Consultant will verify that field panels are installed at the location indicated in the Geomembrane Installer's layout plan, as approved or modified in Section 3.2.3.1.

3.2.3.2.2 Installation Schedule

The CQA Consultant will evaluate every change in the schedule proposed by the Geomembrane Installer and advise the Project Manger on the acceptability of that change. The CQA Consultant will verify that the condition of the supporting soil has not changed detrimentally during installation.

The CQA Consultant will record the identification code, location, and date of installation of each field panel.

3.2.3.2.3 Placement of Geomembrane

The CQA Consultant will verify that project specification related restrictions on placement of geomembrane are fulfilled. Additionally, the CQA Consultant will verify that the supporting soil has not been damaged by weather conditions.

The CQA Consultant will inform the Project Manager if the above conditions are not fulfilled.

3.2.3.2.4 Damage

The CQA Consultant will visually observe each panel, after placement and prior to seaming, for damage. The CQA Consultant will advise the Project Manager which panels, or portion of panels, should be rejected, repaired, or accepted. Damaged panels or portions of damaged panels which have been rejected will be marked and their removal from the work area recorded by the CQA Consultant. Repairs will be made according to procedures described in the project specifications.

As a minimum, the CQA Consultant will document that:

- the panel is placed in such a manner that it is unlikely to be damaged; and
- any tears, punctures, holes, thin spots, etc., are either marked by the Geomembrane Installer for repair or the panel is rejected.

3.2.4 Field Seaming

3.2.4.1 Seam Layout

The Geomembrane Installer will provide the CQA Consultant with a seam layout drawing, i.e., a drawing of the facility to be lined showing all expected seams. The CQA Consultant and Engineer will review the seam layout drawing and verify that it is consistent with the accepted state of practice and this CQA Plan. In addition, no panels not specifically shown on the seam layout drawing may be used without the Project Manager's prior approval.

A seam numbering system compatible with the panel numbering system will be agreed upon at the Resolution and/or Preconstruction Meeting, Section 1.7. An on-going written record of the seams and repair areas shall be maintained by the Geomembrane Installer with weekly review by the CQA Consultant.

3.2.4.2 Requirements of Personnel

The Geomembrane Installer will provide the CQA Consultant with a list of proposed seaming personnel and their experience records. This document will be reviewed by the Project Manager and the CQA Consultant for compliance with project specifications.

3.2.4.3 Seaming Equipment and Products

Field seaming processes must comply with project specifications. Proposed alternate processes will be documented and submitted to the CQA Consultant for his approval. Only seaming apparatus which have been specifically approved by make and model will be used. The CQA Consultant will submit all documentation to the Engineer for his concurrence.

3.2.4.4 Nondestructive Seam Continuity Testing

The Geomembrane Installer will nondestructively test all field seams over their full length using test methods approved by the project specifications. The CQA Consultant shall periodically observe the nondestructive testing to ensure conformance with this CQA Plan and the project specifications.

For approximately 10% of the noncomplying tests, the CQA Consultant will:

- observe continuity testing of the repaired areas performed by the Geomembrane Installer;

- confirm the record location, date, test unit number, name of tester, and compile the record of testing provided by the Geomembrane Installer;

- provide a walkthrough inspection of all impacted seam areas and verify that the areas have been tested in accordance with the CQA Plan and project specifications; and

- verify that the Geomembrane Installer has marked repair areas with the appropriate color-coded marking pencil.

3.2.4.5 Destructive Seam Testing

Destructive seam tests will be performed by the CQC consultant at locations and a frequency in accordance with the project specifications. The CQA Consultant will perform conformance tests on a minimum of 10% of the CQC destructive seam test samples obtained. Additional destructive seam tests may be required at the CQA Consultant's discretion. Selection of such locations may be prompted by suspicion of contamination, excessive grinding, offcenter and/or offset seams, or any other potential cause of imperfect seaming.

3.2.4.5.1. Geosynthetics Construction Quality Assurance Laboratory Testing

Destructive test samples will be packaged and shipped by the CQA Consultant in a manner that will not damage the test sample. The Project Manager will be responsible for storing the archive samples. These procedures will be fully outlined at the Resolution Meeting, Section 1.7. Test samples will be tested by the Geosynthetics CQA Laboratory.

Conformance testing will include "Seam Strength" and "Peel Adhesion" (ASTM D6392 using one-inch strips and a strain rate of two inches per minute) in accordance with the project specifications. All geomembrane destructive test samples that fail to meet project specifications shall be saved and sent to the CQA Consultant for observation.

The Geosynthetics CQA Laboratory will provide preliminary test results no more than 24 hours after they receive the samples. The CQA Consultant will review laboratory test results as soon as they become available.

3.2.4.5.2 Defining Extent of Destructive Seam Test Failure

All defective seam test failures must be bounded by seam tests from which destructive samples passing laboratory tests have been taken. The CQA Consultant will document repair actions taken in conjunction with all destructive seam test failures.

3.2.5 Defects and Repairs

All seams and nonseam areas of the geomembrane will be examined by the CQC Consultant for identification of defects, holes, blisters, undispersed raw materials, and any sign of contamination by foreign matter. Each suspected location, both in seam and nonseam areas, will be nondestructively tested using methods in accordance with the project specifications. Each location which fails the nondestructive testing will be marked by the CQC Consultant and repaired by the Geomembrane Installer. Repair procedures will be in accordance with project specifications or procedures agreed to by the Project Manager in the preconstruction meeting. The CQA Consultant will observe all repair procedures and advise the Project Manager of any problems.

3.2.6 Backfilling of Anchor Trench

Anchor trenches will be will be backfilled and compacted as outlined in the project specifications. The CQA Consultant will review the backfilling operation and advise the Project Manager of any problems.

3.2.7 Liner System Acceptance

The Geomembrane Installer and the Geosynthetic Manufacturers will retain all ownership and responsibility for the geosynthetics in the landfill cell until acceptance by the Owner.

The geomembrane component of the liner system will be accepted by the Owner when:

- the installation is finished;
- verification of the adequacy of all seams and repairs, including associated testing, is complete;
- CQC Consultant provides the CQA Consultant and Project Manager with a final copy of the nondestructive test documentation, repair information, and as-built drawings.
- CQA Consultant furnishes the Project Manager with certification that the geomembrane was installed in accordance with the Geosynthetic Manufacturer's recommendations as well as the Plans and project specifications;

- all documentation of installation is completed including the CQA Consultant's final report; and

- certification by the CQA Consultant, including Record Drawing(s), sealed by a Professional Engineer registered in the state in which the project is located, has been received by the Project Manger.

The CQA Consultant will certify that the installation has proceeded in accordance with this CQA Plan and the project specifications for the project except as noted to the Project Manager.

3.2.8 Materials in Contact with Geomembranes

The quality assurance procedures indicated in this Subsection are only intended to assure that the installation of these materials does not damage the geomembrane. Although protective geosynthetics and geotextiles have been incorporated into the liner system, all reasonable measures to protect the geomembrane and provide additional quality assurance procedures are necessary to assure that systems built with these materials will be constructed to ensure proper performance.

3.2.8.1 Soils

Prior to placement, the CQA Consultant will visually confirm that all soil materials to be placed against the geomembrane comply with project specifications. The Geomembrane Installer will provide the CQA Consultant a written surface acceptance certificate in accordance with Section 3.2. 1. All soil materials shall be placed and compacted in accordance with project specifications.

3.2.8.2 Sumps and Appurtenances

The CQA Consultant will verify that:

- installation of the geomembrane in appurtenance areas, and connection of the geomembrane to appurtenances have been made according to the project specifications;

- extreme care is taken while seaming around appurtenances since neither nondestructive nor destructive testing may be feasible in these areas;

- the geomembrane has not been visibly damaged while making connections to appurtenances;

- The installation of the geomembrane shall be exercised so as not to damage sumps; and

- the CQA Consultant will inform the Project Manager if the above conditions are not fulfilled.

SECTION 4.0
LCR CONSTRUCTION QUALITY ASSURANCE

4.1 INTRODUCTION

This section of the CQA plan addresses the sand and gravel drains, and the soil buffer layer of the LCR system. By reference to Sections 5.0 and 6.0 of this CQA Plan, this section also addresses the perforated plastic pipes and geotextile filters and cushions that are included in the LCR system. This section outlines the CQA program to be implemented with regard to materials confirmation, laboratory and field test requirements, overview and interfacing with the Contractor's CQC Program, and resolution of problems.

4.2 GRANULAR LEACHATE COLLECTION SYSTEM

4.2.1 Protective Cover (Leachate Collection Layer) Material

The LCR layer shall be placed and compacted in accordance with the project specifications. The CQC Consultant will provide gradation and density testing of the granular material at the frequency specified in the project specifications. The CQA Consultant will observe that placement of the granular material is done in a manner to protect the geomembrane, and review the gradation and density test data provided by the CQC Consultant. The CQA Consultant may conduct confirmation gradation and density testing as deemed appropriate.

4.2.2 Sump and LCR Pipe Drain Material

The drain material placed in the sumps and surrounding the LCR drainage pipe shall be placed in accordance with the project specifications. The CQC Consultant will provide gradation and mineralogical testing of the gravel material at the frequency specified in the project specifications. The CQA Consultant will observe that placement of the gravel is done in a manner to protect the geomembrane and plastic pipe and review the gradation and density test data provided by the CQC Consultant. The CQA Consultant may conduct confirmation gradation and additional testing as deemed appropriate.

4.3 RELATED MATERIALS

4.3.1 Geotextile Cushion and Filter Material

The geotextile cushion placed beneath the sand drainage layer, and the geotextile separator placed between the drainage layer and the opertational layer shall be placed in accordance with project specifications. The CQA program for these materials is presented in Section 5.0 of this CQA Plan.

4.3.2 High Density Polyethylene (HDPE) Pipe Material

The perforated HDPE pipe placed within the gravel drain material shall be placed in accordance with project specifications. The CQA program for this material is presented in Section 6.0 of this CQA Plan.

4.3.3 Operational Layer Material

The operational layer material shall be placed and compacted in accordance with project specifications. The CQC Consultant will provide classification testing of the material at the frequency specified in the project specifications. The CQA Consultant will observe that the placement of the soil is done in a manner to protect the separator geotextile and review the classification data provided by the CQC Consultant. The CQA Consultant may conduct confirmation classification testing as deemed appropriate.

4.4 MATERIALS TESTING

4.4.1 Test Methods

All testing used to evaluate the suitability or conformance of LCR materials will be carried out in accordance with the project specifications.

4.4.2 Material Testing Requirements

The material CQC testing must comply with the minimum frequencies presented in the project specifications. The frequency of CQA testing will be determined by the CQA Consultant in light of the potential variability of the materials and the acceptance/failure rate of the CQC testing.

4.5 LCR CONSTRUCTION QUALITY ASSURANCE

CQA will be performed on all components of the LCR system construction. CQA evaluation will consist of: (1) monitoring the work and observing the CQC testing, and (2) performing laboratory and field conformance tests. Laboratory CQA conformance tests will be conducted on samples taken at the borrow source, stockpile, and during the course of work prior to construction. Field conformance tests will be conducted during the course of the work.

4.5.1 Monitoring

The CQA Consultant shall monitor and document the construction of all LCR components. Monitoring the construction work for the natural materials of the LCR system includes the following:

- reviewing CQC testing for gradation and other physical properties of the natural materials and compilation of the data;
- monitoring the minimum vertical buffer maintained between field equipment and the geomembrane; and
- monitoring the placement of the natural materials does not fold or damage the geomembrane in any way.

4.5.2 Deficiencies

If a defect is discovered in the earthwork product, the CQC Consultant will immediately determine the extent and nature of the defect and report it to the CQA Consultant. If the defect is indicated by an unsatisfactory test result, the CQC Consultant will determine the extent of the deficient area by additional tests, observations, a review of records, or other means that the CQA Consultant deems appropriate.

4.5.2.1 Notification

After determining the extent and nature of a defect, the CQC Consultant will notify the Project Manager and Contractor and schedule appropriate retests when the work deficiency is corrected. The CQA Consultant shall observe all retests on defects.

4.5.2.2 Repairs and Retesting

The Contractor will correct the deficiency to the satisfaction of the CQA Consultant. If a project specification criterion cannot be met, or unusual weather conditions hinder work, then the CQC Consultant will develop and present to the Project Manager suggested solutions for his approval.

All retests recommended by the CQC Consultant must verify that the defect has been corrected before any additional work is performed by the Contractor in the area of the deficiency. The CQA Consultant will verify that all installation requirements are met and that all submittals are provided.

4.5.2.3 Penalties

Refer to Specification Section 02775.

SECTION 5.0
GEOTEXTILE MATERIAL AND INSTALLATION QUALITY ASSURANCE

5.1 MANUFACTURING

The Contractor will provide the CQA Consultant with a list of guaranteed "minimum average roll value" properties (as defined by the Federal Highway Administration), for the type of geotextile to be delivered. The Contractor will also provide the CQA Consultant with a written certification from the Geotextile Manufacturer that the materials actually delivered have "minimum average roll value" properties which meet or exceed all property values guaranteed for that type of geotextile.

The CQA Consultant will examine all manufacturer certifications to ensure that the property values listed on the certifications meet or exceed those specified for the particular type of geotextile. Any deviations will be reported to the Project Manager.

The inspection methods, handling techniques, and property values identified in this section for the separator geotextile shall also apply to geotextile portion of the drainage composite (see Section 7.0 for more detail).

5.2 LABELING

The Geotextile Manufacturer will identify all rolls of geotextile in conformance with the project specifications. The CQA Consultant will examine rolls upon delivery and any deviation from the above requirements will be reported to the Project Manager.

5.3 SHIPMENT AND STORAGE

During shipment and storage, the geotextile will be protected as required by manufacturer's recommendations and the project specifications. The CQA Consultant will observe rolls upon delivery at the site and any deviation from the above requirements will be reported to the Project Manager.

5.4 HANDLING AND PLACEMENT

The Geosynthetic Installer will handle all geotextiles in such a manner as required by the project specifications. Any noncompliance will be noted by the CQA Consultant and reported to the Project Manager.

5.5 SEAMS AND OVERLAPS

All geotextiles will be seamed or overlapped in accordance with project specifications or as approved by the CQA Consultant and Engineer.

5.6 REPAIR

Any holes or tears in the geotextile will be repaired in accordance with the project specifications. The CQA Consultant will observe any repair and note any noncompliance with the above requirements and report them to the Project Manager.

5.7 PLACEMENT AND MATERIALS

All soil materials located on top of a geotextile shall be placed in accordance with the project specifications. Any noncompliance will be noted by the CQA Consultant and reported to the Project Manager.

SECTION 6.0

HIGH DENSITY POLYETHYLENE MANHOLES, PIPE AND FITTINGS CONSTRUCTION QUALITY ASSURANCE

6.1 MATERIAL REQUIREMENTS

All HDPE manholes, pipe, and fittings shall be produced in accordance with the project specifications.

6.2 MANUFACTURER

Prior to the installation of HDPE manholes or pipes, the Manufacturer will provide to the Contractor and the CQA Consultant the following:

- a properties sheet including, at a minimum, all specified properties, measured using test methods indicated in the project technical specifications;
- a list of quantities and descriptions of materials other than the base resin which comprise the pipe;
- the sampling procedure and results of testing; and
- a certification by the HDPE Pipe Manufacturer that values given in the properties sheet are minimum values and are guaranteed by the HDPE Pipe Manufacturer.

The CQA Consultant will review these documents and verify that:

- the property values certified by the HDPE Pipe Manufacturer meet all of the project technical specifications; and
- the measurements of properties by the HDPE Pipe Manufacturer are properly documented and that the test methods used are acceptable.
- Report any discrepancies with the above requirements to the Project Manager.

6.2.1 Verification and Identification

Prior to shipment, the Contractor will provide the Project Manager and the CQA Consultant with a quality control certification for each lot/batch of HDPE pipe provided. The quality control certificate will be signed by a responsible party employed by the HDPE Pipe Manufacturer, such as the Production Manger. The quality control certificate will include:

- lot/batch number and identification; and
- sampling procedures and results of quality control tests.

The CQA Consultant will:

- verify that the quality control certificates have been provided at the specified frequency for all lots/batches of pipe, and that each certificate identifies the pipe lot/batch related to it; and
- review the quality control certificates and verify that the certified properties meet the project technical specifications.

6.3 NONDESTRUCTIVE TESTING

6.3.1 Nondestructive Testing of Joints

All nonperforated HDPE joints must be nondestructively tested. These pipe joints will be tested using the pressure test as provided in the project technical specifications. Other nondestructive test methods may be used only when:

- the Geosynthetic Installer can prove its effectiveness;
- the method is approved by the Pipe Manufacturer; and
- the method is approved by the Engineer.

The Project Manager and the CQA Consultant will verify the effectiveness and validity of the alternative test method,

The CQA Consultant will report any nonconformance of testing methods to the Project Manager.

SECTION 7.0
DRAINAGE COMPOSITE CONSTRUCTION QUALITY ASSURANCE

7.1 MATERIAL REQUIREMENTS

All drainage composite shall be produced in accordance with the project specifications.

7.2 MANUFACTURING

The Drainage Composite Manufacturer will provide the Contractor and the CQC Consultant with a written certification, signed by a responsible party, that the geonets actually delivered have properties which meet or exceed the guaranteed properties.

The CQA Consultant will examine all manufacturer's certifications to ensure that the property values listed on the certifications meet or exceed the project specifications. Any deviations will be reported to the Project Manager.

7.3 LABELING

The Drainage Composite Manufacturer will identify all rolls of drainage composite in accordance with project specifications. The CQA Consultant will examine rolls upon delivery and any deviation from the above requirements will be reported to the Project Manager.

7.4 SHIPMENT AND STORAGE

Geonet cleanliness is essential to its performance; therefore, the shipping and storage of geonet must be in accordance with the project specifications. The CQA Consultant will examine rolls upon delivery and any deviation from the above requirements will be reported to the Project Manager.

The CQA Consultant will verify that the drainage composites are free of dirt and dust just before installation. The CQA Consultant will report the outcome of this verification to the Project Manager; and, if the drainage composites are judged dirty or dusty, they will be washed by the Drainage Composite Installer prior to installation.

Washing operations will be observed by the CQA Consultant and improper washing operations will be reported to the Project Manager.

7.5 HANDLING AND PLACEMENT

The Drainage Composite Installer will handle all geonets in a manner in accordance with the project specifications. The CQA Consultant will note any noncompliance and report it to the Project Manager.

7.6 JOINING

Adjacent drainage composites will be joined according to construction drawings and project specifications. The CQA Consultant will note any noncompliance and report it to the Project Manager.

7.7 REPAIR

Any holes or tears in the drainage composite will be repaired in accordance with project specifications. The CQA Consultant will observe any repair, note any noncompliance with the above requirements, and report them to the Project Manager.

7.8 PLACEMENT OF SOIL MATERIALS

All soil materials placed over the drainage composite should be placed in accordance with project specifications so as to ensure:

- the drainage composite and underlying geomembrane are not damaged;
- minimal slippage of the drainage composite on the underlying geomembrane occurs; and
- no excess tensile stresses occur in the drainage composite.

Any noncompliance will be noted by the CQA Consultant and reported to the Project Manager.

SECTION 8.0
GEOSYNTHETIC CLAY LINER (GCL) MATERIAL AND INSTALLATION QUALITY ASSURANCE

8.1 MANUFACTURING

The Contractor will provide the CQA Consultant with a list of guaranteed "minimum average roll value" properties (as defined by the Federal Highway Administration) for the GCL to be delivered. The Contractor will also provide the CQA Consultant with a written certification from the GCL Manufacturer that the materials actually delivered have "minimum average roll value" properties which meet or exceed all property values guaranteed for the GCL.

The CQA Consultant will examine all manufacturer certifications to determine if the property values listed on the certifications meet or exceed those specified for the GCL. Any deviations will be reported to the Engineer.

8.2 LABELING

The GCL Manufacturer will identify all rolls of GCL in conformance with the project specifications. The CQA Consultant will examine rolls upon delivery and any deviation from the above requirements will be reported to the Engineer.

8.3 SHIPMENT AND STORAGE

During shipment and storage, the GCL will be protected as required by the project specifications. The CQA Consultant will observe rolls upon delivery at the site and any deviation from the above requirements will be reported to the Engineer.

8.4 HANDLING AND PLACEMENT

The Geosynthetic Installer will handle the GCL in such a manner as required by the project specifications. Any noncompliance will be noted by the CQA Consultant and reported to the Engineer.

8.5 SEAMS AND OVERLAPS

The GCL will be seamed or overlapped in accordance with project specifications or as approved by the CQA Consultant and Engineer.

8.6 REPAIR

Any holes or tears in the GCL will be repaired in accordance with the project specifications. The CQA Consultant will observe any repair and note any noncompliance with the above requirements and report them to the Engineer.

8.7 PLACEMENT AND MATERIALS

All soil materials located on top of the GCL shall be placed in accordance with the project specifications. Any noncompliance will be noted by the CQA Consultant and reported to the Engineer.

SECTION 9.0
SURVEYING CONSTRUCTION QUALITY CONTROL

9.1 INTRODUCTION

Surveying of lines and grades is conducted on an ongoing basis during construction of the component liner and leachate collection systems. Close CQC of the surveying is absolutely essential to ensure that slopes are properly constructed. The surveying conducted at the site shall be performed by the Contractor.

9.2 SURVEY CONTROL

Permanent benchmarks and baseline control points are to be established for the site at locations convenient for daily tie-in. The vertical and horizontal controls for this benchmark will be established within normal land surveying standards.

9.3 SURVEYING PERSONNEL

The Contractor's survey crew will consist of a Senior Surveyor, and as many Surveying CQC Monitors as are required to satisfactorily undertake the requirements for the work. All Surveying CQC personnel will be experienced in the provision of these services, including detailed, accurate documentation.

All surveying will be performed under the direct supervision of a Registered Professional Engineer (PE) or Licensed Land Surveyor (PLS) licensed in the state in which the project is located. The Licensed Land Surveyor may be the Senior Surveyor.

9.4 PRECISION AND ACCURACY

A wide variety of survey equipment is available to meet the requirements of this project. The survey instruments used for this work should be sufficiently precise and accurate to meet the needs of the project. All survey instruments should be capable of reading to a precision of 0.01 foot and with a setting accuracy of 20 seconds. (5.6×10^{-3} degrees).

9.5 LINES AND GRADES

The following surfaces shall be surveyed to verify the lines and grades achieved during construction. The survey should at least include (as deemed appropriate by the Engineer and CQA Consultant):

- one or more construction baselines;

- a working grid with a sufficient number of benchmarks;
- surface of the subgrade;
- all existing structures;
- surface of the soil liner component;
- invert elevation of and location of leachate collection/header and force main piping at each lateral intersection and endpoint, and every 50 feet between the intersections and endpoints;
- inverts of sumps and manholes;
- surface of the leachate collection layer (protective cover);
- elevations of and locations of temporary berms;
- top/toe of all perimeter berms, roads, and channels;
- location of edge of liner, tie-in seam to adjacent existing liner system (as applicable);
- corners/intersections of all geosynthetic rolls or panels; and
- location of anchor trenches.

Laser planes are highly recommended for achieving the correct lines and grades during construction of each surface.

9.6 FREQUENCY AND SPACING

All surveying will be carried out immediately upon completion of a given installation to facilitate progress and avoid delaying commencement of the next installation. In addition, spot checks, as determined by the Senior Surveyor, CQA Consultant, or Project Manager, during construction may be necessary to assist the Contractor in complying with the required grades.

The following spacings and locations will be provided by the CQC Surveyor, as a minimum, for survey points:

- surfaces with slopes less than 10 percent will be surveyed on a square grid not wider than 100 feet;

- on slopes greater than 10 percent, a square grid not wider than 100 feet will be used, but, in any case, a line of survey points at the crest, midpoint, and toe of the slope will be taken;

- a line of survey points no farther than 100 feet apart will be taken along any slope break (this will include the inside edge and outside edge of any bench on a slope);

- a line of survey points not farther than 50 feet apart will be taken for all ~~piping used for leachate collection/detection lines, in~~ particular, at the lateral intersection and line end points;

- at a minimum, a line of survey points no farther than 50 feet apart will be taken for all cleanout risers;

- at a minimum, every 100 feet along the perimeter of the primary and secondary liner system; and

- at a minimum, a line of survey points no farther than 50 feet apart will be taken for all piping used for the leachate collection/detection lines.

9.7 THICKNESS MEASUREMENTS

The CQC surveyor as a representative of the Contractor shall obtain top and bottom elevations of the soil liner at a maximum 100-foot grid points and at all grade break lines prior to placement of the geomembrane liner system. The procedure for obtaining top and bottom elevations of the soil liner shall be agreed to by the CQA Consultant and Engineer prior to construction. The CQC Surveyor shall review the survey information with the Contractor to ensure that the survey demonstrates compliance with the project technical specifications. The Contractor is responsible for identifying and reporting to the CQA Consultant any areas of non-compliance evidenced by the survey, and for repairing such areas. The CQA Consultant and Contractor shall review the thickness measurements of the soil liner component prior to placement of the geomembrane liner.

9.8 TOLERANCES

Except for liner components where no minus tolerances are acceptable, the following are maximum tolerances for survey points:

- on surfaces, the maximum tolerances shall be 0.2 foot. This tolerance must be set to the record elevation of the surface below it and not the design elevation;

- on piping for leachate collection/detection lines, the maximum tolerance shall be 0.02 foot. This tolerance must be set to the record elevation of the surface below it and not the design elevation; and

- on cleanout risers, the tolerance shall be 0.2 foot This tolerance must be set to the record elevation of the surface below it and not the design elevation.

9.9 DOCUMENTATION

All field survey notes will be retained by the Senior Surveyor. The results from the field surveys will be documented on a set of Survey Record (As-Built) Drawings by the Contractor for submittal to the CQA Consultant. The Contractor shall certify to the CQA Consultant and Engineer that the results of the survey demonstrates compliance with the Contract Documents. These drawings shall, at a minimum, show the final elevations and locations of all surfaces and appurtenances surveyed in Subsection 2.5 of this CQA/CQC Plan. Survey records drawings shall resemble Figure 9-1. Record drawings shall be signed and sealed by a registered land surveyor in the State of North Carolina, and submitted on mylar or other reproducible print. Additionally, an electronic file (i.e., Autocad R14) shall be submitted to the Engineer.

(1) Hydraulic conductivity tests shall be performed on recompacted samples of the proposed material, compacted according to criteria developed by the CQC Consultant using data from tests conducted in accordance with ASTM D698.

6. Test Parameter for Soil to be Used in Bentonite Amended Soil:
   a. Parameters and reporting for soils to be used in bentonite amended soil shall be the same as for natural fine-grained soil.
   b. Tests required under this paragraph are part of the BSCS. Additional tests on the bentonite amended soil product are required for soil liner acceptance. See 2.1E.

D. Borrow Soils Conformance Testing:

1. Following acceptance of a borrow source for natural fine-grained soils and soils for bentonite amendment, the following tests shall be performed by the CQC Consultant on samples taken from the excavated material using the methods and at the frequencies indicated below:

Test	Test Method	Minimum Frequency
Percent Fines	ASTM D1140	1 per 5,000 cu yd
Atterberg Limits	ASTM D4318	1 per 5,000 cu yd
Standard Proctor	ASTM D698	1 per 10,000 cu yd

2. The CQC Consultant shall conduct tests more often if variation in test results is occurring, or if material appears to depart from Specifications.
3. The CQA Consultant may also conduct independent tests to confirm the accuracy of the CQC testing.
4. If tests indicate material does not meet Specification requirements, Contractor shall terminate material placement until corrective measures are taken.
5. Contractor shall remove and replace material which does not meet Specification requirements at no additional cost to the Owner.

E. Bentonite Amended Soil Conformance Testing (where applicable):

1. Following acceptance of a source for soils to be used in bentonite amended soils, the CQC Consultant shall perform a Design Mix Analysis and submit certifications for the imported bentonite material as described below.
2. Design Mix Analysis:
   a. Collect two of the coarsest samples of the soil taken from the approved borrow area (based on percent retained on #200 sieve). Soil samples for testing shall be at least 100 pounds each.
   b. Trial mix samples shall be prepared by mixing each soil sample with three trial application rates of bentonite. Compact each trial mix sample to a dry density equal to 95 percent relative compaction and at a moisture content within the range of optimum to optimum plus 3 percent (ASTM D-698) for the unamended soil.
   c. Test the hydraulic conductivity of the trial mix samples using ASTM D5084 and report all data to CQA Consultant. Graph measured hydraulic conductivity vs. percent bentonite.
   d. Contractor shall select a minimum bentonite content needed to consistently achieve the required in-place hydraulic conductivity.
3. After mix design and initial testing, CQC Consultant shall conduct tests of the mixed bentonite amended soil, after it has been discharged from the pugmill and before this is placed in the work using the following methods and at the following frequencies.

Test	Method	Minimum Frequency
Standard Proctor	ASTM D698	1 per 10,000 cu yd

4. Bentonite: CQC Consultant shall submit certifications from the supplier of the bentonite material that it meets the requirements specified under PART 2, PRODUCTS.

F. Fine-Grained Material Dewatering, Mixing, and Staging

SECTION 10.0
CONSTRUCTION QUALITY ASSURANCE DOCUMENTATION

10.1 DOCUMENTATION

An effective CQA plan depends largely on recognition of all construction activities that should be monitored and on assigning responsibilities for the monitoring of each activity. This is most effectively accomplished and verified by the documentation of quality assurance activities. The CQA Consultant will document that all quality assurance requirements have been addressed and satisfied.

This CQA plan integrates the testing and inspection performed by the CQC Consultant in accordance with the project specifications with the CQA overview and conformance testing performed by the CQA Consultant, in accordance with this CQA Plan.

The CQA Consultant will provide the Project Manager with the CQC Consultant's daily and weekly reports including signed descriptive remarks, data sheets, and logs to verify that all CQC monitoring activities have been carried out. The CQA Consultant will also provide the Project manager with a weekly report summarizing CQA activities and identifying potential quality assurance problems. The CQA Consultant will also maintain at the job site a complete file of Plans, Reports, project specifications, a CQA Plan, checklists, test procedures, daily logs, and other pertinent documents.

10.2 RECORDKEEPING

The CQC Consultant's reporting procedures will include preparation of a daily report which, at a minimum, will consist of: a) field notes, including memoranda of meetings and/or discussions with the Contractor; b) observation logs and testing data sheets; and c) construction problem and solution data sheets. The daily report must be completed at the end of each CQC Consultant's shift, prior to leaving the site. This information will be submitted weekly to and reviewed by the CQA Consultant.

The CQC Consultant's weekly reports must summarize the major events that occurred during that week. Critical problems that occur shall be communicated verbally to the Project Manager or CQA Consultant immediately as well as being included in the weekly reports. The CQC Consultant's weekly report must be submitted to the CQA Consultant no later than the Monday following the week reported.

The CQA Consultant's weekly report must summarize the CQC Consultant's weekly and daily reports, CQA conformance testing activities, construction problems that occurred, and the resolution of construction problems. The CQA Consultant's weekly report should identify all potential or actual compliance problems outstanding. The CQA Consultant's weekly report must be submitted to the Project Manager on the Wednesday following the week reported.

10.2.1 Memorandum of Discussion with CQC Consultant or Geosynthetic Installer

A report will be prepared summarizing each discussion between the CQA Consultant and the CQC Consultant or Geosynthetic Installer. At a minimum, the report will include the following information:

- date, project name, location, and other identification;
- name of parties to discussion at the time;
- relevant subject matter or issues;
- activities planned and schedule; and
- signature of the CQA Consultant.

10.2.2 CQA Observation Logs and Testing Data Sheets

CQA observation logs and conformance testing data sheets will be prepared by the CQA Consultant on a weekly basis. At a minimum, these logs and data sheets will include the following information:

- an identifying sheet number for cross referencing and document control;
- date, project name, location, and other identification;
- data on weather conditions;
- a reduced-scale Site Plan showing all proposed work areas and test locations;
- descriptions and locations of ongoing construction;
- descriptions and specific locations of areas, or units, of work being tested and/or observed and documented;
- locations where tests and samples were taken;
- a summary of test results;

- calibrations or recalibrations of test equipment, and actions taken as a result of recalibration;

- off-site materials received, including quality verification documentation;

- decisions made regarding acceptance of units of work, and/or corrective actions to be taken in instances of substandard quality; and

- the CQA Consultant's signature.

10.2.3 CQA Construction Problem and Solution Data Sheets

CQA sheets describing special construction situations will be cross-referenced with specific CQA observation logs and testing data sheets, and must include the following information, where available:

- an identifying sheet number for cross referencing and document control;

- a detailed description of the situation or deficiency;

- the location and probable cause of the situation or deficiency;

- how and when the situation or deficiency was found or located;

- documentation of the response to the situation or deficiency;

- final results of any responses;

- any measures taken to prevent a similar situation from occurring in the future; and

- the signature of the CQA Consultant, and signature of the Project Manager indicating concurrence if required by this CQA Plan.

The Project Manager will be made aware of any significant recurring non-conformance with the project specifications. The Project Manager will then determine the cause of the non-conformance and recommend appropriate changes in procedures or specification. When this type of evaluation is made, the results will be documented, and any revision to procedures or project specifications will be approved by the Owner and Engineer.

10.3 CQA PHOTOGRAPHIC REPORTING DATA SHEETS

Photographic reporting data sheets, where used, will be cross-referenced with CQA observation logs and testing data sheets and/or CQA construction problem and solution data sheets. Photographs shall be taken at regular intervals during the construction process and in all areas deemed critical.

These photographs will serve as a pictorial record of work progress, problems, and mitigation activities. The basic file will contain color prints; negatives will also be stored in a separate file in chronological order. These records will be presented to the Project Manager upon completion of the project.

In lieu of photographic documentation, videotaping may be used to record work progress, problems, and mitigation activities. The Project Manager may require that a portion of the documentation be recorded by photographic means in conjunction with video taping.

10.4 DESIGN AND/OR PROJECT TECHNICAL SPECIFICATION CHANGES

Design and/or project specification changes may be required during construction. In such cases, the CQA Consultant will notify the Project Manager and the Engineer. The Project Manager will then notify the appropriate agency, if necessary.

Design and/or project specification changes will be made only with the written agreement of the Project Manager and the Engineer, and will take the form of an addendum to the project specifications. All design changes shall include a detail (if necessary) and state which detail it replaces in the plans.

10.5 CQA PROGRESS REPORTS

The CQA Consultant will prepare a summary progress report each week, or at time intervals established at the pre-construction meeting. As a minimum, this report will include the following information;

- a unique identifying sheet number for cross-referencing and document control;
- the date, project name, location, and other information;
- a summary of work activities during progress reporting period;
- a summary of construction situations, deficiencies, and/or defects occurring during the progress reporting period;

- summary of all test results, failures and retests, and
- signature of the CQA Consultant.

10.6 SIGNATURE AND FINAL REPORT

At the completion of each major construction activity at the landfill unit, the CQA Consultant will certify all required forms, observation logs, field and laboratory testing data sheets including sample location plans, construction problems and solution data sheets. The CQA Consultant will also provide a final report which will certify that the work has been performed in compliance with the plans and project technical specifications, and that the supporting documents provide the necessary information.

The CQA Consultant will also provide summaries of all the data listed above with the report. The Record Drawings will include scale drawings depicting the location of the construction and details pertaining to the extent of construction (e.g., depths, plan dimensions, elevations, soil component thicknesses, etc.). All surveying and base maps required for development of the Record Drawings will be done by the Construction Surveyor. These documents will be certified by the Contractor and CQC Consultant and delivered to the CQA Consultant and included as part of the CQA documentation (Certification) report.

It may be necessary to prepare interim certifications, as allowed by the regulatory agency to expedite completion and review.

10.7 STORAGE OF RECORDS

All handwritten data sheet originals, especially those containing signatures, will be stored by the Project Manager in a safe repository on site. Other reports may be stored by any standard method which will allow for easy access. All written documents will become property of the Owner.

Appendix F

DEED TO SUBSTATION PROPERTY

North Carolina - Guilford County
The certificate (s) of

4620-1479
3-142-502-43

092944

RECORDED
KATHERINE LEE PAYNE
REGISTER OF DEEDS
GUILFORD COUNTY, NC

BOOK: 4620
PAGE(S): 1479 TO 1486

12/10/1997 11:16:18

12/10/1997	92944	
1 DEEDS		$6.00
7 DEEDS ADDN PGS		$14.00
1 PROBATE FEE		$2.00
1 EXCISE TAX STAMP		$24.00

Keith E. Jacobs
Kathryn B. Kimble

A Notary (Notaries) Public is (are) certified to be correct. This instrument and this certificate are duly registered at the date and time shown herein.

KATHERINE LEE PAYNE, REGISTER OF DEEDS
Deborah Johnson
Assistant/Deputy Register of Deeds

Excise Tax $24.00

Recording Time, Book and Page

Tax Lot No.: 3-142-502-43 Parcel Identifier No. ______
Verified by ______ County on the ______ day of ______, 19__
by ______

Mail after recording to City of Greensboro Property Management PO Box 3136 Greensboro, NC 27402

This instrument was prepared by Parker, Poe, Adams & Bernstein L.L.P. [DU020-65502]

Brief Description For The Index:

NORTH CAROLINA NON-WARRANTY DEED

THIS DEED made this 10th day of December, 1997, by and between

GRANTOR	GRANTEE
DUKE ENERGY CORPORATION, formerly DUKE POWER COMPANY, a North Carolina corporation, formerly a New Jersey Corporation	CITY OF GREENSBORO Post Office Box 3136 Greensboro, NC 27402-3136 Attn: Property Management

001479

Enter in appropriate block for each party: name, address, and, if appropriate, character of entity, e.g. corporation or partnership.

The designation Grantor and Grantee as used herein shall include said parties, their heirs, successors and assigns, and shall include singular, plural, masculine, feminine or neuter as required by context.

WITNESSETH, that Grantor, for valuable consideration paid by Grantee, the receipt of which is hereby acknowledged, has and by these presents does grant, bargain, sell and convey unto Grantee in fee simple, subject to the reservations in favor of Grantor set forth herein, all that certain lot or parcel of land situated in the City of Greensboro, Gilmer Township, Guilford County, North Carolina and more particularly described as follows:

See Exhibit A, attached hereto and incorporated by reference herein (the "Property")

Grantor reserves unto itself, its successors and assigns, the Easement set forth and defined on Exhibit B and the Utility Equipment and Improvements described on Exhibit B, which Exhibit B is attached hereto and incorporated herein by reference.

Grantee joins in this deed to agree to the covenants of Grantee contained herein

STATE OF NORTH CAROLINA 12/10/1997 24.00 Real Estate Excise Tax Guilford County

PPAB-CHI/231649.1

4620-1480

The property hereinabove described was acquired by Grantor by instrument recorded in Deed Book 1848 Page 189 in the Office of the Register of Deeds, Guilford County North Carolina

A map showing the above described property is recorded in Plat Book ___, ___.

TO HAVE AND TO HOLD the aforesaid lot or parcel of land and all privileges and appurtenances thereto belonging to the Grantee in fee simple, subject to the reservations in favor of Grantor set forth herein.

The Grantor makes no warranty, express or implied, as to title to the Property hereinabove described.

IN WITNESS WHEREOF, the Grantor has hereunto set his hand and seal, or if corporate, has caused this instrument to be signed in its corporate name by its duly authorized officers and its seal to be hereunto affixed by authority of its Board of Directors, the day and year first above written.

DUKE ENERGY CORPORATION,
formerly, DUKE POWER COMPANY
(Corporate Name)

By: Larry G. Bost
GEN. MGR. FACILITY AND ~~President~~
REAL ESTATE SERVICES

ATTEST: [signature]
ASST. Secretary (Corporate Seal)

CITY OF GREENSBORO (SEAL)

By: Carolyn Allen (SEAL)
Mayor

ATTEST:
Barbara E. Johnson (SEAL)
Deputy City Clerk (Corporate Seal)

APPROVED AS TO FORM AND LEGALITY

SEE ATTACHED NOTARY ACKNOWLEDGMENT PAGES

STATE OF NORTH CAROLINA
COUNTY OF Guilford

I, Kathryn A. Kimble, a Notary Public for the above State and County, hereby certify that Barbara E. Johnson personally came before me this day and acknowledged that she/he is ___ Secretary of ___, a ___ corporation, and that by authority duly given and as the acts of said corporation, the foregoing instrument was signed in its name by its ___ President, sealed with its corporate seal and attested by him/her as its Assistant Secretary.

WITNESS my hand and official seal, this the 10th day of December, 1997.

___
Notary Public

My Commission Expires ___

[NOTARY SEAL]

The foregoing Certificate(s) of ___

___

is/are certified to be correct. This instrument and this certificate are duly registered at the date and time and in the Book and Page shown on the first page hereof.

___ REGISTER OF DEEDS FOR ___ COUNTY

By ___ ___ Deputy/Assistant - Register of Deeds

001480

4620-1481

NOTARY ACKNOWLEDGMENT PAGE

STATE OF NORTH CAROLINA

COUNTY OF Mecklenburg

I, Keith E. Jacobs, Notary Public of said County and State, do hereby certify that Carol D. Denton personally appeared before me this day and acknowledged that ~~he~~/she is Asst Secretary of Duke Energy Corporation, formerly Duke Power Company, a North Carolina corporation, formerly a New Jersey corporation, Grantor, and that by authority duly given and as the act of the corporation, the foregoing instrument was signed in its name by its ________ ~~President/Chairman~~, sealed with its corporate seal, and attested by ~~himself~~/herself as its Asst Secretary. Gen. Mgr. Facility & Real Estate Svcs

Witness my hand and official seal, this 10TH day of October, 1997.

Keith E. Jacobs
Notary Public

My Commission Expires: June 6, 1998

[NOTARY STAMP/SEAL]

NOTARY PUBLIC MECKLENBURG COUNTY, N.C.

184100

STATE OF NORTH CAROLINA

COUNTY OF GUILFORD

I, Kathryn R. Kimble, Notary Public of said County and State, do hereby certify that Barbara E. Johnson personally appeared before me this day and acknowledged that ~~he~~/she is Deputy City Clerk of the City of Greensboro, a municipal corporation, Grantee, and that by authority duly given and as the act of the municipal corporation, the foregoing instrument was signed in its name by its Mayor, sealed with its corporate seal, and attested by ~~himself~~/herself as its Deputy City Clerk.

Witness my hand and official seal, this 10th day of December, 1997.

Kathryn R. Kimble
Notary Public

My Commission Expires: April 14, 2002

[NOTARY STAMP/SEAL]

KATHRYN R. KIMBLE NOTARY PUBLIC GUILFORD COUNTY, N.C.

ASSISTANT SECRETARY CERTIFICATE

I, Carol D. Denton, Assistant Secretary of Duke Energy Corporation, do hereby certify that the following is a true and correct excerpt of a Resolution adopted February 27, 1995, by the Management Committee of the Board of Directors of Duke Energy Corporation, and that said quoted Resolution has not been rescinded or amended.

FURTHER RESOLVED, that effective October 17, 1994, the General Manager of the Real Estate Division be and hereby is authorized to execute any contract, lease, deed, or other instrument relating to real property without further action or approval by the Board of Directors or this Committee when deemed by said General Manager to be necessary or desirable in the operation of the Company's business, subject, however, to a monetary limit of $1,500,000.00 consideration or value in any single transaction, and to execute such documents in any such transaction which is approved by a resolution of this Committee.

FURTHER RESOLVED, That the Secretary or any Assistant Secretary be and hereby is authorized to attest and affix the corporate seal to any contracts, leases, deeds, or other instruments executed under authority of this resolution and may execute any certificate that may be required to certify the incumbency and authority of the officer or manager executing such documents.

I further certify that on October 13, 1997, Larry G. Best was the General Manager, Facility and Real Estate Services, hereby by reason of holding said position and pursuant to the above quoted Management Committee's Resolution, had full authority to represent and act on behalf of Duke Energy Corporation with respect to the conveyance of 1.162 acres of land in Gilmer Township, Guilford County, North Carolina, and to execute on behalf of Duke Energy Corporation all documents and instruments relating in any way thereto.

001482

WITNESS my hand and seal of said Company this 13 day of October, 1997.

SEAL

[signature: Carol D. Denton]
Assistant Secretary

-4620- 1483

Exhibit A
to North Carolina Non Warranty Deed from
Duke Energy Corporation
to
City of Greensboro

All that tract or parcel of land in the County of Guilford and State of North Carolina, in Gilmer Township, adjoining the lands of others and bounded as follows:

BEGINNING at the center of the Duke Power right-of-way, a corner with James H. Neal and the Tract he sold to the City of Greensboro, and running thence with his line South 09-14-30 East 56.85 feet to the City's southwest corner; thence with their south line South 88-39 East 401.68 feet to an iron pipe; thence with Mildred F. Lewis' west line North 02-28 East 149.49 feet to a point on the north line of Duke Power's right-of-way; thence with the line of the right-of-way south 84-02-20 West 425.87 feet to a point; thence South 09-14-30 East 40.07 feet to the point of BEGINNING containing 1.162 acres and being all of the property conveyed to Grantor by the City of Greensboro, North Carolina by deed recorded in the Office of Register of Deeds of Guilford County, North Carolina in Book 1848, Page 189.

For further reference see Drawing PW3644 on file with the City of Greensboro, Engineering and Inspections Department.

001483

Exhibit B
to North Carolina Non Warranty Deed from
Duke Energy Corporation
to
City of Greensboro

Grantee is the owner and operator of a municipal solid waste facility on Grantee's adjacent land ("Grantee's Adjacent Land"). Grantor is executing the deed at Grantee's request to accommodate Grantee in meeting legal requirements imposed on the operation of the municipal solid waste facility. Grantor operates an electric substation upon the Property and must reserve the rights, privileges and easements contained herein for its benefit in order to continue to operate the electric substation. In consideration of the foregoing and other valuable consideration, the parties agree as follows:

1. Easement. Grantor reserves unto itself, its successors and assigns, a permanent exclusive right, privilege and easement over, upon, across and under the Property (the "Easement") (during the pendency of which Grantor shall have the exclusive right to enter upon and use the Property) for the construction, maintenance, operation, repair, affixing, removal, replacement and use of aboveground, surface level and underground electric or natural gas apparatus, towers, poles, wires, conduits, appliances, pipes, lines, culverts, electric or natural gas equipment, transformers, substations, fencing, telecommunications equipment, personal property, fixtures and other related improvements (whether or not affixed to the Property) now or hereafter placed upon the Property (all of which is collectively called the "Utility Equipment and Improvements") used or useful in the production, transmitting and/or distribution of electricity and/or natural gas and/or the operation of telecommunication system(s) for so long as Grantor needs or desires to use the Property for such purposes. Grantor reserves unto itself, its successors and assigns, all right, title and interest in and to the Utility Equipment and Improvements including the right to remove any or all of the Utility Equipment and Improvements at any time. Grantor may terminate this Easement at any time upon written notice to Grantee.

001184

2. Use. Grantor shall use and occupy the Property for the purposes set forth above and no other purposes except with the mutual written consent of the parties hereto. In no event shall the Property or any part thereof be used for any purpose constituting a nuisance or in any manner which is in violation of present or future laws or government regulations.

3. Maintenance. Grantor shall, at its own expense, keep the Property and all the Utility Equipment and Improvements thereon in good and safe condition and shall make all necessary repairs and replacements to the Property.

4. Indemnification. Grantor shall indemnify Grantee and save it harmless from and against any and all claims, actions, damages, liability and expense, including attorneys fees in connection with the loss of life, personal injury and/or damage to property from or out of any occurrence in, upon or at the Property or the occupancy or use by Grantor of the Property or any part thereof, or occasioned wholly or in part by any act or omission of Grantor, its agents, contractors, employees, invitees, visitors, or servants. Likewise, Grantee shall indemnify Grantor and save it harmless from and against any and all claims, actions, damages, liability and expense, including attorneys fees, including but not limited to, any claims under CERCLA, in connection with the loss of life, personal injury and/or damage to property, including, but not limited to, damage to the Property, from or out of any occurrence in, upon, under or at Grantee's Adjacent Land or the occupancy or use by Grantee of the Grantee's Adjacent Land or any part thereof, or occasioned wholly or in part by any act or omission of Grantee, its agents, contractors, employees, invitees, visitors, or servants. In case either party without fault on its part, is made a party to any litigation commenced by or against the other party, then the other party shall protect and hold harmless and shall pay all cost, expenses and reasonable attorney's fees incurred or paid by the party without fault in connection with such litigation. Each party shall also pay all cost, expenses

and reasonable attorney's fees that may be incurred by the other party in successfully enforcing the covenants and agreements in this deed.

5. Environment. Grantor agrees not to discharge, or allow to be discharged upon the Property, any regulated contaminant in the environment, soil or ground water of the Easement. In the event of any such discharge of contamination either, accidentally or intentionally, Grantor shall immediately report the discharge to the Grantee and other proper authorities as required by law and the affected land shall be remediated, either actively or passively as allowed, by Grantor in accordance with applicable law. Grantee agrees not to discharge, or allow to be discharged on the Easement from Grantee's Adjacent Land or from the Property, any contaminant in the environment, soil or ground water. In the event of any such discharge or contamination either, accidentally or intentionally, Grantee shall immediately report the discharge to Grantor and other proper authorities as required by law and the affected land shall be remediated, either actively or passively as allowed, by Grantee in accordance with applicable law.

6. As Is. Except as specifically provided herein, the Property is sold AS IS without covenant, representation or warranty of any kind, including without limitation, the environmental condition of the Property. Grantee acknowledges that Grantee has had ample opportunity to inspect and has inspected the Property and has determined the condition of the Property. Grantee has satisfied itself that the condition of the Property, including without limitation, the environmental condition of the Property is satisfactory to Grantee. The Property is conclusively presumed to be without environmental contamination as of the date of this deed and Grantee shall indemnify and save Grantor harmless from and against any and all claims, actions, damages, liability and expense, including reasonable attorneys fees, in connection with the past, present and/or future presence of any hazardous waste, hazardous substances and/or other waste or contamination (including groundwater contamination) on the Property, except as specifically provided herein. Grantor represents, as of the date of this deed, that Grantor neither knows of, nor has been advised of, any legal or administrative proceedings, claims or alleged claims, violations or alleged violations, infractions or alleged infractions of any law, rules or regulations relating to the environmental condition of the Property and Grantor has no knowledge that any hazardous wastes or hazardous substances have been brought upon and/or discharged upon the Property by Grantor. Grantor shall indemnify and hold Grantee harmless from and against any and all claims, actions, damages, liability and expense, including reasonable attorneys fee in connection with any past, present or future hazardous waste or hazardous substance as to which it is established by clear and convincing evidence was brought upon and/or discharged upon the Property by Grantor. 001485

7. Notices. All notices required hereunder shall be in writing by registered mail, to the following addresses:

Duke Energy Corporation
422 South Church Street
Charlotte, North Carolina 28242
Attn: W. Wallace Gregory, Jr.

City of Greensboro
Post Office Box 3136
Greensboro, North Carolina 27402-3136
Attn: Property Management

8. Entire Agreement. This deed contains the entire agreement and understanding between the parties as to the Property and the Easement. There are no oral understandings, terms, or conditions, and neither party has relied upon any representation, express or implied, not contained in this deed. All prior understandings, terms, and conditions are deemed merged in this deed. This deed shall not be changed orally, but only upon an agreement in writing and signed by the party against whom enforcement or any waiver, change, modification, or discharge is sought.

9. Binding Effect. The rights and obligations contained in this deed shall inure to the benefit and be binding upon the parties, their successors and assigns.

0011486

Appendix G

VOLUME CALCULATIONS

New gboro project to replace corrupted

Project: gboro99 Wed Oct 06 17:05:33 1999

Site Volume Table: Unadjusted

Cut yards	Fill yards	Net yards	Method
Site: cell123			
Stratum: vol13 123-r 321f			
0	6660855	6660855 (F)	End area
0	6524601	6524601 (F)	Prismoidal
Stratum: vol17 123-r cell3			
15	5573814	5573800 (F)	Prismoidal
15	5494280	5494265 (F)	End area
Stratum: vol15 b11-6 123-r			
25849	16221	9627 (C)	End area
25642	16075	9568 (C)	Prismoidal
Stratum: vol18 123-r 4-1			
136	5644843	5644707 (F)	End area
188	5643476	5643288 (F)	Prismoidal
Stratum: vol19 b11-6 cell3			
0	5569602	5569602 (F)	Prismoidal
0	5571030	5571030 (F)	End area

avg 5,643,998 Permit Mod

avg. 5,570,316 CPA

73,682 ⇒ 1.3% increase in gross volume

123-r = Permit Modification Base grades

4-1 = " " Final grades (4:1)

~~B-11-6~~

B11-6 = Basegrades in Construction Permit Application (CPA)

Cell 3 = 4:1 Final grades in " " "

This Permit Modification is a 1.3% increase in gross volume (Final vs. base grades)

Appendix H

NC DENR GUIDANCE DOCUMENT

SWANA “WHITE PAPER”

North Carolina Department of
Environment and Natural Resources
Division of Waste Management

NCDENR

James B. Hunt Jr.
Governor

Wayne McDevitt
Secretary

William L. Meyer
Director

SOLID WASTE SECTION
Permitting Guidance For Alternative Composite Liner Systems
June 1, 1998

The Solid Waste Management Rules, 15A NCAC 13B Section .1600 contain the requirements for Municipal Solid Waste Landfill Facilities (MSWLFS). Rule .1624 of that Section contains the construction and design requirements for MSWLF Facilities and MSWLF units. On May 20, 1998, the Commission for Health Services adopted revisions to this Rule that allow **alternative** base liner systems, if the owner and operator can demonstrate compliance with the design and construction requirements in the Rule. Prior to adoption of these revisions, the only acceptable base liner design was the standard composite base liner. The revisions to the rule allow two defined alternative composite base liners and an undefined alternative base liner. The North Carolina Division of Waste Management, Solid Waste Section, has prepared the following technical guidance to assist in the preparation of permit applications for the two defined alternative composite landfill liner systems.

The Rule requires that the owner or operator proposing an undefined alternative base liner demonstrate compliance with the design and construction requirements through site-specific, two-phase modeling approach acceptable to the Division. Owners and designers proposing an undefined alternative base liner should contact the Solid Waste Section for site-specific modeling requirements.

Certain MSWLFS in the state currently have five-year phase construction permits. These permits specify that the standard Subtitle D composite base liner system will be constructed. Owners and operators who wish to modify the existing permit to allow for construction of an alternative base liner system must submit a permit modification in accordance with Rule .1617(c). A complete submittal will include the revised engineering drawings, demonstrations, modeling, and technical specifications applicable to the alternative liner. The Section considers the modification to the base liner system for currently permitted MSWLFS to be a major modification to the effective permit. As such, the revised permit will be published in draft form, and the public will be given a fifteen-day opportunity to comment on the draft permit. A public hearing could be held on the basis of sufficient public interest. The scope of any public hearing would be limited to the new, proposed base liner system.

401 Oberlin Road, Suite 150, Raleigh, NC 27605
Phone 919-733-4996 FAX 919-715-3605

ALTERNATIVE COMPOSITE BASE LINERS

Rule .1624(b)(1)(A)(ii) and (iii) contains the requirements for two alternative composite liners:

The first alternative composite liner, described in Rule .1624(b)(1)(A)(ii), utilizes a geosynthetic clay liner(GCL). The composite liner is one liner that consists of three components: a geomembrane liner installed above and in uniform contact with a GCL overlying a compacted clay liner(CCL) with a minimum thickness of 18 inches (0.46 m) and a permeability of no more than 1.0×10^{-5} cm/sec. The composite liner must be designed and constructed in accordance with Subparagraphs (8), (9), and (10). The GCL must have a permeability of approximately 5×10^{-9} cm/sec.

The second alternative composite liner, described in Rule .1624(b)(1)(A)(iii), utilizes two geomembrane liners. The composite liner consists of three components; two geomembrane liners each with an overlying leachate drainage system designed to reduce the maximum predicted head acting on the lower membrane liner to less than one (1) inch. The lower membrane liner must overlie a CCL with a minimum thickness of 12 inches (0.31m) and a permeability of no more than 1.0×10^{-5} cm/sec. The composite liner system must be designed and constructed in accordance with Subparagraphs (8) and (10)

GENERAL DISCUSSION

In June of 1997, a technical committee of the North Carolina Chapter of the Solid Waste Association of North America (SWANA), prepared a "white paper" reviewing the performance of two alternative liner designs in comparison with the standard composite liner. The paper concluded that the calculated flow rates through the GCL alternative composite liner and the dual geomembrane alternative liner were less than the calculated flow rate through the standard composite liner. The performance of both designs was evaluated assuming the liner was placed on structural fill or subgrade having a maximum permeability of 1×10^{-5}cm/sec.

These two alternative liners have been approved in many other states and have been utilized successfully. Neighboring states including Georgia, Virginia, South Carolina and Tennessee have operating landfills with one or both of these liner designs. The state of Florida did an extensive study (1) on the leakage rates of a variety of liner systems. The study calculated the theoretical leakage rate and compared that to the actual rate of liquid collected in secondary leachate collection system. The study found that even though the theoretical calculations overestimated the amount of leakage, the results correlated well with actual performance.

These two alternative liner designs with the additional requirement of a underlying compacted clay liner(CCL) to "guarantee" subgrade conditions assumed in the white paper, constitute the two alternative composite liner designs approved in the recent rule revisions.

EPA MODELING REQUIREMENT

Rule .1624(b)(1)(A) contains a requirement of site specific groundwater modeling if the owner or operator proposes one of the two alternative composite liners. This requirement is derived from the federal EPA modeling requirements for municipal solid waste landfills. North Carolina is a fully authorized state for implementation of the Solid Waste Management Program and, as such, its state rules must comply with the requirements in federal law.

The revised Rule .1624(b)(1)(A), also contains a provision such that the Division may waive the site-specific modeling requirement at some time in the future. The decision to waive the modeling requirement will be made on a case-by-case basis. The Division may waive the site-specific modeling requirement if it can be demonstrated that the site, or a previous site for which a model was approved had similar hydrogeologic characteristics, climatic factors, and volume and physical and chemical leachate characteristics.

Comparison of designs for alternative liner systems usually takes a two pronged approach. The barrier layers are evaluated with respect to engineering and performance criteria. The second test is to evaluate the performance of the liner system in achieving a certain groundwater standard at the relative point of compliance. The objective of the technical demonstration is to compare the performance of the alternative liner to the standard composite liner. Three factors are usually considered when evaluating the engineering performance of equivalent liner systems (2). These include:

- The flow rate through the liner system, i.e. how many gallons per acre per day
- The "break-through time" defined as the time required for liquids to travel through the system and be released to the environment
- An equivalent chemical-absorption capacity

The EPA, in the preamble to Subtitle D (3), explicitly stated that an alternative demonstration must use a "point of compliance" demonstration, not a liner leakage comparison to the standard composite (Subtitle D) liner. In making a point of compliance demonstration, one uses knowledge of the hydrogeology, the liner design, the leachate characteristics and precipitation at the site to show that the concentration of specific chemicals in the groundwater are less than their listed maximum concentration levels, (MCLs).

The EPA has published guidance for permitting alternative liners for MSWLFS (4,5,6). Solid Waste Section staff have reviewed the EPA guidance as well as documentation on engineered determination of equivalence. Because the recently approved alternative composite liners are composite liners, (i.e. they contain a CCL) the liners likely meet the factors listed above. As stated earlier, SWANA addressed the leakage issue in a white paper prepared for the Section. As discussed later, it will not be necessary to repeat the equivalence demonstrations for the two alternative composite liners.

MULTIMED

The EPA prepared guidance for demonstrating point of compliance through the use of a computer model called the Multimedia Exposure Assessment Model (MULTIMED). Section staff have reviewed the EPA guidance (4,5,6) and determined that for the alternative composite liners listed above, the federal demonstration, which utilizes the EPA groundwater model, MULTIMED, can be used to meet the requirements of the rules. Other models could also be used. Designers who wish to use any other method for demonstrating compliance should contact the Section for guidance.

The EPA's MULTIMED model for exposure assessment simulates the movement of contaminants leaching from a landfill (6) . When applying MULTIMED to Subtitle D facilities, only flow and transport through the unsaturated zone and transport in the saturated zone can be considered. A steady-state, one-dimensional, semi-analytical module simulates flow in the unsaturated zone. The output from this module is used as input to the unsaturated zone transport module. The transport module simulates transient, one-dimensional (vertical) transport in the unsaturated zone and includes the effects of longitudinal dispersion, linear adsorption, and first-order decay. The unsaturated zone transport module calculates steady-state or transient contaminant concentration. Output from both unsaturated zone modules is used to couple the unsaturated zone transport module with the steady-state or transient, semi analytical saturated zone transport module. The saturated zone transport module includes one-dimensional uniform flow, three -dimensional dispersion, linear adsorption, first-order decay, and dilution due to direct infiltration into the groundwater plume.

MULTIMED (6) utilizes analytical and semi-analytical solution techniques to solve the mathematical equations describing flow and transport. The simplifying assumptions required to obtain the analytical solutions limit the complexity of the systems that can be represented by MULTIMED. The model does not account for site-specific spatial variability, the shape of the land disposal facility, site-specific boundary conditions, or multiple aquifers and pumping wells. Nor can MULTIMED simulate processes, such as flow in fractures and chemical reactions between contaminates, which can have a significant effect on the concentration of contaminants at the site.

The U.S. EPA has developed several restrictions for Subtitle D applications of MULTIMED(6). These restrictions were made in an effort to develop a conservative approach for simulating leachate migration from Subtitle D facilities.

- Only the Saturated and /or Unsaturated Modules may be active in Subtitle D applications.
- Only steady-state transport simulations are allowed for Subtitle D applications. No decay of the source term is allowed; the concentration of contaminants entering the aquifer system must be constant in time. The contaminant plume is assumed continuous and constant for the duration of the simulation.
- The receptor must be located directly down gradient of the facility, so that it intercepts the

center of the contaminant plume. In addition, the contaminant concentration must be calculated at the top of the aquifer.

- Only Gaussian source geometry is allowed in Subtitle D applications.

By its nature and design the conditions and assumptions used in running a MULTIMED simulation are over simplified, and very conservative. The output of the model is a Dilution Attenuation Factor or DAF. The EPA uses a threshold DAF of 100 to define an acceptable design. The maximum allowable leachate concentration of chemicals expected to exist in a municipal solid waste, or Subtitle D Landfill is 100 times the Maximum Contaminate Level (MCL) for each chemical.(6).

As a result of the above assumptions, it is not necessary to model each chemical individually. The input leachate concentration is set to 1.0 mg/l and the default characteristics of the program are used.

It is not the intent of this technical bulletin to be a user manual of MULTIMED. It is incumbent upon the designer, engineer, or geologist to obtain the computer model and the appropriate documentation .

ACCEPTABLE INPUT PARAMETERS

The model needs several input parameters which must be available to the modeler. The following is a brief discussion of the inputs that the permittee must collect or estimate, for modeling purposes.

- Input flow rate- The input flow rate for the model is an estimation of the output flow rate from the engineered barrier. The HELP model (7), water balance model or other methods may be used to determine the input flow rate. However, the Section believes that the initial model run should be performed with the flow rates as determined in the SWANA white paper. These values are very conservative in that they presume the presence of a constant 30 cm head on the liner, an unlikely occurrence, and that there are as many as eight small holes per acre in the liner. The following values should be used as input to MULTIMED.

Regulatory Composite Liner	1.12 gallons/acre/day
GCL Alternative Composite Liner	0.53 gallons/acre/day
Dual Geomembrane Alternative Liner	0.15 gallons/acre/day

- Leachate concentration- 1 mg/l, as described previously

- Site specific hydrogeologic data- This data may include aquifer particle size, porosity, bulk density, hydraulic conductivity, gradient, groundwater velocity, dispersivities and thickness, distance to the relative point of compliance. Most if not all of the above is collected or derived from a properly performed hydrogeologic study already necessary for obtaining a permit to construct. The thickness and properties of both the saturated and unsaturated zone are required.

- MSW Unit properties- The flow rate out of the landfill is needed, the SWANA derived numbers are recommended. The dimensions of the landfill are needed.

OBTAINING MULTIMED

MULTIMED is a shareware product developed by the US EPA. It may downloaded via the internet. The web address for obtaining the computer model is:

ftp://ftp.epa.gov/epa_ceam/wwwhtml/softwdos.htm

A new version of the documentation is also available online. A copy of the original documentation (5,6) is available from NTIS for a fee. The NTIS publication number is located at the end of the reference citation. The phone number for ordering is (800) 553-6847.

SUMMARY

It is important to reiterate that this technical guidance may be used only for the two alternative composite liner designs defined in the rules. The rules require site-specific two-phase modeling for any proposed undefined alternative liner. These modeling requirements will be determined on a case-by-case basis depending on the proposed liner design and site-specific characteristics. Also, Rule .1624 contains other design and construction requirements, including some revisions, that must be addressed in the permit application. In particular, changes to the design and operational requirements for the leachate collection system have been made. Requirements for materials used, construction, and certification of geosynthetic clay liners(GCL) have also been added to the rules. A complete copy of the revisions to Rule .1624 are available from the Division.

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Alternate Subtitle-D Liner Systems

SOLID WASTE ASSOCIATION OF NORTH AMERICA
NORTH CAROLINA CHAPTER
TECHNICAL COMMITTEE

June, 1997

Prepared By: Subcommittee on Alternate Liner Systems

FINAL DRAFT

Alternative Subtitle-D Liner Systems

Introduction

Alternative liner systems for new municipal waste landfills are allowed under Federal RCRA-Subtitle D regulations (40 CFR §258.40). This provision of Subtitle D was adopted by all States receiving authorization from EPA, with the exception of North Carolina. This provision of Subtitle D allows the use of an alternative liner system if it can be shown that the liner system will limit contaminant migration such that contamination concentrations in the uppermost aquifer at the closest down-gradient monitoring well are less than MCLs specified by the Clean Water Act (CWA) or more restrictive State requirements. This performance based liner system is commonly referred to as a "point of compliance" liner. The concept of a "point of compliance" liner equivalence differs significantly from earlier concepts of comparing the "performance" of alternative liner systems to that of the regulatory required liner system. The "point of compliance" liner equivalence is dependent on the rate of leakage of liquid from the landfill and the particular site geology.

Earlier regulatory liner systems, e.g., RCRA-C as defined in 40 CFR §264, are designed with the goal to allow no more than the "de minimis" leakage of contaminants. The concept of "de minimus" comes from the legal principal "de minimis non curat lex" (i.e., the law does not concern itself with trifles). Specific levels of acceptable leakage are not codified but three factors are usually considered in evaluating the performance or equivalence of barrier systems (Koerner and Daniel, 1993):

- the flow rate through the liner system (i.e., how many gallons per acre per day),
- the "break-out time" defined as the time required for liquids to travel through the system and be released to the environment, and
- an equivalent chemical adsorption capacity.

Subtitle D did not incorporate an equivalence requirement because it was felt that such a requirement would be overly conservative for arid and semi-arid regions of the West. The low rainfall in such regions may allow the use of a liner allowing more leakage than the Subtitle D composite liner.

This paper reviews the performance of the current composite liner system required by North Carolina and the performance of alternative liner systems using the "point of compliance" evaluation. This comparison is limited to a comparison of leakage rates since site specific considerations such as geology cannot be reviewed. Next the paper will present a summary of current uasage of the alternative liner systems in other states.

Performance of North Carolina Regulatory Liner System

Currently, North Carolina requires the default Subtitle D composite liner system that includes a 2-foot thick compacted clay liner (CCL) overlain by a geomembrane. A typical section detail for the regulatory composite liner is shown on Figure 1-a. The CCL must be constructed with clayey soils that have a permeability less than 1 x 10^{-7} cm/sec. In North Carolina, such clayey soils are not commonly available which has forced the use of expensive amendment procedures to improve available soils. This amendment has included the addition of Wyoming bentonite clay to available soils at a significant cost to the owner.

The geomembrane used in the regulatory composite liner is typically a 60-mil thick membrane formed of High Density Polyethylene (HDPE). HDPE is the polymer commonly used to make gallon milk jugs and has exceptional chemical stability. The performance of a geomembrane is influenced primarily by the number of defects, i.e., holes, that exist in the geomembrane when it is placed into service. These penetrations may be caused by manufacturing defects or damage inflicted during the construction of the liner system. The number of penetrations is minimized by a formal program of inspection/testing during the construction of the liner system. This inspection program is commonly referred to as Construction Quality Assurance (CQA). EPA data (Giroud and Bonaparte, 1989) indicates that a good CQA program can limit the number of defects to less than 8 small (1 cm^2) holes per acre. The liner comparisons presented in this paper assume that a comprehensive CQA programs is performed on each alternative so that a single defect per acre can be assumed for the geomembrane in all alternatives.

Flow Rate Through the Liner System ---- The maximum rate that leachate can be released from a composite lined landfill requires estimating the maximum head acting on the liner system. For Subtitle-D landfills this must be less than 30 cm. The actual head can be estimated using the HELP model. Alternatively, the highest rate of leakage can be estimated by assuming 30 cm of leachate is acting on the geomembrane (GM). This represents the most conservative case, i.e., the most leakage, as compared to performing a HELP model analysis of the proposed landfill. Assuming good contact between the geomembrane and the compacted clay liner (CCL), the leakage through the liner system is calculated as follows (Giroud and Bonaparte, 1989):

$$Q = 0.21\ h^{0.9}\ a^{0.1}\ K^{0.74} \qquad \text{(Eq.1)}$$

where h is the height of water standing on the geomembrane (m), a is the area of the hole (m^2), and K is the permeability of the underlying clay (m/sec). It is important to note that the leakage rate is influenced by the height of liquid standing on the liner, the number/size of penetrations, and the permeability of the clay beneath the geomembrane. Again using a single 1 cm^2 hole, h of 30 cm, and K of 1 x 10^{-7} cm/sec, the flow through the composite barrier can be calculated to equal **0.14 gallon/day/penetration**. Assuming eight holes per acre, the leakage out of the liner system is approximately **1.12 gallons/acre/day**.

Alternative Liner Systems

Two alternative liner systems are currntly being used in Subtitle D landfills. These two alternatives are significantly different in operating/design principals but both have been successfully used in Subtitle D landfills. These two alternative liner systems are discussed below.

Geosynthetic Clay Liner (GCL) Composite Liner Alternative ---- This alternative substitutes a GCL for the CCL in the composite liner. A GCL contains approximately one pound of bentonite per square foot laminated to either a geotextile or geomembrane carrier. The GCL is installed much like a carpet with a simple overlap between adjacent rolls. The bentonite has a permeability less than 1×10^{-9} cm/sec and is a common waterproofing media. Like the CCL, the GCL limits the rate that liquids can flow through defects in the overlying geomembrane. Typically the GCL is used in combination with an 18 to 24-inch thick structural fill layer. The permeability of the structural fill layer is commonly required to be less than 1×10^{-5} cm/sec. A typical section detail for a GCL alternative liner system is shown on Figure 1-b.

Double Geomembrane/Drainage Layer Alternative ---- The double geomembrane alternative liner system achieves a low leakage by limiting the head of liquid acting on the lower geomembrane. A typical section of the double geomembrane alternative is shown on Figure 1-c. Both of the leachate drainage systems are over designed so that the heads are significantly less than the 30 cm requirement of Subtitle D. This reduction in head across two successive geomembranes allows an acceptable leakage rate through the liner system without the need for a low permeability soil layer.

Performance of Alternative Liner System - GCL Composite Liner

The liner performance of the GCL alternative can be evaluated using the criteria previously evaluated for the current regulatory liner, i.e., the flow rate through the liner system.

Flow Rate Through the Liner System ---- The maximum rate that leachate can be released from the GCL alternative composite is calculated by the following (Giroud, et al.,1992):

$$Q = 0.21\, i_{ave}\, a^{0.1}\, h^{0.9}\, K^{0.74} \qquad \text{(Eq.6)}$$

where

$i_{ave} = 1 + Eh/t_{GCL}$ $\quad$ t_{GCL}=thickness of GCL

$E = 1 / [2 \ln (2R/b)]$ $\quad$ b=dia. of hole (m)

$R = 0.61\, a^{0.05}\, h^{0.45}\, K^{-0.13}$.

Most commercial GCLs use Wyoming bentonite that develops a permeability of approximately 5×10^{-9} cm/sec in the GRI-GCL-2 test. This test uses an effective confining stress of only 10 psi. Actual long-term confining stresses acting on the GCL will be larger than this and result in lower GCL permeabilities. The flow through a single 1 cm^2 hole having 30 cm of water standing on it can be calculated to be **0.066 gallon/day/penetration**. Again assuming eight holes per acre, the leakage out of the liner system is approximately **0.53 gallons/acre/day**.

The predicted leachate flux rates through a single puncture in the GM-GCL composite are less than one half that through the regulatory GM-CCL composite. This means that, for a given level of CQA program, i.e., number of penetrations per acre, the alternative composite liner systems will have half the leakage of the conventional composite liner.

Performance of Alternative Liner System - Dual Liner/Leachate Collection

The liner performance of the Dual Liner/Leachate Collection alternative can be evaluated using the criteria previously evaluated for the current regulatory cover, i.e., the flow rate through the liner system.

Flow Rate Through the Liner System ---- The maximum rate that leachate can be released from the double geomembrane liner system is estimated by first predicting the leakage through the upper geomebrane, then estimating the head acting on the lower geomembrane due to this inflow, and finally estimating the leakage through the lower composite liner resulting from this reduced head. This is shown graphically on Figure 2. The flow through the upper geomembrane can be estimated using the following equation (Bonaparte, et. al., 1989) :

$$Q = 3a^{0.75}h^{0.75}k_d^{0.5} \qquad \text{(Eq.10)}$$

where Q is the steady-state rate of leakage (m^3/s) through one geomembrane hole, a is the area of the hole (m^2), h is the head of liquid acting over the geomembrane, and k_d is the permeability of the drainage layer overlying the geomembrane. Assuming that the head is equal to the 30 cm maximum allowed by Subtitle D and a sand leachate collection system, the flow through a single hole in the upper geomembrane is given by

$$Q = 3\,(.0001)^{.75}(.3)^{.75}(.00001)^{.5} = 3.85 \times 10^{-6}\ m^3/sec = 87.8\ gallon/day \qquad \text{(Eq.11)}$$

Again assuming we have a maximum of eight such holes per acre, the maximum leakage into the leak detection system between the geomembranes is equal to approximately 700 gallons/acre/day.

The drainage system between the two geomembranes is constructed using a synthetic drainage media called a geonet. These are designed to fully drain in less than one day. The geonets are typically approximately 0.2 inches thick and have a storage volume of approximately 3200 gallons/acre. Thus the maximum inflow of leachate into the geonet is less than its drainage capacity. This means the geonet is not saturated and the head acting on the lower geomembrane must be less than the thickness of the geonet. The flow through the lower geomembrane can be calculated using Equation 1. Assuming the lower geomembrane is placed on structural fill having a maximum permeability of 1×10^{-5} cm/sec, the flow through a single one cm^2 hole is equal to **0.018 gallons/day/penetration**. Again assuming eight holes per acre, the leakage out of the liner system is approximately **0.15 gallons/acre/day**.

Subtitle D Application of Alternative Liner Systems

Since the implementation of Subtitle D on October 9, 1993, the alternative liner systems have been used on a significant number of MSW landfills located across the country. Table 1 lists the GCL Subtitle D alternative liners that have been identified by the authors. The significant number and geographic distribution of GCL alternative landfill applications speaks to the broad acceptability of the GCL alternative liner system.

The dual geomembrane liner system has seen most extensive use in Subtitle D landfills in Florida. This alternative liner system was actually written into the solid waste regulations in Florida and has survived legal challenge in Federal court in response to a citizen suit there brought by environmental defense groups. Table 2 lists the double geomembrane landfills currently operating within Florida.

Summary

RCRA-D regulations in 40 CFR 258 provide for an alternative method of evaluating liner equivalence. In these regulations, a point of compliance method allows the use of an alternative liner system if it can be shown that the liner will limit contaminant migration such that contamination concentrations at the closest down-gradient monitoring well are less than MCLs specified by the Clean Water Act (CWA). The demonstration requires first estimating the rate that leachate is leaving the liner system as has been done in this paper. Next the movement of the leachate from the liner to the monitoring well is modeled. Presently, EPA requires this evaluation to be performed using the EPA generated computer model MULTIMED (Salhotra, et al., 1993). This model uses a closed-form solution to the contaminant transport problem and incorporates default chemical transport data. *This analysis neglects the significant break out times required for the liner systems and all natural attenuation of the contaminants. Such natural attenuation may be due to the actual breakdown of the contaminant with time, adsorption onto clay particles, and the finite quantity of waste in the landfill.* The Subtitle D point of compliance demonstration must be performed using these EPA required modeling restrictions (Allison, 1992, and Sharp-Hansen et al., 1993).

The point of compliance evaluation places significant value on the rate of leakage from the liner system. The analyses presented in this paper have shown that the maximum leakage rates for the current regulatory liner and the two most common alternatives under equal service conditions assuming 8 small holes per acre are as follows:

Regulatory Composite Liner	1.12 gallons/acre/day
GCL Alternative Composite Liner	0.53 gallons/acre/day
Dual Geomembrane Alternative Liner	0.15 gallons/acre/day

Based on these performance comparisons, it is apparent that the current regulatory composite liner system would not be acceptable if evaluated using the Point of Compliance evaluation at those sites where the alternative liner systems reviewed failed the Point of Compliance evaluation. Thus the designer should be free to select one of the three liner systems evaluated in this paper. This selection would be based on site conditions, i.e., available clays, and anticipated construction costs.

Table 1 Post '93 Permitted Subtitle D La 'lls Liners Using GCL Composite Liner

State	Owner	Landfill Name	State	Owner	Landfill Name
Alabama	Dothan	City of Dothan	Michigan	United Waste	Menominee
Alaska	City of Anchorage	Eastwind - Phase 2	Michigan	BFI	Allis Park
Arizona	?	Big D	Michigan	Phillip Envirn.	McGill Road
California	Los Angeles Sanit.	Lopez Canyon - Area C	Michigan	BFI	Vienna Junction
California	Kern county	Shafter-Wasco - Module 2	Ohio	BFI	Carbon Limestone
California	Los Angeles Sanit	Puente Hills - Phase 1B	Oregon	Valley Landfills	Coffin Butte
California	Los Angeles Sanit	Sunshine Canyon - Phase I	Oregon	Rogue Disposal	Dry Creek
California	BFI	Vasco Road - Unit 6	Pennsylvania	BFI	Imperial
California	Norcal	B&J - Module 2.2	Pennsylvania	USA/CH	Duapin Meadows
California	Norcal	Cummings Road	Pennsylvania	United	Kelly Run
California	City of Whittier	Calabasas	Pennsylvania	Arnoni	Arnoni
California	Santa Cruz	Buena Vista	Pennsylvania	MCSWA	Kness
California	Sacto Co.	Kiefer Road	Pennsylvania	Chrin Brothers	Chrin Brothers
California	Laidlaw	Chiquita Canyon	Pennsylvania	Clinton County	Clinton County
Colorado	Rio Grande City	Rio Grande	Pennsylvania	Greater Lebanon RA	Lebonon
Florida	Chambers	Berman Road - Cells 3, 7	Pennsylvania	Vogel Disposal	Seneca
Georgia	Habersham County	Habersham County	New Mexico	City of Carlsbad	Carlesbad
Georgia	Addington	Swift Creek	New Mexico	City of Gonzales	Johnson Canyon
Georgia	Southern States	Taylor County	New Mexico	Sunland Park	JOAB
Georgia	Sanifill	Bolton Road ?	New York	Jamestown?	Ellery
Georgia	Gordon Co.	Red Bone Ridge	South Carolina	Greenville County	Enoree
Hawaii	County of Kauai	Kekaha	Texas	Midland	City of Midland
Idaho	Kootenai County	Kootenai County	Texas	Odessa	City of Odessa
Kentucky	Addington	Epperson	Virginia	Bramble USA	Atlantic Waste
Kentucky	Kelchner Envirn.	Walton	Virginia	Chambers	Charles City
Kentucky	Rumpke	Butler	Virginia	Chambers	Amelia
Maryland	USA/CH	Mountain View	Wyoming	City of Cheyenne	Cheyenne

Table 2 Permitted Dual Liner/Leachate Subtitle D Landfills in Florida

Landfill	LCS Type	Primary Liner	LDS Type	Secondary Liner
Medley Expansion	24" sand + geonet	60 mil HDPE	geonet	HDPE + 6" 1 x 10^{-5} cm/sec
Winfield	24" sand	60 mil HDPE	geonet	HDPE + 6" 1 x 10^{-5} cm/sec
Site 7	24" sand + geonet	60 mil HDPE	12" sand + geonet	HDPE + 6" 3.8 x 10^{-3} cm/sec
Broward Interim	24" sand	60 mil HDPE	12" sand + geonet	HDPE + 6" 1 x 10^{-4} cm/sec
West Pasco	24" sand	60 mil HDPE	12" sand + geonet	HDPE + 6" 1 x 10^{-5} cm/sec

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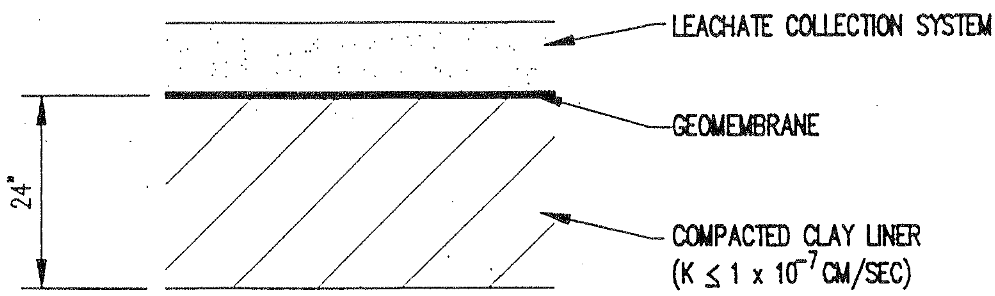
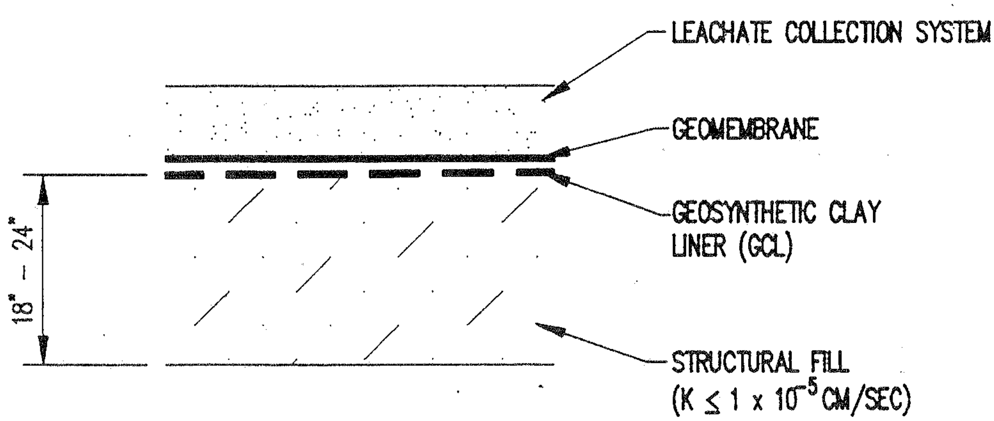
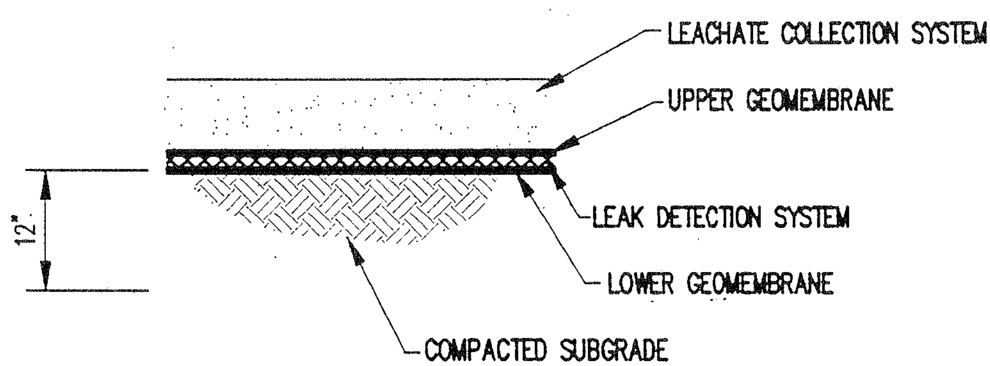


1A. DEFAULT SUBTITLE D LINER SYSTEM



1B. GCL ALTERNATIVE LINER SYSTEM



1C. DOUBLE GEOMEMBRANE ALTERNATIVE LINER SYSTEM

SUBTITLE D AND ALTERNATIVE LINER SYSTEMS

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SCALE:	DRAWN BY:	CHECKED BY:	DATE:	PROJECT NO.	FIGURE NO.
1' = 2'	GGM	P.K.S.	NOV. 1996		1