APPENDIX VI-H

COVER SYSTEM CALCULATIONS

APPENDIX VI-H.1

GEOCOMPOSITE DRAINAGE LAYER EVALUATION

Geosyntec consultants

COMPUTATION COVER SHEET

Client: DRPI **Project:** DRPI Landfill Expansion **Project #:** ME1571 **Task #:** 1

TITLE OF COMPUTATIONS FINAL COVER DRAINAGE LAYER EVALUATION

COMPUTATIONS BY: Signature [signature] 2/19/2018 DATE

Printed Name and Title: Chunling Li, Project Engineer

ASSUMPTIONS AND PROCEDURES CHECKED BY: (Peer Reviewer) Signature [signature] 2/20/2018 DATE

Printed Name and Title: Andrew Stallings, Senior Staff Engineer

COMPUTATIONS CHECKED BY: Signature [signature] 2/20/2018 DATE

Printed Name and Title: Andrew Stallings, Senior Staff Engineer

COMPUTATIONS BACKCHECKED BY: (Originator) Signature [signature] 2/20/2018 DATE

Printed Name and Title: Chunling Li, Project Engineer

APPROVED BY: (PM or Designate) Signature [signature] 2/21/2018 DATE

Printed Name and Title: David Espinoza, Senior Principal

APPROVAL NOTES:

REVISIONS (Number and initial all revisions)

NO.	SHEET	DATE	BY	CHECKED BY	APPROVAL

FINAL COVER SYSTEM DRAINAGE LAYER EVALUATION

PURPOSE

The purpose of this calculation package is to present and verify the adequacy of the design of the drainage and filter components of the final cover system for the proposed vertical expansion at the Delaware Recyclable Products, Inc. (DRPI) Landfill in New Castle, Delaware.

BACKGROUND

Two alternatives of the final cover system proposed for DRPI consists of the following components:

Alternative 1:

- 6-in thick topsoil layer;
- 18-in thick protective soil layer;
- geocomposite drainage layer;
- 40-mil HDPE geomembrane; and
- prepared subbase (including grading layer).

Alternative 2:

- 6-in thick topsoil layer;
- 18-in thick protective soil layer;
- geotextile filter;
- 50-mil combination HDPE or LLDPE geomembrane/ drainage layer; and
- prepared subbase (including grading layer).

The 50-mil combination HDPE or LLDPE geomembrane/ drainage layer (e.g., Super Gripnet or similar product) is a geomembrane with a drainage layer on top of it. The purpose of the drainage layer is to convey the water infiltrating from the cover soil to the cover system drainage terraces and perimeter channels to prevent seepage forces and buoyancy effects from reducing the slope stability of the cover soil. The purpose of the geotextile is to allow for free flow of percolated water from the overlying cover soil into the drainage layer and to prevent the migration of particles of the cover soil into the drainage layer. The purpose of the geomembrane cover is to act as an infiltration barrier for the water.

The drainage capacity of the drainage layer and the geotextile filter are evaluated next. The flow capacity of the drainage layer is considered to be adequate if the hydraulic head on the geomembrane cover is less than the thickness of the drainage layer. Additionally, the amount of water which leaks through the geomembrane as compared to the total precipitation on the cover is used to calculate the hydraulic efficiency of the cover system.

GEOTEXTILE FILTER EVALUATON

Assume that a typical needle-punched non-woven geotextile will be used as a filter for Alternative 2 Cover. The selected geotextile should be designed such that the hydraulic conductivity, apparent opening size, and mechanical properties are compatible with the overlying final cover soil. The requirement obtained from this evaluation is also applicable to the geotextile component of the geocomposite for Alternative 1 Cover.

Based on Geosyntec's project experience and guidelines presented by FHWA [1990], the following design criteria must be satisfied:

1. the geotextile must retain particles of the protective soil;
2. the geotextile must be permeable enough to allow free flow of any water that infiltrates through the protective soil;
3. the geotextile must not clog during the design life of the facility; and
4. the geotextile must have sufficient mechanical properties for survivability and durability during the post-closure period.

Required Properties

Retention Criterion

Based on Geosyntec project experience, the apparent opening size of the geotextile (O_{95}) should meet the following design criteria:

$$O_{95}/d_{85} < 2 \quad \text{and} \quad O_{95}/d_{15} > 2$$

where d_{85} and d_{15} are the particle sizes for the protective soil for which 85 and 15 percent, respectively, of the particles are finer by weight and O_{95} is the apparent opening size (AOS). According to the manufacturer's information, a typical 7 to 8 oz/yd^2 (240 to 270 g/m^2) geotextile has an apparent opening size (O_{95}) of 0.18 to 0.21 mm. Therefore, for this type of geotextile, the protective soil should meet the following grain size distribution requirements:

d_{85} > 0.09 to 0.105 mm (170 to 140 U.S. Std. Sieve); and

d_{15} < 0.09 to 0.105 mm (170 to 140 U.S. Std. Sieve).

Hydraulic Conductivity Criterion

It is recommended that the minimum hydraulic conductivity of the geotextile be greater than or equal to ten times the maximum hydraulic conductivity for the overlying soil (i.e., protective soil) [FHWA, 1990].

$$k_{geotextile\text{-}min} > 10\ k_{protective\ soil}$$

If it is conservatively assumed that the maximum hydraulic conductivity of the protective soil material is 1×10^{-3} cm/s, then the minimum hydraulic conductivity of the geotextile must be greater than or equal to 1×10^{-2} cm/s. Therefore, to have a minimum k of 1×10^{-2} cm/s, the minimum required permittivity for a typical 8-oz/yd^2 (270 g/m^2) geotextile (typically 95-mil (2.4-mm) thick) is 0.04 sec^{-1}. Manufacturer's literature indicates that this permittivity can be met by most needlepunched non-woven geotextiles.

Clogging Criterion

The minimum porosity (η_g) recommended for the geotextile is $\eta_g > 30\%$. This property value can be met by most non-woven geotextiles.

Mechanical Properties

The geotextile component of the geocomposite drainage layer must satisfy the following:

Property	Test Method	Specification
Grab strength	ASTM D 4632	min. 180 lb
Tear strength	ASTM D 4533	min. 75 lb
Puncture strength	ASTM D 4833	min. 75 lb

DRAINAGE COMPONENT OF GEOMEMBRANE

The hydraulic transmissivity of the drainage layer should be high enough so that the hydraulic head on the geomembrane cover (and within the geocomposite) is less than the thickness of the drainage layer.

The USEPA Hydrologic Evaluation of Landfill Performance (HELP) model is used to evaluate the hydraulic head on the geomembrane. The HELP model is capable of estimating the volume of infiltration into the final cover system as a function of precipitation and climate, landfill cover system geometry, and soil properties.

The HELP model is used to estimate the average head on the geomembrane cover for a 30-year simulation. In selecting the hydraulic conductivity of the drainage layer for HELP modeling, a combined reduction factor of 10.4 was applied to account for the effects of creep, degradation and clogging, following the recommendation of Koerner [2004]. The following input parameters are used in the HELP model.

HELP Model Input and Output	Comments
Climate	Wilmington, Delaware (precipitation, temperature, and weather) Wilmington, Delaware (evapotranspiration)
SCS Curve Number	Compute based on 4 percent slope with a length of 500 feet and good ground cover
Topsoil and Protective Cover	24-in. thick vertical percolation layer, Material Texture Number 7, k_{sat} = $0.52X10^{-3}$ cm/s
Drainage Layer of Super Gripnet Geomembrane (Alternative 2)	0.13-in. thick drainage net, lateral percolation layer, k_{sat} = 4.8 cm/s, Slope = 2%, Length = 50 ft
Geocomposite Drainage Layer (Alternative 1)	0.25-in. thick drainage net, lateral percolation layer, k_{sat} = 1 cm/s, Slope = 2%, Length = 50 ft

The HELP model output is included as Attachment A. As shown in the output, the head above the geomembrane component for Alternatives 1 and 2 is calculated to be 0.039 inch and 0.008 inch (annual average value), respectively. These calculated heads are less than the thickness of the drainage layer (i.e., 0.25 inch for Alternative 1, and 0.13 inch for Alternative 2). Thus, the drainage capacity is considered to be sufficient.

HYDRAULIC EFFICIENCY OF FINAL COVER SYSTEM

The efficiency of the cover geomembrane is evaluated by comparing the precipitation that falls on the landfill to the calculated infiltration through the final cover system. The following equation is used:

$$\varepsilon = \frac{P_y - I}{P_y} \times 100\%$$

where:

- ε = cover system efficiency (percent);
- P_y = average annual total precipitation (in.); and
- I = average annual total infiltration (in.).

Infiltration through the geomembrane is estimated using the HELP Model output shown in Appendix A. In the analysis, it is conservatively assumed that the geomembrane defects are 1 cm^2/acre, and the quality of placement is poor. The subgrade soil is conservatively neglected (i.e., water percolates through the geomembrane defects freely). For the worst case of Alternatives 1 and 2 cover system, the HELP model predicts a percolation rate of 0.0071 inch out of a 40.7 total annual precipitation. Thus, the cover system efficiency is calculated as:

$$\varepsilon = \frac{40.7 - 0.0071}{40.7} = 99.98\%$$

Based on the results presented above, the hydraulic efficiency of the proposed final cover system at DRPI is adequate.

REFERENCES

FHWA (by STS Consultants, Ltd., and GeoServices, Inc.), *Geotextile Design and Construction Guidelines*, Washington, D.C., Apr 1990.

Giroud, J.P. and Bonaparte, R., "Leakage Through Liners Constructed with Geomembranes; Part I: Geomembrane Liners", Geotextiles and Geomembranes, Vol 8, No. 1, 1989, pp. 27-67.

Giroud, J.P., Khatami, A. And Badu-Tweneboah, K., "Evaluation of the Rate of Leakage Through Composite Liners", Geotextiles and Geomembranes, Vol. 8, No. 4, 1989, pp. 337-340.

Koerner, R.M., "Designing with Geosynthetics", Prentice Hall, 2004.

United States Environmental Protection Agency, "Hydrologic Evaluation of Landfill Performance", Version 3.03, Sept 1994.

FIGURE

High Density Polyethylene Super Gripnet® Liner

agru america

Product Data

Property	Test Method	Values			
Thickness (min. ave.), mil (mm)	ASTM D5994*	50 (1.25)	60 (1.5)	80 (2.0)	100 (2.5)
Thickness (lowest indiv.), mil (mm)	ASTM D5994*	50 (1.25)	54 (1.35)	72 (1.8)	90 (2.25)
*The thickness values may be changed due to project specifications (i.e., absolute minimum thickness)					
Drainage Stud Height (min. ave.), mil (mm)	ASTM D7466	130 (3.30)	130 (3.30)	130 (3.30)	130 (3.30)
Friction Spike Height (min. ave.), mil (mm)	ASTM D7466	175 (4.45)	175 (4.45)	175 (4.45)	175 (4.45)
Density, g/cc, minimum	ASTM D792, Method B	0.94	0.94	0.94	0.94
Tensile Properties (ave. both directions)	ASTM D6693, Type IV				
Strength @ Yield (min. ave.), lb/in width (N/mm)	2 in/minute	110 (19.3)	132 (23.1)	176 (30.8)	220 (38.5)
Elongation @ Yield (min. ave.), % (GL=1.3in)	5 specimens in each direction	13	13	13	13
Strength @ Break (min. ave.), lb/in width (N/mm)		110 (19.3)	132 (23.1)	176 (30.8)	220 (38.5)
Elongation @ Break (min. ave.), % (GL=2.0in)		200	200	200	200
Tear Resistance (min. ave.), lbs. (N)	ASTM D1004	38 (169)	40 (178)	53 (236)	64 (285)
Puncture Resistance (min. ave.), lbs. (N)	ASTM D4833	80 (356)	90 (400)	120 (534)	150 (667)
Carbon Black Content (range in %)	ASTM D4218	2 - 3	2 - 3	2 - 3	2 - 3
Carbon Black Dispersion (Category)	ASTM D5596	Only near spherical agglomerates			
	for 10 views: 9 views in Cat. 1 or 2, and 1 view in Cat. 3				
Stress Crack Resistance (Single Point NCTL), hours	ASTM D5397, Appendix	300	300	300	300
Oxidative Induction Time, minutes	ASTM D3895, 200°C, 1 atm O_2	≥100	≥100	≥100	≥100
Melt Flow Index, g/10 minutes	ASTM D1238, 190°C, 2.16kg	≤1.0	≤1.0	≤1.0	≤1.0
Oven Aging	ASTM D5721	80	80	80	80
with HP OIT, (% retained after 90 days)	ASTM D5885, 150°C, 500psi O_2				
UV Resistance	GRI GM11	20hr. Cycle @ 75°C/4 hr. dark condensation @ 60°C			
with HP OIT, (% retained after 1600 hours)	ASTM D5885, 150°C, 500psi O_2	50	50	50	50

These product specifications meet or exceed GRI's GM13

Supply Information (Standard Roll Dimensions)

Thickness		Width		Length		Area (approx.)		Weight (average)*	
mil	mm	ft	m	ft	m	ft²	m²	lbs	kg
50	1.25	23	7	300	91.435	6,900	640.05	2,800	1,270.06
60	1.5	23	7	300	91.435	6,900	640.05	2,900	1,315.42
80	2.0	23	7	300	91.435	6,900	640.05	3,100	1,406.14
100	2.5	23	7	300	91.435	6,900	640.05	4,000	1,814.40

Notes:

All rolls are supplied with two slings. All rolls are wound on a 6 inch core. Special lengths are available on request. All roll lengths and widths have a tolerance of ±1%
**The weight values may change due to project specifications (i.e. absolute minimum thickness or special roll lengths) or shipping requirements (i.e. international containerized shipments).*

All information, recommendations and suggestions appearing in this literature concerning the use of our products are based upon tests and data believed to be reliable; however, it is the users responsibility to determine the suitability for their own use of the products described herein. Since the actual use by others is beyond our control, no guarantee or warranty of any kind, expressed or implied, is made by Agru/America as to the effects of such use or the results to be obtained, nor does Agru/America assume any liability in connection herewith. Any statement made herein may not be absolutely complete since additional information may be necessary or desirable when particular or exceptional conditions or circumstances exist or because of applicable laws or government regulations. Nothing herein is to be construed as permission or as a recommendation to infringe any patent.

500 Garrison Road, Georgetown, South Carolina 29440 843-546-0600 800-373-2478 Fax: 843-527-2738
email: salesmkg@agruamerica.com www.agruamerica.com

© Agru America, Inc. 2011

Figure 1 Specification of Super Gripnet Geomembrane

ATTACHMENT A

HELP MODEL OUTPUT

```
↑
******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              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:    E:\DRPI\DATA4.D4
TEMPERATURE DATA FILE:      E:\DRPI\DATA7.D7
SOLAR RADIATION DATA FILE:  E:\DRPI\DATA13.D13
EVAPOTRANSPIRATION DATA:    E:\DRPI\DATA11.D11
SOIL AND DESIGN DATA FILE:  E:\DRPI\ALT1TOP.D10
OUTPUT DATA FILE:           E:\DRPI\ALT1TOP.OUT


TIME:  11:43     DATE:   4/27/2018


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

     TITLE:  DRPI Vertical Expansion. Alternative 1 2% Top Slope

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


     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   7
       THICKNESS                   =     24.00   INCHES
       POROSITY                    =      0.4730 VOL/VOL
       FIELD CAPACITY              =      0.2220 VOL/VOL
       WILTING POINT               =      0.1040 VOL/VOL
       INITIAL SOIL WATER CONTENT  =      0.2640 VOL/VOL
       EFFECTIVE SAT. HYD. COND.   =  0.520000001000E-03 CM/SEC
     NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  3.00
              FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.


                                   LAYER  2
                                   --------

                        TYPE 2 - LATERAL DRAINAGE LAYER
                         MATERIAL TEXTURE NUMBER   0
       THICKNESS                   =      0.25   INCHES
       POROSITY                    =      0.8500 VOL/VOL
       FIELD CAPACITY              =      0.0100 VOL/VOL
       WILTING POINT               =      0.0050 VOL/VOL
       INITIAL SOIL WATER CONTENT  =      0.1811 VOL/VOL
       EFFECTIVE SAT. HYD. COND.   =   1.00000000000     CM/SEC
       SLOPE                       =      2.00   PERCENT
       DRAINAGE LENGTH             =     50.0    FEET


                                   LAYER  3
                                   --------

                        TYPE 4 - FLEXIBLE MEMBRANE LINER
                         MATERIAL TEXTURE NUMBER  35
       THICKNESS                   =      0.04   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       =  4 - POOR
```

LAYER 4

TYPE 1 - VERTICAL PERCOLATION LAYER
MATERIAL TEXTURE NUMBER 7

```
THICKNESS                  =     24.00   INCHES
POROSITY                   =      0.4730 VOL/VOL
FIELD CAPACITY             =      0.2220 VOL/VOL
WILTING POINT              =      0.1040 VOL/VOL
INITIAL SOIL WATER CONTENT =      0.2220 VOL/VOL
EFFECTIVE SAT. HYD. COND.  =  0.520000001000E-03 CM/SEC
```

GENERAL DESIGN AND EVAPORATIVE ZONE DATA

NOTE: SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT SOIL DATA BASE USING SOIL TEXTURE # 7 WITH A FAIR STAND OF GRASS, A SURFACE SLOPE OF 2.% AND A SLOPE LENGTH OF 50. FEET.

```
SCS RUNOFF CURVE NUMBER            =     77.00
FRACTION OF AREA ALLOWING RUNOFF   =    100.0    PERCENT
AREA PROJECTED ON HORIZONTAL PLANE =      1.000  ACRES
EVAPORATIVE ZONE DEPTH             =     21.0    INCHES
INITIAL WATER IN EVAPORATIVE ZONE  =      5.441  INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE =      9.933  INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE =      2.184  INCHES
INITIAL SNOW WATER                 =      0.000  INCHES
INITIAL WATER IN LAYER MATERIALS   =     11.708  INCHES
TOTAL INITIAL WATER                =     11.708  INCHES
TOTAL SUBSURFACE INFLOW            =      0.00   INCHES/YEAR
```

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM WILMINGTON DELAWARE

```
STATION LATITUDE                     =  39.80 DEGREES
MAXIMUM LEAF AREA INDEX              =   2.00
START OF GROWING SEASON (JULIAN DATE) =   107
```



```
END OF GROWING SEASON (JULIAN DATE)    =    298
EVAPORATIVE ZONE DEPTH                 =  21.0  INCHES
AVERAGE ANNUAL WIND SPEED              =   9.20 MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY  =  67.00 %
AVERAGE 2ND QUARTER RELATIVE HUMIDITY  =  67.00 %
AVERAGE 3RD QUARTER RELATIVE HUMIDITY  =  72.00 %
AVERAGE 4TH QUARTER RELATIVE HUMIDITY  =  71.00 %
```

NOTE: PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING COEFFICIENTS FOR WILMINGTON DELAWARE

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
3.11	2.99	3.87	3.39	3.23	3.51
3.90	4.03	3.59	2.89	3.33	3.54

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING COEFFICIENTS FOR WILMINGTON DELAWARE

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
31.20	33.20	41.80	52.40	62.20	71.20
76.00	74.80	67.80	56.30	45.60	35.50

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING COEFFICIENTS FOR WILMINGTON DELAWARE AND STATION LATITUDE = 39.80 DEGREES

****

AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 30

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	3.22	2.34	3.98	3.24	3.36	3.74
	4.05	4.24	3.82	2.66	3.04	3.03
STD. DEVIATIONS	1.79	0.97	1.40	1.29	1.55	1.72
	1.83	2.28	2.24	1.38	1.45	1.97
RUNOFF						
TOTALS	0.427	0.559	0.352	0.005	0.003	0.010
	0.065	0.050	0.101	0.045	0.018	0.057
STD. DEVIATIONS	0.517	0.560	0.681	0.020	0.010	0.026
	0.238	0.125	0.216	0.152	0.049	0.206
EVAPOTRANSPIRATION						
TOTALS	0.776	0.739	2.341	3.450	3.356	4.453
	3.627	4.011	2.423	1.537	1.271	0.875
STD. DEVIATIONS	0.312	0.452	0.489	0.740	1.004	1.260
	1.260	1.777	0.862	0.263	0.167	0.145
LATERAL DRAINAGE COLLECTED FROM LAYER 2						
TOTALS	1.4001	0.9134	2.7086	0.7944	0.2820	0.1955
	0.0776	0.1470	0.3710	0.8889	0.9170	1.4878
STD. DEVIATIONS	1.3968	1.2462	1.4541	0.5848	0.4469	0.4626
	0.3214	0.4370	0.9933	1.5566	1.3654	1.4448
PERCOLATION/LEAKAGE THROUGH LAYER 3						
TOTALS	0.0009	0.0008	0.0022	0.0003	0.0001	0.0001
	0.0000	0.0001	0.0002	0.0008	0.0005	0.0011
STD. DEVIATIONS	0.0013	0.0012	0.0018	0.0002	0.0002	0.0002
	0.0002	0.0001	0.0006	0.0019	0.0010	0.0019
PERCOLATION/LEAKAGE THROUGH LAYER 4						
TOTALS	0.0015	0.0010	0.0031	0.0003	0.0002	0.0001
	0.0000	0.0000	0.0002	0.0011	0.0006	0.0013
STD. DEVIATIONS	0.0023	0.0017	0.0026	0.0005	0.0004	0.0003

	0.0002	0.0002	0.0006	0.0027	0.0014	0.0025

AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)

DAILY AVERAGE HEAD ON TOP OF LAYER 3						
AVERAGES	0.0940	0.0944	0.2585	0.0139	0.0049	0.0047
	0.0041	0.0023	0.0273	0.0933	0.0471	0.1153
STD. DEVIATIONS	0.1601	0.1671	0.2564	0.0141	0.0103	0.0162
	0.0212	0.0072	0.0740	0.2505	0.1169	0.2819

****

****

AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 30

	INCHES		CU. FEET	PERCENT
PRECIPITATION	40.71	(5.898)	147789.4	100.00
RUNOFF	1.693	(0.9927)	6144.74	4.158
EVAPOTRANSPIRATION	28.857	(3.2849)	104752.56	70.880
LATERAL DRAINAGE COLLECTED FROM LAYER 2	10.18309	(3.61919)	36964.621	25.01169
PERCOLATION/LEAKAGE THROUGH LAYER 3	0.00713	(0.00341)	25.900	0.01752
AVERAGE HEAD ON TOP OF LAYER 3	0.063	(0.039)		
PERCOLATION/LEAKAGE THROUGH LAYER 4	0.00941	(0.00474)	34.141	0.02310
CHANGE IN WATER STORAGE	-0.029	(0.9961)	-106.67	-0.072

****

****

PEAK DAILY VALUES FOR YEARS 1 THROUGH 30

	(INCHES)	(CU. FT.)
PRECIPITATION	5.26	19093.801
RUNOFF	1.509	5476.8501
DRAINAGE COLLECTED FROM LAYER 2	0.93583	3397.05103
PERCOLATION/LEAKAGE THROUGH LAYER 3	0.002729	9.90451
AVERAGE HEAD ON TOP OF LAYER 3	13.975	
MAXIMUM HEAD ON TOP OF LAYER 3	16.348	
LOCATION OF MAXIMUM HEAD IN LAYER 2 (DISTANCE FROM DRAIN)	31.8 FEET	
PERCOLATION/LEAKAGE THROUGH LAYER 4	0.002945	10.69198
SNOW WATER	4.03	14622.6279

MAXIMUM VEG. SOIL WATER (VOL/VOL) 0.3917

MINIMUM VEG. SOIL WATER (VOL/VOL) 0.1040

*** 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.

****

****

FINAL WATER STORAGE AT END OF YEAR 30

LAYER	(INCHES)	(VOL/VOL)
1	5.5562	0.2315
2	0.0114	0.0455
3	0.0000	0.0000
4	5.2591	0.2191
SNOW WATER	0.000	

****
****

```
******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              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:    E:\DRPI\DATA4.D4
TEMPERATURE DATA FILE:      E:\DRPI\DATA7.D7
SOLAR RADIATION DATA FILE:  E:\DRPI\DATA13.D13
EVAPOTRANSPIRATION DATA:    E:\DRPI\DATA11.D11
SOIL AND DESIGN DATA FILE:  E:\DRPI\ALT2TOP.D10
OUTPUT DATA FILE:           E:\DRPI\ALT2TOP.OUT


TIME:  11:44     DATE:   4/27/2018


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

     TITLE:  DRPI Vertical Expansion. Alternative 2 2% Top Slope

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


     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   7
  THICKNESS                  =     24.00   INCHES
  POROSITY                   =      0.4730 VOL/VOL
  FIELD CAPACITY             =      0.2220 VOL/VOL
  WILTING POINT              =      0.1040 VOL/VOL
  INITIAL SOIL WATER CONTENT  =      0.2679 VOL/VOL
  EFFECTIVE SAT. HYD. COND.   =  0.520000001000E-03 CM/SEC
NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  3.00
         FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.


                                   LAYER  2
                                   --------

                      TYPE 2 - LATERAL DRAINAGE LAYER
                       MATERIAL TEXTURE NUMBER   0
  THICKNESS                  =      0.13   INCHES
  POROSITY                   =      0.8500 VOL/VOL
  FIELD CAPACITY             =      0.0100 VOL/VOL
  WILTING POINT              =      0.0050 VOL/VOL
  INITIAL SOIL WATER CONTENT  =      0.0881 VOL/VOL
  EFFECTIVE SAT. HYD. COND.   =   4.80000019000     CM/SEC
  SLOPE                      =      2.00   PERCENT
  DRAINAGE LENGTH            =     50.0    FEET


                                   LAYER  3
                                   --------

                      TYPE 4 - FLEXIBLE MEMBRANE LINER
                       MATERIAL TEXTURE NUMBER  35
  THICKNESS                  =      0.04   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       =  4 - POOR
```

LAYER 4

TYPE 1 - VERTICAL PERCOLATION LAYER
MATERIAL TEXTURE NUMBER 7

THICKNESS	=	24.00 INCHES
POROSITY	=	0.4730 VOL/VOL
FIELD CAPACITY	=	0.2220 VOL/VOL
WILTING POINT	=	0.1040 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.2220 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.520000001000E-03 CM/SEC

GENERAL DESIGN AND EVAPORATIVE ZONE DATA

NOTE: SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT SOIL DATA BASE USING SOIL TEXTURE # 7 WITH A FAIR STAND OF GRASS, A SURFACE SLOPE OF 2.% AND A SLOPE LENGTH OF 50. FEET.

SCS RUNOFF CURVE NUMBER	=	77.00
FRACTION OF AREA ALLOWING RUNOFF	=	100.0 PERCENT
AREA PROJECTED ON HORIZONTAL PLANE	=	1.000 ACRES
EVAPORATIVE ZONE DEPTH	=	21.0 INCHES
INITIAL WATER IN EVAPORATIVE ZONE	=	5.517 INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE	=	9.933 INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE	=	2.184 INCHES
INITIAL SNOW WATER	=	0.000 INCHES
INITIAL WATER IN LAYER MATERIALS	=	11.769 INCHES
TOTAL INITIAL WATER	=	11.769 INCHES
TOTAL SUBSURFACE INFLOW	=	0.00 INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM WILMINGTON DELAWARE

STATION LATITUDE	=	39.80 DEGREES
MAXIMUM LEAF AREA INDEX	=	2.00
START OF GROWING SEASON (JULIAN DATE)	=	107

END OF GROWING SEASON (JULIAN DATE)	=	298
EVAPORATIVE ZONE DEPTH	=	21.0 INCHES
AVERAGE ANNUAL WIND SPEED	=	9.20 MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY	=	67.00 %
AVERAGE 2ND QUARTER RELATIVE HUMIDITY	=	67.00 %
AVERAGE 3RD QUARTER RELATIVE HUMIDITY	=	72.00 %
AVERAGE 4TH QUARTER RELATIVE HUMIDITY	=	71.00 %

NOTE: PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING COEFFICIENTS FOR WILMINGTON DELAWARE

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
3.11	2.99	3.87	3.39	3.23	3.51
3.90	4.03	3.59	2.89	3.33	3.54

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING COEFFICIENTS FOR WILMINGTON DELAWARE

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
31.20	33.20	41.80	52.40	62.20	71.20
76.00	74.80	67.80	56.30	45.60	35.50

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING COEFFICIENTS FOR WILMINGTON DELAWARE AND STATION LATITUDE = 39.80 DEGREES

****

AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 30

ALT2top

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	3.22	2.34	3.98	3.24	3.36	3.74
	4.05	4.24	3.82	2.66	3.04	3.03
STD. DEVIATIONS	1.79	0.97	1.40	1.29	1.55	1.72
	1.83	2.28	2.24	1.38	1.45	1.97
RUNOFF						
TOTALS	0.437	0.567	0.358	0.005	0.003	0.011
	0.070	0.050	0.106	0.047	0.020	0.063
STD. DEVIATIONS	0.522	0.566	0.690	0.020	0.010	0.027
	0.242	0.126	0.230	0.154	0.052	0.216
EVAPOTRANSPIRATION						
TOTALS	0.776	0.739	2.339	3.448	3.350	4.493
	3.628	4.013	2.419	1.525	1.267	0.874
STD. DEVIATIONS	0.311	0.451	0.488	0.742	1.001	1.259
	1.254	1.778	0.852	0.262	0.167	0.145
LATERAL DRAINAGE COLLECTED FROM LAYER 2						
TOTALS	1.3849	0.8633	2.6941	0.8072	0.2922	0.1929
	0.0743	0.1387	0.3812	0.8655	0.9234	1.5160
STD. DEVIATIONS	1.3744	1.2007	1.4177	0.5904	0.4556	0.4630
	0.3323	0.4203	0.9987	1.4675	1.3644	1.4820
PERCOLATION/LEAKAGE THROUGH LAYER 3						
TOTALS	0.0002	0.0001	0.0004	0.0001	0.0000	0.0000
	0.0000	0.0000	0.0001	0.0001	0.0001	0.0002
STD. DEVIATIONS	0.0002	0.0002	0.0003	0.0001	0.0000	0.0000
	0.0000	0.0000	0.0001	0.0002	0.0001	0.0004
PERCOLATION/LEAKAGE THROUGH LAYER 4						
TOTALS	0.0003	0.0001	0.0004	0.0001	0.0000	0.0000
	0.0000	0.0000	0.0001	0.0001	0.0001	0.0003
STD. DEVIATIONS	0.0005	0.0003	0.0006	0.0003	0.0000	0.0002

ALT2top

	0.0000	0.0002	0.0003	0.0005	0.0003	0.0008

AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)

DAILY AVERAGE HEAD ON TOP OF LAYER 3						
AVERAGES	0.0105	0.0082	0.0341	0.0025	0.0009	0.0006
	0.0002	0.0004	0.0043	0.0071	0.0043	0.0172
STD. DEVIATIONS	0.0195	0.0183	0.0440	0.0018	0.0014	0.0014
	0.0010	0.0012	0.0168	0.0254	0.0109	0.0558

****

****

AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 30

	INCHES	CU. FEET	PERCENT
PRECIPITATION	40.71 (5.898)	147789.4	100.00
RUNOFF	1.737 (1.0125)	6304.30	4.266
EVAPOTRANSPIRATION	28.870 (3.2890)	104796.57	70.909
LATERAL DRAINAGE COLLECTED FROM LAYER 2	10.13361 (3.63531)	36784.988	24.89014
PERCOLATION/LEAKAGE THROUGH LAYER 3	0.00133 (0.00059)	4.819	0.00326
AVERAGE HEAD ON TOP OF LAYER 3	0.008 (0.006)		
PERCOLATION/LEAKAGE THROUGH LAYER 4	0.00151 (0.00097)	5.477	0.00371
CHANGE IN WATER STORAGE	-0.028 (0.9597)	-101.94	-0.069

****

****

PEAK DAILY VALUES FOR YEARS 1 THROUGH 30

	(INCHES)	(CU. FT.)
PRECIPITATION	5.26	19093.801
RUNOFF	1.511	5485.0737
DRAINAGE COLLECTED FROM LAYER 2	1.52263	5527.14551
PERCOLATION/LEAKAGE THROUGH LAYER 3	0.001109	4.02600
AVERAGE HEAD ON TOP OF LAYER 3	4.750	
MAXIMUM HEAD ON TOP OF LAYER 3	5.806	
LOCATION OF MAXIMUM HEAD IN LAYER 2 (DISTANCE FROM DRAIN)	21.5 FEET	
PERCOLATION/LEAKAGE THROUGH LAYER 4	0.001489	5.40613
SNOW WATER	4.03	14622.6279

MAXIMUM VEG. SOIL WATER (VOL/VOL) 0.3866

MINIMUM VEG. SOIL WATER (VOL/VOL) 0.1040

*** 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.

****

****

FINAL WATER STORAGE AT END OF YEAR 30

LAYER	(INCHES)	(VOL/VOL)
1	5.6008	0.2334
2	0.0036	0.0275
3	0.0000	0.0000
4	5.3223	0.2218
SNOW WATER	0.000	

****
****

APPENDIX VI-H.2

COVER SYSTEM VENEER STABILITY ON SIDE SLOPES

Geosyntec consultants

COMPUTATION COVER SHEET

Client: DRPI **Project:** DRPI Landfill Expansion **Project #:** ME1571 **Task #:** 1

TITLE OF COMPUTATIONS FINAL COVER VENEER STABILITY EVALUATION

COMPUTATIONS BY:

Signature [signature] 2/19/2018
DATE

Printed Name and Title: Chunling Li, Project Engineer

ASSUMPTIONS AND PROCEDURES CHECKED BY: (Peer Reviewer)

Signature [signature] 2/20/2018
DATE

Printed Name and Title: Andrew Stallings, Senior Staff Engineer

COMPUTATIONS CHECKED BY:

Signature [signature] 2/20/2018
DATE

Printed Name and Title: Andrew Stallings, Senior Staff Engineer

COMPUTATIONS BACKCHECKED BY: (Originator)

Signature [signature] 2/20/2018
DATE

Printed Name and Title: Chunling Li, Project Engineer

APPROVED BY: (PM or Designate)

Signature [signature] 2/21/2018
DATE

Printed Name and Title: David Espinoza, Senior Principal

APPROVAL NOTES:

REVISIONS (Number and initial all revisions)

NO.	SHEET	DATE	BY	CHECKED BY	APPROVAL

FINAL COVER SYSTEM VENEER STABILITY EVALUATION

PURPOSE:

The purpose of this engineering calculation is to evaluate the veneer slope stability for failure along the interfaces of the various components of the cover system to be used for the proposed vertical expansion at the Delaware Recyclable Products, Inc. (DRPI) landfill in New Castle, Delaware.

PROCEDURE:

The veneer slope stability factor of safety of the final cover system will be evaluated based on a method presented by Giroud, et al. [1995a,b]. The method is based on a limit equilibrium analysis and takes into account soil buttressing effect, geosynthetic tensile forces, and seepage forces within the final system caused by rainfall and is based on the most critical interface that exists within the final cover system. This method considers failure surfaces both above (Case 1) and below (Case 2) the geomembrane.

The veneer stability factor of safety will be calculated using the following equation from Giroud et al. [1995a,b]:

$$FS = \lambda \frac{\tan\delta}{\tan\beta} + \frac{a/\sin\beta}{\gamma_t(t-t_w)+\gamma_{sat}t_w} + \frac{\gamma_t(t-t_w^*)+\gamma_b t_w^*}{\gamma_t(t-t_w)+\gamma_{sat}t_w}\frac{t}{h}\frac{\sin\phi}{\sin 2\beta\cos(\beta+\phi)} + \frac{ct/h}{\gamma_t(t-t_w)+\gamma_{sat}t_w}\frac{\cos\phi}{\sin\beta\cos(\beta+\phi)} + \frac{T/h}{\gamma_t(t-t_w)+\gamma_{sat}t_w} \qquad \text{Eq. (1)}$$

where:

$$\lambda = \begin{cases} \dfrac{\gamma_t(t-t_w)+\gamma_b t_w}{\gamma_t(t-t_w)+\gamma_{sat}t_w} & \text{for failure surface above the geomembrane (dimensionless)} \\ 1 & \text{for failure surface below the geomembrane (dimensionless)} \end{cases}$$

FS = Factor of Safety (dimensionless)
γ_t = total unit weight of soil (pcf)
γ_{sat} = saturated unit weight of soil (pcf)
γ_b = buoyant unit weight of soil (pcf)
t = thickness of soil layer (ft)
t_w = thickness of water flow along slope (ft)
t^*_w = thickness of water flow in toe of slope (ft)

β = slope angle (degrees)
δ = interface friction angle along slip surface (degrees)
a = interface adhesion (psf)
ϕ = internal friction angle of soil above critical surface (degrees)
h = height of slope (ft)
T = tension in geosynthetics (lbs/ft)
c = cohesion of soil above critical surface (psf)

According to a technical manual published by the USEPA entitled "Solid Waste Disposal Facility Criteria" [USEPA, 1993], when there is no imminent danger to human life or threat of major environmental impact, the minimum recommended slope stability factor of safety is 1.25. Because a veneer stability failure of the liner system does not pose a threat to human life or the environment and a failure could be easily repaired, the stability of the final cover system will be considered acceptable if the factor of safety is greater than or equal to 1.25.

SOIL AND GEOSYNTHETIC PROPERTIES

Figure 1 shows the proposed final cover grading plan. The maximum slope inclination for the liner system is 3H:1V and the maximum vertical slope height is approximately 30 ft. The proposed final cover system on the side slopes consists of the following components, from top to bottom:

Alternative 1:

- 6-in thick topsoil layer;
- 18-in thick protective soil layer;
- geocomposite drainage layer;
- 40-mil HDPE geomembrane; and
- prepared subbase (including grading layer).

Alternative 2:

- 6-in thick topsoil layer;
- 18-in thick protective soil layer;
- geotextile filter;
- 50-mil combination HDPE or LLDPE geomembrane/ drainage layer; and
- prepared subbase (including grading layer).

Typical geosynthetic material interface shear strength values are shown in Table 1. Interface shear strength for Alternative 1 is selected based on Table 1. The critical interface above the geomembrane is considered to be that between the geocomposite and HDPE geomembrane, which is assumed to have a friction angle of 22 degrees and zero adhesion. The critical interface below the geomembrane is considered to be that between the geomembrane and subgrade, which is assumed to have a friction angle of 22 degrees and zero adhesion. This interface friction angle was estimated using assumed subgrade friction angle of 30 degrees and $\tan\delta/\tan\phi=0.7$ (ϕ= internal soil friction angle and δ= interface friction angle).

For Alternative 2, the combination HDPE or LLDPE geomembrane is a manufactured geomembrane with drainage capacity. The material data supplied by the manufacturer are shown in Attachment A. For this analysis, the critical interface friction angle above and below the geomembrane is conservatively assumed to be $\delta = 25^o$, based on Geosyntec's previous experience with this product. This selected interface friction angle is less than the typical interface friction angle with representative material (28 degrees, see Attachment A)

WATER FLOW ALONG SLOPE

A calculation was conducted to estimate the thickness of water flow on top of the geomembrane using the HELP3 model [USEPA, 1994]. Runoff from the top deck of the landfill will be directed towards the downchutes using diversion berm. Therefore, the runoff from the top deck will not flow continuously down the sideslope.

For veneer slope stability analysis, the water depth along the sideslope is evaluated in the following two cases were analyzed:

(1) 3H:1V slope with an assumed drainage distance of 95 ft (i.e., distance between drainage terraces spaced at 30 ft vertical height) with Alternative 1 Final Cover System.
(2) 3H:1V slope with an assumed drainage distance of 95 ft (i.e., distance between drainage terraces spaced at 30 ft vertical height) with Alternative 2 Final Cover System.

For Alternative 1, the geocomposite is assumed to have a thickness of 250 mil. The hydraulic conductivity is assumed 1 cm/sec, estimated using the default hydraulic conductivity of 10 cm/sec and a combined reduction factor of 10 to account for long-term effects such as creep, intrusion, degradation and clogging. For Alternative 2, the drainage stud height is modeled as a geonet with a thickness of 130 mil. The transmissivity of the drainage stud depends on the overlaying geotextile type as well as the normal loading and gradient. West [2011] reported the transmissivity ranging from 1.6×10^{-3} to 3.6×10^{-3} m^2/sec. Using the lower bound transmissivity value of 1.6×10^{-3} m^2/sec and nominal stud height of 130 mil (0.0033 m), the hydraulic conductivity of the drainage stud is estimated as 48 cm/sec. Using a reduction factor of 10, the long-term hydraulic conductivity used in the analysis is assumed to be 4.8 cm/sec.

The simulation was conducted for a 30-year period. The analysis is presented in Attachment B. Based on the results of this calculation; the peak daily values for hydraulic head above the geomembrane are summarized below:

Slope	Average Head along Slope inch (ft)	Head at Toe of Slope inch (ft)
3H:1V (Alternative 1)	0.245 (0.020)	0.207 (0.017)
3H:1V (Alternative 2)	0.018 (0.0015)	0.058 (0.0048)

CALCULATION

Below is a summary of parameters used for the final cover veneer slope stability evaluation

γ_t = 110 pcf

γ_{sat} = 110 pcf

γ_b = 47.6 pcf

t_w = 0.020 ft for Alternative 1 and 0.0015 for Alternative 2 (failure surface above geomembrane), 0 ft for failure surface below geomembrane.

t^*_w = 0.017 ft for Alternative 1 and 0.0048 for Alternative 2 (failure surface above geomembrane), 0 ft for failure surface below geomembrane

β = 18.43°

a = 0

ϕ = 30°

h = 30 ft (distance between terraces)

T = 0 (neglect tension contribution)

c = 0

δ = 22 ° (above and below the geomembrane for Alternative 1); 25 ° (above and below the geomembrane for Alternative 2);

Calculations of the factors of safety are conducted using Excel Spreadsheet, which is included in Attachment C to this calculation package. The calculated factors of safety are summarized below:

Case Analyzed	Factor of Safety	
	Above Geomembrane	Below Geomembrane
3H:1V (Alternative 1)	1.29	1.30
3H:1V (Alternative 2)	1.48	1.48

As shown above, the factors of safety for sliding above or below the geomembrane are all greater than the minimum required factor of safety of 1.25.

REFERENCES

Eid, H.T. and Stark, T.D. (1997). "Shear Behavior of an Unreinforced Geosynthetic Clay Liner," *Geosynthetics International*, Vol. 4, No. 6, pp. 645-659.

Eigenbrod, K.K. and Locker, J.G. (1987), "Determination of Friction Values for the Design of Side Slopes Lined or Protected with Geosynthetics," *Canadian Geotechnical Journal*, Vol. 24, No. 4, pp. 509-519.

Giroud, J.P., Williams, N.D., Pelte, T., and Beech, J.F., "Stability of Geosynthetic - Soil Layered Systems on Slopes," Industrial Fabrics Association International, *Geosynthetics International*, Vol. 2, No. 6, St. Paul, MN, pp. 1115-1148, 1995a.

Giroud, J.P., Bachus, R.C., and Bonaparte, R., "Influence of Water Flow on the Stability of Geosynthetic - Soil Layered Systems on Slopes," Industrial Fabrics Association International, *Geosynthetics International,* Vol. 2, No. 6, St. Paul, MN, pp. 1149-1180, 1995b.

Koerner, R.M., Martin, J.P., and Koerner, G.R. (1986). "Shear Strength Parameters Between Geomembranes and Cohesive Soils", *Geotextiles and Geomembranes*, Vol. 4, No. 1, pp. 21-30.

Martin, J.P., Koerner, R.M., and Whitty, J.E. (1984). "Experimental Friction Evaluation of Slippage Between Geomembranes, Geotextiles, and Soils", *Proceedings: International Conference on Geomembranes*, Denver, Colorado, pp. 191-196.

Naval Facilities Engineering Command (NAVFAC) (1986). "*Foundations & Earth Structures*", Design Manual DM 7.02.

Sabatini, P.J., Schmertmann, G.R., and Swan, R.H. (1998). "Issues in Clay / Textured Geomembrane Testing", *Sixth International Conference on Geosynthetics*, pp. 423-426.

Stark, T.D., Arellano, D., Evans, W.D., Wilson, V.L., and Gonda, J.M. (1998). "Unreinforced Geosynthetic Clay Liner Case History," *Geosynthetics International*, Vol. 5, No. 5, pp. 521-544.

Williams N.D. and Houlihan, M.F. (1986). "Evaluation of Friction Coefficients Between Geomembranes, Geotextiles, and Related Products", *Third International Conference on Geotextiles*, Vienna, Austria, pp. 891-896.

Williams N.D. and Houlihan, M.F. (1987). "Evaluation of Interface Friction Properties Between Geosynthetics and Soils", *Geosynthetics '87 Conference*, New Orleans, LA, pp. 616-627.

Williams, N.D. and Luna, J. (1987). "Selection of Geotextiles for Use with Synthetic Drainage Products," *Geotextiles and Geomembranes*, Vol. 5, pp. 45-61.

USEPA (1993), *"Solid Waste Disposal Facility Criteria"*, Document No. EPA 530-R-93-017, United States Environmental Protection Agency, November 1993.

USEPA (1994), "*The Hydrologic Evaluation of Landfill Performance (HELP) Model, Vol. II, Users Guide for Version 3*", EPA/530-SW-84-010, US Environmental Protection Agency, Washington, DC, June 1994, 120p.

West, C (2011). "Structured Geomembrane Liners in Landfill Base and Closure Systems", World of Coal Ash Conference, May 2011, Denver Colorado.

TABLE

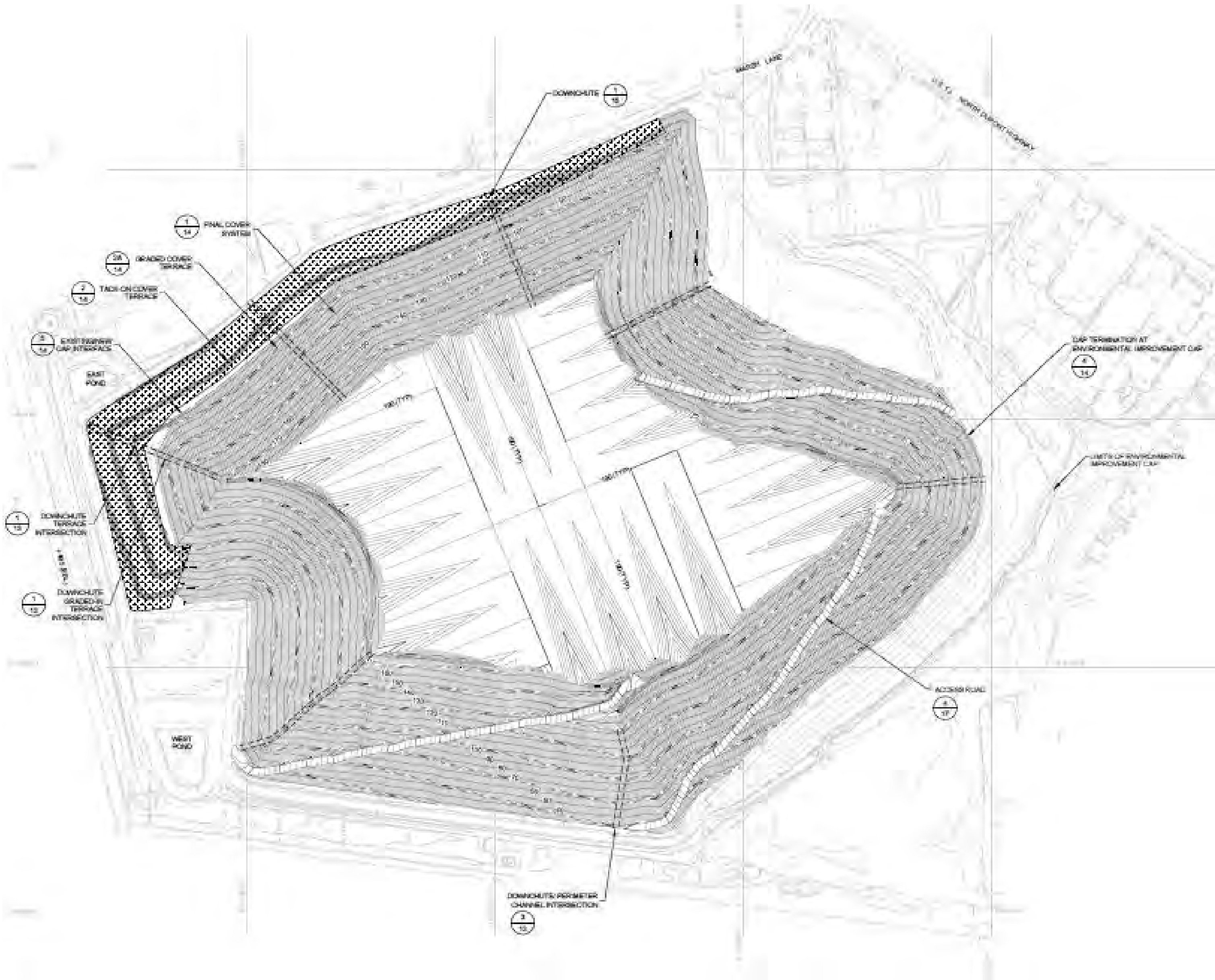
Table 1. Summary of Documented Interface Friction Values.

GEOSYNTHETIC / GEOSYNTHETIC	δ_p (1) (degrees)	δ_{ld} (1) (degrees)
Smooth HDPE Geomembrane / Nonwoven Geotextile	7 - 12	6 - 11
Smooth LLDPE Geomembrane / Nonwoven Geotextile	10 - 12	
Textured HDPE Geomembrane / Nonwoven Geotextile	22 - 35	
Smooth HDPE Geomembrane / Geonet	7 - 15	
Textured HDPE Geomembrane / Geonet	7 - 15	
Textured HDPE Geomembrane / Geocomposite	17 - 29	13 - 20
Geonet / Nonwoven Geotextile	13 - 22	
Smooth HDPE Geomembrane / GCL (hydrated)	8 - 12	
Textured HDPE Geomembrane / GCL (hydrated)	18 - 37	6 - 10
GEOSYNTHETIC / SOIL	$\tan\delta_p/\tan\phi_p$ (1)	$\tan\delta_{ld}/\tan\phi_{ld}$ (1)
Smooth HDPE Geomembrane / Clay	0.4 - 0.7	0.3 - 0.7
Textured HDPE Geomembrane / Clay	0.8 - 0.9	0.6 - 0.9
Smooth HDPE Geomembrane / Sand	0.5 - 0.6	
Textured HDPE Geomembrane / Sand	0.7 - 0.8	
Needlepunched Nonwoven Geotextile / Sand	0.8 - 1.0	
Needlepunched Nonwoven Geotextile / Angular Gravel	0.7 - 0.9	
Needlepunched Nonwoven Geotextile / Rounded Gravel	0.6 - 0.8	

Data Source: Martin et al. (1984), Williams and Houlihan (1986), Koerner et al. (1986), Williams and Houlihan (1987),Williams and Luna (1987), Eid and Stark (1997), Sabatini et al. (1998), Stark et al. (1998), manufacturer's literature, and unpublished results from Geosyntec Consultants.

Note: (1) δ = interface friction angle; ϕ = soil internal friction angle; subscript p = peak and subscript ld = large displacement

FIGURE



FINAL COVER GRADING PLAN

Geosyntec consultants

Figure 1

Maryland | July 2018

Scale: NTS

ATTACHMENT A

MANUFACTURER'S INFORMATION ON SUPER GRIPNET GEOMEMBRANE

High Density Polyethylene Super Gripnet® Liner

Product Data

Property	Test Method	Values			
Thickness (min. ave.), mil (mm)	ASTM D5994*	50 (1.25)	60 (1.5)	80 (2.0)	100 (2.5)
Thickness (lowest indiv.), mil (mm)	ASTM D5994*	50 (1.25)	54 (1.35)	72 (1.8)	90 (2.25)
***The thickness values may be changed due to project specifications (i.e., absolute minimum thickness)**					
Drainage Stud Height (min. ave.), mil (mm)	ASTM D7466	130 (3.30)	130 (3.30)	130 (3.30)	130 (3.30)
Friction Spike Height (min. ave.), mil (mm)	ASTM D7466	175 (4.45)	175 (4.45)	175 (4.45)	175 (4.45)
Density, g/cc, minimum	ASTM D792, Method B	0.94	0.94	0.94	0.94
Tensile Properties (ave. both directions)	ASTM D6693, Type IV				
Strength @ Yield (min. ave.), lb/in width (N/mm)	2 in/minute	110 (19.3)	132 (23.1)	176 (30.8)	220 (38.5)
Elongation @ Yield (min. ave.), % (GL=1.3in)	5 specimens in each direction	13	13	13	13
Strength @ Break (min. ave.), lb/in width (N/mm)		110 (19.3)	132 (23.1)	176 (30.8)	220 (38.5)
Elongation @ Break (min. ave.), % (GL=2.0in)		200	200	200	200
Tear Resistance (min. ave.), lbs. (N)	ASTM D1004	38 (169)	40 (178)	53 (236)	64 (285)
Puncture Resistance (min. ave.), lbs. (N)	ASTM D4833	80 (356)	90 (400)	120 (534)	150 (667)
Carbon Black Content (range in %)	ASTM D4218	2 - 3	2 - 3	2 - 3	2 - 3
Carbon Black Dispersion (Category)	ASTM D5596	Only near spherical agglomerates			
	for 10 views: 9 views in Cat. 1 or 2, and 1 view in Cat. 3				
Stress Crack Resistance (Single Point NCTL), hours	ASTM D5397, Appendix	300	300	300	300
Oxidative Induction Time, minutes	ASTM D3895, 200°C, 1 atm O_2	≥100	≥100	≥100	≥100
Melt Flow Index, g/10 minutes	ASTM D1238, 190°C, 2.16kg	≤1.0	≤1.0	≤1.0	≤1.0
Oven Aging	ASTM D5721	80	80	80	80
with HP OIT, (% retained after 90 days)	ASTM D5885, 150°C, 500psi O_2				
UV Resistance	GRI GM11	20hr. Cycle @ 75°C/4 hr. dark condensation @ 60°C			
with HP OIT, (% retained after 1600 hours)	ASTM D5885, 150°C, 500psi O_2	50	50	50	50

These product specifications meet or exceed GRI's GM13

Supply Information (Standard Roll Dimensions)

Thickness		Width		Length		Area (approx.)		Weight (average)*	
mil	mm	ft	m	ft	m	ft^2	m^2	lbs	kg
50	1.25	23	7	300	91.435	6,900	640.05	2,800	1,270.06
60	1.5	23	7	300	91.435	6,900	640.05	2,900	1,315.42
80	2.0	23	7	300	91.435	6,900	640.05	3,100	1,406.14
100	2.5	23	7	300	91.435	6,900	640.05	4,000	1,814.40

Notes:

All rolls are supplied with two slings. All rolls are wound on a 6 inch core. Special lengths are available on request. All roll lengths and widths have a tolerance of ±1%
**The weight values may change due to project specifications (i.e. absolute minimum thickness or special roll lengths) or shipping requirements (i.e. international containerized shipments).*

All information, recommendations and suggestions appearing in this literature concerning the use of our products are based upon tests and data believed to be reliable; however, it is the users responsibility to determine the suitability for their own use of the products described herein. Since the actual use by others is beyond our control, no guarantee or warranty of any kind, expressed or implied, is made by Agru/America as to the effects of such use or the results to be obtained, nor does Agru/America assume any liability in connection herewith. Any statement made herein may not be absolutely complete since additional information may be necessary or desirable when particular or exceptional conditions or circumstances exist or because of applicable laws or government regulations. Nothing herein is to be construed as permission or as a recommendation to infringe any patent.

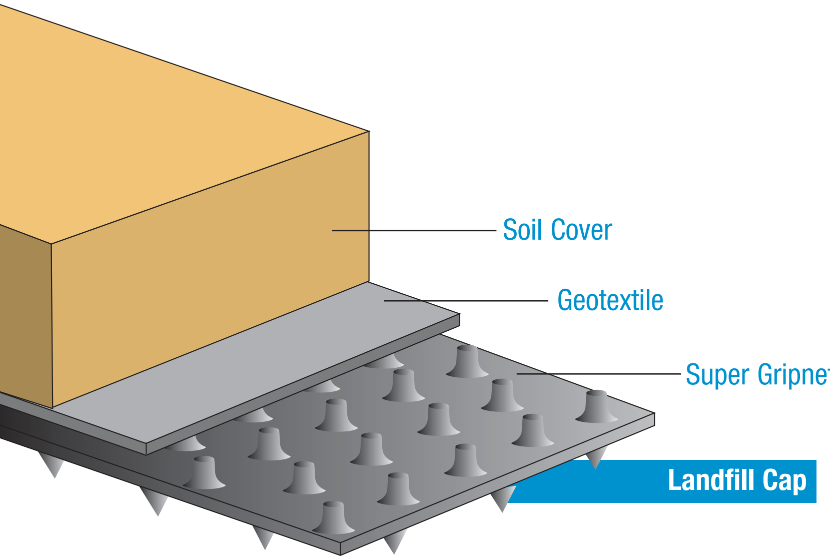
500 Garrison Road, Georgetown, South Carolina 29440 843-546-0600 800-373-2478 Fax: 843-527-2738
email: salesmkg@agruamerica.com www.agruamerica.com

© Agru America, Inc. 2011

Super Gripnet® Geomembrane

Applications for HDPE and LLDPE Agru Super Gripnet® include projects where drainage and high interface friction as well as cost savings are critical i.e. landfill caps, landfill slopes and mining reclamation projects. Recent bids for installations have indicated cost savings of over $3,000.00 per acre with the use of Super Gripnet® as a replacement for traditional geocomposite overlying a textured geomembrane.

Agru America's structured geomembranes are manufactured on state-of-the-art manufacturing equipment using a flat cast extrusion manufacturing process as opposed to blown film extrusion. Agru America uses only the highest grade of HDPE and LLDPE resins manufactured in North America. The structured geomembrane is manufactured by a continuous horizontal flat die extrusion into profile rollers. The machined rollers give the product the final structured surface with drainage studs and spikes which are an integral (homogenous) part of the liner and have a smooth edge for on site welding. This process provides a consistent core thickness resulting in higher sheet tensile strength, consistent high profile texturing resulting in higher interface friction capabilities as well as consistent drain capacity.



Interface Shear – Cap Loading Conditions ASTM D 5321

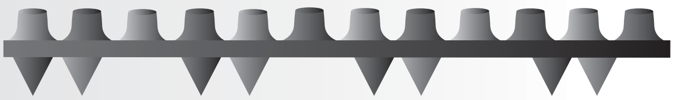
Soil/Grip Liner Surface	P	LD
Coarse Sand	35°	31°
Glacial Till	38°	34°
Silty Sand	28°	26°
Non Woven GT	31°	26°
Soil/Drain Liner Surface with GT		
Coarse Sand	30°	30°

Note: The above values are representative friction angles only. It is recommended that site specific conformance testing be carried out using the actual soils, geosynthetics and loading conditions for a specific project.

P = Maximum or Peak Interface Shear Value in degrees
LD = Large Displacement Interface Shear Value in degrees
GT = Geotextile

Super Gripnet® Geomembrane

- Combines Drainage with Shear Resistance
- High Water Flow Rate on Top Side
- Spike/Texture Bottom
- Consistent Drain and Structure Pattern
- Combine with Smooth
- Combine with Fabric



US Patent - No. 5.258.217

The machine rollers provide the final structured surface with a 3.6 mm (0.145 in.) high studded drain surface on the top side and 4.4 mm (0.175 in.) high spiked friction surface on the bottom side. The 7 m (23 ft.) wide rolls of finished product include a smooth edge on both sides of the roll for ease of thermal welding in the field. Due to the molded structure, core thickness does not vary as with blown film textured sheet, thus mechanical properties of the sheet are not affected. In addition, the consistent high profile texture insures optimum interface friction characteristics at any point on the sheet surface.

The top surface integral drain structure consists of 3.2 mm (0.13 in.) diameter studs 3.6 mm (0.145 in.) in height and spaced on a diamond pattern of 12.5 mm (0.5 in.) spacing. A filter/protection geotextile is required to be placed on the drain profile. The geotextile is heat set on one side (placed against the drain structure) to reduce intrusion into the drain. Large-scale flow rate testing with this configuration, overlying soils and expected normal loads resulted in high planar flow rates.

The bottom spiked friction surface with 4.4 mm (0.175 in.) high spikes and patterned texture provides maximum interface friction and high factor of safety against sliding.

Thus, the Super Gripnet® Liner is a synthetic drainage media which has decided advantages over conventional geocomposites:

- ***Cost Savings*** – The drain media and liner are one and installed as one panel
  – No waste due to fitting of geocomposite sections or discarding roll ends
- ***Improved Planar Flow*** – Less reduction for chemical/biological clogging considerations
- ***Consistent Material*** – Studs and spikes (drainage and friction) totally integrated with the geomembrane
- ***High Interface Shear*** – Exceptional shear resistance between soil & geotextile components allows flexibility and stability during protective cover material placement
- ***Meets/exceeds Project Requirements*** – Excellent fluid barrier
  – Excellent drainage medium
  – Excellent friction characteristics

Agru's Super Gripnet® geomembrane is a high performance liner system with integrated top surface drainage supplying the functional needs for any project with the added benefit of substantial cost savings.

Why specify or use anything else!

Agru has over 20 years experience with Geomembranes and 50 years experience with Thermoplastic Extrusion
Agru offers a wide range of concrete protective liners (Sure Grip), pipe fittings and semi-finished materials.

Executive Offices: 500 Garrison Road, Georgetown, SC 29440 843-546-0600 800-321-1379 Fax: 843-546-0516
Sales Office: 700 Rockmead, Suite 150, Kingwood, TX 77339 281-358-4741 800-373-2478 Fax: 281-358-5297
email: salesmkg@agruamerica.com www.agruamerica.com
© Agru America, Inc. 2009

ATTACHMENT B

WATER DEPTH ABOVE GEOMEMBRANE
(HELP ANALYSIS)

```
******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              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\drpi\DATA4.D4
TEMPERATURE DATA FILE:      C:\HELP3\drpi\DATA7.D7
SOLAR RADIATION DATA FILE:  C:\HELP3\drpi\DATA13.D13
EVAPOTRANSPIRATION DATA:    C:\HELP3\drpi\DATA11.D11
SOIL AND DESIGN DATA FILE:  C:\HELP3\drpi\ALT1SIDE.D10
OUTPUT DATA FILE:           C:\HELP3\drpi\alt1side.OUT

TIME:  16:44     DATE:   3/ 5/2018

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

     TITLE:  DRPI Vertical Expansion. Alternative 1 3H:1V sideslope

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

     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   7
           THICKNESS                  =     24.00   INCHES
           POROSITY                   =      0.4730 VOL/VOL
           FIELD CAPACITY             =      0.2220 VOL/VOL
           WILTING POINT              =      0.1040 VOL/VOL
           INITIAL SOIL WATER CONTENT =      0.2685 VOL/VOL
           EFFECTIVE SAT. HYD. COND.   =  0.520000001000E-03 CM/SEC
         NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  3.00
                FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.

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



```
                    TYPE 2 - LATERAL DRAINAGE LAYER
                      MATERIAL TEXTURE NUMBER   0
           THICKNESS                  =      0.25   INCHES
           POROSITY                   =      0.8500 VOL/VOL
           FIELD CAPACITY             =      0.0100 VOL/VOL
           WILTING POINT              =      0.0050 VOL/VOL
           INITIAL SOIL WATER CONTENT =      0.0355 VOL/VOL
           EFFECTIVE SAT. HYD. COND.   =   1.00000000000     CM/SEC
           SLOPE                      =     33.00   PERCENT
           DRAINAGE LENGTH            =     95.0    FEET

                                  LAYER  3
                                  --------

                    TYPE 4 - FLEXIBLE MEMBRANE LINER
                      MATERIAL TEXTURE NUMBER  35
           THICKNESS                  =      0.04   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      =  4 - POOR

                                  LAYER  4
                                  --------

                    TYPE 1 - VERTICAL PERCOLATION LAYER
                      MATERIAL TEXTURE NUMBER   7
           THICKNESS                  =     24.00   INCHES
           POROSITY                   =      0.4730 VOL/VOL
           FIELD CAPACITY             =      0.2220 VOL/VOL
           WILTING POINT              =      0.1040 VOL/VOL
           INITIAL SOIL WATER CONTENT =      0.2220 VOL/VOL
           EFFECTIVE SAT. HYD. COND.   =  0.520000001000E-03 CM/SEC

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

         NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
                SOIL DATA BASE USING SOIL TEXTURE # 7 WITH A
                FAIR STAND OF GRASS, A SURFACE SLOPE OF 33.%
                AND A SLOPE LENGTH OF   95. FEET.

           SCS RUNOFF CURVE NUMBER            =    78.00
           FRACTION OF AREA ALLOWING RUNOFF   =   100.0    PERCENT
           AREA PROJECTED ON HORIZONTAL PLANE =     1.000  ACRES
           EVAPORATIVE ZONE DEPTH             =    21.0    INCHES
           INITIAL WATER IN EVAPORATIVE ZONE  =     5.528  INCHES
           UPPER LIMIT OF EVAPORATIVE STORAGE =     9.933  INCHES
```

ALT1SIDE

LOWER LIMIT OF EVAPORATIVE STORAGE = 2.184 INCHES
INITIAL SNOW WATER = 0.000 INCHES
INITIAL WATER IN LAYER MATERIALS = 11.781 INCHES
TOTAL INITIAL WATER = 11.781 INCHES
TOTAL SUBSURFACE INFLOW = 0.00 INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
WILMINGTON DELAWARE

STATION LATITUDE = 39.80 DEGREES
MAXIMUM LEAF AREA INDEX = 2.00
START OF GROWING SEASON (JULIAN DATE) = 107
END OF GROWING SEASON (JULIAN DATE) = 298
EVAPORATIVE ZONE DEPTH = 21.0 INCHES
AVERAGE ANNUAL WIND SPEED = 9.20 MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY = 67.00 %
AVERAGE 2ND QUARTER RELATIVE HUMIDITY = 67.00 %
AVERAGE 3RD QUARTER RELATIVE HUMIDITY = 72.00 %
AVERAGE 4TH QUARTER RELATIVE HUMIDITY = 71.00 %

NOTE: PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR WILMINGTON DELAWARE

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
3.11	2.99	3.87	3.39	3.23	3.51
3.90	4.03	3.59	2.89	3.33	3.54

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR WILMINGTON DELAWARE

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
31.20	33.20	41.80	52.40	62.20	71.20
76.00	74.80	67.80	56.30	45.60	35.50

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR WILMINGTON DELAWARE
AND STATION LATITUDE = 39.80 DEGREES

****

ALT1SIDE

AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 30

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	3.22	2.34	3.98	3.24	3.36	3.74
	4.05	4.24	3.82	2.66	3.04	3.03
STD. DEVIATIONS	1.79	0.97	1.40	1.29	1.55	1.72
	1.83	2.28	2.24	1.38	1.45	1.97
RUNOFF						
TOTALS	0.443	0.569	0.364	0.006	0.005	0.015
	0.080	0.062	0.124	0.055	0.025	0.075
STD. DEVIATIONS	0.524	0.566	0.693	0.023	0.014	0.035
	0.263	0.148	0.256	0.170	0.062	0.252
EVAPOTRANSPIRATION						
TOTALS	0.775	0.739	2.338	3.451	3.350	4.497
	3.626	4.013	2.421	1.524	1.266	0.874
STD. DEVIATIONS	0.311	0.451	0.488	0.742	1.002	1.255
	1.252	1.774	0.852	0.262	0.167	0.145
LATERAL DRAINAGE COLLECTED FROM LAYER 2						
TOTALS	1.3694	0.8726	2.6812	0.8128	0.2898	0.1871
	0.0694	0.1260	0.3643	0.8582	0.9120	1.5026
STD. DEVIATIONS	1.3651	1.2065	1.4088	0.5949	0.4532	0.4562
	0.3152	0.3905	0.9785	1.4576	1.3528	1.4588
PERCOLATION/LEAKAGE THROUGH LAYER 3						
TOTALS	0.0001	0.0001	0.0002	0.0001	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001
STD. DEVIATIONS	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0001	0.0001	0.0001	0.0001
PERCOLATION/LEAKAGE THROUGH LAYER 4						
TOTALS	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0001	0.0002
STD. DEVIATIONS	0.0002	0.0003	0.0004	0.0000	0.0002	0.0000
	0.0000	0.0000	0.0002	0.0002	0.0003	0.0004

AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)

DAILY AVERAGE HEAD ON TOP OF LAYER 3						
AVERAGES	0.0025	0.0018	0.0055	0.0015	0.0005	0.0004
	0.0001	0.0002	0.0007	0.0016	0.0017	0.0027

STD. DEVIATIONS	0.0025	0.0026	0.0032	0.0011	0.0008	0.0009
	0.0006	0.0007	0.0018	0.0026	0.0025	0.0026

****

****

AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 30

	INCHES		CU. FEET	PERCENT
PRECIPITATION	40.71	(5.898)	147789.4	100.00
RUNOFF	1.823	(1.0431)	6616.01	4.477
EVAPOTRANSPIRATION	28.873	(3.2960)	104808.95	70.918
LATERAL DRAINAGE COLLECTED FROM LAYER 2	10.04524	(3.60365)	36464.234	24.67311
PERCOLATION/LEAKAGE THROUGH LAYER 3	0.00061	(0.00020)	2.230	0.00151
AVERAGE HEAD ON TOP OF LAYER 3	0.002	(0.001)		
PERCOLATION/LEAKAGE THROUGH LAYER 4	0.00060	(0.00061)	2.177	0.00147
CHANGE IN WATER STORAGE	-0.028	(0.9601)	-101.99	-0.069

****

♀
****

PEAK DAILY VALUES FOR YEARS 1 THROUGH 30

	(INCHES)	(CU. FT.)
PRECIPITATION	5.26	19093.801
RUNOFF	1.511	5486.6572
DRAINAGE COLLECTED FROM LAYER 2	1.81743	6597.27734
PERCOLATION/LEAKAGE THROUGH LAYER 3	0.000084	0.30641
AVERAGE HEAD ON TOP OF LAYER 3	0.245	
MAXIMUM HEAD ON TOP OF LAYER 3	0.207	
LOCATION OF MAXIMUM HEAD IN LAYER 2 (DISTANCE FROM DRAIN)	0.0 FEET	
PERCOLATION/LEAKAGE THROUGH LAYER 4	0.001206	4.37905
SNOW WATER	4.03	14622.6279

MAXIMUM VEG. SOIL WATER (VOL/VOL)	0.3866
MINIMUM VEG. SOIL WATER (VOL/VOL)	0.1040

*** 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.

****

♀
****

FINAL WATER STORAGE AT END OF YEAR 30

LAYER	(INCHES)	(VOL/VOL)
1	5.6066	0.2336
2	0.0038	0.0151
3	0.0000	0.0000
4	5.3278	0.2220
SNOW WATER	0.000	

****
****

```
******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              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\drpi\DATA4.D4
TEMPERATURE DATA FILE:      C:\HELP3\drpi\DATA7.D7
SOLAR RADIATION DATA FILE:  C:\HELP3\drpi\DATA13.D13
EVAPOTRANSPIRATION DATA:    C:\HELP3\drpi\DATA11.D11
SOIL AND DESIGN DATA FILE:  C:\HELP3\drpi\ALT2SIDE.D10
OUTPUT DATA FILE:           C:\HELP3\drpi\alt2side.OUT


TIME:  10:41     DATE:   3/ 6/2018


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

     TITLE:  DRPI Vertical Expansion. Alternative 2 3H:1V sideslope

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


     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   7
          THICKNESS                  =     24.00   INCHES
          POROSITY                   =      0.4730 VOL/VOL
          FIELD CAPACITY             =      0.2220 VOL/VOL
          WILTING POINT              =      0.1040 VOL/VOL
          INITIAL SOIL WATER CONTENT =      0.2696 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  =  0.520000001000E-03 CM/SEC
        NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  3.00
               FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.


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



```
                      TYPE 2 - LATERAL DRAINAGE LAYER
                        MATERIAL TEXTURE NUMBER   0
          THICKNESS                  =      0.13   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.  =   4.80000019000     CM/SEC
          SLOPE                      =     33.00   PERCENT
          DRAINAGE LENGTH            =     95.0    FEET


                                  LAYER  3
                                  --------

                      TYPE 4 - FLEXIBLE MEMBRANE LINER
                        MATERIAL TEXTURE NUMBER  35
          THICKNESS                  =      0.04   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      =  4 - POOR


                                  LAYER  4
                                  --------

                      TYPE 1 - VERTICAL PERCOLATION LAYER
                        MATERIAL TEXTURE NUMBER   7
          THICKNESS                  =     24.00   INCHES
          POROSITY                   =      0.4730 VOL/VOL
          FIELD CAPACITY             =      0.2220 VOL/VOL
          WILTING POINT              =      0.1040 VOL/VOL
          INITIAL SOIL WATER CONTENT =      0.2220 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  =  0.520000001000E-03 CM/SEC


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

   NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
          SOIL DATA BASE USING SOIL TEXTURE # 7 WITH A
          FAIR STAND OF GRASS, A SURFACE SLOPE OF 33.%
          AND A SLOPE LENGTH OF   95. FEET.

  SCS RUNOFF CURVE NUMBER            =     78.00
  FRACTION OF AREA ALLOWING RUNOFF   =    100.0    PERCENT
  AREA PROJECTED ON HORIZONTAL PLANE =      1.000  ACRES
  EVAPORATIVE ZONE DEPTH             =     21.0    INCHES
  INITIAL WATER IN EVAPORATIVE ZONE  =      5.549  INCHES
  UPPER LIMIT OF EVAPORATIVE STORAGE =      9.933  INCHES
```

ALT2SIDE

```
LOWER LIMIT OF EVAPORATIVE STORAGE  =      2.184  INCHES
INITIAL SNOW WATER                  =      0.000  INCHES
INITIAL WATER IN LAYER MATERIALS    =     11.801  INCHES
TOTAL INITIAL WATER                 =     11.801  INCHES
TOTAL SUBSURFACE INFLOW             =      0.00   INCHES/YEAR
```

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM WILMINGTON DELAWARE

```
STATION LATITUDE                        =  39.80 DEGREES
MAXIMUM LEAF AREA INDEX                 =   2.00
START OF GROWING SEASON (JULIAN DATE)   =   107
END OF GROWING SEASON (JULIAN DATE)     =   298
EVAPORATIVE ZONE DEPTH                  =  21.0  INCHES
AVERAGE ANNUAL WIND SPEED               =   9.20 MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY   =  67.00 %
AVERAGE 2ND QUARTER RELATIVE HUMIDITY   =  67.00 %
AVERAGE 3RD QUARTER RELATIVE HUMIDITY   =  72.00 %
AVERAGE 4TH QUARTER RELATIVE HUMIDITY   =  71.00 %
```

NOTE: PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING COEFFICIENTS FOR WILMINGTON DELAWARE

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
3.11	2.99	3.87	3.39	3.23	3.51
3.90	4.03	3.59	2.89	3.33	3.54

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING COEFFICIENTS FOR WILMINGTON DELAWARE

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
31.20	33.20	41.80	52.40	62.20	71.20
76.00	74.80	67.80	56.30	45.60	35.50

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING COEFFICIENTS FOR WILMINGTON DELAWARE AND STATION LATITUDE = 39.80 DEGREES

****

ALT2SIDE

AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 30

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	3.22	2.34	3.98	3.24	3.36	3.74
	4.05	4.24	3.82	2.66	3.04	3.03
STD. DEVIATIONS	1.79	0.97	1.40	1.29	1.55	1.72
	1.83	2.28	2.24	1.38	1.45	1.97
RUNOFF						
TOTALS	0.443	0.572	0.365	0.007	0.005	0.016
	0.082	0.062	0.123	0.056	0.025	0.075
STD. DEVIATIONS	0.520	0.569	0.694	0.025	0.014	0.037
	0.266	0.148	0.253	0.170	0.062	0.239
EVAPOTRANSPIRATION						
TOTALS	0.759	0.723	2.189	3.361	3.375	4.392
	3.352	3.693	2.267	1.456	1.183	0.812
STD. DEVIATIONS	0.295	0.430	0.515	0.663	0.943	1.240
	1.168	1.733	0.842	0.281	0.217	0.174
LATERAL DRAINAGE COLLECTED FROM LAYER 2						
TOTALS	1.3674	0.8116	2.6184	0.8876	0.3674	0.3036
	0.3654	0.4446	0.5961	1.0355	1.0612	1.4903
STD. DEVIATIONS	1.3578	1.1510	1.3956	0.6567	0.5224	0.4649
	0.3624	0.3733	0.9466	1.3415	1.2661	1.3959
PERCOLATION/LEAKAGE THROUGH LAYER 3						
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
PERCOLATION/LEAKAGE THROUGH LAYER 4						
TOTALS	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0002	0.0000	0.0004	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002

AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
DAILY AVERAGE HEAD ON TOP OF LAYER 3						
AVERAGES	0.0005	0.0003	0.0010	0.0003	0.0001	0.0001
	0.0001	0.0002	0.0002	0.0004	0.0004	0.0006

STD. DEVIATIONS	0.0005	0.0005	0.0005	0.0003	0.0002	0.0002
	0.0001	0.0001	0.0004	0.0005	0.0005	0.0005

****

****

AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 30

	INCHES	CU. FEET	PERCENT
PRECIPITATION	40.71 (5.898)	147789.4	100.00
RUNOFF	1.829 (1.0405)	6640.27	4.493
EVAPOTRANSPIRATION	27.562 (3.2109)	100050.37	67.698
LATERAL DRAINAGE COLLECTED FROM LAYER 2	11.34901 (3.56035)	41196.914	27.87542
PERCOLATION/LEAKAGE THROUGH LAYER 3	0.00022 (0.00006)	0.810	0.00055
AVERAGE HEAD ON TOP OF LAYER 3	0.000 (0.000)		
PERCOLATION/LEAKAGE THROUGH LAYER 4	0.00020 (0.00045)	0.725	0.00049
CHANGE IN WATER STORAGE	-0.027 (1.2776)	-98.89	-0.067

****

****

PEAK DAILY VALUES FOR YEARS 1 THROUGH 30

	(INCHES)	(CU. FT.)
PRECIPITATION	5.26	19093.801
RUNOFF	1.512	5488.1606
DRAINAGE COLLECTED FROM LAYER 2	1.55934	5660.41992
PERCOLATION/LEAKAGE THROUGH LAYER 3	0.000015	0.05447
AVERAGE HEAD ON TOP OF LAYER 3	0.018	
MAXIMUM HEAD ON TOP OF LAYER 3	0.058	
LOCATION OF MAXIMUM HEAD IN LAYER 2 (DISTANCE FROM DRAIN)	0.0 FEET	
PERCOLATION/LEAKAGE THROUGH LAYER 4	0.001199	4.35363
SNOW WATER	4.03	14622.6279

MAXIMUM VEG. SOIL WATER (VOL/VOL)	0.3839
MINIMUM VEG. SOIL WATER (VOL/VOL)	0.1040

*** 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.

****

****

FINAL WATER STORAGE AT END OF YEAR 30

LAYER	(INCHES)	(VOL/VOL)
1	5.6541	0.2356
2	0.0016	0.0120
3	0.0000	0.0000
4	5.3277	0.2220
SNOW WATER	0.000	

****
****

ATTACHMENT C

VENEER SLOPE STABILITY CALCULATION

Project:	DPRI Landfill Vertical Expansion				Performed by:	CL		
Date:	3/6/2018							
Modified:					Case 1	**Alternative 1_Above geomembrane**		

Unit Weights		Cover		Slope and Strengths			
γ_w, pcf =	62.4	$t_{w,}$ in. =	0.245	β, deg =	18.43		
γ_t, pcf =	110	t_w*, in. =	0.207	β, rad =	0.321664		
γ_s, pcf =	110	t, in. =	24	δ, deg =	22	a, psf =	0
γ_b, pcf =	47.6	t_w/t =	0.010208	δ, rad =	0.383972		
		t_w*/t =	0.008625	ϕ, deg =	30	c, psf =	0
		h, ft. =	30	ϕ, rad =	0.523599		
		h, in. =	360				

FS = FS1 + FS2 + FS3 + FS4 + FS4 **FS = 1.29**

Infinite slope friction term = FS1
Infinite slope adhesion term = FS2
Buttress resistance friction term = FS3
Buttress resistance cohesion term = FS4
Geosynthetic tension term = FS5

FS1 =	1.205407
FS2 =	0
FS3 =	0.083336
FS4 =	0
FS5 =	0
FS =	1.288743

Project:	DPRI Landfill Vertical Expansion	Performed by:	CL
Date:	3/6/2018		
Modified:		Case 2	**Alternative 1_ Below geomembrane**

Unit Weights		Cover		Slope and Strengths			
γ_w, pcf =	62.4	$t_{w,}$ in. =	0	β, deg =	18.43		
γ_t, pcf =	110	t_w*, in. =	0	β, rad =	0.321664		
γ_s, pcf =	110	t, in. =	24	δ, deg =	22	a, psf =	0
γ_b, pcf =	47.6	t_w/t =	0	δ, rad =	0.383972		
		t_w*/t =	0	ϕ, deg =	30	c, psf =	0
		h, ft. =	30	ϕ, rad =	0.523599		
		h, in. =	360				

FS = FS1 + FS2 + FS3 + FS4 + FS4 **FS = 1.30**

Infinite slope friction term = FS1
Infinite slope adhesion term = FS2
Buttress resistance friction term = FS3
Buttress resistance cohesion term = FS4
Geosynthetic tension term = FS5

FS1 =	1.212428
FS2 =	0
FS3 =	0.083746
FS4 =	0
FS5 =	0
FS =	1.296174

Project:	DPRI Landfill Vertical Expansion	Performed by:	CL
Date:	3/6/2018		
Modified:		Case 3	**Alternative 2_Above geomembrane**

Unit Weights		Cover		Slope and Strengths			
γ_w, pcf =	62.4	t_w, in. =	0.018	β, deg =	18.43		
γ_t, pcf =	110	t_w*, in. =	0.058	β, rad =	0.321664		
γ_s, pcf =	110	t, in. =	24	δ, deg =	25	a, psf =	0
γ_b, pcf =	47.6	t_w/t =	0.00075	δ, rad =	0.436332		
		t_w*/t =	0.002417	ϕ, deg =	30	c, psf =	0
		h, ft. =	30	ϕ, rad =	0.523599		
		h, in. =	360				

FS = FS1 + FS2 + FS3 + FS4 + FS4 **FS = 1.48**

Infinite slope friction term = FS1
Infinite slope adhesion term = FS2
Buttress resistance friction term = FS3
Buttress resistance cohesion term = FS4
Geosynthetic tension term = FS5

FS1 =	1.39873
FS2 =	0
FS3 =	0.083631
FS4 =	0
FS5 =	0
FS =	1.482362

Project: DPRI Landfill Vertical Expansion

Date: 3/6/2018

Modified:

Performed by: CL

Case 4 **Alternative 2_below geomembrane**

Unit Weights		Cover		Slope and Strengths			
γ_w, pcf =	62.4	$t_{w,}$ in. =	0	β, deg =	18.43		
γ_t, pcf =	110	t_w*, in. =	0	β, rad =	0.321664		
γ_s, pcf =	110	t, in. =	24	δ, deg =	25	a, psf =	0
γ_b, pcf =	47.6	t_w/t =	0	δ, rad =	0.436332		
		t_w*/t =	0	ϕ, deg =	30	c, psf =	0
		h, ft. =	30	ϕ, rad =	0.523599		
		h, in. =	360				

FS = FS1 + FS2 + FS3 + FS4 + FS4 **FS = 1.48**

Infinite slope friction term = FS1
Infinite slope adhesion term = FS2
Buttress resistance friction term = FS3
Buttress resistance cohesion term = FS4
Geosynthetic tension term = FS5

FS1 =	1.399326
FS2 =	0
FS3 =	0.083746
FS4 =	0
FS5 =	0
FS =	1.483072