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May 13, 2020

Mr. Sage Kiyonaga, P.E.
Department of Environmental Management
Solid Waste Division
County of Maui
2200 Main Street, Suite 225
Wailuku, Hawaii 96793

SUBJECT: RESPONSE TO COMMENTS, PHASE III SWFP APPLICATION, CENTRAL MAUI LANDFILL (CML) SOLID WASTE MANAGEMENT PERMIT LF-0074-13

Dear Mr. Kiyonaga:

A-Mehr, Inc., at the request of the County of Maui, has reviewed comments received via an email on April 17, 2020 from Mr. Glenn Haae, P.E. of the Department of Health (DOH), Solid Waste Section. The comments pertained to the Phase III SWFP Application.

This letter and attachments are submitted in response to these comments. The itemized responses 1 through 8 reflect and follow the order of the comments as they were received in the April 17, 2020 DOH email.

1. Will there be any account for potentially fractured flow or lateral flow of leachate within the waste mass to ensure no leachate recirculation will occur over the Phase II over-liner, such as an offset away from the over-liner for injection of recirculation leachate?

   Response: recirc trench offset 10' min from Ph II slope improve area

   The leachate recirculation over the Phase III prescriptive liner and LCRS will not extend over the Phase II areas. The recirculation trenches will have a minimum horizontal offset of 10 feet from the toe of the Phase II area. Therefore, the Phase II area refuse fill will be offset from all leachate recirculation trenches by no less than 10 feet and as much as 587 feet.

   Leachate recirculation in the Phase III-A area will commence no earlier than approximately 2 years after initial landfilling operations and we expect that recirculation over the Phase III area will be addressed in a future permit application submittal to DOH.

2. Please provide HELP analysis accounting for the proposed leachate recirculation.

   Response: no HELP w/ leachate recirc provided

   In the interest of time and the fact that leachate recirculation in the Phase III-A area will commence no earlier than approximately 2 years after initial landfilling operations, we expect this item will be *addressed in a future permit application submittal to DOH.*

3. Please provide the crushing calculations for the LCRS pipe. Calculations should take into account perforations in the SDR 11 HDPE pipe.

   Response:
   The LCRS trench where we have specified an 8-inch diameter SDR 11 HDPE pipe is designed at slopes of 1.3% and the LCRS gravel alone is sufficient to convey the design leachate quantities to the LCRS sump. The Phase III floor liner is designed with a minimum slope of 2% and is consistent with the minimum State and Federal requirements. Hydraulic conductivity of the typical drainage rock used for LCRS drainage media is approximately 5 to 8 cm/s (five to eight times better than 1 cm/sec required in the project specification), and with specified hydraulic conductivity of 1 cm/sec the LCRS design for this project meets the prescriptive standard with no LCRS pipe. With the combination of low leachate volumes, the sloped floor and trench, and the drainage media hydraulic conductivity, the LCRS pipe is a redundant LCRS component and is provided to facilitate the leachate removal flow during operation, and the pipe's structural integrity is not a necessary consideration when evaluating the project design. While not required or necessarily relevant, the following discussion of the structural adequacy of the LCRS pipe is provided.

   The Plastic Pipe Institute (PPI) has compiled recommended pipe design and analysis tools tailored specifically for HDPE pipe applications. Specific to the question of pipe crushing or crush strength, the PPI notes these terms are often "misapplied to HDPE pipe". Crush strength implies brittle failure when compressed, such as buckling or cracking to the pipe wall, whereas flexible HDPE pipe can actually deflect in excess of 25% with no signs of wall buckling, cracking, or splitting. To determine if the particular HDPE pipe will have sufficient performance characteristics in a buried application, such as that proposed for the perforated 8-inch diameter SDR 11 LCRS pipe, the following values can be determined to confirm the pipe performance limits are adequate to the specific application:

   a. *Compressive ring thrust stress*
   b. *Ring deflection*
   c. *Constrained pipe wall buckling*

   For purposes of analyzing the effects of the perforations on the performance of the pipe, the volume of pipe wall material removed from the pipe by the perforations was calculated and used to reduce the overall pipe wall thickness for the length of the pipe. The reduced wall thickness was then used in calculations to analyze the perforated pipe performance. Attachment 1 provides the calculations for the performance metrics for the perforated portions of the LCRS pipe. The results are summarized as follows:

   a. *Compressive ring thrust stress*
      - *Calculated Stress = 433 psi*
      - *Allowable = 780 psi*
      - *Conclusion: within acceptable pipe performance limits*
   b. *Ring deflection*
      - *Calculated Deflection = 9.08%*
      - *Allowable (based on observed field performance) = 25%*
      - *Conclusion: within acceptable pipe performance limits*
   c. *Constrained pipe wall buckling*
      - *Calculated critical constrained buckling pressure = 189.4 psi*

- *Calculated vertical load pressure = 76.7 psi*
- *Factor of Safety = 189.4/76.7 = 2.48*
- *Conclusion: within acceptable limits*

4. Please provide the gradation and permeability specification for the 24-inch thick protective (operations) layer. Specifications in Section 2250, Parts 1 and 2 of the project specifications are:

   PART I GENERAL

   A. Work shall consist primarily of placing, grading and protecting protective soil above the liner and leachate collection system.
   B. The Contractor shall submit the results of Conformance Tests to the Engineer.

   PART II MATERIALS

   A. Protective soil shall conform to the following:
      - On side slopes, 100 percent passing a 2-inch sieve according to ASTM C136
      - On the cell floor above leachate collection gravel and geotextile, 100 percent smaller than 6 inches in the largest dimension
   B. Prior to construction of the protective soil cover, source evaluation tests shall be performed to confirm the adequacy of protective soil cover materials procured from each on or off-site source area. The Earthwork Contractor shall submit the results of source evaluation tests to the Engineer. The material shall be accepted or rejected by the Engineer according to these results.

   Therefore, any soil material within these limited specifications may be used, including narrowly graded angular material. Theses specifications ensure assumptions made in design are carried through into construction, which includes but not limited to the protection of specified synthetics to ensure designed performance, hydraulic conductivity (as assumed in the HELP model), and static and seismic stability (as required by regulations under siting criteria). All of these assumptions were used to demonstrate regulatory compliance, thus should be carried through to construction.

   Response:
   Although specifying a permeability specification for protective soil is not consistent with the industry standards and is not required by landfill regulations, to address this comment we revised the Specification Section 2250 incorporating a permeability specification of $1x10^{-2}$ cm/sec for protective soil cover over the liner and LCRS components.

5. Is there a concern with stability on the interface of select waste placed over the rain cap (over Phase II) due to waste saturation or leachate mounding? If there is no lateral drainage layer between the waste and rain cap, is it expected that the rain cap will be punctured sufficiently as it appears to be modeled in the HELP analysis (no barrier layer included in model)?

   Response:
   The leachate mounding is not expected over the Phase II area due to the steep slope condition of the area and relatively high hydraulic conductivity of refuse. To be conservative, in our original HELP Model analysis we did not include the rain cap so that we could calculate a maximum leachate head over the area. To address this comment, we prepared an updated HELP Model analysis incorporating the rain cap material. It should be noted that the rain cap material is not intended to be a liner but rather used to prevent rain water intrusion into the underlying lateral drainage layer prior to being covered by refuse and will be in direct contact with the overlying refuse.

The results of the updated HELP Model analysis is presented in Table 3, Attachment 2 and indicates no leachate head build up on the rain cap layer during the 10-year operational period and a head on the rain cap of 0.042 inches during the 30-year operational period.

6. Will potential future sub-surface elevated temperature events or the existing waste subsidence under the over-liner affect stability of leachate collection?

   Response:

   The County has not experienced elevated sub-surface temperatures in the Phase II waste mass in recent years at or near the interface area. Continuous inspection and maintenance routines are expected to be effective during construction and operation of Phase III in preventing elevated sub-surface temperature events in the Phase II waste and the Phase III waste. Therefore, no impact to the containment and leachate collection system should be expected.

   The County regularly monitors the landfill and the landfill gas collection system to ensure the final cover is maintained in a good condition and the gas collection system is properly operated. Regular inspection of the final cover system ensures the cover integrity is maintained and ensures any deficiencies in the cover are addressed in a timely manner. Regular monitoring of the gas collection system ensures the system is operated properly and prevents the potential for overdraw of the system.

   Subsidence of the Phase II waste is expected to be relatively uniform over the length of the slope and maintain a substantial positive slope draining to the Phase III lined area after waste placement and settlement. The anticipated uniform settlement in combination with the low permeability final cover and the Phase II slope improvements will provide an efficient leachate collection and transmission conduit from the Phase II slope area to the Phase III LCRS.

   Since the completion of the final closure cover on the Phase II slope in 2007 through to the current, the County has monitored settlement of the closed area through periodic visual inspections and with annual aerial topographic surveys. To date, no incidents of differential settlement have been observed in the Phase II area. Roads and drainage benches located in the portion of the Phase II slope that is to receive Phase III refuse have maintained their slope and have continued to perform as intended and are evidence of the uniform settlement process occurring in the area. Comparison of the 2007 and 2018 topographic maps of the area indicate the overall slope settlement during this time period has been uniform and averages approximately 0.2 inches of settlement per 1 foot horizontal run.

   Under the load of additional refuse fill placed during the operational life of Phase III, it is expected the Phase II slope would continue to settle relatively uniformly over the length of the slope. With settlement, the Phase II slope will gradually flatten and any such flattening will enhance overall slope stability of the refuse fill.

   The steep Phase II side slopes that the new landfill will be constructed with the proposed Phase II slope improvements are an ideal combination of a low permeability layer and drainage layer that can effectively function as a liner system and LCRS that will protect underlying groundwater, while also able to accommodate the anticipated settlement of the Phase II slope. The compacted soil layer (low permeability layer), unlike geomembrane layers, can move and settle with the underlying refuse while maintaining its integrity. Under load, the soil layer will continue to be compressed and will "self-heal" and close any cracks or fissures due to this compressive force. The 2-foot thick lateral *drainage/protective soil layer of crushed rock placed above the compacted soil layer will provide enhanced stability and drainage of leachate off the Phase II slope and into the Phase III LCRS system.*

7. The results of the HELP analysis (Table 1, attached) shows that more infiltration seems to occur through the proposed final cover than through the intermediate cover (10-year operational vs. 30-year post closure). This seem counterintuitive. The final cover is an alternative design. Is it contributing to increased leachate generation versus no final cover?

Table 1 – HELP Model Analysis Results

Period of Model Analysis	Liquid Head on Phase II Final Cover Low Permeability Layer(inches)		Rate of Leakage Through Base of Phase II Refuse (cf/acre/day)		Impermeable Liner - Rate of Percolation (cf/acre/day)	Phase II Slope Improvements Exceed Performance of Impermeable Liner?	Factor by which Phase II Exceeds Impermeable Liner Performance
	Existing Phase II Slope	Phase II Slope with 2' Lateral Drainage/ Protective Layer	Existing Phase II Slope*	Phase II Slope with 2' Lateral Drainage/ Protective Layer			
Operational - 10 Years	0.000	0.000	0.0148	0.0148	18.5	Yes	1250
Post Closure - 30 Years	0.027	0.038	0.2208	0.0649	18.5	Yes	285

<u>Response:</u>
The primary purpose for the HELP model analysis summarized in Table 1 was to demonstrate the proposed Phase II slope improvements satisfy the regulatory requirements of maintaining leachate head levels at less than 12 inches, and meets the impermeable layer and percolation rate requirements. The analysis demonstrates compliance in both the 10-year operational period and the 30-year post-closure period. The results of the 10 and 30 years HELP Model analysis are consistent with the performance of a typical MSW landfills.

The HELP model does not provide the most accurate analysis of the final cover system, and therefore the Phase III Closure Plan (Attachment P-4 of the Permit Application submittal) includes an evaluation of the proposed final cover system using the UNSAT-H program which is generally recognized as a preferred method for evaluation of alternative final covers like that proposed for Phase III. Appendix A of the Closure Plan contains the final cover evaluation which concludes that infiltration through the final cover system is essentially zero. With no infiltration occurring through the final cover, the leachate head level on the Phase II slope will not increase during the 30-year post-closure period.

8. The Phase II slope improvement alternative liner design uses the definition of permeability to determine that a liner simply needs to meet a value of $1.0x10^{-7}$ to meet regulatory requirements for compliance. This is not true. The regulatory requirement is either a prescribed liner or that the liner be designed such that concentration values are not exceeded in the uppermost aquifer at the point of compliance.

<u>Response:</u>
We concur with this statement. That is why the Design Report included a contaminant fate and

transport model to demonstrate the Phase II slope improvement alternative liner will provide protection of the underlying groundwater resources at the point of compliance in a manner that is equivalent to or exceeds that of an impermeable liner as defined by HAR 11-58.1-3. The modeling results are presented in Appendix G of the Design Report and indicate all groundwater monitoring parameters will be less than their respective MCLs at the point of compliance.

Should you have any questions, please contact me at 949-206-0157.

Sincerely,

A-Mehr, Inc.
M. Ali Mehrazarin, P.E.
Principal Engineer

Attachment 1 – Evaluation of Perforated LCRS Pipe

The pipe evaluated in the following represents the perforated LCRS trench collector pipe. The LCRS pipe is to have three (3) holes with a diameter of 3/8", spaced at equal intervals around the circumference of the pipe, at 6-inch intervals along the length of the pipe. Therefore, the pipe will have 2 sets of perforations per 1-foot length of pipe. For this evaluation, the volume of pipe wall material removed from the pipe per 1-foot length of pipe as a result of the perforations is calculated, and that volume is used to reduce the overall pipe thickness per 1-foot length of pipe. The reduced wall thickness is then used in the calculations for the performance metrics of the perforated pipe.

Volume of Pipe Material Removed per 1-Foot Length by Perforations =
= 2 sets of holes/ft x 3 holes/set x pipe wall thickness x area of 3/8" hole
= 2 sets of holes/ft x 3 holes/set x 0.784" x $(((3/8")/12"/ft)/2)^2 \times \pi$
= 0.0003 cf

Volume of Material in 1-Foot Length of Solid Pipe =
= Pipe wall thickness x pipe circumference x 1'
= (0.784"/12"/ft) x 2π((8"/12"/ft)/2) x 1'
= 0.1368 cf

Pipe Volume Reduced by Hole Volume = 0.1368 - 0.0003 = 0.1365 cf

Reduction Factor = Hole Volume/Volume of Solid Pipe = 0.0003/0.1365 = 0.0022

Pipe Thickness Reduced = 0.784" x (1 – 0.0022) = 0.782 inches

The following parameters apply to the pipe and the proposed service conditions:

Outside Diameter (D_0) (in)	8.63
Inside Diameter (D_I) (in)	4.315
Minimum Wall Thickness (REDUCED) (t) (in)	0.782
Pipe Dimension Ratio (D_r)	11.0077
Coverage Over Pipe (depth of final cover, refuse/daily cover) (ft)	170
Unit Weight of refuse (lb/cf)	65

The following discussion, equations, and calculations are sourced from the Plastic Pipe Institute Handbook of Polyethylene Pipe, Chapters 3 and 6.

A. <u>Compressive Ring Thrust Stress</u>

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

Project Calculated Value: VAF = 0.88 – 0.71 ((0.42 – 1)/(0.42 + 2.5)) = 1.0215

S_A is calculated as follows:

(3-22) $$S_A = \frac{1.43\, M_S\, r_{CENT}}{EA}$$

Where: r_{cent} = radius to centroidal axis of pipe (in) = 3.872
M_s = one dimensional modulus of soil, psi (Table 3-12) = 1251.0
E = apparent modulus of elasticity of pipe material, psi (Table B.1.1 & B.1.2, Chapter 3, Appendix) = 29,000 x 0.73 (temperature correction) = 21,170
A = wall thickness (in) = 0.782

Project Calculated Value: S_A = (1.43 x 1251.0 x 3.872)/(21,170 x 0.782) = 0.42

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

Vertical Soil Stress = 76.7
Ms = 1251.0

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

Vertical Soil Stress (psi) = (170' x 65 lbs/cf)/144 = 76.7 psi

Industry standard for currently manufactured HDPE pipe used for landfill applications

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.

Apparent Modulus of Elasticity of Pipe Material (E) = 29,000

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

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

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

Where: P_{RD} = radial directed earth pressure (lb/sf)
VAF = Vertical Arching Factor (calculated above) = 1.0215
w = unit weight of refuse/soil (lb/cf) = 65
H = depth of refuse/soil (ft) = 170

Project Calculated Value: P_{RD} = 1.0215 x 170 x 65 = 11,287

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

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

Where: P_E = vertical soil pressure due to refuse/soil load (lb/sf) (use P_{RD} from Eq. 3-23) = 11,287
P_l = vertical pressure due to live load (lb/sf) = 0
S = pipe wall compressive stress (psi)
DR = Dimension Ratio, D_o/t = 11.036

Project Calculated Value: S = ((11,287 + 0) x 11.036)/288 = 433

Allowable compressive stress for HDPE is calculated by multiplying the allowable stress from Table C.1 and applying the temperature correction factor from Table A.2.

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

	Pe Pipe Material Designation Code[1]					
	PE 2406 PE 2708		PE3408 PE 3608 PE 3708 PE 3710 PE 4708		PE 4710	
	psi	MPa	psi	MPa	psi	MPa
Allowable Compressive Stress	800	5.52	1000	6.90	1150	7.93

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

TABLE A.2
Temperature Compensating Multipliers for Converting a Base Temperature HDS or PR to HDS or PR for Another Temperature Between 40 and 100°F (4 and 38°C)

Maximum Sustained Temperature, °F (°C) (1)	Multiplier (2,3)
40 (4)	1.25
50 (10)	1.17
60 (15)	1.10
73 (23)	1.00
80 (27)	0.94
90 (32)	0.86
100 (38)	0.78

(1) Temporary and relatively minor increases in temperature beyond a sustained temperature have little effect on the long-term strength of a PE pipe material and thus, can be ignored.

(2) The multipliers in this table apply to a PE pipe that is made from a material having at least, an established hydrostatic design stress (HDS) for water, for 73°F (23°C). This HDS is designated by the last two numerals in the PE's standard designation code (e.g., the last two digits in PE4710 designate that the HDS for water, for 73°F (23°C), is 1,000psi – See Introduction and Chapter 5 for a more complete explanation.)

(3) For a temperature of interest that falls within any pair of listed temperatures the reader may apply an interpolation process to determine the appropriate multiplier.

Project Calculated Value: Allowable Compressive Stress = 1000 x 0.78 = 780

Calculated compressive stress on LCRS pipe (433 psi) is less than the allowable compressive stress (780 psi). Pipe is within acceptable limits.

B. Ring Deflection

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, DF, 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 DF factor. The designer using the Watkins-Gaube Graph 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 the pipe and soil, which is given by the Rigidity Factor (Rf) (Equation 3-24).

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

Where: DR = Dimension Ratio, D_o/t = 11.036
E_S= Sequent modulus of soil (psi) (calculated in following) = 929.3
E = Apparent modulus of elasticity of pipe material (psi) (calculated previously) = 21,170

Project Calculated Value: R_F = ((12 x 929.3) x (11.036 – 1)^3)/21,170 = 533

The secant modulus of the soil may be obtained by the following equation where μ is the soil's Poisson ratio.

$$\text{(3-26)} \quad E_S = M_S \frac{(1+\mu)(1-2\mu)}{(1-\mu)}$$

Where: E_S= Sequent modulus of soil (psi)
M_s = one dimensional modulus of soil, psi (Table 3-12) = 1251.0
μ = Poisson's ratio for LCRS pipe bedding gravel = 0.3

Project Calculated Value: E_S = 1251.0 x ((1 + 0.3)(1-(2 x 0.3))/(1 – 0.3)) = 929.3

Next, the designer determines the Deformation Factor, DF, 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 DF times the soil settlement. If DF is less than 1.0 in Fig. 3-6, use 1.0.

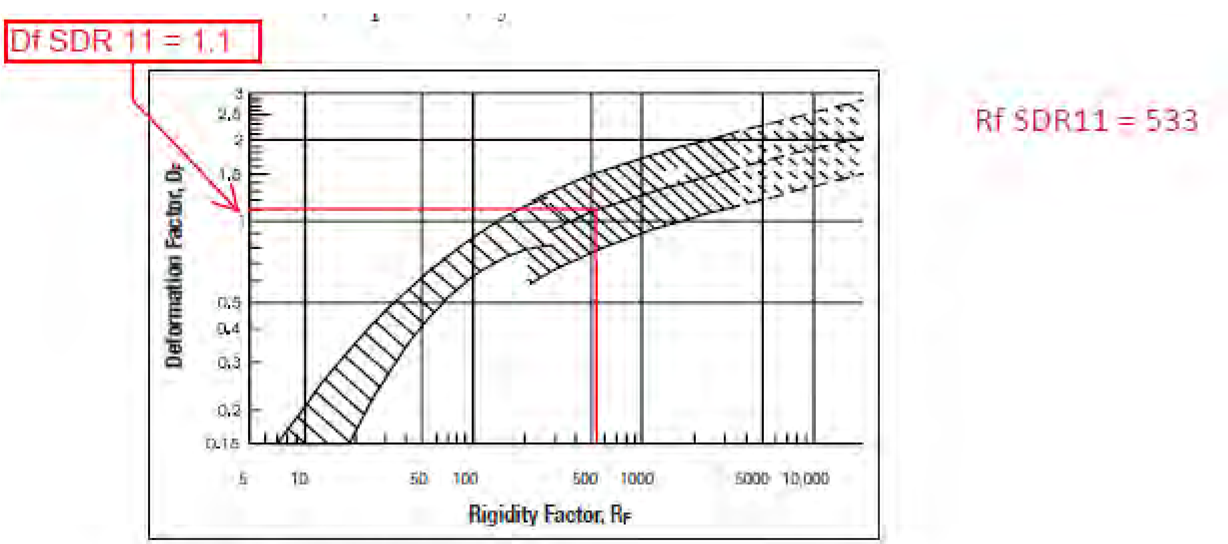


Figure 3-6 Watkins-Gaube Graph

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, εS, may be determined from geotechnical analysis or from the following equation:

$$\text{(3-27)} \quad \varepsilon_S = \frac{wH}{144 E_S} \times 100 = \text{Soil Strain}$$

Where: E_S= Sequent modulus of soil (psi) = 929.3
w = unit weight of refuse/soil (lb/cf) = 65
H = depth of refuse/soil (ft) = 170

Project Calculated Value: εS = (65 x 170 x 100)/(144 x 929.3) = 8.26

The designer can find the pipe deflection as a percent of the diameter by multiplying the soil strain, in percent, by the deformation factor:

$$\text{(3-28)} \quad \frac{\Delta X}{D_M}(100) = D_F \varepsilon_S = \text{\% Deflection}$$

Project Calculated Value: % Deflection = D_F x εS = 1.1 x 8.26 = 9.08%

Allowable deflection, based on observed field performance of HDPE pipe, can exceed 25% with no signs of wall buckling, cracking, or splitting. Pipe is within acceptable limits.

C. Constrained Pipe Wall Buckling

As discussed previously, a compressive thrust stress exists in buried pipe. When this thrust stress approaches a critical value, the pipe can experience a local instability or large deformation and collapse.

The Moore-Selig Equation for critical buckling pressure follows: (Critical buckling pressure is the pressure at which buckling will occur. A safety factor should be provided.)

$$\text{(3-29)} \quad P_{CR} = \frac{2.4 \varphi R_H}{D_M}(EI)^{\frac{1}{3}}(E_S^*)^{\frac{2}{3}}$$

Where:
- P_{CR} = Critical constrained buckling pressure (psi)
- ϕ = Calibration factor = 0.55 for granular soils
- R_H = Geometry factor = 1.0
- D_M = Mean diameter = $(D_O + D_I)/2$ = 7.798
- E = Apparent modulus of elasticity of pipe material (psi) (calculated previously) = 21,170
- I = Pipe wall moment of inertia = $t^3/12 = (0.782)^3/12 = 0.0398$
- $E^*_S = E_S/(1-\mu) = 1327.6$
- E_S= Sequent modulus of soil (psi) = 929.3

Project Calculated Value: $P_{CR} = ((2.4 \times 0.55 \times 1.0)/7.798) \times (21{,}170 \times 0.0398)^{1/3} \times (1327.6)^{2/3} = 189.4$

Safety Factor Against Buckling = P_{CR}/ P_E

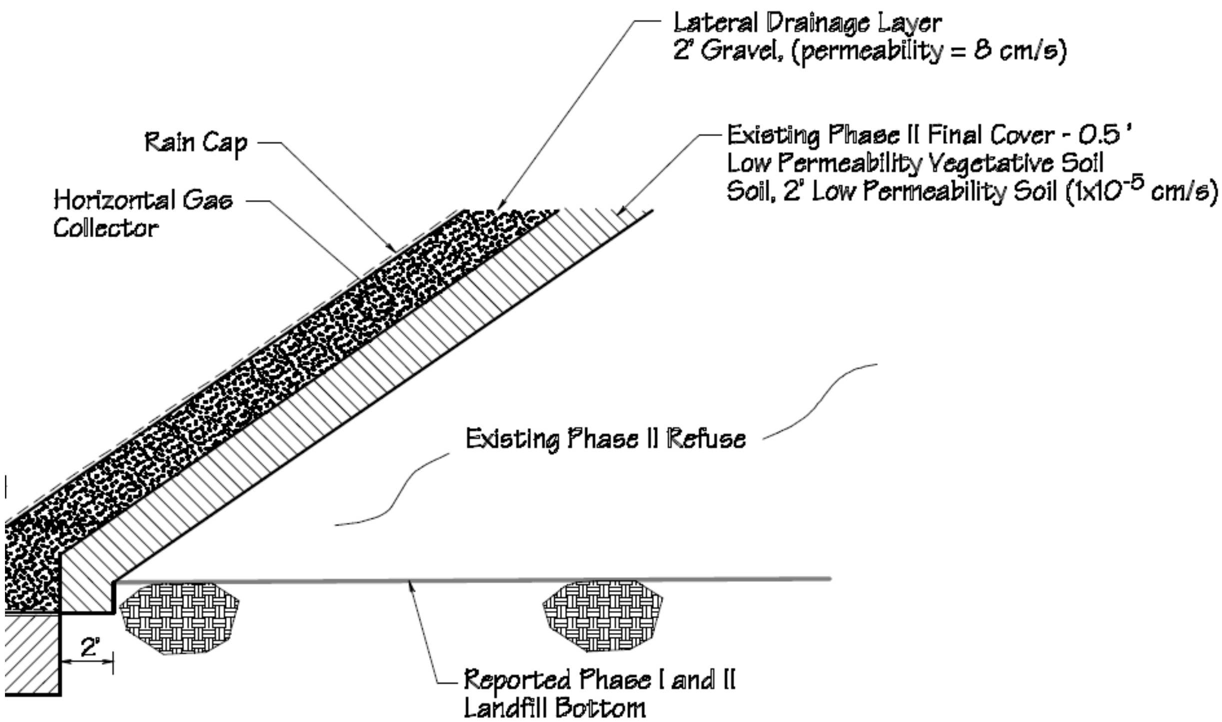
Where:
- P_{CR} = Critical constrained buckling pressure (psi) = 189.4
- P_E = Vertical soil pressure (psi) = 76.7

Project Calculated Value: Factor of Safety = 189.4/76.7 = 2.48

Pipe is within acceptable limits.

Attachment 2 – Updated HELP Model Analysis of Phase II Slope Improvements with Rain Cap

The following presents updated HELP Model analysis of the Phase II slope improvements. The model profiles have been updated to include the rain cap (Dura Skrim 12WB) and are summarized on the model input Table 1 and Table 2. All other profile materials and weather conditions remain the same from the prior model submitted with the original permit application package. The detail below illustrates the Phase II slope improvement components in cross-section.



The update model results are summarized in Table 3.

The HELP Model summary output reports are provided after Table 3. (Summary output reports provide pages summarizing model input and model output results for the end of period modeled. Output pages for individual year calculations are not included but are available from A-Mehr, Inc. upon request)

Table 1 - Model Input: Regraded Phase II Slope w/ DuraSkrim Rain Cap and 2' Lateral Drainage/Protective Soil Layer, 10-Year Operational Period

Layer No.	Layer Name	Layer Data	Regraded Phase II Slope w/ 2' Lateral Drainage/Protective Soil Layer
1	Interim Cover		
		Thickness (ft)	1
		Slope (%)	30
		K (cm/s)	1.9x10E-4
		Initial Moisture (vol/vol)	0.28
2	Ph III Refuse		
		Thickness (ft)	65
		Slope (%)	30
		Initial Moisture (vol/vol)	0.247
3	Rain Cap (DuraSkrim 12WB, HDPE geomebrane)		
		Slope (%)	22
		K (cm/s)	2x10E-13
		Pin Hole Density (#/ha)	8
		Installation Defects (#/ha)	37
		Placement Quality	4
4	Ph III Gravel Drain Layer		
		Thickness (ft)	2
		Slope (%)	22
		K (cm/s)	8
		Initial Moisture (vol/vol)	0.03
5	Ph II Final Cover		
		Thickness (ft)	2
		Slope (%)	22
		K (cm/s)	1x10E-5
6	Ph II Refuse		
		Thickness (ft)	45
		Slope (%)	22
		Initial Moisture (vol/vol)	0.276
	Case Settings		
		Runoff Method	Model Calculated
		Initial Mositure	User Specified
	Surface Water Settings		
		Runoff Area %	100
		Initial Surface Water	0
		Vegetation Class	Bare Soil

Table 2 - Model Input: Regraded Phase II Slope w/ 2' DuraSkrim Rain Cap and Lateral Drainage/Protective Soil Layer, 30-Year Post Closure Period

Layer No.	Layer Name	Layer Data	Regraded Phase II Slope w/ 2' Lateral Drainage/Protective Soil Layer
1	Final Cover Vegetative Layer		
		Thickness (ft)	1
		Slope (%)	30
		K (cm/s)	1.9x10E-4
		Initial Moisture (vol/vol)	0.28
2	Final Cover		
		Thickness (ft)	2
		Slope (%)	30
		K (cm/s)	5x10E-5
3	Interim Cover		
		Thickness (ft)	1
		Slope (%)	30
		K (cm/s)	1x10E-4
		Initial Moisture (vol/vol)	0.1565
4	Ph III Refuse		
		Thickness (ft)	65
		Slope (%)	30
		Initial Moisture (vol/vol)	0.2531
5	Rain Cap (DuraSkrim 12WB, HDPE geomebrane)		
		Slope (%)	22
		K (cm/s)	2x10E-13
		Pin Hole Density (#/ha)	8
		Installation Defects (#/ha)	37
		Placement Quality	4
6	Ph III Gravel Drain Layer		
		Thickness (ft)	2
		Slope (%)	22
		K (cm/s)	8
		Initial Moisture (vol/vol)	0.03
7	Ph II Final Cover		
		Thickness (ft)	2
		Slope (%)	22
		K (cm/s)	1x10E-5
8	Ph II Refuse		
		Thickness (ft)	45
		Slope (%)	22
		Initial Moisture (vol/vol)	0.276
	Case Settings		
		Runoff Method	Model Calculated
		Initial Mositure	Moisture Values Output from 10-Yr Operational Period Model
	Surface Water Settings		
		Runoff Area %	100
		Initial Surface Water	0
		Vegetation Class	Fair Stand of Grass

Table 3 - HELP Model Analysis Results

Period of Model Analysis	Liquid Head on Rain Cap, Phase II Improved Slope (inches)		Liquid Head on Phase II Final Cover Low Permeability Layer (inches)		Rate of Leakage Through Base of Phase II Refuse (cf/acre/day)		Impermeable Liner - Rate of Percolation (cf/acre/day)	Phase II Slope Improvements Exceed Performance of Impermeable Liner?	Factor by which Phase II Exceeds Impermeable Liner Performance
	Existing Phase II Slope*	Phase II Slope with Rain Cap and 2' Lateral Drainage/ Protective Layer	Existing Phase II Slope*	Phase II Slope with Rain Cap and 2' Lateral Drainage/ Protective Layer	Existing Phase II Slope*	Phase II Slope with Rain Cap and 2' Lateral Drainage/ Protective Layer			
Operational - 10 Years	0.000	0.000	0.000	0.000	0.0148	0.0148	18.5	Yes	1250
Post Closure - 30 Years	0.027	0.042	0.027	0.000	0.2208	0.1147	18.5	Yes	161

* -Please note the existing final cover with no additional improvement also meets the regulatory definition of impermeable liner of 18.5 cf/acre/day.

Model Input: Regraded Phase II Slope w/ Rain Cap,
2' Lateral Drainage/Protective Soil Layer, 10-Year Operational Period

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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:\WHI\VHELP22\data\P4836.VHP_weather1.dat
TEMPERATURE DATA FILE: C:\WHI\VHELP22\data\P4836.VHP_weather2.dat
SOLAR RADIATION DATA FILE: C:\WHI\VHELP22\data\P4836.VHP_weather3.dat
EVAPOTRANSPIRATION DATA: C:\WHI\VHELP22\data\P4836.VHP_weather4.dat
SOIL AND DESIGN DATA FILE: C:\WHI\VHELP22\data\P4836.VHP\I_390539.inp
OUTPUT DATA FILE: C:\WHI\VHELP22\data\P4836.VHP\O_390539.prt

TIME: 10: 3 DATE: 5/11/2020

****

TITLE: PhIII MSW SKRIM,Gravel & IntCvr Overlay of Ph II 22

Ph III Intermediate Cover
Ph III Refuse Thickness 65'; Ph I-II Refuse Thickness 45';
Initial Moist for 10 yr run (85%/95% of default) Ph III = 0.247, Ph II = 0.276
DuraSkrim 12WB rain cap
2' LATERAL DRAINAGE LAYER (k = 8 cm/s) between Ph I/II Final Cvr & Ph III Refuse
Kahului Airport Rainfall Data

Output File: PhIII IntCvr ovr PhII FinCvr-Avg 22% slope, 10yr, grave, skrim
****

NOTE: INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER
WERE SPECIFIED BY THE USER.

LAYER 1

TYPE 1 - VERTICAL PERCOLATION LAYER
MATERIAL TEXTURE NUMBER 9
THICKNESS = 30.48 CM
POROSITY = 0.5010 VOL/VOL
FIELD CAPACITY = 0.2840 VOL/VOL
WILTING POINT = 0.1350 VOL/VOL
INITIAL SOIL WATER CONTENT = 0.2800 VOL/VOL
EFFECTIVE SAT. HYD. COND. = 0.190000000000E-03 CM/SEC
NOTE: SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY 5.00
FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.

LAYER 2

TYPE 1 - VERTICAL PERCOLATION LAYER
MATERIAL TEXTURE NUMBER 18
THICKNESS = 1981.20 CM
POROSITY = 0.6710 VOL/VOL
FIELD CAPACITY = 0.2920 VOL/VOL
WILTING POINT = 0.0770 VOL/VOL
INITIAL SOIL WATER CONTENT = 0.2470 VOL/VOL
EFFECTIVE SAT. HYD. COND. = 0.100000000000E-02 CM/SEC

LAYER 3

TYPE 4 - FLEXIBLE MEMBRANE LINER
MATERIAL TEXTURE NUMBER 135
THICKNESS = 0.03 CM
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. = 0.200000000000E-12 CM/SEC
FML PINHOLE DENSITY = 8.00 HOLES/HECTARE
FML INSTALLATION DEFECTS = 37.00 HOLES/HECTARE
FML PLACEMENT QUALITY = 4 - POOR

LAYER 4

TYPE 2 - LATERAL DRAINAGE LAYER
MATERIAL TEXTURE NUMBER 90
THICKNESS = 60.96 CM
POROSITY = 0.3970 VOL/VOL
FIELD CAPACITY = 0.0320 VOL/VOL
WILTING POINT = 0.0130 VOL/VOL
INITIAL SOIL WATER CONTENT = 0.0300 VOL/VOL
EFFECTIVE SAT. HYD. COND. = 8.00000000000 CM/SEC
SLOPE = 22.00 PERCENT
DRAINAGE LENGTH = 121.9 METERS

LAYER 5

TYPE 3 - BARRIER SOIL LINER
MATERIAL TEXTURE NUMBER 99
THICKNESS = 60.96 CM
POROSITY = 0.4750 VOL/VOL
FIELD CAPACITY = 0.3780 VOL/VOL
WILTING POINT = 0.2650 VOL/VOL
INITIAL SOIL WATER CONTENT = 0.4750 VOL/VOL
EFFECTIVE SAT. HYD. COND. = 0.100000000000E-04 CM/SEC

LAYER 6

TYPE 1 - VERTICAL PERCOLATION LAYER
MATERIAL TEXTURE NUMBER 18
THICKNESS = 1371.60 CM
POROSITY = 0.6710 VOL/VOL
FIELD CAPACITY = 0.2920 VOL/VOL
WILTING POINT = 0.0770 VOL/VOL
INITIAL SOIL WATER CONTENT = 0.2760 VOL/VOL
EFFECTIVE SAT. HYD. COND. = 0.100000224000E-02 CM/SEC

GENERAL DESIGN AND EVAPORATIVE ZONE DATA

NOTE: SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
SOIL DATA BASE USING SOIL TEXTURE # 9 WITH BARE
GROUND CONDITIONS, A SURFACE SLOPE OF 30.% AND
A SLOPE LENGTH OF 30. METERS.

SCS RUNOFF CURVE NUMBER = 92.71
FRACTION OF AREA ALLOWING RUNOFF = 100.0 PERCENT
AREA PROJECTED ON HORIZONTAL PLANE = 0.4047 HECTARES
EVAPORATIVE ZONE DEPTH = 25.4 CM
INITIAL WATER IN EVAPORATIVE ZONE = 7.112 CM
UPPER LIMIT OF EVAPORATIVE STORAGE = 12.725 CM
LOWER LIMIT OF EVAPORATIVE STORAGE = 3.429 CM
INITIAL SNOW WATER = 0.000 CM
INITIAL WATER IN LAYER MATERIALS = 907.237 CM
TOTAL INITIAL WATER = 907.237 CM
TOTAL SUBSURFACE INFLOW = 0.00 MM/YR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
Kahului HI

STATION LATITUDE = 20.86 DEGREES
MAXIMUM LEAF AREA INDEX = 5.00
START OF GROWING SEASON (JULIAN DATE) = 0
END OF GROWING SEASON (JULIAN DATE) = 365
EVAPORATIVE ZONE DEPTH = 10.0 INCHES
AVERAGE ANNUAL WIND SPEED = 11.70 MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY = 72.00 %
AVERAGE 2ND QUARTER RELATIVE HUMIDITY = 66.00 %
AVERAGE 3RD QUARTER RELATIVE HUMIDITY = 66.00 %
AVERAGE 4TH QUARTER RELATIVE HUMIDITY = 70.00 %

NOTE: PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR Kahului HI

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
2.87	1.89	2.45	1.55	0.74	0.20
0.50	0.50	0.38	1.20	2.20	3.35

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR Kahului HI

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
72.60	72.90	74.40	75.70	77.50	79.10
80.10	81.00	80.60	79.50	76.60	74.00

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR Kahului HI
AND STATION LATITUDE = 20.86 DEGREES

Model Output Pages: Regraded Phase II Slope w/ Rain Cap,
2' Lateral Drainage/Protective Soil Layer, 10-Year Operational Period

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AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 10

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	1.76	2.05	1.94	1.18	1.08	0.16
	0.61	0.43	0.39	1.42	2.56	3.51
STD. DEVIATIONS	0.74	1.37	0.72	0.78	0.61	0.11
	0.33	0.20	0.19	0.69	1.28	1.57
RUNOFF						
TOTALS	0.067	0.084	0.148	0.070	0.001	0.000
	0.000	0.000	0.001	0.020	0.157	0.361
STD. DEVIATIONS	0.069	0.114	0.202	0.146	0.003	0.000
	0.000	0.000	0.002	0.033	0.193	0.379
EVAPOTRANSPIRATION						
TOTALS	1.939	2.119	1.832	1.185	1.013	0.253
	0.604	0.419	0.403	1.375	2.230	2.474
STD. DEVIATIONS	0.869	0.908	0.613	0.643	0.588	0.176
	0.331	0.192	0.192	0.644	1.112	0.755
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
LATERAL DRAINAGE COLLECTED FROM LAYER 4						
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 5						
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 6						
TOTALS	0.0015	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0047	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 3

AVERAGES 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

DAILY AVERAGE HEAD ON TOP OF LAYER 5

AVERAGES 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

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

	INCHES	CU. FEET	PERCENT
PRECIPITATION	17.09 (1.156)	62020.8	100.00
RUNOFF	0.910 (0.4913)	3302.39	5.325
EVAPOTRANSPIRATION	15.846 (1.2534)	57519.98	92.743
PERCOLATION/LEAKAGE THROUGH LAYER 3	0.00000 (0.00000)	0.000	0.00000
AVERAGE HEAD ON TOP OF LAYER 3	0.000 (0.000)		
LATERAL DRAINAGE COLLECTED FROM LAYER 4	0.00000 (0.00000)	0.000	0.00000
PERCOLATION/LEAKAGE THROUGH LAYER 5	0.00000 (0.00000)	0.000	0.00000
AVERAGE HEAD ON TOP OF LAYER 5	0.000 (0.000)		
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.00149 (0.00472)	5.416	0.00873
CHANGE IN WATER STORAGE	0.329 (0.7474)	1193.04	1.924

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PEAK DAILY VALUES FOR YEARS 1 THROUGH 10 and their dates (DDDYYYY)

	(INCHES)	(CU. FT.)	
PRECIPITATION	1.78	6461.25917	3570007
RUNOFF	0.651	2364.78242	3460008
PERCOLATION/LEAKAGE THROUGH LAYER 3	0.000000	0.00000	0
AVERAGE HEAD ON TOP OF LAYER 3	0.000		
DRAINAGE COLLECTED FROM LAYER 4	0.00000	0.00000	0
PERCOLATION/LEAKAGE THROUGH LAYER 5	0.000000	0.00000	0
AVERAGE HEAD ON TOP OF LAYER 5	0.000		
MAXIMUM HEAD ON TOP OF LAYER 5	0.000		
LOCATION OF MAXIMUM HEAD IN LAYER 4 (DISTANCE FROM DRAIN)	0.0 FEET		
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.014921	54.16135	10001
SNOW WATER	0.00	0.0000	0
MAXIMUM VEG. SOIL WATER (VOL/VOL)	0.3475		
MINIMUM VEG. SOIL WATER (VOL/VOL)	0.1350		

*** 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	1.8774	0.1565
2	197.4441	0.2531
3	0.0000	0.0000
4	0.7200	0.0300
5	11.4000	0.4750
6	149.0251	0.2760
SNOW WATER	0.000	

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****

Model Input: Regraded Phase II Slope w/ Rain Cap,
2' Lateral Drainage/Protective Soil Layer, 30-Year Post Closure Period

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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:\WHI\VHELP22\data\P5048.VHP_weather1.dat
TEMPERATURE DATA FILE: C:\WHI\VHELP22\data\P5048.VHP_weather2.dat
SOLAR RADIATION DATA FILE: C:\WHI\VHELP22\data\P5048.VHP_weather3.dat
EVAPOTRANSPIRATION DATA: C:\WHI\VHELP22\data\P5048.VHP_weather4.dat
SOIL AND DESIGN DATA FILE: C:\WHI\VHELP22\data\P5048.VHP\I_390793.inp
OUTPUT DATA FILE: C:\WHI\VHELP22\data\P5048.VHP\O_390793.prt

TIME: 10:12 DATE: 5/11/2020

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TITLE: PhIII MSW SKRIM Gravel & FinCvr Overlay of Ph II 2

Ph III Final Cover 5x10E-6 cm/s
Ph III Refuse Thickness 65'; Ph I-II Refuse Thickness 45';
10-yr input for Int Moist PhII=0.276 PhIII=0.247
DuraSkrim 12WB rain cap
2' LATERAL DRAINAGE LAYER (k=8 cm/s) between Ph I/II Final Cvr & Ph III Refuse
Kahului Airport Rainfall Data

Output File: PhIII FinCvr ovr PhII FinCvr-Avg 22%slope,30yr,grave, skrim
****

NOTE: INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER
WERE SPECIFIED BY THE USER.

LAYER 1

TYPE 1 - VERTICAL PERCOLATION LAYER
MATERIAL TEXTURE NUMBER 9
THICKNESS = 30.48 CM
POROSITY = 0.5010 VOL/VOL
FIELD CAPACITY = 0.2840 VOL/VOL
WILTING POINT = 0.1350 VOL/VOL
INITIAL SOIL WATER CONTENT = 0.2800 VOL/VOL
EFFECTIVE SAT. HYD. COND. = 0.190000000000E-03 CM/SEC
NOTE: SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY 5.00
FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.

LAYER 2

TYPE 3 - BARRIER SOIL LINER
MATERIAL TEXTURE NUMBER 88
THICKNESS = 60.96 CM
POROSITY = 0.4750 VOL/VOL
FIELD CAPACITY = 0.3780 VOL/VOL
WILTING POINT = 0.2650 VOL/VOL
INITIAL SOIL WATER CONTENT = 0.4750 VOL/VOL
EFFECTIVE SAT. HYD. COND. = 0.500000000000E-05 CM/SEC

LAYER 3

TYPE 1 - VERTICAL PERCOLATION LAYER

MATERIAL TEXTURE NUMBER 9

THICKNESS = 30.48 CM
POROSITY = 0.5010 VOL/VOL
FIELD CAPACITY = 0.2840 VOL/VOL
WILTING POINT = 0.1350 VOL/VOL
INITIAL SOIL WATER CONTENT = 0.1565 VOL/VOL
EFFECTIVE SAT. HYD. COND. = 0.190000000000E-03 CM/SEC

LAYER 4

TYPE 1 - VERTICAL PERCOLATION LAYER

MATERIAL TEXTURE NUMBER 18

THICKNESS = 1981.20 CM
POROSITY = 0.6710 VOL/VOL
FIELD CAPACITY = 0.2920 VOL/VOL
WILTING POINT = 0.0770 VOL/VOL
INITIAL SOIL WATER CONTENT = 0.2531 VOL/VOL
EFFECTIVE SAT. HYD. COND. = 0.100000000000E-02 CM/SEC

LAYER 5

TYPE 4 - FLEXIBLE MEMBRANE LINER

MATERIAL TEXTURE NUMBER 135

THICKNESS = 0.03 CM
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. = 0.200000000000E-12 CM/SEC
FML PINHOLE DENSITY = 8.00 HOLES/HECTARE
FML INSTALLATION DEFECTS = 37.00 HOLES/HECTARE
FML PLACEMENT QUALITY = 4 - POOR

LAYER 6

TYPE 2 - LATERAL DRAINAGE LAYER

MATERIAL TEXTURE NUMBER 90

THICKNESS = 60.96 CM
POROSITY = 0.3970 VOL/VOL
FIELD CAPACITY = 0.0320 VOL/VOL
WILTING POINT = 0.0130 VOL/VOL
INITIAL SOIL WATER CONTENT = 0.0300 VOL/VOL
EFFECTIVE SAT. HYD. COND. = 8.00000000000 CM/SEC
SLOPE = 22.00 PERCENT
DRAINAGE LENGTH = 121.9 METERS

LAYER 7

TYPE 3 - BARRIER SOIL LINER

MATERIAL TEXTURE NUMBER 99

THICKNESS = 60.96 CM
POROSITY = 0.4750 VOL/VOL
FIELD CAPACITY = 0.3780 VOL/VOL
WILTING POINT = 0.2650 VOL/VOL
INITIAL SOIL WATER CONTENT = 0.4750 VOL/VOL
EFFECTIVE SAT. HYD. COND. = 0.100000000000E-04 CM/SEC

LAYER 8

TYPE 1 - VERTICAL PERCOLATION LAYER
MATERIAL TEXTURE NUMBER 18
THICKNESS = 1371.60 CM
POROSITY = 0.6710 VOL/VOL
FIELD CAPACITY = 0.2920 VOL/VOL
WILTING POINT = 0.0770 VOL/VOL
INITIAL SOIL WATER CONTENT = 0.2760 VOL/VOL
EFFECTIVE SAT. HYD. COND. = 0.100000224000E-02 CM/SEC

GENERAL DESIGN AND EVAPORATIVE ZONE DATA

NOTE: SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
SOIL DATA BASE USING SOIL TEXTURE # 9 WITH A
FAIR STAND OF GRASS, A SURFACE SLOPE OF 30.%
AND A SLOPE LENGTH OF 0. METERS.

SCS RUNOFF CURVE NUMBER = 0.00
FRACTION OF AREA ALLOWING RUNOFF = 100.0 PERCENT
AREA PROJECTED ON HORIZONTAL PLANE = 0.4047 HECTARES
EVAPORATIVE ZONE DEPTH = 25.4 CM
INITIAL WATER IN EVAPORATIVE ZONE = 7.112 CM
UPPER LIMIT OF EVAPORATIVE STORAGE = 12.725 CM
LOWER LIMIT OF EVAPORATIVE STORAGE = 3.429 CM
INITIAL SNOW WATER = 0.000 CM
INITIAL WATER IN LAYER MATERIALS = 953.049 CM
TOTAL INITIAL WATER = 953.049 CM
TOTAL SUBSURFACE INFLOW = 0.00 MM/YR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
Kahului HI

STATION LATITUDE = 20.86 DEGREES
MAXIMUM LEAF AREA INDEX = 5.00
START OF GROWING SEASON (JULIAN DATE) = 0
END OF GROWING SEASON (JULIAN DATE) = 365
EVAPORATIVE ZONE DEPTH = 10.0 INCHES
AVERAGE ANNUAL WIND SPEED = 11.70 MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY = 72.00 %
AVERAGE 2ND QUARTER RELATIVE HUMIDITY = 66.00 %
AVERAGE 3RD QUARTER RELATIVE HUMIDITY = 66.00 %
AVERAGE 4TH QUARTER RELATIVE HUMIDITY = 70.00 %

NOTE: PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR Kahului HI

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
2.87	1.89	2.45	1.55	0.74	0.20
0.50	0.50	0.38	1.20	2.20	3.35

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR Kahului HI

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
72.60	72.90	74.40	75.70	77.50	79.10
80.10	81.00	80.60	79.50	76.60	74.00

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR Kahului HI
AND STATION LATITUDE = 20.86 DEGREES

Model Output Pages: Regraded Phase II Slope w/ Rain Cap,
2' Lateral Drainage/Protective Soil Layer, 30-Year Post Closure Period
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AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 30

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	2.62	1.56	2.20	1.33	0.82	0.23
	0.55	0.38	0.41	1.23	2.33	3.36
STD. DEVIATIONS	1.37	1.09	0.95	0.77	0.55	0.18
	0.27	0.24	0.20	0.57	1.07	1.78
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	2.324	1.981	2.023	1.463	0.838	0.280
	0.543	0.388	0.421	1.181	2.133	2.327
STD. DEVIATIONS	0.878	0.978	0.821	0.829	0.541	0.190
	0.260	0.251	0.197	0.561	0.919	0.978
PERCOLATION/LEAKAGE THROUGH LAYER 2						
TOTALS	0.5631	0.0767	0.0331	0.0463	0.0016	0.0000
	0.0000	0.0000	0.0000	0.0004	0.0168	0.4354
STD. DEVIATIONS	0.9360	0.3179	0.1750	0.1585	0.0088	0.0000
	0.0001	0.0000	0.0000	0.0017	0.0425	0.5543
PERCOLATION/LEAKAGE THROUGH LAYER 5						
TOTALS	0.0135	0.0282	0.0213	0.0168	0.0128	0.0070
	0.0037	0.0016	0.0005	0.0001	0.0014	0.0040
STD. DEVIATIONS	0.0409	0.0781	0.0607	0.0426	0.0354	0.0203
	0.0114	0.0054	0.0020	0.0006	0.0074	0.0158
LATERAL DRAINAGE COLLECTED FROM LAYER 6						
TOTALS	0.0009	0.0054	0.0053	0.0026	0.0022	0.0010
	0.0004	0.0002	0.0000	0.0000	0.0000	0.0002
STD. DEVIATIONS	0.0032	0.0191	0.0166	0.0080	0.0066	0.0032
	0.0015	0.0006	0.0002	0.0000	0.0000	0.0010
PERCOLATION/LEAKAGE THROUGH LAYER 7						
TOTALS	0.0058	0.0171	0.0193	0.0138	0.0142	0.0090
	0.0055	0.0031	0.0010	0.0001	0.0001	0.0021
STD. DEVIATIONS	0.0197	0.0473	0.0514	0.0366	0.0356	0.0242
	0.0166	0.0101	0.0043	0.0006	0.0002	0.0110
PERCOLATION/LEAKAGE THROUGH LAYER 8						
TOTALS	0.0005	0.0022	0.0026	0.0035	0.0027	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0027	0.0094	0.0071	0.0116	0.0090	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 2

AVERAGES	0.2510	0.0117	0.0102	0.0080	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0008	0.1159
STD. DEVIATIONS	0.6776	0.0602	0.0559	0.0390	0.0002	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0033	0.2260

DAILY AVERAGE HEAD ON TOP OF LAYER 5

AVERAGES	0.0610	0.1584	0.0983	0.0729	0.0497	0.0241
	0.0103	0.0036	0.0010	0.0002	0.0052	0.0146
STD. DEVIATIONS	0.1954	0.4645	0.2963	0.1926	0.1471	0.0753
	0.0345	0.0132	0.0040	0.0008	0.0284	0.0575

DAILY AVERAGE HEAD ON TOP OF LAYER 7

AVERAGES	0.0001	0.0002	0.0002	0.0002	0.0002	0.0001
	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0002	0.0007	0.0007	0.0005	0.0004	0.0003
	0.0002	0.0001	0.0000	0.0000	0.0000	0.0001

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

	INCHES	CU. FEET	PERCENT
PRECIPITATION	17.04 (2.667)	61870.8	100.00
RUNOFF	0.000 (0.0000)	0.00	0.000
EVAPOTRANSPIRATION	15.904 (2.3597)	57729.79	93.307
PERCOLATION/LEAKAGE THROUGH LAYER 2	1.17340 (0.96189)	4259.337	6.88424
AVERAGE HEAD ON TOP OF LAYER 2	0.033 (0.056)		
PERCOLATION/LEAKAGE THROUGH LAYER 5	0.11100 (0.28092)	402.909	0.65121
AVERAGE HEAD ON TOP OF LAYER 5	0.042 (0.110)		
LATERAL DRAINAGE COLLECTED FROM LAYER 6	0.01827 (0.05204)	66.326	0.10720
PERCOLATION/LEAKAGE THROUGH LAYER 7	0.09112 (0.22273)	330.775	0.53462
AVERAGE HEAD ON TOP OF LAYER 7	0.000 (0.000)		
PERCOLATION/LEAKAGE THROUGH LAYER 8	0.01153 (0.02619)	41.871	0.06767
CHANGE IN WATER STORAGE	1.111 (1.1434)	4032.81	6.518

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PEAK DAILY VALUES FOR YEARS 1 THROUGH 30 and their dates (DDDYYYY)

	(INCHES)	(CU. FT.)	
PRECIPITATION	2.70	9800.78638	3390013
RUNOFF	0.000	0.00000	0
PERCOLATION/LEAKAGE THROUGH LAYER 2	0.232861	845.26582	230015
AVERAGE HEAD ON TOP OF LAYER 2	8.860		
PERCOLATION/LEAKAGE THROUGH LAYER 5	0.012899	46.82277	330027
AVERAGE HEAD ON TOP OF LAYER 5	2.332		
DRAINAGE COLLECTED FROM LAYER 6	0.00475	17.24466	380027
PERCOLATION/LEAKAGE THROUGH LAYER 7	0.010989	39.88743	390027
AVERAGE HEAD ON TOP OF LAYER 7	0.004		
MAXIMUM HEAD ON TOP OF LAYER 7	0.000		
LOCATION OF MAXIMUM HEAD IN LAYER 6 (DISTANCE FROM DRAIN)	0.0 FEET		
PERCOLATION/LEAKAGE THROUGH LAYER 8	0.029201	105.99781	740027
SNOW WATER	0.00	0.0000	0
MAXIMUM VEG. SOIL WATER (VOL/VOL)	0.4431		
MINIMUM VEG. SOIL WATER (VOL/VOL)	0.1350		

*** 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 30

LAYER	(INCHES)	(VOL/VOL)
1	2.3820	0.1985
2	11.4000	0.4750
3	3.4080	0.2840
4	227.7600	0.2920
5	0.0000	0.0000
6	0.7680	0.0320
7	11.4000	0.4750
8	151.4277	0.2804
SNOW WATER	0.000	