ATLANTIC COAST
CONSULTING, INC.

7 E. Congress Street
Suite 801
Savannah, GA 31401
(912) 236-3471
www.atlcc.net

April 25, 2017

Ouida Johnson
Mayor
City of Homeland
401 Pennsylvania Ave.
Homeland, Georgia 31537

RE: Notification of Submittal of a Coal Combustion Residuals (CCR) Management Plan
Waste Management of North Florida, Inc.- Chesser Island Road Landfill
Charlton County, Georgia

Dear Mrs. Johnson,

Rules and regulations of the State of Georgia (391-3-4-.07(5)) require that you be notified of the initial submittal of a proposed Coal Combustion Residuals (CCR) Management Plan for solid waste disposal facilities permitted by the Georgia Department of Natural Resources Environmental Protection Division (EPD). On April 21, 2017, a Minor Modification Permit Application for Chesser Island Road Landfill was submitted to EPD. On behalf of Waste Management of North Florida, Inc., this letter is to provide such notice. You will also be notified if an amended CCR Management Plan is submitted to EPD.

Sincerely,
ATLANTIC COAST CONSULTING

Marc Liverman, PE

Cc: Shawn Carroll, WM
File

ATLANTIC COAST
CONSULTING, INC.

7 E. Congress Street
Suite 801
Savannah, GA 31401
(912) 236-3471
www.atlcc.net

April 25, 2017

L.H. Pender Lloyd
City Manager
Folkston, Georgia
541 First St.
Folkston, Georgia 31537

RE: Notification of Submittal of a Coal Combustion Residuals (CCR) Management Plan
Waste Management of North Florida, Inc.- Chesser Island Road Landfill
Charlton County, Georgia

Dear Mr. Lloyd,

Rules and regulations of the State of Georgia (391-3-4-.07(5)) require that you be notified of the initial submittal of a proposed Coal Combustion Residuals (CCR) Management Plan for solid waste disposal facilities permitted by the Georgia Department of Natural Resources Environmental Protection Division (EPD). On April 21, 2017, a Minor Modification Permit Application for Chesser Island Road Landfill was submitted to EPD. On behalf of Waste Management of North Florida, Inc., this letter is to provide such notice. You will also be notified if an amended CCR Management Plan is submitted to EPD.

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7 E. Congress Street
Suite 801
Savannah, GA 31401
(912) 236-3471
www.atlcc.net

April 25, 2017

Shawn Boatright
County Administrator
Charlton County
68 Kingsland Dr. Suite B
Folkston, Georgia 31537

RE: Notification of Submittal of a Coal Combustion Residuals (CCR) Management Plan
Waste Management of North Florida, Inc.- Chesser Island Road Landfill
Charlton County, Georgia

Dear Mr. Boatright,

Rules and regulations of the State of Georgia (391-3-4-.07(5)) require that you be notified of the initial submittal of a proposed Coal Combustion Residuals (CCR) Management Plan for solid waste disposal facilities permitted by the Georgia Department of Natural Resources Environmental Protection Division (EPD). On April 21, 2017, a Minor Modification Permit Application for Chesser Island Road Landfill was submitted to EPD. On behalf of Waste Management of North Florida, Inc., this letter is to provide such notice. You will also be notified if an amended CCR Management Plan is submitted to EPD.

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Marc Liverman, PE

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File

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CONSULTING, INC.

7 E. Congress Street
Suite 801
Savannah, GA 31401
(912) 236-3471
www.atlcc.net

RECEIVED

APR 25 2017

SOLID WASTE
MANAGEMENT PROGRAM

April 20, 2017

William Cook
Solid Waste Management Program
Georgia Environmental Protection Division
4244 International Parkway, Suite 104
Atlanta, Georgia 30354

RE: Waste Management of North Florida, Inc.
Chesser Island MSWLF
Minor Modification – Coal Combustible Residuals (CCR) Management Plans
Permit Number: 024-006D (SL)

Dear William,

Please find enclosed an executed minor modification form and four copies of the revised Plan Sheets Cover, 25A, 26, 26A, 27, and 29 for the above referenced facility. This proposed modification to the permit revises the Design and Operation Plan to incorporate a CCR Management Plan in accordance with EPD's Solid Waste Management Rule 391-3-4-.07(5) as well as the EPD guidance document issued December 22, 2016. Below is a summary of the revisions incorporated into the current D&O plan for compliance with the CCR Management Plan Guidance.

CCR Guidance General Requirements

1) *The CCR Management Plan shall be submitted as a request for modification to the facility's Design and Operational (D&O) Plan. Modifications which substantially alter the design of the facility, management practices, the types of wastes being handled, or the method of waste handling, and due to the nature of the changes would likely have an impact on the ability of the facility to adequately protect human health and the environment will require a major modification.*

   Response: The Chesser Island facility is currently accepting CCR material. This request for modification will not substantially alter the design, management, types of waste or methods of waste handling. Therefore, it is being submitted as a minor modification to the facility's current permit.

2) *CCR Management Plans will be approved for a duration of one year. Facilities must submit a sealed professional engineer's Annual CCR Management and Dust Control Review describing activities, issues and any non-compliance*

from the prior year (for more on Fugitive Dust Control requirements, see below). Based on the annual review, Georgia EPD will either issue written approval to continue CCR management under the existing plan or will request the facility to amend their Plan. Amendments to the plan shall include any changes necessitated by the prior year's operations. The facility shall place the written EPD approval in the facility operating record. Facilities requested to amend their CCR Management Plan must obtain an approved amended Plan within 30 days of EPD's request or cease receipt of CCR until such approval is granted.

Revision: Section 39 has been added to the Operational Narrative on Sheet 26A to define the annual reporting requirements related to CCR management and fugitive dust control.

The current source of CCR for this facility is defined in Section 3 of the Operational Narrative on Sheet 26. This section also requires that EPD approval be obtained prior to accepting new types of CCR or increases in ash ratio.

3) *Plan sheets should be the same size (24"x30" to 24"x36") and have a standard title block.*

Response: All plan sheets match the size of the current D&O plan and have a standard title block.

4) *A professional engineer registered to practice in Georgia must stamp and sign all sheets*

Response: All modified plan sheets are stamped and signed by a Georgia Registered Professional Engineer.

CCR Management Plan Components

1) *The estimated total amount of CCR to be accepted on annual basis and the daily maximum amount of CCR to be accepted must be listed in the Plan.*

For sites that will dispose of comingled CCR and MSW, the amount of MSW received and the maximum ratio of CCR to MSW for placement in the landfill must be listed in the Plan. The facility must be designed to address Section 4, Design Consistency, for comingling waste up to this maximum ratio. The facility may not dispose of comingled waste at a ratio that exceeds the maximum considered in the design calculations. Dedicated CCR cells that were previously approved for MSW disposal must also be redesigned to address the requirements of section 4. Design Consistency.

Revision: Section 1 of the Operational Narrative on Sheet 26 has been modified to define the estimated daily and annual tonnages of CCR to be

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accepted at the facility. Additionally, Section 1 defines the estimated maximum ratio of MSW to CCR for co-mingled areas.

The design calculations that are affected by the CCR waste stream are included as attachments to this submittal.

2) *Procedures for waste placement, cover, and recovery*
The CCR Management Plan must include the following:

a. *A description of how the working face will be managed at facilities where CCR and other wastes will be comingled, or identification of proposed CCR monofill cells.*

   Revision: Section 2 of the Operational Narrative on Sheet 26 has been modified to define the procedures governing the controlled unloading of CCR material at the working face, co-mingling with MSW, and CCR placement in individual lifts. There are no CCR monofill cells designated for this facility.

b. *Description of waste placement procedures including (but not limited to):*

   i. *the initial layer placement of CCR above the liner and leachate collection system,*

      Revision: Section 33 of the Operational Narrative on Sheet 26A has been modified to state that no CCR material will be co-mingled in the initial lift. This section also states that no CCR only layers will be allowed in the initial lift.

   ii. *placement and compaction requirements of CCR lifts to maintain stability,*

      Response: The CCR will be co-mingled with MSW or placed in individual lifts. Section 5 of the Operational Narrative on Sheet 26 has been modified to describe the compaction requirements CCR only layers.

   iii. *placement and compaction procedures for comingled wastes.*

      Revision: The procedures currently in-place to spread and compact co-mingled MSW and CCR will remain the same as areas receiving MSW only. However, different procedures are required to ensure proper compaction of CCR only layers. Therefore, Section 5 of the Operational Narrative on Sheet 26 has been amended to define the procedures for co-mingled waste areas and CCR only layers.

c. *Procedures and criteria for daily cover of comingled CCR and MSW.*

Atlantic Coast Consulting, Inc.

Revision: Section 6 of the Operational Narrative on Sheet 26 has been modified to require daily cover of co-mingled MSW and CCR and CCR only layers in accordance with current procedures.

d. *The working face must be maintained at a size that is compatible with the facility's available equipment for spreading and compacting waste, and for suppressing dust. Describe the proposed maximum working face area and the equipment needed to manage a working face of this area.*

Revision: The size requirements of the working face will not change. However, Section 2 of the Operational Narrative on Sheet 26 has been revised to describe co-mingling of CCR with MSW and CCR only lifts at the working face. Additionally, Section 21 on Sheet 26 has been modified to define dust control procedures for a working face receiving CCR wastes.

e. *Operator inspection procedures for maintaining and documenting compliance with the CCR Management Plan must be given.*

Revision: Section 2 of the Operational Narrative on Sheet 26 has been revised to specify operator training related to CCR waste streams.

f. *If applicable, procedures for onsite liquid waste solidification operations using CCR.*

Revision: Sections 35 and 36 on Sheet 26A of the Operational Narrative has been modified to clarify that CCR waste streams will not be used in the solidification processes.

g. *If applicable, procedures must be given for recovery of previously disposed CCR for beneficial reuse. EPD must be notified prior to disturbing and excavating previously disposed CCR for beneficial reuse*

Response: The D&O plan does not allow recovery of previously disposed CCR material for beneficial re-use.

3) *Fugitive Dust Control*

The CCR Management Plan must include measures that will minimize CCR from becoming airborne at the facility. Potential CCR fugitive dust emissions originating from CCR disposal units, roads, conditioning areas, and other CCR management and material handling activities must be minimized.

a. *Performance Standard: The percent opacity from CCR and any other fugitive dust source listed in Air Quality Rule 391-3-1-.02(2)(n)1 shall not exceed the limits set therein.*

Revision: Section 21 of the Operational Narrative on Sheet 26 has been modified to require compliance with Air Quality Rule 391-3-1-.02(2)(n)1.

b. *The Dust Control Plan must describe measures that the owner or operator will use to minimize CCR from becoming airborne, such as the following:*
   i. *locating CCR inside an enclosure/partial enclosure*
   ii. *operating a water spray or fogging system*
   iii. *reducing fall distances at material drop points*
   iv. *using wind barriers, compaction, or vegetative covers*
   v. *establishing vehicle speed limits*
   vi. *paving and sweeping roads*
   vii. *covering trucks transporting CCR*
   viii. *reducing or halting operations during high wind events*
   ix. *applying daily cover or more frequent cover as needed*

   Revision: Section 21 of the Operational Narrative on Sheet 26 has been modified to require wetting of CCR disposal areas with a water truck to control dust, if needed.

c. *The Dust Control Plan must provide an explanation of how the selected measures are applicable and appropriate for the existing site conditions.*

   Response: The use of a water truck to provide dust control was selected as it is equipment currently available at the facility.

d. *The Dust Control Plan must provide procedures to emplace CCR with adequate moisture content or other suppressants added to minimize dust.*

   Revision: Section 21 of the Operational Narrative on Sheet 26 has been modified to require wetting of CCR disposal areas with a water truck to control dust, if needed.

e. *Citizen Complaints: Procedures to log citizen complaints received by the owner or operator must be described in the Plan.*

   Revision: Section 21 of the Operational Narrative on Sheet 26 has been modified to specify the use of Waste Management's 1-800 citizen comment number for documenting citizen CCR complaints.

f. *An "Annual Fugitive Dust Control Report" report will be due 12 months after the approval of the CCR Management Plan, and one year later for each subsequent report. The report shall include a description of the actions taken to control fugitive dust, a record of all citizen complaints, a summary of any corrective measures taken and, if applicable, recommendations to improve the dust control measures in the future.*

   Revision: Section 21 of the Operational Narrative on Sheet 26 has been modified to require preparation and submission of an annual dust control report. Additionally, Section 39 on Sheet 26A was added to

allow for the annual fugitive dust report to be included with the annual CCR management plan renewal requirements.

4. *Design Consistency*
   The CCR Management Plan must address the following landfill design considerations:

   a. *A demonstration that the design grades of the landfill are stable (i.e., for short operations and long-term static and seismic conditions).*

      Revision: A revised stability analysis is included as an attachment to demonstrate that the facility's waste mass will remain stable with the addition of a CCR waste stream.

   b. *A demonstration that the liner system is designed to account for chemical exposure to CCR-generated leachate.*

      Revision: CCR are defined by the EPA as a solid waste to be regulated under Subtitle D (EO 12866 CCR 2050-AE81). CCR waste material accepted for disposal at the landfill will not require non-hazardous certification. Additionally, CCR generated leachate will not subject the liner system to additional chemical exposure beyond what it endures from typical MSW.

   c. *The cell floor grading and construction plans shall account for settlement caused by the weight of the CCR or the comingled waste. Cell floor subsidence and leachate collection pipe crushing shall be evaluated, and a demonstration of adequate post-settlement cell floor grades, leachate pipe grades, and resistance to crushing shall be provided in the design calculations.*

      Revision: Revised base grade settlement analysis and pipe crushing calculations are included as an attachment to demonstrate that the integrity of the facility's base grades and leachate collection piping are adequate.

   d. *The Leachate Collection and Removal System (LCRS) shall continue to maintain its functionality and limit the head of leachate on the liner system to a maximum of 30 centimeters. Drainage nets, filter fabrics, and other features of the LCRS must be demonstrated to be compatible with CCR. Pipes must be able to support the weight of the CCR without damage.*

      Revision: The leachate collection system was evaluated with the addition of CCR material to ensure that the 30 cm head of leachate on the liner system is not exceeded. The HELP model calculations are included as an attachment to this submittal.

e. *The landfill gas collection system design shall account for comingling of MSW and CCR waste.*

Revision: Standard MSWL GCCS systems are designed to account for gas produced from a mixed waste mass of MSW, C&D, and other inert materials (like CCR). Therefore, the current GCCS system design will not be affected by the co-mingling of CCR.

f. *Construction, operation, and maintenance of waste units to be used for CCR disposal shall remain consistent with recognized and generally accepted good engineering practices for the maximum volume of CCR to be disposed.*

Revision: Co-mingling of CCR does not require revisions to the D&O plan's specified construction, operation or maintenance of the waste units other than those issues addressed herein. Additionally, Section 5 of the Operational Narrative on Sheet 26 has been modified to account for construction of CCR only layers.

g. *The plan must define any events or circumstances that represent a safety emergency, along with a description of the procedures that will be followed to detect a safety emergency in a timely manner.*

Revision: CCR does not present any significant safety concern beyond what is typically experienced at the site on a daily basis. The site has existing onsite safety procedures, contingency plans, and training materials to address routine emergencies. Section 10 of the Operational Narrative on Sheet 26 has been amended to require regular training of facility employees that will enable them to better detect and respond to safety emergencies.

h. *The plan must provide a detailed description of leachate and contact water management that demonstrates surface water contacting MSW or CCR will not be discharged into the stormwater management system. Describe or provide details for any required structures (such as chimney drains) and any management practices such as placement of diversion berms between the working face or exposed CCR and the stormwater collection ditches.*

Revision: Addition of CCR waste stream to the LF mass does not require revisions to the D&O plan's specified leachate or stormwater management requirements. Co-mingled MSW and CCR waste leachate and contact water will be managed in accordance with established practices that govern MSW only waste streams.

i. *Design calculations supporting the CCR Management Plan are to be performed by or be done under the direction of a Professional Engineer and shall be submitted as auxiliary materials to the Plan.*

Revision: Design calculations are included with this submittal and are sealed and signed by a Professional Engineer.

j. *CCR shall not be placed in any previously constructed cell, either comingled or as a monofill, without a demonstration that the cell, as constructed, was designed or can be retrofitted (e.g., lowering of final grades) to accommodate CCR disposal.*

Revision: Previously constructed areas include portions of Phase 4 and all of Phase 3. Based on construction documentation and information provided by WM of North Florida, Inc, these cells contain leachate collection systems that are capable of withstanding the addition of CCR material at the designated ratios up to currently permitted final grades. Calculations supporting this determination are included as attachments to this submittal.

5. *Waste Compatibility Analysis*
The Plan must show that CCR waste is compatible (non-reactive) with MSW or industrial waste streams received at the facility, and that different CCR waste streams received are compatible with one another. In demonstrating compatibility, the plan shall contain at a minimum the following components:

a. *List of source(s) of CCR waste streams*

Revision: Section 3 of the Operational Narrative on Sheet 26 has been modified to specify the sources of CCR waste.

b. *Chemical analyses of CCR waste streams*

Revision: CCR are defined by the EPA as a solid waste to be regulated under Subtitle D (EO 12866 CCR 2050-AE81). CCR waste material accepted for disposal at the landfill will not require non-hazardous certification. The current list of sources of CCR waste streams and pre-acceptance chemical analysis are detailed in Section 3 of the Operational Narrative on Sheet 26.

c. *Documentation of compatibility analyses for use in a solidification process, if applicable.*

Revision: The facility's solidification plan on Sheet 26A (Section 35) has been modified to allow for the use of CCR material in the solidification process.

The chemical analyses may be submitted as auxiliary materials to the Plan. If a new type of CCR is proposed for disposal, a plan modification application must be submitted if, based on the above analyses, acceptance of the new CCR material necessitates changes to the facility's design or operations.

<u>Revision:</u> The current source of CCR for this facility is defined in Section 3 of the Operational Narrative on Sheet 26. This section also requires that EPD approval be obtained prior to accepting new sources of CCR.

6. *Closure and Post-Closure Care Impacts*
   The CCR Management Plan shall evaluate impacts to the landfill's closure and post-closure care cost estimates. If CCR management changes either or both of these estimates, these plan sections must be revised to comply with 391-3-4-.11 or 391-3-4-.12. Groundwater monitoring costs should be updated to reflect the additional constituents monitored for landfills that have accepted CCR. If the largest open waste-accepting area increases due to CCR acceptance, closure cost estimates must be updated accordingly.

   <u>Revision:</u> The Closure/Post Closure Care Plan on Sheet 27 has been revised to address the additional groundwater monitoring costs during post closure care. The closure costs and largest waste accepting area open are unaffected by the CCR management plan.

7. *Groundwater Monitoring*
   Appendix III and IV constituents (including boron) must be incorporated into the facility's groundwater monitoring plan in accordance with 391-3-4-.14(21)(c) and 391-3-4-.14(25).

   <u>Revision:</u> Sheet 25A has been added to the Groundwater Monitoring Plan to address the additional groundwater monitoring requirements related to acceptance of CCR wastes.

8. *Modification Procedures*
   The CCR Management Plan must be modified and submitted for EPD's approval if changes in either operating procedures or the facility design are necessary to comply with the requirements for CCR management.

   <u>Revision:</u> Section 39 of the Operational Narrative on Sheet 26A has been revised to require submittal of revised plans if operating procedures or facility design are necessary due to changes in the CCR waste stream.

9. *Documentation of Notification to Local Governments*
   The owner or operator shall notify the local governing authorities of the county, and any city within the county, in which the landfill is located upon the initial submittal of a CCR Management Plan or upon submittal of an amended Plan to EPD. Copies of the correspondence to local governing authorities must be provided to EPD with the Plan submittal.

   <u>Revision:</u> Section 39 of the Operational Narrative on Sheet 26A has been revised to specify compliance with notification requirements. Documentation

of notification to the local governments required as part of this initial submittal will be forwarded to EPD.

Please let me know if you have any questions.

Sincerely,

ATLANTIC COAST CONSULTING, INC.

Marc Liverman, P.E.
Project Engineer

cc: Shawn Carroll, WM
Robert Brown, ACC

DEPARTMENT OF NATURAL RESOURCES
ENVIRONMENTAL PROTECTION DIVISION

REQUEST FOR MINOR MODIFICATION TO SOLID WASTE HANDLING PERMIT

Instructions This form must accompany all requests by the Permittee requiring a minor modification for the subject facility. Attached modifications of the Design and Operation (D&O) Plan must be factual and complete. This form and supporting documents must be submitted directly to the EPD Regional office to which the facility is assigned. For modifying a D&O Plan, please include three (3) copies of all pertinent sheets. **Follow-up submittals require the Permittee to submit a new request form.**

APPLICANT TO COMPLETE THE REVERSE SIDE

FOR EPD USE ONLY

Official Facility Name ______________________________

Permit No. ______________ Modification Type ______________

Review Deadline Date ______________________________

Received By ______________ Date ______________ Comments* ______________

Reviewed By ______________ Date ______________ Comments* ______________

Action By ______________ Date ______________ Comments* ______________

*Disposition: Approved/Denied/Incomplete

Reply to Appropriate EPD District Office

1 Georgia EPD Mountain District
P.O. Box 3250
Cartersville, Georgia 30120
(770) 387-4900
ATTN: Mr. James Cooley, Mgr.

2 Georgia EPD West Central District
2640 Shurling Drive
Macon, Georgia 31202
(478) 751-6612
ATTN: Mr. Todd Bethune, Mgr.

3 Georgia EPD Northeast District
745 Gaines School Road
Athens, Georgia 30605
(706) 369-6376
ATTN: Mr. Derrick Williams, Mgr.

4 Georgia EPD East Central District
3524 Walton Way Ext.
Augusta, GA 30909
(706) 667-4343
ATTN: Mr. Jeff Darley, Mgr.

5 Georgia EPD Coastal District
400 Commerce Center Drive
Brunswick, Georgia 31523-8251
(912) 264-7284
ATTN: Mr. Bruce Foisy, Mgr.

6 Georgia EPD Southwest District
2024 Newton Road
Albany, Georgia 31708
(229) 430-4144
ATTN: Ms. Lisa Myler, Mgr.

NOTE: All minor modifications for private industrial facilities except for those facilities located in the Coastal District should be directed to:
Georgia Environmental Protection Division
Solid Waste Management Program
4244 International Parkway, Suite 104
Atlanta, Georgia 30354
(404) 362-2692
ATTN: Solid Waste Management Program

FACILITY Chesser Island Road Landfill, Inc. MSWL PERMIT NO. 024-006D(SL)

Pursuant to the requirements of the Georgia Comprehensive Solid Waste Management Act, O.C.G.A 12-8-20, et seq. and the Rules of the Georgia Department of Natural Resources, Chapter 391-3-4-.02(4), Solid Waste Management, both as amended, the undersigned hereby:

1 Requests a minor modification as represented in the attached modified D&O Plan, and/or supporting documents;

2 Certifies that the Permittee is the rightful owner of the facility and can verify that this proposed modification shall conform to all local zoning/land use ordinances; and

3 Certifies that the information provided in or submitted by the facility Permittee as part of this request form and modified D&O Plan is true and correct, and if approved, the facility Permittee agrees to comply with provisions of this minor modification to the D&O Plan, provisions of the Act Rules, and conditions of the Permit.

I PERMITTEE Chesser Island Road Landfill, Inc.

ADDRESS 367 Chesser Island Landfill Road PHONE (912) 496-7918

CITY Folkston STATE Georgia ZIP 31537

AUTHORIZED OFFICIAL Eric Parker

SIGNATURE [signature] DATE 5/6/2017

TITLE Environmental Protection Manager

MAILING ADDRESS 367 Chesser Island Landfill Road

CITY Folkston STATE Georgia ZIP 31537

II Briefly describe the exact changes to be made to the permit conditions and explain why the change is needed.

Revision of the Facilities Design & Operations Plan to incorporate Coal Combustion Residual Management Plan and Procedures.

III Attached documents include:

Revised Design & Operations Plan Sheets

WASTE MANAGEMENT

CHESSER ISLAND ROAD LANDFILL, INC.

HWY 121 @ CHESSER ISLAND ROAD | FOLKSTON, GEORGIA 31537

CHESSER ISLAND ROAD MSW LANDFILL
CCR MANAGEMENT & GROUNDWATER PLANS

PERMIT #: 024-006D(SL)

DESIGN CALCULATIONS

ATLANTIC COAST CONSULTING, INC.

APRIL 2017

APRIL 2017

Design Calculations Notebook

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Design Calculations Notebook

IN THIS SECTION:

A. Global Slope Stability Analysis

B. Base Liner Stability Analysis

Section 1
A. Global Slope Stability Analysis

OBJECTIVE: Verify the global stability of the final configuration of the waste mass of the Chesser Island Phase 4 MSWLF with the addition of Combustible Coal Residual (CCR) material. The original stability calculations Phase 4 Major Modification, as prepared by Atlantic Coast Consulting, Inc and dated February 2009, will be analyzed with respect to failure surfaces passing through the liner system and the underlying subgrade. The stability of the waste mass was evaluated under static conditions.

METHOD: The waste mass global stability was evaluated with the circular surface search analysis under static and seismic conditions. For the purpose of this analysis, a critical slope was selected from the disposal area which represents the original cross-section evaluated (i.e. Figure 1.1A: Section A-A from the Phase 4 Major Modification D&O plans). The geometry of the landfill and subsurface soils along the analyzed cross sections are shown on Figure 1.2A. The addition of CCR to the waste mass does not impact the design of the final cover system, therefore the final cover stability is not being re-evaluated.

To identify critical failure planes, the computer program SLIDE Version 7.022 was used to perform stability calculations utilizing the Janbu and Bishop method of slices for circular surfaces. SLIDE was utilized to search through the anticipated zone of failures for each phase to identify the critical failure planes with the lowest factor of safety.

To begin the evaluation, the cross-sectional geometry and soil/waste mass was input into SLIDE and static analyses was evaluated over the landfill mass. This allows for the identification of the critical failure planes with the lowest factor of safety.

DATA: The waste parameters used for the calculations were taken from a May 2000 technical paper "Municipal Solid Waste Slope Failure. I: Waste and Foundation Soil Properties", by Eid, Stark, Evans, and Sherry. The soil properties used are from onsite field test as well as specified soil properties for the landfill construction quality assurance plan. The geosynthetic properties are the minimum required by the construction quality assurance plan.

The following assumptions were also used in the preparation of the stability analysis:

- Fully drained conditions within the landfill due to the presence of a leachate collection system

Soil Layer Data: The following material properties were used based on experience with similar materials and the references cited above.

Co-mingled Municipal Solid Waste and CCR (1.7:1) (SLIDE material unit 1)
unit wt. = 73 pcf phi = 35 degrees c=500 psf

Recompacted Liner Base (SLIDE material unit 2)
unit wt. = 130 pcf phi = 20 degrees c = 500 psf

Protective Cover (SLIDE material unit 3)
unit wt. = 110 pcf phi = 20 degrees c = 500 psf

Geocomposite (SLIDE material unit 4)
unit wt. = 60 pcf phi = 15 degrees c = 0 psf

Geosynthetic Clay Liner (SLIDE material unit 5)
unit wt. = 100 pcf phi = 15 degrees c = 0 psf

Textured HDPE Geomembrane Liner (SLIDE material unit 6)
unit wt. = 100 pcf phi = 15 degrees c = 0 psf

Subgrade (SLIDE material unit 7)
unit wt. = 120 pcf phi = 18 degrees c = 500 psf

CCR Layer (SLIDE material unit 8)
unit wt. = 100 pcf phi = 33 degrees c = 120 psf

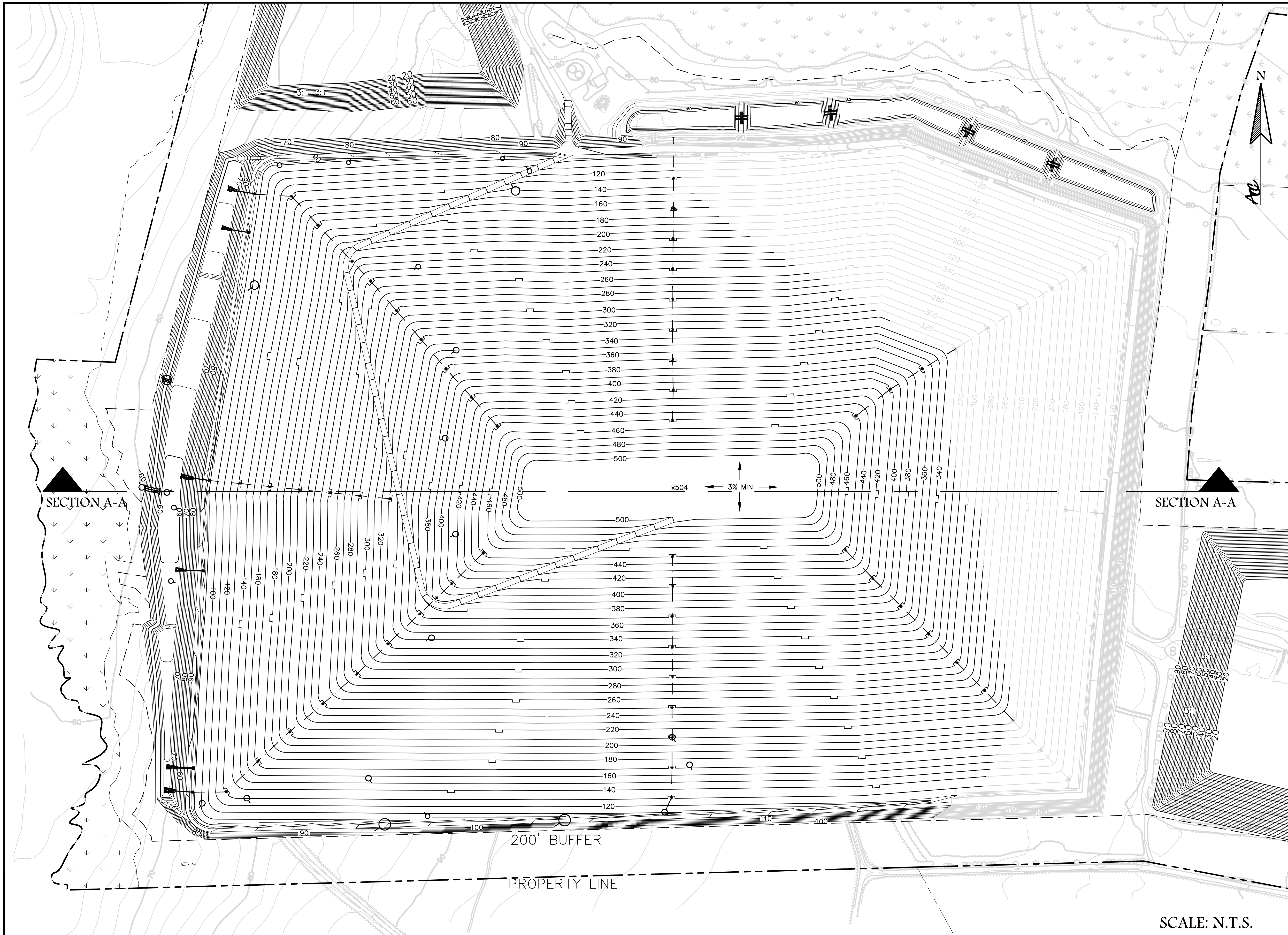
Recirculation of leachate will occur at this site. However, due to the restrictions on loading rates as discussed on the operational narrative, the above referenced MSW material properties will not be effected.

RESULTS: The SLIDE program outputs for the critical analysis show the geometry of the critical cross section evaluated for failure, the location of the critical failure surfaces and the associated factor of safety. The minimum factor of safety against failure for the evaluation scenario for each phase is as follows:

Static:
SLIDE selected critical failure planes:
Factor of Safety (Janbu Circular, static) = 1.793

The calculated factor of safety for static conditions are greater than 1.5, and are therefore considered adequate in terms of long term stability.

CONCLUSION: The analysis indicates that the proposed landfill geometry is adequately designed in consideration of the global slope stability under static and seismic conditions.



ATLANTIC COAST CONSULTING, INC.
630 Colonial Park Drive
Suite 110
Roswell, GA 30075
o 770.594.5998
f 770.594.5967
www.atlcc.net

PROJECT:

CHESSER ISLAND ROAD MSW LANDFILL CCR MANAGEMENT PLAN

CHARLTON COUNTY, GA
PERMIT NO: 024-006D(SL)

WASTE MANAGEMENT

Chesser Island Road Landfill, Inc.
Hwy 121 @ Chesser Island Road
Folkston, GA 31537

Drawn by: MAL

Checked by:

PROJECT NUMBER:

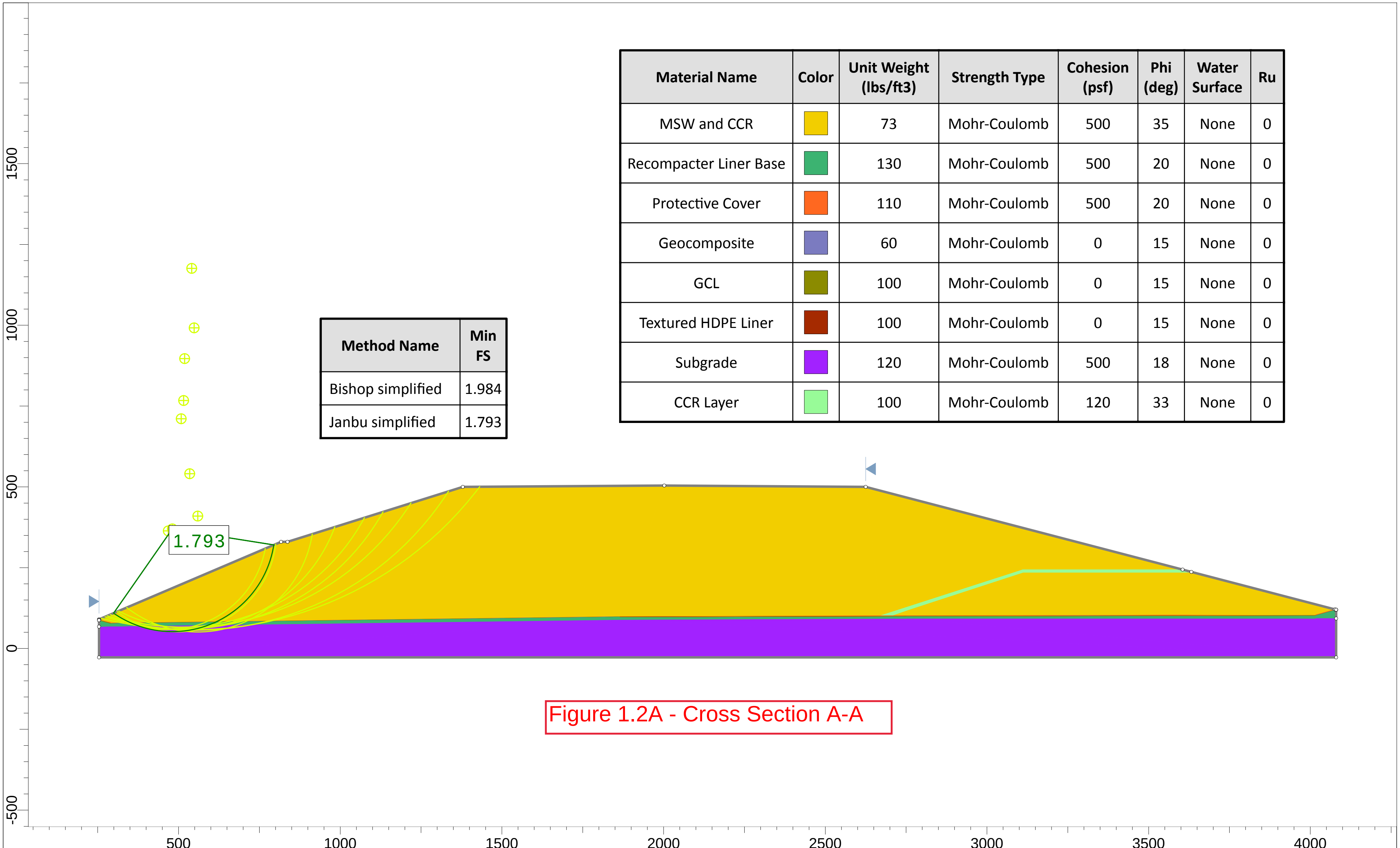
I014-415

April 2017

FINAL GRADES STABILITY ANALYSIS SECTION A-A

FIGURE 1.1A

STATIC ANALYSIS



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
MSW and CCR		73	Mohr-Coulomb	500	35	None	0
Recompacter Liner Base		130	Mohr-Coulomb	500	20	None	0
Protective Cover		110	Mohr-Coulomb	500	20	None	0
Geocomposite		60	Mohr-Coulomb	0	15	None	0
GCL		100	Mohr-Coulomb	0	15	None	0
Textured HDPE Liner		100	Mohr-Coulomb	0	15	None	0
Subgrade		120	Mohr-Coulomb	500	18	None	0
CCR Layer		100	Mohr-Coulomb	120	33	None	0

Method Name	Min FS
Bishop simplified	1.984
Janbu simplified	1.793

Figure 1.2A - Cross Section A-A

Project	Chesser Island Phase 4 Expansion
Analysis Description	Circular - Static
Drawn By	Marc Liverman
Scale	1:4926
Company	Atlantic Coast Consulting
Date	4/5/17
File Name	Chesser Circ Static 4 CCR.slim

SLIDEINTERPRET 7.023

Slide Analysis Information
Chesser Island Phase 4 Expansion

Project Summary

File Name:	Chesser Circ Static 4 CCR.slim
Slide Modeler Version:	7.023
Project Title:	Chesser Island Phase 4 Expansion
Analysis:	Circular - Static
Author:	Marc Liverman
Company:	Atlantic Coast Consulting
Date Created:	4/5/17

General Settings

Units of Measurement:	Imperial Units
Time Units:	seconds
Permeability Units:	feet/second
Failure Direction:	Right to Left
Data Output:	Standard
Maximum Material Properties:	20
Maximum Support Properties:	20

Analysis Options

Slices Type:	Vertical

Analysis Methods Used

	Bishop simplified
	Janbu simplified

Number of slices:	50
Tolerance:	0.005
Maximum number of iterations:	50
Check malpha < 0.2:	Yes
Initial trial value of FS:	3
Steffensen Iteration:	Yes

Groundwater Analysis

Groundwater Method:	Water Surfaces
Pore Fluid Unit Weight [lbs/ft3]:	9.81
Use negative pore pressure cutoff:	Yes
Maximum negative pore pressure [psf]:	0
Advanced Groundwater Method:	None

Random Numbers

Pseudo-random Seed:	10116
Random Number Generation Method:	rand

Surface Options

Surface Type:	Circular
Search Method:	Slope Search
Number of Surfaces:	5000
Upper Angle:	Not Defined
Lower Angle:	Not Defined
Composite Surfaces:	Disabled
Reverse Curvature:	Invalid Surfaces
Minimum Elevation [ft]:	50
Minimum Depth:	Not Defined
Minimum Area:	Not Defined
Minimum Weight:	Not Defined

Seismic

Advanced seismic analysis:	No
Staged pseudostatic analysis:	No

Material Properties

Property	MSW and CCR	Recompacter Liner Base	Protective Cover	Geocomposite	GCL	Textured HDPE Liner	Subgrade	CCR Layer
Color								
Strength Type	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
Unit Weight [lbs/ft3]	73	130	110	60	100	100	120	100
Cohesion [psf]	500	500	500	0	0	0	500	120
Friction Angle [deg]	35	20	20	15	15	15	18	33
Water Surface	None	None	None	None	None	None	None	None
Ru Value	0	0	0	0	0	0	0	0

Global Minimums

Method: bishop simplified

FS	1.983770
Center:	515.755, 767.133
Radius:	706.827
Left Slip Surface Endpoint:	279.614, 100.919
Right Slip Surface Endpoint:	1133.074, 422.865
Resisting Moment:	3.54874e+009 lb-ft
Driving Moment:	1.78889e+009 lb-ft
Total Slice Area:	114365 ft2
Surface Horizontal Width:	853.46 ft
Surface Average Height:	134.001 ft

Method: janbu simplified

FS	1.793130
Center:	480.794, 370.081
Radius:	317.754
Left Slip Surface Endpoint:	299.255, 109.291
Right Slip Surface Endpoint:	794.651, 320.473
Resisting Horizontal Force:	1.99711e+006 lb
Driving Horizontal Force:	1.11376e+006 lb
Total Slice Area:	56572.9 ft2
Surface Horizontal Width:	495.396 ft
Surface Average Height:	114.197 ft

Valid / Invalid Surfaces

Method: bishop simplified

Number of Valid Surfaces: 4749
Number of Invalid Surfaces: 251

Error Codes:

Error Code -106 reported for 96 surfaces
Error Code -108 reported for 83 surfaces
Error Code -114 reported for 72 surfaces

Method: janbu simplified

Number of Valid Surfaces: 4585
Number of Invalid Surfaces: 415

Error Codes:

Error Code -106 reported for 96 surfaces
Error Code -108 reported for 247 surfaces
Error Code -114 reported for 72 surfaces

Error Codes

The following errors were encountered during the computation:

-106 = Average slice width is less than 0.0001 * (maximum horizontal extent of soil region). This limitation is imposed to avoid numerical errors which may result from too many slices, or too small a slip region.
-108 = Total driving moment or total driving force < 0.1. This is to limit the calculation of extremely high safety factors if the driving force is very small (0.1 is an arbitrary number).
-114 = Surface with Reverse Curvature.

Slice Data

Global Minimum Query (bishop simplified) - Safety Factor: 1.98377

Slice Number	Width [ft]	Weight [lbs]	Angle of Slice Base [degrees]	Base Material	Base Cohesion [psf]	Base Friction Angle [degrees]	Shear Stress [psf]	Shear Strength [psf]	Base Normal Stress [psf]	Pore Pressure [psf]	Effective Normal Stress [psf]	Base Vertical Stress [psf]	Effective Vertical Stress [psf]
1	22.4919	14069.3	-18.5553	MSW and CCR	500	35	536.282	1063.86	805.276	0	805.276	625.263	625.263
2	22.4919	41529.4	-16.6422	MSW and CCR	500	35	1010.2	2004	2147.93	0	2147.93	1845.97	1845.97
3	22.4919	67652	-14.748	MSW and CCR	500	35	1448.07	2872.63	3388.47	0	3388.47	3007.28	3007.28
4	7.11618	26901.6	-13.5086	Protective Cover	500	20	989.172	1962.29	4017.63	0	4017.63	3779.99	3779.99
5	0.810193	3244.82	-13.1783	Geocomposite	0	15	558.598	1108.13	4135.59	0	4135.59	4004.79	4004.79
6	0.814298	3294.26	-13.1107	GCL	0	15	564.153	1119.15	4176.72	0	4176.72	4045.32	4045.32
7	0.408707	1667.11	-13.0598	Textured HDPE Liner	0	15	568.745	1128.26	4210.71	0	4210.71	4078.78	4078.78
8	0.820568	3374.61	-13.0086	GCL	0	15	573.348	1137.39	4244.8	0	4244.8	4112.34	4112.34
9	21.2387	101285	-12.0941	Recompacter Liner Base	500	20	1173.06	2327.08	5019.88	0	5019.88	4768.52	4768.52
10	21.2387	127281	-10.3387	Recompacter Liner Base	500	20	1398.31	2773.93	6247.55	0	6247.55	5992.46	5992.46
11	20.8795	148319	-8.60771	Subgrade	500	18	1451.46	2879.37	7322.94	0	7322.94	7103.23	7103.23
12	20.8795	169269	-6.89933	Subgrade	500	18	1611.77	3197.38	8301.68	0	8301.68	8106.65	8106.65
13	20.8795	188638	-5.1971	Subgrade	500	18	1757.97	3487.4	9194.27	0	9194.27	9034.38	9034.38
14	20.8795	206442	-3.49946	Subgrade	500	18	1890.39	3750.1	10002.8	0	10002.8	9887.18	9887.18
15	20.8795	222691	-1.8049	Subgrade	500	18	2009.31	3986	10728.8	0	10728.8	10665.5	10665.5
16	20.8795	237392	-0.111914	Subgrade	500	18	2114.94	4195.56	11373.8	0	11373.8	11369.7	11369.7
17	20.8795	250547	1.58097	Subgrade	500	18	2207.49	4379.16	11938.8	0	11938.8	11999.7	11999.7
18	20.8795	262153	3.27524	Subgrade	500	18	2287.1	4537.08	12424.9	0	12424.9	12555.7	12555.7
19	20.8795	272206	4.97239	Subgrade	500	18	2353.87	4669.54	12832.6	0	12832.6	13037.3	13037.3
20	20.8795	280695	6.67393	Subgrade	500	18	2407.88	4776.68	13162.3	0	13162.3	13444	13444
21	20.8795	287606	8.3814	Subgrade	500	18	2449.15	4858.56	13414.2	0	13414.2	13775.1	13775.1
22	20.8795	292920	10.0964	Subgrade	500	18	2477.7	4915.19	13588.5	0	13588.5	14029.7	14029.7
23	20.9044	296540	11.8217	Recompacter Liner Base	500	20	2749.3	5453.97	13610.9	0	13610.9	14186.4	14186.4
24	20.9044	297660	13.5589	Recompacter Liner Base	500	20	2743.34	5442.16	13578.5	0	13578.5	14240.1	14240.1
25	0.815486	11617.8	14.4646	GCL	0	15	1859.59	3689	13767.6	0	13767.6	14247.3	14247.3
26	0.406166	5787.86	14.5158	Textured HDPE Liner	0	15	1859.81	3689.44	13769.2	0	13769.2	14250.7	14250.7
27	0.809216	11534	14.5667	GCL	0	15	1860.02	3689.85	13770.7	0	13770.7	14254.1	14254.1
28	0.805112	11482.2	14.6343	Geocomposite	0	15	1860.81	3691.41	13776.5	0	13776.5	14262.4	14262.4
29	7.07044	100935	14.9646	Protective Cover	500	20	2737.21	5429.99	13545	0	13545	14276.7	14276.7
30	20.5366	295441	16.1277	MSW and CCR	500	35	4836.94	9595.37	12989.5	0	12989.5	14388.2	14388.2
31	20.5366	299151	17.8688	MSW and CCR	500	35	4843.33	9608.06	13007.6	0	13007.6	14569.1	14569.1
32	20.5366	301823	19.6271	MSW and CCR	500	35	4832.22	9586.02	12976.2	0	12976.2	14699.4	14699.4
33	20.5366	303424	21.4049	MSW and CCR	500	35	4803.46	9528.95	12894.7	0	12894.7	14777.6	14777.6
34	20.5366	303914	23.2046	MSW and CCR	500	35	4756.81	9436.41	12762.5	0	12762.5	14801.7	14801.7
35	20.5366	302250	25.0289	MSW and CCR	500	35	4677.21	9278.5	12537	0	12537	14720.9	14720.9
36	20.5366	290533	26.8808	MSW and CCR	500	35	4450.44	8828.64	11894.5	0	11894.5	14150.5	14150.5
37	20.5366	282295	28.7636	MSW and CCR	500	35	4276.57	8483.73	11401.9	0	11401.9	13749.5	13749.5
38	20.5366	274368	30.681	MSW and CCR	500	35	4108.57	8150.46	10926	0	10926	13363.6	13363.6
39	20.5366	265033	32.6373	MSW and CCR	500	35	3921.98	7780.3	10397.3	0	10397.3	12909.2	12909.2
40	20.5366	254196	34.6375	MSW and CCR	500	35	3716.2	7372.08	9814.33	0	9814.33	12381.6	12381.6
41	20.5366	241749	36.6872	MSW and CCR	500	35	3490.53	6924.4	9175	0	9175	11775.5	11775.5
42	20.5366	227563	38.7932	MSW and CCR	500	35	3244.17	6435.68	8477.01	0	8477.01	11084.8	11084.8
43	20.5366	211481	40.9636	MSW and CCR	500	35	2976.19	5904.07	7717.81	0	7717.81	10301.7	10301.7
44	20.5366	193314	43.2079	MSW and CCR	500	35	2685.52	5327.46	6894.34	0	6894.34	9416.91	9416.91
45	20.5366	172825	45.5384	MSW and CCR	500	35	2370.96	4703.43	6003.13	0	6003.13	8419.07	8419.07
46	20.5366	149717	47.9702	MSW and CCR	500	35	2031.08	4029.2	5040.22	0	5040.22	7293.6	7293.6
47	20.5366	123605	50.5228	MSW and CCR	500	35	1664.33	3301.65	4001.17	0	4001.17	6021.8	6021.8
48	20.5366	93978.1	53.2225	MSW and CCR	500	35	1268.96	2517.32	2881.03	0	2881.03	4578.67	4578.67
49	20.5366	60127.2	56.1056	MSW and CCR	500	35	843.152	1672.62	1674.68	0	1674.68	2929.68	2929.68
50	20.5366	21021.1	59.2253	MSW and CCR	500	35	385.308	764.362	377.548	0	377.548	1024.56	1024.56

Global Minimum Query (janbu simplified) - Safety Factor: 1.79313

Slice Number	Width [ft]	Weight [lbs]	Angle of Slice Base [degrees]	Base Material	Base Cohesion [psf]	Base Friction Angle [degrees]	Shear Stress [psf]	Shear Strength [psf]	Base Normal Stress [psf]	Pore Pressure [psf]	Effective Normal Stress [psf]	Base Vertical Stress [psf]	Effective Vertical Stress [psf]
1	12.5422	6246.01	-33.4864	MSW and CCR	500	35	638.162	1144.31	920.163	0	920.163	497.991	497.991
2	12.5422	18364.2	-30.8137	MSW and CCR	500	35	1108.86	1988.33	2125.56	0	2125.56	1464.18	1464.18
3	12.5422	29764.5	-28.2136	MSW and CCR	500	35	1525.04	2734.59	3191.32	0	3191.32	2373.13	2373.13
4	12.5422	40500.5	-25.6755	MSW and CCR	500	35	1895.66	3399.17	4140.44	0	4140.44	3229.12	3229.12
5	3.92472	14924.2	-24.0333	Protective Cover	500	20	1155.26	2071.54	4317.76	0	4317.76	3802.6	3802.6
6	0.444801	1767.45	-23.6021	Geocomposite	0	15	635.252	1139.09	4251.12	0	4251.12	3973.56	3973.56
7	0.44661	1787.79	-23.5144	GCL	0	15	639.775	1147.2	4281.39	0	4281.39	4003.01	4003.01
8	0.223989	902.261	-23.4485	Textured HDPE Liner	0	15	643.645	1154.14	4307.33	0	4307.33	4028.15	4028.15
9	0.449358	1821.39	-23.3824	GCL	0	15	647.527	1161.1	4333.28	0	4333.28	4053.31	4053.31
10	11.2166	51000.5	-22.2456	Recompacter Liner Base	500	20	1310.58	2350.04	5082.94	0	5082.94	4546.88	4546.88
11	11.2166	61340.4	-20.0762	Recompacter Liner Base	500	20	1500.18	2690.01	6017	0	6017	5468.73	5468.73
12	11.9269	75540.5	-17.8696	Subgrade	500	18	1515.02	2716.62	6822.06	0	6822.06	6333.61	6333.61
13	11.9269	85190.3	-15.623	Subgrade	500	18	1657.08	2971.36	7606.06	0	7606.06	7142.68	7142.68
14	11.9269	94121.7	-13.401	Subgrade	500	18	1785.91	3202.36	8317.02	0	8317.02	7891.53	7891.53
15	11.9269	102356	-11.1992	Subgrade	500	18	1902.15	3410.81	8958.54	0	8958.54	8581.93	8581.93
16	11.9269	109911	-9.01419	Subgrade	500	18	2006.37	3597.68	9533.65	0	9533.65	9215.36	9215.36
17	11.9269	116801	-6.84229	Subgrade	500	18	2099	3763.78	10044.9	0	10044.9	9793.03	9793.03
18	11.9269	123035	-4.68025	Subgrade	500	18	2180.42	3909.78	10494.3	0	10494.3	10315.8	10315.8
19	11.9269	128621	-2.52488	Subgrade	500	18	2250.94	4036.22	10883.3	0	10883.3	10784.1	10784.1
20	11.9269	133564	-0.373079	Subgrade	500	18	2310.78	4143.52	11213.6	0	11213.6	11198.6	11198.6
21	11.9269	137866	1.77819	Subgrade	500	18	2360.13	4232.02	11485.9	0	11485.9	11559.2	11559.2
22	11.9269	141526	3.93198	Subgrade	500	18	2399.12	4301.94	11701.2	0	11701.2	11866.1	11866.1
23	11.9269	144540	6.09135	Subgrade	500	18	2427.84	4353.44	11859.7	0	11859.7	12118.8	12118.8
24	11.9269	146901	8.25946	Subgrade	500	18	2446.32	4386.57	11961.7	0	11961.7	12316.8	12316.8
25	11.9269	148601	10.4396	Subgrade	500	18	2454.55	4401.32	12007	0	12007	12459.2	12459.2
26	11.9269	149626	12.6351	Subgrade	500	18	2452.45	4397.57	11995.5	0	11995.5	12545.3	12545.3
27	11.9269	149961	14.8497	Subgrade	500	18	2439.93	4375.12	11926.4	0	11926.4	12573.3	12573.3
28	11.9269	149586	17.0872	Subgrade	500	18	2416.84	4333.7	11798.9	0	11798.9	12541.8	12541.8
29	11.9269	148475	19.352	Subgrade	500	18	2382.94	4272.92	11611.8	0	11611.8	12448.8	12448.8
30	11.008	135169	21.559	Recompacter Liner Base	500	20	2565.51	4600.3	11265.5	0	11265.5	12279.1	12279.1
31	11.008	132456	23.7102	Recompacter Liner Base	500	20	2498.51	4480.16	10935.4	0	10935.4	12032.7	12032.7
32	0.444276	5282.63	24.8383	GCL	0	15	1661.85	2979.92	11121.2	0	11121.2	11890.4	11890.4
33	0.221448	2632.02	24.9045	Textured HDPE Liner	0	15	1660.83	2978.09	11114.4	0	11114.4	11885.5	11885.5
34	0.441528	5245.57	24.9704	GCL	0	15	1659.81	2976.26	11107.6	0	11107.6	11880.5	11880.5
35	0.439719	5222.89	25.0581	Geocomposite	0	15	1659	2974.81	11102.1	0	11102.1	11877.8	11877.8
36	3.87898	45919.3	25.4893	Protective Cover	500	20	2445.11	4384.4	10672.3	0	10672.3	11838	11838
37	12.5127	147126	27.1446	MSW and CCR	500	35	4057.89	7276.32	9677.57	0	9677.57	11758.1	11758.1
38	12.5127	145807	29.7114	MSW and CCR	500	35	3949.14	7081.32	9399.07	0	9399.07	11652.7	11652.7
39	12.5127	143799	32.3458	MSW and CCR	500	35	3821.45	6852.36	9072.12	0	9072.12	11492.2	11492.2
40	12.5127	141041	35.0596	MSW and CCR	500	35	3673.72	6587.46	8693.83	0	8693.83	11271.9	11271.9
41	12.5127	137460	37.867	MSW and CCR	500	35	3504.57	6284.15	8260.66	0	8260.66	10985.7	10985.7
42	12.5127	132958	40.7863	MSW and CCR	500	35	3312.27	5939.33	7768.15	0	7768.15	10625.8	10625.8
43	12.5127	127412	43.8407	MSW and CCR	500	35	3094.61	5549.03	7210.76	0	7210.76	10182.6	10182.6
44	12.5127	120655	47.0612	MSW and CCR	500	35	2848.74	5108.16	6581.15	0	6581.15	9642.6	9642.6
45	12.5127	112455	50.491	MSW and CCR	500	35	2570.87	4609.91	5869.55	0	5869.55	8987.27	8987.27
46	12.5127	102475	54.1931	MSW and CCR	500	35	2255.82	4044.97	5062.74	0	5062.74	8189.7	8189.7
47	12.5127	90184.7	58.267	MSW and CCR	500	35	1896.05	3399.87	4141.45	0	4141.45	7207.47	7207.47
48	12.5127	74653.8	62.8886	MSW and CCR	500	35	1479.89	2653.64	3075.71	0	3075.71	5966.26	5966.26
49	12.5127	53903.8	68.4357	MSW and CCR	500	35	986.42	1768.78	1812	0	1812	4307.95	4307.95
50	12.5127	20939.9	76.2623	MSW and CCR	500	35	358.963	643.667	205.178	0	205.178	1673.51	1673.51

Interslice Data

Global Minimum Query (bishop simplified) - Safety Factor: 1.98377

Slice Number	X coordinate [ft]	Y coordinate - Bottom [ft]	Interslice Normal Force [lbs]	Interslice Shear Force [lbs]	Interslice Force Angle [degrees]
1	279.614	100.919	0	0	0
2	302.106	93.3693	18123.7	0	0
3	324.598	86.6462	55251.9	0	0
4	347.09	80.7254	107835	0	0
5	354.206	79.0158	121732	0	0
6	355.016	78.8261	122969	0	0
7	355.831	78.6365	124220	0	0
8	356.239	78.5417	124851	0	0
9	357.06	78.3521	126125	0	0
10	378.299	73.8012	173848	0	0
11	399.537	69.9266	227708	0	0
12	420.417	66.766	281114	0	0
13	441.296	64.2396	335690	0	0
14	462.176	62.3405	389802	0	0
15	483.055	61.0636	441985	0	0
16	503.935	60.4057	490935	0	0
17	524.814	60.3649	535492	0	0
18	545.694	60.9412	574635	0	0
19	566.573	62.136	607471	0	0
20	587.453	63.9526	633234	0	0
21	608.332	66.3957	651277	0	0
22	629.212	69.472	661072	0	0
23	650.091	73.1899	662208	0	0
24	670.996	77.5653	660041	0	0
25	691.9	82.6067	648848	0	0
26	692.715	82.8171	647467	0	0
27	693.122	82.9223	646773	0	0
28	693.931	83.1325	645380	0	0
29	694.736	83.3428	643980	0	0
30	701.806	85.2326	637706	0	0
31	722.343	91.171	659756	0	0
32	742.879	97.7917	672952	0	0
33	763.416	105.115	677008	0	0
34	783.953	113.166	671703	0	0
35	804.489	121.97	656885	0	0
36	825.026	131.559	632579	0	0
37	845.562	141.969	600016	0	0
38	866.099	153.242	559176	0	0
39	886.635	165.426	510298	0	0
40	907.172	178.579	453971	0	0
41	927.708	192.766	390938	0	0
42	948.245	208.066	322134	0	0
43	968.782	224.574	248722	0	0
44	989.318	242.403	172148	0	0
45	1009.85	261.694	94222.6	0	0
46	1030.39	282.62	17218.8	0	0
47	1050.93	305.404	-55969.7	0	0
48	1071.46	330.337	-121602	0	0
49	1092	357.811	-174735	0	0
50	1112.54	388.38	-208637	0	0
51	1133.07	422.865	0	0	0

Global Minimum Query (janbu simplified) - Safety Factor: 1.79313

Slice Number	X coordinate [ft]	Y coordinate - Bottom [ft]	Interslice Normal Force [lbs]	Interslice Shear Force [lbs]	Interslice Force Angle [degrees]
1	299.255	109.291	0	0	0
2	311.797	100.994	15638.7	0	0
3	324.339	93.5135	45446.8	0	0
4	336.881	86.7846	86047.9	0	0
5	349.423	80.7551	134788	0	0
6	353.348	79.0049	146879	0	0
7	353.793	78.8106	147988	0	0
8	354.24	78.6163	149106	0	0
9	354.463	78.5191	149668	0	0
10	354.913	78.3248	150801	0	0
11	366.129	73.737	188821	0	0
12	377.346	69.6376	230313	0	0
13	389.273	65.7923	274615	0	0
14	401.2	62.4571	319747	0	0
15	413.127	59.6155	364681	0	0
16	425.054	57.254	408522	0	0
17	436.981	55.362	450490	0	0
18	448.908	53.9309	489900	0	0
19	460.834	52.9544	526153	0	0
20	472.761	52.4285	558723	0	0
21	484.688	52.3508	587154	0	0
22	496.615	52.7211	611050	0	0
23	508.542	53.5409	630071	0	0
24	520.469	54.8137	643932	0	0
25	532.396	56.545	652399	0	0
26	544.323	58.7425	655289	0	0
27	556.25	61.4162	652467	0	0
28	568.177	64.5785	643852	0	0
29	580.104	68.2448	629419	0	0
30	592.031	72.4337	609199	0	0
31	603.039	76.783	588443	0	0
32	614.047	81.6175	563079	0	0
33	614.491	81.8231	561530	0	0
34	614.712	81.926	560755	0	0
35	615.154	82.1316	559204	0	0
36	615.594	82.3371	557651	0	0
37	619.473	84.1864	547400	0	0
38	631.985	90.6018	536089	0	0
39	644.498	97.7422	518389	0	0
40	657.011	105.666	494316	0	0
41	669.524	114.447	463944	0	0
42	682.036	124.177	427425	0	0
43	694.549	134.972	385009	0	0
44	707.062	146.989	337083	0	0
45	719.575	160.436	284231	0	0
46	732.087	175.61	227333	0	0
47	744.6	192.955	167746	0	0
48	757.113	213.189	107674	0	0
49	769.625	237.629	51020.2	0	0
50	782.138	269.29	5992.84	0	0
51	794.651	320.473	0	0	0

List Of Coordinates

External Boundary

X	Y
4080	120
4079.63	120.096
4076.31	120.963
3632	237.003
3605.21	244
2625	500
2002	504
1379	500
837	330
817	330
254	90
254	88.2
254	88
254	87.8
254	87.7
254	87.5
254	67.5
254	-27.6
4080	-27.6
4080	93
4080	119.5
4080	119.7
4080	119.8

Material Boundary

X	Y
254	90
290	80
1864	100
2672	101.823
2706	101.9
3632	103.384
4016	104
4076.31	120.963

Material Boundary

X	Y
2672	102
3112	244
3605.21	244

Material Boundary

X	Y
2706	101.9
3112	234
3632	234

Material Boundary

X	Y
254	88.2
290	78.2
1864	98.2
2750	100.2
4016	102.2
4079.63	120.096

Material Boundary

X	Y
254	88
290	78
1864	98
2750	100
4016	102
4080	120

Material Boundary

X	Y
254	87.8
290	77.8
1864	97.8
2750	99.8
4016	101.8
4080	119.8

Material Boundary

X	Y
254	87.7
290	77.7
1864	97.7
2750	99.7
4016	101.7
4080	119.7

Material Boundary

X	Y
254	87.5
290	77.5
1864	97.5
2750	99.5
4016	101.5
4080	119.5

Material Boundary

X	Y
254	67.5
290	68.5
1864	89
2750	93
4016	93
4080	93

Material Boundary

X	Y
2672	101.823
2672	102

Material Boundary

X	Y
3632	103.384
3632	234
3632	237.003

Section 1
B. Base Liner Stability Analysis

OBJECTIVE: Verify the stability of the waste mass at Chesser Island Phase 4 with respect to failure surfaces passing through the base liner with the inclusion of Combustible Coal Residual (CCR) to the waste mass. The original stability calculations for the Phase 4 Major Modification, as prepared by Atlantic Coast Consulting, Inc and dated February 2009, will be analyzed with respect to failure surfaces passing through the weakest interface of liner system. The analyzed cross section is shown in plan view on Figure 1.1B and the stability of the waste mass along the liner interface through this section was evaluated under static conditions. The objective is to find the minimum interface friction angle required for a stable base liner system within the revised co-mingled (MSW and CCR) waste mass.

METHOD: Evaluate the stability of the waste mass at the base liner system interface. The Simplified Janbu and Bishop Methods for non-circular (block) surfaces was used to evaluate failure at the liner system. The data for these failure planes are summarized below with details provided in the attached SLIDE output files.

The first step in the evaluation is to input the geometry and individual layers' physical properties into SLIDE Version 7.022 and run a static analysis on the landfill mass for the scenario described above.

The evaluation as shown was the result of an iterative process that was used to identify the minimum friction angle that would result in meeting the required design factors of safety.

GEOMETRY: The base liner system will have six possible options, as listed below, from top to bottom:

Option 1
- 24" of $1x10^{-2}$ cm/sec leachate collection material
- textured 60 mil HDPE geomembrane
- 24" of $1x10^{-7}$ cm/sec compacted soil

Option 2
- 24" of protective cover
- double-sided geocomposite
- textured 60 mil HDPE geomembrane
- 24" of $1x10^{-7}$ cm/sec compacted soil

Option 3
- 24" of $1x10^{-2}$ cm/sec leachate collection material
- textured 60 mil HDPE geomembrane
- geosynthetic clay liner (GCL) ($1x10^{-9}$ cm/sec)
- 24" of $1x10^{-4}$ cm/sec compacted soil

Option 4	24" of protective cover double-sided geocomposite textured 60 mil HDPE geomembrane geosynthetic clay liner (GCL) ($1x10^{-9}$ cm/sec) 24" of $1x10^{-4}$ cm/sec compacted soil
Option 5	24" of $1x10^{-2}$ cm/sec leachate collection material textured 60 mil HDPE geomembrane geosynthetic clay liner (GCL) ($1x10^{-9}$ cm/sec) textured 60 mil HDPE geomembrane geosynthetic clay liner (GCL) ($1x10^{-9}$ cm/sec)
Option 6	24" of protective cover double-sided geocomposite textured 60 mil HDPE geomembrane geosynthetic clay liner (GCL) ($1x10^{-9}$ cm/sec) textured 60 mil HDPE geomembrane geosynthetic clay liner (GCL) ($1x10^{-9}$ cm/sec)

For liner stability analysis, the liner system was modeled using the most critical interface within the lining system (i.e. the interface with the lowest interface friction angle). According to the laboratory testing data, liner options 5 and 6 exhibited the lowest friction angle at the interface of the HDPE liner/double-sided geocomposite. Therefore, this interface was utilized to analyze the liner system stability. The lowest friction angle for all options is assumed to be 15 degrees.

The critical section from the original design calculations was evaluated with the inclusion of CCR material into the waste. This section is shown on the attached plan view of the landfill (Figure 1.2B)

DATA: The material and interface properties used in the slope stability analysis are summarized in Table 1. The waste properties for the analysis were taken from a May 2000 technical paper “Municipal Solid Waste Slope Failure. I: Waste and Foundation Soil Properties”, by Eid, Stark, Evans and Sherry. Soils properties used are from onsite field test as well as specified soil properties for the landfill construction. The geosynthetic properties are artificial values used in the iterative design in order to determine the minimum requirements. Whereas the comingled MSW and CCR unit weight of 73 lb/ft^3 is based on a ratio of 10:1 (MSW:CCR) with the CCR values derived from laboratory data.

Table1. Material properties used in slope stability analyses

Material	SLIDE Material Unit ID #	Unit Weight (pcf)	Cohesion (psf)	Peak Friction Angle vs material below (deg)
Co-Mingled Municipal Solid Waste and CCR (1.7:1)	1	73	500	35
Recompacted Liner Base	2	130	500	20
Protective Cover Layer	3	110	500	20
Geocomposite	4	60	0	15
Geosynthetic Clay Liner (GCL)	5	100	0	15
Textured HDPE Geomembrane	6	100	0	15
Recompacted Liner Base	7	120	500	18
CCR Layer	8	100	120	33

The following assumptions were also used in the preparation of the stability analysis:

- Fully drained conditions within the landfill due to the presence of a leachate collection system

RESULTS: The SLIDE computer results for the analysis are attached. Figure 1.1B shows the critical cross section evaluated for failure and corresponding factors of safety for the analysis.

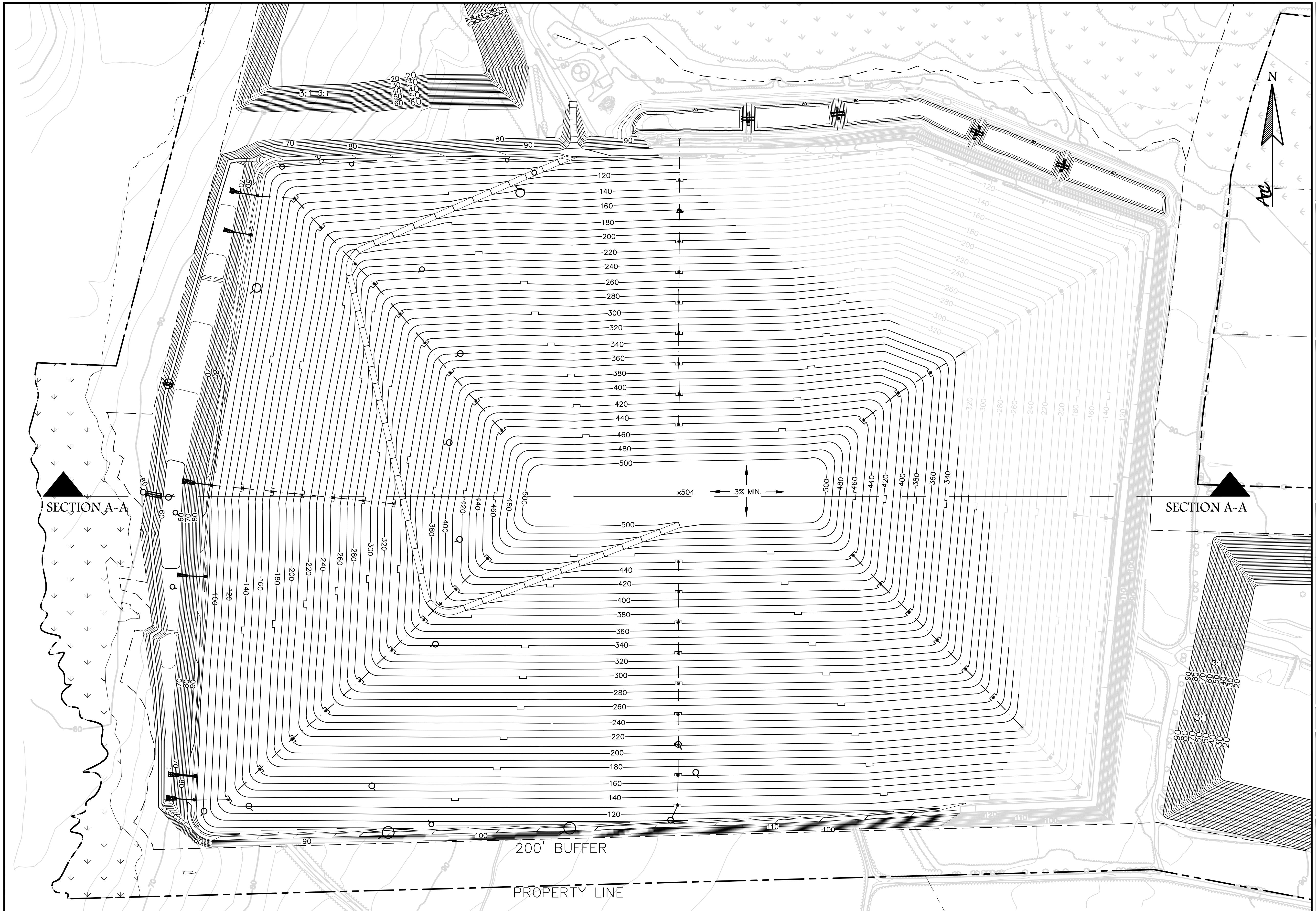
The minimum FOS against failure for the landfill expansion is as follows:

Table 2. Results

Scenario	FOS	SLIDE file
Janbu Block	1.526	Chesser Block Static 4 CCR.slim
Bishop Block	1.594	Chesser Block Static 4 CCR.slim

CONCLUSION:

The static stability analysis of the landfill mass failure at the liner interface produced a minimum calculated factor of safety of 1.526. This values is considered adequate (greater than 1.5) and demonstrate the overall stability of the landfill mass under static conditions.



SCALE: N.T.S.

ATLANTIC COAST CONSULTING, INC.
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PROJECT:

CHESSER ISLAND ROAD MSW LANDFILL CCR MANAGEMENT PLAN

CHARLTON COUNTY, GA
PERMIT NO: 024-006D(SL)

WASTE MANAGEMENT
Chesser Island Road Landfill, Inc.
Hwy 121 @ Chesser Island Road
Folkston, GA 31537

Drawn by: MAL	Checked by:

PROJECT NUMBER:

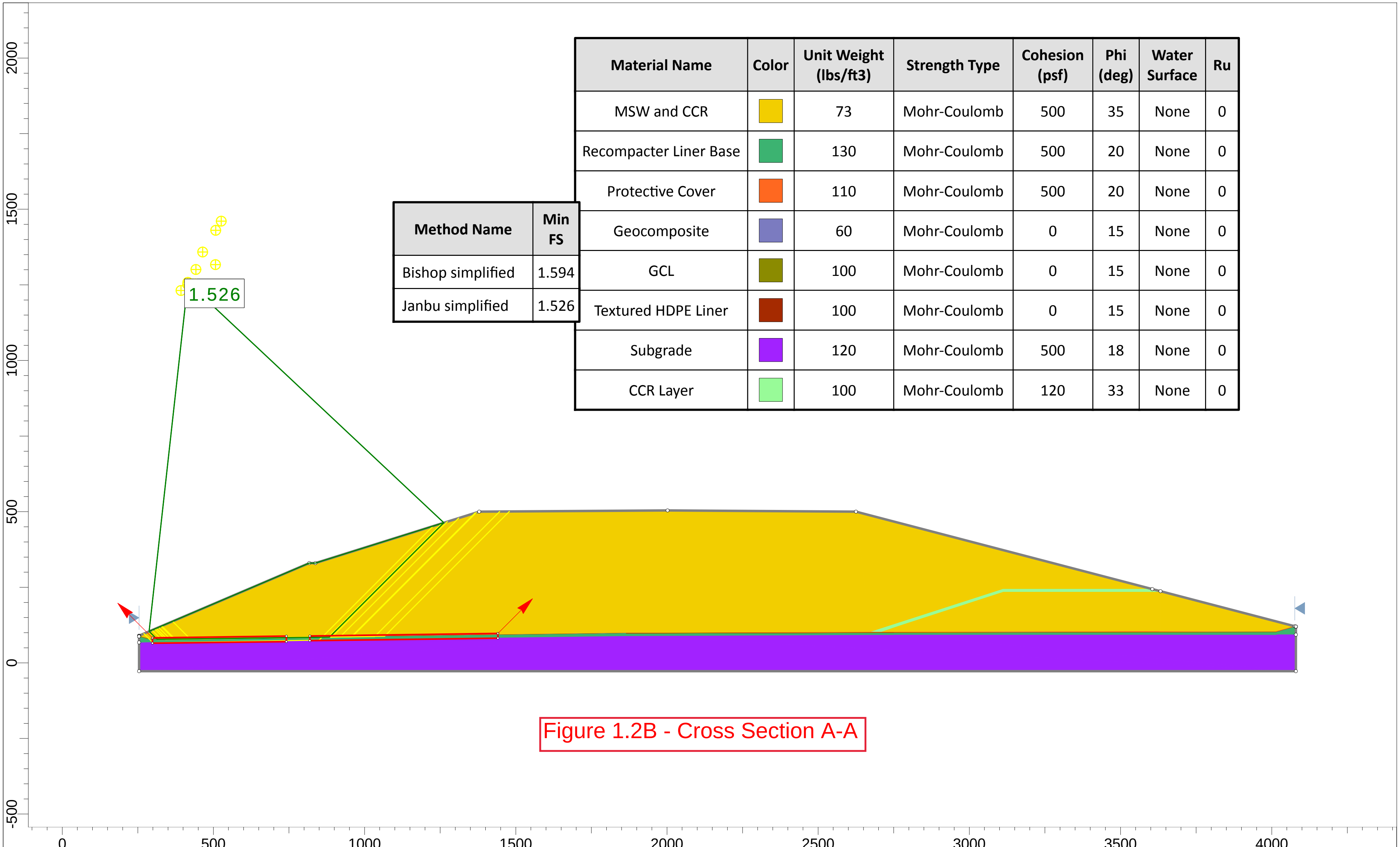
I014-415

April 2017

FINAL GRADES STABILITY ANALYSIS SECTION A-A

FIGURE 1.1B

STATIC ANALYSIS



Method Name	Min FS
Bishop simplified	1.594
Janbu simplified	1.526

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
MSW and CCR		73	Mohr-Coulomb	500	35	None	0
Recompacter Liner Base		130	Mohr-Coulomb	500	20	None	0
Protective Cover		110	Mohr-Coulomb	500	20	None	0
Geocomposite		60	Mohr-Coulomb	0	15	None	0
GCL		100	Mohr-Coulomb	0	15	None	0
Textured HDPE Liner		100	Mohr-Coulomb	0	15	None	0
Subgrade		120	Mohr-Coulomb	500	18	None	0
CCR Layer		100	Mohr-Coulomb	120	33	None	0

Figure 1.2B - Cross Section A-A

Project	Chesser Island Phase 4 Expansion		
Analysis Description	Block Sliding - Static		
Drawn By	Marc Liverman	*Scale* 1:5268	*Company* Atlantic Coast Consulting
Date	4/5/17	*File Name*	Chesser Block Static 4 CCR.slim

SLIDEINTERPRET 7.023

Slide Analysis Information
Chesser Island Phase 4 Expansion

Project Summary

File Name:	Chesser Block Static 4 CCR.slim
Slide Modeler Version:	7.023
Project Title:	Chesser Island Phase 4 Expansion
Analysis:	Block Sliding - Static
Author:	Marc Liverman
Company:	Atlantic Coast Consulting
Date Created:	4/5/17

General Settings

Units of Measurement:	Imperial Units
Time Units:	seconds
Permeability Units:	feet/second
Failure Direction:	Right to Left
Data Output:	Standard
Maximum Material Properties:	20
Maximum Support Properties:	20

Analysis Options

Slices Type: Vertical

Analysis Methods Used	
	Bishop simplified
	Janbu simplified

Number of slices:	50
Tolerance:	0.005
Maximum number of iterations:	50
Check malpha < 0.2:	Yes
Initial trial value of FS:	3
Steffensen Iteration:	Yes

Groundwater Analysis

Groundwater Method:	Water Surfaces
Pore Fluid Unit Weight [lbs/ft3]:	9.81
Use negative pore pressure cutoff:	Yes
Maximum negative pore pressure [psf]:	0
Advanced Groundwater Method:	None

Random Numbers

Pseudo-random Seed:	10116
Random Number Generation Method:	rand

Surface Options

Surface Type:	Non-Circular Block Search
Number of Surfaces:	5000
Multiple Groups:	Disabled
Pseudo-Random Surfaces:	Enabled
Convex Surfaces Only:	Disabled
Left Projection Angle (Start Angle):	135
Left Projection Angle (End Angle):	135
Right Projection Angle (Start Angle):	45
Right Projection Angle (End Angle):	45
Minimum Elevation:	Not Defined
Minimum Depth:	Not Defined
Minimum Area:	Not Defined
Minimum Weight:	Not Defined

Seismic

Advanced seismic analysis:	No
Staged pseudostatic analysis:	No

Material Properties

Property	MSW and CCR	Recompacter Liner Base	Protective Cover	Geocomposite	GCL	Textured HDPE Liner	Subgrade	CCR Layer
Color								
Strength Type	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
Unit Weight [lbs/ft3]	73	130	110	60	100	100	120	100
Cohesion [psf]	500	500	500	0	0	0	500	120
Friction Angle [deg]	35	20	20	15	15	15	18	33
Water Surface	None	None	None	None	None	None	None	None
Ru Value	0	0	0	0	0	0	0	0

Global Minimums

Method: bishop simplified

FS	1.593580
Axis Location:	415.387, 1258.276
Left Slip Surface Endpoint:	287.179, 104.144
Right Slip Surface Endpoint:	1261.768, 463.230
Resisting Moment:	5.17764e+009 lb-ft
Driving Moment:	3.24906e+009 lb-ft
Total Slice Area:	137535 ft2
Surface Horizontal Width:	974.589 ft
Surface Average Height:	141.121 ft

Method: janbu simplified

FS	1.526000
Axis Location:	415.387, 1258.276
Left Slip Surface Endpoint:	287.179, 104.144
Right Slip Surface Endpoint:	1261.768, 463.230
Resisting Horizontal Force:	3.63204e+006 lb
Driving Horizontal Force:	2.38011e+006 lb
Total Slice Area:	137535 ft2
Surface Horizontal Width:	974.589 ft
Surface Average Height:	141.121 ft

Global Minimum Coordinates

Method: bishop simplified

X	Y
287.179	104.144
313.495	77.8271
883.758	85.2199
1261.77	463.23

Method: janbu simplified

X	Y
287.179	104.144
313.495	77.8271
883.758	85.2199
1261.77	463.23

Valid / Invalid Surfaces

Method: bishop simplified

Number of Valid Surfaces: 5000
Number of Invalid Surfaces: 0

Method: janbu simplified

Number of Valid Surfaces: 5000
Number of Invalid Surfaces: 0

Slice Data

Global Minimum Query (bishop simplified) - Safety Factor: 1.59358

Slice Number	Width [ft]	Weight [lbs]	Angle of Slice Base [degrees]	Base Material	Base Cohesion [psf]	Base Friction Angle [degrees]	Shear Stress [psf]	Shear Strength [psf]	Base Normal Stress [psf]	Pore Pressure [psf]	Effective Normal Stress [psf]	Base Vertical Stress [psf]	Effective Vertical Stress [psf]
1	23.8762	29677.6	-45	MSW and CCR	500	35	1533.63	2443.97	2776.27	0	2776.27	1242.64	1242.64
2	1.77742	4642.24	-45	Protective Cover	500	20	1179.66	1879.88	3791.19	0	3791.19	2611.53	2611.53
3	0.197491	542.429	-45	Geocomposite	0	15	555.146	884.669	3301.63	0	3301.63	2746.48	2746.48
4	0.465488	1296.94	-45	Textured HDPE Liner	0	15	563.145	897.417	3349.2	0	3349.2	2786.06	2786.06
5	21.9332	69036.8	0.742729	GCL	0	15	528.095	841.562	3140.75	0	3140.75	3147.6	3147.6
6	21.9332	83548.5	0.742729	GCL	0	15	639.102	1018.46	3800.94	0	3800.94	3809.23	3809.23
7	21.9332	98060.2	0.742729	GCL	0	15	750.11	1195.36	4461.13	0	4461.13	4470.86	4470.86
8	21.9332	112572	0.742729	GCL	0	15	861.118	1372.26	5121.31	0	5121.31	5132.47	5132.47
9	21.9332	127083	0.742729	GCL	0	15	972.119	1549.15	5781.53	0	5781.53	5794.13	5794.13
10	21.9332	141595	0.742729	GCL	0	15	1083.13	1726.05	6441.7	0	6441.7	6455.75	6455.75
11	21.9332	156107	0.742729	GCL	0	15	1194.14	1902.95	7101.88	0	7101.88	7117.36	7117.36
12	21.9332	170618	0.742729	GCL	0	15	1305.14	2079.85	7762.1	0	7762.1	7779.02	7779.02
13	21.9332	185130	0.742729	GCL	0	15	1416.14	2256.74	8422.28	0	8422.28	8440.64	8440.64
14	21.9332	199642	0.742729	GCL	0	15	1527.15	2433.64	9082.46	0	9082.46	9102.25	9102.25
15	21.9332	214153	0.742729	GCL	0	15	1638.16	2610.54	9742.68	0	9742.68	9763.92	9763.92
16	21.9332	228665	0.742729	GCL	0	15	1749.17	2787.44	10402.9	0	10402.9	10425.5	10425.5
17	21.9332	243177	0.742729	GCL	0	15	1860.17	2964.33	11063	0	11063	11087.1	11087.1
18	21.9332	257688	0.742729	GCL	0	15	1971.18	3141.23	11723.3	0	11723.3	11748.8	11748.8
19	21.9332	272200	0.742729	GCL	0	15	2082.19	3318.13	12383.4	0	12383.4	12410.4	12410.4
20	21.9332	286712	0.742729	GCL	0	15	2193.19	3495.03	13043.6	0	13043.6	13072	13072
21	21.9332	301223	0.742729	GCL	0	15	2304.2	3671.93	13703.8	0	13703.8	13733.7	13733.7
22	21.9332	315735	0.742729	GCL	0	15	2415.2	3848.82	14364	0	14364	14395.3	14395.3
23	21.9332	330247	0.742729	GCL	0	15	2526.21	4025.72	15024.2	0	15024.2	15056.9	15056.9
24	21.9332	344758	0.742729	GCL	0	15	2637.22	4202.62	15684.4	0	15684.4	15718.6	15718.6
25	21.9332	359270	0.742729	GCL	0	15	2748.23	4379.52	16344.6	0	16344.6	16380.2	16380.2
26	21.9332	373782	0.742729	GCL	0	15	2859.23	4556.41	17004.8	0	17004.8	17041.8	17041.8
27	21.9332	388279	0.742729	GCL	0	15	2970.13	4733.14	17664.3	0	17664.3	17702.8	17702.8
28	21.9332	394761	0.742729	GCL	0	15	3019.72	4812.16	17959.2	0	17959.2	17998.4	17998.4
29	21.9332	401167	0.742729	GCL	0	15	3068.71	4890.24	18250.6	0	18250.6	18290.4	18290.4
30	21.9332	411723	0.742729	GCL	0	15	3149.46	5018.92	18730.9	0	18730.9	18771.7	18771.7
31	0.328846	6247.98	45	GCL	0	15	2734.91	4358.3	16265.4	0	16265.4	19000.3	19000.3
32	0.202574	3845.52	45	Geocomposite	0	15	2732.55	4354.54	16251.4	0	16251.4	18983.9	18983.9
33	1.82317	34458.9	45	Protective Cover	500	20	3769.79	6007.46	15131.6	0	15131.6	18901.4	18901.4
34	22.0974	403675	45	MSW and CCR	500	35	5794.91	9234.66	12474.4	0	12474.4	18269.3	18269.3
35	22.0974	379210	45	MSW and CCR	500	35	5456.92	8696.04	11705.2	0	11705.2	17162.1	17162.1
36	22.0974	354745	45	MSW and CCR	500	35	5118.92	8157.41	10935.9	0	10935.9	16054.8	16054.8
37	22.0974	330280	45	MSW and CCR	500	35	4780.93	7618.79	10166.7	0	10166.7	14947.6	14947.6
38	22.0974	305814	45	MSW and CCR	500	35	4442.93	7080.17	9397.44	0	9397.44	13840.4	13840.4
39	22.0974	281349	45	MSW and CCR	500	35	4104.94	6541.55	8628.21	0	8628.21	12733.1	12733.1
40	22.0974	256884	45	MSW and CCR	500	35	3766.94	6002.92	7859	0	7859	11625.9	11625.9
41	22.0974	232419	45	MSW and CCR	500	35	3428.95	5464.3	7089.76	0	7089.76	10518.7	10518.7
42	22.0974	207954	45	MSW and CCR	500	35	3090.95	4925.68	6320.53	0	6320.53	9411.48	9411.48
43	22.0974	183489	45	MSW and CCR	500	35	2752.96	4387.06	5551.29	0	5551.29	8304.25	8304.25
44	22.0974	159023	45	MSW and CCR	500	35	2414.97	3848.44	4782.05	0	4782.05	7197.01	7197.01
45	22.0974	134558	45	MSW and CCR	500	35	2076.97	3309.81	4012.84	0	4012.84	6089.81	6089.81
46	22.0974	110093	45	MSW and CCR	500	35	1738.97	2771.19	3243.61	0	3243.61	4982.58	4982.58
47	22.0974	85628	45	MSW and CCR	500	35	1400.98	2232.57	2474.37	0	2474.37	3875.35	3875.35
48	22.0974	61162.9	45	MSW and CCR	500	35	1062.98	1693.95	1705.13	0	1705.13	2768.12	2768.12
49	22.0974	36697.7	45	MSW and CCR	500	35	724.987	1155.33	935.901	0	935.901	1660.89	1660.89
50	22.0974	12232.6	45	MSW and CCR	500	35	386.992	616.703	166.67	0	166.67	553.662	553.662

Global Minimum Query (janbu simplified) - Safety Factor: 1.526

Slice Number	Width [ft]	Weight [lbs]	Angle of Slice Base [degrees]	Base Material	Base Cohesion [psf]	Base Friction Angle [degrees]	Shear Stress [psf]	Shear Strength [psf]	Base Normal Stress [psf]	Pore Pressure [psf]	Effective Normal Stress [psf]	Base Vertical Stress [psf]	Effective Vertical Stress [psf]
1	23.8762	29677.6	-45	MSW and CCR	500	35	1659.41	2532.26	2902.37	0	2902.37	1242.96	1242.96
2	1.77742	4642.24	-45	Protective Cover	500	20	1248.34	1904.97	3860.12	0	3860.12	2611.78	2611.78
3	0.197491	542.429	-45	Geocomposite	0	15	584.991	892.697	3331.59	0	3331.59	2746.6	2746.6
4	0.465488	1296.94	-45	Textured HDPE Liner	0	15	593.421	905.561	3379.6	0	3379.6	2786.18	2786.18
5	21.9332	69036.8	0.742729	GCL	0	15	551.429	841.481	3140.45	0	3140.45	3147.6	3147.6
6	21.9332	83548.5	0.742729	GCL	0	15	667.339	1018.36	3800.58	0	3800.58	3809.23	3809.23
7	21.9332	98060.2	0.742729	GCL	0	15	783.25	1195.24	4460.7	0	4460.7	4470.86	4470.86
8	21.9332	112572	0.742729	GCL	0	15	899.161	1372.12	5120.85	0	5120.85	5132.51	5132.51
9	21.9332	127083	0.742729	GCL	0	15	1015.07	1549	5780.98	0	5780.98	5794.14	5794.14
10	21.9332	141595	0.742729	GCL	0	15	1130.98	1725.88	6441.07	0	6441.07	6455.73	6455.73
11	21.9332	156107	0.742729	GCL	0	15	1246.89	1902.76	7101.2	0	7101.2	7117.36	7117.36
12	21.9332	170618	0.742729	GCL	0	15	1362.8	2079.64	7761.33	0	7761.33	7779	7779
13	21.9332	185130	0.742729	GCL	0	15	1478.72	2256.53	8421.46	0	8421.46	8440.63	8440.63
14	21.9332	199642	0.742729	GCL	0	15	1594.63	2433.41	9081.59	0	9081.59	9102.26	9102.26
15	21.9332	214153	0.742729	GCL	0	15	1710.54	2610.29	9741.72	0	9741.72	9763.9	9763.9
16	21.9332	228665	0.742729	GCL	0	15	1826.45	2787.17	10401.9	0	10401.9	10425.5	10425.5
17	21.9332	243177	0.742729	GCL	0	15	1942.37	2964.05	11062	0	11062	11087.2	11087.2
18	21.9332	257688	0.742729	GCL	0	15	2058.28	3140.93	11722.1	0	11722.1	11748.8	11748.8
19	21.9332	272200	0.742729	GCL	0	15	2174.19	3317.81	12382.2	0	12382.2	12410.4	12410.4
20	21.9332	286712	0.742729	GCL	0	15	2290.1	3494.69	13042.4	0	13042.4	13072.1	13072.1
21	21.9332	301223	0.742729	GCL	0	15	2406.01	3671.57	13702.5	0	13702.5	13733.7	13733.7
22	21.9332	315735	0.742729	GCL	0	15	2521.92	3848.45	14362.6	0	14362.6	14395.3	14395.3
23	21.9332	330247	0.742729	GCL	0	15	2637.83	4025.33	15022.7	0	15022.7	15056.9	15056.9
24	21.9332	344758	0.742729	GCL	0	15	2753.74	4202.21	15682.9	0	15682.9	15718.6	15718.6
25	21.9332	359270	0.742729	GCL	0	15	2869.65	4379.09	16343	0	16343	16380.2	16380.2
26	21.9332	373782	0.742729	GCL	0	15	2985.56	4555.97	17003.1	0	17003.1	17041.8	17041.8
27	21.9332	388279	0.742729	GCL	0	15	3101.36	4732.68	17662.6	0	17662.6	17702.8	17702.8
28	21.9332	394761	0.742729	GCL	0	15	3153.14	4811.69	17957.5	0	17957.5	17998.4	17998.4
29	21.9332	401167	0.742729	GCL	0	15	3204.3	4889.76	18248.8	0	18248.8	18290.4	18290.4
30	21.9332	411723	0.742729	GCL	0	15	3288.62	5018.43	18729	0	18729	18771.7	18771.7
31	0.328846	6247.98	45	GCL	0	15	2837.85	4330.56	16161.9	0	16161.9	18999.7	18999.7
32	0.202574	3845.52	45	Geocomposite	0	15	2835.41	4326.83	16147.9	0	16147.9	18983.4	18983.4
33	1.82317	34458.9	45	Protective Cover	500	20	3904.43	5958.16	14996.2	0	14996.2	18900.6	18900.6
34	22.0974	403675	45	MSW and CCR	500	35	5970.45	9110.9	12297.6	0	12297.6	18268.1	18268.1
35	22.0974	379210	45	MSW and CCR	500	35	5622.21	8579.49	11538.7	0	11538.7	17160.9	17160.9
36	22.0974	354745	45	MSW and CCR	500	35	5273.98	8048.09	10779.8	0	10779.8	16053.8	16053.8
37	22.0974	330280	45	MSW and CCR	500	35	4925.75	7516.69	10020.9	0	10020.9	14946.6	14946.6
38	22.0974	305814	45	MSW and CCR	500	35	4577.51	6985.28	9261.96	0	9261.96	13839.5	13839.5
39	22.0974	281349	45	MSW and CCR	500	35	4229.28	6453.88	8503.02	0	8503.02	12732.3	12732.3
40	22.0974	256884	45	MSW and CCR	500	35	3881.05	5922.48	7744.09	0	7744.09	11625.1	11625.1
41	22.0974	232419	45	MSW and CCR	500	35	3532.81	5391.07	6985.19	0	6985.19	10518	10518
42	22.0974	207954	45	MSW and CCR	500	35	3184.58	4859.67	6226.25	0	6226.25	9410.84	9410.84
43	22.0974	183489	45	MSW and CCR	500	35	2836.34	4328.26	5467.32	0	5467.32	8303.66	8303.66
44	22.0974	159023	45	MSW and CCR	500	35	2488.11	3796.86	4708.42	0	4708.42	7196.53	7196.53
45	22.0974	134558	45	MSW and CCR	500	35	2139.88	3265.46	3949.48	0	3949.48	6089.37	6089.37
46	22.0974	110093	45	MSW and CCR	500	35	1791.64	2734.05	3190.56	0	3190.56	4982.2	4982.2
47	22.0974	85628	45	MSW and CCR	500	35	1443.41	2202.65	2431.64	0	2431.64	3875.05	3875.05
48	22.0974	61162.9	45	MSW and CCR	500	35	1095.18	1671.25	1672.71	0	1672.71	2767.9	2767.9
49	22.0974	36697.7	45	MSW and CCR	500	35	746.948	1139.84	913.79	0	913.79	1660.74	1660.74
50	22.0974	12232.6	45	MSW and CCR	500	35	398.715	608.439	154.866	0	154.866	553.581	553.581

Interslice Data

Global Minimum Query (bishop simplified) - Safety Factor: 1.59358

Slice Number	X coordinate [ft]	Y coordinate - Bottom [ft]	Interslice Normal Force [lbs]	Interslice Shear Force [lbs]	Interslice Force Angle [degrees]
1	287.179	104.144	0	0	0
2	311.055	80.2675	102896	0	0
3	312.832	78.4901	111731	0	0
4	313.03	78.2926	112492	0	0
5	313.495	77.8271	114313	0	0
6	335.429	78.1115	125001	0	0
7	357.362	78.3958	137934	0	0
8	379.295	78.6802	153114	0	0
9	401.228	78.9645	170541	0	0
10	423.161	79.2488	190214	0	0
11	445.094	79.5332	212134	0	0
12	467.028	79.8175	236300	0	0
13	488.961	80.1018	262712	0	0
14	510.894	80.3862	291371	0	0
15	532.827	80.6705	322277	0	0
16	554.76	80.9549	355428	0	0
17	576.694	81.2392	390827	0	0
18	598.627	81.5235	428472	0	0
19	620.56	81.8079	468363	0	0
20	642.493	82.0922	510501	0	0
21	664.426	82.3765	554885	0	0
22	686.36	82.6609	601516	0	0
23	708.293	82.9452	650393	0	0
24	730.226	83.2295	701516	0	0
25	752.159	83.5139	754886	0	0
26	774.092	83.7982	810503	0	0
27	796.026	84.0826	868366	0	0
28	817.959	84.3669	928473	0	0
29	839.892	84.6512	989584	0	0
30	861.825	84.9356	1.05169e+006	0	0
31	883.758	85.2199	1.11542e+006	0	0
32	884.087	85.5488	1.11097e+006	0	0
33	884.29	85.7513	1.10823e+006	0	0
34	886.113	87.5745	1.08752e+006	0	0
35	908.21	109.672	939891	0	0
36	930.308	131.769	801795	0	0
37	952.405	153.867	673229	0	0
38	974.502	175.964	554195	0	0
39	996.6	198.061	444691	0	0
40	1018.7	220.159	344718	0	0
41	1040.79	242.256	254276	0	0
42	1062.89	264.354	173365	0	0
43	1084.99	286.451	101984	0	0
44	1107.09	308.548	40135	0	0
45	1129.18	330.646	-12183.5	0	0
46	1151.28	352.743	-54971.2	0	0
47	1173.38	374.84	-88228	0	0
48	1195.48	396.938	-111954	0	0
49	1217.57	419.035	-126149	0	0
50	1239.67	441.133	-130813	0	0
51	1261.77	463.23	0	0	0

Global Minimum Query (janbu simplified) - Safety Factor: 1.526

Slice Number	X coordinate [ft]	Y coordinate - Bottom [ft]	Interslice Normal Force [lbs]	Interslice Shear Force [lbs]	Interslice Force Angle [degrees]
1	287.179	104.144	0	0	0
2	311.055	80.2675	108917	0	0
3	312.832	78.4901	117997	0	0
4	313.03	78.2926	118771	0	0
5	313.495	77.8271	120620	0	0
6	335.429	78.1115	131822	0	0
7	357.362	78.3958	145378	0	0
8	379.295	78.6802	161288	0	0
9	401.228	78.9645	179554	0	0
10	423.161	79.2488	200173	0	0
11	445.094	79.5332	223148	0	0
12	467.028	79.8175	248477	0	0
13	488.961	80.1018	276160	0	0
14	510.894	80.3862	306198	0	0
15	532.827	80.6705	338591	0	0
16	554.76	80.9549	373338	0	0
17	576.694	81.2392	410440	0	0
18	598.627	81.5235	449896	0	0
19	620.56	81.8079	491707	0	0
20	642.493	82.0922	535873	0	0
21	664.426	82.3765	582393	0	0
22	686.36	82.6609	631268	0	0
23	708.293	82.9452	682497	0	0
24	730.226	83.2295	736081	0	0
25	752.159	83.5139	792019	0	0
26	774.092	83.7982	850312	0	0
27	796.026	84.0826	910960	0	0
28	817.959	84.3669	973959	0	0
29	839.892	84.6512	1.03801e+006	0	0
30	861.825	84.9356	1.1031e+006	0	0
31	883.758	85.2199	1.16991e+006	0	0
32	884.087	85.5488	1.16552e+006	0	0
33	884.29	85.7513	1.16283e+006	0	0
34	886.113	87.5745	1.1426e+006	0	0
35	908.21	109.672	1.00279e+006	0	0
36	930.308	131.769	872048	0	0
37	952.405	153.867	750383	0	0
38	974.502	175.964	637793	0	0
39	996.6	198.061	534278	0	0
40	1018.7	220.159	439838	0	0
41	1040.79	242.256	354474	0	0
42	1062.89	264.354	278184	0	0
43	1084.99	286.451	210971	0	0
44	1107.09	308.548	152832	0	0
45	1129.18	330.646	103769	0	0
46	1151.28	352.743	63780.6	0	0
47	1173.38	374.84	32867.9	0	0
48	1195.48	396.938	11030.4	0	0
49	1217.57	419.035	-1731.88	0	0
50	1239.67	441.133	-5418.85	0	0
51	1261.77	463.23	0	0	0

List Of Coordinates

Block Search Window

X	Y
298.341	82.664
298.341	65.121
741.304	70.01
741.304	88.348

Block Search Window

X	Y
819.038	73.452
1440.94	81.326
1440.94	97.1057
819.038	88.886

External Boundary

X	Y
4080	120
4079.63	120.096
4076.31	120.963
3632	237.003
3605.21	244
2625	500
2002	504
1379	500
837	330
817	330
254	90
254	88.2
254	88
254	87.8
254	87.7
254	87.5
254	67.5
254	-27.6
4080	-27.6
4080	93
4080	119.5
4080	119.7
4080	119.8

Material Boundary

X	Y
254	90
290	80
1864	100
2672	101.823
2706	101.9
3632	103.384
4016	104
4076.31	120.963

Material Boundary

X	Y
2672	102
3112	244
3605.21	244

Material Boundary

X	Y
2706	101.9
3112	234
3632	234

Material Boundary

X	Y
254	88.2
290	78.2
1864	98.2
2750	100.2
4016	102.2
4079.63	120.096

Material Boundary

X	Y
254	88
290	78
1864	98
2750	100
4016	102
4080	120

Material Boundary

X	Y
254	87.8
290	77.8
1864	97.8
2750	99.8
4016	101.8
4080	119.8

Material Boundary

X	Y
254	87.7
290	77.7
1864	97.7
2750	99.7
4016	101.7
4080	119.7

Material Boundary

X	Y
254	87.5
290	77.5
1864	97.5
2750	99.5
4016	101.5
4080	119.5

Material Boundary

X	Y
254	67.5
290	68.5
1864	89
2750	93
4016	93
4080	93

Material Boundary

X	Y
2672	101.823
2672	102

Material Boundary

X	Y
3632	103.384
3632	234
3632	237.003

Liner System Analysis

ATLANTIC COAST CONSULTING, INC.

Design Calculations Notebook

1

2

3

4

IN THIS SECTION:

A. HELP Model Analysis

B. Liner Filter Fabric Analysis

Section 2

A. Help Model Analysis

OBJECTIVE:

Verify the performance of leachate collection system Alternative B as shown on the Chesser Island Road MSW Landfill Phase 4 Expansion D&O Plans. The Phase 4 Expansion design calculations, as prepared by Atlantic Coast Consulting, Inc and dated March 2010, will be analyzed with the addition of Coal Combustion Residuals (CCR) to the waste mass using the Hydrologic Evaluation of Landfill Performance (HELP) Model Version 3.07.

METHODOLOGY:

Using the HELP Model, evaluate the leachate collection and liner system alternatives with different fill heights to verify that they meet the design guidelines. Each of the scenarios described below cannot result in more than 30 centimeters (12 inches) of head on top of the HDPE liner.

INPUT DATA:

- The daily precipitation, temperature, and solar radiation data was synthetically generated in HELP using the coefficients for Jacksonville, Florida, and the mean monthly precipitation and temperature for Jacksonville, Florida. The peak daily rainfall from the synthetically generated record was adjusted to match the 25-year 24-hour storm event precipitation for Charlton County, Georgia (i.e., 8.20 inches) for simulation terms longer than one year.

- The initial waste placement (10 feet) and 50 feet of waste scenarios were modeled using simulation terms of 1 year and 10 years, respectively. The 200 feet of waste scenario, representing a stage halfway through filing operations, and the final waste height (402 feet) were modeled with simulation terms of 50 years.

- All calculations were performed for a unit acre area.

- The base liner slope was set at 1.6% with a drainage length of 200 feet.

- The material properties of each layer used in the analysis was based on the anticipated and/or the required material. Tables 1, 2, 4, and 6 of the HELP User's manual provide default values used. Default values were utilized for all layers except for the following conditions:

  - Parameters for the drainage geocomposite used in leachate collection system alternative B are based on design calculations as performed in Section 2C of this report.

  - Saturated hydraulic conductivity of MSW waste materials was assumed to vary with height. This is based on research as presented in "Estimating the Hydraulic Conductivity of Landfilled Municipal Solid Waste Using Borehole Permeameter Test" by J. Pradeep, J. Powell, T. G. Townsend, and D. Reinhart dated 2006. For the MSW waste, the hydraulic conductivity of was assumed to be 10^{-3} cm/sec for waste heights less than 50' and 10^{-4} cm/sec for waste heights of 50' and more. The saturated hydraulic conductivity of the CCR was assumed to be 4.1×10^{-3} cm/sec based on the default saturated hydraulic conductivity of High-Density Electric Plant Coal Bottom Ash shown in Table 4 of the HELP user manual. Assuming an estimated maximum MSW to CCR ratio by weight of 10:1, and unit weights of 70 lb/ft^3 and 115 lb/ft^3 of MSW and CCR, respectively, the estimated MSW to CCR ratio by volume is 15:1. Therefore, the HELP model utilizes a combined hydraulic conductivity of 1.2×10^{-3} cm/sec for co-mingled MSW and CCR waste heights of less than 50' and 3.5×10^{-4} cm/sec for waste heights of 50' or more.

- The soil modeled for use as intermediate cover, general fill and liner protective cover (on-site material) was HELP soil material #10 based on Phase 4 design calculations.

- The 10' waste height scenario assumed no runoff with 3% top slopes. The 50' and 200' waste height scenarios were modeled with 25% runoff with 3% top slopes. The final waste height scenario was modeled with 100% runoff with 33% top slopes.

- The vegetative cover was selected as "fair" when utilized. Vegetative cover was assumed on all scenarios that assumed 100% runoff. Scenarios that were modeled with 0% or 25% runoff assumed "bare ground" conditions.

- Default SCS curve numbers were utilized based on the ground conditions.

- Recirculation was modeled for scenarios with waste depths of 50 feet and higher. The percentage recirculated within the model varied based on the resulting peak daily head on the liner.

- Base liner option 2 was utilized for all scenarios. The alternate base liner (option 1) was only modeled for the scenario with the maximum peak daily head value on the liner system (scenario 3). Base liner options 2 and 3 vary only by the layers below the geosynthetic clay liner, therefore, base liner option 3 was not modeled.

- Geomembrane in the base liner was assumed to be installed with good placement, a pinhole density of 1 hole per acre and installation defect density of 1 holes per acre. These assumptions will result in modeling that assumes the worst case for the peak daily head on the base liner.

The two base liner/leachate collection system alternatives modeled are described as follows from top to bottom:

Base Liner Option 1/Leachate Collection System Alternative B:

24 inches of Liner Protective Cover (On-Site Material)
Double-Sided Geocomposite Drainage Layer
60 Mil HDPE Textured Geomembrane Liner
24 inches of $1x10^{-7}$ cm/sec Recompacted Liner Base

Base Liner Option 2/Leachate Collection System Alternative B:

24 inches of Liner Protective Cover (On-Site Material)
Double-Sided Geocomposite Drainage Layer
60 Mil HDPE Textured Geomembrane Liner
Geosynthetic Clay Liner ($1x10^{-9}$ cm/sec)
24 inches of $1x10^{-4}$ cm/sec Compacted Soil

RESULTS:
A summary of the scenarios modeled are presented in Table 2A-1. The maximum annual average leachate generation rate occurs in the 50 feet of waste scenario modeled with 25% runoff and 80% recirculation. The maximum peak head on the base liner occur in the 200 feet of waste scenario modeled with 25% runoff, 80% recirculation and base liner option 1.

CONCLUSION:

Each of the scenarios modeled meet the design guidelines. Therefore, the leachate collection/protective cover system and liner system will provide for sufficient leachate collection.

Table 2A – 1

Results Summary

Chesser Island Rd CCR Management

HELP Model Analysis - Summary

Table 2A-1

File Name	Scenario	Description: Base Liner Option	Description: LCS Alternative	Description: Waste Depth (ft)	Description: Runoff (%)	Description: Recirculation (%)	Description: Simulation Term (yrs)	Maximum Base Liner Head per Peak Daily Value (inches)	Annual Average Leachate Generation Rate (CF/Ac/Yr)	Annual Average Leachate Generation Rate (Gal/Ac/Day)	Recirculated Leachate (CF/Ac/Yr)	Recirculated Leachate (Gal/Ac/Day)	Peak Daily Leachate Generation Rate (CF/Ac/Day)
CHESS1.out	1	2	2	10	0	0	1	0.019	35,760	733	-	-	772
CHESS2.out	2	2	2	50	25	80	10	0.046	-	-	56,777	1,164	-
CHESS3.out	3	2	2	200	25	80	50	0.138	-	-	47,243	968	-
CHESS4.out	4	2	2	402	100	80	50	0.136	-	-	29,191	598	-
CHESS5.out	5	1	2	200	25	80	50	0.139	-	-	47,300	969	-

LCS Option 2/Liner System Option 2

with 10' Lift of Waste

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******************************************************************************
**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                **
**                 DEVELOPED BY ENVIRONMENTAL LABORATORY                    **
**                   USAE WATERWAYS EXPERIMENT STATION                      **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                          **
**                                                                          **
******************************************************************************
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PRECIPITATION DATA FILE:    C:\HELP3\CHESPREC.D4
TEMPERATURE DATA FILE:      C:\HELP3\CHESTEMP.D7
SOLAR RADIATION DATA FILE:  C:\HELP3\CHESSOLA.D13
EVAPOTRANSPIRATION DATA:    C:\HELP3\CHESEVAP.D11
SOIL AND DESIGN DATA FILE:  C:\HELP3\CHESS1.D10
OUTPUT DATA FILE:           C:\HELP3\CHESS1.OUT


TIME:  14:47     DATE:   4/12/2017


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     TITLE:  CHESSER ISLAND RD - 10 FT WASTE -OPT2/ALT B

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     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
              COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.


                                   LAYER  1
                                   --------

                    TYPE 1 - VERTICAL PERCOLATION LAYER
                        MATERIAL TEXTURE NUMBER  10
           THICKNESS                 =     12.00   INCHES
           POROSITY                  =      0.3980 VOL/VOL
           FIELD CAPACITY            =      0.2440 VOL/VOL
           WILTING POINT             =      0.1360 VOL/VOL
           INITIAL SOIL WATER CONTENT  =      0.1938 VOL/VOL
           EFFECTIVE SAT. HYD. COND.   =  0.119999997000E-03 CM/SEC
         NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  4.90
                  FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.


                                   LAYER  2
                                   --------
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            TYPE 1 - VERTICAL PERCOLATION LAYER
                MATERIAL TEXTURE NUMBER   0
THICKNESS                    =    120.00   INCHES
POROSITY                     =      0.6710 VOL/VOL
FIELD CAPACITY               =      0.2920 VOL/VOL
WILTING POINT                =      0.0770 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.3126 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.120000006000E-02 CM/SEC


                        LAYER  3
                        --------

            TYPE 1 - VERTICAL PERCOLATION LAYER
                MATERIAL TEXTURE NUMBER  10
THICKNESS                    =     24.00   INCHES
POROSITY                     =      0.3980 VOL/VOL
FIELD CAPACITY               =      0.2440 VOL/VOL
WILTING POINT                =      0.1360 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.2838 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.119999997000E-03 CM/SEC


                        LAYER  4
                        --------

              TYPE 2 - LATERAL DRAINAGE LAYER
                MATERIAL TEXTURE NUMBER   0
THICKNESS                    =      0.20   INCHES
POROSITY                     =      0.8500 VOL/VOL
FIELD CAPACITY               =      0.0100 VOL/VOL
WILTING POINT                =      0.0050 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.0223 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =   49.7000008000     CM/SEC
SLOPE                        =      1.60   PERCENT
DRAINAGE LENGTH              =    200.0    FEET


                        LAYER  5
                        --------

              TYPE 4 - FLEXIBLE MEMBRANE LINER
                MATERIAL TEXTURE NUMBER  35
THICKNESS                    =      0.06   INCHES
POROSITY                     =      0.0000 VOL/VOL
FIELD CAPACITY               =      0.0000 VOL/VOL
WILTING POINT                =      0.0000 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.0000 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.199999996000E-12 CM/SEC
FML PINHOLE DENSITY          =      1.00   HOLES/ACRE
FML INSTALLATION DEFECTS     =      1.00   HOLES/ACRE
FML PLACEMENT QUALITY        =  3 - GOOD
```

LAYER 6

TYPE 3 - BARRIER SOIL LINER
MATERIAL TEXTURE NUMBER 0

THICKNESS	=	0.25	INCHES
POROSITY	=	0.7500	VOL/VOL
FIELD CAPACITY	=	0.7470	VOL/VOL
WILTING POINT	=	0.4000	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.7500	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.999999972000E-09	CM/SEC

GENERAL DESIGN AND EVAPORATIVE ZONE DATA

NOTE: SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT SOIL DATA BASE USING SOIL TEXTURE #10 WITH BARE GROUND CONDITIONS, A SURFACE SLOPE OF 3.% AND A SLOPE LENGTH OF 200. FEET.

SCS RUNOFF CURVE NUMBER	=	94.00	
FRACTION OF AREA ALLOWING RUNOFF	=	0.0	PERCENT
AREA PROJECTED ON HORIZONTAL PLANE	=	1.000	ACRES
EVAPORATIVE ZONE DEPTH	=	22.0	INCHES
INITIAL WATER IN EVAPORATIVE ZONE	=	5.146	INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE	=	11.486	INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE	=	2.402	INCHES
INITIAL SNOW WATER	=	0.000	INCHES
INITIAL WATER IN LAYER MATERIALS	=	46.834	INCHES
TOTAL INITIAL WATER	=	46.834	INCHES
TOTAL SUBSURFACE INFLOW	=	0.00	INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM JACKSONVILLE FLORIDA

STATION LATITUDE	=	30.50	DEGREES
MAXIMUM LEAF AREA INDEX	=	4.00	
START OF GROWING SEASON (JULIAN DATE)	=	0	
END OF GROWING SEASON (JULIAN DATE)	=	367	
EVAPORATIVE ZONE DEPTH	=	22.0	INCHES
AVERAGE ANNUAL WIND SPEED	=	8.20	MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY	=	73.00	%
AVERAGE 2ND QUARTER RELATIVE HUMIDITY	=	72.00	%
AVERAGE 3RD QUARTER RELATIVE HUMIDITY	=	79.00	%
AVERAGE 4TH QUARTER RELATIVE HUMIDITY	=	78.00	%

NOTE: PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING COEFFICIENTS FOR JACKSONVILLE FLORIDA

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
3.07	3.48	3.72	3.32	4.91	5.37
6.54	7.15	7.26	3.41	1.94	2.59

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR JACKSONVILLE FLORIDA

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
53.20	55.10	61.30	67.70	74.10	79.00
81.30	81.00	78.20	69.50	60.80	54.80

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR JACKSONVILLE FLORIDA
AND STATION LATITUDE = 30.50 DEGREES

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AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 1

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	1.44	1.73	0.84	0.07	1.67	3.13
	10.75	7.91	7.74	2.46	4.81	4.64
STD. DEVIATIONS	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00
RUNOFF						
TOTALS	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000
STD. DEVIATIONS	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000
EVAPOTRANSPIRATION						
TOTALS	1.852	2.807	2.032	0.070	1.657	2.573
	6.513	5.741	5.022	3.863	2.977	2.222
STD. DEVIATIONS	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000
LATERAL DRAINAGE COLLECTED FROM LAYER 4						
TOTALS	2.9616	0.4788	0.1460	0.0000	0.0000	0.0000
	0.4581	2.3519	0.9992	1.5075	0.5945	0.3537

STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

PERCOLATION/LEAKAGE THROUGH LAYER 6

TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)

DAILY AVERAGE HEAD ON TOP OF LAYER 5

AVERAGES	0.0042	0.0008	0.0002	0.0000	0.0000	0.0000
	0.0007	0.0034	0.0015	0.0022	0.0009	0.0005
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 1

	INCHES	CU. FEET	PERCENT
PRECIPITATION	47.19 (0.000)	171299.7	100.00
RUNOFF	0.000 (0.0000)	0.00	0.000
EVAPOTRANSPIRATION	37.328 (0.0000)	135499.39	79.101
LATERAL DRAINAGE COLLECTED FROM LAYER 4	9.85124 (0.00000)	35760.012	20.87570
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.00000 (0.00000)	0.006	0.00000
AVERAGE HEAD ON TOP OF LAYER 5	0.001 (0.000)		
CHANGE IN WATER STORAGE	0.011 (0.0000)	40.28	0.024

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PEAK DAILY VALUES FOR YEARS 1 THROUGH 1

	(INCHES)	(CU. FT.)

PRECIPITATION	3.25	11797.500
RUNOFF	0.000	0.0000
DRAINAGE COLLECTED FROM LAYER 4	0.21258	771.65546
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.000000	0.00003
AVERAGE HEAD ON TOP OF LAYER 5	0.009	
MAXIMUM HEAD ON TOP OF LAYER 5	0.019	
LOCATION OF MAXIMUM HEAD IN LAYER 4 (DISTANCE FROM DRAIN)	0.0 FEET	
SNOW WATER	0.00	0.0000

MAXIMUM VEG. SOIL WATER (VOL/VOL)	0.3577
MINIMUM VEG. SOIL WATER (VOL/VOL)	0.1092

*** Maximum heads are computed using McEnroe's equations. ***

Reference: Maximum Saturated Depth over Landfill Liner
by Bruce M. McEnroe, University of Kansas
ASCE Journal of Environmental Engineering
Vol. 119, No. 2, March 1993, pp. 262-270.

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FINAL WATER STORAGE AT END OF YEAR 1

LAYER	(INCHES)	(VOL/VOL)
1	2.3256	0.1938
2	37.5145	0.3126
3	6.8135	0.2839
4	0.0045	0.0225
5	0.0000	0.0000
6	0.1875	0.7500
SNOW WATER	0.000	

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LCS Option 2/Liner System Option 2

with 50' of Waste and 80% Recirculation

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**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                **
**                  DEVELOPED BY ENVIRONMENTAL LABORATORY                   **
**                    USAE WATERWAYS EXPERIMENT STATION                     **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************


PRECIPITATION DATA FILE:     C:\HELP3\CHESPREC.D4
TEMPERATURE DATA FILE:       C:\HELP3\CHESTEMP.D7
SOLAR RADIATION DATA FILE:  C:\HELP3\CHESSOLA.D13
EVAPOTRANSPIRATION DATA:    C:\HELP3\CHESEVAP.D11
SOIL AND DESIGN DATA FILE:  C:\HELP3\CHESS2.D10
OUTPUT DATA FILE:           C:\HELP3\CHESS2.OUT


TIME:  15: 5     DATE:   4/12/2017


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     TITLE:  CHESSER ISLAND RD - 50 FT WASTE -OPT2/ALT B

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     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
              COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.


                                   LAYER  1
                                   --------

                     TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER  10
          THICKNESS                  =     12.00   INCHES
          POROSITY                   =      0.3980 VOL/VOL
          FIELD CAPACITY             =      0.2440 VOL/VOL
          WILTING POINT              =      0.1360 VOL/VOL
          INITIAL SOIL WATER CONTENT =      0.1954 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  =  0.119999997000E-03 CM/SEC
        NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  4.90
                 FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.


                                   LAYER  2
                                   --------
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             TYPE 1 - VERTICAL PERCOLATION LAYER
                 MATERIAL TEXTURE NUMBER   0
  THICKNESS                   =    600.00   INCHES
  POROSITY                    =      0.6710 VOL/VOL
  FIELD CAPACITY              =      0.2920 VOL/VOL
  WILTING POINT               =      0.0770 VOL/VOL
  INITIAL SOIL WATER CONTENT  =      0.3028 VOL/VOL
  EFFECTIVE SAT. HYD. COND.   =  0.349999988000E-03 CM/SEC
NOTE:   80.00 PERCENT OF THE DRAINAGE COLLECTED FROM LAYER # 4
         IS RECIRCULATED INTO THIS LAYER.


                          LAYER  3
                          --------

             TYPE 1 - VERTICAL PERCOLATION LAYER
                 MATERIAL TEXTURE NUMBER  10
  THICKNESS                   =     24.00   INCHES
  POROSITY                    =      0.3980 VOL/VOL
  FIELD CAPACITY              =      0.2440 VOL/VOL
  WILTING POINT               =      0.1360 VOL/VOL
  INITIAL SOIL WATER CONTENT  =      0.2619 VOL/VOL
  EFFECTIVE SAT. HYD. COND.   =  0.119999997000E-03 CM/SEC


                          LAYER  4
                          --------

               TYPE 2 - LATERAL DRAINAGE LAYER
                 MATERIAL TEXTURE NUMBER   0
  THICKNESS                   =      0.20   INCHES
  POROSITY                    =      0.8500 VOL/VOL
  FIELD CAPACITY              =      0.0100 VOL/VOL
  WILTING POINT               =      0.0050 VOL/VOL
  INITIAL SOIL WATER CONTENT  =      0.0206 VOL/VOL
  EFFECTIVE SAT. HYD. COND.   =   15.3000002000     CM/SEC
  SLOPE                       =      1.60   PERCENT
  DRAINAGE LENGTH             =    200.0    FEET
NOTE:   80.00 PERCENT OF THE DRAINAGE COLLECTED FROM THIS
         LAYER IS RECIRCULATED INTO LAYER #  2.


                          LAYER  5
                          --------

               TYPE 4 - FLEXIBLE MEMBRANE LINER
                 MATERIAL TEXTURE NUMBER  35
  THICKNESS                   =      0.06   INCHES
  POROSITY                    =      0.0000 VOL/VOL
  FIELD CAPACITY              =      0.0000 VOL/VOL
  WILTING POINT               =      0.0000 VOL/VOL
  INITIAL SOIL WATER CONTENT  =      0.0000 VOL/VOL
  EFFECTIVE SAT. HYD. COND.   =  0.199999996000E-12 CM/SEC
  FML PINHOLE DENSITY         =      1.00   HOLES/ACRE
  FML INSTALLATION DEFECTS    =      1.00   HOLES/ACRE
  FML PLACEMENT QUALITY       =  3 - GOOD
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                     LAYER  6
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               TYPE 3 - BARRIER SOIL LINER
               MATERIAL TEXTURE NUMBER   0
  THICKNESS                   =      0.25   INCHES
  POROSITY                    =      0.7500 VOL/VOL
  FIELD CAPACITY              =      0.7470 VOL/VOL
  WILTING POINT               =      0.4000 VOL/VOL
  INITIAL SOIL WATER CONTENT  =      0.7500 VOL/VOL
  EFFECTIVE SAT. HYD. COND.   =  0.999999972000E-09 CM/SEC



         GENERAL DESIGN AND EVAPORATIVE ZONE DATA
         ----------------------------------------

 NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
          SOIL DATA BASE USING SOIL TEXTURE #10 WITH BARE
          GROUND CONDITIONS, A SURFACE SLOPE OF  3.% AND
          A SLOPE LENGTH OF  200. FEET.

SCS RUNOFF CURVE NUMBER             =     94.00
FRACTION OF AREA ALLOWING RUNOFF    =     25.0    PERCENT
AREA PROJECTED ON HORIZONTAL PLANE  =      1.000  ACRES
EVAPORATIVE ZONE DEPTH              =     22.0    INCHES
INITIAL WATER IN EVAPORATIVE ZONE   =      5.294  INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE  =     11.486  INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE  =      2.402  INCHES
INITIAL SNOW WATER                  =      0.000  INCHES
INITIAL WATER IN LAYER MATERIALS    =    190.516  INCHES
TOTAL INITIAL WATER                 =    190.516  INCHES
TOTAL SUBSURFACE INFLOW             =      0.00   INCHES/YEAR



          EVAPOTRANSPIRATION AND WEATHER DATA
          -----------------------------------

 NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
          JACKSONVILLE          FLORIDA

     STATION LATITUDE                         =  30.50 DEGREES
     MAXIMUM LEAF AREA INDEX                  =   4.00
     START OF GROWING SEASON (JULIAN DATE)    =      0
     END OF GROWING SEASON (JULIAN DATE)      =    367
     EVAPORATIVE ZONE DEPTH                   =  22.0  INCHES
     AVERAGE ANNUAL WIND SPEED                =   8.20 MPH
     AVERAGE 1ST QUARTER RELATIVE HUMIDITY    =  73.00 %
     AVERAGE 2ND QUARTER RELATIVE HUMIDITY    =  72.00 %
     AVERAGE 3RD QUARTER RELATIVE HUMIDITY    =  79.00 %
     AVERAGE 4TH QUARTER RELATIVE HUMIDITY    =  78.00 %


 NOTE:  PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
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COEFFICIENTS FOR JACKSONVILLE FLORIDA

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
3.07	3.48	3.72	3.32	4.91	5.37
6.54	7.15	7.26	3.41	1.94	2.59

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR JACKSONVILLE FLORIDA

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
53.20	55.10	61.30	67.70	74.10	79.00
81.30	81.00	78.20	69.50	60.80	54.80

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR JACKSONVILLE FLORIDA
AND STATION LATITUDE = 30.50 DEGREES

****

AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 10

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	3.85	3.37	3.01	3.71	4.10	5.78
	7.51	7.10	7.11	3.41	1.53	3.44
STD. DEVIATIONS	2.81	1.37	2.16	2.31	2.70	2.21
	2.02	2.53	2.58	1.93	1.27	1.94
RUNOFF						
TOTALS	0.284	0.155	0.168	0.235	0.297	0.329
	0.448	0.508	0.468	0.195	0.036	0.196
STD. DEVIATIONS	0.538	0.138	0.187	0.222	0.425	0.210
	0.220	0.364	0.365	0.157	0.058	0.223
EVAPOTRANSPIRATION						
TOTALS	2.052	3.006	3.636	3.754	3.614	5.093
	6.005	5.454	4.817	3.793	2.029	1.475
STD. DEVIATIONS	0.521	0.187	0.914	2.135	1.587	1.726
	1.112	1.101	0.457	0.278	0.689	0.496

LATERAL DRAINAGE RECIRCULATED INTO LAYER 2

TOTALS	1.1940	1.1291	1.3115	1.2839	1.4056	1.3303
	1.3835	1.3525	1.1823	1.2832	1.2912	1.4943
STD. DEVIATIONS	0.5325	0.5620	0.4223	0.3919	0.3816	0.4183
	0.3684	0.4665	0.3826	0.3703	0.5069	0.3167

LATERAL DRAINAGE COLLECTED FROM LAYER 4

TOTALS	0.2985	0.2823	0.3279	0.3210	0.3514	0.3326
	0.3459	0.3381	0.2956	0.3208	0.3228	0.3736
STD. DEVIATIONS	0.1331	0.1405	0.1056	0.0980	0.0954	0.1046
	0.0921	0.1166	0.0957	0.0926	0.1267	0.0792

LATERAL DRAINAGE RECIRCULATED FROM LAYER 4

TOTALS	1.1940	1.1291	1.3115	1.2839	1.4056	1.3303
	1.3835	1.3525	1.1823	1.2832	1.2912	1.4943
STD. DEVIATIONS	0.5325	0.5620	0.4223	0.3919	0.3816	0.4183
	0.3684	0.4665	0.3826	0.3703	0.5069	0.3167

PERCOLATION/LEAKAGE THROUGH LAYER 6

TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)

DAILY AVERAGE HEAD ON TOP OF LAYER 5

AVERAGES	0.0069	0.0072	0.0076	0.0077	0.0082	0.0080
	0.0080	0.0079	0.0071	0.0075	0.0078	0.0087
STD. DEVIATIONS	0.0031	0.0036	0.0025	0.0024	0.0022	0.0025
	0.0021	0.0027	0.0023	0.0022	0.0030	0.0018

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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 10

	INCHES	CU. FEET	PERCENT
PRECIPITATION	53.90 (7.218)	195671.5	100.00
RUNOFF	3.319 (1.1230)	12046.29	6.156
EVAPOTRANSPIRATION	44.728 (3.9185)	162363.67	82.978
DRAINAGE RECIRCULATED	15.64118 (4.35239)	56777.496	29.01674

INTO LAYER 2				
LATERAL DRAINAGE COLLECTED FROM LAYER 4	3.91030 (	1.08810)	14194.374	7.25419
DRAINAGE RECIRCULATED FROM LAYER 4	15.64118 (	4.35239)	56777.496	29.01674
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.00000 (	0.00000)	0.009	0.00000
AVERAGE HEAD ON TOP OF LAYER 5	0.008 (	0.002)		
CHANGE IN WATER STORAGE	1.943 (	4.7424)	7053.51	3.605

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PEAK DAILY VALUES FOR YEARS 1 THROUGH 10

	(INCHES)	(CU. FT.)
PRECIPITATION	8.20	29766.000
RUNOFF	1.660	6027.1606
DRAINAGE RECIRCULATED INTO LAYER 2	0.12811	465.03055
DRAINAGE COLLECTED FROM LAYER 4	0.03203	116.25764
DRAINAGE RECIRCULATED FROM LAYER 4	0.12811	465.03055
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.000000	0.00003
AVERAGE HEAD ON TOP OF LAYER 5	0.023	
MAXIMUM HEAD ON TOP OF LAYER 5	0.046	
LOCATION OF MAXIMUM HEAD IN LAYER 4 (DISTANCE FROM DRAIN)	1.6 FEET	
SNOW WATER	0.19	690.8433
MAXIMUM VEG. SOIL WATER (VOL/VOL)		0.4434
MINIMUM VEG. SOIL WATER (VOL/VOL)		0.1092

*** Maximum heads are computed using McEnroe's equations. ***

Reference: Maximum Saturated Depth over Landfill Liner
by Bruce M. McEnroe, University of Kansas
ASCE Journal of Environmental Engineering
Vol. 119, No. 2, March 1993, pp. 262-270.

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FINAL WATER STORAGE AT END OF YEAR 10

LAYER	(INCHES)	(VOL/VOL)
1	2.4662	0.2055
2	200.0928	0.3335
3	7.1909	0.2996
4	0.0099	0.0494
5	0.0000	0.0000
6	0.1875	0.7500
SNOW WATER	0.000	

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LCS Option 2/Liner System Option 2

with 200’ of Waste and 80% Recirculation

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**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                **
**                 DEVELOPED BY ENVIRONMENTAL LABORATORY                    **
**                   USAE WATERWAYS EXPERIMENT STATION                      **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                          **
**                                                                          **
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PRECIPITATION DATA FILE:    C:\HELP3\CHESPREC.D4
TEMPERATURE DATA FILE:      C:\HELP3\CHESTEMP.D7
SOLAR RADIATION DATA FILE:  C:\HELP3\CHESSOLA.D13
EVAPOTRANSPIRATION DATA:    C:\HELP3\CHESEVAP.D11
SOIL AND DESIGN DATA FILE:  C:\HELP3\CHESS3.D10
OUTPUT DATA FILE:           C:\HELP3\CHESS3.OUT


TIME:  15:15     DATE:   4/12/2017


******************************************************************************

     TITLE:  CHESSER ISLAND RD - 200 FT WASTE -OPT2/ALT B

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     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
              COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.


                                    LAYER  1
                                    --------

                       TYPE 1 - VERTICAL PERCOLATION LAYER
                           MATERIAL TEXTURE NUMBER  10
           THICKNESS                  =     12.00   INCHES
           POROSITY                   =      0.3980 VOL/VOL
           FIELD CAPACITY             =      0.2440 VOL/VOL
           WILTING POINT              =      0.1360 VOL/VOL
           INITIAL SOIL WATER CONTENT =      0.1846 VOL/VOL
           EFFECTIVE SAT. HYD. COND.  =  0.119999997000E-03 CM/SEC
         NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  4.90
                  FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.


                                    LAYER  2
                                    --------
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              TYPE 1 - VERTICAL PERCOLATION LAYER
                  MATERIAL TEXTURE NUMBER   0
  THICKNESS                   =   2400.00   INCHES
  POROSITY                    =      0.6710 VOL/VOL
  FIELD CAPACITY              =      0.2920 VOL/VOL
  WILTING POINT               =      0.0770 VOL/VOL
  INITIAL SOIL WATER CONTENT  =      0.2948 VOL/VOL
  EFFECTIVE SAT. HYD. COND.   =  0.349999988000E-03 CM/SEC
NOTE:   80.00 PERCENT OF THE DRAINAGE COLLECTED FROM LAYER # 4
         IS RECIRCULATED INTO THIS LAYER.


                         LAYER  3
                         --------

              TYPE 1 - VERTICAL PERCOLATION LAYER
                  MATERIAL TEXTURE NUMBER  10
  THICKNESS                   =     24.00   INCHES
  POROSITY                    =      0.3980 VOL/VOL
  FIELD CAPACITY              =      0.2440 VOL/VOL
  WILTING POINT               =      0.1360 VOL/VOL
  INITIAL SOIL WATER CONTENT  =      0.2600 VOL/VOL
  EFFECTIVE SAT. HYD. COND.   =  0.119999997000E-03 CM/SEC


                         LAYER  4
                         --------

                TYPE 2 - LATERAL DRAINAGE LAYER
                  MATERIAL TEXTURE NUMBER   0
  THICKNESS                   =      0.20   INCHES
  POROSITY                    =      0.8500 VOL/VOL
  FIELD CAPACITY              =      0.0100 VOL/VOL
  WILTING POINT               =      0.0050 VOL/VOL
  INITIAL SOIL WATER CONTENT  =      0.0436 VOL/VOL
  EFFECTIVE SAT. HYD. COND.   =   4.80000019000     CM/SEC
  SLOPE                       =      1.60   PERCENT
  DRAINAGE LENGTH             =    200.0    FEET
NOTE:   80.00 PERCENT OF THE DRAINAGE COLLECTED FROM THIS
         LAYER IS RECIRCULATED INTO LAYER #  2.


                         LAYER  5
                         --------

                TYPE 4 - FLEXIBLE MEMBRANE LINER
                  MATERIAL TEXTURE NUMBER  35
  THICKNESS                   =      0.06   INCHES
  POROSITY                    =      0.0000 VOL/VOL
  FIELD CAPACITY              =      0.0000 VOL/VOL
  WILTING POINT               =      0.0000 VOL/VOL
  INITIAL SOIL WATER CONTENT  =      0.0000 VOL/VOL
  EFFECTIVE SAT. HYD. COND.   =  0.199999996000E-12 CM/SEC
  FML PINHOLE DENSITY         =      1.00   HOLES/ACRE
  FML INSTALLATION DEFECTS    =      1.00   HOLES/ACRE
  FML PLACEMENT QUALITY       =  3 - GOOD
```

LAYER 6

TYPE 3 - BARRIER SOIL LINER
MATERIAL TEXTURE NUMBER 0

THICKNESS	=	0.25 INCHES
POROSITY	=	0.7500 VOL/VOL
FIELD CAPACITY	=	0.7470 VOL/VOL
WILTING POINT	=	0.4000 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.7500 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.999999972000E-09 CM/SEC

GENERAL DESIGN AND EVAPORATIVE ZONE DATA

NOTE: SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT SOIL DATA BASE USING SOIL TEXTURE #10 WITH BARE GROUND CONDITIONS, A SURFACE SLOPE OF 3.% AND A SLOPE LENGTH OF 200. FEET.

SCS RUNOFF CURVE NUMBER	=	94.00	
FRACTION OF AREA ALLOWING RUNOFF	=	25.0	PERCENT
AREA PROJECTED ON HORIZONTAL PLANE	=	1.000	ACRES
EVAPORATIVE ZONE DEPTH	=	22.0	INCHES
INITIAL WATER IN EVAPORATIVE ZONE	=	5.199	INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE	=	11.486	INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE	=	2.402	INCHES
INITIAL SNOW WATER	=	0.000	INCHES
INITIAL WATER IN LAYER MATERIALS	=	716.273	INCHES
TOTAL INITIAL WATER	=	716.273	INCHES
TOTAL SUBSURFACE INFLOW	=	0.00	INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM JACKSONVILLE FLORIDA

STATION LATITUDE	=	30.50	DEGREES
MAXIMUM LEAF AREA INDEX	=	4.00	
START OF GROWING SEASON (JULIAN DATE)	=	0	
END OF GROWING SEASON (JULIAN DATE)	=	367	
EVAPORATIVE ZONE DEPTH	=	22.0	INCHES
AVERAGE ANNUAL WIND SPEED	=	8.20	MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY	=	73.00	%
AVERAGE 2ND QUARTER RELATIVE HUMIDITY	=	72.00	%
AVERAGE 3RD QUARTER RELATIVE HUMIDITY	=	79.00	%
AVERAGE 4TH QUARTER RELATIVE HUMIDITY	=	78.00	%

NOTE: PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING

COEFFICIENTS FOR JACKSONVILLE FLORIDA

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
3.07	3.48	3.72	3.32	4.91	5.37
6.54	7.15	7.26	3.41	1.94	2.59

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR JACKSONVILLE FLORIDA

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
53.20	55.10	61.30	67.70	74.10	79.00
81.30	81.00	78.20	69.50	60.80	54.80

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR JACKSONVILLE FLORIDA
AND STATION LATITUDE = 30.50 DEGREES

****

AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 50

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	3.23	3.47	3.98	3.14	4.68	5.30
	6.81	6.99	6.94	3.31	1.91	2.37
STD. DEVIATIONS	1.69	1.75	1.97	1.87	2.79	2.41
	2.39	2.95	2.72	1.55	1.31	1.65
RUNOFF						
TOTALS	0.166	0.192	0.266	0.179	0.370	0.298
	0.410	0.486	0.501	0.165	0.069	0.117
STD. DEVIATIONS	0.286	0.174	0.219	0.204	0.374	0.228
	0.273	0.433	0.332	0.131	0.086	0.161
EVAPOTRANSPIRATION						
TOTALS	1.890	2.918	3.919	3.671	3.785	4.713
	5.506	5.286	4.778	3.545	1.980	1.403
STD. DEVIATIONS	0.493	0.273	0.766	1.566	1.601	1.653
	1.314	1.088	0.578	0.754	0.626	0.501

LATERAL DRAINAGE RECIRCULATED INTO LAYER 2

TOTALS	1.1122	0.9996	0.9846	1.0697	1.1541	1.1373
	1.1438	1.0956	1.0387	1.0050	1.1411	1.1330
STD. DEVIATIONS	0.4538	0.4122	0.4869	0.4183	0.4639	0.3904
	0.4419	0.4163	0.4335	0.4861	0.4412	0.4281

LATERAL DRAINAGE COLLECTED FROM LAYER 4

TOTALS	0.2780	0.2499	0.2461	0.2674	0.2885	0.2843
	0.2860	0.2739	0.2597	0.2512	0.2853	0.2832
STD. DEVIATIONS	0.1135	0.1031	0.1217	0.1046	0.1160	0.0976
	0.1105	0.1041	0.1084	0.1215	0.1103	0.1070

LATERAL DRAINAGE RECIRCULATED FROM LAYER 4

TOTALS	1.1122	0.9996	0.9846	1.0697	1.1541	1.1373
	1.1438	1.0956	1.0387	1.0050	1.1411	1.1330
STD. DEVIATIONS	0.4538	0.4122	0.4869	0.4183	0.4639	0.3904
	0.4419	0.4163	0.4335	0.4861	0.4412	0.4281

PERCOLATION/LEAKAGE THROUGH LAYER 6

TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)

DAILY AVERAGE HEAD ON TOP OF LAYER 5

AVERAGES	0.0206	0.0203	0.0182	0.0205	0.0214	0.0218
	0.0212	0.0203	0.0199	0.0186	0.0218	0.0210
STD. DEVIATIONS	0.0084	0.0083	0.0090	0.0080	0.0086	0.0075
	0.0082	0.0077	0.0083	0.0090	0.0084	0.0079

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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 50

	INCHES		CU. FEET	PERCENT
PRECIPITATION	52.14	(6.893)	189283.5	100.00
RUNOFF	3.220	(0.7977)	11687.52	6.175
EVAPOTRANSPIRATION	43.397	(3.4128)	157530.75	83.225
DRAINAGE RECIRCULATED	13.01452	(4.57261)	47242.699	24.95870

```
  INTO LAYER  2

LATERAL DRAINAGE COLLECTED      3.25363 (  1.14315)     11810.675    6.23968
  FROM LAYER  4

DRAINAGE RECIRCULATED          13.01452 (  4.57261)     47242.699   24.95870
  FROM LAYER  4

PERCOLATION/LEAKAGE THROUGH     0.00000 (  0.00000)         0.010     0.00001
  LAYER  6

AVERAGE HEAD ON TOP             0.020 (    0.007)
  OF LAYER  5

CHANGE IN WATER STORAGE         2.273   (  4.0959)       8251.23      4.359
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                PEAK DAILY VALUES FOR YEARS    1 THROUGH   50
   ------------------------------------------------------------------------
                                                   (INCHES)      (CU. FT.)
                                                  ----------    -------------
     PRECIPITATION                                   8.20          29766.000

     RUNOFF                                          1.820          6605.7187

     DRAINAGE RECIRCULATED INTO LAYER  2             0.12247         444.55368

     DRAINAGE COLLECTED FROM LAYER  4                0.03062         111.13842

     DRAINAGE RECIRCULATED FROM LAYER  4             0.12247         444.55368

     PERCOLATION/LEAKAGE THROUGH LAYER  6            0.000000          0.00004

     AVERAGE HEAD ON TOP OF LAYER  5                 0.070

     MAXIMUM HEAD ON TOP OF LAYER  5                 0.138

     LOCATION OF MAXIMUM HEAD IN LAYER  4
           (DISTANCE FROM DRAIN)                     3.3 FEET

     SNOW WATER                                      0.55           1997.6433


     MAXIMUM VEG. SOIL WATER (VOL/VOL)                       0.4988

     MINIMUM VEG. SOIL WATER (VOL/VOL)                       0.1092


      ***  Maximum heads are computed using McEnroe's equations.  ***

           Reference:  Maximum Saturated Depth over Landfill Liner
                       by Bruce M. McEnroe, University of Kansas
                       ASCE Journal of Environmental Engineering
                       Vol. 119, No. 2, March 1993, pp. 262-270.

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FINAL WATER STORAGE AT END OF YEAR 50

LAYER	(INCHES)	(VOL/VOL)
1	1.5891	0.1324
2	820.9767	0.3421
3	7.1446	0.2977
4	0.0287	0.1437
5	0.0000	0.0000
6	0.1875	0.7500
SNOW WATER	0.000	

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LCS Option 2/Liner System Option 2

with 402’ of Waste and 80% Recirculation

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**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                **
**                  DEVELOPED BY ENVIRONMENTAL LABORATORY                   **
**                    USAE WATERWAYS EXPERIMENT STATION                     **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************


PRECIPITATION DATA FILE:    C:\HELP3\CHESPREC.D4
TEMPERATURE DATA FILE:      C:\HELP3\CHESTEMP.D7
SOLAR RADIATION DATA FILE:  C:\HELP3\CHESSOLA.D13
EVAPOTRANSPIRATION DATA:    C:\HELP3\CHESEVAP.D11
SOIL AND DESIGN DATA FILE:  C:\HELP3\CHESS4.D10
OUTPUT DATA FILE:           C:\HELP3\CHESS4.OUT


TIME:  15:17     DATE:   4/12/2017


******************************************************************************

     TITLE:  CHESSER ISLAND RD - 402 FT WASTE -OPT2/ALT B

******************************************************************************


     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
              COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.


                                   LAYER  1
                                   --------

                     TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER  10
           THICKNESS                  =     12.00   INCHES
           POROSITY                   =      0.3980 VOL/VOL
           FIELD CAPACITY             =      0.2440 VOL/VOL
           WILTING POINT              =      0.1360 VOL/VOL
           INITIAL SOIL WATER CONTENT =      0.1842 VOL/VOL
           EFFECTIVE SAT. HYD. COND.  =  0.119999997000E-03 CM/SEC
         NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  4.90
                  FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.


                                   LAYER  2
                                   --------
```

```
             TYPE 1 - VERTICAL PERCOLATION LAYER
                 MATERIAL TEXTURE NUMBER   0
  THICKNESS                    =   4824.00   INCHES
  POROSITY                     =      0.6710 VOL/VOL
  FIELD CAPACITY               =      0.2920 VOL/VOL
  WILTING POINT                =      0.0770 VOL/VOL
  INITIAL SOIL WATER CONTENT   =      0.2933 VOL/VOL
  EFFECTIVE SAT. HYD. COND.    =  0.349999988000E-03 CM/SEC
NOTE:   80.00 PERCENT OF THE DRAINAGE COLLECTED FROM LAYER # 4
         IS RECIRCULATED INTO THIS LAYER.
```

LAYER 3

```
             TYPE 1 - VERTICAL PERCOLATION LAYER
                 MATERIAL TEXTURE NUMBER  10
  THICKNESS                    =     24.00   INCHES
  POROSITY                     =      0.3980 VOL/VOL
  FIELD CAPACITY               =      0.2440 VOL/VOL
  WILTING POINT                =      0.1360 VOL/VOL
  INITIAL SOIL WATER CONTENT   =      0.2601 VOL/VOL
  EFFECTIVE SAT. HYD. COND.    =  0.119999997000E-03 CM/SEC
```

LAYER 4

```
               TYPE 2 - LATERAL DRAINAGE LAYER
                 MATERIAL TEXTURE NUMBER   0
  THICKNESS                    =      0.20   INCHES
  POROSITY                     =      0.8500 VOL/VOL
  FIELD CAPACITY               =      0.0100 VOL/VOL
  WILTING POINT                =      0.0050 VOL/VOL
  INITIAL SOIL WATER CONTENT   =      0.0676 VOL/VOL
  EFFECTIVE SAT. HYD. COND.    =   2.79999995000     CM/SEC
  SLOPE                        =      1.60   PERCENT
  DRAINAGE LENGTH              =    200.0    FEET
NOTE:   80.00 PERCENT OF THE DRAINAGE COLLECTED FROM THIS
         LAYER IS RECIRCULATED INTO LAYER #  2.
```

LAYER 5

```
               TYPE 4 - FLEXIBLE MEMBRANE LINER
                 MATERIAL TEXTURE NUMBER  35
  THICKNESS                    =      0.06   INCHES
  POROSITY                     =      0.0000 VOL/VOL
  FIELD CAPACITY               =      0.0000 VOL/VOL
  WILTING POINT                =      0.0000 VOL/VOL
  INITIAL SOIL WATER CONTENT   =      0.0000 VOL/VOL
  EFFECTIVE SAT. HYD. COND.    =  0.199999996000E-12 CM/SEC
  FML PINHOLE DENSITY          =      1.00   HOLES/ACRE
  FML INSTALLATION DEFECTS     =      1.00   HOLES/ACRE
  FML PLACEMENT QUALITY        =  3 - GOOD
```

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                    LAYER  6
                    --------

          TYPE 3 - BARRIER SOIL LINER
          MATERIAL TEXTURE NUMBER   0
THICKNESS                  =      0.25   INCHES
POROSITY                   =      0.7500 VOL/VOL
FIELD CAPACITY             =      0.7470 VOL/VOL
WILTING POINT              =      0.4000 VOL/VOL
INITIAL SOIL WATER CONTENT =      0.7500 VOL/VOL
EFFECTIVE SAT. HYD. COND.  =  0.999999972000E-09 CM/SEC



         GENERAL DESIGN AND EVAPORATIVE ZONE DATA
         ----------------------------------------

 NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
          SOIL DATA BASE USING SOIL TEXTURE #10 WITH A
          FAIR STAND OF GRASS, A SURFACE SLOPE OF 33.%
          AND A SLOPE LENGTH OF  200. FEET.

SCS RUNOFF CURVE NUMBER            =     87.00
FRACTION OF AREA ALLOWING RUNOFF   =    100.0    PERCENT
AREA PROJECTED ON HORIZONTAL PLANE =      1.000  ACRES
EVAPORATIVE ZONE DEPTH             =     22.0    INCHES
INITIAL WATER IN EVAPORATIVE ZONE  =      5.191  INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE =     11.486  INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE =      2.402  INCHES
INITIAL SNOW WATER                 =      0.000  INCHES
INITIAL WATER IN LAYER MATERIALS   =   1423.591  INCHES
TOTAL INITIAL WATER                =   1423.591  INCHES
TOTAL SUBSURFACE INFLOW            =      0.00   INCHES/YEAR


            EVAPOTRANSPIRATION AND WEATHER DATA
            -----------------------------------

 NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
          JACKSONVILLE          FLORIDA

     STATION LATITUDE                         =  30.50 DEGREES
     MAXIMUM LEAF AREA INDEX                  =   4.00
     START OF GROWING SEASON (JULIAN DATE)    =      0
     END OF GROWING SEASON (JULIAN DATE)      =    367
     EVAPORATIVE ZONE DEPTH                   =  22.0  INCHES
     AVERAGE ANNUAL WIND SPEED                =   8.20 MPH
     AVERAGE 1ST QUARTER RELATIVE HUMIDITY    =  73.00 %
     AVERAGE 2ND QUARTER RELATIVE HUMIDITY    =  72.00 %
     AVERAGE 3RD QUARTER RELATIVE HUMIDITY    =  79.00 %
     AVERAGE 4TH QUARTER RELATIVE HUMIDITY    =  78.00 %


 NOTE:  PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
```

COEFFICIENTS FOR JACKSONVILLE FLORIDA

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
3.07	3.48	3.72	3.32	4.91	5.37
6.54	7.15	7.26	3.41	1.94	2.59

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR JACKSONVILLE FLORIDA

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
53.20	55.10	61.30	67.70	74.10	79.00
81.30	81.00	78.20	69.50	60.80	54.80

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR JACKSONVILLE FLORIDA
AND STATION LATITUDE = 30.50 DEGREES

****

AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 50

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	3.23	3.47	3.98	3.14	4.68	5.30
	6.81	6.99	6.94	3.31	1.91	2.37
STD. DEVIATIONS	1.69	1.75	1.97	1.87	2.79	2.41
	2.39	2.95	2.72	1.55	1.31	1.65
RUNOFF						
TOTALS	0.219	0.221	0.344	0.215	0.584	0.338
	0.501	0.711	0.702	0.151	0.051	0.141
STD. DEVIATIONS	0.746	0.288	0.375	0.415	0.793	0.365
	0.503	0.964	0.645	0.194	0.111	0.282
EVAPOTRANSPIRATION						
TOTALS	1.869	2.918	3.927	3.681	3.771	4.649
	5.505	5.297	4.785	3.521	1.968	1.393
STD. DEVIATIONS	0.509	0.288	0.760	1.571	1.550	1.632
	1.326	1.072	0.571	0.753	0.624	0.498

LATERAL DRAINAGE RECIRCULATED INTO LAYER 2

TOTALS	0.6933	0.6320	0.5626	0.6574	0.7166	0.6965
	0.7381	0.6878	0.6983	0.5877	0.6662	0.7050
STD. DEVIATIONS	0.2411	0.2401	0.2358	0.2778	0.2315	0.2138
	0.2452	0.2142	0.2118	0.2377	0.2540	0.2175

LATERAL DRAINAGE COLLECTED FROM LAYER 4

TOTALS	0.1733	0.1580	0.1406	0.1643	0.1791	0.1741
	0.1845	0.1720	0.1746	0.1469	0.1665	0.1763
STD. DEVIATIONS	0.0603	0.0600	0.0589	0.0695	0.0579	0.0535
	0.0613	0.0535	0.0529	0.0594	0.0635	0.0544

LATERAL DRAINAGE RECIRCULATED FROM LAYER 4

TOTALS	0.6933	0.6320	0.5626	0.6574	0.7166	0.6965
	0.7381	0.6878	0.6983	0.5877	0.6662	0.7050
STD. DEVIATIONS	0.2411	0.2401	0.2358	0.2778	0.2315	0.2138
	0.2452	0.2142	0.2118	0.2377	0.2540	0.2175

PERCOLATION/LEAKAGE THROUGH LAYER 6

TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)

DAILY AVERAGE HEAD ON TOP OF LAYER 5

AVERAGES	0.0220	0.0220	0.0179	0.0216	0.0228	0.0229
	0.0234	0.0218	0.0229	0.0187	0.0219	0.0224
STD. DEVIATIONS	0.0077	0.0083	0.0075	0.0091	0.0074	0.0070
	0.0078	0.0068	0.0070	0.0075	0.0083	0.0069

****

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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 50

	INCHES		CU. FEET	PERCENT
PRECIPITATION	52.14	(6.893)	189283.5	100.00
RUNOFF	4.179	(1.6590)	15169.27	8.014
EVAPOTRANSPIRATION	43.284	(3.4758)	157122.34	83.009
DRAINAGE RECIRCULATED	8.04147	(1.87138)	29190.545	15.42160

INTO LAYER 2				
LATERAL DRAINAGE COLLECTED FROM LAYER 4	2.01037 (	0.46784)	7297.636	3.85540
DRAINAGE RECIRCULATED FROM LAYER 4	8.04147 (	1.87138)	29190.545	15.42160
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.00000 (	0.00000)	0.010	0.00001
AVERAGE HEAD ON TOP OF LAYER 5	0.022 (	0.005)		
CHANGE IN WATER STORAGE	2.670 (	3.4858)	9691.55	5.120

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PEAK DAILY VALUES FOR YEARS 1 THROUGH 50

	(INCHES)	(CU. FT.)
PRECIPITATION	8.20	29766.000
RUNOFF	5.045	18312.2441
DRAINAGE RECIRCULATED INTO LAYER 2	0.07012	254.54373
DRAINAGE COLLECTED FROM LAYER 4	0.01753	63.63593
DRAINAGE RECIRCULATED FROM LAYER 4	0.07012	254.54373
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.000000	0.00004
AVERAGE HEAD ON TOP OF LAYER 5	0.069	
MAXIMUM HEAD ON TOP OF LAYER 5	0.136	
LOCATION OF MAXIMUM HEAD IN LAYER 4 (DISTANCE FROM DRAIN)	3.3 FEET	
SNOW WATER	0.55	1997.6433
MAXIMUM VEG. SOIL WATER (VOL/VOL)		0.3811
MINIMUM VEG. SOIL WATER (VOL/VOL)		0.1092

*** Maximum heads are computed using McEnroe's equations. ***

Reference: Maximum Saturated Depth over Landfill Liner
by Bruce M. McEnroe, University of Kansas
ASCE Journal of Environmental Engineering
Vol. 119, No. 2, March 1993, pp. 262-270.

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FINAL WATER STORAGE AT END OF YEAR 50

LAYER	(INCHES)	(VOL/VOL)
1	1.5891	0.1324
2	1548.2191	0.3209
3	7.0455	0.2936
4	0.0423	0.2115
5	0.0000	0.0000
6	0.1875	0.7500
SNOW WATER	0.000	

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LCS Option 2/Liner System Option 1

with 200’ of Waste and 80% Recirculation

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**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                **
**                DEVELOPED BY ENVIRONMENTAL LABORATORY                     **
**                  USAE WATERWAYS EXPERIMENT STATION                       **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************


PRECIPITATION DATA FILE:    C:\HELP3\CHESPREC.D4
TEMPERATURE DATA FILE:      C:\HELP3\CHESTEMP.D7
SOLAR RADIATION DATA FILE:  C:\HELP3\CHESSOLA.D13
EVAPOTRANSPIRATION DATA:    C:\HELP3\CHESEVAP.D11
SOIL AND DESIGN DATA FILE:  C:\HELP3\CHESS5.D10
OUTPUT DATA FILE:           C:\HELP3\CHESS5.OUT


TIME:  15:51     DATE:   4/12/2017


******************************************************************************

     TITLE:  CHESSER ISLAND RD - 200 FT WASTE -OPT1/ALT B

******************************************************************************


     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
              COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.


                                    LAYER  1
                                    --------

                     TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER  10
           THICKNESS                 =     12.00   INCHES
           POROSITY                  =      0.3980 VOL/VOL
           FIELD CAPACITY            =      0.2440 VOL/VOL
           WILTING POINT             =      0.1360 VOL/VOL
           INITIAL SOIL WATER CONTENT  =      0.1846 VOL/VOL
           EFFECTIVE SAT. HYD. COND.   =  0.119999997000E-03 CM/SEC
         NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  4.90
                FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.


                                    LAYER  2
                                    --------
```

```
            TYPE 1 - VERTICAL PERCOLATION LAYER
                MATERIAL TEXTURE NUMBER   0
  THICKNESS                   =   2400.00   INCHES
  POROSITY                    =      0.6710 VOL/VOL
  FIELD CAPACITY              =      0.2920 VOL/VOL
  WILTING POINT               =      0.0770 VOL/VOL
  INITIAL SOIL WATER CONTENT  =      0.2948 VOL/VOL
  EFFECTIVE SAT. HYD. COND.   =  0.349999988000E-03 CM/SEC
NOTE:   80.00 PERCENT OF THE DRAINAGE COLLECTED FROM LAYER # 4
         IS RECIRCULATED INTO THIS LAYER.
```

```
                         LAYER  3
                         --------

            TYPE 1 - VERTICAL PERCOLATION LAYER
                MATERIAL TEXTURE NUMBER  10
  THICKNESS                   =     24.00   INCHES
  POROSITY                    =      0.3980 VOL/VOL
  FIELD CAPACITY              =      0.2440 VOL/VOL
  WILTING POINT               =      0.1360 VOL/VOL
  INITIAL SOIL WATER CONTENT  =      0.2600 VOL/VOL
  EFFECTIVE SAT. HYD. COND.   =  0.119999997000E-03 CM/SEC
```

```
                         LAYER  4
                         --------

              TYPE 2 - LATERAL DRAINAGE LAYER
                MATERIAL TEXTURE NUMBER   0
  THICKNESS                   =      0.20   INCHES
  POROSITY                    =      0.8500 VOL/VOL
  FIELD CAPACITY              =      0.0100 VOL/VOL
  WILTING POINT               =      0.0050 VOL/VOL
  INITIAL SOIL WATER CONTENT  =      0.0436 VOL/VOL
  EFFECTIVE SAT. HYD. COND.   =   4.80000019000     CM/SEC
  SLOPE                       =      1.60   PERCENT
  DRAINAGE LENGTH             =    200.0    FEET
NOTE:   80.00 PERCENT OF THE DRAINAGE COLLECTED FROM THIS
         LAYER IS RECIRCULATED INTO LAYER #  2.
```

```
                         LAYER  5
                         --------

              TYPE 4 - FLEXIBLE MEMBRANE LINER
                MATERIAL TEXTURE NUMBER  35
  THICKNESS                   =      0.06   INCHES
  POROSITY                    =      0.0000 VOL/VOL
  FIELD CAPACITY              =      0.0000 VOL/VOL
  WILTING POINT               =      0.0000 VOL/VOL
  INITIAL SOIL WATER CONTENT  =      0.0000 VOL/VOL
  EFFECTIVE SAT. HYD. COND.   =  0.199999996000E-12 CM/SEC
  FML PINHOLE DENSITY         =      1.00   HOLES/ACRE
  FML INSTALLATION DEFECTS    =      1.00   HOLES/ACRE
  FML PLACEMENT QUALITY       =  3 - GOOD
```

LAYER 6

TYPE 3 - BARRIER SOIL LINER
MATERIAL TEXTURE NUMBER 0

```
THICKNESS                    =     24.00   INCHES
POROSITY                     =      0.7500 VOL/VOL
FIELD CAPACITY               =      0.7470 VOL/VOL
WILTING POINT                =      0.4000 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.7500 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.100000001000E-06 CM/SEC
```

GENERAL DESIGN AND EVAPORATIVE ZONE DATA

NOTE: SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT SOIL DATA BASE USING SOIL TEXTURE #10 WITH BARE GROUND CONDITIONS, A SURFACE SLOPE OF 3.% AND A SLOPE LENGTH OF 200. FEET.

```
SCS RUNOFF CURVE NUMBER             =     94.00
FRACTION OF AREA ALLOWING RUNOFF    =     25.0    PERCENT
AREA PROJECTED ON HORIZONTAL PLANE  =      1.000  ACRES
EVAPORATIVE ZONE DEPTH              =     22.0    INCHES
INITIAL WATER IN EVAPORATIVE ZONE   =      5.199  INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE  =     11.486  INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE  =      2.402  INCHES
INITIAL SNOW WATER                  =      0.000  INCHES
INITIAL WATER IN LAYER MATERIALS    =    734.086  INCHES
TOTAL INITIAL WATER                 =    734.086  INCHES
TOTAL SUBSURFACE INFLOW             =      0.00   INCHES/YEAR
```

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
JACKSONVILLE FLORIDA

```
STATION LATITUDE                         =  30.50 DEGREES
MAXIMUM LEAF AREA INDEX                  =   4.00
START OF GROWING SEASON (JULIAN DATE)    =      0
END OF GROWING SEASON (JULIAN DATE)      =    367
EVAPORATIVE ZONE DEPTH                   =  22.0  INCHES
AVERAGE ANNUAL WIND SPEED                =   8.20 MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY    =  73.00 %
AVERAGE 2ND QUARTER RELATIVE HUMIDITY    =  72.00 %
AVERAGE 3RD QUARTER RELATIVE HUMIDITY    =  79.00 %
AVERAGE 4TH QUARTER RELATIVE HUMIDITY    =  78.00 %
```

NOTE: PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING

CHESS5.OUT

COEFFICIENTS FOR JACKSONVILLE FLORIDA

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
3.07	3.48	3.72	3.32	4.91	5.37
6.54	7.15	7.26	3.41	1.94	2.59

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR JACKSONVILLE FLORIDA

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
53.20	55.10	61.30	67.70	74.10	79.00
81.30	81.00	78.20	69.50	60.80	54.80

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR JACKSONVILLE FLORIDA
AND STATION LATITUDE = 30.50 DEGREES

****

AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 50

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	3.23	3.47	3.98	3.14	4.68	5.30
	6.81	6.99	6.94	3.31	1.91	2.37
STD. DEVIATIONS	1.69	1.75	1.97	1.87	2.79	2.41
	2.39	2.95	2.72	1.55	1.31	1.65
RUNOFF						
TOTALS	0.166	0.192	0.266	0.179	0.370	0.298
	0.410	0.486	0.501	0.165	0.069	0.117
STD. DEVIATIONS	0.286	0.174	0.219	0.204	0.374	0.227
	0.273	0.433	0.331	0.131	0.086	0.161
EVAPOTRANSPIRATION						
TOTALS	1.892	2.920	3.917	3.682	3.786	4.699
	5.501	5.288	4.777	3.544	1.981	1.403
STD. DEVIATIONS	0.492	0.275	0.767	1.565	1.601	1.649
	1.319	1.086	0.581	0.752	0.625	0.501

LATERAL DRAINAGE RECIRCULATED INTO LAYER 2

TOTALS	1.1140	1.0009	0.9843	1.0746	1.1564	1.1417
	1.1375	1.0987	1.0369	1.0064	1.1424	1.1364
STD. DEVIATIONS	0.4573	0.4139	0.4882	0.4218	0.4674	0.3899
	0.4414	0.4177	0.4342	0.4851	0.4434	0.4284

LATERAL DRAINAGE COLLECTED FROM LAYER 4

TOTALS	0.2785	0.2502	0.2461	0.2687	0.2891	0.2854
	0.2844	0.2747	0.2592	0.2516	0.2856	0.2841
STD. DEVIATIONS	0.1143	0.1035	0.1221	0.1054	0.1168	0.0975
	0.1104	0.1044	0.1086	0.1213	0.1108	0.1071

LATERAL DRAINAGE RECIRCULATED FROM LAYER 4

TOTALS	1.1140	1.0009	0.9843	1.0746	1.1564	1.1417
	1.1375	1.0987	1.0369	1.0064	1.1424	1.1364
STD. DEVIATIONS	0.4573	0.4139	0.4882	0.4218	0.4674	0.3899
	0.4414	0.4177	0.4342	0.4851	0.4434	0.4284

PERCOLATION/LEAKAGE THROUGH LAYER 6

TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)

DAILY AVERAGE HEAD ON TOP OF LAYER 5

AVERAGES	0.0206	0.0203	0.0182	0.0206	0.0214	0.0219
	0.0211	0.0204	0.0199	0.0186	0.0219	0.0211
STD. DEVIATIONS	0.0085	0.0084	0.0090	0.0081	0.0087	0.0075
	0.0082	0.0077	0.0083	0.0090	0.0085	0.0079

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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 50

	INCHES	CU. FEET	PERCENT
PRECIPITATION	52.14 (6.893)	189283.5	100.00
RUNOFF	3.219 (0.7976)	11685.59	6.174
EVAPOTRANSPIRATION	43.390 (3.4095)	157505.73	83.212
DRAINAGE RECIRCULATED	13.03020 (4.59128)	47299.637	24.98878

INTO LAYER 2				
LATERAL DRAINAGE COLLECTED FROM LAYER 4	3.25755 (	1.14782)	11824.909	6.24720
DRAINAGE RECIRCULATED FROM LAYER 4	13.03020 (	4.59128)	47299.637	24.98878
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.00001 (	0.00000)	0.045	0.00002
AVERAGE HEAD ON TOP OF LAYER 5	0.020 (	0.007)		
CHANGE IN WATER STORAGE	2.277 (	4.1053)	8263.98	4.366

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PEAK DAILY VALUES FOR YEARS 1 THROUGH 50

	(INCHES)	(CU. FT.)
PRECIPITATION	8.20	29766.000
RUNOFF	1.820	6605.7187
DRAINAGE RECIRCULATED INTO LAYER 2	0.12262	445.09824
DRAINAGE COLLECTED FROM LAYER 4	0.03065	111.27456
DRAINAGE RECIRCULATED FROM LAYER 4	0.12262	445.09824
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.000000	0.00034
AVERAGE HEAD ON TOP OF LAYER 5	0.070	
MAXIMUM HEAD ON TOP OF LAYER 5	0.139	
LOCATION OF MAXIMUM HEAD IN LAYER 4 (DISTANCE FROM DRAIN)	3.3 FEET	
SNOW WATER	0.55	1997.6433
MAXIMUM VEG. SOIL WATER (VOL/VOL)	0.4988	
MINIMUM VEG. SOIL WATER (VOL/VOL)	0.1092	

*** Maximum heads are computed using McEnroe's equations. ***

Reference: Maximum Saturated Depth over Landfill Liner
by Bruce M. McEnroe, University of Kansas
ASCE Journal of Environmental Engineering
Vol. 119, No. 2, March 1993, pp. 262-270.

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FINAL WATER STORAGE AT END OF YEAR 50

LAYER	(INCHES)	(VOL/VOL)
1	1.5891	0.1324
2	821.1469	0.3421
3	7.1500	0.2979
4	0.0290	0.1448
5	0.0000	0.0000
6	18.0000	0.7500
SNOW WATER	0.000	

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ATLANTIC COAST CONSULTING, INC.

Section 2
B. Liner Filter Fabric Analysis

OBJECTIVE:

Evaluate the performance of the geotextile filter component of the geocomposite used in leachate collection system Alternative B for the Chesser Island Road MSW Landfill. The analysis applies to the condition when borrowed soil from on-site will be placed over the geotextile filter used in seperation from the geocomposite drainage system. For application purposes the geotextile filter is designed to provide permeability for water while also preventing clogging of the underlying geocomposite drainage system by soil particles.

METHODOLOGY:

This geotextile filter design is based upon the publication "Geotextile Filter Design, Application and Product Selection Guide," by Mirafi, See Attachment 1. The design is a seven step process used to select the appropriate geotextile filter.

Step 1: Define Application Filter Requirements

(i) Drainage material adjacent to the geotextile will consist of an HDPE geonet. This corresponds to a relatively low void volume condition and will not result in sharp contact points as can be expected with a regular gravel or rock.

(ii) Since the void volume is relatively small a high degree of retention from the filter will be necessary.

Step 2: Boundary Conditions

(i) Since the geotextile is being used in base liner leachate collection system construction, confining pressures will be high.

(ii) Since the flow will only be in a downward direction into the drainage net, a steady flow condition is applicable.

Step 3: Soil Retention Requirements

The soil to be retained (i.e., liner protective cover) was presumed to be derived from on-site materials. The particle size distribution tests for on-site soils were performed by Terracon Consultants, Inc. during Borrow Area 1 Subsurface Investigation for Chesser Island Road Landfill. The results of the testing are attached in Attachment 2, and summarized in Table 1. The average particle size distribution of anticipated liner protective cover is shown in Table 1.

Step 4: Geotextile Permeability Requirements

Minimum allowable geotextile permeability = $k_g \geq i_s k_s$

Soil d_{20} is predominantly greater than 0.002mm and d_{10} is less than 0.07mm. A permeability of 1.2E-05 cm/s is estimated for the soil based on soil testing performed.

k_s= 1.2E-05 cm/s

Hydraulic Gradient, i_s = 1.5 for landfill leachate collection systems based on Giroud 1988

Therefore, required geotextile permeability:

1.7E-05 cm/s

From Attachment 3, the Permeability for a 8 oz/sy fabric is 0.3 cm/s

Step 5: Anti-Clogging Requirements

The largest opening size that satisfies the AOS criteria will be selected to satisfy this requirement.

From Chart 1, since d_{20}>0.002 mm, and d_{10}<0.07 mm ; soil is less than 20% clay and more than 10% silt. Since the average PI=28 and the soil is non-dispersive, O_{95} < 0.21mm.

Step 6: Survivability Requirements

Since the application is for subsurface drainage with rounded drainage media, high confining stress and heavy compaction, the following criteria are selected for survivability.

Grab strength ≥ 157 lb, Elongation ≥ 50%

Puncture strength ≥ 56 lb, Burst strength ≥ 189 psi, Trapezoidal Tear ≥ 56 lb

Step 7: Durability Requirements

Since the geotextile will not be left exposed to sunlight, nor exposed to adverse chemicals, special durability requirements do not apply.

Results:

Based on opening size, permeability, and survivablility requirements, the Skaps GE-180 8 oz/yd^2 geotextile fabric was considered as a typical product meeting the selection criteria. The property sheet from the manufacturer is attached in Attachment 3.

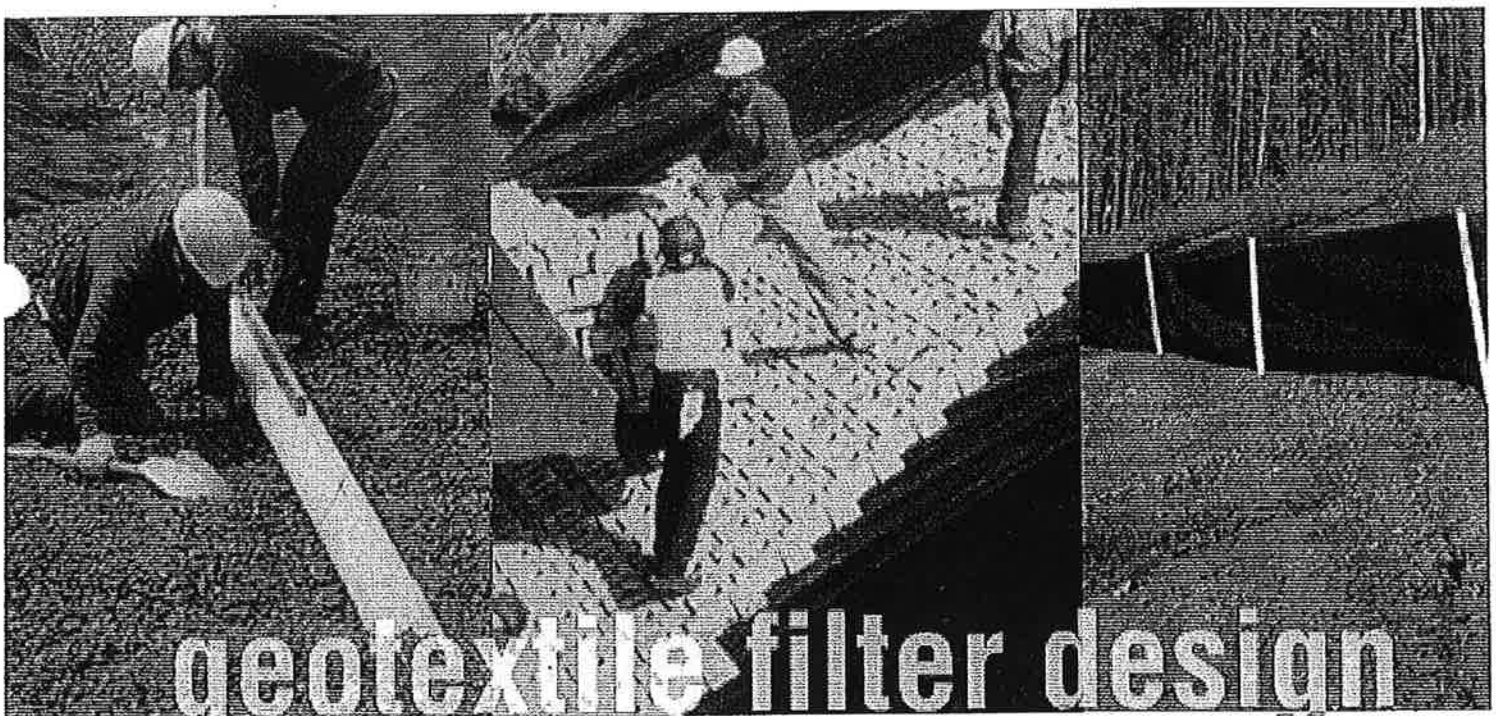
Conclusion:

8.0 oz/yd^2 nonwoven geotextile is suitable for this application

Maximum AOS per ASTM D-4751 = 0.21; OK

MIRAFI®

geotextile filter design, application, and product selection guide



Marine & Transportation Engineering

Ten Cate Nicolon

Attachment 1

MIRAFI®

GEOTEXTILE FILTER DESIGN, APPLICATION, AND PRODUCT SELECTION GUIDE

Drainage and Erosion Control Applications

TABLE OF CONTENTS

INTRODUCTION AND EXPLANATION OF THE PROBLEM

Drainage

Aggregate trench and blanket drains are commonly used to drain water from surrounding soils or waste materials. These drains are typically installed less than three feet deep. They may be at greater depths in situations where there is a need to significantly lower the groundwater table or to drain leachate.

In loose or gap graded soils, the groundwater flow can carry soil particles toward the drain. These migrating particles can clog drainage systems.

Erosion Control

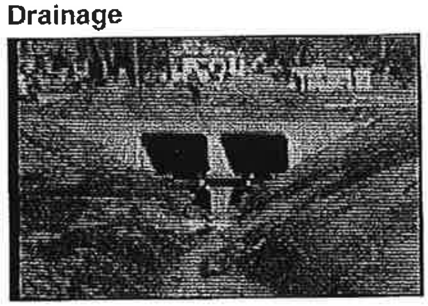
Stone and concrete revetments are often used on waterway slopes to resist soil erosion. These armored systems, when placed directly on the soil, have not sufficiently prevented erosion. Fluctuating water levels cause seepage in and out of embankment slopes resulting in the displacement of fine soil particles.

As with trench drains, these fine soil particles are carried away with receding flows. This action eventually leads to undermining of the armor system.

Typical Solutions

Specially graded fill material which is intended to act as a soil filter is frequently placed between the drain or revetment and the soil to be protected. This graded filter is often difficult to obtain, expensive to purchase, time consuming to install and segregates during placement, thus compromising its filtration ability.

Drainage



Geotextile filters retain soil particles while allowing seeping water to drain freely. Fine soil particles are prevented from clogging drainage systems.

Erosion Control

Geotextile filters retain soil particles while allowing water to pass freely. Buildup of hydrostatic pressures in protected slopes is prevented, thus enhancing slope stability.

THE MIRAFI® SOLUTION

Filtration geotextiles provide alternatives to graded filters.

Designing with Geotextile Filters

Geotextiles are frequently used in armored erosion control and drainage applications. Some of the most common applications include slopes, dam embankments/spillways, shorelines armored with riprap, flexible block mats and concrete filled fabric formed systems. Drainage applications include pavement edge drains, french drains, prefabricated drainage panels and leachate collection/leak detection systems.

In all of the above applications, geotextiles are used to retain soil particles while allowing liquid to pass freely. But the fact that geotextiles are widely used where their primary function is filtration, there remains much confusion about proper filtration design procedures.

For this reason, Mirafi® commissioned Geosyntec Consultants, Inc. to develop a generic *Geotextile Filter Design Manual.* The manual offers a systematic approach to solving most common filtration design problems. It is available to practicing designers exclusively through Mirafi®. This *Geotextile Filter Design, Application, and Product Selection Guide* is excerpted from the manual.

Mechanisms of Filtration

A filter should prevent excessive migration of soil particles, while at the same time allowing liquid to flow freely through the filter layer. Filtration is therefore summarized by two seemingly conflicting requirements.

- The filter must retain soil, implying that the size of filter pore spaces or openings should be smaller than a specified maximum value; and
- The filter must be permeable enough to allow a relatively free flow through it, implying that the size of filter pore spaces and number of openings should be larger than a specified minimum value.

Geotextile Filter Requirements

Before the introduction of geotextiles, granular materials were widely used as filters for geotechnical engineering applications. Drainage criteria for geotextile filters is largely derived from those for granular filters. The criteria for both are, therefore, similar.

In addition to retention and permeability criteria, several other considerations are required for geotextile filter design. Some considerations are noted below:

- **Retention:** Ensures that the geotextile openings are small enough to prevent excessive migration of soil particles.
- **Permeability:** Ensures that the geotextile is permeable enough to allow liquids to pass through without causing significant upstream pressure buildup.
- **Anti-clogging:** Ensures that the geotextile has adequate openings, preventing trapped soil from clogging openings and affecting permeability.
- **Survivability:** Ensures that the geotextile is strong enough to resist damage during installation.
- **Durability:** Ensures that the geotextile is resilient to adverse chemical, biological and ultraviolet (UV) light exposure for the design life of the project.

The specified numerical criteria for geotextile filter requirements depends on the application of the filter, filter boundary conditions, properties of the soil being filtered, and construction methods used to install the filter. These factors are discussed in the following step-by-step geotextile design methodology

SYSTEMATIC DESIGN APPROACH

Design Methodology

The proposed design methodology represents years of research and experience in geotextile filtration design. The approach presents a logical progression through seven steps.

Step 1: Define the Application Filter Requirements

Step 2: Define Boundary Conditions

Step 3: Determine Soil Retention Requirements

Step 4: Determine Permeability Requirements

Step 5: Determine Anti-Clogging Requirements

Step 6: Determine Survivability Requirements

Step 7: Determine Durability Requirements

STEP ONE:

DEFINE APPLICATION FILTER REQUIREMENTS

Geotextile filters are used between the soil and drainage or armoring medium. Typical drainage media include natural materials such as gravel and sand, as well as geosynthetic materials such as geonets and cuspated drainage cores. Armoring material is often riprap or concrete blocks. Often, an armoring system includes a sand bedding layer beneath the surface armor. The armoring system can be considered to act as a "drain" for water seeping from the protected slope.

Identifying the Drainage Material

The drainage medium adjacent to the geotextile must be identified. The primary reasons for this include:

- Large voids or high pore volume can influence the selection of the retention criterion
- Sharp contact points such as highly angular gravel or rock will influence the geosynthetic survivability requirements.

Retention vs. Permeability Trade-Off

The drainage medium adjacent to the geotextile often affects the selection of the retention criterion. Due to the conflicting nature of filter requirements, it is necessary to decide whether retention or permeability is the favored filter characteristic.

For example, a drainage material that has relatively little void volume (i.e., a geonet or a wick drain) requires a high degree of retention from the filter. Conversely, where the drainage material void volume is large (i.e., a gravel trench or riprap layer), the permeability and anti-clogging criteria are favored.

STEP TWO:

DEFINE BOUNDARY CONDITIONS

Evaluate Confining Stress

The confining pressure is important for several reasons:

- High confining pressures tend to increase the relative density of coarse grained soil, increasing the soil's resistance to particle movement. This affects the selection of retention criteria.
- High confining pressures decrease the hydraulic conductivity of fine grained soils, increasing the potential for soil to intrude into, or through, the geotextile filter.
- For all soil conditions, high confining pressures increase the potential for the geotextile and soil mass to intrude into the flow paths. This can reduce flow capacity within the drainage media, especially when geosynthetic drainage cores are used.

Define Flow Conditions

Flow conditions can be either steady-state or dynamic. Defining these conditions is important because the retention criteria for each is different. Examples of applications with steady-state flow conditions include standard dewatering drains, wall drains and leachate collection drains. Inland waterways and shoreline protection are typical examples of applications where waves or water currents cause dynamic flow conditions.

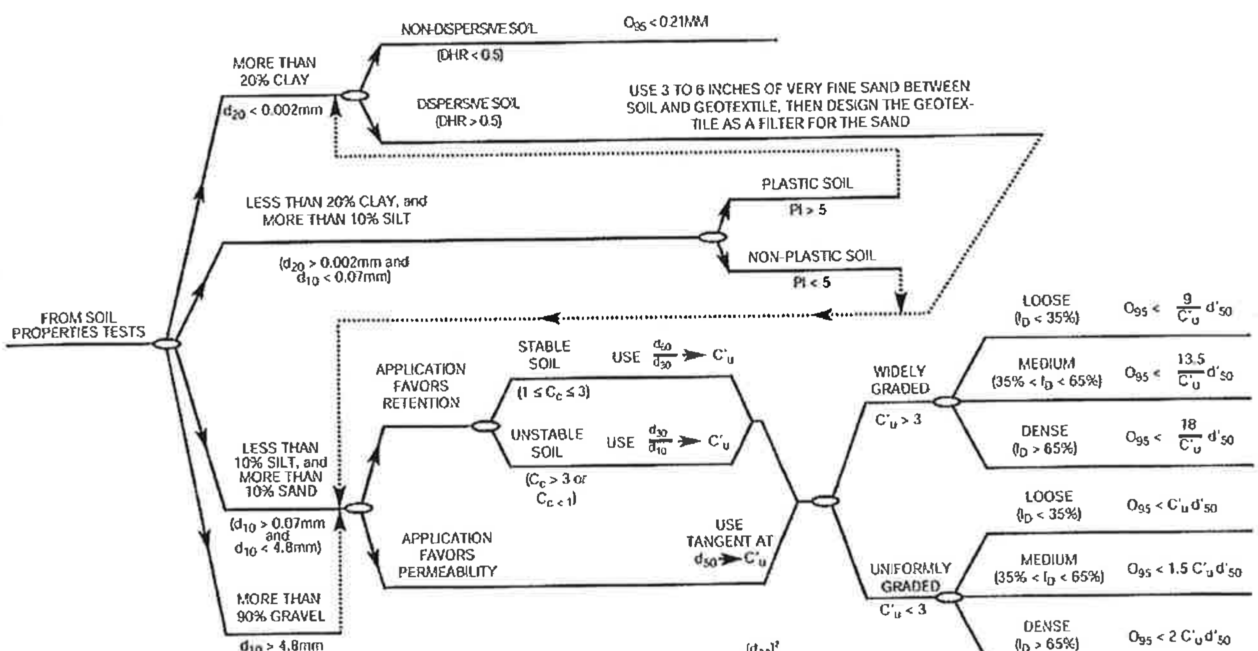
STEP THREE:

DETERMINE SOIL RETENTION REQUIREMENTS

Charts 1 and 2 indicate the use of particle-size parameters for determing retention criteria. These charts show that the amount of gravel, sand, silt and clay affects the retention criteria selection process. Chart 1 shows the numerical retention criteria for steady-state flow conditions; Chart 2 is for dynamic flow conditions.

For predominantly coarse grained soils, the grain-size distribution curve is used to calculate specific parameters such as C_u, C'_u, C_c, that govern the retention criteria.

Chart 1. Soil Retention Criteria of Steady-State Flow Conditions



NOTES:

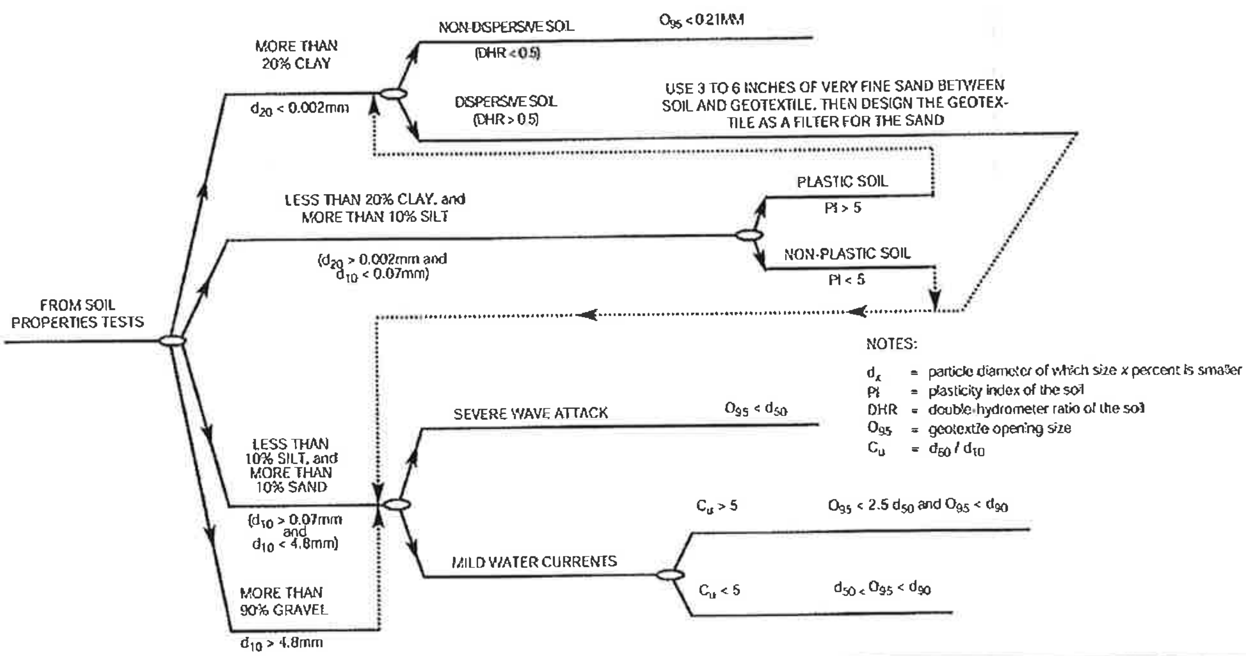
d_x = particle diameter of which size x percent is smaller

$C'_u = \sqrt{\dfrac{d'_{100}}{d'_0}}$ where: d'_{100} and d'_0 are the extremeties of a straight line drawn through the particle-size distribution, as directed above and d'_{50} is the midpoint of this line

$C_c = \dfrac{(d_{30})^2}{d_{60} \times d_{10}}$

I_D = relative density of the soil
PI = plasticity index of the soil
DHR = double-hydrometer ratio of the soil
O_{95} = geotextile opening size

Chart 2. Soil Retention Criteria of Dynamic Flow Conditions



Analysis of the soil to be protected is critical to proper filtration design.

Define Soil Particle-Size Distribution

The particle-size distribution of the soil to be protected should be determined using test method ASTM D 422. The grain size distribution curve is used to determine parameters necessary for the selection of numerical retention criteria.

Define Soil Atterberg Limits

For fine-grained soils, the plasticity index (PI) should be determined using the Atterberg Limits test procedure (ASTM D 4318). Charts 1 and 2 show how to use the PI value for selecting appropriate numerical retention criteria.

Determine the Maximum Allowable Geotextile Opening Size (O_{95})

The last step in determining soil retention requirements is evaluating the maximum allowable opening size (O_{95}) of the geotextile which will provide adequate soil retention. The O_{95} is also known as the geotextile's Apparent Opening Size (AOS) and is determined from test procedure ASTM D 4751. AOS can often be obtained from manufacturer's literature.

STEP FOUR:

DETERMINE GEOTEXTILE PERMEABILITY REQUIREMENTS

Define the Soil Hydraulic Conductivity (k_s)

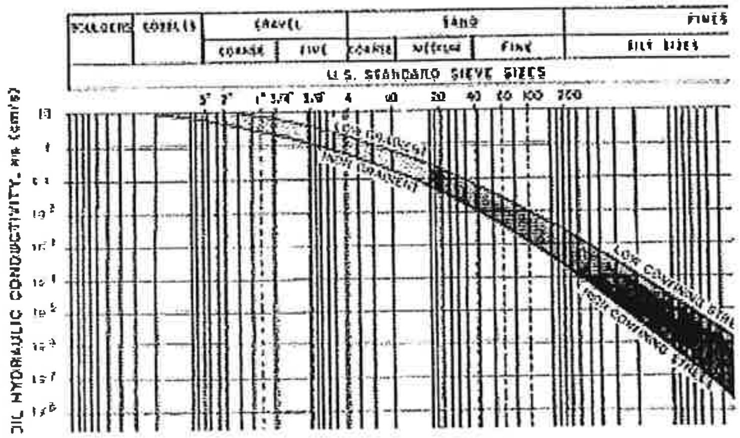
Determine the soil hydraulic conductivity, often referred to as permeability, using one of the following methods:

- For critical applications, such as earth dams, soil permeability should be lab measured using representative field conditions in accordance with test procedure ASTM D 5084.
- For non-critical applications, estimate the soil-hydraulic conductivity using the characteristic grain diameter d_{15}, of the soil (see Figure 2 on the following page).

STEP FOUR:

DETERMINE GEOTEXTILE PERMEABILITY REQUIREMENTS (continued)

Figure 2. Typical Hydraulic Conductivity Values



Define the Hydraulic Gradient for the Application (i_s)

The hydraulic gradient will vary depending on the filtration application. Anticipated hydraulic gradients for various applications may be estimated using Table 1 below.

Table 1. Typical Hydraulic Gradients[a]

Drainage Applications	Typical Hydraulic Gradient
Channel Lining	1.0
Standard Dewatering Trench	1.0
Vertical Wall Drain	1.5
Pavement Edge Drain	1.0
Landfill LCDRS	1.5
Landfill LCRS	1.5
Landfill SWCRS	1.5
Shoreline Protection	
Current Exposure	1.0[b]
Wave Exposure	10[b]
Dams	10[b]
Liquid Impoundments	10[b]

[a] *Table developed after Giroud, 1988.*
[b] *Critical applications may require designing with higher gradients than those given.*

Determine the Minimum Allowable Geotextile Permeability (k_g)

The requirement of geotextile permeability can be affected by the filter application, flow conditions and soil type. The following equation can be used for all flow conditions to determine the minimum allowable geotextile permeability (Giroud, 1988):

$$k_g \geq i_s k_s$$

Permeability of the geotextile can be calculated from the permittivity test procedure (ASTM D 4491). This value is often available from manufacturer's literature. Geotextile permeability is defined as the product of the permittivity, Ψ, and the geotextile thickness, t_g:

$$k_g = \Psi t_g$$

STEP FIVE:

DETERMINE ANTI-CLOGGING REQUIREMENTS

To minimize the risk of clogging, follow this criteria:

- Use the largest opening size (O_{95}) that satisfies the retention criteria.
- For nonwoven geotextiles, use the largest porosity available, never less than 30%.
- For woven geotextiles, use the largest percentage of open area available, never less than 4%.

NOTE: For critical soils and applications, laboratory testing is recommended to determine geotextile clogging resistance.

STEP SIX:

DETERMINE SURVIVABILITY REQUIREMENTS

Both the type of drainage or armor material placed adjacent to the geotextile and the construction techniques used in placing these materials can result in damage to the geotextile. To ensure construction survivability, specify the minimum strength properties that fit with the severity of the installation. Use Table 2 as a guide in selecting required geotextile strength properties to ensure survivability for various degrees of installation conditions. Some engineering judgement must be used in defining this severity.

Table 2. Survivability Strength Requirements (after AASHTO, 1996)

Application	Installation Conditions	GRAB STRENGTH (LBS)	ELONGATION (%)	SEWN SEAM STRENGTH (LBS)	PUNCTURE STRENTH (LBS)	BURST STRENTH (LBS)	TRAPEZOID TEAR (LBS)
SUBSURFACE DRAINAGE	HIGH CONTACT STRESSES (ANGULAR DRAINAGE MEDIA) (HEAVY COMPACTION) or (HEAVY CONFINING STRESSES)	247	< 50% *	222	90	392	56
		157	≥ 50%	142	56	189	56
	LOW CONTACT STRESSES (ROUNDED DRAINAGE MEDIA) (LIGHT COMPACTION) or (LIGHT CONFINING STRESSES)	180	< 50% *	162	67	305	56
		112	≥ 50%	101	40	138	40
ARMORED EROSION CONTROL	HIGH CONTACT STRESSES (DIRECT STONE PLACEMENT) (DROP HEIGHT > 3 FT)	247	< 50% *	222	90	392	56
		202	≥ 50%	182	79	247	79
	LOW CONTACT STRESSES (SAND OR GEOTEXTILE CUSHION) and (DROP HEIGHT < 3 FT)	247	< 50% *	222	90	292	56
		157	≥ 50%	142	56	189	56

* Only woven monofilament geotextiles are acceptable as < 50% elongation filtration geotextiles. No woven slit film geotextiles are permitted.

STEP SEVEN:

DETERMINE DURABILITY REQUIREMENTS

During installation, if the geotextile filter is exposed to sunlight for extended periods, a high carbon black content and UV stabilizers are recommended for added resistance to UV degradation. Polypropylene is one of the most durable geotextiles today. It is inert to most naturally occurring chemicals in civil engineering applications.

However, if it is known that the geotextile may exposed to adverse chemicals (such as in waste containment landfill applications), use test method ASTM D5322 to determine its compatibility.

References

Giroud, J.P., "Review of Geotextile Filter Design Criteria." Proceedings of First Indian Conference on Reinforced Soil and Geotextiles, Calcutta, India, 1988.

Heerten, G., "Dimensioning the Filtration Properties of Geotextiles Considering Long-Term Conditions." Proceedings of Second International Conference on Geotextiles, Las Vegas, Nevada, 1982.

AASHTO, "Standard Specification for Geotextile Specification for Highway Applications", M288-96

GEOTEXTILE FILTER FABRIC SELECTION GUIDE

		Silty Gravel w/Sand (GM)	Well-Graded Sand (SW) #1	Well-Graded Silty Sand (SW) #2	Silty Sand (SM)
SOIL PROPERTIES		k_s = .005cm/s PI = 0 C_c = 2.8 C'_u = 34 d'_{50} = 3.5mm C_u = 211 d_{50} = 5.0mm d_{90} = 22mm	k_s = .005cm/s PI = 0 C_c = 1.0 C'_u = 9.1 d'_{50} = .52mm C_u = 8.4 d_{50} = .60mm d_{90} = 2.7mm	k_s = .001cm/s PI = 0 C_c = 2.1 C'_u = 5.3 d'_{50} = .28mm C_u = 6.6 d_{50} = .28mm d_{90} = 1.6mm	k_s = .00005cm/s PI = 0 C_c = 3.0 C'_u = 16.2 d'_{50} = .21 C_u = 67 d_{50} = .22mm d_{90} = .95mm (Note: Moderate to Heavy Compaction Required)
SUBSURFACE DRAINAGE[2]	Soil Retention[1]	1.85 mm	1.03 mm	.95 mm	.18 mm
	Permeability	5×10^{-3}	5×10^{-3}	1×10^{-3}	5×10^{-5}
	Clogging Resistance	P.O.A. > 6%	P.O.A. > 6%	P.O.A. > 6%	n > 30%
	Survivability Req't	LOW	LOW	LOW	LOW
	Gradation	Widely Graded	Widely Graded	Widely Graded	Widely Graded
	Relative Soil Density	Dense	Dense	Dense	Medium
	RECOMMENDED FABRIC	**FILTERWEAVE 400**	**FILTERWEAVE 400**	**FILTERWEAVE 400**	**MIRAFI 180N**
	Soil Retention[1]	.93 mm	.51 mm	.48 mm	.18 mm
	Permeability	5×10^{-3}	5×10^{-3}	1×10^{-3}	5×10^{-5}
	Clogging Resistance	P.O.A. > 6%	P.O.A. > 6%	P.O.A. > 6%	n > 30%
	Survivability Req't	HIGH	HIGH	HIGH	HIGH
	Gradation	Widely Graded	Widely Graded	Widely Graded	Widely Graded
	Relative Soil Density	Loose	Loose	Loose	Medium
	RECOMMENDED FABRIC	**FILTERWEAVE 404**	**FILTERWEAVE 404**	**FILTERWEAVE 404**	**MIRAFI 180N**
ARMORED EROSION CONTROL[3] — Mild Current Exposure, Minimal Drawdown Potential, Non-Vegetated	Soil Retention[1]	12.5 mm	1.5 mm	0.7 mm	0.55 mm
	Permeability	5×10^{-3}	5×10^{-3}	1×10^{-3}	5×10^{-5}
	Clogging Resistance	P.O.A. > 6%	P.O.A. > 6%	P.O.A. > 6%	P.O.A. > 6%
	Flow Conditions	Mild Currents	Mild Currents	Mild Currents	Mild Currents
	RECOMMENDED FABRIC	**FILTERWEAVE 400**	**FILTERWEAVE 400**	**FILTERWEAVE 400**	**FILTERWEAVE 400**
ARMORED EROSION CONTROL[3] — Wave Exposure, High Velocity Channel Lining, Spillway Overtopping	Soil Retention[1]	5.0 mm	0.60 mm	0.28 mm	0.22 mm
	Permeability	$.5 \times 10^{-2}$	$.5 \times 10^{-2}$	1×10^{-2}	5×10^{-4}
	Clogging Resistance	P.O.A. > 6%	P.O.A. > 6%	P.O.A. > 6%	P.O.A. > 6%
	Flow Conditions	Severe Wave Attack	Severe Wave Attack	Severe Wave Attack	Severe Wave Attack
	RECOMMENDED FABRIC	**FILTERWEAVE 404**	**FILTERWEAVE 404**	**FILTERWEAVE 500**	**FILTERWEAVE 700**

[1] Maximum opening size of geotextile (O_{95}) to retain soil. [2] Steady state flow condition. [3] Dynamic Flow Conditions

	Clayey Sand (SC)	Sandy Silt (ML)	Lean Clay (CL)
	k_s = .00001cm/s PI = 16.0 C_c = 20 C'_u = n/a d'_{50} = n/a C_u = 345 d_{50} = .55mm d_{90} = 5.8mm > 10% silt < 20% clay	k_s = .00005cm/s PI = 0 C_c = 2.9 C'_u = 1.7 d'_{50} = .07 C_u = 10.8 d_{50} = .072mm d_{90} = .13mm	k_s = .0000001cm/s PI = 16.7 C_c = 3.3 C'_u = n/a d'_{50} = n/a C_u = 36 d_{50} = .014mm d_{90} = .05mm > 16% silt < 20% clay
	.21 mm 1×10^{-5} n > 30% LOW Non-dispersive	.24 mm 5×10^{-5} n > 30% LOW Uniformly Graded Dense	.21 mm 1×10^{-7} n > 30% LOW Non-dispersive
	MIRAFI 140N Series	**MIRAFI 140N Series**	**MIRAFI 140N Series**
	.21 mm 1×10^{-5} n > 30% HIGH Non-dispersive	.18 mm 5×10^{-5} n > 30% HIGH Uniformly Graded Medium	.21 mm 1×10^{-7} n > 30% HIGH Non-dispersive
	MIRAFI 160N	**MIRAFI 180N**	**MIRAFI 160N**
	1.4 mm 1×10^{-5} P.O.A. > 6% Mild Currents	0.13 mm 5×10^{-5} n > 30% Mild Currents	0.035 mm 1×10^{-7} n > 30% Mild Currents
	FILTERWEAVE 400	**MIRAFI 1100N**	**MIRAFI 1160N**
	0.55 mm 1×10^{-4} P.O.A. > 6% Severe Wave Attack	0.07 mm 5×10^{-4} P.O.A. > 6% Severe Wave Attack	0.014 mm 1×10^{-6} n > 30% Severe Wave Attack
	FILTERWEAVE 404	**MIRAFI 1160N**	**MIRAFI 1160N**

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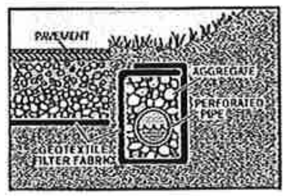
DISCLAIMER

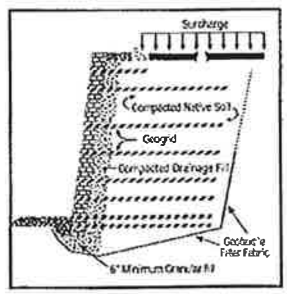
The information presented herein will not apply to every installation. Applicability of products will vary as a result of site conditions and installation procedures. Final determination of the suitability of any information or material for the use contemplated, of its manner of use, and whether the use infringes any patents, is the sole responsibility of the user.

TYPICAL SECTIONS AND APPLICATIONS:

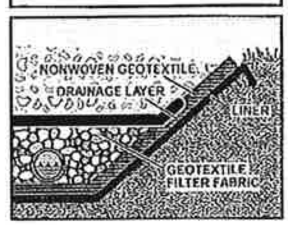
DRAINAGE



- Seepage Cut-off
- Pavement Edge Drains
- Slope Seepage Cut-off
- Surface Water Recharge
- Trench or "French" Drains

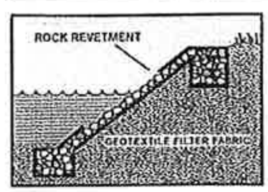


- Structure Pressure Relief
- Foundation Wall Drains
- Retaining Wall Drains
- Bridge Abutment Drains
- Planter Drains



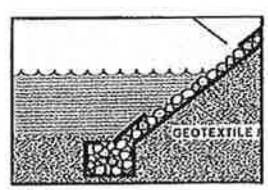
- Leachate Collection and Removal
- Blanket Drains
- Subsurface Gas Collection

ARMORED EROSION CONTROL



- River and Streambed Lining
- Culvert Inlet and Discharge Aprons
- Abutment Scour Protection
- Access Ramps

Proper installation of filtration geotextiles includes anchoring the geotextile in key trenches at the top and bottom of



- Coastal Slope Protection
- Shoreline Slope Protection
- Pier Scour Protection
- Sand Dune Protection

Underwater geotextile placement is common and must include anchorage of the toe to resist scour.

Ten Cate Nicolon

For more information on Mirafi® Geotextiles Filters in drainge and armored erosion control applications, contact one of the following offices:

In North America contact:
Ten Cate Nicolon
365 South Holland Drive
Pendergrass, Ga. 30567
706-693-2226
Toll free: 888-795-0808
Fax: 706-695-4400

In Europe contact:
Ten Cate Nicolon Europe
Sluiskade NZ 14
Postbus 236
7600 AE Almelo
The Netherlands
Tel: +31-546-544487
Fax: +31-546-544490

In Asia contact:
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47301 Petaling Jaya
Selangor Darul Ehsan
Malaysia
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5800 Monroe Road
Charlotte
North Carolina 28212
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Tel: 704-531-5801
Fax: 704-531-5801

log on to our website:
www.tcnicolon.com

Summary of Laboratory Results

BORING ID	Depth	USCS Classification and Soil Description	Liquid Limit	Plastic Limit	Plasticity Index	% Gravel	% Sand	% Silt	% Clay	Water Content (%)	Optimum Moisture	Maximum Dry Density	Hydraulic Conductivity
BA1B-1	18.5 - 19.75	FAT CLAY with SAND(CH)	57	17	40	0.0	29.6			75.1			
BA1B-1	28.5 - 30	FAT CLAY with SAND(CH)	64	25	39	0.0	24.4			70.8			
BA1B-1	33.5 - 35	SANDY FAT CLAY(CH)	137	41	96	0.0	42.4			62.0			
BA1B-2	8 - 10	FAT CLAY with SAND(CH)	65	25	40	0.6	27.4			66.0			
BA1B-4	8 - 10	FAT CLAY(CH)	57	23	34	0.0	11.3			51.8			
BA1B-5	13.5 - 15	CLAYEY SAND(SC)	48	15	33	2.0	62.8			73.1			
BA1B-5	33.5 - 35	SILTY SAND(SM)	57	34	23	0.0	85.6			73.1			
BA1B-6	23.5 - 24.08	SILTY SAND(SM)	NP	NP	NP	0.0	73.4			61.0			
BA1B-7	38.5 - 40	SANDY FAT CLAY(CH)	72	24	48	0.0	32.9			65.1			
BA1B-9	13.5 - 15	LEAN CLAY with SAND(CL)	43	25	18	0.0	19.8			38.1			
BA1B-10	18.5 - 20	FAT CLAY(CH)	69	25	44	0.0	6.4			57.0			
BA1B-10	28.5 - 30	SILTY SAND(SM)	97	49	48	1.0	78.5			92.6			
BA1B-10	43.5 - 45	FAT CLAY(CH)	80	33	47	0.1	14.1			62.3			
BA1B-1	0-10	SILTY SAND(SM)	NP	NP	NP	0.2	82.3			16.3	10.4	121.1	7.22E-06
BA1B-1	10-17	SANDY FAT CLAY(CH)	54	22	32	0.1	32.4			62.3	22.1	97.44	1.38E-08
BA1B-3	5-15	CLAYEY SAND(SC)	31	17	14	0.0	84.2			33.1	15.1	112.7	4.25E-08
BA1B-6	0-10	CLAYEY SAND(SC)	51	26	25	0.2	82.6			18.8	13.2	114.6	4.98E-07
BA1B-6	10-15	SANDY FAT CLAY(CH)	52	18	34	0.1	49.8			38.9	27.9	90.33	1.00E-08
BA1B-7	10-20	CLAYEY SAND(SC)	51	22	29	0.0	81.1			25.4	19.8	103.3	1.39E-08
BA1B-8	0-10	SILTY SAND(SM)	NP	NP	NP	0.0	87.2			12.5	11.3	108.8	8.48E-05
BA1B-8	10-15	POORLY GRADED SAND with CLAY(SP-SC)	35	14	21	0.0	93.3			26.6	13.1	114.9	7.64E-08

PROJECT: Cells 3C and 4C

SITE: Chesser Island Road Landfill
Folkston, Georgia

Terracon

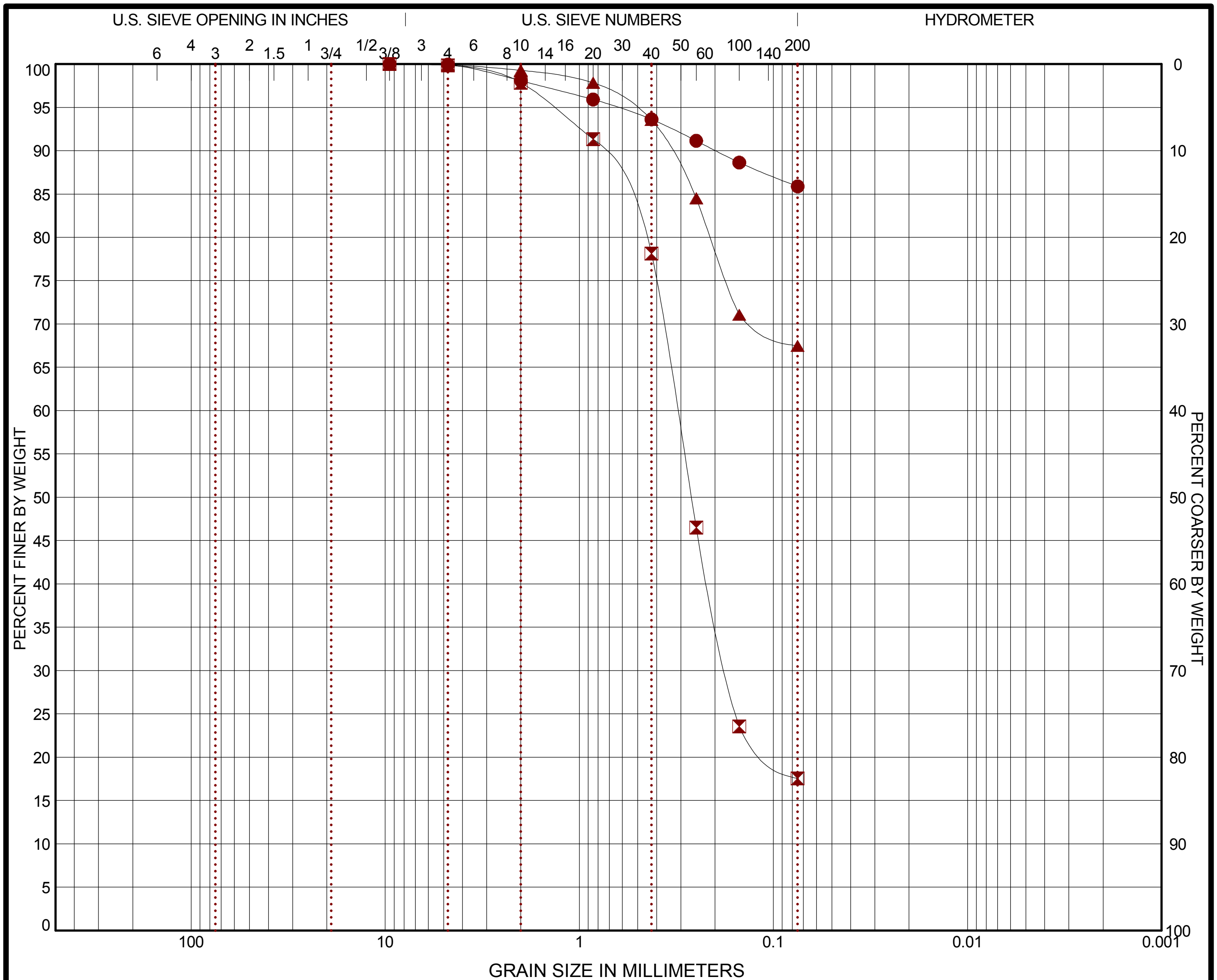
240 Heritage Walk, Suite 103
Woodstock, Georgia

PROJECT NUMBER: EJ127492

CLIENT: Waste Management of Florida, Inc.
Milton, FL

Table 1

GRAIN SIZE DISTRIBUTION ASTM D422



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

	BORING ID	DEPTH	% COBBLES	% GRAVEL	% SAND	% SILT	% FINES	% CLAY	USCS
●	**BA1B-10**	**43.5 - 45**	**0.0**	**0.1**	**14.1**		**85.9**		**CH**
⧗	**BA1B-1 0-10**	**0**	**0.0**	**0.2**	**82.3**		**17.5**		**SM**
▲	**BA1B-1 10-17**	**10**	**0.0**	**0.1**	**32.4**		**67.5**		**CH**

	GRAIN SIZE		
	●	⧗	▲
D_{60}		**0.313**	
D_{30}		**0.173**	
D_{10}			
	COEFFICIENTS		
C_C			
C_U			

SIEVE (size)	PERCENT FINER ●	PERCENT FINER ⧗	PERCENT FINER ▲
1 1/2"			
1"			
3/4"			
1/2"			
3/8"	**100.0**	**100.0**	**100.0**
#4	**99.94**	**99.84**	**99.91**
#10	**98.07**	**97.85**	**99.27**
#20	**95.91**	**91.35**	**97.83**
#40	**93.62**	**78.14**	**93.54**
#60	**91.14**	**46.52**	**84.5**
#100	**88.63**	**23.56**	**71.07**
#200	**85.88**	**17.55**	**67.48**

SOIL DESCRIPTION

● FAT CLAY(CH)

⧗ SILTY SAND(SM)

▲ SANDY FAT CLAY(CH)

REMARKS

●

⧗

▲

PROJECT: Cells 3C and 4C

SITE: Chesser Island Road Landfill
Folkston, Georgia

Terracon
240 Heritage Walk, Suite 103
Woodstock, Georgia

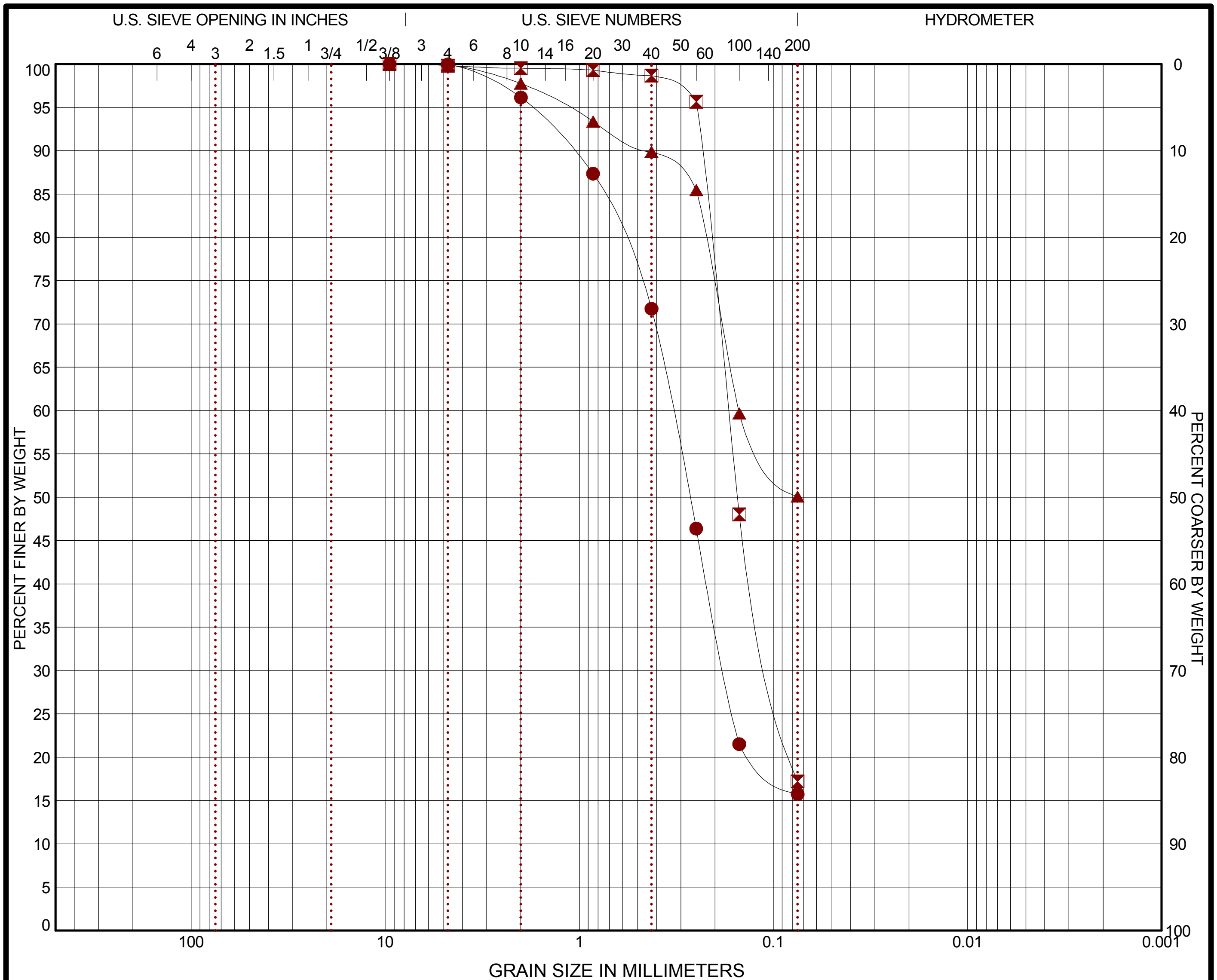
PROJECT NUMBER: EJ127492

CLIENT: Waste Management of Florida, Inc.
Milton, FL

Attachment 2

LABORATORY TESTS ARE NOT VALID IF SEPARATED FROM ORIGINAL REPORT. GRAIN SIZE: USCS 1 EJ127492.CHESSER ISLAND LF.GPJ TERRACON2012.GDT 11/13/12

GRAIN SIZE DISTRIBUTION ASTM D422



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

	BORING ID	DEPTH	% COBBLES	% GRAVEL	% SAND	% SILT	% FINES	% CLAY	USCS
●	**BA1B-3 5-15**	**5**	**0.0**	**0.0**	**84.2**		**15.8**		**SC**
⧗	**BA1B-6 0-10**	**0**	**0.0**	**0.2**	**82.6**		**17.2**		**SC**
▲	**BA1B-6 10-15**	**10**	**0.0**	**0.1**	**49.8**		**50.1**		**CH**

	GRAIN SIZE		
	●	⧗	▲
D_{60}	**0.332**	**0.171**	**0.151**
D_{30}	**0.179**	**0.1**	
D_{10}			
	COEFFICIENTS		
C_C			
C_U			

SIEVE (size)	PERCENT FINER		
	●	⧗	▲
1 1/2"			
1"			
3/4"			
1/2"			
3/8"	**100.0**	**100.0**	**100.0**
#4	**99.95**	**99.82**	**99.88**
#10	**96.14**	**99.51**	**97.74**
#20	**87.35**	**99.29**	**93.37**
#40	**71.76**	**98.67**	**89.87**
#60	**46.39**	**95.64**	**85.46**
#100	**21.52**	**48.03**	**59.68**
#200	**15.75**	**17.22**	**50.08**

SOIL DESCRIPTION
● CLAYEY SAND(SC)
⧗ CLAYEY SAND(SC)
▲ SANDY FAT CLAY(CH)

REMARKS
●
⧗
▲

PROJECT: Cells 3C and 4C

SITE: Chesser Island Road Landfill
Folkston, Georgia

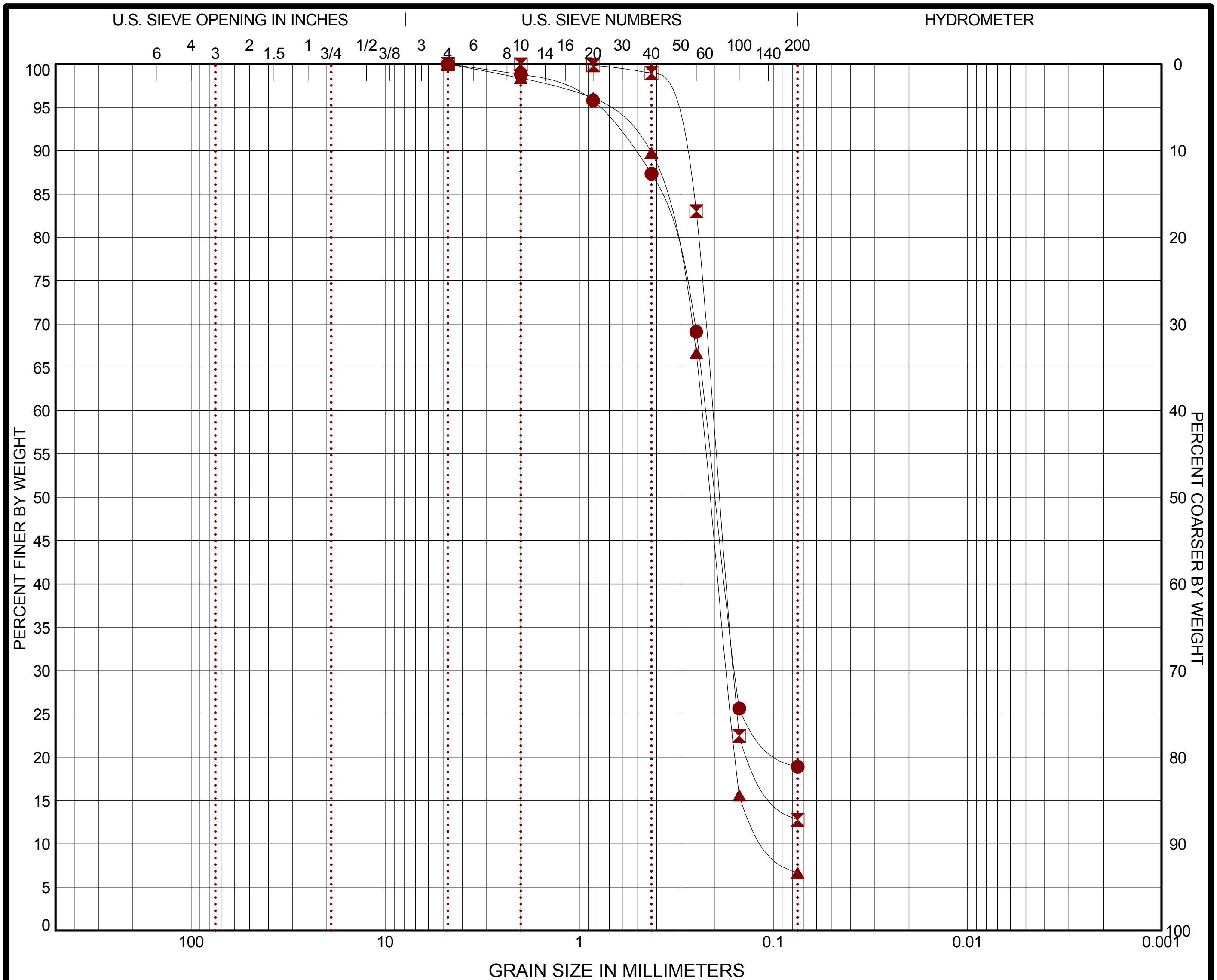
Terracon
240 Heritage Walk, Suite 103
Woodstock, Georgia

PROJECT NUMBER: EJ127492

CLIENT: Waste Management of Florida, Inc.
Milton, FL

LABORATORY TESTS ARE NOT VALID IF SEPARATED FROM ORIGINAL REPORT. GRAIN SIZE: USCS 1 EJ127492.CHESSER ISLAND LF.GPJ TERRACON2012.GDT 11/13/12

GRAIN SIZE DISTRIBUTION ASTM D422



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

	BORING ID	DEPTH	% COBBLES	% GRAVEL	% SAND	% SILT	% FINES	% CLAY	USCS
●	**BA1B-7 10-20**	**10**	**0.0**	**0.0**	**81.1**		**18.9**		**SC**
⧗	**BA1B-8 0-10**	**0**	**0.0**	**0.0**	**87.2**		**12.8**		**SM**
▲	**BA1B-8 10-15**	**10**	**0.0**	**0.0**	**93.3**		**6.7**		**SP-SC**

	GRAIN SIZE		
	●	⧗	▲
D_{60}	**0.225**	**0.206**	**0.234**
D_{30}	**0.158**	**0.16**	**0.173**
D_{10}			**0.097**
	COEFFICIENTS		
C_C			**1.32**
C_U			**2.41**

SIEVE (size)	PERCENT FINER ●	PERCENT FINER ⧗	PERCENT FINER ▲
1 1/2"			
1"			
3/4"			
1/2"			
3/8"			
#4	**100.0**	**100.0**	**100.0**
#10	**98.8**	**99.95**	**98.36**
#20	**95.81**	**99.85**	**96.07**
#40	**87.33**	**98.95**	**89.77**
#60	**69.11**	**83.03**	**66.64**
#100	**25.63**	**22.48**	**15.62**
#200	**18.91**	**12.81**	**6.66**

SOIL DESCRIPTION
● CLAYEY SAND(SC)
⧗ SILTY SAND(SM)
▲ POORLY GRADED SAND with CLAY(SP-SC)

REMARKS
●
⧗
▲

PROJECT: Cells 3C and 4C

SITE: Chesser Island Road Landfill
Folkston, Georgia

Terracon
240 Heritage Walk, Suite 103
Woodstock, Georgia

PROJECT NUMBER: EJ127492

CLIENT: Waste Management of Florida, Inc.
Milton, FL

NON-WOVEN GEOTEXTILES
FOR ENVIRONMENTAL APPLICATION

COMPARATIVE PRODUCT SPECIFICATION CHART

SKAPS

SKAPS INDUSTRIES
335 Athena Drive,
Athens, GA 30601
Ph: (706)-354-3700
Fax: (706)-354-3737
Email: contact@skaps.com

PROPERTY	TEST METHOD	UNIT	M.A.R.V. (Minimum Average Roll Value)							
			GE140	GE160	GE170	GE180	GE110	GE112	GE114	GE116
Weight	ASTM D 5261	oz/yd^2	4	6	7	8	10	12	14	16
		g/m^2	135	203	237	271	339	407	475	542
Thickness*	ASTM D 5199	mils	70	85	90	100	110	120	135	175
		mm	1.77	2.16	2.29	2.5	2.79	3.05	3.43	4.45
Grab Tensile	ASTM D 4632	lbs	105	160	200	225	270	330	390	425
		kN	0.467	0.711	0.889	1	1.2	1.47	1.73	1.89
Grab Elongation	ASTM D 4632	%	50	50	50	50	50	50	50	50
Trapezoid Tear Strength	ASTM D 4533	lbs	45	65	75	90	100	125	135	150
		kN	0.2	0.29	0.33	0.4	0.44	0.556	0.6	0.667
CBR Puncture Resistance	ASTM D 6241	lbs	305	450	540	600	725	900	1045	1200
		kN	1.36	2	2.4	2.67	3.22	4	4.65	5.34
Permittivity*	ASTM D 4491	sec^{-1}	2	1.63	1.41	1.26	0.94	0.9	0.64	0.57
Permeability*	ASTM D 4491	cm/sec	0.55	0.48	0.46	0.3	0.3	0.3	0.25	0.25
Water Flow*	ASTM D 4491	gpm/ft^2	160	125	110	100	75	70	50	45
		$l/min/m^2$	6518	5080	4470	4074	3055	2544	2037	1833
AOS*	ASTM D 4751	US Sieve	70	70	70	80	100	100	100	100
		mm	0.212	0.212	0.212	0.18	0.15	0.15	0.15	0.15
UV Resistance at 500 hrs	ASTM D 4355	%	70	70	70	70	70	70	70	70

** At the time of manufacturing. Handling may change these properties.*

PACKAGING DETAILS

Roll Dimension (ft)	15 x 1350	15 x 900	15 x 780	15 x 690	15 x 570	15 x 480	15 x 390	15 x 360
Square Yards/Roll	2250	1500	1300	1150	950	800	650	600
Estimated Roll Weight (lbs)	620	620	620	620	620	620	620	620

Attachment 3

Base Grade Settlement Analysis

Atlantic Coast Consulting, Inc.

Design Calculations Notebook

1

2

3

4

IN THIS SECTION:

Base Grade Settlement Analysis

Section 3
Base Grade Settlement Analysis

OBJECTIVE: Evaluate the base grade settlement as a result of the change in stress in the subgrade soils due to placement of waste in the landfill. Determine effects of the estimated settlement (overall and differential) on the proposed waste containment systems.

METHOD: The compression of the subgrade soils as a result of placement of waste in the landfill and the resulting impact on the landfill liner system was evaluated. The overall settlement is a sum of the primary and secondary settlements of the subgrade. The first step in the evaluation was to review the geometry and soils and waste mass and the physical properties of the soils and waste at discreet points along a selected cross section and perform a one-dimensional settlement analysis at critical analysis locations. This allows for an estimation of post settlement base grades and the resulting tensile stresses in the liner system.

Primary Settlement (Sc)

The following equation is used to estimate the *primary settlement* in normally consolidated clays or loose granular materials:

$$S_c = \left(\frac{C_c}{1+e_0}\right) \cdot H \cdot \log\left(\frac{\sigma_0^{'} + \Delta\sigma_0^{'}}{\sigma_0^{'}}\right) \qquad (6.1)$$

where H = thickness of the layer after excavation to be evaluated,
C_c = primary compression index,
e_o = initial void ratio,
σ_o' = effective vertical stress at the middle of the layer after excavation, but before loading, and
$\Delta\sigma_o$' = increase or change in effective vertical stress due to loading.

The following equation is used to estimate the consolidation settlement in overconsolidated clays. Dense cohesionless materials do not settle significantly and thus, do not have to be evaluated using this equation.

$$S_c = \left(\frac{C_r}{1+e_0}\right) \cdot H \cdot \log\left(\frac{\sigma_0^{'} + \Delta\sigma_0^{'}}{\sigma_0^{'}}\right) \qquad (6.2)$$

where C_r = recompressive index.

Secondary Settlement (S_s)

Secondary settlement can be calculated using the following equation:

$$S_s = \frac{C_\alpha}{1 + e_p} \cdot H \cdot \log\left(\frac{t_s}{t_{pf}}\right) \qquad (6.4)$$

where C_a = *secondary compression* index of the *compressible layer*,
H = thickness of the layer to be evaluated after excavation, but before loading
t_s = time over which *secondary compression* is to be calculated (use 100 years plus the maximum time it will take to complete *primary consolidation* under the facility unless some other time frame is acceptable to Ohio EPA for a specific facility), and
t_{pf} = time to complete *primary consolidation* in the consolidating layer in the field, and
e_p = the void ratio at the time of complete *primary consolidation* in the test specimen of the *compressible layer*.

Both t_s and t_{pf} must be expressed in the same units (e.g., days, months, years).

DATA: Design drawings of the liner system and final cover grades of the landfill were used to identify a representative cross section for settlement analysis. The critical section was chosen to coincide with Phase 4 that includes the designed highest waste fill grades and the cells sump area. The selected cross section location is shown in Figure 3.1. The results of a previous subsurface exploration outlined in the Site Acceptability Report titled “Chesser Island Road MSW Landfill Proposed Phase 4 Expansion” by Aquaterra Engineering, LLC., dated April 10, 2007 was used to characterize the subsurface stratigraphy used in this analysis. The geometry of the landfill and subsurface soils along the analyzed cross section is shown in Figure 3.2.

Soil Layer Data:
The subgrade soil at the site consists of a few separate layers as discussed in the cited report. Below the proposed landfill base grades, the compressible layer is a Fine Sand and Clayey Sand with sandy clay layers. These calculations assume that the layers beneath it are not affected by the landfill loading. The following subgrade soil material properties were used based on experience and the references cited.

Layer 1 – Fine Sand and Clayey Sand

This layer was modeled as an normally consolidated soil due to the lab reported liquidity index (between 0 and 0.02). The void ratio was calculated on the undisturbed samples. The Re-Compression Index was calculated based on the equation from Nagaraj and Murthy(1985) as shown on the attached spreadsheet . The layer was assumed to have a total average unit weight of 122 pcf as computed from the undisturbed samples.

The placement of liner soil (unit weight 120 pcf), municipal solid waste (unit weight 73 pcf), and the final cover soil (unit weight 120 pcf) were assumed to result in an increase in stress in the underlying layers. The change in stress was estimated at the midpoint of each layer, and the resulting change in layer thickness was estimated using either elastic or consolidation properties. The total change in stress for all underlying layers was computed at the settlement at the landfill subgrade level. The difference in settlement between two adjacent points was used to compute the change in slope and, any induced tensile stresses.

RESULTS: The output for the spreadsheet computation of the base grade settlement analysis is attached. As indicated, the estimated settlement ranges from 0.56 to 0.29 ft under the landfill liner. Based on this computed settlement, the maximum tensile stress in the liner system is anticipated to be 0.00% (which is less than the typically acceptable value of 5%), while the overall landfill Leachate Collection System slope towards the sump is maintained.

CONCLUSION: The analysis indicates that the proposed landfill geometry is adequately designed to accommodate the anticipated base grade settlements.

Table 1

Chesser Island Road Landfill - Phase 4 Expansion

Soil Stratigraphic Characterization

Stratum No. I — **Termed "FINE SAND and CLAYEY SAND"**

General Description	Loose to dense, tan to black, fine poorly graded SAND, slightly silty (SP) and CLAYEY SAND (SC).
Depth Range	Present from ground surface to as deep as 35 feet in B-4 and as shallow as 9 feet in B-5.
Variations	With silty and clayey sand inclusions in some borings, becoming more prominent in the lower reaches of Stratum I. Some borings encountered a limestone layer at the interface of Stratum I and II. See soil boring logs in Appendix A for detailed conditions at each boring.

Stratum No. II — **Termed "SANDY CLAY and CLAY"**

General Description	Soft to stiff, light gray and red to dark gray SANDY CLAY (CL) and CLAY (CH).
Depth Range	Generally present to the terminal depth of the borings at 35 feet. Not present in Borings 4, 12, and 13.
Variations	Some borings encountered layers of fossilized limestone fragments (shells). See soil boring logs in Appendix A for detailed conditions at each boring.

Note:
The information provided on this table is general and provided to summarize conditions. For specific conditions, refer to the soil boring logs in Appendix A.

aquaterra engineering

Table 2

Chesser Island Road Landfill

Phase 4 Expansion

Summary of Laboratory Testing

Stratum No.	I	II
Description	**FINE SAND and CLAYEY SAND** with sandy clay layers	**SANDY CLAY and CLAY** with clayey sand layers in upper reaches
N-Value (blows/ft)		
No. Tests	77	8
Average	22	24
Maximum (1)	51	51
Minimum	3	3
Std. Deviation	16.6	22.6
Shear Strength (ksf)		
No. Tests	0	4
Average		1786
Maximum		2866
Minimum		850
Std. Deviation		866.7
Moisture Content (%)		
No. Tests	24	19
Average	27	63
Maximum	43	111
Minimum	15	40
Std. Deviation	7	18
Dry Density (pcf)		
No. Tests	1	5
Average	95	58
Maximum	95	83
Minimum	95	37
Std. Deviation	NA	21
Liquid Limit, LL		
No. Tests	1	9
Average	NA	65
Maximum	NA	94
Minimum	NA	32
Std. Deviation	NA	NA
Plastic Limit, PL		
No. Tests	1	6
Average	16	29
Maximum	16	42
Minimum	16	16
Std. Deviation	NA	NA

Summary of Laboratory Testing

Stratum No.	**I**	**II**
Description	**FINE SAND and CLAYEY SAND** with sandy clay layers	**SANDY CLAY and CLAY** with clayey sand layers in upper reaches
Plasticity Index, PI		
No. Tests	1	9
Average	11	36
Maximum	11	52
Minimum	11	14
Std. Deviation	NA	NA

aquaterra engineering

Table 2

Chesser Island Road Landfill

Phase 4 Expansion

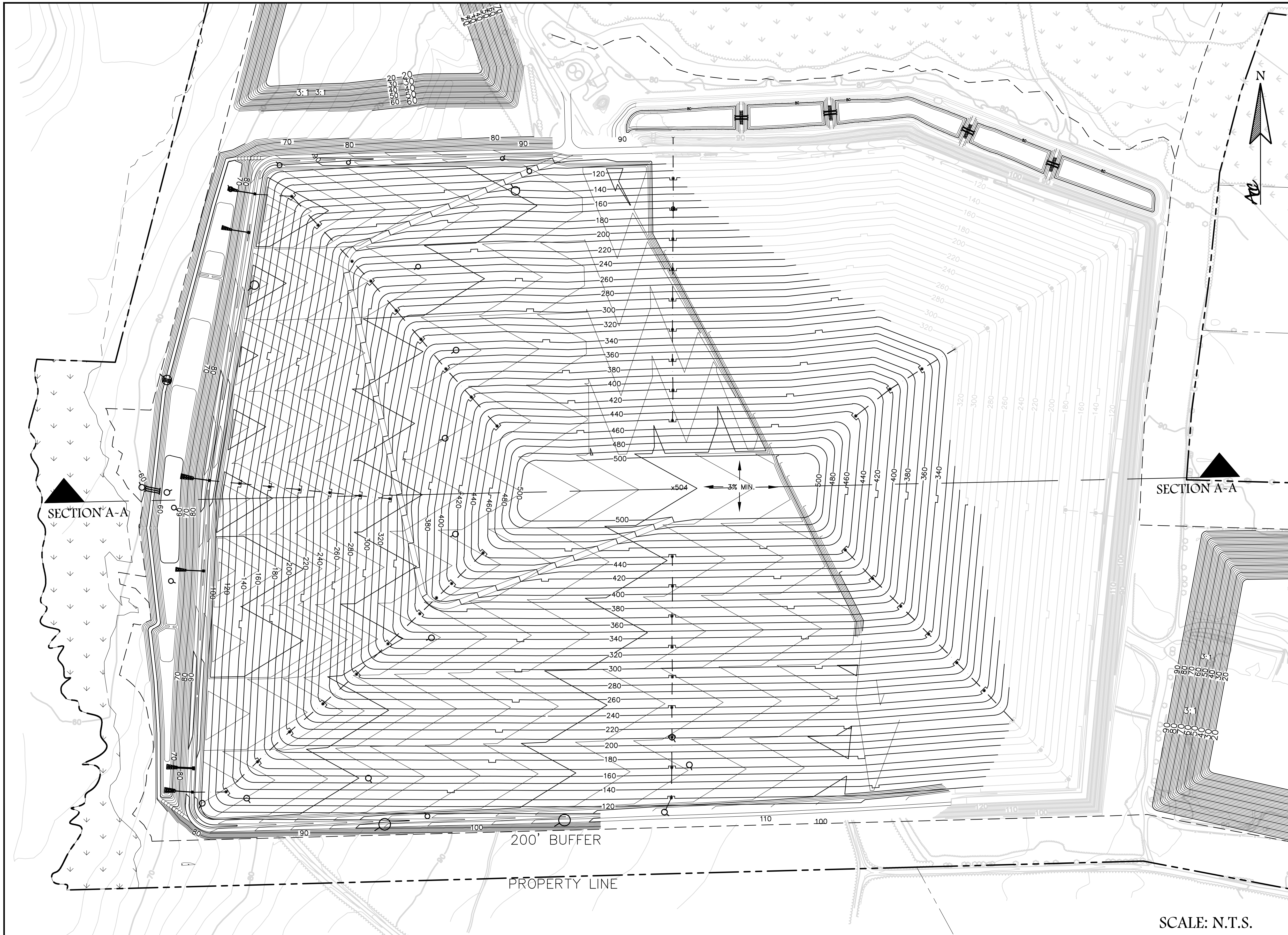
Summary of Laboratory Testing

Stratum No.	I	II
Description	**FINE SAND and CLAYEY SAND** with sandy clay layers	**SANDY CLAY and CLAY** with clayey sand layers in upper reaches
Permeability, k (cm/sec)		
No. Tests	1	5
Average	1.2E-07	6.5E-08
Maximum	1.2E-07	9.7E-08
Minimum	1.2E-07	4.1E-08
Std. Deviation	NA	NA
Percent Passing #200 Sieve		
No. Tests	4	0
Average	21.5	
Maximum	42.5	
Minimum	9.4	
Std. Deviation	15.2	

Note: (1) 51 denotes 50+ blows per foot

Note:
The information provided on this table is general and provided to summarize conditions. For specific conditions, refer to the soil boring logs in Appendix A.

Point No.	A	B
Horizontal Distance	0.00	1942
Top of Final Cover Elevation (ft MSL)	504.00	104.00
Top of Waste Elevation (ft MSL)	500.00	100.00
Top of Liner Elevation (ft MSL)	99.50	79.00
Subgrade Elevation (ft MSL)	97.50	77.00
Existing Ground Elevation (ft MSL)	88.00	68.00
Groundwater Elevation (ft MSL)	84.70	66.70
Cut (ft)	0.00	0.00
Fill (ft)	9.50	9.00
Soil Density (pcf)	110.0	110.0
Liner Soil Thickness (ft)	2.00	2.00
Liner Soil Density (pcf)	120	120
Cover Soil Thickness (ft)	4.00	4.00
Cover Soil Density (pcf)	120	120
Waste Thickness (ft)	400.50	21.00
Waste Density (pcf)	73.0	73.0
Change in Stress (psf)	31001.50	3243.00
Primary Settlement		
Layer 1 (Fine Sand and Clayey Sand)		
Top Elevation (ft MSL)	97.50	77.00
Bottom Elevation (ft MSL)	88.00	68.00
Mid Point Elevation (ft MSL)	92.75	72.50
Soil Density (pcf)	122.0	122.0
Layer Thickness (ft)	9.50	9.00
Effective Initial Stress before loading(psf)	579.50	549.00
Initial Void Ratio	0.67	0.67
Re-compression Index	0.05	0.05
Primary Layer Settlement (ft)	0.494	0.226
Secondary Settlement		
Layer 1 (Fine Sand and Clayey Sand)		
Top Elevation (ft MSL)	97.50	77.00
Bottom Elevation (ft MSL)	88.00	68.00
Mid Point Elevation (ft MSL)	92.75	72.50
Soil Density (pcf)	122.0	122.0
Layer Thickness (ft)	9.50	9.00
Time for secondary compression (years)	200.00	200.00
Time for primary compression (years)	100.00	100.00
Void Ratio after primary consolidation	0.134	0.134
Secondary compression Index	0.03	0.03
Secondary Settlement (ft)	0.063	0.060
Total Settlement (ft)	0.56	0.29
Initial Length of Liner Segment (ft)		1942.11
Final Length of Liner Segment (ft)		1942.10
Strain (%, Tensile Negative)		0.00
Initial Liner Slope (ft/f)		1.06%
Final Liner Slope (ft/ft)		1.02%



ATLANTIC COAST CONSULTING, INC.
630 Colonial Park Drive
Suite 110
Roswell, GA 30075
o 770.594.5998
f 770.594.5967
www.atlcc.net

PROJECT:

CHESSER ISLAND ROAD MSW LANDFILL CCR MANAGEMENT PLAN

CHARLTON COUNTY, GA
PERMIT NO: 024-006D(SL)

WASTE MANAGEMENT

Chesser Island Road Landfill, Inc.
Hwy 121 @ Chesser Island Road
Folkston, GA 31537

Drawn by: MAL

Checked by:

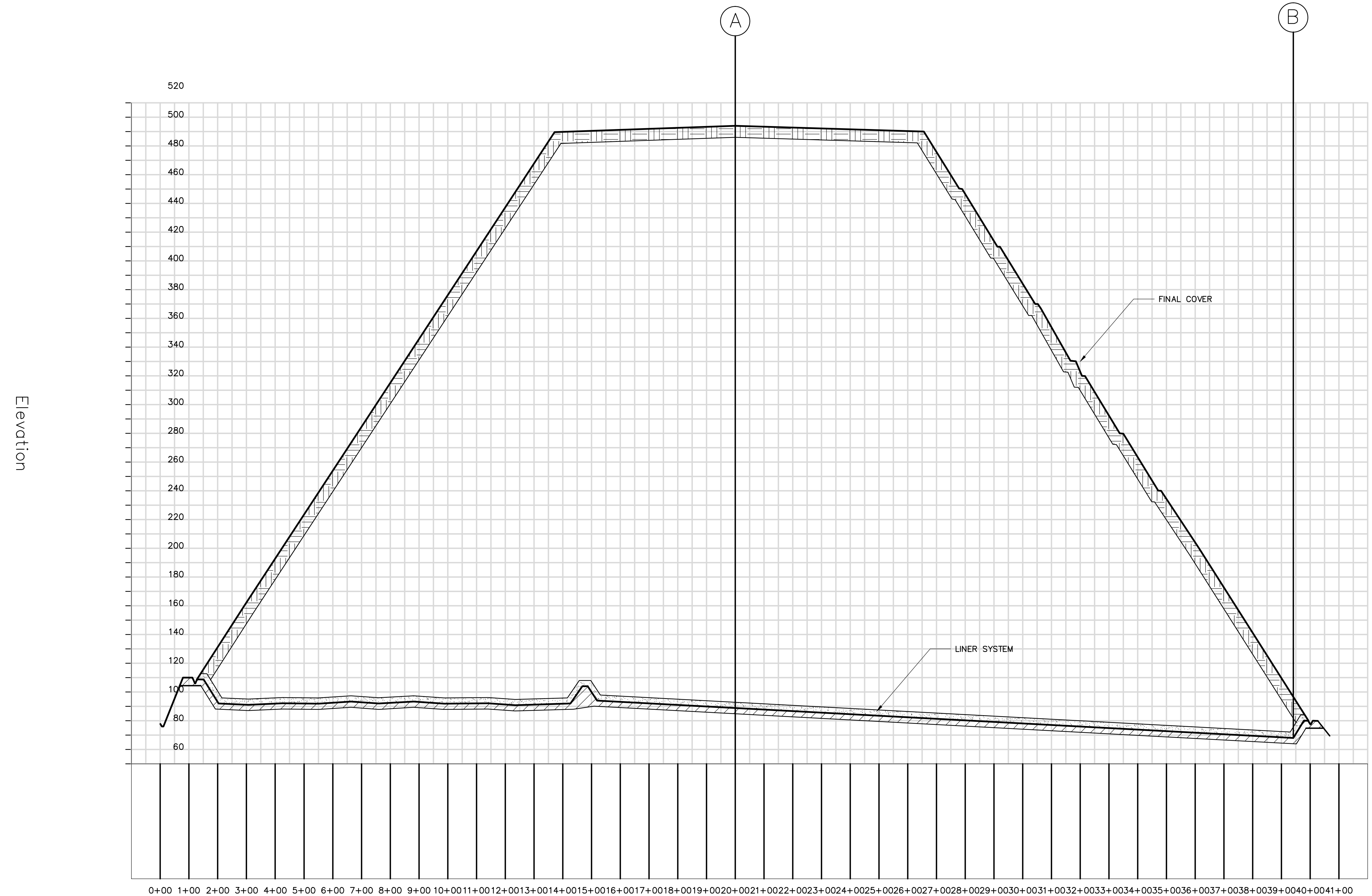
PROJECT NUMBER:

I014-415

April 2017

BASE GRADE SETTLEMENT ANALYSIS SECTION A-A

FIGURE 3.1



SCALE: N.T.S.

ATLANTIC COAST CONSULTING, INC.
630 Colonial Park Drive
Suite 110
Roswell, GA 30075
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PROJECT:

CHESSER ISLAND ROAD MSW LANDFILL CCR MANAGEMENT PLAN

CHARLTON COUNTY, GA
PERMIT NO: 024-006D(SL)

WASTE MANAGEMENT

Chesser Island Road Landfill, Inc.
Hwy 121 @ Chesser Island Road
Folkston, GA 31537

Drawn by: MAL

Checked by:

PROJECT NUMBER:

I014-415

April 2017

BASE GRADE SETTLEMENT ANALYSIS SECTION A-A

FIGURE 3.2

Leachate Collection Pipe Design

Atlantic Coast Consulting, Inc.

1

Design Calculations Notebook

2

IN THIS SECTION:

3

Leachate Collection Pipe Design

4

Section 4
Leachate Collection Pipe Design

Project #:	I014-415			
Project Name:	Chesser Island Rd CCR	By: JLY	Date	04/07/17
Subject:	Leachate Pipe Design - Phase 4	Checked: MAL	Date	04/20/17

Leachate Collection Pipe Design SDR 11

Determine the required thickness of the HDPE leachate collection pipes

Pipes are to be placed in the center of the low point of each lined cell. The 8" perforated pipes will be covered in 2-1/2 feet of gravel (see detail).

SDR=	11		
PE Pipe Material Code=	PE 4710		
compressive yield, σ_y =	1150	psi	(See Appendix C, Table C.1, 2nd Ed. Handbook of PE Pipe by PPI)
Normal outer Diameter, B_c=	8.625	inches	(IPS)
minimum wall thickness, t=	0.784	inches	
Average Inner Diameter, B_i=	6.96	inches	
mean radius, r= $(B_i+2t)/2$ =	4.26	inches	
Unit Weights			
Liner System (gravel)	120	lb/ft^3	
Final Cover System	120	lb/ft^3	
MSW Waste	70	lb/ft^3	
CCR	100	lb/ft^3	
Combined MSW and CCR	73	lb/ft^3	(When MSW to CCR ratio by weight is at estimated maximum 10:1)

Total External Pressure

$P_T = P_S + P_L + P_I$

P_T = total pressure

P_S = total Static Pressure

P_L = total Dynamic pressure

P_I= total Internal Pressure

Static Load, Post Closure: $P_S = P_{LS} + P_{FC} + P_{MSW} + P_{MSW/CCR} = \rho_{LS}*D_{LS} + \rho_{FC}*D_{FC} + \rho_{MSW}*D_{MSW} + \rho_{MSW/CCR}*D_{MSW/CCR}$

P_{LS} = Pressure from Liner System =	Liner System unit weight,	120	(lb/ft^3) * Depth of Liner System,	2.5	ft =	300	lb/ft^2
P_{FC} = Pressure from Final Cover =	Final Cover unit weight,	120	(lb/ft^3) * Depth of Final Cover,	4	ft =	480	lb/ft^2
P_{MSW} = Pressure from $_{MSW}$ =	MSW unit weight,	70.0	(lb/ft^3) * Depth of MSW,	8	ft =	560	lb/ft^3
$P_{MSW/CCR}$ = Pressure from $_{MSW/CCR}$ =	MSW/CCR unit weight,	73.0	(lb/ft^3) * Depth of MSW/CCR,	392	ft =	28616	lb/ft^2

*Note: The initial 8 ft of waste is MSW only.

P_s = 29,956 psf For Full Cell, P_T= 29956 psf (PL and PI = 0)

Dynamic Load, Active Operation $P_L = 3I_fW_wH^3/(2\pi r^5)$ psf (Boussinesq Equation - page 203, Chapter 6, 2nd Edition Handbook of PE Pipe by PPI)

P_L = vertical soil pressure due to live load, psf

W_w = Wheel load, Single truck Load (lbs) (split load between two wheels assume two axles)

H = Vertical depth to pipe crown, ft

I_f = impact factor = 2.0 since load is traveling

r = distance from point of load application to pipe crown, ft (See Figure 3-4 on page 203 referenced above)

$r = (X_2 + H_2)^{1/2}$

For empty cell max stess: (Assume directly beneath one wheel)

W =	24,000	lbs	
x_1 =	0	ft	For Wheel load directly above pipe
x_2 =	6	ft (width of axle)	For Wheel load at the other side of axle
H =	2.5	ft	
r_1 =	2.5	ft	
r_2 =	6.50	ft	
P_{L1} =	3,667	psf	Due to wheel load directly above point on pipe
P_{L2} =	31	psf	Due to wheel at the other end of the axle
P_L=	3,698	psf	

Internal Pressure due to Vacuum

P_I= 0 psf

For an empty cell, $P_T = P_S + P_L + P_I$ = 3,998 psf, or
27.8 psi

Compressive Ring Thrust Stress

For burial depth greater than 50', the use of Spangler's modified Iowa formula is impractical since it ignores arching effect. Due to full landfill development depth, CRT should include vertical arching factor per McGrath's modification of the Burns and Richard's equations (see pages 226 and 227, Chapter 6, 2nd Edition Handbook of PE Pipe by PPI).

$$\text{VAF} = 0.88 - 0.71\frac{S_A - 1}{S_A + 2.5}$$

VAF = Vertical Arching Factor
S_A = Hoop Thrust Stiffness Ratio

$$S_A = \frac{1.43\ \text{Ms rcent}}{\text{EA}}$$

r_{cent} =	radius of centroidal axis of pipe, in	r_{cent} =	4.26	in
M_s =	one-dimensional modulus of soil, psi	M_s =	5,165	(Table 3-12, 90%, extrapolated to P_s, See Chart 1)
E =	apparent modulus of elasticity of pipe material, psi	E =	22,960	(Table B1.1 & B1.2, 100 yrs, PE4710, 90°F)
A =	profile wall average cross sectional area, in^2/in	A =	0.784	in

S_A = 1.75
VAF = 0.75

P_{rd} = (VAF)wH

P_{rd} = radial directed earth pressure, psf
w = unit weight of cover, pcf
H = depth of cover, ft
wH = P_s for post closure condition

P_{rd} = 22,610 psf

S = (P_{rd} * B_c)/(288 * A)

S = pipe wall compressive stress (psi)
B_c = pipe outside diameter (in.)
A = pipe wall thickness (in.)

S = 863.7 psi
Allowable Compressive Stress, psi = 1150

Since 863.7 psi is < 1150 psi; design OK

Design for Wall Crushing (see page 219, Chapter 6, 2nd Edition Handbook of PE Pipe by PPI)

$$S = \frac{P_t * B_c}{288 * t}$$ (Equation 3-14)

S= pipe wall compressive stress (psi)
P_t= vertical load applied to the pipe (psf)
B_c= pipe outside diameter (in.)
t= pipe wall thickness (in.)

S= 1144.3 psi Since 1144.3 psi is < 1150 psi so OK ; FS= 1.0

Design for Ring Deflection

Use Watkins-Gaube Method per pages 229-231 of Chapter 6, 2nd Edition Handbook of PE Pipe by PPI

R_F= Relative stiffness between pipe and soil

$$R_F = \frac{12*Es(SDR-1)^3}{E}$$

E= Modulus of elasticity of the pipe material, (psi) — E= 22,960 (Table B1.1 & B1.2, 100 yrs, PE4710, 90°F)

E_s = Secant modulus of soil, (psi)

SDR= standard dimension ratio — SDR= 11

$E_s = M_s * (1+\mu)(1-2\mu)/(1-\mu)$

μ = Poisson's Ratio — μ = 0.15 (Table 3-13)

M_s = one-dimensional modulus of soil, psi — M_s = 5,165 (Table 3-12, 90%, extrapolated to P_s, See Chart 1)

E_s = 4,891.1 psi

$$\varepsilon_s = \frac{w*H}{144*E_s}$$

ε_s= soil strain, %

w = unit weight of cover, pcf

H = depth of cover, ft

wH = Ps for post closure condition — wH = 29,956 psf

ε_s= 4.25 %

R_F= 2556.3

Using Watkins-Gaube Graph (Figure 3-6)

D_F= 1.5

$$\frac{\Delta X}{D_i}(100) = Df * \varepsilon_s$$

ΔX= horizontal deflection or change in diameter, (in)

D_i= inside pipe Diameter, (in)

ε_s= soil strain, %

$\%\Delta X/D_i$= 6.38 % — Since 6.38 is < 7.5 OK; FS= 1.2

Wall Buckling

$$P_{wc} = \frac{5.65}{SF}\sqrt{R*B'*E'*\frac{E}{12(SDR-1)^3}}$$

(Equation 3-15, page 221, Chapter 6, 2nd Edition Handbook of PE Pipe by PPI)

P_{wc}= Allowable wall buckling pressure (psf)

SF= Safety Factor; 2

R= Buoyancy reduction factor; R=1-(0.33*Hw/H)

H_w= groundwater height above pipe (ft); 1 ft

H= Cover above pipe = 406.5 ft

B'= elastic support factor; $B'=1/(1+4e^{-0.065H})$

E'= modulus of soil reaction for pipe bedding (psf);

E= long-term modulus of elasticity of the pipe material (psf);

SDR= standard dimension ratio of the pipe

R= 1

B'= 1

E'= 3000 psi — (Table 3-7, slightly compacted crushed rock)

E= 22,960 psi — (Table B1.1 & B1.2, 100 yrs, PE4710, 90°F)

SDR= 11

P_{wc}= 214.0 psi — ≥ 208 psi so OK ; FS= 1.0

Leachate Sump Riser Design SDR 17

Determine the required thickness of the HDPE leachate sump sideslope riser pipes
The maximum waste depth above the sideslope riser pipes is 35 feet. The 18" perforated pipes will be covered in 2-1/2 feet of gravel (see detail).

SDR=	17		
PE Pipe Material Code=	PE 4710		
compressive yield, σ_y =	1150	psi	(See Appendix C, Table C.1, 2nd Ed. Handbook of PE Pipe by PPI)
Normal outer Diameter, B_c=	18	inches	(IPS)
minimum wall thickness, t=	1.059	inches	
Average Inner Diameter, B_i=	15.76	inches	
mean radius, r= $(B_i+2t)/2$ =	8.94	inches	
Unit Weights			
Liner System (gravel)	120	lb/ft^3	
Final Cover System	120	lb/ft^3	
MSW Waste	70	lb/ft^3	
CCR	100	lb/ft^3	
Combined MSW and CCR	73	lb/ft^3	(When MSW to CCR ratio by weight is at estimated maximum 10:1)

Total External Pressure

$P_T = P_S + P_L + P_I$

P_T = total pressure
P_S = total Static Pressure
P_L = total Dynamic pressure
P_I= total Internal Pressure

Static Load, Post Closure: $P_S = P_{LS} + P_{FC} + P_{MSW} + P_{MSW/CCR} = \rho_{LS}*D_{LS} + \rho_{FC}*D_{FC} + \rho_{MSW}*D_{MSW} + \rho_{MSW/CCR}*D_{MSW/CCR}$

P_{LS} = Pressure from Liner System =	Liner System unit weight,	120	(lb/ft^3) * Depth of Liner System,	2.5 ft =	300	lb/ft^2
P_{FC} = Pressure from Final Cover =	Final Cover unit weight,	120	(lb/ft^3) * Depth of Final Cover,	4 ft =	480	lb/ft^2
P_{MSW} = Pressure from $_{MSW}$ =	MSW unit weight,	70.0	(lb/ft^3) * Depth of MSW,	8 ft =	560	lb/ft^3
$P_{MSW/CCR}$ = Pressure from $_{MSW/CCR}$ =	MSW/CCR unit weight,	73.0	(lb/ft^3) * Depth of MSW/CCR,	27 ft =	1971	lb/ft^2

*Note: The initial 8 ft of waste is MSW only.

P_s = 3,311 psf — For Full Cell, P_T= 3311 psf (PL and PI = 0)

Dynamic Load, Active Operation — $P_L = 3I_fW_wH^3/(2\pi r^5)$ psf — (Boussinesq Equation - page 203, Chapter 6, 2nd Edition Handbook of PE Pipe by PPI)

P_L = vertical soil pressure due to live load, psf
W_w = Wheel load, Single truck Load (lbs) (split load between two wheels assume two axles)
H = Vertical depth to pipe crown, ft
I_f = impact factor = 2.0 since load is traveling
r = distance from point of load application to pipe crown, ft — (See Figure 3-4 on page 203 referenced above)

$r = (X_2 + H_2)^{1/2}$

For empty cell max stess: (Assume directly beneath one wheel)

W =	24,000	lbs	
x_1 =	0	ft	For Wheel load directly above pipe
x_2 =	6	ft (width of axle)	For Wheel load at the other side of axle
H =	2.5	ft	
r_1 =	2.5	ft	
r_2 =	6.50	ft	
P_{L1} =	3,667	psf	Due to wheel load directly above point on pipe
P_{L2} =	31	psf	Due to wheel at the other end of the axle
P_L=	3,698	psf	

Internal Pressure due to Vacuum

P_I= 0 psf

For an empty cell, $P_T = P_S + P_L + P_I$ = 3,998 psf, or
27.8 psi

Design for Wall Crushing (see page 219, Chapter 6, 2nd Edition Handbook of PE Pipe by PPI)

$$S = \frac{P_t * B_c}{288 * t}$$ (Equation 3-14)

S= pipe wall compressive stress (psi)
P_t= vertical load applied to the pipe (psf)
B_c= pipe outside diameter (in.)
t= pipe wall thickness (in.)

S= 195.4 psi Since 195.4 psi is < 1150 psi so OK ; FS= 5.9

Design for Ring Deflection

Use Spangler's Modified Iowa Formula per page 211 of Chapter 6, 2nd Edition Handbook of PE Pipe by PPI

$$\frac{\Delta X}{D_M} = \frac{1}{144}\left(\frac{K_{BED} L_{DL} P_S}{\frac{2E}{3}\left(\frac{1}{SDR-1}\right)^3 + 0.061E'}\right)$$

K_{BED}= Bedding Factor, typically 0.1
L_{DL} = Deflection Lag Factor, assume 1.0
E = apparent modulus of elasticity of pipe material, psi — E= 22,960 (Table B1.1 & B1.2, 100 yrs, PE4710, 90°F)
SDR= standard dimension ratio — SDR= 17
E'= modulus of soil reaction for pipe bedding, psi — E'= 3000 (Table 3-7, slightly compacted crushed rock)

$\%\Delta X/D_M$= 1.23 % Since 1.23 is < 7.5 OK; FS= 6.1

Wall Buckling

$$P_{wc} = \frac{5.65}{SF}\sqrt{R * B' * E' * \frac{E}{12(SDR-1)^3}}$$ (Equation 3-15, page 221, Chapter 6, 2nd Edition Handbook of PE Pipe by PPI)

P_{wc}= Allowable wall buckling pressure (psf)
SF= Safety Factor; 2
R= Buoyancy reduction factor; R=1-(0.33*Hw/H)
H_w= groundwater height above pipe (ft); 1 ft
H= Cover above pipe = 41.5 ft
B'= elastic support factor; $B'=1/(1+4e^{-0.065H})$
E'= modulus of soil reaction for pipe bedding (psf);
E= long-term modulus of elasticity of the pipe material (psf);
SDR= standard dimension ratio of the pipe

R= 1
B'= 1
E'= 3000 psi (Table 3-7, slightly compacted crushed rock)
E= 22,960 psi (Table B1.1 & B1.2, 100 yrs, PE4710, 90°F)
SDR= 17

P_{wc}= 105.8 psi ≥ 23 psi so OK ; FS= 4.6

Leachate Collection Pipe Design SDR 11

Evaluate the thickness of the existing HDPE leachate collection pipes

These calculations assume that a 10 foot layer of CCR will be placed above the MSW waste in Phase 3 prior to placement of the co-mingled MSW and CCR (with MSW to CCR ratio by weight of 10:1). The maximum waste height above the Phase 3 leachate collection pipes (394 feet) occurs in Stage 2. Pipes are placed in the center of the low point of each lined cell. The 8" perforated pipes are covered in 2-1/2 feet of gravel (see detail).

SDR=	11		
PE Pipe Material Code=	PE 4710		
compressive yield, σ_y =	1150	psi	(See Appendix C, Table C.1, 2nd Ed. Handbook of PE Pipe by PPI)
Normal outer Diameter, B_c=	8.625	inches	(IPS)
minimum wall thickness, t=	0.784	inches	
Average Inner Diameter, B_i=	6.96	inches	
mean radius, r= $(B_i+2t)/2$ =	4.26	inches	
Unit Weights			
Liner System (gravel)	120	lb/ft^3	
Final Cover System	120	lb/ft^3	
MSW Waste	70	lb/ft^3	
CCR	100	lb/ft^3	
Combined MSW and CCR	73	lb/ft^3	(When MSW to CCR ratio by weight is at estimated maximum 10:1)

Total External Pressure

$P_T = P_S + P_L + P_I$

P_T = total pressure

P_S = total Static Pressure

P_L = total Dynamic pressure

P_I= total Internal Pressure

Static Load, Post Closure: $P_S = P_{LS} + P_{FC} + P_{MSW} + P_{MSW/CCR} = \rho_{LS}*D_{LS} + \rho_{FC}*D_{FC} + \rho_{MSW}*D_{MSW} + \rho_{MSW/CCR}*D_{MSW/CCR}$

P_{LS} = Pressure from Liner System =	Liner System unit weight,	120	(lb/ft^3) * Depth of Liner System,	2.5	ft =	300	lb/ft^2
P_{FC} = Pressure from Final Cover =	Final Cover unit weight,	120	(lb/ft^3) * Depth of Final Cover,	4	ft =	480	lb/ft^2
P_{MSW} = Pressure from $_{MSW}$ =	MSW unit weight,	70.0	(lb/ft^3) * Depth of MSW,	28	ft =	1960	lb/ft^3
P_{CCR} = Pressure from $_{CCR}$ =	CCR unit weight,	100.0	(lb/ft^3) * Depth of CCR,	10	ft =	1000	lb/ft^2
$P_{MSW/CCR}$ = Pressure from $_{MSW/CCR}$ =	MSW/CCR unit weight,	73.0	(lb/ft^3) * Depth of MSW/CCR,	356	ft =	25988	lb/ft^3

*Note: The initial 8 ft of waste is MSW only.

P_s = 29,728 psf For Full Cell, P_T= 29728 psf (PL and PI = 0)

Dynamic Load, Active Operation $P_L = 3I_fW_wH^3/(2\pi r^5)$ psf (Boussinesq Equation - page 203, Chapter 6, 2nd Edition Handbook of PE Pipe by PPI)

P_L = vertical soil pressure due to live load, psf

W_w = Wheel load, Single truck Load (lbs) (split load between two wheels assume two axles)

H = Vertical depth to pipe crown, ft

I_f = impact factor = 2.0 since load is traveling

r = distance from point of load application to pipe crown, ft (See Figure 3-4 on page 203 referenced above)

$r = (X_2 + H_2)^{1/2}$

For empty cell max stess: (Assume directly beneath one wheel)

W =	24,000	lbs	
x_1 =	0	ft	For Wheel load directly above pipe
x_2 =	6	ft (width of axle)	For Wheel load at the other side of axle
H =	2.5	ft	
r_1 =	2.5	ft	
r_2 =	6.50	ft	
P_{L1} =	3,667	psf	Due to wheel load directly above point on pipe
P_{L2} =	31	psf	Due to wheel at the other end of the axle
P_L=	3,698	psf	

Internal Pressure due to Vacuum

P_I= 0 psf

For an empty cell, $P_T = P_S + P_L + P_I$ = 3,998 psf, or
27.8 psi

Compressive Ring Thrust Stress

For burial depth greater than 50', the use of Spangler's modified Iowa formula is impractical since it ignores arching effect. Due to full landfill development depth, CRT should include vertical arching factor per McGrath's modification of the Burns and Richard's equations (see pages 226 and 227, Chapter 6, 2nd Edition Handbook of PE Pipe by PPI).

$$\text{VAF} = 0.88 - 0.71\,\frac{S_A - 1}{S_A + 2.5}$$

VAF = Vertical Arching Factor
S_A = Hoop Thrust Stiffness Ratio

$$S_A = \frac{1.43\ \text{Ms rcent}}{\text{EA}}$$

r_{cent} =	radius of centroidal axis of pipe, in	r_{cent} =	4.26	in
M_s =	one-dimensional modulus of soil, psi	M_s =	5,136	(Table 3-12, 90%, extrapolated to P_s, See Chart 1)
E =	apparent modulus of elasticity of pipe material, psi	E =	22,960	(Table B1.1 & B1.2, 100 yrs, PE4710, 90°F)
A =	profile wall average cross sectional area, in^2/in	A =	0.784	in

S_A = 1.74
VAF = 0.76

P_{rd} = (VAF)wH

P_{rd} = radial directed earth pressure, psf
w = unit weight of cover, pcf
H = depth of cover, ft
wH = P_s for post closure condition

P_{rd} = 22,478 psf

S = (P_{rd} * B_c)/(288 * A)

S = pipe wall compressive stress (psi)
B_c = pipe outside diameter (in.)
A = pipe wall thickness (in.)

S = 858.6 psi
Allowable Compressive Stress, psi = 1150

Since 858.6 psi is < 1150 psi; design OK

Design for Wall Crushing (see page 219, Chapter 6, 2nd Edition Handbook of PE Pipe by PPI)

$$S = \frac{P_t * B_c}{288 * t} \qquad \text{(Equation 3-14)}$$

S= pipe wall compressive stress (psi)
P_t= vertical load applied to the pipe (psf)
B_c= pipe outside diameter (in.)
t= pipe wall thickness (in.)

S= 1135.6 psi Since 1135.6 psi is < 1150 psi so OK ; FS= 1.0

Design for Ring Deflection

Use Watkins-Gaube Method per pages 229-231 of Chapter 6, 2nd Edition Handbook of PE Pipe by PPI

R_F= Relative stiffness between pipe and soil

$$R_F=\frac{12*Es(SDR-1)^3}{E}$$

E= Modulus of elasticity of the pipe material, (psi) — E= 22,960 (Table B1.1 & B1.2, 100 yrs, PE4710, 90°F)

E_s = Secant modulus of soil, (psi)

SDR= standard dimension ratio — SDR= 11

$E_s = M_s * (1+\mu)(1-2\mu)/(1-\mu)$

μ = Poisson's Ratio — μ = 0.15 (Table 3-13)

M_s = one-dimensional modulus of soil, psi — M_s = 5,136 (Table 3-12, 90%, extrapolated to P_s, See Chart 1)

E_s = 4,864.1 psi

$$\varepsilon_s = \frac{w * H}{144 * E_s}$$

ε_s= soil strain, %

w = unit weight of cover, pcf

H = depth of cover, ft

wH = Ps for post closure condition — wH = 29,728 psf

ε_s= 4.24 %

R_F= 2542.2

Using Watkins-Gaube Graph (Figure 3-6)

D_F= 1.5

$$\frac{\Delta X}{D_i}(100) = Df * \varepsilon_s$$

ΔX= horizontal deflection or change in diameter, (in)

D_i= inside pipe Diameter, (in)

ε_s= soil strain, %

$\%\Delta X/D_i$= 6.37 % — Since 6.37 is < 7.5 OK; FS= 1.2

Wall Buckling

$$P_{wc} = \frac{5.65}{SF}\sqrt{R * B' * E' * \frac{E}{12(SDR-1)^3}}$$

(Equation 3-15, page 221, Chapter 6, 2nd Edition Handbook of PE Pipe by PPI)

P_{wc}= Allowable wall buckling pressure (psf)

SF= Safety Factor; 2

R= Buoyancy reduction factor; R=1-(0.33*Hw/H)

H_w= groundwater height above pipe (ft); 1 ft

H= Cover above pipe = 400.5 ft

B'= elastic support factor; $B'=1/(1+4e^{-0.065H})$

E'= modulus of soil reaction for pipe bedding (psf);

E= long-term modulus of elasticity of the pipe material (psf);

SDR= standard dimension ratio of the pipe

R= 1

B'= 1

E'= 3000 psi — (Table 3-7, slightly compacted crushed rock)

E= 22,960 psi — (Table B1.1 & B1.2, 100 yrs, PE4710, 90°F)

SDR= 11

P_{wc}= 214.0 psi — ≥ 206.4 psi so OK ; FS= 1.0

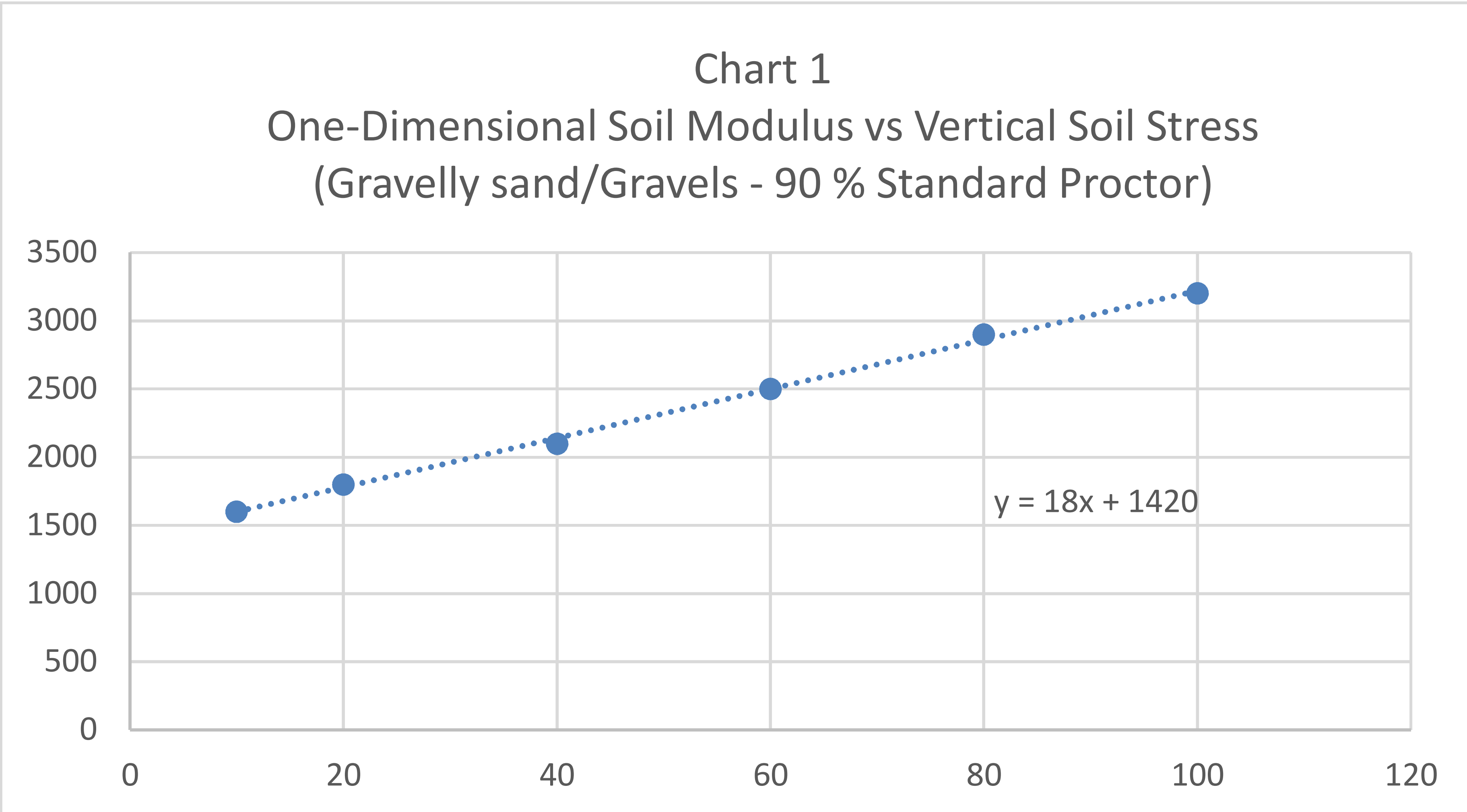
Chart 1
One-Dimensional Soil Modulus vs Vertical Soil Stress
(Gravelly sand/Gravels - 90 % Standard Proctor)
3500
3000
2500
2000
1500
1000
500
0
0
20
40
60
80
100
120
y = 18x + 1420

Appendix B
Apparent Elastic Modulus

B.1 – Apparent Elastic Modulus for the Condition of Either a Sustained Constant Load or a Sustained Constant Deformation

B.1.1 – Design Values for the Base Temperature of 73°F (23°C)

TABLE B.1.1
Apparent Elastic Modulus for 73°F (23°C)

Duration of Sustained Loading	Design Values For 73°F (23°C) (1,2,3)					
	PE 2XXX		PE3XXX		PE4XXX	
	psi	MPa	psi	MPa	psi	MPa
0.5hr	62,000	428	78,000	538	82,000	565
1hr	59,000	407	74,000	510	78,000	538
2hr	57,000	393	71,000	490	74,000	510
10hr	50,000	345	62,000	428	65,000	448
12hr	48,000	331	60,000	414	63,000	434
24hr	46,000	317	57,000	393	60,000	414
100hr	42,000	290	52,000	359	55,000	379
1,000hr	35,000	241	44,000	303	46,000	317
1 year	30,000	207	38,000	262	40,000	276
10 years	26,000	179	32,000	221	34,000	234
50 years	22,000	152	28,000	193	29,000	200
100 years	21,000	145	27,000	186	28,000	193

(1) Although there are various factors that determine the exact apparent modulus response of a PE, a major factor is its ratio of crystalline to amorphous content – a parameter that is reflected by a PE's density. Hence, the major headings PE2XXX, PE3XXX and, PE4XXX, which are based on PE's Standard Designation Code. The first numeral of this code denotes the PE's density category in accordance with ASTM D3350 (An explanation of this code is presented in Chapter 5).

(2) The values in this table are applicable to both the condition of sustained and constant loading (under which the resultant strain increases with increased duration of loading) and that of constant strain (under which an initially generated stress gradually relaxes with increased time).

(3) The design values in this table are based on results obtained under uni-axial loading, such as occurs in a test bar that is being subjected to a pulling load. When a PE is subjected to multi-axial stressing its strain response is inhibited, which results in a somewhat higher apparent modulus. For example, the apparent modulus of a PE pipe that is subjected to internal hydrostatic pressure – a condition that induces bi-axial stressing – is about 25% greater than that reported by this table. Thus, the Uni-axial condition represents a conservative estimate of the value that is achieved in most applications.

It should also be kept in mind that these values are for the condition of continually sustained loading. If there is an interruption or a decrease in the loading this, effectively, results in a somewhat larger modulus.

In addition, the values in this table apply to a stress intensity ranging up to about 400psi, a value that is seldom exceeded under normal service conditions.

B.1.2 – Values for Other Temperatures

The multipliers listed in Table B.1.2 when applied to the base temperature value (Table B.1.1) yield the value for another temperature.

TABLE B.1.2
Temperature Compensating Multipliers for Determination of the Apparent Modulus of Elasticity at Temperatures Other than at 73°F (23°C)
Equally Applicable to All Stress-Rated PE's (e.g., All PE2xxx's, All PE3xxx's and All PE4xxx's)

Maximum Sustained Temperature of the Pipe °F (°C)	Compensating Multiplier
-20 (-29)	2.54
-10 (-23)	2.36
0 (-18)	2.18
10 (-12)	2.00
20 (-7)	1.81
30 (-1)	1.65
40 (4)	1.49
50 (10)	1.32
60 (16)	1.18
73.4 (23)	1.00
80 (27)	0.93
90 (32)	0.82
100 (38)	0.73
110 (43)	0.64
120 (49)	0.58
130 (54)	0.50
140 (60)	0.43

B.2 – Approximate Values for the Condition of a Rapidly Increasing Stress OR Strain

B.2.1 – Values for the Base Temperature of 73°F (23°C)

TABLE B.2.1

Rate of Increasing Stress	Approximate Values of Apparent Modulus for 73°F (23°C)					
	For Materials Coded PE2XXX (1)		For Materials Coded PE3XXX (1)		For Materials Coded PE4XXX (1)	
	psi	MPa	psi	MPa	psi	MPa
"Short term" (Results Obtained Under Tensile Testing) (2)	100,000	690	125,000	862	130,000	896
"Dynamic" (3)	150,000psi (1,034MPa), For All Designation Codes					

(1) See Chapter 5 for an explanation of the PE Pipe Material Designation Code. The X's designate any numeral that is recognized under this code.

(2) Under ASTM D638, "Standard Test Method for Tensile Properties of Plastics", a dog–bone shaped specimen is subjected to a constant rate of pull. The "apparent modulus" under this method is the ratio of stress to strain that is achieved at a certain defined strain. This apparent modulus is of limited value for engineering design.

(3) The dynamic modulus is the ratio of stress to strain that occurs under instantaneous rate of increasing stress, such as can occur in a water-hammer reaction in a pipeline. This modulus is used as a parameter for the computing of a localized surge pressure that results from a water hammer event.

B.2.2 – Values for Other Temperatures

The values for other temperatures may be determined by applying a multiplier, as follows, to the base temperature value:

- For Short-Term Apparent Modulus – Apply the multipliers in Table B.1.2
- For Dynamic Apparent Modulus – Apply the multipliers in Table B.2.2

TABLE B.2.2
Dynamic Modulus, Temperature Compensating Multipliers

Temperature , °F (°C)	Multiplier
40 (4)	1.78
50 (10)	1.52
60 (16)	1.28
73.4 (23)	1.00
80 (27)	0.86
90 (32)	0.69
100 (38)	0.53
110 (43)	0.40
120 (49)	0.29

Appendix C
Allowable Compressive Stress

Table C.1 lists allowable compressive stress values for 73°F (23°C). Values for allowable compressive stress for other temperatures may be determined by application of the same multipliers that are used for pipe pressure rating (See Table A.2).

TABLE C.1
Allowable Compressive Stress for 73°F (23°C)

<table>
<tr><td rowspan="7"></td><td colspan="6">Pe Pipe Material Designation Code [(1)]</td></tr>
<tr><td colspan="2">PE 2406</td><td colspan="2">PE3408</td><td colspan="2" rowspan="5">PE 4710</td></tr>
<tr><td colspan="2" rowspan="4">PE 2708</td><td colspan="2">PE 3608</td></tr>
<tr><td colspan="2">PE 3708</td></tr>
<tr><td colspan="2">PE 3710</td></tr>
<tr><td colspan="2">PE 4708</td></tr>
<tr><td>psi</td><td>MPa</td><td>psi</td><td>MPa</td><td>psi</td><td>MPa</td></tr>
<tr><td>Allowable Compressive Stress</td><td>800</td><td>5.52</td><td>1000</td><td>6.90</td><td>1150</td><td>7.93</td></tr>
</table>

(1) See Chapter 5 for an explanation of the PE Pipe Material Designation Code.

Appendix D
Poisson's Ratio

Poisson's Ratio for ambient temperature for all PE pipe materials is approximately 0.45.

This 0.45 value applies both to the condition of tension and compression. While this value increases with temperature, and vice versa, the effect is relatively small over the range of typical working temperatures.

Boussinesq Equation

The Boussinesq Equation gives the pressure at any point in a soil mass under a concentrated surface load. The Boussinesq Equation may be used to find the pressure transmitted from a wheel load to a point that is not along the line of action of the load. Pavement effects are neglected.

(3-4)
$$P'_L = \frac{3 I_f W_w H^3}{2\pi r^5}$$

WHERE

P_L = vertical soil pressure due to live load lb/ft2

W_W = wheel load, lb

H = vertical depth to pipe crown, ft

I_f = impact factor

r = distance from the point of load application to pipe crown, ft

(3-5)
$$r = \sqrt{X^2 + H^2}$$

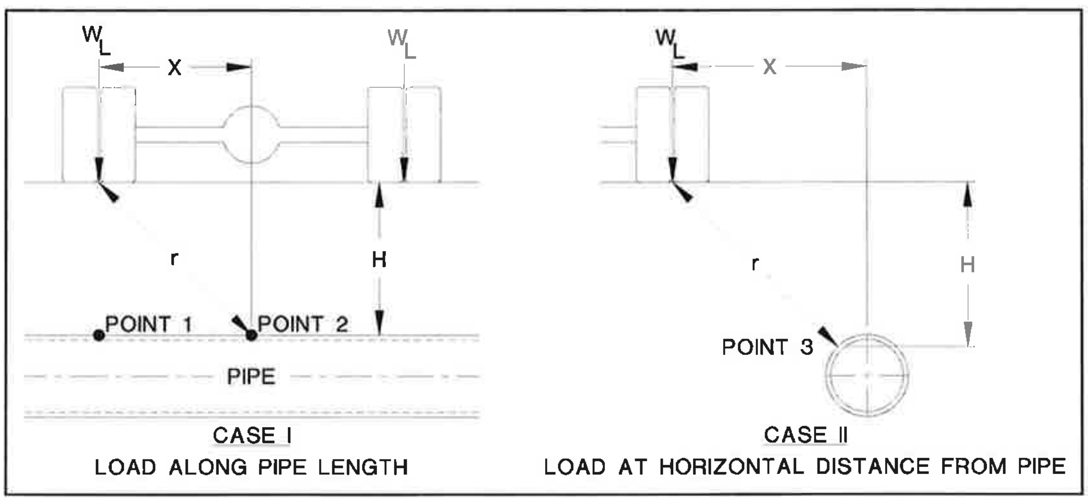

Figure 3-4 Illustration of Boussinesq Point Loading

Example Using Boussinesq Point Loading Technique

Determine the vertical soil pressure applied to a 12" pipe located 4 ft deep under a dirt road when two vehicles traveling over the pipe and in opposite lanes pass each other. Assume center lines of wheel loads are at a distance of 4 feet. Assume a wheel load of 16,000 lb.

Installation Category 1: Standard Installation - Trench or Embankment

Pipe Reaction to Earth, Live, and Surcharge Loads

Now might be a good time to review the "Design Process" that appeared earlier in Section 3. After calculating the vertical pressure applied to the pipe the next design step is to choose a trial pipe (DR or profile). Then, based on the Installation Category and the selected embedment and compaction, calculate the anticipated deflection and resistance to crush and buckling.

The Standard Installation category applies to pipes that are installed between 18 inches and 50 feet of cover. Where surcharge, traffic, or rail load may occur, the pipe must have at least one full diameter of cover. If such cover is not available, then the application design must also consider limitations under the Shallow Cover Vehicular Loading Installation category. Where the cover depth exceeds 50 ft an alternate treatment for dead loads is given under the Deep Fill Installation category. Where ground water occurs above the pipe's invert and the pipe has less than two diameters of cover, the potential for the occurrence of flotation or upward movement of the pipe may exist. See Shallow Cover Flotation Effects.

While the Standard Installation is suitable for up to 50 feet of cover, it may be used for more cover. The 50 feet limit is based on A. Howard's [3] recommended limit for use of E' values. Above 50 feet, the E' values given in Table B.1.1 in Chapter 3 Appendix are generally thought to be overly conservative as they are not corrected for the increase in embedment stiffness that occurs with depth as a result of the higher confinement pressure within the soil mass. In addition, significant arching occurs at depths greater than 50 feet.

The Standard Installation, as well as the other design categories for buried PE pipe, looks at a ring or circumferential cross-section of pipe and neglects longitudinal loading, which is normally insignificant. They also ignore the re-rounding effect of internal pressurization. Since re-rounding reduces deflection and stress in the pipe, ignoring it is conservative.

Ring Deflection

Ring deflection is the normal response of flexible pipes to soil pressure. It is also a beneficial response in that it leads to the redistribution of soil stress and the initiation of arching. Ring deflection can be controlled within acceptable limits by the selection of appropriate pipe embedment materials, compaction levels, trench width and, in some cases, the pipe itself.

The magnitude of ring deflection is inversely proportional to the combined stiffness of the pipe and the embedment soil. M. Spangler [4] characterized this relationship in the Iowa Formula in 1941. R. Watkins [5] modified this equation to allow a simpler approach for soil characterization, thus developing the Modified Iowa Formula. In 1964, Burns and Richards [6] published a closed-form solution for ring deflection and pipe stress based on classical linear elasticity. In 1976 M. Katona et. al. [7] developed a finite element program called CANDE (Culvert Analysis and Design) which is now available in a PC version and can be used to predict pipe deflection and stresses.

The more recent solutions may make better predictions than the Iowa Formula, but they require detailed information on soil and pipe properties, e.g. more soil lab testing. Often the improvement in precision is all but lost in construction variability. Therefore, the Modified Iowa Formula remains the most frequently used method of determining ring deflection.

Spangler's Modified Iowa Formula can be written for use with solid wall PE pipe as:

(3-10)

$$\frac{\Delta X}{D_M} = \frac{1}{144}\left(\frac{K_{BED}\, L_{DL} P_E + K_{BED} P_L}{\frac{2E}{3}\left(\frac{1}{DR-1}\right)^3 + 0.061 F_S E'}\right)$$

and for use with ASTM F894 profile wall pipe as:

(3-11)

$$\frac{\Delta X}{D_I} = \frac{P}{144}\left(\frac{K_{BED} L_{DL}}{\frac{1.24(RSC)}{D_M} + 0.061 F_S E'}\right)$$

WHERE

ΔX = **Horizontal deflection, in**

K_{BED} = **Bedding factor, typically 0.1**

L_{DL} = **Deflection lag factor**

P_E = **Vertical soil pressure due to earth load, psf**

P_L = **Vertical soil pressure due to live load, psf**

E = **Apparent modulus of elasticity of pipe material, lb/in^2**

E' = **Modulus of Soil reaction, psi**

F_S = **Soil Support Factor**

RSC = **Ring Stiffness Constant, lb/ft**

DR = **Dimension Ratio, OD/t**

D_M = **Mean diameter (D_I+2z or D_O-t), in**

z = **Centroid of wall section, in**

t = **Minimum wall thickness, in**

D_I = **pipe inside diameter, in**

D_O = **pipe outside diameter, in**

TABLE 3-7
Values of E' for Pipe Embedment (See Howard [8])

Soil Type-pipe Embedment Material (Unified Classification System)[1]	E' for Degree of Embedment Compaction, lb/in^2			
	Dumped	Slight, <85% Proctor, <40% Relative Density	Moderate, 85%-95% Proctor, 40%-70% Relative Density	High, >95% Proctor, >70% Relative Density
Fine-grained Soils (LL > 50)[2] Soils with medium to high plasticity; CH, MH, CH-MH	No data available: consult a competent soils engineer, otherwise, use E' = 0.			
Fine-grained Soils (LL < 50) Soils with medium to no plasticity, CL, ML, ML-CL, with less than 25% coarse grained particles.	50	200	400	1000
Fine-grained Soils (LL < 50) Soils with medium to no plasticity, CL, ML, ML-CL, with more than 25% coarse grained particles; Coarse-grained Soils with Fines, GM, GC, SM, SC[3] containing more than 12% fines.	100	400	1000	2000
Coarse-grained soils with Little or No Fines GW, GP, SW, SP[3] containing less than 12% fines	200	1000	2000	3000
Crushed Rock	1000	3000	3000	3000
Accuracy in Terms of Percentage Deflection[4]	±2%	±2%	±1%	±0.5%

[1] ASTM D-2487, USBR Designation E-3
[2] LL = Liquid Limit
[3] Or any borderline soil beginning with one of these symbols (i.e., GM-GC, GC-SC).
[4] For ±1% accuracy and predicted deflection of 3%, actual deflection would be between 2% and 4%.

Note: Values applicable only for fills less than 50 ft (15 m). Table does not include any safety factor. For use in predicting initial deflections only; appropriate Deflection Lag Factor must be applied for long-term deflections. If embedment falls on the borderline between two compaction categories, select lower E' value, or average the two values. Percentage Proctor based on laboratory maximum dry density from test standards using 12,500 ft-lb/cu ft (598,000 J/m^2) (ASTM D-698, AASHTO T-99, USBR Designation E-11). 1 psi = 6.9 KPa.

Compressive Ring Thrust

Earth pressure exerts a radial-directed force around the circumference of a pipe that results in a compressive ring thrust in the pipe wall. (This thrust is exactly opposite to the tensile hoop thrust induced when a pipe is pressurized.) See Figure 3-1B. Excessive ring compressive thrust may lead to two different performance limits: crushing of the material or buckling (loss of stability) of the pipe wall. See Figure 3-1C. This section will discuss crushing, and the next section will discuss buckling.

As is often the case, the radial soil pressure causing the stress is not uniform around the pipe's circumference. However, for calculation purposes it is assumed uniform and equal to the vertical soil pressure at the pipe crown.

Pressure pipes often have internal pressure higher than the radial pressure applied by the soil. As long as there is pressure in the pipe that exceeds the external pressure, the net thrust in the pipe wall is tensile rather than compressive, and wall crush or buckling checks are not necessary. Whether one needs to check this or not can be quickly determined by simply comparing the internal pressure with the vertical soil pressure.

Crushing occurs when the compressive stress in the wall exceeds the compressive yield stress of the pipe material. Equations 3-13 and 3-14 give the compressive stress resulting from earth and live load pressure for conventional extruded DR pipe and for ASTM F894 profile wall PE Pipe:

(3-13)
$$S = \frac{(P_E + P_L)\,DR}{288}$$

(3-14)
$$S = \frac{(P_E + P_L)\,D_O}{288A}$$

WHERE

P_E = **vertical soil pressure due to earth load, psf**

P_L = **vertical soil pressure due to live-load, psf**

S = **pipe wall compressive stress, lb/in²**

DR = **Dimension Ratio, D_O/t**

D_O = **pipe outside diameter (for profile pipe $D_O = D_I + 2H_P$), in**

D_I = **pipe inside diameter, in**

H_P = **profile wall height, in**

A = **profile wall average cross-sectional area, in²/in**
(Obtain the profile wall area from the manufacturer of the profile pipe.)

(Note: These equations contain a factor of 144 in the denominator for correct units conversions.)

raised to a power. Therefore the lower the DR, the higher the resistance. Buried pipe has an added resistance due to support (or constraint) from the surrounding soil.

Non-pressurized pipes or gravity flow pipes are most likely to have a net compressive stress in the pipe wall and, therefore, the allowable buckling pressure should be calculated and compared to the total (soil and ground water) pressure. For most pressure pipe applications, the fluid pressure in the pipe exceeds the external pressure, and the net stress in the pipe wall is tensile. Buckling needs only be considered for that time the pipe is not under pressure, such as during and immediately after construction and during system shut-downs and, in cases in which a surge pressure event can produce a temporary negative internal pressure. Under these circumstances the pipe will react much stiffer to buckling as its modulus is higher under short term loading. When designing, select a modulus appropriate for the duration of the negative external pressure. For pipe that are subjected to negative pressure due to surge, consideration should be given to selecting a DR that gives the pipe sufficient unconstrained collapse strength to resist the full applied negative pressure without support for the soil. This is to insure against construction affects that result in the embedment material not developing its full design strength.

This chapter gives two equations for calculating buckling. The modified Luscher Equation is for buried pipes that are beneath the ground water level, subject to vacuum pressure, or under live load with a shallow cover. These forces act to increase even the slightest eccentricity in the pipe wall by following deformation inward. While soil pressure alone can create instability, soil is less likely to follow deformation inward, particularly if it is granular. So, dry ground buckling is only considered for deep applications and is given by the Moore-Selig Equation found in the section, "Buckling of Pipes in Deep, Dry Fills".

Luscher Equation for Constrained Buckling Below Ground Water Level

For pipes below the ground water level, operating under a full or partial vacuum, or subject to live load, Luscher's equation may be used to determine the allowable constrained buckling pressure. Equation 3-15 and 3-16 are for DR and profile pipe respectively.

(3-15)

$$P_{WC} = \frac{5.65}{N}\sqrt{RB'E'\frac{E}{12(DR-1)^3}}$$

(3-16)

$$P_{WC} = \frac{5.65}{N}\sqrt{RB'E'\frac{EI}{D_M{}^3}}$$

WHERE

P_{WC} = **allowable constrained buckling pressure, lb/in²**

N = **safety factor**

(3-17)
$$R = 1 - 0.33\frac{H_{GW}}{H}$$

WHERE

R = **buoyancy reduction factor**

H_{GW} = **height of ground water above pipe, ft**

H = **depth of cover, ft**

(3-18)
$$B' = \frac{1}{1 + 4e^{(-0.065H)}}$$

WHERE

e = **natural log base number, 2.71828**

E' = **soil reaction modulus, psi**

E = **apparent modulus of elasticity, psi**

DR = **Dimension Ratio**

I = **pipe wall moment of inertia, in^4/in ($t^3/12$, if solid wall construction)**

D_M = **Mean diameter (D_I + 2z or D_O – t), in**

Although buckling occurs rapidly, long-term external pressure can gradually deform the pipe to the point of instability. This behavior is considered viscoelastic and can be accounted for in Equations 3-15 and 3-16 by using the apparent modulus of elasticity value for the appropriate time and temperature of the loading. For instance, a vacuum event is resisted by the short-term value of the modulus whereas continuous ground water pressure would be resisted by the 50 year value. For modulus values see Appendix, Chapter 3.

For pipes buried with less than 4 ft or a full diameter of cover, Equations 3-15 and 3-16 may have limited applicability. In this case the designer may want to use Equations 3-39 and 3-40.

The designer should apply a safety factor commensurate with the application. A safety factor of 2.0 has been used for thermoplastic pipe.

The allowable constrained buckling pressure should be compared to the total vertical stress acting on the pipe crown from the combined load of soil, and ground water or floodwater. It is prudent to check buckling resistance against a ground water level for a 100-year-flood. In this calculation the total vertical stress is typically taken as the prism load pressure for saturated soil, plus the fluid pressure of any floodwater above the ground surface.

Determine the earth pressure coefficient:

$$K = \frac{1+\sin(30)}{1-\sin(30)} = \frac{1+0.5}{1-0.5} = 3.0$$

The live load pressure incipient to failure equals:

$$P_{WAT} = \frac{(12)120(3.0*3.0)^2}{40.04} + \frac{7387*0.171}{40.04^2(1.44)}(3000 - \frac{120(40.04)3.0}{288*0.470})$$

$$P_{WAT} = 2904 + 1584 = 4498\ psf$$

The resulting safety factor equals:

$$N = \frac{P_{WAT}}{p_L} = \frac{4498}{1697} = 2.65$$

Installation Category #3: Deep Fill Installation

The performance limits for pipes in a deep fill are the same as for any buried pipe. They include:

1. Compressive ring thrust stress
2. Ring deflection
3. Constrained pipe wall buckling

The suggested calculation method for pipe in deep fill applications involves the introduction of design routines for each performance limit that are different than those previously given.

Compressive ring thrust is calculated using soil arching. The arching calculation may also be used for profile pipe designs in standard trench applications. Profile pipes are relatively low stiffness pipes where significant arching may occur at relatively shallow depths of cover.

At a depth of around 50 feet or so it becomes impractical to use Spangler's equation as published in this chapter because it neglects the significant load reduction due to arching and the inherent stiffening of the embedment and consequential increase in E' due to the increased lateral earth pressure applied to the embedment. This section gives an alternate deflection equation for use with PE pipes. It was first introduced by Watkins et al. (1) for metal pipes, but later Gaube extended its use to include PE pipes. (15)

Where deep fill applications are in dry soil, Luscher's equation (Eq. 3-15 or 3-16) may often be too conservative for design as it considers a radial driving force from ground water or vacuum. Moore and Selig[17] developed a constrained pipe wall buckling equation suitable for pipes in dry soils, which is given in a following section.

Considerable care should be taken in the design of deeply buried pipes whose failure may cause slope failure in earthen structures, or refuse piles or whose failure may have severe environmental or economical impact. These cases normally justify the use of methods beyond those given in this Chapter, including finite element analysis and field testing, along with considerable professional design review.

Compressive Ring Thrust and the Vertical Arching Factor

The combined horizontal and vertical earth load acting on a buried pipe creates a radially-directed compressive load acting around the pipe's circumference. When a PE pipe is subjected to ring compression, thrust stress develops around the pipe hoop, and the pipe's circumference will ever so slightly shorten. The shortening permits "thrust arching," that is, the pipe hoop thrust stiffness is less than the soil hoop thrust stiffness and, as the pipe deforms, less load follows the pipe. This occurs much like the vertical arching described by Marston.[18] Viscoelasticity enhances this effect. McGrath[19] has shown thrust arching to be the predominant form of arching with PE pipes.

Burns and Richard[6] have published equations that give the resulting stress occurring in a pipe due to arching. As discussed above, the arching is usually considered when calculating the ring compressive stress in profile pipes. For deeply buried pipes McGrath [19] has simplified the Burns and Richard's equations to derive a vertical arching factor as given by Equation 3-21.

(3-21)

$$VAF = 0.88 - 0.71 \frac{S_A - 1}{S_A + 2.5}$$

WHERE

VAF = **Vertical Arching Factor**

S_A = **Hoop Thrust Stiffness Ratio**

(3-22)

$$S_A = \frac{1.43 M_S r_{CENT}}{EA}$$

WHERE

r_{CENT} = **radius to centroidal axis of pipe, in**

M_S = **one-dimensional modulus of soil, psi**

E = **apparent modulus of elasticity of pipe material, psi (See Appendix, Chapter 3)**

A = **profile wall average cross-sectional area, in^2/in, or wall thickness (in) for DR pipe**

One-dimensional modulus values for soil can be obtained from soil testing, geotechnical texts, or Table 3-12 which gives typical values. The typical values in Table 3-12 were obtained by converting values from McGrath [20].

TABLE 3-12
Typical Values of M_S, One-Dimensional Modulus of Soil

Vertical Soil Stress[1] (psi)	Gravelly Sand/Gravels 95% Std. Proctor (psi)	Gravelly Sand/Gravels 90% Std. Proctor (psi)	Gravelly Sand/Gravels 85% Std. Proctor (psi)
10	3000	1600	550
20	3500	1800	650
40	4200	2100	800
60	5000	2500	1000
80	6000	2900	1300
100	6500	3200	1450

* Adapted and extended from values given by McGrath[20]. For depths not shown in McGrath[20], the MS values were approximated using the hyperbolic soil model with appropriate values for K and n where n=0.4 and K=200, K=100, and K=45 for 95% Proctor, 90% Proctor, and 85% Proctor, respectively.

[1] Vertical Soil Stress (psi) = [soil depth (ft) x soil density (pcf)]/144

The radial directed earth pressure can be found by multiplying the prism load (pressure) by the vertical arching factor as shown in Eq. 3-23.

$$P_{RD} = (VAF)wH \tag{3-23}$$

WHERE

P_{RD} **= radial directed earth pressure, lb/ft²**
W **= unit weight of soil, pcf**
H **= depth of cover, ft**

The ring compressive stress in the pipe wall can be found by substituting P_{RD} from Equation 3-23 for P_E in Equation 3-13 for DR pipe and Equation 3-14 for profile wall pipe.

Earth Pressure Example

Determine the earth pressure acting on a 36" profile wall pipe buried 30 feet deep. The following properties are for one unique 36" profile pipe made from PE3608 material. Other 36" profile pipe may have different properties. The pipe's cross-sectional area, A, equals 0.470 inches²/inch, its radius to the centroidal axis is 18.00 inches plus 0.58 inches, and its apparent modulus is 27,000 psi. Its wall height is 2.02 in and its D_O equals 36 in +2 (2.02 in) or 40.04 in. Assume the pipe is installed in a clean granular soil compacted to 90% Standard Proctor (Ms = 1875 psi), the insitu soil is as stiff as the embedment, and the backfill weighs 120 pcf. (Where the excavation is in a stable trench, the stiffness of the insitu soil can generally be ignored in this calculation.) The following series of equations calculates the hoop compressive stress, S, in the pipe wall due to the earth pressure applied by the soil above the pipe. The earth pressure is reduced from the prism load by the vertical arching factor.

(From Equation 3-22)

$$S_A = \frac{1.43(1875\frac{lbs}{inch^2})(18.58\,inch)}{(28250\frac{lbs}{inch^2})(0.470\frac{inch^2}{inch})} = 3.93$$

(From Equation 3-21)

$$VAF = 0.88 - 0.71\frac{3.75-1}{3.75+2.5} = 0.56$$

(From Equation 3-23)

$$P_{RD} = 0.57(120\ pcf)(30\ ft) = 2016\frac{lb}{ft^2}$$

(From Equation 3-14)

$$S = \frac{P_{RD}D_O}{288A} = \frac{2052\ psf(40.04\ in)}{288\ (0.470\ in^2\ /\ in)} = 596\ psi \le 1000\ psi$$

(Allowable compressive stress per Table C.1, Appendix to Chapter 3)

Ring Deflection of Pipes Using Watkins-Gaube Graph

R. Watkins[1] developed an extremely straight-forward approach to calculating pipe deflection in a fill that does not rely on E'. It is based on the concept that the deflection of a pipe embedded in a layer of soil is proportional to the compression or settlement of the soil layer and that the constant of proportionality is a function of the relative stiffness between the pipe and soil. Watkins used laboratory testing to establish and graph proportionality constants, called Deformation Factors, D_F , for the stiffness ranges of metal pipes. Gaube[15, 16] extended Watkins' work by testing to include PE pipes. In order to predict deflection, the designer first determines the amount of compression in the layer of soil in which the pipe is installed using conventional geotechnical equations. Then, deflection equals the soil compression multiplied by the D_F factor. This bypasses some of the inherent problems associated with using the soil reaction modulus, E', values. The designer using the Watkins-Gaube Graph (Figure 3-6) should select conservative soil modulus values to accommodate variance due to installation. Two other factors to consider when using this method is that it assumes a constant Deformation Factor independent of depth of cover and it does not address the effect of the presence of ground water on the Deformation Factor.

To use the Watkins-Gaube Graph, the designer first determines the relative stiffness between pipe and soil, which is given by the Rigidity Factor, R_F. Equation 3-24 and 3-25 are for DR pipe and for profile pipe respectively:

(3-24)
$$R_F = \frac{12\, E_S\, (DR-1)^3}{E}$$

(3-25)
$$R_F = \frac{E_S D_m^{\ 3}}{EI}$$

WHERE

DR = **Dimension Ratio**

E_S = **Secant modulus of the soil, psi**

E = **Apparent modulus of elasticity of pipe material, psi**

I = **Pipe wall moment of inertia of pipe, in^4/in**

D_m = **Mean diameter (D_I + 2z or D_O – t), in**

The secant modulus of the soil may be obtained from testing or from a geotechnical engineer's evaluation. In lieu of a precise determination, the soil modulus may be related to the one-dimensional modulus, M_S, from Table 3-12 by the following equation where μ is the soil's Poisson ratio.

(3-26)
$$E_S = M_S \frac{(1+\mu)(1-2\mu)}{(1-\mu)}$$

TABLE 3-13
Typical range of Poisson's Ratio for Soil (Bowles [21])

Soil Type	Poisson's Ratio, μ
Saturated Clay	0.4-0.5
Unsaturated Clay	0.1-0.3
Sandy Clay	0.2-0.3
Silt	0.3-0.35
Sand (Dense)	0.2-0.4
Coarse Sand (Void Ratio 0.4-0.7)	0.15
Fine-grained Sand (Void Ratio 0.4-0.7)	0.25

Next, the designer determines the Deformation Factor, D_F, by entering the Watkins-Gaube Graph with the Rigidity Factor. See Fig. 3-6. The Deformation Factor is the proportionality constant between vertical deflection (compression) of the soil layer containing the pipe and the deflection of the pipe. Thus, pipe deflection can be obtained by multiplying the proportionality constant D_F times the soil settlement. If D_F is less than 1.0 in Fig. 3-6, use 1.0.

The soil layer surrounding the pipe bears the entire load of the overburden above it without arching. Therefore, settlement (compression) of the soil layer is proportional to the prism load and not the radial directed earth pressure. Soil strain, ε_S, may be determined from geotechnical analysis or from the following equation:

(3-27)

$$\varepsilon_S = \frac{wH}{144 E_S}$$

WHERE

w = unit weight of soil, pcf

H = depth of cover (height of fill above pipe crown), ft

E_S = secant modulus of the soil, psi

The designer can find the pipe deflection as a percent of the diameter by multiplying the soil strain, in percent, by the deformation factor:

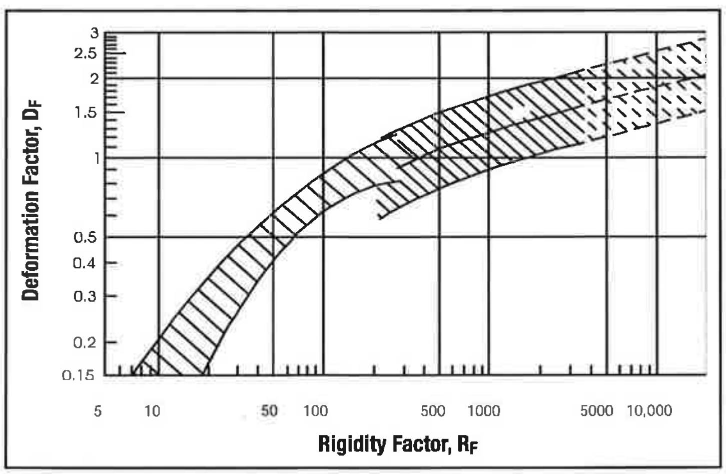

Figure 3-6 Watkins-Gaube Graph

(3-28)

$$\frac{\Delta X}{D_M}(100) = D_F \varepsilon_S$$

WHERE

$\Delta X/D_M$ multiplied by 100 gives percent deflection.

OD			Pipe inside diameter (d)	Minimum Wall Thickness (t)	Weight (w)
Nominal in.	Actual in.	DR	in.	in.	lb. per foot
		7	6.01	1.232	12.433
		7.3	6.12	1.182	12.010
		9	6.59	0.958	10.054
		9.3	6.66	0.927	9.771
		11	6.96	0.784	8.425
8	8.625	11.5	7.04	0.750	8.096
		13.5	7.27	0.639	7.001
		15.5	7.45	0.556	6.164
		17	7.55	0.507	5.657
		21	7.75	0.411	4.637
		26	7.92	0.332	3.784
		7	7.49	1.536	19.314
		7.3	7.63	1.473	18.656
		9	8.22	1.194	15.618
		9.3	8.30	1.156	15.179
		11	8.68	0.977	13.089
10	10.750	11.5	8.77	0.935	12.578
		13.5	9.06	0.796	10.875
		15.5	9.28	0.694	9.576
		17	9.41	0.632	8.788
		21	9.66	0.512	7.204
		26	9.87	0.413	5.878
		32.5	10.05	0.331	4.742
		7	8.89	1.821	27.170
		7.3	9.05	1.747	26.244
		9	9.75	1.417	21.970
		9.3	9.84	1.371	21.353
		11	10.29	1.159	18.412
12	12.750	11.5	10.40	1.109	17.693
		13.5	10.75	0.944	15.298
		15.5	11.01	0.823	13.471
		17	11.16	0.750	12.362
		21	11.46	0.607	10.134
		26	11.71	0.490	8.269
		32.5	11.92	0.392	6.671

OD			Pipe inside diameter (d)	Minimum Wall Thickness (t)	Weight (w)
Nominal in.	Actual in.	DR	in.	in.	lb. per foot
		7	9.76	2.000	32.758
		7.3	9.93	1.918	31.642
		9	10.70	1.556	26.489
		9.3	10.81	1.505	25.745
		11	11.30	1.273	22.199
14	14.000	11.5	11.42	1.217	21.332
		13.5	11.80	1.037	18.445
		15.5	12.09	0.903	16.242
		17	12.25	0.824	14.905
		21	12.59	0.667	12.218
		26	12.86	0.538	9.970
		32.5	13.09	0.431	8.044
		7	11.15	2.286	42.786
		7.3	11.35	2.192	41.329
		9	12.23	1.778	34.598
		9.3	12.35	1.720	33.626
		11	12.92	1.455	28.994
16	16.000	11.5	13.05	1.391	27.862
		13.5	13.49	1.185	24.092
		15.5	13.81	1.032	21.214
		17	14.00	0.941	19.467
		21	14.38	0.762	15.959
		26	14.70	0.615	13.022
		7	12.55	2.571	54.151
		7.3	12.77	2.466	52.307
		9	13.76	2.000	43.788
		9.3	13.90	1.935	42.558
		11	14.53	1.636	36.696
18	18.000	11.5	14.68	1.565	35.263
		13.5	15.17	1.333	30.491
		15.5	15.54	1.161	26.849
		17	15.76	1.059	24.638
		21	16.18	0.857	20.198
		26	16.53	0.692	16.480
		32.5	16.83	0.554	13.296

Chesser Island Road MSW Landfill | CCR Management Plans
Design Calculations

Chesser Island Road MSW Landfill
CCR Management Plans
Design Calculations

Chesser Island Road MSW Landfill
CCR Management Plans
Design Calculations
April 2017

ATLANTIC COAST
CONSULTING, INC.

Roswell, GA
630 Colonial Park Drive
Suite 110
Roswell, GA 30075
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212 S. Peters Road
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Phone: 865.531.9143

ATTACHEMENT I

October 2016 CCR Leachate Sample Results
R&B Site 2 Landfill

	Parameter	CCR Leachate	Units
General Chemistry/Water Quality	Alkalinity, Total	87.8	mg/L
	Chemical Oxygen Demand	17.2	mg/L
	Field pH	5.78	SU
	Field Turbidity	2.4	NTU
	Specific Conductance	1020	uS/cm
	Sulfate	378	mg/L
	Temperature	23.8	Celsius
	Total Dissolved Solids	711	mg/L
Metals	Antimony	ND	mg/L
	Arsenic	ND	mg/L
	Barium	0.048	mg/L
	Beryllium	ND	mg/L
	Boron	0.21	mg/L
	Calcium	59.7	mg/L
	Chloride	22.2	mg/L
	Chromium	ND	mg/L
	Cobalt	0.62	mg/L
	Copper	ND	mg/L
	Fluoride	0.34	mg/L
	Lead	ND	mg/L
	Nickel	0.09	mg/L
	Selenium	ND	mg/L
	Silver	ND	mg/L
	Thallium	ND	mg/L
	Vanadium	ND	mg/L
	Zinc	ND	mg/L

Notes:
ND = Not detected
NR = Not required
mg/L = milligrams per liter
uS/cm = milliSiemens per centimeter
SU = Standard Units
NTU = nephelometric turbidity units

ATTACHEMENT II

15 May 2017

John Workman
Waste Management

RE: LEACHATE COMPATIBILITY CERTIFICATION

Dear Mr. Workman,

I have reviewed the leachate analysis for the October 2016 CCR Leachate that you provided to us. Polyethylene geomembranes are compatible with and unaffected by the constituent contained therein. We expect no deleterious effects in performance as a result of exposure to this. I have also attached a technical note from CP Chem that details chemical compatibility of polyethylene in more detail. If you have any additional questions or concerns, please let me know.

Sincerely,

Nathan Ivy
Corporate Quality Control/Technical Manager
Agru America

Executive Offices: 500 Garrison Road, Georgetown, SC 29440 • 843 546-0600 • 800 321-1379 •
Sales Office: 800 Rockmead, Suite 122, Kingwood, TX 77339 • 281 358-4741 • 800 373-2478 •
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PREMIUM EXTRUSION AND RIGID PACKAGING RESINS

PE TIB-2 PACKAGING PROPERTIES

INTRODUCTION

The growth of plastic materials into the packaging market has been phenomenal in recent years. The versatility and design flexibility of high density polyethylene (HDPE) lends itself to injection molded, blow molded, extruded and rotationally molded applications. Technological developments such as coextrusion with barrier resins allow packages to be tailored to meet product-specific requirements, thus expanding the market at an ever-increasing rate.

Chevron Phillips Chemical Company LP (Chevron Phillips Chemical) has provided almost 50 years of plastic product development and processing expertise to the packaging industry. Marlex® high density polyethylene resins from Chevron Phillips Chemical continue to offer the excellent balance of physical and chemical properties needed for packaging applications: toughness, chemical resistance, gas/liquid permeation resistance and environmental stress-crack resistance. Realizing the increasing demands being placed on packaging materials by the proliferation of new products, Chevron Phillips Chemical continues to work closely with the packaging industry to develop improved Marlex® HDPE resins.

The feasibility of packaging a product in any plastic container depends heavily on the shelf life and display conditions to which it will be subjected. The only way to ensure the suitability of any package/product combination is to test it under

Top-load testing of Marlex® HDPE containers

representative conditions. Most resin suppliers and processors are equipped to evaluate the effect of the product on the package, but any evaluation of changes to the product itself requires specialized expertise, and generally must be tested by the manufacturer of that product.

PACKAGING PROPERTIES

The suitability of Marlex® HDPE for packaging applications is related to the density, melt index and molecular weight distribution of the resin. As the density increases, for example, the stiffness, softening temperature, resistance to permeation, and chemical resistance of the finished item will increase. Conversely, when melt index decreases, impact strength (toughness) will increase. Environmental stress-crack resistance (ESCR) is dependent on molecular weight distribution as well as density and melt index. In any one resin series, when density is constant, ESCR improves as the melt index decreases.

Marlex® HDPE molding and extrusion grade resins meet specifications published in the Federal Register by the Food and Drug Administration. The critical guidelines are covered in their document 21 CFR 177.1520.

Although it is difficult to recommend a particular grade of Marlex® HDPE for packaging applications without knowing the use environment, the following guidelines can assist in resin selection:

1. High melt index (lower molecular weight) resins are recommended for injection molded containers, due to the processing requirements.

2. For extrusion, thermoforming or blow molding, when maximum part rigidity is the primary objective, a low melt index (higher molecular weight), high density resin is recommended.

3. To obtain maximum environmental stress-crack resistance for extruded, thermoformed or blow molded packaging applications, a low-melt index (higher molecular weight) copolymer should be used.

Table 1 summarizes the general HDPE packaging guidelines based on packaging tests performed to date. From these tests, it can be determined which classes of products are packageable in HDPE. For example, most alcohols, ketones, or water soluble and water-based chemicals are packageable in HDPE, while some strong oxidizing agents (even though they are water based) cannot be successfully contained for any reasonable storage period.

Aromatic hydrocarbons permeate polyethylenes beyond acceptable packaging limits, and halogenated hydrocarbons permeate small polyethylene containers almost 100% in a short period of time.

TABLE 1
General Guidelines for HDPE Packaging

Water-Based Products
Most water-based products like household bleach and detergents are packageable. Gas permeation may be a problem with some products. Oxygen permeation into a container causes catsup to darken, and carbon dioxide is quickly lost from a carbonated beverage.

Aliphatic Hydrocarbons
High molecular weight products such as mineral oils, vegetable oils and motor oil can be packaged, although some consideration should be given to package deformation and permeability. Package size becomes important for such low molecular weight products as heptane and hexane. DOT regulations should also be reviewed.

Aromatic Hydrocarbons
Most of these products permeate excessively and cause package deformation. Typical products are benzene and orange oil.

Halogenated Hydrocarbons
Permeation levels are high and package deformation excessive. Carbon tetrachloride is an example.

Alcohols, Ketones, Aldehydes
Most of these products are packageable. Some may cause stress-cracks, but good resin selection can eliminate this problem. Package size is often the determining factor in many cases. Ethylene glycol and ethyl alcohol are both packageable.

Acids
Most acids are packageable; however, strong oxidizing acids like concentrated nitric acid and fuming sulfuric are exceptions. Two commercially packaged products are hydrofluoric acid and battery acid, which is dilute sulfuric.

PACKAGING TEST RESULTS

Data on the packageability of various products (such as food products, pharmaceuticals, industrial chemicals, etc.) in Marlex® high density polyethylene is presented in Appendix I. Although this data is useful in determining the effect a product will have on the resin, the importance of package design cannot be ignored. Such factors as wall thickness, part size and part geometry can make the difference between an acceptable or unacceptable package. This is especially true for those products that affect the package by such means as permeation, softening or distortion.

CHEMICAL RESISTANCE

To be suitable as a packaging material, the plastic must not have a chemical reaction to the product being packaged. The level of chemical resistance can be measured by the retention or loss of its physical properties. Chemical resistance is especially dependent on temperature, and the storage shelf life may have a significant bearing. Marlex® HDPE is considered a very effective packaging material, since it is one of the most chemically resistant plastics commercially available.

The chemical resistance data shown in Appendix I was obtained by immersing ASTM D638, Type IV tensile bars in the testing media for as long as three months at 80°F, 120°F and 150°F, then checking for weight change, tensile strength, staining, softening and embrittlement. The results are reported as follows:

Excellent
This product had no effect on Marlex® HDPE.

Good
Slight absorption occurs, but has little or no effect on the physical properties.

Fair
A loss of physical properties occurs. Package design and use conditions will determine whether or not HDPE can be used.

Poor
Significant loss of strength, softening or embrittlement occurs. High density polyethylenes are unsuitable for prolonged contact.

These classifications have been based on continuous exposure to the product for extended periods of time. A rating of "poor" does not always mean that the chemical environment would have an adverse effect on a Marlex® HDPE package. If the exposure period were very short, even at an elevated temperature, the package might still be acceptable. Only sufficient testing can confirm the suitability of the package. Additional chemical resistance data are shown in Appendix II.

PERMEABILITY

Permeation is one of the main factors governing the use of HDPE containers in product packaging. Primarily, permeation is considered a physical migration of a product through the container walls and its subsequent vaporization from outside surfaces. Obviously, an appreciable loss of product during shelf storage would prohibit a container's use in packaging applications. A weight loss of 3% per year (with no visual changes or substantial permeation of an essential component) is generally recognized as the maximum product loss acceptable.

If permeation is borderline, i.e., slightly above 3%, packaging in a large container may still prove acceptable due to the increased volume/surface-area ratio.

The permeability results shown in Appendix I were obtained using 4 oz. Boston Round bottles, filled with the liquid and stored for 4 months at 80°F. The bottles were weighed periodically and the average loss rate of the contents per week was established. The average loss per year was then calculated, and expressed as a percent of the original liquid weight. This is similar to the procedure described in ASTM D2684.

PRODUCT ALTERATION

As a result of permeation, product alteration can occur. There is the possibility that outside elements could permeate into a container and cause a weight gain. However, a weight gain or loss in a complex mixture of chemicals could change the concentration of key ingredients in the total product, making the package unreliable. For example, many perfumes and cosmetic products cannot be packaged in HDPE because, while the product base is contained, the scent is lost.

Another form of product alteration is the reaction of the product with a minute quantity of oxygen permeating through the walls into the headspace of the container. Normally, this small amount of oxygen is not prohibitive. In some products, however, a discoloration or an actual change of the active ingredients can occur. Product taste is another factor to be considered.

These potential product alterations highlight the necessity to pre-determine the effects of a proposed package on the product.

ENVIRONMENTAL STRESS-CRACK RESISTANCE

The environmental stress crack resistance of a container is a combination of the inherent resistance of the resin, the design and molding quality of the finished container, and the type of product packaged.

Under certain conditions, HDPE may exhibit mechanical failure by cracking. Even though ESCR test results may be negative under a given set of circumstances, there are several options that can be used to help rectify the situation. For example, a more resistant (higher molecular weight) resin, or a change in container design or manufacturing technique may be employed separately or in combination to overcome many environmental stress-crack problems.

To determine whether or not a liquid product will cause stress-crack, tests can be run on compression molded sheets using ASTM D1693. This is commonly referred to as the Bell Laboratory bent strip test. Often, it is desirable to test the container itself for stress-crack resistance. In this case, ASTM D2561 is a suitable test procedure. Appendix I includes the results of stress-crack testing.

GAS PERMEABILITY

As indicated by the data in Appendix I, high density polyethylene is an excellent barrier for many products, including gases. Table 2 summarizes the permeability rate of some common gases through Marlex® HDPE. Since the permeability rate is influenced by the density of the barrier as well as functional groups of the permeating gas, these rates are considerably lower than those obtained with low density polyethylene.

TABLE 2
Gas Permeability of Marlex® HDPE

Gas	**Rate** cc/mil/24 hrs/100 in^2
Carbon Dioxide	345
Ethane	236
Hydrogen	321
Natural Gas	113
Oxygen	111
Freon 12	95
Helium	247
Nitrogen	53
Sulfur Dioxide	306

PREMIUM EXTRUSION AND RIGID PACKAGING RESINS

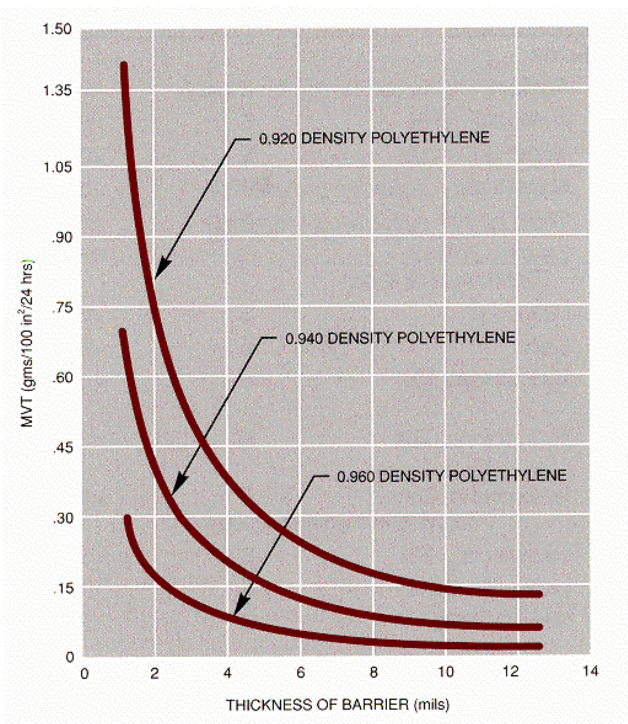
WATER VAPOR TRANSMISSION

In many packaging applications, HDPE is used because of its moisture barrier properties. As with other gases and liquids, the density of the barrier affects the transmission rate; i.e., the higher the density the more efficient the barrier.

Figure 1 shows the effect of film thickness and density on the water vapor transmission through three polyethylene resins of different densities. This indicates that at any given film thickness the high density film is the superior barrier. These data were obtained by ASTM E96, Procedure E, which specifies a temperature of 100°F and 90% relative humidity.

FIGURE 1

Effect of Film Thickness on Water Vapor Transmission



SUMMARY

The list of products packaged in HDPE has grown considerably in recent years. Chevron Phillips Chemical has established itself as a leader in the plastics packaging arena by offering consistently high quality Marlex® HDPE resins, backed by knowledgeable Plastics Technical Center support. Our outstanding technical staff has developed specialized grades of Marlex® resins to meet the varying requirements of such products as light weight milk bottles, durable and resealable motor oil "cans", and laundry detergent/bleach containers.

For additional information on a Marlex® resin suited to your packaging needs, please contact our Sales and Marketing groups for help. Detailed contact information is provided at the end of this document.

Support Information

The appendixes on the following pages present detailed packageability and chemical resistance information for our Marlex® HDPE resins.

APPENDIX 1

Packageability of Various Products in Marlex® HDPE

Product	Chemical Resistance	Permeability % Loss/Year	Can Cause Stress Cracking?	Remarks
Acids				
Acetic, 1 - 10%	E	<3	Yes	
Acetic, 10 - 60%	E	<3	Yes	
Acetic, 80-100%	E	<3	Yes	
Aqua Regia	P	<3	-	Attack occurs at ambient temperature.
Chromic, 20%	E	<3	No	
Cleaning Solution (Dichromate-Sulfuric)	G	<3	No	Staining and brittleness will occur at elevated temperature.
Citric	E	<3	No	
Gallic	E	<3	No	
Hydrochloric, 10%	E	<3	No	A slight staining may occur at elevated temperature.
Hydrochloric. 35%	E	<3	No	A slight staining may occur at elevated temperature.
Hydrochloric, Conc.	E	<3	No	A slight staining may occur at elevated temperature.
Hydrofluoric, 75%	E	<3	No	
Lactic, 10 - 90%	E	<3	No	
Nitric, 0 - 30%	G	<3	No	A slight staining may occur at elevated temperature.
Nitric, 30 - 50%	G	<3	No	Staining will occur at elevated temperature.
Nitric, 95 - 98%	P	<3	-	Staining and brittleness will occur at ambient temperature.
Phosphoric, 30 - 90%	E	<3	No	
Stearic, 100%	E	-	No	
Sulfuric, 70%	G	<3	No	Stiffening and embrittlement will occur at elevated temperature.
Sulfuric, 80%	G	<3	No	Stiffening and embrittlement will occur at elevated temperature.
Sulfuric, Fuming	P	<3	No	Stiffening and embrittlement will occur at elevated temperature.
Bases				
Ammonium Hydroxide, 30%	E	<3	No	
Barium Hydroxide, 30%	E	<3	No	
Calcium Hydroxide, 30%	E	<3	No	
Potassium Hydroxide, 30%	E	<3	No	
Sodium Hydroxide, 30%	E	<3	No	

Legend: E – Excellent G – Good F – Fair P – Poor

APPENDIX 1

Packageability of Various Products in Marlex® HDPE

Product	Chemical Resistance	Permeability % Loss/Year	Can Cause Stress-Cracking?	Remarks
Food & Food Products				
Beet Juice	E	<3	No	A slight staining will occur.
Beer	E	<3	No	
Carrot Juice	E	<3	No	
Catsup (tomato based sauce)	E	<3	No	A slight staining will occur.
Cherries	E	<3	No	A slight staining will occur.
Cider	E	<3	Yes	
Cocoa, hot	E	<3	No	
Coffee, hot	E	<3	No	
Cola	E	<3	No	
Dyes (Vegetable)	E	<3	No	
Gelatine	E	Nil	No	
Gin	E	<3	No	
Glucose, Saturated	E	<3	No	
Lard	G	<3	Yes	Container distortion may occur.
Lemon Juice	E	<3	No	
Margarine	G	<3	Yes	
Marmalade & Jam	E	<3	No	
Milk	E	<3	No	
Molasses	E	<3	No	
Orange Extract	E	<3	No	
Prune Juice	E	<3	No	A slight staining will occur.
Salt (sodium chloride)	E	Nil	No	
Sugar	E	Nil	No	
Tomato Juice	E	<3	No	A slight staining will occur.
Vinegar	E	<3	Yes	
Vanilla Extract	E	<3	Yes	
Whiskey	E	<3	No	
Wine	E	<3	No	
Yeast	E	Nil	No	

APPENDIX 1

Packageability of Various Products in Marlex® HDPE

Product	Chemical Resistance	Permeability % Loss/Year	Can Cause Stress-Cracking?	Remarks
Household, Toiletries & Pharmaceutical Products				
Bleaches	E	<3	No	
Deodorants (all types)	E	<3	No	
Detergents (standard)	E	<3	Yes	
Detergents (heavy duty)	E	<3	Yes	
Dry Cleaners	G	<3	Yes	
Glycerine	E	<3	No	
Hair Oil	E	<3	Yes	
Hair Shampoo	E	<3	Yes	
Hair Wave Lotions	E	<3	Yes	
Hand Creams	E	<3	Yes	
Hydrogen Peroxide, 3%	E	<3	No	
Inks	E	<3	No	A slight staining may occur.
Iodine (tincture)	G	<3	No	A light staining and embrittlement may occur after prolonged use.
Lighter Fluid	G	High	Yes	
Lipstick	E	Nil	No	Some staining may occur.
Mascara	E	Nil	No	
Mercurochrome	G	<3	No	Some staining may occur after prolonged use.
Nail Polish	F	4	Yes	Some softening will occur after prolonged contact
Rouge	E	Nil	No	
Shaving Lotion	G	<3	Yes	Some stiffening will occur.
Shoe Polish (liquid)	G	High	Yes	Some stiffening will occur.
Shoe Polish (paste)	G	-	Yes	Some staining will occur.
Soap	E	<3	Yes	
Suntan Lotion	E	<3	No	
Turpentine	P	8.5	No	
Wax (liquid & paste)	E	<3	Yes	

APPENDIX 1

Packageability of Various Products in Marlex® HDPE

Product	Chemical Resistance	Permeability % Loss/Year	Can Cause Stress-Cracking?	Remarks
Industrial Chemicals				
Acetone	G	3.4	No	A slight softening will occur.
Alums (all types) Conc.	E	<3	No	
Ammonium Nitrate, Sat'd	E	<3	No	
Amyl Acetate	G	4.0	No	A slight softening will occur.
Amyl Alcohol, 100%	E	<3	Yes	
Amyl Chloride, 100%	G	High	No	Softening will occur.
Benzaldehyde	E	<3	No	
Benzene	G	High	No	
Boric Acid, Conc. Solution	E	<3	No	
Butyl Alcohol	E	<3	No	
Calcium Chloride Saturated Solution	E	<3	No	
Carbon Tetrachloride	P	80	Yes	Softening and part deformation will occur at elevated temperature.
Chlorobenzene	P	High	Yes	Softening and part deformation will occur
Chloroform	P	High	Yes	Softening and part deformation will occur
Cyclohexanol	G	<3	Yes	
Developers, Photographic	E	<3	No	
Dibutylphthalate	E	<3	No	
Ethylene Glycol	E	<3	No	
Ethyl Acetate	F	9	No	Softening and part deformation will occur.
Ethyl Alcohol	E	<3	Yes	
Ethyl Ether	F	140	No	Softening and part distortion will occur.
Ethylene Chloride	P	High	No	Softening and part distortion will occur.
Formaldehyde, 40%	E	<3	No	
Furfural, 100%	E	<3	No	
Gasoline	G	High	No	
Glycerol	E	<3	No	
Mercury	E	Nil	No	
Methyl Alcohol	E	<3	Yes	
Phenol, 90%	E	<3	No	
Pickling & Plating Solution	E	<3	No	Sulfuric acid/nitric acid mixtures will cause embrittlement at high temp.

APPENDIX 1

Packageability of Various Products in Marlex® HDPE

Product	Chemical Resistance	Permeability % Loss/Year	Can Cause Stress-Cracking?	Remarks
Industrial Chemicals				
Potassium Dichromate	E	Nil	No	
Propyl Alcohol	E	<3	Yes	
Silver Nitrate Solution	E	<3	No	
Sodium Bicarbonate, Sat'd.	E	<3	No	
Toluene	P	High	No	Softening, swelling and part distortion will occur.
Trichloroethylene	P	High	No	Softening, swelling and part distortion will occur.
Oils				
Camphor	F	High	No	A slight softening will occur.
Castor	G	<3	Yes	A slight softening will occur at elevated temperature
Cottonseed	G	<3	Yes	A slight softening and part distortion will occur at high temp.
Linseed	G	<3	No	A slight softening and part distortion will occur at elevated temperature
Mineral	G	<3	Yes	A slight softening and part distortion will occur.
Motor Oil (SAE 10)	G	<3	No	A slight softening and part distortion will occur at high temp.
Orange	G	High	No	A slight softening and part distortion will occur
Peppermint	G	High	Yes	A slight softening and part distortion will occur
Transformer	G	<3	No	A slight softening and part distortion will occur
Vegetable	G	<3	Yes	A slight softening and part distortion will occur at high temp.
Pine	G	High	Yes	A slight softening and part distortion will occur.

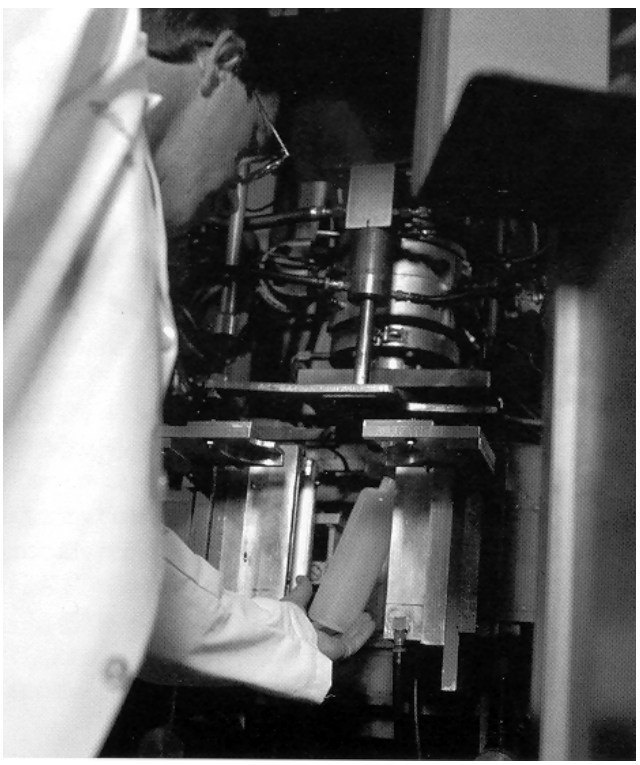
Legend: E – Excellent G – Good F – Fair P – Poor

APPENDIX II

Chemical Resistance of Polyethylene

Chemical attack may be accompanied by any one, or a combination of the following: swelling, discoloration, brittleness or loss of strength. The following data are derived from laboratory tests using non-stressed immersed specimens under static conditions. The ratings shown are based mainly on chemical attack, solvent swelling and changes in physical properties under such conditions.

Legend: "S" - Satisfactory
"O" - Some attack
"U" - Unsatisfactory



Coextrusion blow molding at Bartlesville Technology Center

	High Density	
Reagent	70 ºF	140 ºF
Acrylic Emulsions	S	S
Aluminum Chloride Dilute	S	S
Aluminum Chloride Concentrated	S	S
Aluminum Fluoride Concentrated	S	S
Aluminum Sulfate Concentrated	S	S
Ammonia 100% Dry Gas	S	S
Ammonium Carbonate	S	S
Ammonium Chloride Saturated	S	S
Ammonium Fluoride 20%	S	S
Ammonium Metaphosphate Saturated	S	S
Ammonium Persulfate Saturated	S	S
Ammonium Sulfate Saturated	S	S
Ammonium Sulfide Saturated	S	S
Ammonium Thiocyanate Saturated	S	S
Aniline 100%	S	--
Antimony Chloride	S	S
Barium Carbonate Saturated	S	S
Barium Chloride Saturated	S	S
Barium Sulfate Saturated	S	S
Barium Sulfide Saturated	S	S
Benzene Sulfonic Acid	S	S
Bismuth Carbonate Saturated	S	S
Black Liquor	S	S
Borax Cold Saturated	S	S
Boric Acid Dilute	S	S
Bromic Acid 10%	S	S
Bromine Liquid 100%	O	U
Butanediol10%	S	S
Butanediol 60%	S	S
Butanediol100%	S	S
Butyl Acetate 1 00%	O	U
Calcium Bisulfide	S	S
Calcium Carbonate Saturated	S	S
Calcium Chlorate Saturated	S	S
Calcium Hypochlorite Bleach Solution	S	S
Calcium Nitrate 50%	S	S
Calcium Sulfate	S	S
Carbon Dioxide 100% Dry	S	S
Carbon Dioxide 100% Wet	S	S
Carbon Dioxide Cold Saturated	S	S
Carbon Disulfide	--	U
Carbon Monoxide	S	S
Chlorine Liquid	O	U
Chlorosulfonic Acid 100%	U	U
Chrome Alum Saturated	S	S
Chromic Acid 50%	S	O
Cider	S	S
Coconut Oil Alcohols	S	S
Copper Chloride Saturated	S	S
Copper Cyanide Saturated	S	S
Copper Fluoride 2%	S	S
Copper Nitrate Saturated	S	S
Copper Sulfate Dilute	S	S
Copper Sulfate Saturated	S	S
Cuprous Chloride Saturated	S	S
Cyclohexanone	U	U

Reagent	High Density 70 ºF	High Density 140 ºF
Dextrin Saturated	S	S
Dextrose Saturated	S	S
Disodium Phosphate	S	S
Diethylene Glycol	S	S
Emulsions Photographic	S	S
Ethyl Chloride	O	U
Ferric Chloride Saturated	S	S
Ferric Nitrate Saturated	S	S
Ferrous Chloride Saturated	S	S
Ferrous Sulfate	S	S
Fluoboric Acid	S	S
Fluorine	S	U
Fluosilicic Acid 32%	S	S
Fluosilicic Acid Concentrate	S	S
Formic Acid 20%	S	S
Formic Acid 50%	S	S
Formic Acid 100%	S	S
Fructose Saturated	S	S
Fuel Oil	S	U
Glycol	S	S
Glycolic Acid 30%	S	S
Hydrobromic Acid 50%	S	S
Hydrocyanic Acid Saturated	S	S
Hydrochloric Acid 30%	S	S
Hydrofluoric Acid 40%	S	S
Hydrofluoric Acid 60%	S	S
Hydrogen 100%	S	S
Hydrogen Bromide 10%	S	S
Hydrogen Chloride Gas Dry	S	S
Hydroquinone	S	S
Hydrogen Sulfide	S	S
Hypochlorous Acid Concentrated	S	S
Lead Acetate Saturated	S	S
Magnesium Carbonate Saturated	S	S
Magnesium Chloride Saturated	S	S
Magnesium Hydroxide Saturated	S	S
Magnesium Nitrate Saturated	S	S
Magnesium Sulfate Saturated	S	S
Mercuric Chloride	S	S
Mercuric Cyanide Saturated	S	S
Mercurous Nitrate Saturated	S	S
Methyl Ethyl Ketone 100%	U	U
Methyl Bromide	O	U
Methylsulfuric Acid	S	S
Methylene Chloride 100%	U	U
Nickel Chloride Saturated	S	S
Nickel Nitrate Concentrated	S	S
Nickel Sulfate Saturated	S	S
Nicotinic Acid	S	S
Nitric Acid <50%	S	O
Nitrobenzene 100%	U	U
Oleum Concentrated	U	U
Oxalic Acid Dilute	S	S
Oxalic Acid Saturated	S	S
Petroleum Ether	U	U
Phosphoric Acid 0 - 30%	S	S
Phosphoric Acid 90%	S	S
Photographic Solutions	S	S
Potassium Bicarbonate Saturated	S	S
Potassium Borate 1%	S	S
Potassium Bromate 10%	S	S
Potassium Bromide Saturated	S	S
Potassium Carbonate	S	S
Potassium Chlorate Saturated	S	S
Potassium Chloride Saturated	S	S
Potassium Chromate 40%	S	S
Potassium Cyanide Saturated	S	S
Potassium Ferri/Ferro Cyanide	S	S
Potassium Fluoride	S	S
Potassium Nitrate Saturated	S	S
Potassium Perborate Saturated	S	S
Potassium Perchlorate 10%	S	S
Potassium Permanganate 20%	S	S
Potassium Sulfate Concentrated	S	S
Potassium Sulfide Concentrated	S	S
Potassium Sulfite Concentrated	S	S
Potassium Persulfate Saturated	S	S
Propargyl Alcohol	S	S
Propylene Glycol	S	S
Rayon Coagulating Bath	S	S
Sea Water	S	S
Shortening	S	S
Silicic Acid	S	S
Sodium Acetate Saturated	S	S
Sodium Benzoate 35%	S	S
Sodium Bisulfate Saturated	S	S
Sodium Bisulfite Saturated	S	S
Sodium Borate	S	S
Sodium Bromide Oil Solution	S	S
Sodium Carbonate Concentrated	S	S
Sodium Carbonate	S	S
Sodium Chlorate Saturated	S	S
Sodium Chloride Saturated	S	S
Sodium Cyanide	S	S
Sodium Dichromate Saturated	S	S
Sodium Ferricyanide Saturated	S	S
Sodium Ferrocyanide	S	S
Sodium Fluoride Saturated	S	S
Sodium Nitrate Sodium Sulfate	S	S
Sodium Sulfide 25% to Saturated	S	S
Sodium Sulfite Saturated	S	S
Stannous Chloride Saturated	S	S
Stannic Chloride Saturated	S	S
Starch Solution Saturated	S	S
Sulfuric Acid <50%	S	S
Sulfuric Acid 96%	O	U
Sulfuric Acid 98% Concentrated	O	U
Sulfurous Acid	S	S
Tannic Acid 1 0%	S	S
Tartaric Acid Saturated	--	--
Tetralin	U	U
Tetrahydrofuran	O	O
Transformer Oil	S	O
Trichloroacetic Acid 10%	S	S
Trisodium Phosphate Saturated	S	S
Urea	S	S
Urine	S	S
Wetting Agents	S	S
Xylene	U	U
Zinc Chloride Saturated	S	S
Zinc Sulfate Saturated	S	S

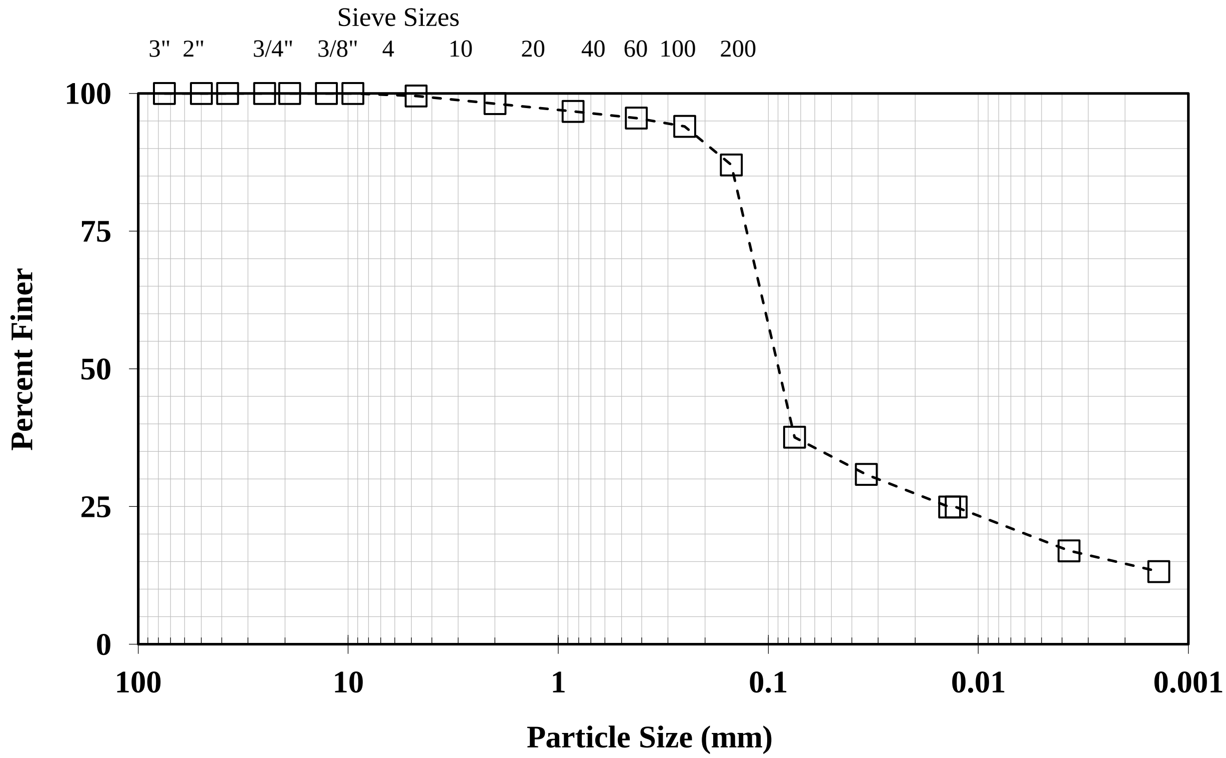
If we may be of further assistance, please contact our Polyethylene Sales and Marketing team. Contact information is available at this web site http://www.cpchem.com/index.asp, along with links to our polyethylene resins and MSDS sheets.

Additional information regarding the chemical resistance of Marlex® polyethylene is presented in other Plastic Technical Center publications. This data is provided for use only as guidelines in preliminary determination of packageability because chemical compatibility is highly dependent on storage and use conditions. Furthermore, many products are combinations of chemicals so the ultimate compatibility with the packaging material involves testing the combination of the product material and its proposed container.

Last revised April 2005

Particle Size Analysis for Soils

Client: Atlantic Coast Consulting, Inc. TRI Log#: 20096.1
Project: Southern Company Brunswick Test Method: ASTM D422
Sample: CA-1



Sieve Analysis	
Sieve Size	Percent Passing
3 in. (76.2 mm)	100.0
2 in. (50.8 mm)	100.0
1.5 in. (38.1 mm)	100.0
1 in. (25.4 mm)	100.0
3/4 in. (19.0 mm)	100.0
1/2 in. (12.7 mm)	100.0
3/8 in. (9.51 mm)	100.0
No. 4 (4.76 mm)	99.5
No. 10 (2.00 mm)	98.2
No. 20 (0.841 mm)	96.7
No. 40 (0.420 mm)	95.5
No. 60 (0.250 mm)	94.0
No. 100 (0.149 mm)	87.0
No. 200 (0.074 mm)	37.6
Hydrometer Analysis	
Particle Size	Percent Passing
0.005 mm	- -
0.002 mm	14.6

USCS Classification (ASTM D2487)	- -	
As-Received Moisture Content (%)	(ASTM D2216)	- -
Atterberg Limits (ASTM D4318, Method A : Multipoint)	Liquid Limit	- -
	Plastic Limit	- -
	Plastic Index	- -
Notes: Specimen was air dried.. (NL = No Liquid Limit, NP = No Plastic Limit)		
Specific Gravity	(ASTM D854)	- -
Organic Content (%)	(ASTM D2974)	- -
Carbonate Content (%)	(ASTM D4373)	- -

Jeffrey A. Kuhn, Ph.D., P.E., 4/15/2016
Quality Review/Date
Tested by: KH & PC