HDR

May 12, 2017

Mr. Steven Chang, PE, Chief
State of Hawaii Department of Health
Solid & Hazardous Waste Branch
919 Ala Moana Boulevard, #212
Honolulu, HI 96814

Attention: Ms. Lene Ichinotsubo

SUBJECT: Final Cover System Alternatives Evaluation for South Hilo Sanitary Landfill

Dear Mr. Chang,

On behalf of the County of Hawaii's Department of Environmental Management, Solid Waste Division, HDR is herewith submitting this Final Cover System Alternatives Evaluation for South Hilo Sanitary Landfill (SHSL) report. The report presents potential final cover alternatives associated with closure of the SHSL and recommends a final cover system alternative.

With this submittal we are requesting a meeting to discuss the recommendations of the report. The intent of the meeting is to come to an agreement on the proposed cover system alternative and to incorporate the recommended cover system into the landfill closure permit application process. We are requesting to meet the week of May 29, 2017.

Should you have any questions don't hesitate to call me at (808) 697-6202, Mr. Tim Steinberger at (808) 697 6218, or Mr. Gene Quiamas with Hawaii County Department of Environmental Management at (808) 961-8058.

Sincerely,
HDR Engineering, Inc.

A. M. K

Aaron Kreitzer, PE
Project Manager Engineer

Attachments

cc: Mr. Gene Quiamas, County of Hawaii
Mr. Greg Goodall, County of Hawaii

May
2017

Final Cover System Alternatives Evaluation for South Hilo Sanitary Landfill

PREPARED FOR:

Department of Environmental Management
Solid Waste Division
County of Hawaii

PREPARED BY:

HDR Engineering, Inc.

Final Cover System Alternatives Evaluation for

South Hilo Sanitary Landfill Closure

May 2017

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Department of Environmental Management
Solid Waste Division
County of Hawaii

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Executive Summary

The County of Hawaii (County) contracted with HDR Engineering Inc. (HDR) to design a final cover system, and to submit a permit application to the Hawaii Department of Health (DOH) for final closure of the South Hilo Sanitary Landfill (SHSL). The SHSL is an unlined landfill that has accepted waste since 1973. The SHSL is currently active and expected to be at capacity within the next couple of years.

Several municipal solid waste (MSW) landfill final cover system design alternatives for the SHSL were examined and reviewed in detail. Based on site specific performance parameters, the list of alternatives was narrowed to three closure system alternatives. The three closure system alternatives considered for the SHSL are presented in this report and include:

- Alternative 1. A ClosureTurf™/Geomembrane Cover System developed by Agru America and ClosureTurf ™;
- Alternative 2. A Combination Cover System consisting of an Evapotranspiration Cover System for the side slopes and a Geosynthetic/Soil Composite Cover System for the top deck; and
- Alternative 3. The USEPA Subtitle D prescribed cover system.

Each cover system alternative has recognized advantages and disadvantages for closure at the SHSL. It was determined during the initial review of the final cover system alternatives that the alternatives for closure of the SHSL are limited due to the relative steepness of 2:1 (horizontal:vertical) of the side slopes. This relative side slope steepness eliminates the ability to utilize common composite cover systems which combine geosynthetics and soil.

The three closure system alternatives were ranked separately for the side slopes and for the top deck of the SHSL because there are both technical and cost differences in construction and maintenance of the different areas. Based on the preliminary closure plan, the side slope area is approximately 23.2 acres including 4.3 acres of terraces, while the top deck area is approximately 13.9 acres.

Alternative 1: ClosureTurf™/Geomembrane Cover System

The ClosureTurf™/Geomembrane cover system is an American product which consists of a 50-mil thick geomembrane overlain with a synthetic turf layer that is ballasted with sand. For side slope areas, sand can be amended with a bonding agent so it adheres to the synthetic turf and will not easily erode from wind and rain. This cover system is essentially impermeable, meets the minimum required factor of safety for veneer stability under static and seismic conditions for Hawaii County, can be deployed relatively quickly, and has prior regulatory approval in California and Washington for final closure at MSW landfills. ClosureTurf™ provides a high aesthetic value with the green turf surface and has a straightforward maintenance program, which is of particular importance on the 2:1 side slopes.

Alternative 2: Combination Cover System

The combination cover system consisting of the ET cover and the soil/geomembrane cover ranked second. The ET cover system is suitable only for side slopes due to infiltration limitations, and the soil/geomembrane cover system is suitable only for top deck and terraces due to stability limitations. It is important to note that there is a risk and time factor associated with the ET cover portion of the system. ET covers generally cannot meet performance leakage requirements in tropical wet climate conditions such as Hilo. Although a previous theoretical modeling confirms that an ET cover can meet required regulatory performance standards on the side slopes, a field scale demonstration may be necessary (similarly in other states) to show that the designed leakage requirements can indeed be achieved. This effort could add a significant amount of time to the closure schedule. Also, there is additional risk of not being able to achieve the minimum required permeability with readily available soils on Hawaii Island and having either to resubmit an alternate design to DOH for approval or to import materials to improve ET cover performance.

The combination cover system would require two distinct construction and maintenance plans for the site. Cover material soils, particularly for the top deck, can be found locally on the island since there is not a low permeability restriction for the soil/geomembrane cover system. However, for the ET cover, there is a permeability restriction and therefore, soil material available on Hawaii Island may require further processing to achieve the permeability requirements as previously modeled. Local labor would be available to construct and maintain the combination cover system, but note that soil/vegetative caps require considerably more maintenance than geosynthetic caps to meet design performance, particularly in tropical and coastal areas with higher erosion characteristics on 2:1 slopes. Construction and maintenance of the ET cover on the 2:1 side slopes present additional challenges compared to the installation and maintenance of the ClosureTurf™/Geomembrane cover system.

Alternative 3: EPA Subtitle D Prescribed Cover System

The prescribed cover is comprised of 18-inches of soil cover compacted to meet a permeability no greater than 1×10^{-5} cm/sec. This alternative ranked lowest of the three alternatives as the soils available on the island cannot meet the permeability requirements without the addition of an amendment. This complicates construction where a batch mixing regimen would be followed by material placement and compaction. It is important to note that compacting the material on 2:1 side slopes would be challenging. The batch mixing process may also lead to variability in cover material properties and the possibility of preferential pathways and/or saturated zones. Also, this cover system requires significant maintenance (mowing, soil replacement and compaction) effort which could be challenging on the 2:1 side slopes. The soil cover system vegetation also has the potential to become a habitat for birds which is undesirable given the SHSL's proximity to Hilo Airport.

Overall Ranking of Alternatives

The three final cover alternatives for the SHSL were evaluated based on the following parameters:

- Closure costs,
- Overall site work cost,
- Technical feasibility,
- Construction complexity,
- Requirement for specialized labor and equipment,
- Post closure care,
- Prior Region 9 approval for similar closure systems, and
- Acceptance by the community and the State of Hawaii Department of Transportation, Airports Division.

The evaluation examined the top deck and side slope areas separately for the parameters listed above. This was because of the wide difference in steepness between the top deck and the side slope areas.

Based on the evaluation of the alternatives, the ClosureTurf™/Geomembrane Cover System is the recommended alternative because it was the highest ranking final cover system for both the side slopes and the top deck for SHSL, as indicated in the following Tables ES-1 and ES-2. Of particular importance, the ClosureTurf™/Geomembrane Cover System has the lowest construction complexity than the other final cover system alternatives. This system also has prior approval for MSW landfill closures in Region 9, lower post-closure maintenance requirements, an impermeable barrier layer to prevent stormwater intrusion, and a likely favorability because of its grass-like appearance and use of local sand as ballast material.

Also, because of SHSL's proximity to the airport, the ClosureTurf™/Geomembrane Cover System has a likely favorability from the airport because of its low attraction of birds to the top deck of the landfill. The vegetative/soil covers on the top deck have the potential to provide habitat for birds and therefore score lower in the rankings. In addition the ClosureTurf™/ Geomembrane system has the highest potential ability to construct a solar photovoltaic system in the future if the County chose to explore this alternative.

The other two final cover system alternatives fall below the ClosureTurf™/Geomembrane Cover System when they are applied to the SHSL final closure. The soil/vegetative covers suffer from high maintenance requirements of mowing and soil replacement that is especially complex on 2:1 side slopes. The ET cover as part of the combination cover system has yet to be confirmed in the field for its technical feasibility under the tropical wet climatic conditions similar to SHSL. The EPA Subtitle D prescribed cover system has a very challenging construction complexity that involves soil/bentonite mixing and achieving the required compaction requirements on the 2:1 side slopes.

ES-1: Overall Ranking of Closure Alternatives for Side Slopes

EVALUATION FACTOR	ALTERNATIVE 1		ALTERNATIVE 2		ALTERNATIVE 3	
	ClosureTurf™/ Geomembrane	**Rank**	**Evapotranspiration (ET)**	**Rank**	**EPA Prescribed System**	**Rank**
Closure Costs ($/acre)	$249,925	1	$251,671	2	$324,762	3
Overall Site Work Cost ($)	$2,266,000	1	$2,428,000	3	$2,428,000	3
Technical Feasibility	Feasible	1	May require further testing	3	Feasible	1
Construction Complexity	Less Challenging	1	Challenging	2	Very Challenging	3
Expert Labor Required	Requires Import	3	Locally Available	1	Locally Available	1
Post Closure Care ($/acre/year)	$2,270	1	$2,350	2	$2,350	2
Prior Region 9 Approval for Similar Closure System	Yes	1	Yes	1	Yes	1
Community & DOT Airports Division Acceptance	Most Favorable	1	Favorable	2	Favorable	2
Overall Evaluation Ranking – Side Slopes Cover Alternatives	**1**		**2**		**3**	

ES-2: Overall Ranking of Closure Alternatives for Top Deck

EVALUATION FACTOR	ALTERNATIVE 1		ALTERNATIVE 2		ALTERNATIVE 3	
	ClosureTurf^{TM}/ Geomembrane	**Rank**	**Geosynthetic/Soil Composite**	**Rank**	**EPA Prescribed System**	**Rank**
Closure Costs ($/acre)	$178,074	1	$213,060	2	$316,224	3
Overall Site Work Cost ($)	$2,266,000	1	$2,428,000	3	$2,428,000	3
Technical Feasibility	Feasible	1	Feasible	1	Feasible	1
Construction Complexity	Less Challenging	1	Less Challenging	1	Very Challenging	3
Expert Labor Required	Requires Import	3	Requires Import	2	Locally Available	1
Post Closure Care ($/acre/year)	$1,170	2	$1,600	3	$1,600	3
Prior Region 9 Approval for Similar Closure System	Yes	1	Yes	1	Yes	1
Community & DOT Airports Division Acceptance	Most Favorable	1	Favorable	2	Favorable	2
Ability to Accept a Solar Array in the Future	High	1	Moderate	2	Low	3
Overall Evaluation Ranking – Top Deck Cover Alternatives	**1**		**2**		**3**	

1 Introduction

HDR Engineering, Inc. (HDR) was contracted to conduct an evaluation of cover system design alternatives for the closure of the South Hilo Sanitary Landfill (SHSL). Over the last ten years, innovative landfill capping technologies have been developed in the United States (US) as options to traditional landfill cover systems prescribed by the United States Environmental Protection Agency (USEPA), Subtitle D, Subpart F 258.60(B) which addresses alternative final cover designs and state regulatory equivalency approval. This rule states that the Director of an approved state (a state which EPA has delegated authority to and whose rules meet the Subtitle D requirements), such as Hawaii, may approve alternative final cover systems that can achieve equivalent performance at the minimum design specified in Section 258.60(a) or HAR §11-58.1-17(2). This rule provides an opportunity to incorporate different technologies or improvements into cover designs and to address specific site conditions.

In general, traditional Subtitle D prescribed covers can be more costly to construct than alternative cover systems, Many alternative cover systems have been introduced that are centered around improved engineering performance features to address specific site conditions. This is evident in landfills designed with long and/or steep slopes that must rely on maintaining the grass turf and the underlying percolation and drainage layers to maintain cover performance and slope stability. One other important factor that can also impact the cost and performance of a landfill final cover system is the availability of construction materials such as nearby soils that can meet the strict specifications of a modern landfill final cover system.

A variety of alternative cover systems were investigated based on how they would perform with respect to the site specific parameters of the SHSL, and identified three final cover systems that can achieve the regulatory requirements set forth by the State of Hawaii (HAR §11-58.1-17(2)). Two of these alternatives were examined as options to the Subtitle D prescribed landfill cover with the intent of avoiding the costly importation of soil materials that would meet the specified soil permeability requirements, and which are not locally available on Hawaii Island for use at SHSL. The third alternative is the Subtitle D prescribed cover system.

The following three alternatives are examined in further detail below:

- Alternative 1. A ClosureTurf™/Geomembrane Cover System developed by Agru America and ClosureTurf ™;
- Alternative 2. A Combination Cover System consisting of an Evapotranspiration Cover System for the side slopes and a Geosynthetic/Soil Composite Cover System for the top deck; and
- Alternative 3. The USEPA Subtitle D prescribed cover system for SHSL.

The three alternatives were evaluated on the basis of closure construction cost, overall site work cost, technical feasibility, construction complexity, expert labor, post-closure care, prior Region 9 approval for similar closure systems, and community and State DOT Airports Division acceptance. The findings of the evaluation were used to compare and rank the potential final cover alternatives for closure of the SHSL.

Based on HDR's experience, each of the selected cover alternatives listed above can be designed and constructed to meet the regulatory requirements. However, due to the potential non-availability of specific soil materials and the potential lack of specialized skilled labor in the County to deploy geosynthetic materials, the cost of construction is estimated to be higher as compared to similar cover installation costs on the mainland US. The cost of soil/gravel delivered to the site was obtained from local material suppliers. The cost of geosynthetic materials delivered to Hilo was provided by material manufacturers. The construction/installation costs were estimated from RS Means while incorporating a Hilo location factor. In addition, RS Means estimates were further escalated by a factor of 1.25 as recommended by local estimators.

2 Site Background

The SHSL is an active 41.3-acre unlined municipal solid waste landfill (MSWLF). The SHSL has accepted waste since 1973 and waste tonnages accepted at the landfill have been recorded through facility scales since 1996.

In 2006, Bryan A. Stirrat (BAS) and Associates prepared a permit application to modify the landfill design to increase airspace at the SHSL. This application included a conceptual closure plan that consisted of a "sliver fill" to expand the landfill capacity without horizontally expanding landfill footprint and maintaining the same maximum fill elevation. The revised fill plan has been followed by the County, and as part of this design modification, the exterior side slopes of the landfill have been steepened to 2(H):1(V). This design modification created approximately 23.2 acres of exterior side slopes with 2(H):1(V) slopes, 4.3 acres of drainage terraces and 13.9 acres of top deck with a more gradual slope of approximately 3%. Due to the landfill's steepened side slopes created by the "sliver fill" design, a composite closure cover with soils overlying a lateral drainage layer and geosynthetic barrier is no longer applicable because of a veneer stability factor of safety reduction. However, a composite geosynthetic/soil cover remains a viable alternative for the top deck due to its shallower slopes.

3 Descriptions of Final Cover Alternatives

The final cover alternatives described in this section were selected from a review of several different cover options that have been successfully permitted and implemented on MSWLF sites across the U.S. The criteria for selecting the final cover alternatives that can potentially be deployed for final closure at the SHSL includes:

1. Does it meet regulatory requirements for infiltration?
2. Does it meet engineering design requirements for constructability, slope stability and long-term performance?
3. Does it meet physical site specific performance parameters for rainfall, wind, and natural exposure?
4. Is it economically feasible?
5. What are post-closure repair and maintenance requirements?

Alternatives were only selected that could meet the five criteria as well as potentially compare favorably to prescribed final cover engineering performance and estimated cost.

3.1 Geomembrane Barrier Overlain with ClosureTurf™ (ClosureTurf™/Geomembrane) Cover System

Agru America and ClosureTurf™, LLC currently manufacture a patented final cover system designed and manufactured in the United States that utilizes a linear low density polyethylene (LLDPE) or high density polyethylene (HDPE) geomembrane (50-mil structured geomembrane - Agru Super Gripnet or MicroSpike) in conjunction with a layer of woven geotextile and synthetic turf (or ClosureTurf™). The ClosureTurf™/Geomembrane system provides a low maintenance final cover system that can be deployed easily and exceeds the prescribed cover performance characteristics for permeability.

The ClosureTurf™ is typically green but can be manufactured in a variety of colors. The ClosureTurf™ layer provides protection to the underlying impermeable geomembrane barrier as well as providing an aesthetically pleasing cover that also acts as a ballasting surface. The ballast is typically comprised of a 1/2 to 1 inch thick sand layer (D_{50} approximately 0.6 mm). The sand ballast and ClosureTurf™ work to protect the impermeable geomembrane from long-term degradation from ultraviolet (UV) exposure, hail damage, shear stress from light equipment, and wind uplift. Geomembrane barrier overlain by ClosureTurf™ alternative can be deployed on both the SHSL top deck and side slopes. The grading plan and closure sections of this alternative are illustrated in Drawing 1 of Appendix G. The ClosureTurf™/Geomembrane installation location map, wind uplift calculations and longevity information is provided in Appendix A. Figure 1 illustrates an installed final cover system at a MSW landfill.

Figure 1: Installed ClosureTurf™ Cover for a MSW Landfill Final Cover in Baldwin County, Georgia

ClosureTurf™/Geomembrane was first installed as a landfill final cover system in 2008 in Louisiana (USEPA Region 6). Since then, the system has been installed and approved as final cover at MSW landfills in Louisiana, Pennsylvania (USEPA Region 3), California (USEPA Region 9), Georgia (USEPA Region 4), Tennessee (USEPA Region 4), South Carolina (USEPA Region 4), Connecticut (USEPA Region 1), New York (USEPA Region 2), Rhode Island (USEPA Region 1, Virginia (USEPA Region 3), Washington (USEPA Region 10), and Massachusetts (USEPA Region 1). The ClosureTurf™ protection layer replaces the grass and soil of the erosion layer in traditional composite landfill final cover systems to provide easier surface water management and better erosion control with no significant turbidity. Manufacturer testing information shows 100+ year functional longevity (with proper maintenance) and provides a cover system 20-year warranty (Refer to Geosyntec, 2015). Considering side slopes steepness, ArmorFill is proposed for SHSL instead of a traditional sand application on side slope areas. ArmorFill consists of the originally specified infill sand combined with a polymer material (Armor) to bind the sand to the ClosureTurf™. This creates an erosion layer in which the sand will not shift or significantly wash down the steep side slope areas during heavy rainfall and wind events. The manufacturer suggests that ArmorFill may require recharge at every 5 years with 20% of original material.

Overall feedback for ClosureTurf™/Geomembrane final covers from landfill owners and regulators has been positive and it is becoming more prevalent for both MSWLF covers and other industrial landfill covers such as for coal ash and mine tailings. Table 1lists the advantages and disadvantages of the ClosureTurf™/Geomembrane cover system for SHSL.

Table 1: Advantages and Disadvantages of ClosureTurf^{TM}/Geomembrane Cover System

	Advantages		Disadvantages
1	Can be deployed on top deck, terraces, and sideslopes (all areas) for final closure	1	More stormwater runoff and detention requirements than the other cover system options alternatives
2	An impermeable barrier layer with lower infiltration rate than the other alternatives	2	A bedding layer of fine sand is required
3	Shorter construction time than other cover system options alternatives	3	The sand-binder mixture must be reapplied periodically
4	Less regrading for slopes and benches and no downcommer pipes are necessary to convey stormwater	4	ClosureTurf is a patented technology
5	Reduced post closure care maintenance costs compared to soil/vegetative covers	5	Specified sand ballast may not be readily available without additional processing
6	Will not provide a habitat for birds	6	A landfill gas venting system is required
7	The synthetic turf/sand is formulated to remain in place resulting in low turbidity stormwater runoff	7	A ClosureTurf system has not been installed in Hawaii and permitting may take longer than other cover system alternatives
8	Aging tests indicate 30+ years of service life for exposed HDPE turf layer	8	Material and labor from outside the Hawaii County will likely be required
9	Synthetic turf/sand layer provides a protective cover over the impermeable geomembrane from UV and environmental exposure	9	Some repair and replacement of the exposed protective synthetic cover is eventually required to maintain system design and operation parameters
10	Green turf provides a high level of aesthetic appeal		
11	Has been approved by regulatory agencies in USEPA Region 9 for final closure		
12	Can provide a suitable platform for ballasted solar panel array system on top deck.		

3.2 Combination Cover System: Evapotranspiration Cover System and Geosynthetic/Soil Composite Cover System

The combination cover system was first proposed in the Bryan A. Stirrat and Associates (BAS) (2006) report as an alternative to the prescribed cover for SHSL. The combination cover system utilizes an evapotranspiration (ET) cover system for the side slope areas and a geosynthetic/soil composite cover system for the top deck, terraces, and road. Drawing 2 of Appendix G illustrates the ET cover system. Drawing 3 of Appendix G illustrates the geosynthetic/soil composite cover system.

The ET cover system is designed to minimize infiltration of stormwater into the waste by encouraging surface runoff, and relying on soil moisture uptake through evaporation and transpiration from increased soil moisture storage and native plant cover. The ET cover is comprised from bottom to top of a 12-inch intermediate cover layer and a 36-inch monolithic soil cover as shown in Drawing 2. The 36-inch monolithic soil layer shall meet the following requirements:

- 2.5-inch maximum particle size
- Minimum 1% finer than 5 microns
- 4% finer than #200 sieve
- Permeability less than $5.0x10^{-3}$ cm/s

Based on soil materials observed in the County, there are locally available soils whose characteristics meet the requirements listed above for monolithic soil layer. The grading plan utilizing ET cover on the side slopes is shown in Drawing 2 where areas shaded in yellow indicate locations where ET cover could be deployed.

The objective of an ET cover is to minimize infiltration into the waste mass by utilizing its monolithic soil layer to hold sufficient moisture to allow evaporation and transpiration to occur during dryer periods. BAS modelled a theoretical ET cover system to show that it could for the tropical environment at SHSL. However, the model showed that the ET cover only works on the 2:1 slopes because it relies on the majority of rainfall to be collected as surface water runoff as opposed to getting retained within the monolithic soil layer. Based on the modeling exercise performed by BAS, ET cover cannot be used as the cover system on top deck and terraces due to decreased runoff and increased stormwater infiltration into the waste mass due to their shallow slopes.

ET covers are generally suited for arid or semiarid climatic conditions where the ratio of precipitation and potential evapotranspiration is less than 0.75. Although ET covers are installed in humid regions such as Georgia, Iowa, and Nebraska they did not perform well per the USEPA-funded alternative cover assessment project. Waste Management of Hawaii previously conducted a demonstration project for an ET cover for the DOH for the Waimanalo Gulch Landfill on Oahu. However, per our understanding it was conducted at an active site (i.e. not restricted with a closure deadline schedule) in an arid location.

For geosynthetic/soil composite cover, a geomembrane is ballasted and protected by an overlying soil/vegetative layer. This is a traditional Subtitle D cover system design. These systems have been the most common types of Subtitle D final cover systems on MSW landfills in the US since 1992. With this type of system the landfill final cover typically consists from top to bottom of:

- 6-inch vegetative support layer
- 18-inches of erosion/drainage layer
- 16-oz nonwoven geotextile
- 40 mil LLDPE geomembrane liner
- 16-oz nonwoven geotextile
- 12-inch intermediate cover

A section of the geosynthetic/soil cover is shown in Drawing 3 of Appendix G. As a result of combining geosynthetics with soil, a weak interface is created between the two material types. Through the evaluation it was confirmed that the interface friction angle between soil and geosynthetics creates a situation where composite cover systems cannot meet the required veneer stability factor of safety under static and seismic conditions (refer to Appendix B). Accordingly, a composite system can be implemented on the top deck and terraces, but is not suitable for the side slopes. Alternative 2 cover system therefore is a combination of the geosynthetic/soil composite cover system on the top deck and terraces with the ET cover system on the side slopes. The SHSL can be fully covered using locally available soils can meet physical requirements needed for drainage/erosion/vegetative layers.

Table 2 lists the advantages and disadvantages of the combination cover system for SHSL.

Table 2: Advantages and Disadvantages of ET Cover

	Advantages		Disadvantages
1	Can be installed with local materials and labor	1	Further modeling and testing may be required by DOH to achieve regulatory approval as final cover
2	Landfill gas venting system may not be necessary	2	Cannot be deployed on top deck, road and terraces and therefore must be used in combination with another final cover system
3	Infiltration rate is lower than or equal to prescribed cover	3	Some re-grading of the landfill is required for stormwater management
4	No patented materials are required for construction	4	Vegetation will experience an establishment period in which the cover is vulnerable to significant erosion
5	Lowest stormwater runoff than any other option	5	Maintenance and replacement of vegetation and soil on steep sideslopes will be necessary
6	Native plants can be used to provide a high level of aesthetic landscaping	6	Establishing vegetation on 2:1 side slopes is challenging
		7	Soil covers are susceptible to burrowing animals
		8	Vegetated soil covers are a potential habitat for birds

Table 3: Advantages and Disadvantages of Geosynthetic/Soil Composite Cover System

	Advantages		Disadvantages
1	No significant permitting challenges due to DOH familiarity with similar final cover systems	1	Cannot be deployed on side slopes and therefore will require a combination cover design with other options
2	Cover can be relatively easily installed on top deck	2	Landfill gas venting system will be necessary
3	Due to the impermeable geomembrane cover, the infiltration rate is lower than the prescribed cover	3	The post-closure care is more intensive than with other cover systems utilizing a geosynthetic surface due to the continued cover/vegetation maintenance
4	Native plants can be used providing a high level of aesthetic landscaping	4	Soil /vegetative cover on the top deck could be a potential habitat for birds
5	Local soils can be used for the erosion/drainage layer	5	Specialized non-local labor is needed for geosynthetic installation

3.3 Prescribed Final Cover System

In accordance with Hawaii Administrative Rule (HAR) §11-58.1-17(1)(A) or per 40 CFR §258.60, the final cover system must be comprised of an erosion layer underlain by an infiltration layer and must meet the following criteria:

(A) Have a permeability less than or equal to the permeability of any bottom liner system or natural subsoils present, or a permeability no greater than 1×10^{-5} cm/sec, whichever is less,

(B) Minimize infiltration through the closed MSWLF by the use of an infiltration layer that contains a minimum eighteen inches of earthen material, and

(C) Minimize erosion of the final cover by the use of an erosion layer that contains a minimum six inches of earthen material that is capable of sustaining native plant growth.

In the case of prescribed final cover, the major challenge to the County is to locate, acquire, haul, and compact enough soil materials to meet infiltration layer requirements which include 18-inches of soil and/or amended soil material that can meet a permeability of 1×10^{-5} cm/s or less. It is assumed that amended soil material would comprise of a mixture of local soil and imported bentonite to achieve the permeability requirement. It is important to note that a local soil source has not been identified that can confidently meet specific permeability requirements with or without further processing. Erosion layer requirements are less challenging for SHSL on both a quantity basis (6-inch thickness requirement) and a suitability basis (ability to sustain vegetation). Drawing 4 of Appendix G illustrates the section of prescribed final cover and grading plan for SHSL. Table 4 lists prescribed covers system advantages and disadvantages for SHSL.

Table 4: Advantages and Disadvantages of Prescribed Cover System

	Advantages		Disadvantages
1	Relatively straightforward permitting process with DOH	1	Some re-grading of the landfill is required for stormwater management
2	Constructed with earthen materials with local labor	2	Minimum permeability requirements may not be achievable without imported bentonite amendment
3	Can be deployed on top deck, terraces, and sideslopes (all areas) for final closure	3	Possible variability of cover soil conditions
4	No patented materials are required for construction	4	Achieving soil compaction requirements on 2:1 side slopes is challenging to meet permeability requirements
5	No veneer stability issues on sideslopes	5	Maintenance of soil/vegetation on 2:1 sideslopes is challenging
		6	Gas venting system will be required
		7	Additional lab testing and test pads will be necessary to confirm soil/bentonite mixing ratios and compaction requirements
		8	Continued reapplication of soil amendment mixture may be required as part of maintenance
		9	Maintenance and replacement of vegetation and soil on 2:1 sideslopes will be necessary
		10	Soil covers are susceptible to burrowing animals
		11	Vegetated soil covers are a potential habitat for birds near the airport

4 Cover System Cost Comparison for SHSL

The following cost estimate tables were developed and used to compare the cover system alternatives. Table 5 compares the estimated costs of construction and maintenance of the SHSL side slopes. Table 6 compares the estimated costs of construction and maintenance of the SHSL top deck. Table 7 illustrates site work associated with each alternative. Table 8 compiles the overall cost estimates for the closure and site work for the three alternatives. Table 8 indicates that the prescribed cover has the overall highest cost of the three alternatives for closure and post-closure care. ClosureTurf^{TM}/geomembrane cover system and combination cover system have similar overall costs. A more detailed cost estimate will be developed for the selected alternative for construction and maintenance.

Table 5: Cost Comparison of Final Cover System for Side Slope Areas

Description	ClosureTurf™/ Geomembrane Cover	Evapotranspiration Cover	Prescribed Cover System
Closure Construction			
Construction Costs ($/acre)	**$249,925**	**$251,672**	**$324,762**
Annual Post-Closure Maintenance			
Vegetation Maintenance including fertilizer, mulch application, watering ($/acre)	---	$800	$800
Stormwater System and Erosion Maintenance ($/acre)	$70	$350	$350
Cover Maintenance ($/acre)	$2,000	$1,000	$1,000
General Inspections ($/acre)	$200	$200	$200
Total Annual Post-Closure Care (1-acre closure)	**$2,270**	**$2,350**	**$2,350**

Notes:
1. Costs for closure are based on importation of off-site soils from local borrow sources. Costs for gas vents and stormwater control are included.
2. ClosureTurf™/Geomembrane construction cost is based on manufacturer's budgetary cost of $3.97/square foot with Supper Gripnet geomembrane. Additional costs for gas vents, ballast sand and stormwater control are included. Manufacturer suggests allocating $2,000 per year per acre to recharge ArmorFill at every 5 years.
4. Due to steep slopes mowing is challenging for Prescribed Cover and Evapotranspiration Cover

Table 6 Cost Comparison of Final Cover System Alternatives for Top Deck

Description	ClosureTurfTM/ Geomembrane Cover	Geosynthetic/Soil Cover	Prescribed Cover System
Closure Construction			
Construction Costs ($/acre)	**$178,075**	**$185,039**	**$316,224**
Annual Post-Closure Maintenance			
Vegetation Maintenance including fertilizer, mulch application and watering ($/acre)	---	$800	$800
Stormwater System and Erosion Maintenance ($/acre)	$70	$200	$200
Cover Maintenance ($/acre)	$1,000	$500	$500
General Inspections ($/acre)	$100	$100	$100
Total Annual Post-Closure Care (1-acre closure)	**$1,170**	**$1,600**	**$1,600**

Notes:
1. Costs for closure are based on importation of off-site soils. Costs for gas vents and stormwater control are included.
2. ClosureTurf^{TM}/Geomembrane Cover construction cost is based on manufacturer's budgetary cost of $2.91/square foot with Microspike geomembrane for top deck. Additional costs for gas vents, ballast sand and stormwater control are included. No ArmorFill on top deck.

Table 7: Site Work Cost

Description	Cost
Prescribed or ET/Geosynthetic/Soil Cover System	$2,428,000
ClosureTurf™/Geomembrane Cover System	$ 2,266,000

Table 8: Overall Cost Comparison for Closure and Site Work

Description	Cost
Overall Cost for an ClosureTurf™/Geomembrane Cover System	$ 11,592,000
Overall Cost of Geosynthetic/Soil Composite Cover (top deck) and ET Cover (side slope) Combined System	$ 12,287,000
Overall Cost for a Prescribed Cover System	$15,722,000

5 Overall Ranking

The SHSL final cover system alternatives were evaluated based on the following factors:

- *Closure Cost:* This factor includes construction related cost associated with closure. The cost estimations are based on soil/gravel delivered from Pahoa quarry owned by Sanford's Service Center, Inc., manufacturer estimations and RS Means while adjusting for city factor.
- *Overall Site Work Cost:* This factor includes required site work to implement a select closure alternative.
- *Technical Feasibility:* This factor includes considerations related to: (i) reliability and experience with the proposed engineering systems (e.g. liner system, final cover, foundation support system, stormwater management etc.) used in the closure alternative; and (ii) ability of the closure design to meet regulatory design requirements and performance standards.
- *Construction Complexity:* Whether highly specialized expertise would be needed by a contractor to construct the closure and availability of material such as soil suitable for closure. In general, all of the closure alternatives are based on reliable, well-established design concepts that have been shown to be constructible without unique difficulties or contractor requirements.
- *Expert Labor:* This includes whether or not local labor can be utilized during construction. For example, if installing a geomembrane liner is required as part of the design, then the liner crews and equipment may require mobilization from the mainland.
- *Post Closure Care:* This factor includes closure maintenance requirements during post closure care period which is approximately 30 years.
- *Prior Region 9 Approval for Similar Closure Systems:* This factor includes considerations related to permitting, ability of the design to meet current DOH permitting requirements, and the likely acceptability of the design to DOH personnel.
- *Community and Airport Acceptance:* This is a subjective factor that is included to consider the relative acceptability of the proposed expansion alternatives to the surrounding community and airport.
- *Overall Evaluation Ranking:* After considering all of the above mentioned evaluation criteria, the alternatives were ranked based on our knowledge and best judgment.

Tables 9 and 10 below summarize the ranking of the closure system alternatives for the side slopes and top deck, respectively, based on our experience as well as the site specific parameters of the SHSL.

Table 9: Overall Ranking of Closure Alternatives for Side Slopes

EVALUATION FACTOR	ALTERNATIVE 1		ALTERNATIVE 2		ALTERNATIVE 3	
	ClosureTurf™/ Geomembrane	**Rank**	**Evapotranspiration (ET)**	**Rank**	**EPA Prescribed System**	**Rank**
Closure Costs ($/acre)	$249,925	1	$251,671	2	$324,762	3
Overall Site Work Cost ($)	$2,266,000	1	$2,428,000	3	$2,428,000	3
Technical Feasibility	Feasible	1	May require further testing	3	Feasible	1
Construction Complexity	Less Challenging	1	Challenging	3	Very Challenging	3
Expert Labor Required	Requires Import	3	Locally Available	1	Locally Available	1
Post Closure Care ($/acre/year)	$2,270	1	$2,350	2	$2,350	2
Prior Region 9 Approval for Similar Closure System	Yes	1	Yes	1	Yes	1
Community & DOT Airports Division Acceptance	Most Favorable	1	Favorable	2	Favorable	2
Overall Evaluation Ranking – Side Slopes Cover Alternatives	**1**		**2**		**3**	

Table 10: Overall Ranking of Closure Alternatives for Top Deck

EVALUATION FACTOR	ALTERNATIVE 1		ALTERNATIVE 2		ALTERNATIVE 3	
	ClosureTurf™/ Geomembrane	**Rank**	**Geosynthetic/Soil Composite**	**Rank**	**EPA Prescribed System**	**Rank**
Closure Costs ($/acre)	$178,074	1	$213,060	2	$316,224	3
Overall Site Work Cost ($)	$2,266,000	1	$2,428,000	3	$2,428,000	3
Technical Feasibility	Feasible	1	Feasible	1	Feasible	1
Construction Complexity	Less Challenging	1	Less Challenging	1	Very Challenging	3
Expert Labor Required	Requires Import	3	Requires Import	2	Locally Available	1
Post Closure Care ($/acre/year)	$1,170	1	$1,600	2	$1,600	2
Prior Region 9 Approval for Similar Closure System	Yes	1	Yes	1	Yes	1
Community & DOT Airports Division Acceptance	Most Favorable	1	Favorable	2	Favorable	2
Ability to Accept a Solar Array in the Future	High	1	Moderate	2	Low	3
Overall Evaluation Ranking – Top Deck Cover Alternatives	**1**		**2**		**3**	

6 Conclusions and Recommendations

The ClosureTurf™/Geomembrane Cover System is the highest ranking final cover system for both the side slopes and top deck for SHSL. The ClosureTurf™/Geomembrane Cover System likely requires expert labor to install. However, with all of the other evaluation factors the ClosureTurf™/Geomembrane Cover System is ranked highest in comparison to the other two systems.

Of particular importance for the side slopes is that this system has the lowest construction complexity than the other final cover system alternatives. This system also has prior approval for MSW landfill closures in Region 9, lower post-closure maintenance requirements, an impermeable barrier layer to prevent storm water intrusion, and a likely favorability because of its clean appearance and use of local sand as ballast material. This system benefits from having a simplified maintenance requirement for the side slopes that requires sand/adhesive mix to be applied every five years.

The ClosureTurf™/Geomembrane Cover System is also the highest ranking final closure system for the top deck for SHSL. It is important to note that because of SHSL's proximity to the airport, the ClosureTurf™/Geomembrane Cover System has a likely favorability from the airport because of its low attraction of birds to the top deck of the landfill. The vegetative/soil covers on the top deck have the potential to provide habitat for birds and therefore score lower in the rankings. The ClosureTurf™/Geomembrane Cover System on the top deck also can serve as an ideal platform on which to ballast a solar array as has been performed at other landfill closures in the United States as a beneficial secondary use application.

The other two final cover system alternatives fall below the ClosureTurf™/Geomembrane Cover System when they are applied to the side slopes of the SHSL final closure. The other two alternatives each have characteristics that are not suitable for SHSL. The ET Cover, as part of the combination cover system, has yet to be confirmed in the field for its technical feasibility under the tropical conditions similar to SHSL, and the Prescribed Cover System has a very challenging construction complexity that involves soil/bentonite mixing and achieving the required compaction requirements on the 2:1 side slopes.

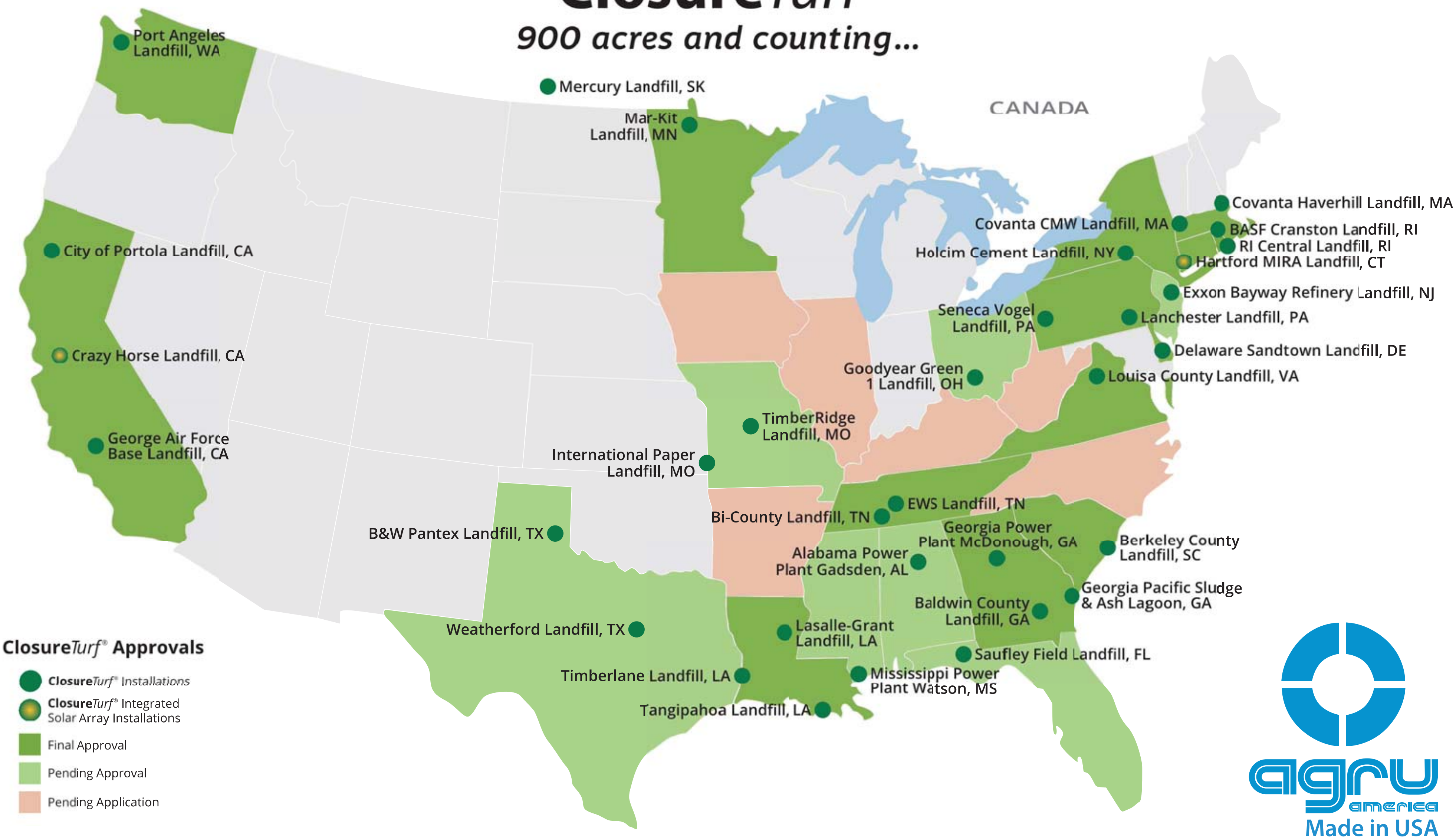
For the top deck, the other two final cover systems alternatives are also less suitable than the ClosureTurf™/Geomembrane Cover System for SHSL. The soil/vegetative covers suffer from high maintenance requirements of mowing and soil replacement. In particular, the Prescribed Cover System requires a high degree of soil/bentonite mixing that could potentially create inconsistent areas of permeability and therefore a higher potential for ponded areas and/or preferential pathways for stormwater intrusion. The Geosynthetic/Soil Composite Cover System can only be deployed on the top deck and requires a different system to be deployed on the side slopes. Just as the ET cover can only be deployed on the side slopes and not on the top deck or the terraces, a combined cover system creates a more complicated post closure care regimen with multiple maintenance activities for the closed landfill.

Alternative 1, ClosureTurf™/Geomembrane Cover System, is the engineer's recommended closure alternative for the final cover system for SHSL. While the overall closure and post-closure costs for the Combined Cover Systems are similar, the importance of constructing a single type of cover system over the entire landfill surface (top deck and side slopes) that can be constructed, monitored, and maintained following a straightforward closure and post-closure care plan makes the ClosureTurf™/Geomembrane alternative the best closure system alternative for SHSL.

Appendix A
ClosureTurf™/Geomembrane Wind Uplift Calculations and Longevity Information

ClosureTurf®

900 acres and counting...



ClosureTurf® Approvals

- ClosureTurf® Installations
- ClosureTurf® Integrated Solar Array Installations
- Final Approval
- Pending Approval
- Pending Application

agru america Made in USA

Job No. 10040916	No.

HDR Engineering, Inc.

Project	SHSL Closure Turf Option	Computed	K. Perera	Date	3/6/2017
Task	Final Cover Wind Stability Analysis	Checked	M. Roberts	Date	3/6/2017

Problem
Evaluate the design of the final cover system sand ballast and anchor system for wind uplift considerations.

Assumptions
1. The design wind speed event is 105 mph. This number is compatible the 2006 International Building Code.

Calculations
A suitable ballast is needed for the synthetic turf system so it does not fail during a high wind event. According to the analysis in GeogiaTec (2010), there are two methods of failure: one is lift-off due to the formation of normal suction-type forces and the other is slippage due to shear force from the wind. Failure is assumed to occur on the geotextile/geomembrane interface. The frictional forces of the geomembrane and ballast of sand and geotextile make the geomembrane less likely to fail. Analysis and design values were provided by Closure Turf, LLC which had wind tunnel testing performed at the Georgia Tech Research Institute.

The equation for required height of sand is provided by the Equation 2 in GeogiaTec (2010). Separate equations are solved for interior and perimeter conditions.

$$h_{sand} = \frac{1}{\gamma_{sand}}\left(\frac{\tau}{\mu_S} + P\right)\frac{12in}{1ft} \qquad \mu_S = \tan\varphi$$

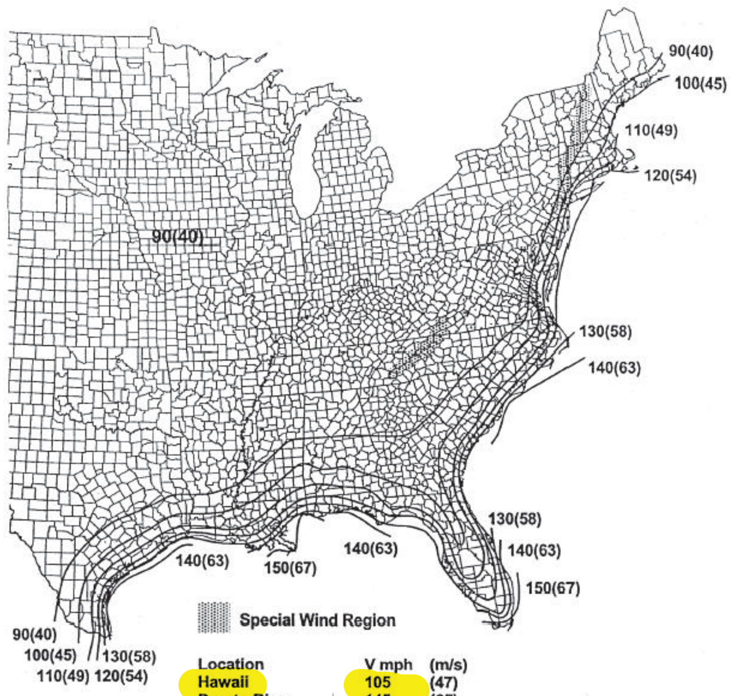
Perimeter Conditions where,

γ_{sand}	90	density of sand, lb/ft^3	specification
τ	3.274285	shear stress, lb/ft^3	GeogiaTec (2010) Table 1, based on 105 mph
ϕ	38	friction coefficient, degrees	specification from Closure Turf, LLC
$\tan\phi = \mu$	0.781286	coefficient of static friction	
P	-0.21588	normal force loading, lb/ft^3	GeogiaTec (2010) Table 1, based on 105 mph
h_{sand}	0.530002	inches required sand-in fill height for perimeter installation	

Interior Conditions

γ_{sand}	90	density of sand, lb/ft^3	
τ	0.641021	shear stress, lb/ft^3	GeogiaTec (2010) Table 2, based on 105 mph
ϕ	38	friction coefficient, degrees	
$\tan\phi = \mu$	0.781286	coefficient of static friction	from Closure Turf, LLC
P	-0.36909	normal force loading, lb/ft^3	GeogiaTec (2010) Table 2, based on 105 mph
h_{sand}	0.0602	required sand-in fill height for interior installation	

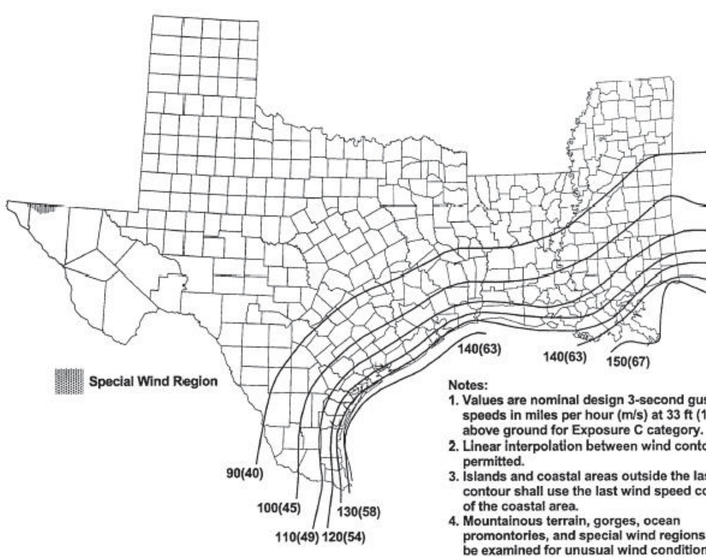
Conclusions
The height of soil in the anchor trench (2-feet) is well above the 0.53 in requirement and the height of sand in the interior (0.5-inch) is well above the 0.06-inch calculated value. Therefore, the system will be sufficient for a 105 mph wind event based on manufacturer-provided wind tunnel testing.



Location	V mph	(m/s)
Hawaii	105	(47)
Puerto Rico	145	(65)
Guam	170	(76)
Virgin Islands	145	(65)
American Samoa	125	(56)

Notes:
1. Values are nominal design 3-second gust wind speeds in miles per hour (m/s) at 33 ft (10 m) above ground for Exposure C category.
2. Linear interpolation between wind contours is permitted.
3. Islands and coastal areas outside the last contour shall use the last wind speed contour of the coastal area.
4. Mountainous terrain, gorges, ocean promontories, and special wind regions shall be examined for unusual wind conditions.

FIGURE 1609—continued
BASIC WIND SPEED (3-SECOND GUST)



Notes:
1. Values are nominal design 3-second gust wind speeds in miles per hour (m/s) at 33 ft (10 m) above ground for Exposure C category.
2. Linear interpolation between wind contours is permitted.
3. Islands and coastal areas outside the last contour shall use the last wind speed contour of the coastal area.
4. Mountainous terrain, gorges, ocean promontories, and special wind regions shall be examined for unusual wind conditions.

FIGURE 1609—continued
BASIC WIND SPEED (3-SECOND GUST)
WESTERN GULF OF MEXICO HURRICANE COASTLINE

July 8, 2010

Mr. Michael R. Ayres, P.E.
Closure Turf, LCC
3005 Breckinridge Blvd.
Duluth, GA 30096

Subject: **Aerodynamic Evaluations of Closure Turf Ground Cover Materials**

References: **1: Contract # AGR DTD 5/14/10**

Dear Mr. Ayres and Closure Turf LCC affiliates:

The Georgia Tech Research Institute is pleased to submit the attached Report, covering the period from May 14 to July 8, 2010, in fulfillment of Reference. This document details the tasks and analysis made on contracted work performed by the GTRI Aerospace, Transportation and Advanced Systems Laboratory and its team members on Phase I of the Project entitled "Aerodynamic Evaluations of Closure Turf Ground Cover Materials".

We look forward to continuation of this work for/with Closure Turf, LCC upon the adoption of Phase II activities related to aerodynamic investigation of Closure Turf Material or other desired evaluations.

Sincerely,

Graham M. Blaylock
Principal Investigator

Aerodynamic Evaluations of Closure Turf Ground Cover

Phase I REPORT

May 14 – July 8, 2010

Project Expires: August 14, 2010

Contract No. AGR DTD 5/14/10

Proposal No. ATASL-AATD-10-1119

GTRI Project No. D-6244

Prepared for:

Mr. Michael R. Ayres, P.E.
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Introduction

GTRI has been contracted by Closure Turf, LCC to **experimentally evaluate the aerodynamic properties and ballast requirements** of a novel synthetic ground-cover system under a range of wind speed conditions (V_{inf}). The Closure Turf Material was tested full-scale in **GTRI's subsonic Model Test Facility (MTF) wind tunnel** wherein the normal force loading (lb_f/ft^2) and the shear stress (lb_f/ft^2) were determined for a suitable section of the material. The turf material was tested in two configurations, one representing the perimeter of the turf installation (Fig 5) and the 2nd at a representative interior section (Fig 6). Both installations were evaluated on a **flat level surface**. The installation is shown in Figures 1a-d below.

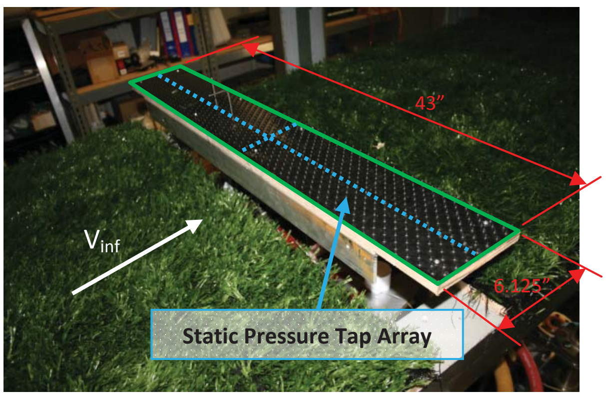


Figure 1a – Model Before Final Turf Layer

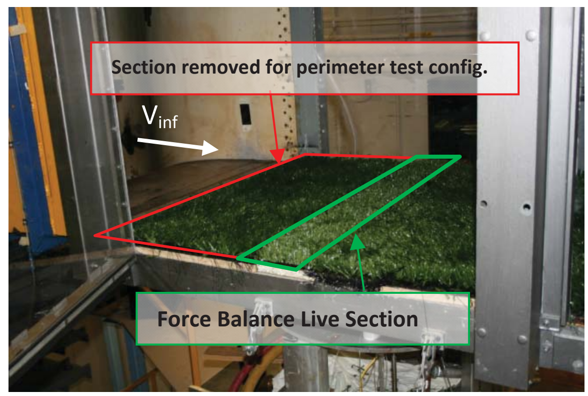


Figure 1b – Turf Installed & Model Lowered

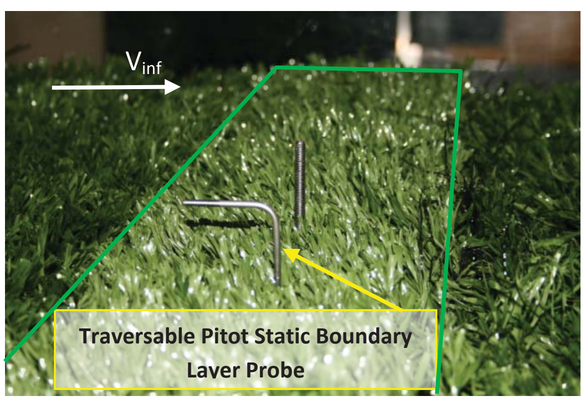


Figure 1c - Pitot Static Boundary Layer Probe

Figure 1d – Full Installation Looking Downstream

Program Description

Closure Turf system - The Closure Turf ground cover system consists of two independent layers. The first layer is a **geomembrane** to cap the upper soil layer. This is then covered with a **geotextile** turf layer (Fig 2a and 2b)

Geomembrane Layer -The impermeable geomembrane is made from Agru 50-mil LLDPE Super Gripnet® material and is used to cap the terrain being covered. It has an array of spikes to interface to the soil below and an array of studs to interface with the turf covering above. Throughout the testing and subsequent analysis of the Closure Turf system, **it was assumed that the geomembrane will be sufficiently installed to prevent movement of that layer.**

Geotextile Turf Layer – This component is designed to be installed on top of the geomembrane. The turf is intended to remain in place without an anchoring system linking it to the geomembrane below. It relies on the interface friction and sand ballast added on top of the turf to ensure that it remains immobile under all environmental conditions. It is constructed of two permeable sheets of woven HDPE mesh material which are linked together with synthetic blades of grass that are looped through the two HDPE substrates (Fig 2a).

Figure 2a – Closure Turf Synthetic Ground Cover System

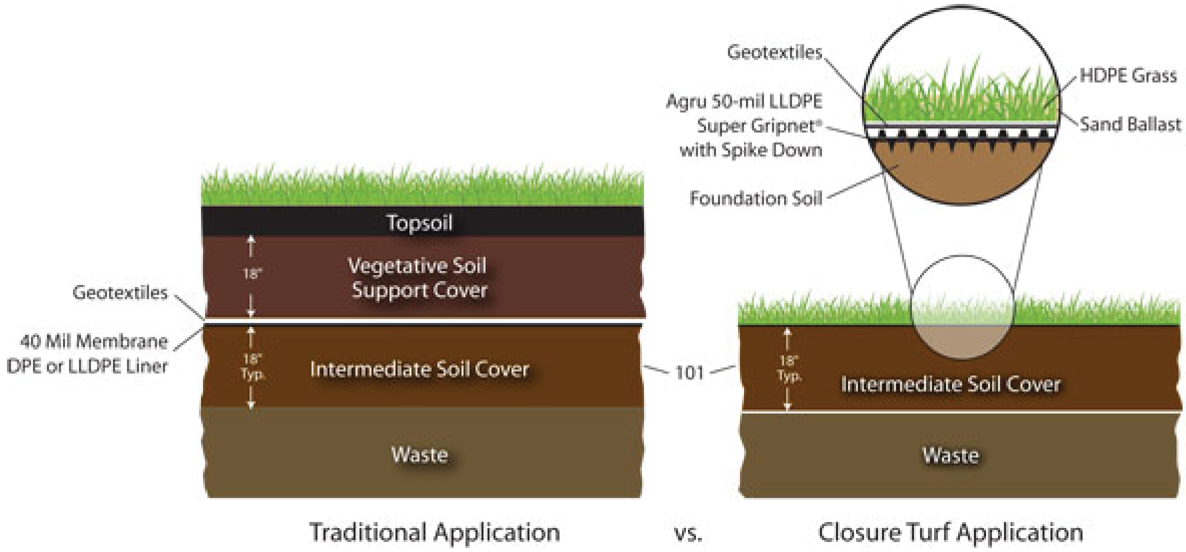


Figure 2b – Installation of Closure Turf

Purpose – The scope of this program was to conduct a full-scale wind tunnel test and experimentally isolate and measure the aerodynamic forces acting on a section of the permeable upper geotextile turf layer alone as installed above the impermeable geomembrane. The wind tunnel install configuration would simulate a wide range of wind speeds flowing over a **flat and level terrain installation** of the Closure Turf ground cover system (Fig 1a-d). The sand ballast requirements needed to counteract the resulting aerodynamic forces could then be determined. The purpose of the ballast is twofold. It serves to prevent both lift-off and tangential motion of the turf material along the geomembrane underlayment **resulting from aerodynamic lift and drag acting on the turf layer**.

<u>Methodology</u>

Model Design – The model represented a full-scale 2D section of the Closure Turf material with a 6.125" chord (stream-wise dimension) with a width of 43" that spanned the tunnel wall to wall. This area constituted the live balance section upon which the total sum of all aerodynamic forces could be measured by a 6 component force balance located under the test section. The model consisted of 4 layers listed below from the lower to uppermost turf layer

1) ¾" Furniture grade plywood support base – This incorporated several pressure taps on the underside in order to measure the ambient pressure (P_{amb}) to determine the vertical force (F_{amb}) due to pressure acting upward on the lower surface of the model.
2) Foam Filler Layer – This represented the soil layer surrounding the lower geomembrane spikes.
3) Impermeable Goemembrane Layer – This was fixed rigidly to the base. An array of static pressure taps was installed on the upper side of this layer, shown schematically in Fig. 1a. These

pressures were integrated numerically to determine the force (F_{geo}) due to pressure acting down on the membrane.

4) Geotextile Turf Layer – The turf was first mounted to a thin wire support frame to maintain the geometry and to provide a safety measure to prevent material from dislodging in the tunnel. The frame was then mounted rigidly on top of the lower construction flush with the top of the geomembrane upper surface studs.

Pitot Static Boundary Layer Probe – In general, pressure variation through the height of the boundary layer is due to viscous forces which cause deficits in the total pressure as the bounding flat and level surface is approached. The static pressure remains constant. However, the unique characteristics of the flexible and permeable turf layer warranted investigating the boundary layer formation on the Closure Turf system. To accomplish this, a traverse system was built into the model to actuate a Pitot static probe vertically through the boundary layer (Fig 1c). This allows the measurement of the total and static pressure as a function of the probe height, defined as h = 0" at the upper surface of the turf HDPE woven mesh. From these measurements the flow velocity distribution was determined. This characterizes the shape of the boundary layer which is by its nature a transition from the no slip condition at the surface ($V = 0$) to free stream conditions ($V = V_{inf}$). The characteristics of this boundary layer profile such as the BL thickness, the height required for the flow to reach free stream velocity, provide valuable insight into the observed results.

Force Balance – An under floor 6 component force balance was utilized to measure the aerodynamic lift (L) and the total drag (D) of the model. These forces were transmitted to the balance through a vertical strut which mounted to the underside of the model base. It should be noted that these forces represent the total sum of all pressure distributions acting on the model resolved vertically and tangentially. As such the isolated vertical force acting on just the turf layer (L_{turf}) is found by Equation 1.

$$L_{turf} = L - L_{amb} + L_{geo} \qquad \text{(Eq 1)}$$

Under the confines of this program, it was not feasible to separate the drag acting on just the turf from skin friction and pressure drag acting on the geomembrane. That being the case, the total drag as measured from the force balance was taken as the drag acting on the turf. This results in a conservative overestimation of the actual turf drag force present.

Installation Conditions – Two installation conditions were examined separately. To more accurately simulate the actual installation conditions, both geomembrane and turf layers were installed upstream and downstream of the balance live model (Fig 1b and 1d). This represents an **interior** condition and in this case the model was located approximately 18" inboard of the **perimeter**. It was also suspected that the perimeter, if unaccounted for, could lead to a worse case situation. To determine the nature of this the upstream turf was removed leaving just the geomembrane as a stand in for a typical surface soil roughness that could be expected at the edge of a real world installation. This left the model mounted turf exposed at the leading edge.

Results and Discussion

These results represent the required thickness of sand for the Closure Turf system as installed on **flat and level terrain**. The density of the sand was provided by Closure Turf. If a different material density is to be used as ballast, the results can be recalculated via Equation 2.

In all cases, **the driving parameter for the depth of the sand is tangential slip due to the aerodynamic formation of shear stress**. The sand ballast requirements have been illustrated in Figures 5 and 6 for several assumed representative interface coefficients of static friction (μ_s). The **minimum** required sand ballast height is found by Equation 2.

$$h_{sand}(in) = \frac{1}{\rho_{sand}}\left(\frac{\tau}{\mu_s} + P\right)\frac{12in}{ft} \quad \text{(Eq 2)}$$

Where:

$$\rho_{sand} = Weight\ Density\ of\ Ballast(sand) = 110\ \frac{lb_f}{ft^3}$$

$$\tau = \frac{D}{Area} = Shear\ Stress, \frac{lb_f}{ft^2}$$

$$P = \frac{L_{turf}}{Area} = Normal\ Force\ Loading, \frac{lb_f(+tve\ up)}{ft^2}$$

The measured data for determining the sand depth are shown in Table I and Table II and plotted in Figures 5 and 6 for the perimeter and interior configurations respectively. The last column of each table gives the resulting sand height requirement, based on Equation 2, for μ_s = 0.93. This value was determined independently from the efforts of this program by Closure Turf affiliates and supplied for use in this analysis.

Perimeter Condition (PC) – The ballast requirement resulting from this configuration are substantially greater than the interior condition. For the given μ_s =0.93 a **minimum** sand height of 0.4" or 3.6 lb_f/ft^2 is needed to provide the ballast based on the resulting shear at 175 ft/s. The lifting pressure will be satisfied by this loading as shown in Figure 4. It should be noted that the required ballast height due to uplift goes from positive to negative at around 115 ft/s. There are several factors contributing to these results.

PC Boundary Layer (BL) – The profile for the perimeter condition is shown in Figure 4 (Red Curve). One characteristic to note is that the boundary layer thickness reaches 99% of free stream velocity at a height of approximately 2". This subjects the turf to up to 89% of the total free stream based on a max vertical blade height of 1.25". This has several resulting effects which can be followed in Figures 3a to 3f. The cascade of effects proceeds as follows.

The blades are subject to higher velocities and thus higher increasing drag as the wind speed increases. The higher drag increases the bending of the blades back onto the mesh substrate. The effect of this has 2 **counteracting effects on the net lift**. At lower velocities (Fig3a-b) the blades are bent slightly with the flow being deflected and accelerated of over the perimeter as shown by the tufts. This flow acceleration increases the **local** velocity and lowers the local static pressure **below** that of free stream static which creates the pressure differential building up in 3a and b Additionally, in this installation, the perimeter exposes the gap between the turf and the geomembrane which allows for some uplift pressure recovery beneath the turf. However, as the free stream velocity increases, the drag is increased further by virtue of greater velocity exposure in the relatively thin boundary layer, the bending angle of the turf also increases (Fig 3b-c). This bending produces an increasing down force reaction which starts to counteract the suction created by the local flow acceleration. Simultaneously, the slightly reduced turf profile geometry (caused by the increased bending) shown in Figure 3c-d begins to reduce the relative local flow acceleration and thus also reduces the suction. This continues until the net vertical force becomes zero at about 110 ft/s (Fig 3d) and continues to decrease through Figure 3f.

Interior Condition (IC) – This condition owes its behavior to the formation of a drastically different boundary layer than the perimeter as shown by the blue profile in Figure 4. Compared to the Perimeter profile it is 25% thicker with no measurable velocity until the height is greater than 50% of the turf length (0.75"). The blades thusly experience a maximum velocity of 45% of free stream. This reduces the drag acting on the turf layer. Furthermore, the static pressure remains constant as a function of height through the BL which effectively prevents the formation of a pressure differential on the flat and level permeable turf membrane.

The cause for the deficient boundary layer is created by longer flow paths over a given surface and all boundaries grow in thickness and increase in turbulence with increasing distance. In the case of Closure Turf, the interaction of the flow with the flexible blades causes this growth to occur quite rapidly. The distance producing the profile in Fig 4 was 18" however, the effect of the growing boundary layer can be seen even in the perimeter condition development in Figures 3a –f. The Model section (highlighted in yellow) is 6.125" wide. It is clearly seen that little to no defection occurs in the turf at a distance just over 6 inches behind the perimeter edge. Thus the boundary layer at further distances than 18" and greater from the perimeter can be expected to have minimal interaction with the turf. Figure 6 shows these results by producing measurements requiring minimal ballast.

Final Comments and Executive Summary

GTRI was contracted by Closure Turf to determine the effective required ballast in terms of sand thickness needed to counteract the aerodynamic forces versus wind velocity acting on a permeable geotextile synthetic turf ground covering material that is to be overlaid onto an impermeable geomembrane underlayment. *It was found that in both perimeter and interior loading conditions, the shear acting on the material serves as the more demanding factor for determining the ballast.*

- **The resulting measurements represent the forces acting on the permeable Turf Layer *only*. The impermeable geomembrane layer was to be assumed immobile as a founding assumption of this program**

- **If it is determined that the static interface friction coefficient (μ_s) between the soil and the lower side of the membrane is lower than that occurring between the turf and the membrane upper surface studs, the lower μ_s should be used in Equation 2 to recalculate the sand depth required by shear. The same shear data given in Tables I & II will apply because, as discussed within the methodology section, the measured shear could not be feasibly separated between the two layers independently and thus represents their combined effect.**
- **The sand ballast depths represented in Figures 5 & 6 and Tables I & II are the Minimum depths required, the proper factor of safety has been left to be determined by Closure Turf, LCC and the authorized building permit issuing agencies.**
- **The perimeter of the turf installation is much more demanding than interior sections.**
- **All measurements were made on a rigidly constrained system. It was not within the scope of this investigation to determine what dynamic effects might occur, including gusts or erosion of sand ballast or any possible unstable perturbations.**
- **All configurations consisted of flat and level terrain installation.**
- **All calculations and measurements assume that the blade length is increased to account for any added ballast material. This is to ensure that the installation matches the conditions as tested.**

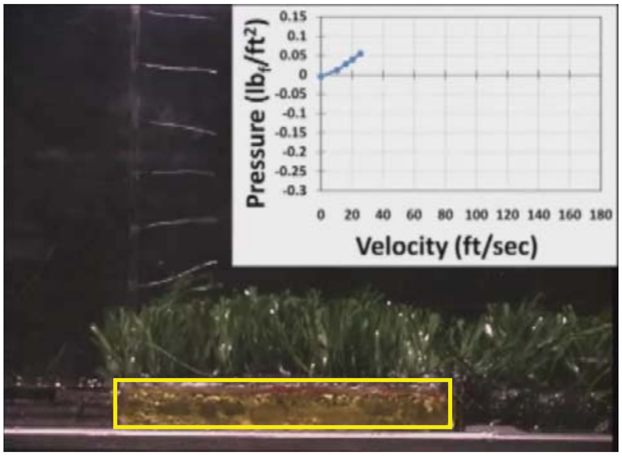


Figure 3a: Vinf = 25 ft/sec

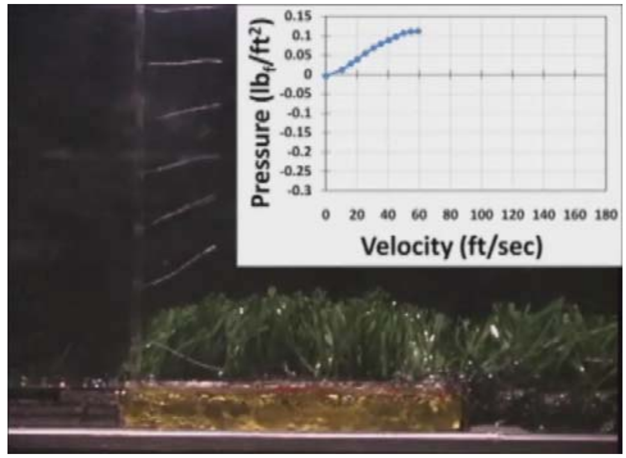


Figure 3b: Vinf = 60 ft/sec

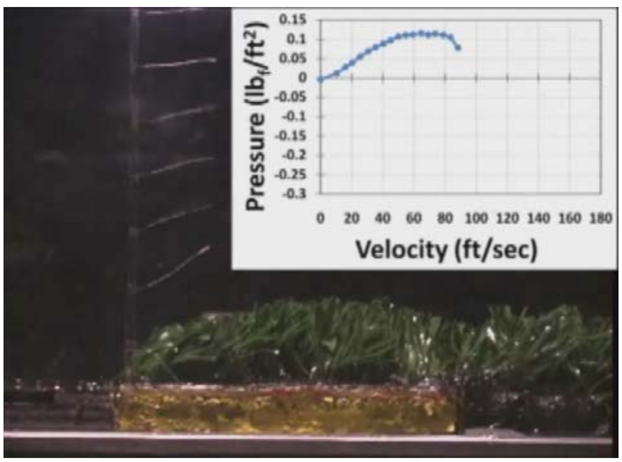


Figure 3c: Vinf = 90 ft/sec

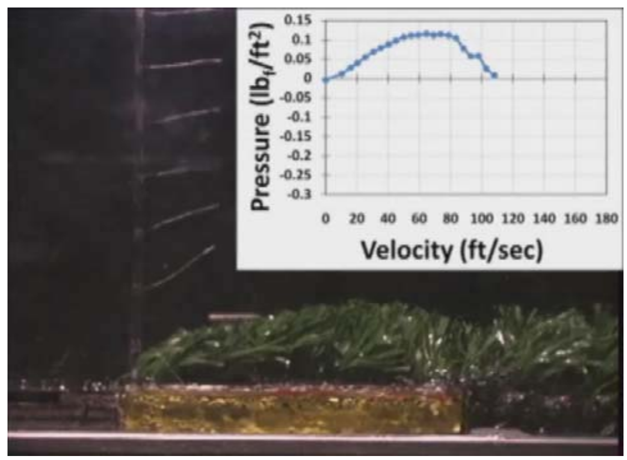


Figure 3d: Vinf = 110 ft/sec

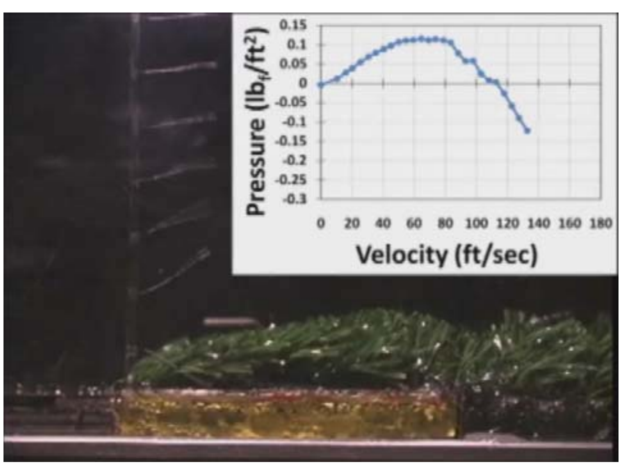


Figure 3e: Vinf = 135 ft/sec

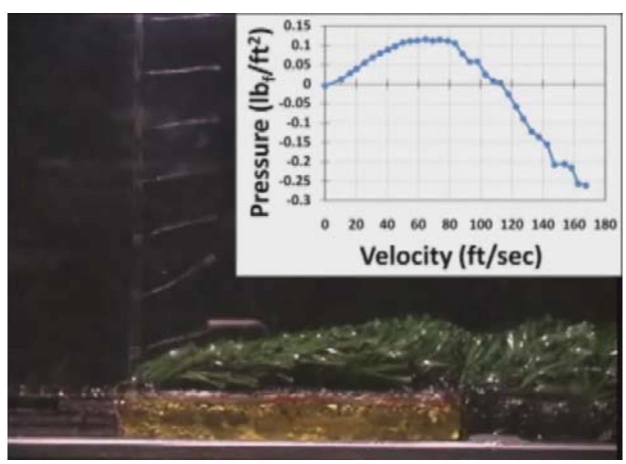


Figure 3f: Vinf = 170 ft/sec

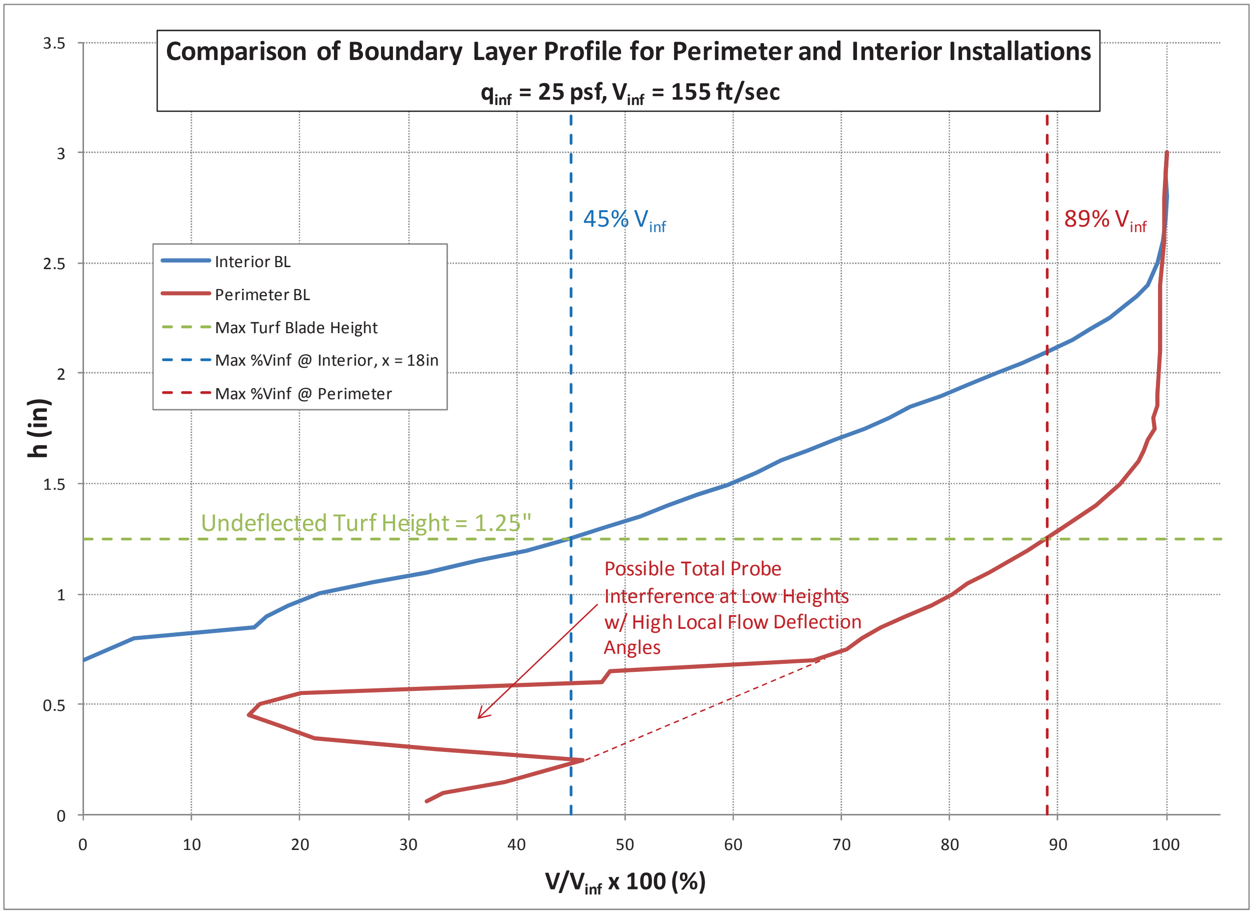


Figure 4 – Non-Dimensional Boundary Layer Profiles for Perimeter and Interior Installations

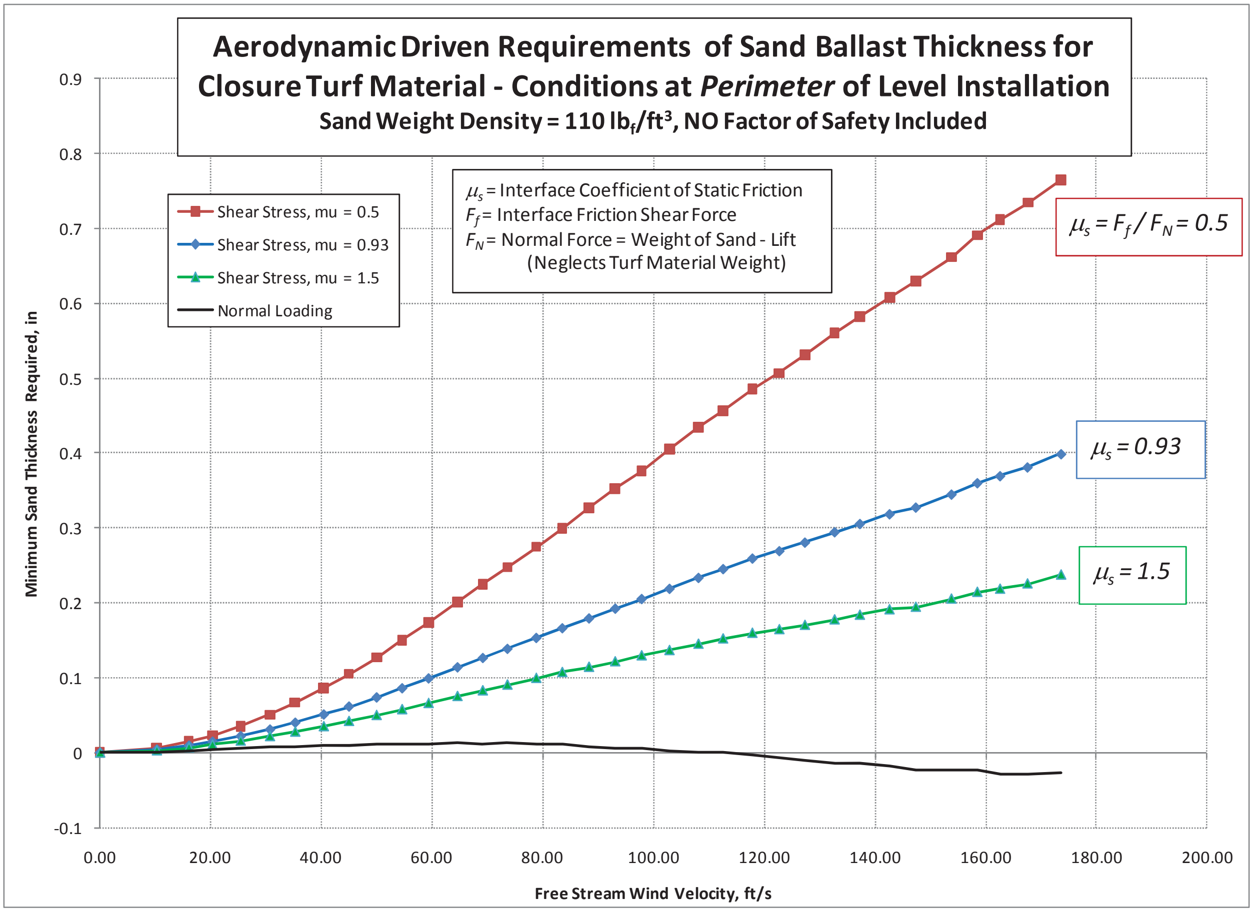


Figure 5 – Sand Ballast Minimum Requirement at the *Perimeter* of Turf Installation

Table I - Perimeter Installation				
Wind Speed (*ft/s*)	Wind Speed (*mi/hr*)	Turf Normal Force Loading (lb_f/ft^2)	Turf Shear Stress ($\mathrm{lb_f/ft^2}$)	Sand Height Due to Shear (*in*)
0.00	0.00	0	0	0
10.26	6.99	0.011689	0.023784	0.0040651
16.06	10.95	0.027798	0.053106	0.009262
20.31	13.84	0.039396	0.086922	0.0144939
25.40	17.32	0.054936	0.136103	0.0219582
30.70	20.93	0.06927	0.198423	0.0308322
35.26	24.04	0.078777	0.266915	0.0399035
40.42	27.56	0.088429	0.351918	0.0509275
44.97	30.66	0.096783	0.434606	0.0615383
49.97	34.07	0.10646	0.529776	0.0737576
54.57	37.21	0.110561	0.630469	0.0860165
59.36	40.47	0.111817	0.741903	0.099225
64.58	44.03	0.115373	0.865046	0.1140578
69.15	47.15	0.111526	0.975305	0.1265718
73.60	50.18	0.114496	1.076528	0.1387694
78.82	53.74	0.111457	1.204017	0.1533926
83.52	56.94	0.104976	1.320714	0.1663744
88.34	60.23	0.077354	1.458158	0.1794835
93.08	63.46	0.057303	1.588598	0.192597
97.86	66.72	0.058201	1.697814	0.2055063
102.89	70.15	0.024978	1.844449	0.2190825
108.12	73.72	0.007601	1.985703	0.2337562
112.58	76.76	0.002646	2.090641	0.2455251
117.87	80.37	-0.026041	2.237684	0.2596441
122.74	83.69	-0.058742	2.352732	0.2695721
127.36	86.84	-0.089852	2.479185	0.2810115
132.72	90.49	-0.122289	2.627843	0.2949108
137.29	93.61	-0.135769	2.734267	0.305924
142.65	97.26	-0.155489	2.863465	0.3189279
147.40	100.50	-0.208034	2.98848	0.3278602
153.84	104.89	-0.206002	3.134988	0.3452676
158.51	108.08	-0.21588	3.274285	0.3605298
162.63	110.88	-0.256805	3.392572	0.3699406
167.59	114.26	-0.261535	3.496667	0.3816351
173.66	118.41	-0.23928	3.626641	0.3993092

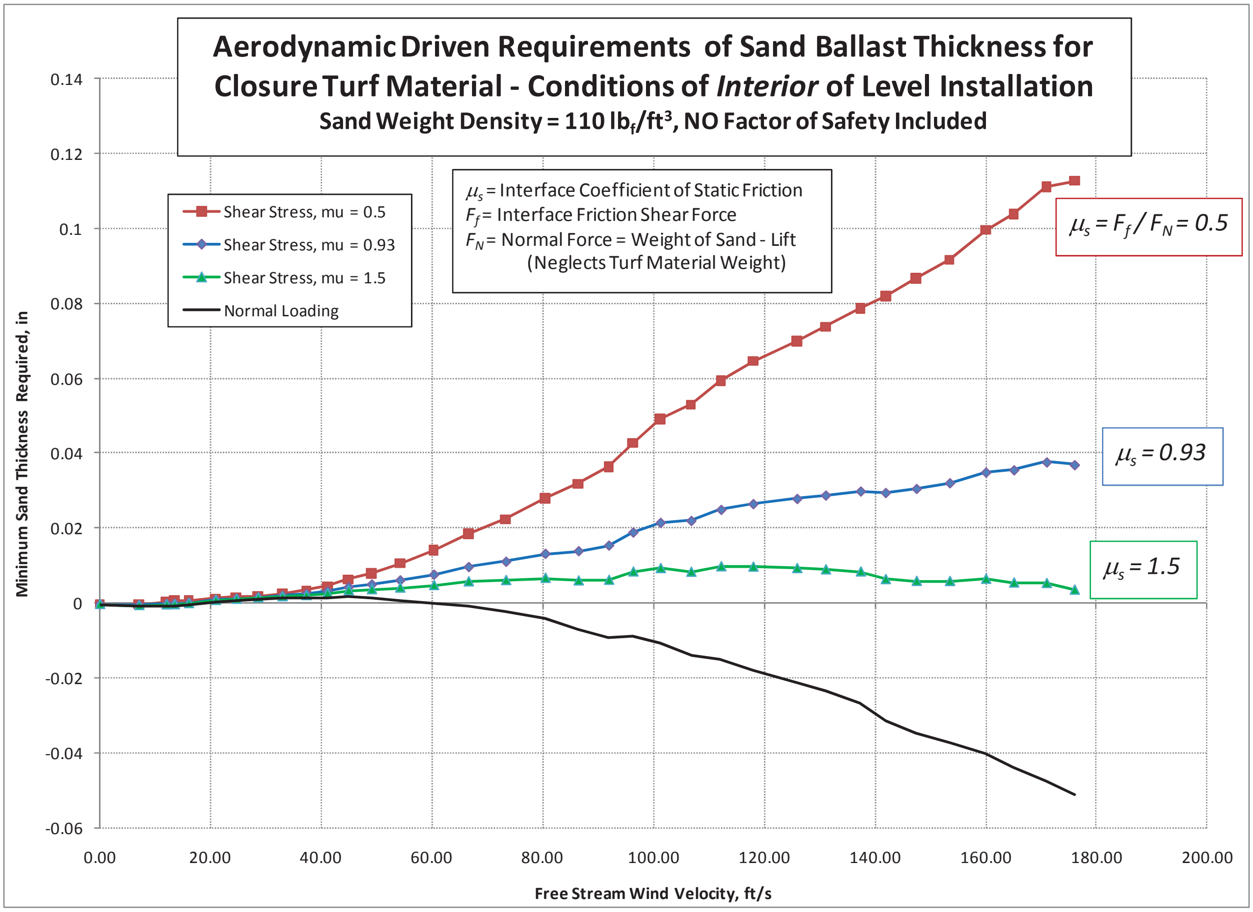


Figure 6 – Minimum Sand Ballast Requirement in the *Interior* of Turf Installation

Table I - Interior Installation				
Wind Speed (ft/s)	Wind Speed (mi/hr)	Turf Normal Force Loading (lb_f/ft^2)	Turf Sheer Stress (lb_f/ft^2)	Sand Height Due to Shear (*in*)
0.00	0.00	-0.00419	0.000471	0
7.07	4.82	-0.00858	0.002819	-0.000605326
12.02	8.20	-0.00858	0.005658	-0.000272305
13.47	9.18	-0.009201	0.006927	-0.000191194
16.05	10.94	-0.005314	0.005174	2.72117E-05
20.91	14.26	0.003753	0.0034	0.000808245
24.64	16.80	0.006062	0.004099	0.00114213
28.56	19.47	0.009925	0.003388	0.001480147
32.94	22.46	0.011669	0.005393	0.001905592
37.27	25.41	0.011221	0.009767	0.002369798
41.09	28.01	0.013608	0.013502	0.003068321
44.90	30.61	0.015886	0.02088	0.004182285
49.08	33.47	0.011842	0.03072	0.004895374
54.21	36.96	0.006407	0.045273	0.006009561
60.31	41.12	-0.000648	0.064883	0.007540218
66.57	45.39	-0.006394	0.087581	0.009575904
73.32	49.99	-0.019878	0.112271	0.01100111
80.43	54.84	-0.037311	0.146631	0.013129826
86.42	58.92	-0.06477	0.178237	0.013841748
91.90	62.66	-0.083261	0.208285	0.01534924
96.30	65.66	-0.081403	0.236369	0.018846242
101.24	69.02	-0.097454	0.273298	0.021427071
106.76	72.79	-0.129489	0.30751	0.021945482
112.17	76.48	-0.138401	0.341067	0.024909568
117.97	80.43	-0.163997	0.378085	0.026459565
125.89	85.83	-0.193612	0.417441	0.027845377
131.07	89.36	-0.215792	0.445855	0.028758761
137.38	93.67	-0.245542	0.482763	0.029842691
141.88	96.73	-0.289393	0.520185	0.029448623
147.46	100.54	-0.317409	0.555461	0.030530279
153.47	104.64	-0.340708	0.59023	0.032067045
159.99	109.08	-0.369093	0.641021	0.034928388
165.05	112.53	-0.4029	0.677722	0.035545455
170.96	116.56	-0.437374	0.727691	0.037646121
176.00	120.00	-0.469865	0.751682	0.036915842

SGI TESTING SERVICES
A GEORGIA LIMITED LIABILITY COMPANY

27 June 2010

Mr. Jose Urrutia
Closure Turf, LLC
3005 Breckinridge Blvd., Suite 240
Duluth, Georgia 3096

Subject: Laboratory Test Results Transmittal
Interface Direct Shear Testing
Closure Turf Cover System

Dear Mr. Urrutia,

SGI Testing Services, LLC (SGI) is pleased to present the attached test results for the above-mentioned project. The note section below addresses sample preparation, sample disposal and a disclosure statement.

SGI appreciates the opportunity to provide laboratory testing services to Closure Turf, LLC. Should you have any questions regarding the attached document(s), or if you require additional information, please do not hesitate to contact the undersigned.

Sincerely,

Zehong Yuan, Ph.D., P.E.
Laboratory Manager

Attachments

NOTES:
(1) Unless otherwise noted in the test results the sample(s)/specimen(s) were prepared in accordance with the applicable test standards or generally accepted sampling procedures.
(2) Contaminated/chemical samples and all related laboratory generated waste (i.e., test liquids, PPE, absorbents, etc.) will be returned to the client or designated representative(s), at the client's cost, within 60 days following the completion of the testing program, unless special arrangements for proper disposal are made with SGI.
(3) Materials that are not contaminated will be discarded after test specimens and archived specimens are obtained. Archived specimens will be discarded 30 days after the completion of the testing program, unless long-term storage arrangements are specifically made with SGI.
(4) The reported results apply only to the materials and test conditions used in the laboratory testing program. The results do not necessarily apply to other materials or test conditions. The test results should not be used in engineering analysis unless the test conditions model the anticipated field conditions. The testing was performed in accordance with general engineering testing standards and requirements. The reported results are submitted for the exclusive use of the client to whom they are addressed.

SGI10007.REPORT.2010.06

MAIL TO: SGI TESTING SERVICES, LLC
P.O. BOX 2427
LILBURN, GA 30048-2427

FACILITY LOCATION
4405 INTERNATIONAL BLVD., SUITE B-117
NORCROSS, GA 30093

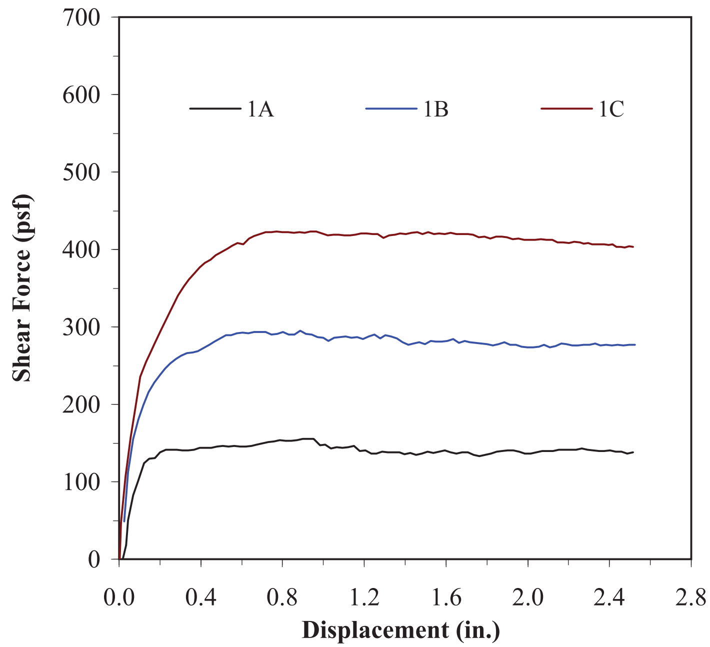
WEB SITE: WWW.INTERACTIONSPECIALISTS.COM
PHONE: 770.931.8222 FAX: 770.931.8240

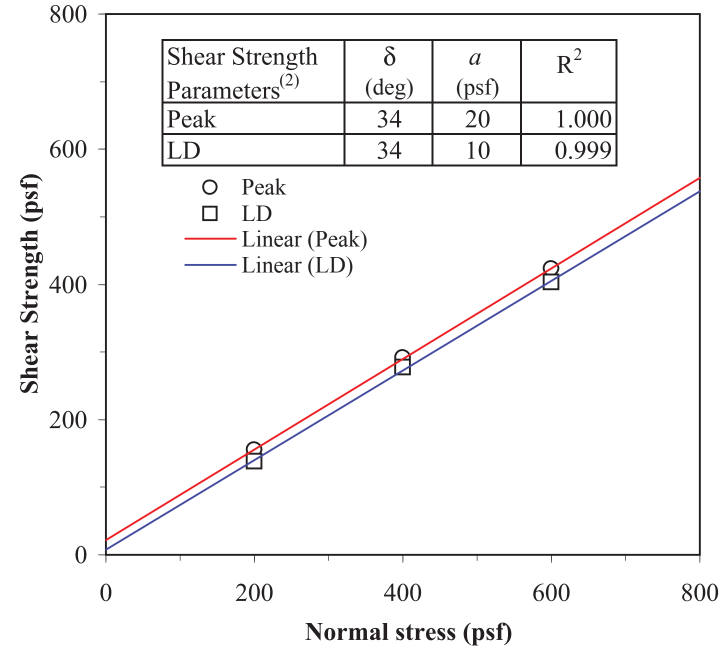
ATTACHMENT A

TEST RESULTS

CLOSURE TURF LLC -LANDFILL COVER SYSTEM
INTERFACE DIRECT SHEAR TESTING (ASTM D 5321)

Upper Shear Box: Concrete sand nominally compacted/
Artificial grass with grass side (green yarns) side up
Lower Shear Box: Concrete sand





Test No.	Shear Box Size (in. x in.)	Normal Stress (psf)	Shear Rate (in./min)	Soaking		Consolidation		Concrete Sand			Upper Soil			GCL		Shear Strengths		Failure Mode
				Stress (psf)	Time (hour)	Stress (psf)	Time (hour)	γ_d (pcf)	ω_i (%)	ω_f (%)	γ_d (pcf)	ω_i (%)	ω_f (%)	ω_i (%)	ω_f (%)	τ_P (psf)	τ_{LD} (psf)	
1A	12 x 12	200	0.04	200	24	-	-	-	-	-	-	-	-	-	-	155	138	(1)
1B	12 x 12	400	0.04	400	24	-	-	-	-	-	-	-	-	-	-	292	277	(1)
1C	12 x 12	600	0.04	600	24	-	-	-	-	-	-	-	-	-	-	423	403	(1)

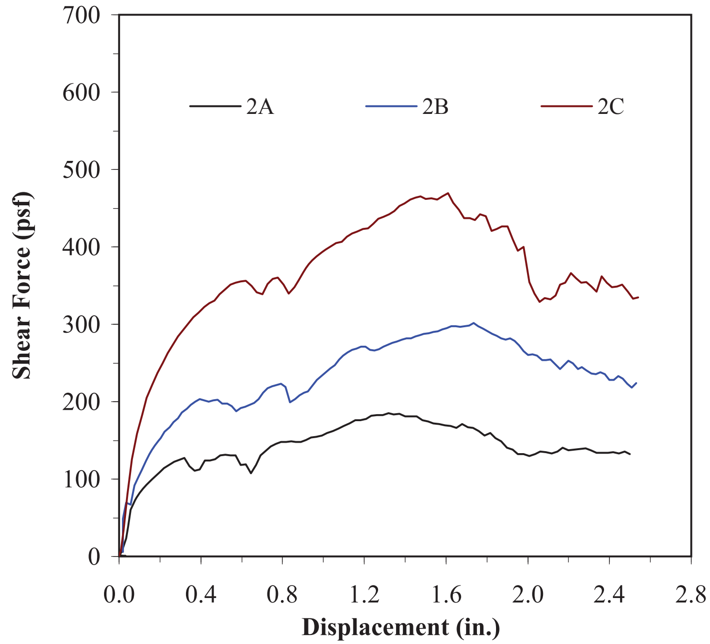
NOTES:
(1) Sliding (i.e., shear failure) occurred at the interface between the upper concrete sand and grass side of the artificial grass.
(2) The reported total-stress parameters of friction angle and adhesion were determined from a best-fit line drawn through the test data. Caution should be exercised in using these strength parameters for applications involving normal stresses outside the range of the stresses covered by the test series. The large-displacement (LD) shear strength was calculated using the shear fo measured at the end of the test.

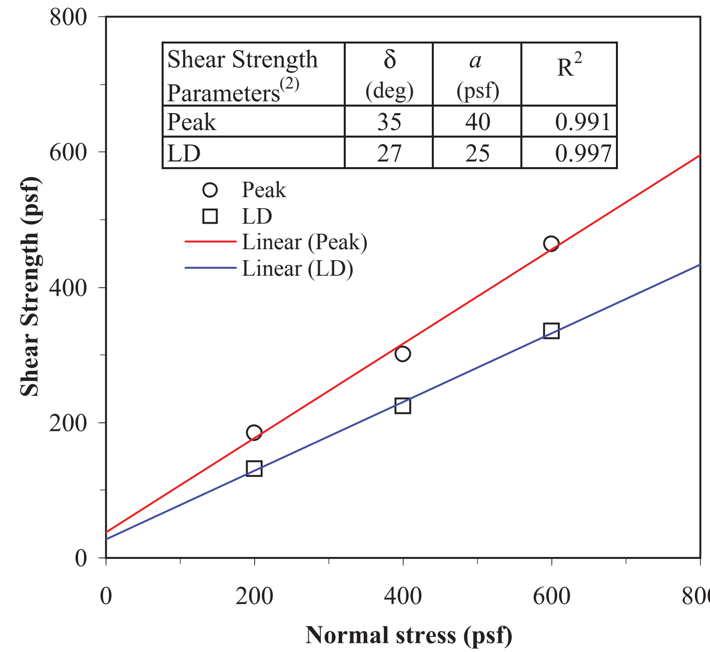
DATE OF TEST:	4/27/2010
FIGURE NO.	C-1
PROJECT NO.	SGI10007
DOCUMENT NO.	
FILE NO.	

SGI TESTING SERVICES, LLC

CLOSURE TURF LLC -LANDFILL COVER SYSTEM
INTERFACE DIRECT SHEAR TESTING (ASTM D 5321)

Upper Shear Box: Concrete sand nominally compacted
Artificial grass with grass side (green yarns) up/
Agru 50 mil LLDPE Super Gripnet geomembrane with studs side up/
Lower Shear Box: Concrete sand





Test No.	Shear Box Size (in. x in.)	Normal Stress (psf)	Shear Rate (in./min)	Soaking		Consolidation		Concrete Sand			Upper Soil			GCL		Shear Strengths		Failure Mode
				Stress (psf)	Time (hour)	Stress (psf)	Time (hour)	γ_d (pcf)	ω_i (%)	ω_f (%)	γ_d (pcf)	ω_i (%)	ω_f (%)	ω_i (%)	ω_f (%)	τ_P (psf)	τ_{LD} (psf)	
2A	12 x 12	200	0.04	200	24	-	-	-	-	-	-	-	-	-	-	185	132	(1)
2B	12 x 12	400	0.04	400	24	-	-	-	-	-	-	-	-	-	-	302	224	(1)
2C	12 x 12	600	0.04	600	24	-	-	-	-	-	-	-	-	-	-	464	335	(1)

NOTES:
(1) Sliding (i.e., shear failure) occurred at the interface between the geotextile of the artificial grass and studs side of the geomembrane.
(2) The reported total-stress parameters of friction angle and adhesion were determined from a best-fit line drawn through the test data. Caution should be exercised in using these strength parameters for applications involving normal stresses outside the range of the stresses covered by the test series. The large-displacement (LD) shear strength was calculated using the shear fo measured at the end of the test.

DATE OF TEST:	4/27/2010
FIGURE NO.	C-2
PROJECT NO.	SGI10007
DOCUMENT NO.	
FILE NO.	

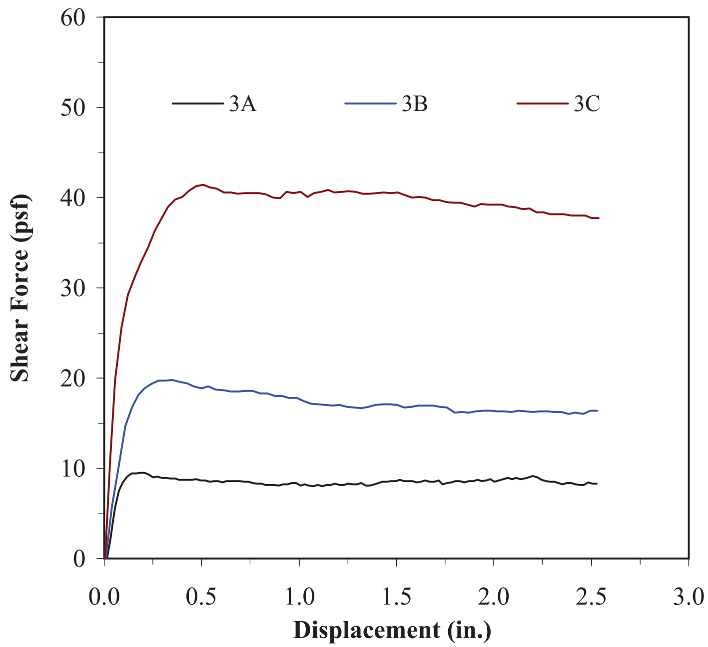
SGI TESTING SERVICES, LLC

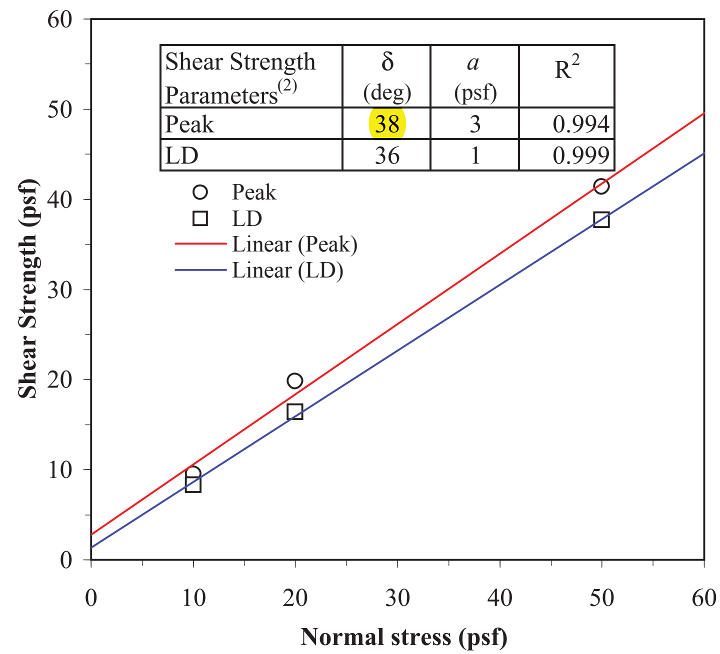
ATTACHMENT B

TEST RESULTS (LOW NORMAL STRESS)

CLOSURETURF LLC -LANDFILL COVER SYSTEM
INTERFACE DIRECT SHEAR TESTING (ASTM D 5321)

Upper Shear Box: Concrete sand nominally compacted/
Artificial grass with grass side (green yarns) side up
Lower Shear Box: Concrete sand





Test No.	Shear Box Size (in. x in.)	Normal Stress (psf)	Shear Rate (in./min)	Soaking		Consolidation		Lower Soil			Upper Soil			GCL		Shear Strengths		Failure Mode
				Stress (psf)	Time (hour)	Stress (psf)	Time (hour)	γ_d (pcf)	ω_i (%)	ω_f (%)	γ_d (pcf)	ω_i (%)	ω_f (%)	ω_i (%)	ω_f (%)	τ_P (psf)	τ_{LD} (psf)	
3A	12 x 12	10	0.04	10	24	-	-	-	-	-	-	-	-	-	-	10	8	(1)
3B	12 x 12	20	0.04	20	24	-	-	-	-	-	-	-	-	-	-	20	16	(1)
3C	12 x 12	50	0.04	50	24	-	-	-	-	-	-	-	-	-	-	41	38	(1)

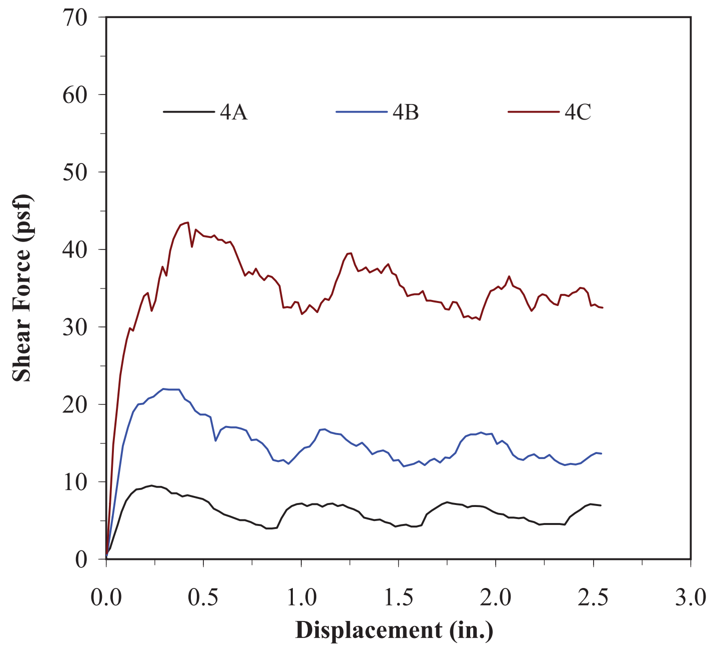
NOTES:
(1) Sliding (i.e., shear failure) occurred at the interface between the upper concrete sand and grass side of the artificial grass.
(2) The reported total-stress parameters of friction angle and adhesion were determined from a best-fit line drawn through the test data. Caution should be exercised in using these strength parameters for applications involving normal stresses outside the range of the stresses covered by the test series. The large-displacement (LD) shear strength was calculated using the shear force measured at the end of the test.

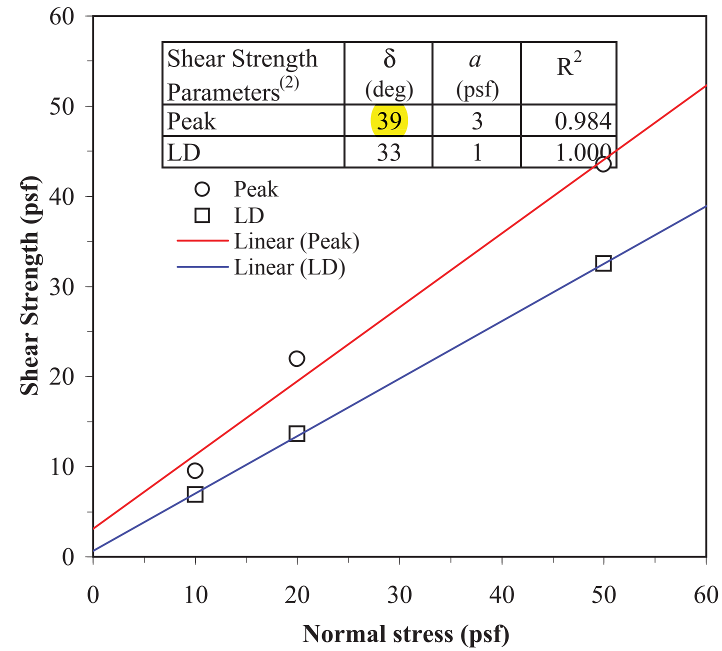
SGI TESTING SERVICES, LLC

DATE OF TEST:	5/15/2010
FIGURE NO.	C-3
PROJECT NO.	SGI10007
DOCUMENT NO.	
FILE NO.	

CLOSURETURF LLC -LANDFILL COVER SYSTEM
INTERFACE DIRECT SHEAR TESTING (ASTM D 5321)

Upper Shear Box: Concrete sand nominally compacted
Artificial grass with grass side (green yarns) up/
Agru 50 mil LLDPE Super Gripnet geomembrane with studs side up/
Lower Shear Box: Concrete sand





Test No.	Shear Box Size (in. x in.)	Normal Stress (psf)	Shear Rate (in./min)	Soaking Stress (psf)	Soaking Time (hour)	Consolidation Stress (psf)	Consolidation Time (hour)	Lower Soil γ_d (pcf)	Lower Soil ω_i (%)	Lower Soil ω_f (%)	Upper Soil γ_d (pcf)	Upper Soil ω_i (%)	Upper Soil ω_f (%)	GCL ω_i (%)	GCL ω_f (%)	Shear Strengths τ_P (psf)	Shear Strengths τ_{LD} (psf)	Failure Mode
4A	12 x 12	10	0.04	10	24	-	-	-	-	-	-	-	-	-	-	10	7	(1)
4B	12 x 12	20	0.04	20	24	-	-	-	-	-	-	-	-	-	-	22	14	(1)
4C	12 x 12	50	0.04	50	24	-	-	-	-	-	-	-	-	-	-	44	33	(1)

NOTES:
(1) Sliding (i.e., shear failure) occurred at the interface between the geotextile of the artificial grass and studs side of the geomembrane.
(2) The reported total-stress parameters of friction angle and adhesion were determined from a best-fit line drawn through the test data. Caution should be exercised in using these strength parameters for applications involving normal stresses outside the range of the stresses covered by the test series. The large-displacement (LD) shear strength was calculated using the shear force measured at the end of the test.

SGI TESTING SERVICES, LLC

DATE OF TEST:	5/15/2010
FIGURE NO.	C-4
PROJECT NO.	SGI10007
DOCUMENT NO.	
FILE NO.	

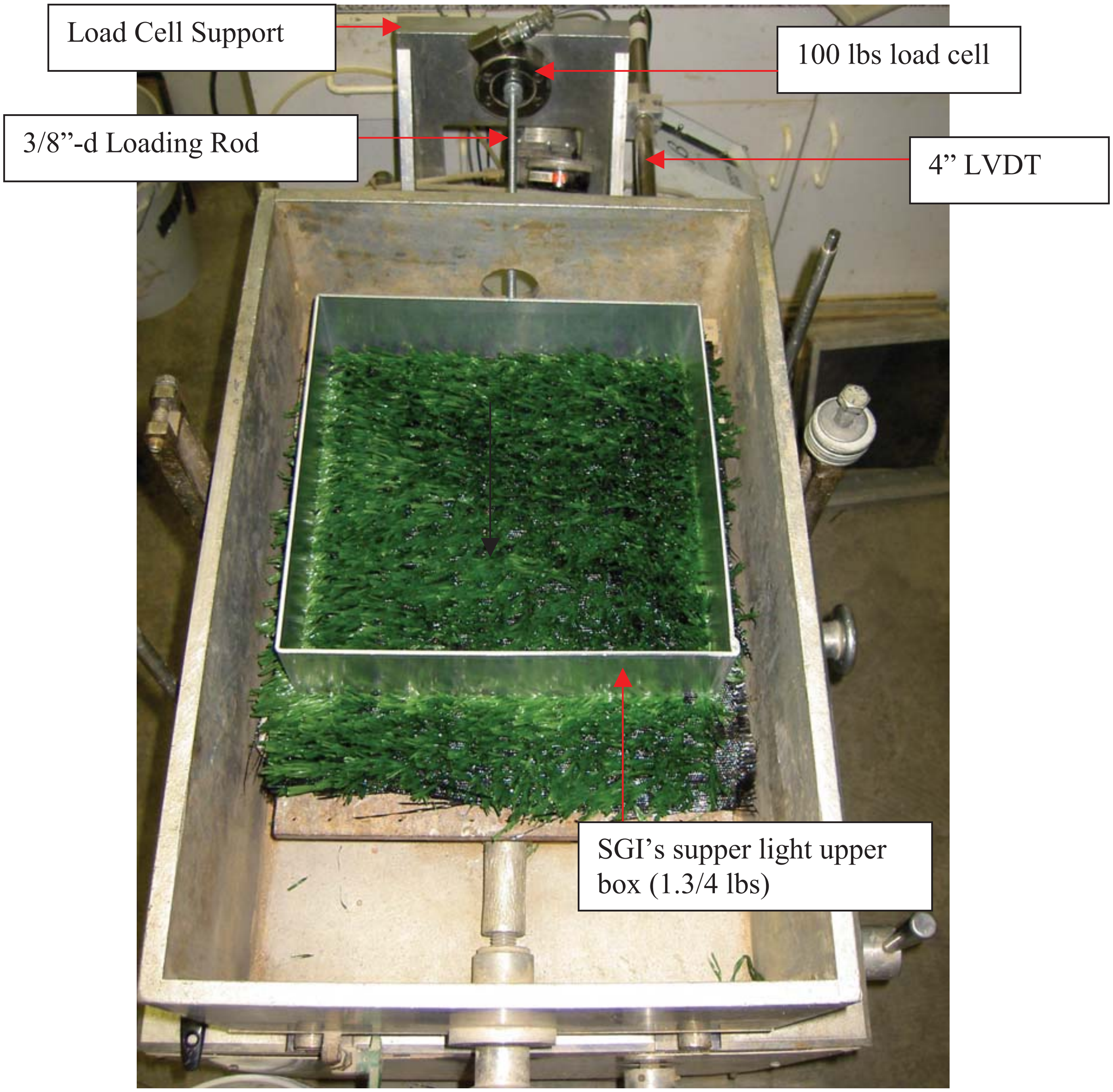


Figure 1. SGI's low pressure interface direct shear test setup.

Figure 2. Sand/grass interface test at a normal stress of 20 psf.

Longevity Information

Geosyntec consultants

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www.geosyntec.com

15 May 2015

José Urrutia, P.E.
Vice President of Engineering
Watershed Geosynthetics
11400 Atlantis Place, Suite 200
Alpharetta, GA 30022

Subject: Literature Review and Assessment of ClosureTurf® UV Longevity

Dear Mr. Urrutia:

Watershed Geosynthetics, Inc. (Watershed) has patented an alternative landfill closure system termed, ClosureTurf®. ClosureTurf® consists of high-density polyethylene (HDPE) grass blades tufted through a polypropylene (PP) geotextile backing which overlies Super Gripnet®, an HDPE or linear low-density polyethylene (LLDPE) geomembrane manufactured by AGRU America Inc. The addition of a layer of sand ballast during installation completes the system. The sand ballast provides cover for the lower portion of the HDPE grass blades, the PP geotextile backing, and the Super Gripnet® (Figure 1). The ClosureTurf® system, therefore, is a "hybrid" closure system in the sense that it is neither a traditional soil cover or an exposed geomembrane. ClosureTurf® has been used to close a number of landfills throughout the United States. A select list of sites where it has been used is shown in Table 1. Applications extend to other facilities as well, such as capping of coal ash ponds.

Watershed has requested that Geosyntec Consultants, Inc. (Geosyntec) provide an assessment of the longevity of the ClosureTurf® system with regard to UV degradation. Since ClosureTurf® has elements (i.e., the HDPE grass blades) that are permanently exposed to UV radiation, this assessment will be particularly focused on the exposed portion of the system. However, the UV longevity of the PP geotextile backing and HDPE geomembrane will also be addressed by reference.

Geosyntec's approach to this assessment has been to conduct a literature review of pertinent documents available (journal papers, white papers, presentations, etc.), distill the results of the review, and perform limited analysis. This report concludes with a summary of the review and analysis along with brief discussion for recommendations.

EXECUTIVE SUMMARY

The UV longevity assessment of the ClosureTurf® system (Figure 1) began with a literature review. In general, relatively little published information was discovered regarding exposed HDPE grass blade degradation. The information that is available consists of retained tensile strength test results of HDPE grass blades after exposure (1, 5, 7 and 10 years) at a field test facility in New River, Arizona (Watershed, 2014). Extrapolation of this data by Watershed (2014) resulted in a prediction of 65% retained tensile strength after 100 years of service. In addition, Richgels *et al* (2015) published half-life (i.e., 50% retained tensile strength) predictions of exposed HDPE grass blades using a laboratory data release from the Geosynthetics Institute (GSI) on HDPE geomembrane strips exposed to UV lamp irradiation. Richgels *et al* (2015) obtains an upper bound and lower bound half-life predictions of 247 years and 176 years, respectively. Extrapolation of the field data from New River, Arizona yielded a half-life of 216 years.

Geosyntec checked the calculations shown in Richgels *et al* (2015) and obtained 277 years and 214 years for the upper and lower bound estimates of HDPE grass blade half-life. Differences in the results between Geosyntec and Richgels *et al* (2015) are attributed to rounding. Geosyntec attempted to repeat these calculations for actual performance requirements (i.e., 12.5% of original tensile strength) of the HDPE grass blades rather than a randomly assigned half-life, however the predictions resulted in service lives that were too lengthy to be reasonable. The most likely explanation is that the laboratory data has not degraded enough to allow for service life predictions using 12.5% retained tensile strength. Future data releases from GSI will aid in providing more accurate predictions below the half-life.

Based on Richgels *et al* (2015) predictions, as well as the prediction given in Watershed (2014) it appears that the half-life of the HDPE grass blades exposed to Arizona-like conditions is on the order of 100 years. These results are promising; however additional field test data is needed to improve the half-life predictions, particularly since half-life predictions for exposed HDPE geomembrane are also approximately 100 years (Koerner *et al*, 2015). Understanding the differences in weathering between HDPE grass blades in a synthetic turf and an HDPE geomembrane will provide additional insight into the similar half-life predictions of the two geosynthetics. Finally, the service life of the HDPE grass blades in the ClosureTurf® system should ideally be based on its performance requirements rather than a half-life which will result in a longer service life prediction.

In addition to the HDPE grass blades, there are two unexposed elements of the ClosureTurf® system: (i) the PP geotextile backing for turf component; and (ii) the Super Gripnet® which consist of a HDPE geomembrane (see Figure 1).

Watershed has incorporated UV degradation inhibitors into the PP geotextile backing which, according to Watershed has lead to an improvement in UV resistance by a factor of 14 over the original prediction of 65% retained tensile strength after 100 years (Watershed, 2014). Koerner (2011) has estimated that covered HDPE geomembrane will have a half-life of 446 years at 20 degrees Celsius and 265 years at 25 degrees Celsius.

Therefore, the most critical component of the ClosureTurf® appears to be the exposed HDPE grass blades when it comes to UV degradation. However, degradation of the HDPE grass blades to unserviceable levels can be remediated by replacement of the turf component of the ClosureTurf® system.

BACKGROUND AND LITERATURE REVIEW SUMMARY

In total, Geosyntec has reviewed approximately 40 technical documents to date. The database is a combination of documents provided to Geosyntec by Watershed as well as documents collected by Geosyntec. A complete reference list of the documents in the database can be made available upon request.

In general, relatively little information was found on the topic of exposed HDPE grass blades with respect to degradation due to UV radiation. The documents that were obtained and reviewed are listed below.

1. Field test data provided by Watershed from the New River, Arizona testing facility on the HDPE grass blades (Watershed, 2014).

2. Testing results (Atlas-MTS) discussing the UV longevity of polyethylene and polypropylene grass used for outdoor European athletic facilities.

3. Technical paper by Richgels, *et al.* (2015a) published in the conference proceedings for Geosynthetics 2015 in Portland, Oregon.

4. Presentation by Richgels., C. at the Geosynthetics Conference for 2015 in Portland, Oregon (Richgels, 2015b).

5. Presentation by Diguilio, D. at the Northern New England SWANA Conference on 25 September 2013 (Diguilio, 2013).

The following documents on the topic of HDPE Geomembrane degradation due to UV exposure were reviewed and found to contain useful information regarding this assessment.

1. Geosynthetic Research Institute (GRI) White Paper #6 (Koerner *et al.*, 2011). This white paper contained degradation data (% retained strength and elongation) on laboratory aged samples of 1.5 mm HDPE geomembrane. Aging was completed using a UV Fluorescent device per ASTM D7238 at 70 degrees Celsius (^{o}C).

2. Geosynthetic Institute (GSI) webinar presentation by Koerner *et al.*, (2015). This presentation contained a slide that compared predicted (laboratory vs. field) half-life of geomembranes of various resins, including HDPE, as well as a suggestion for estimating lower bound half-life.

3. Journal paper authored by Rowe *et al.* (2010) published in the Journal of Geotechnical and Geoenvironmental Engineering.

DISCUSSION OF DOCUMENTS AND DATA

The data from the New River, AZ testing facility on the artificial grass component of ClosureTurf® (Watershed, 2014) appears to be the only data set of its kind in our compiled database. The data consists of tensile property testing from field samples exposed to the Arizona environment at approximate exposure periods of 1, 5, 7 and 10 years. At each of the four exposure periods, 20 samples were tested for a total of 80 tests. The average values for tensile strength retained at each corresponding time period is 97%, 90%, 84% and 83%, respectively (Figure 2).

One additional data point was found in the Atlas-MTS document. That data point indicated that approximately 90% of tensile strength of polyethylene grass would be available after 20 years of field exposure assuming average European climatic conditions (temperature, irradiance, etc.). However, the average European irradiance is approximately one-half to one-third that of Arizona (Figure 3) notwithstanding temperature effects. Therefore, the Atlas-MTS data point will be consistent with the data from the New River, AZ facility in the 7 to 10 year time frame once adjusted for the relative levels of exposure and temperature between Europe and Arizona. As such, this data point will not extend the exposure duration covered by the New River, AZ data.

The paper and corresponding presentation by Richgels (2015a, 2015b) utilized the laboratory data released from the GSI on UV degradation of HDPE samples to make upper and lower bound estimates of the field half-life of the HDPE grass blades. The upper bound method utilizes Arrhenius modeling of lab data to project exposure times at half-life to site temperatures combined with ratios of UV irradiance between the laboratory lamp and monthly average irradiance at New River, AZ to develop half-life loss per month. A similar procedure using a linear extrapolation (rather than Arrhenius) was demonstrated for a lower bound estimate. The Watershed (2014) field data set was plotted in between the upper and lower bound estimates. This method is further discussed in the section below titled, "HDPE Grass Blade Service Life Calculations".

Koerner *et al.* (2011) discusses the UV longevity of both exposed and unexposed geomembranes made from various resins, including HDPE based on GSI's laboratory testing program. This document is particularly useful in regard to the ClosureTurf® elements that are considered non-exposed (i.e., the PP geotextile backing for the turf component and the underlying HDPE geomembrane).

The presentation by Koerner *et al.* (2015) includes estimates of half-life of exposed HDPE geomembranes as well as a recommendation for linear data extrapolation as a lower bound limit that was implemented by Richgels (2015b).

PERFORMANCE REQUIREMENTS

The definition of service life of an HDPE (or other resin) geosynthetic (grass blades and geotextiles/geomembranes) typically invokes the half-life criteria. However, the half-life criteria is arbitrary and while useful as a general indicator for comparison it does not directly relate to any aspect of field performance for ClosureTurf® or any other geosynthetic. Therefore it is more appropriate to define the service life in terms of field requirements placed on the material.

HDPE Grass Blades

For the case of the HDPE grass blades on the ClosureTurf® system, tensile strength requirements fall in the range of 2.5 to 3.5 lbs, based on applied loads of pullout forces from equipment operation and water runoff forces (Diguilo, 2013). The ClosureTurf® HDPE grass blades are manufactured with 20 lbs. of tensile strength immediately following the process (Diguilo, 2013). Therefore, without considering a factor of safety, the required tensile strength of the HDPE grass blade is equal to approximately 12.5% to 17.5% of original strength capacity.

PP Geotextile Backing and HDPE Geomembrane

Performance requirements for the PP geotextile backing and HDPE geomembrane depend on more site-specific parameters (e.g., steepness of slopes, seismicity, etc.) than the HDPE grass blades. Therefore until a parametric study is completed which will define the performance requirements over a range of expected conditions, the half-life will have to be used as a benchmark for degradation of the PP geotextile and HDPE geomembrane.

HDPE GRASS BLADE SERVICE LIFE CALCULATIONS

In order to develop a prediction for the longevity of the HDPE grass blades with respect to UV degradation, Geosyntec implemented the method found in Richgels (2015a, 2015b) for two levels of retained tensile strength. The first level is the 50% of tensile strength, or half-life, criterion that is commonly used as a benchmark for geosynthetic service life. Geosyntec performed this calculation to compare our results with the results presented by Richgels (2015a, 2015b). Once the half-life estimates were calculated, Geosyntec attempted to repeat the calculations using a retained tensile strength of 12.5% of an HPDE grass blade.

Half-Life Estimation (50% of Retained Strength)

The assessment utilized by Richgels (2015a, 2015b) begins with a laboratory data release from GSI (Figure 4). The data includes retained tensile strength of HDPE samples that have been incubated under a UV lamp at elevated temperatures, which accelerates the UV weathering process in accordance with ASTM D7238.

As mentioned, the GSI data includes samples tested at three elevated temperatures: (i) 80 degrees Celsius (^{o}C); (ii) 70^{o}C; and (iii) 60^{o}C. The testing program appears to have originally included only the 70^{o}C data, with the 80 ^{o}C and 60^{o}C testing added at a later date (therefore, weathering is not as advanced). The 70^{o}C data set has reached approximately 66%, while the 80^{o}C and 60^{o}C data sets have reached approximately 78% and 86%, respectively. Nonetheless, logarithmic extrapolations to 50% retained strength were performed for each data set. The amount of exposure time (on a log scale) corresponding to the 50% retained strength plotted vs. the inverse of the corresponding temperature (80^{o}C, 70^{o}C and 60^{o}C) is shown in Figure 5. Figure 5 allows for extrapolation to find the laboratory exposure time required to achieve 50% retained strength at temperatures lower than the test temperatures (i.e., actual field temperatures).

Once the curve is defined relating any temperature to a level of laboratory lamp exposure, the remaining task is to develop a relationship between laboratory exposure and field exposure for a particular site. In this case, the testing site in New River, AZ where Watershed has performed tests on HDPE grass blades, was selected.

Richgels (2015a, 2015b) presents monthly averages at the site for: (i) peak turf temperature; and (ii) irradiance as a fraction of the laboratory lamp irradiance. Using these two values for a given month combined with the Arrhenius model, an estimate of half-life loss per month is obtained. Summation of the half-life lost per month over a year yields the annual half-life loss. The inverse of the annual half-life loss is the predicted half-life in years. Using this method, Richgels obtains a half-life of approximately 247 years, while Geosyntec obtained a half-life of 277 years using the same data (Table 2). The difference is attributable to rounding errors in the logarithmic projections.

Following the suggestion of Koerner *et al.* (2015), Richgels (2015b) treated the results of the half-life mentioned above as an upper bound estimate. For the lower bound estimate, Koerner *et al.* (2015) suggests performing a linear extrapolation of the laboratory data to lower field temperatures, rather than using the Arrhenius model.

With the linear extrapolation, the ratio of monthly irradiance to laboratory lamp irradiance is scaled linearly to calculate the number of months required to reach half-life at 80C, 70C and 60C. Linear extrapolations per month are made from the elevated temperatures to the corresponding peak turf temperature in that month. The resulting half-life loss per month is summed to obtained half-life loss per year. The inverse of that result is the half-life in years. Richgels (2015b) calculates a half-life of 176 years using this linear model. Geosyntec's calculation using the same data resulted in a half-life of 214 years (Table 3 and Figure 6). The difference in the calculations is approximately the same as with the calculation using the Arrhenius (logarithmic) model.

Figure 7 shows the calculated upper (Arrhenius - logarithmic) and lower (linear) bound curves calculated by Richgels (2015b) along with the field data on the HDPE grass blades provided by Watershed (2014). As shown in Figure 7, the trend line fit to the field data falls in between the upper and lower bound curves produced by Richgels (2015b). Note that the first point from the field data at approximately 1 year is omitted from the trend line. This is because the first data point is assumed to be within the anti-oxidant phase of degradation rather than the polymer oxidation stage as suggested by Rowe *et al.* (2010). Additional discussion regarding the stages of degradation for polyolefin materials can be found in CUR 243 (2012).

Service Life Estimation Based on Performance Requirements (12.5% of Retained Strength)

Geosyntec repeated the calculations discussed above for the estimation of half-life, but extrapolated the GSI laboratory data down to 12.5% rather than 50% at 80C, 70C and 60C. Upper bound

(Arrhenius – logarithmic) and lower bound (linear) estimates were 2,500 years and 2,043 years, respectively.

These estimates of service life are simply too large to be reasonable. A likely explanation is that the samples tested at 80C, 70C and 60C have not degraded enough to produce accurate predictions at 12.5% retained strength. As previously mentioned, the data for 80C has reached 78% retained strength; the data for 70C has reached 66% retained strength; and the data for 60C has reached 86% retained strength. Therefore, the extrapolation for each of these data sets to 50% retained strength will be much more accurate than extrapolations to 12.5%. In addition, small uncertainties in log-based extrapolations will greatly influence results.

For these reasons, it is not practical or useful at this time to quantitatively assess service life in terms of actual performance requirements when those requirements are substantially below the half-life. There is some value, however in a qualitative use of performance requirements in comparisons with half-life estimates (i.e., to establish the factor of safety remaining at 50% degradation).

SUMMARY AND CONCLUSIONS

Geosyntec's literature review of approximately 40 documents yielded few sources of UV degradation data for exposed HDPE grass blades. Relevant data that was found included the field test data from the New River, AZ testing facility provided by Watershed (2014) and one data point from Atlas-MTS. The Atlas-MTS data point indicated that HDPE grass blades in average European climatic conditions would retain approximately 90% of its original strength after 20 years of field exposure. Taking into account the differences in temperature and UV irradiance between New River, AZ and European averages, the data point is consistent with the New River, AZ test data in the 7 to 10 year range.

Following the method presented in Richgels (2015a, 2015b) for HDPE grass blades, Geosyntec calculated an upper bound half-life of 277 years compared with Richgels 247 years using the Arrhenius (semi-log) extrapolations to site temperatures and ratio of laboratory lamp to field irradiance. Geosyntec calculated a lower bound half-life based on linear temperature extrapolations, as suggested by Koerner *et al.* (2015), of 214 years compared with 176 years obtained by Richgels (2015b). The differences between Geosyntec and Richgels calculations were attributed to rounding. As shown in Figure 7, the field data from New River, AZ suggests a half-life of 216 years when considering only the last three data points (i.e., polymer oxidation stage).

Another prediction of HDPE grass blade degradation is included in Watershed (2014) using the same (New River, AZ) field data. That prediction of retained tensile strength at 100 years of service life is 65%.

Therefore, it appears that the half-life of the HDPE grass blades will be on the order of 100 years based on the existing field data set and extrapolation methods found in the literature and presented herein. The results are promising; however additional field test data is needed to improve the half-life prediction, particularly since the half-life predictions for exposed HDPE geomembranes are also approximately 100 years (Koerner, 2015). Half-life predictions presented herein will also need to be revisited when additional labratory data is released from the GSI testing program.

Geosyntec attempted to calculate the service life of the HDPE grass blades using 12.5% of retained strength, rather than an arbitrarily assigned half-life. However, the calculation resulted in unreasonably long service life. This result is likely due to uncertainties in extrapolating the laboratory data released from GSI down to the 12.5% retained strength level. The data release has degraded to 78%, 66% and 86% for the 80 ^{o}C, 70 ^{o}C, and 60 ^{o}C test temperatures. Therefore, extrapolations to 50% may be warranted while extrapolations to 12.5% may not be until additional lab data is available. That being said, it should be recognized that half-life, or 50% of retained strength, has a factor of safety of 2.8 to 4.0 when considering the tensile capacity performance requirements of HDPE grass blades.

With regard to the unexposed elements of the ClosureTurf® system, Watershed (2014) indicates that the retained tensile strength of the PP geotextile backing prior to the addition of UV inhibitors is 65% after 100 years. This estimate is based on exhumed samples of the geotextile from the LaSalle-Grant Landfill in Louisiana. According to Watershed (2014), the addition of proprietary UV inhibitors to the PP geotextile backing has led to an improvement in UV resistance by a factor of 14. The final geosynthetic in the ClosureTurf® system is the covered HDPE geomembrane. Koerner (2011) estimates that the half-life of a covered HDPE geomembrane is 446 years at 20C, and 265 years at 25C. Furthermore, the degradation of the unexposed elements of the ClosureTurf® system invoke the half-life criteria. As discussed with regard the exposed HPDE grass blades, actual performance requirements should ideally be used to determine system longevity. However, the existing testing programs need to be allowed to degrade further before projections to lower values are made.

It is worth reiterating that applications of ClosureTurf® in areas of the United States where the UV irradiance and the temperatures are lower will result in longer half-life predictions than discussed above. In some cases (e.g., the Northeastern States), the differences will likely be quite large when compared with Arizona.

Finally, once UV degradation of the most susceptible component of ClosureTurf® (i.e., the exposed HDPE grass blades) does result in a tensile break, replacement of the HDPE grass and PP geotextile backing can be performed.

CLOSING

Geosyntec appreciates the opportunity to assist Watershed in the development of its ClosureTurf® products. Questions and comments may be directed to either of the undersigned at 678-202-9500.

Sincerely,

Will Tanner, P.E.
Project Engineer

Ming Zhu, Ph.D., P.E.
Senior Engineer

Attachments:	References Tables Figures
Copies to:	Bill Gaffigan (Geosyntec) Mike Ayers (Watershed)

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Koerner, R., Koerner, G., and Hsuan, Y. (2015) “Lifetime Predictions of Covered and Exposed Geomembranes”. Webinar GSI-W14, January 14, 2015.

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Richgels, C. (2015b) “Estimation of Geographic Ultraviolet Radiation Levels and Impact on Geosynthetic Cover Systems”. Geosynthetics 2015, Portland, Oregon, February 15-18, 2015.

Rowe, K., Islam, M., Hsuan, Y., (2010) “Effects of Thickness of the Aging of HDPE Geomembranes”. Journal of Geotechnical and Geoenvironmental Engineering, ASCE, 136(2), p.299-309.

Watershed Geosynthetics, (2014) “Technical Submittal for ClosureTurf^{TM} – Alternative Final Cover, Closure of Municipal Soild Waste Landfill Units”, December 2, 2014.

TABLES

Table 1. Selected Sites where ClosureTurf® has been Installed.

Select ClosureTurf® Installations				
Installation	**Type**	**Acres**	**State**	**Year**
Progressive - Weatherford	Public – MSW	8.5	Texas	2010
Progressive - Timberland	Public - MSW	4	Louisiana	2011
Crazy Horse (Salinas SWA – Monterey)	City – MSW	65	California	2012
Saufley Landfill (Escambia)	Public – C&D	22.5	Florida	2012
Georgia Pacific	Independent	70	Georgia	2013
Berkeley County Landfill	City - MSW	12	South Carolina	2013
Lanchester Landfill (Chester)	City - MSW	7	Pennsylvania	2013
Tangipahoa Parish	City – MSW	22	Louisiana	2013
Sandtown – (Berkeley County)	City – MSW	4	Delaware	2013
Si-County Landfill	EPA – Region 6	5	Texas	2014
Holcim Cement Landfill (Kiln Dust)	Independent	46	New York	2015

Table 2. HDPE Grass Blade Upper Bound Half-Life Calculations (Geosyntec)

Month	UV Lamp On(1) (hrs/day)	Peak Turf Temp(2) (C)	Peak Turf Temp (K)	Peak Turf Temp (1/K)	Reaction Rate(3)	Lab Half-Life(4) (lamp hrs)	Field Equivalent(5) (days)	Field Equivalent(6) (months)	Half Life Loss per Month(7)
January	4.00	27.99	301.14	0.0033	-15.67	6385286	1596322	51494	1.94196E-05
February	4.94	27.96	301.11	0.0033	-15.67	6401982	1296604	46307	2.15949E-05
March	6.13	33.94	307.09	0.0033	-15.11	3632197	593012	19129	5.22755E-05
April	6.94	40.58	313.73	0.0032	-14.50	1983742	285945	9531	0.000104915
May	7.25	51.21	324.36	0.0031	-13.58	792646	109330	3527	0.000283544
June	7.31	61.52	334.67	0.0030	-12.75	344593	47124	1571	0.00063662
July	6.94	66.82	339.97	0.0029	-12.34	228887	32993	1064	0.000939599
August	7.00	64.80	337.95	0.0030	-12.50	267230	38176	1273	0.000785841
September	6.94	59.43	332.58	0.0030	-12.91	406208	58553	1889	0.000529439
October	5.88	47.74	320.89	0.0031	-13.88	1062504	180852	5834	0.000171411
November	4.56	36.38	309.53	0.0032	-14.88	2899472	635501	21183	4.72069E-05
December	3.69	24.68	297.83	0.0034	-15.99	8826208	2393548	77211	1.29515E-05
Lab	20							**Yearly Half-life Loss(8)**	0.003604818
								Half-life(9) (years)	277.41

Notes:

(1) UV Lamp On (hours per day) is given in Richgels (2015a, 2015b).
(2) Peak Turf Temps for New River, AZ given in Richgels (2015a, 2015b).
(3) Reaction Rate is calculated from the regression curve shown in Figure 4 for the upper bound (logarithmic) case.
(4) Lab half-life in hours is equal to 1/e^(Reaction Rate).
(5) Field equivalent (days) is calculated by dividing the lab half-life in hours by the UV lamp on hours per day.
(6) Field equivalent in days is converted to months using the given days in that particular month.
(7) Half-life loss per month is the inverse of the corresponding field equivalent in months.
(8) The yearly half-life loss is the sum of each individual months half-life loss.
(9) The half-life in years is the inverse of the yearly half-life loss.

Table 3. HDPE Grass Blade Lower Bound Half-Life Calculations (Geosyntec)

Month	UV Lamp On[(1)] (hours/day)	Months @ 80 C[(2)]	Months @ 70 C[(2)]	Months @ 60 C[(2)]	Peak Turf Temp[(3)] (C.)	Half-life Months (from Regression)	Half-life Loss per month
January	4.00	692	1507	3078	27.99	6948	0.000143933
February	4.94	620	1352	2761	27.96	6256	0.000159849
March	6.13	452	984	2010	33.94	4059	0.00024637
April	6.94	412	898	1834	40.58	3213	0.000311281
May	7.25	382	832	1698	51.21	2248	0.000444747
June	7.31	391	852	1740	61.52	1580	0.000633027
July	6.94	399	869	1775	66.82	1237	0.00080834
August	7.00	395	861	1759	64.80	1371	0.000729293
September	6.94	412	898	1834	59.43	1826	0.000547629
October	5.88	471	1026	2095	47.74	3070	0.000325779
November	4.56	627	1365	2788	36.38	5321	0.000187929
December	3.69	750	1635	3339	24.68	7945	0.000125871
Lab	20					**Yearly Half-life Loss**	0.00466405
						Half-life (years)	214.41

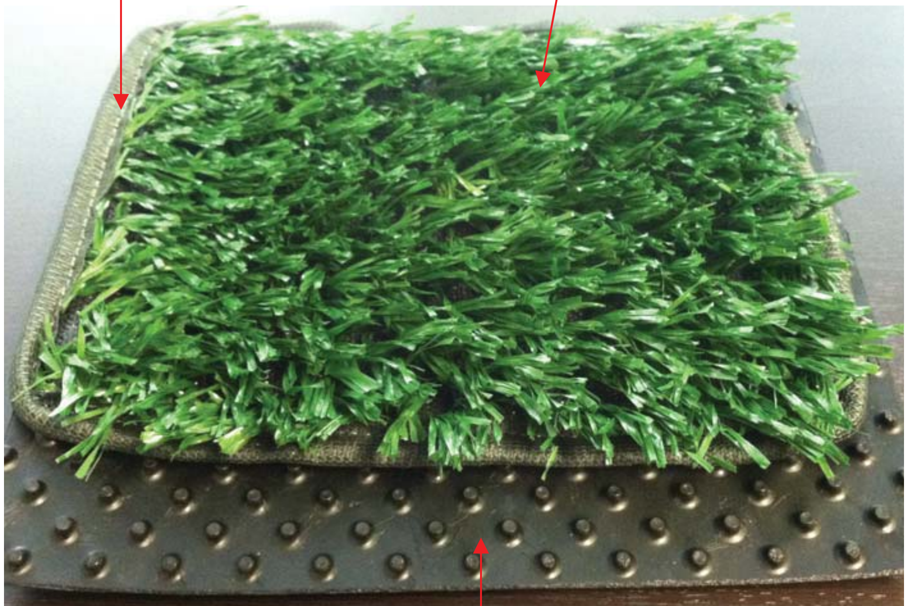
Notes:

(1) UV Lamp On (hours per day) is given in Richgels (2015a, 2015b).

(2) The months required at each temperature is calculated using the regressions from Figure 4 for each temperature, projected down to half-life, then dividing the lamp-hours at half-life by the UV lamp on hours per day for a given month. Once this calculation is done for 80, 70 and 60 C, a linear regression (as shown in Figure 5) is used to obtain the half-life months at the corresponding peak turf temp.

(3) Peak turf temperatures given in Richgels (2015a, 2015b).

FIGURES



Note: The sand ballast infill is not shown in the sample photo on the left, but is shown in a field application photo on the right.

ClosureTurf® Components

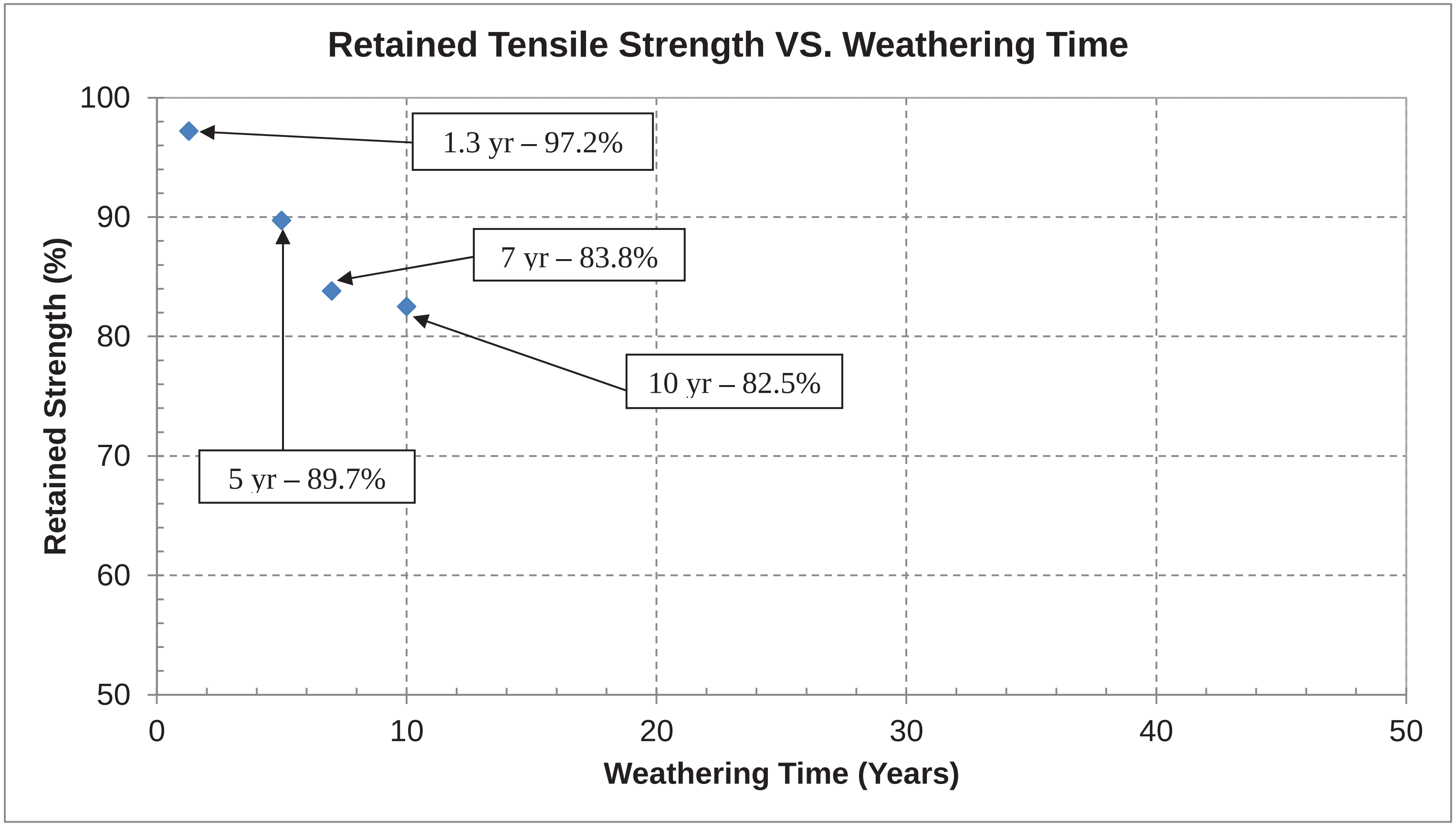
Watershed Geosynthetics – ClosureTurf® UV Assessment

Geosyntec consultants

Figure 1

Kennesaw, GA

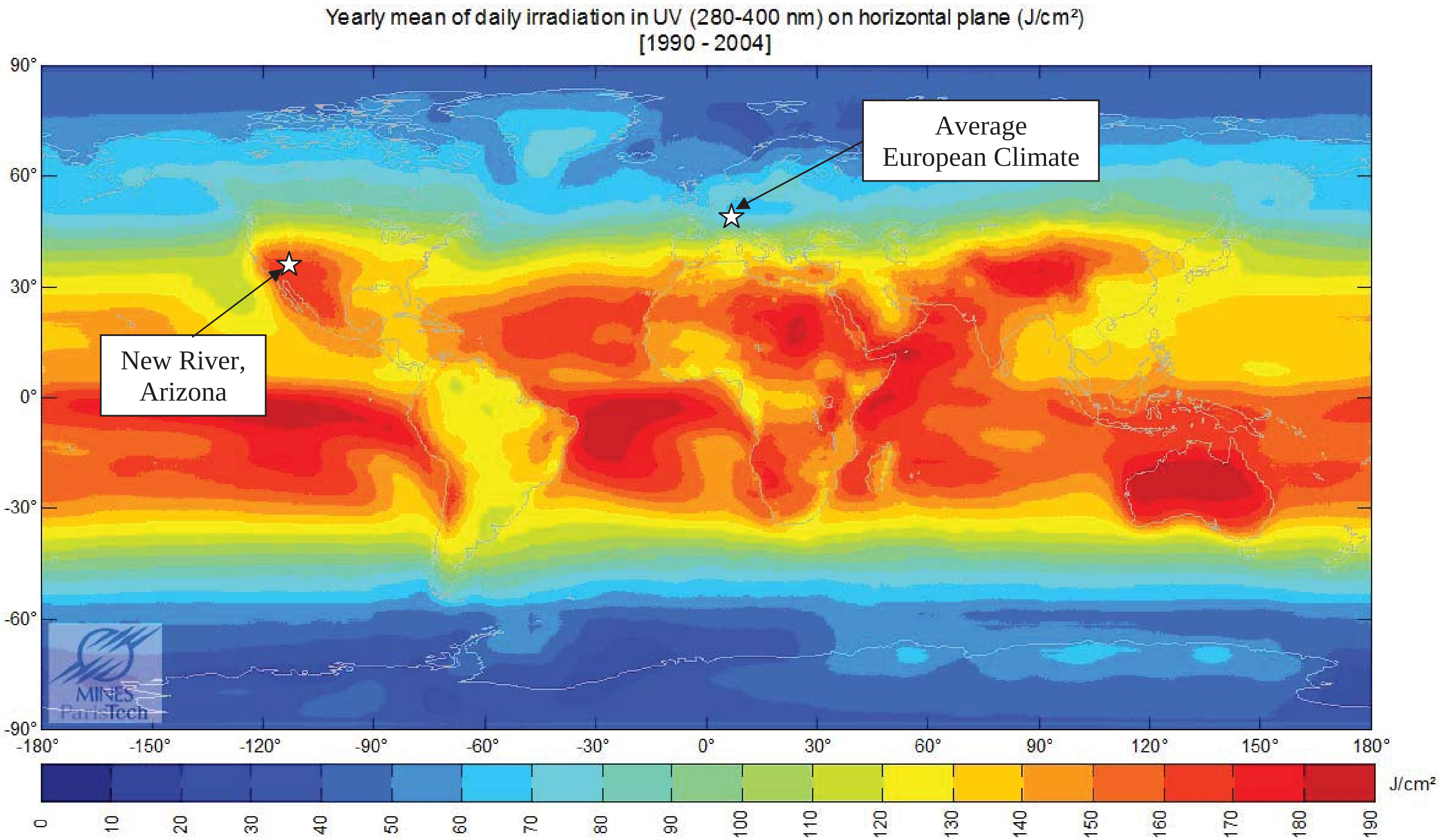
23-April-2015



Notes:

1. The first data point at Weathering Time of 1.3 years is considered to be within the initial stage of UV degradation (i.e., anti-oxidant depletion), rather than polymer oxidation which is represented by the final three data points.
2. Each data point represents the average result of 20 tensile break tests.

Field Test Data (Watershed, 2014) **New River, AZ Atlas Testing Facility** Watershed Geosynthetics – ClosureTurf® UV Assessment		
Geosyntec consultants		Figure **2**
Kennesaw, GA	25-April-2015	



1 J/cm^2 = 4.755 ft-lbs/in^2

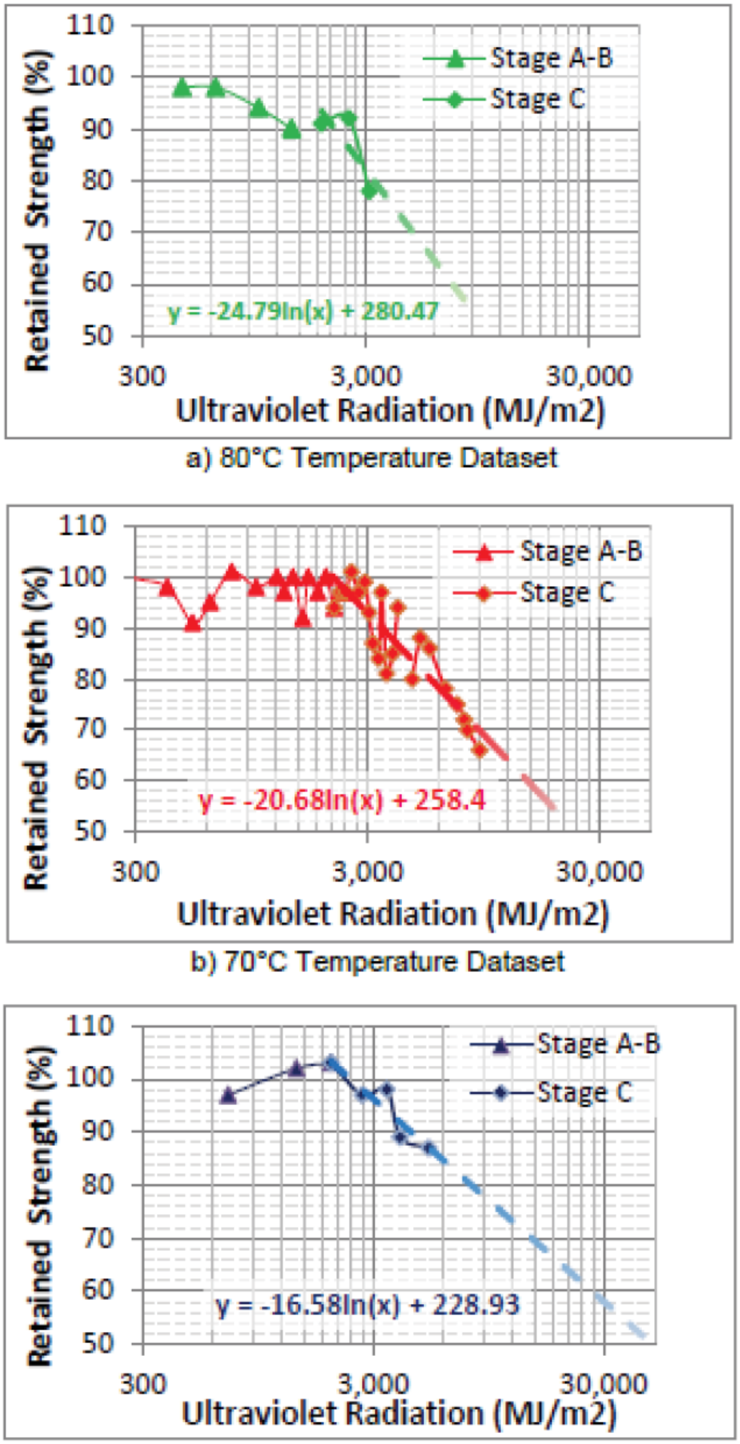
Yearly Irradiation in the Ultraviolet Range

Watershed Geosynthetics – ClosureTurf® UV Assessment

Geosyntec consultants

Figure 3

Kennesaw, GA | 23-April-2015



a) 80°C Temperature Dataset

b) 70°C Temperature Dataset

c) 60°C Temperature Dataset

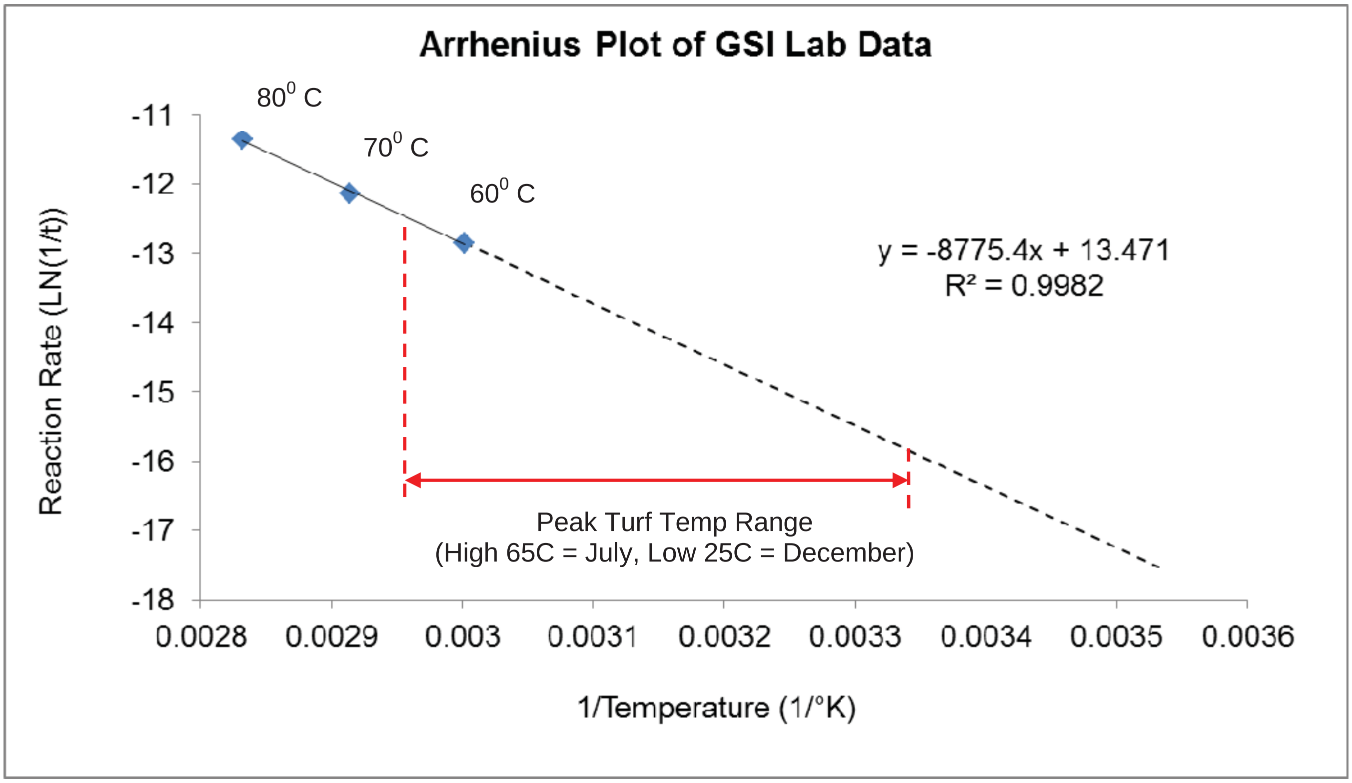
GSI Data Release - Three Stage Oxidation of HDPE for Different Temperatures

Watershed Geosynthetics – ClosureTurf® UV Assessment

Geosyntec consultants

Figure 4

Kennesaw, GA | 23-April-2015



Note: Richgels (2015b) mentions that the use of peak turf temperature is conservative since it only occurs for approximately one hour per day.

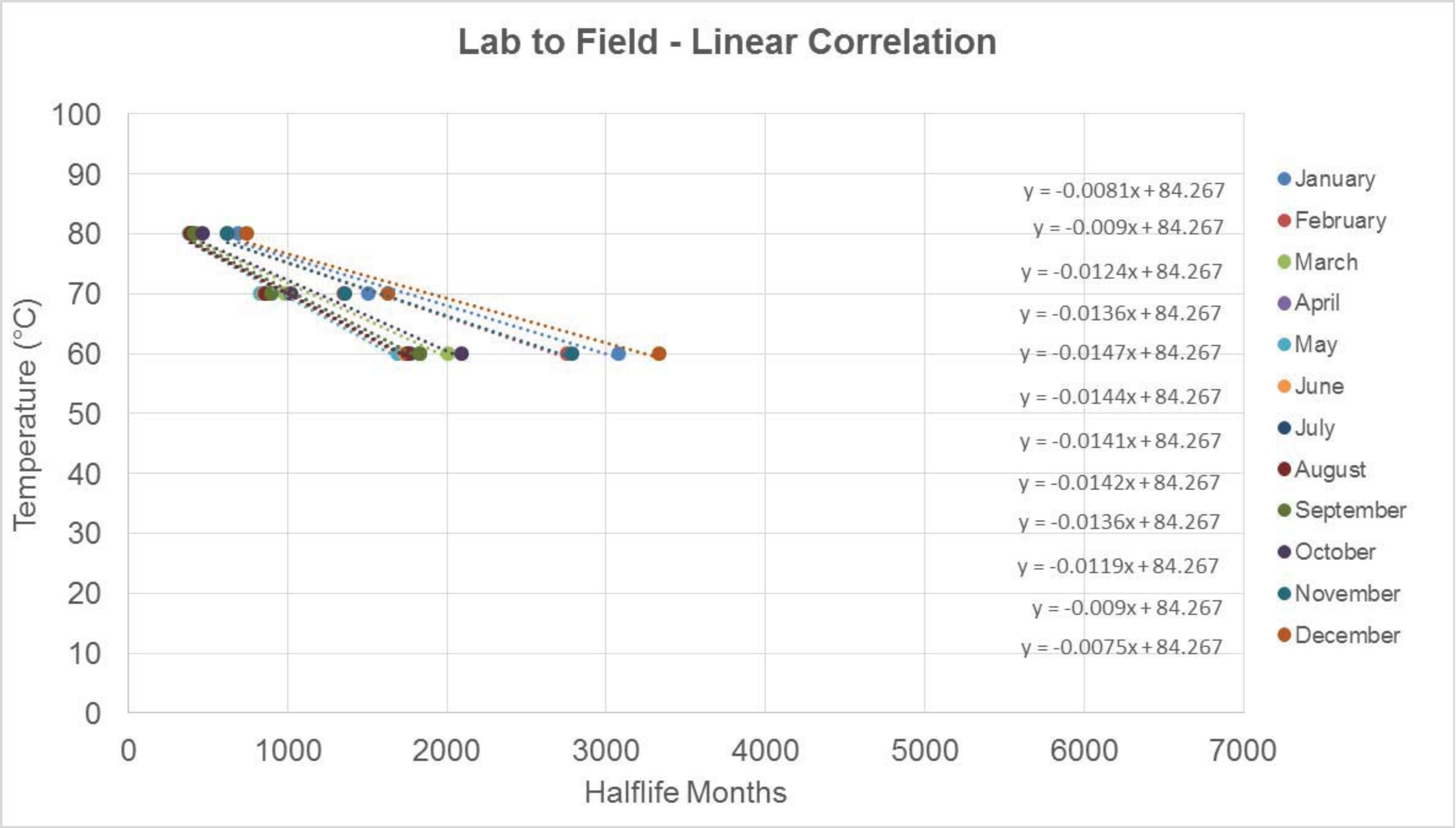
Arrhenius Plot of Lab Data

Watershed Geosynthetics – ClosureTurf® UV Assessment

Geosyntec consultants

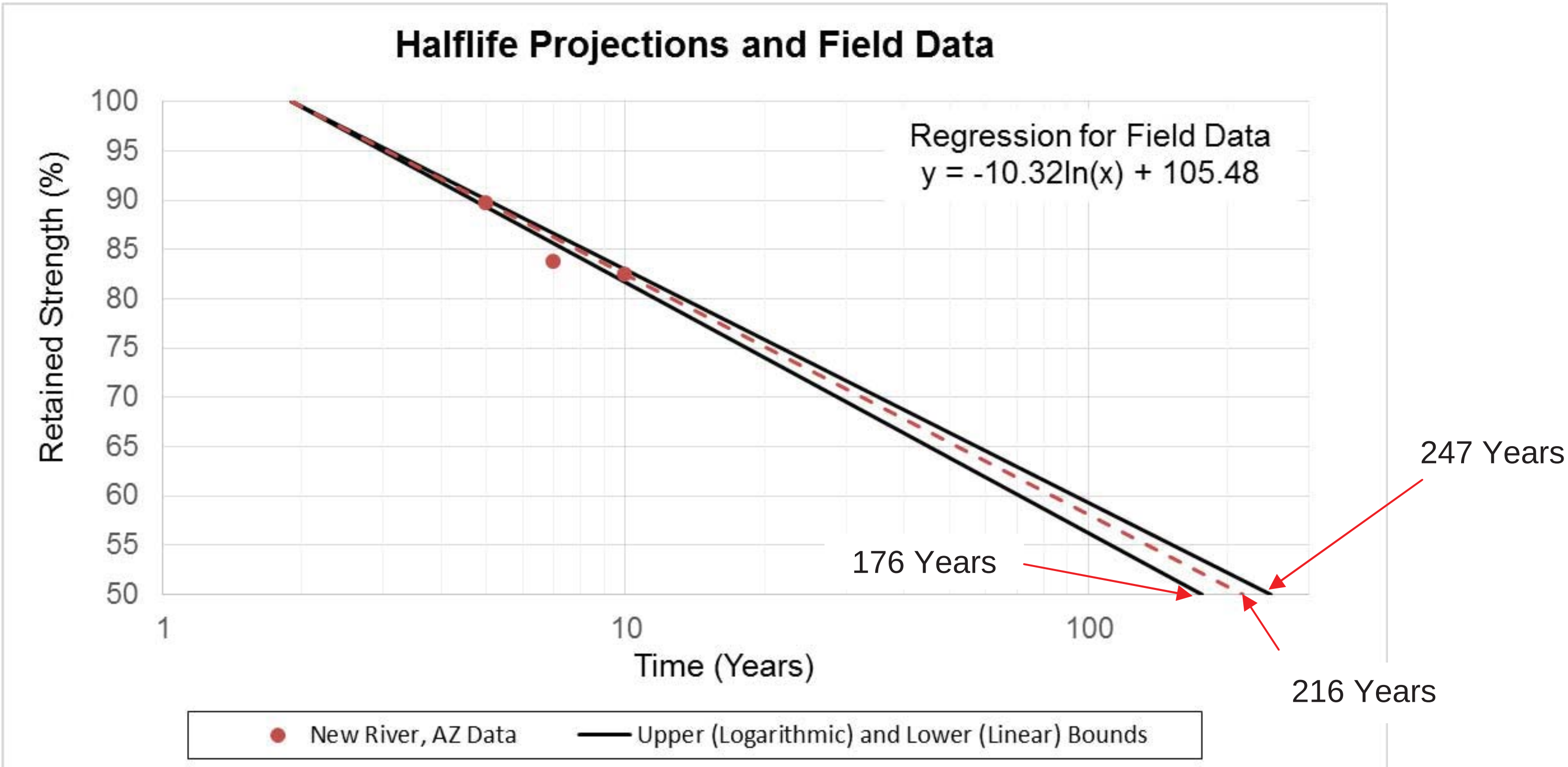
Figure 5

Kennesaw, GA | 23-April-2015



Note: Each month was projected down to the peak turf temperature given in Table 3 to get the half-life months. The inverse of half-life months is half-life loss per month. The sum of all the half-life losses for each month in a year is the yearly half-life loss, the inverse of which is the half-life.

Linear Extrapolations for Half-life Months Watershed Geosythetics – ClosureTurf® UV Assessment		
Geosyntec consultants		Figure 6
Kennesaw, GA	23-April-2015	



Note: Geosyntec calculated an upper bound half-life of 277 years and a lower bound half-life of 214 years using the same data and method. Difference between Geosyntec and Richgels calculations are attributed to rounding.

Halflife Projections (Richgels, 2015a, 2015b)
Upper and Lower Bound Estimates
Watershed Geosythetics – ClosureTurf® UV Assessment

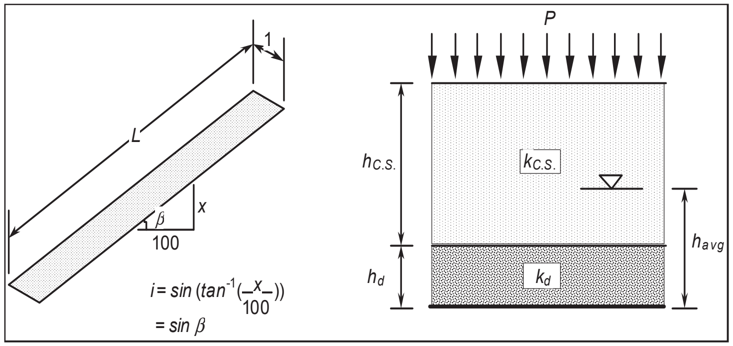
Geosyntec consultants

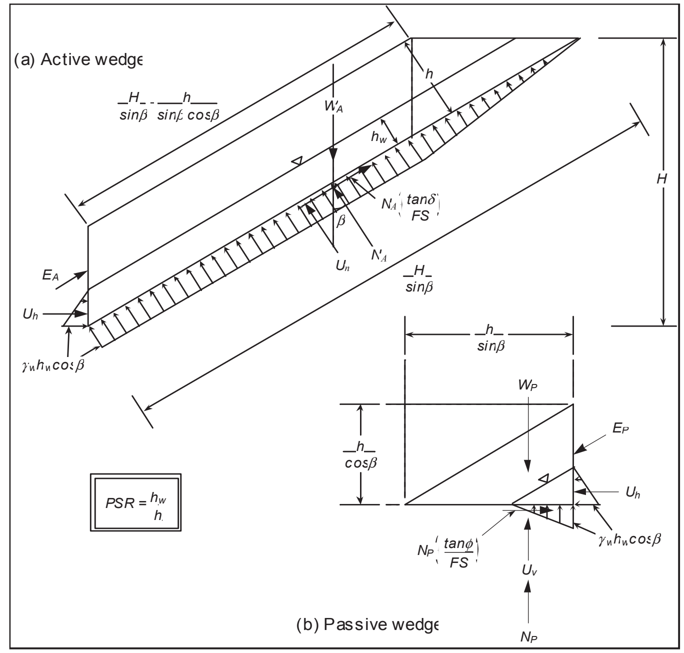
Figure **7**

Kennesaw, GA | 23-March-2015

Appendix B
Veneer Slope Stability Analysis

Calculation of DLC and PSR: Final Cover-Side Slope (Static Conditions)





L =	37.0	m	i =	0.4478		
β =	26.6	°	$L(\cos\beta)$ =	33.08	m	
			x =	16.57	m	
$h_{C.S.}$ =	150	mm	$h_{C.S.}$ =	0.2	m	
h_d or t_{GS} =	450	mm	h_d or t_{GS} =	0.45	m	
			$h_{C.S.} + h_d$ =	0.60	m	
$k_{C.S.}$ =	5.0E-03	cm/s	$k_{C.S.}$ =	5.0E-05	m/s	
k_d or k_{GS} =	1.0E+00	cm/s	k_d or k_{GS} =	1.0E-02	m/s	
P =	323.00	mm/hr	P (RC) =	32.3	mm/hr	
RC =	0.1		Actual runoff =	143.00	mm/hr	
			PERC =	180.00	mm/hr	
			$FLUX_{actual}$ =	5.955	m^3/hr	
			$FLUX_{allow}$ =	7.254	m^3/hr	**DLC = 1.2181**
			q =	1.7E-03	m^3/sec	
			h_{avg} =	0.37	m	
						PSR = 0.616

DLC =	**1.218**
PSR	**0.616**
FS	**0.719**

* Note: if only one soil layer above GM, treat it as the drainage layer.

Calculation of FS

Active Wedge:

W_A = 444.143 kN
U_n = 118.406 kN
U_h = 0.66945 kN
N_A = 278.427 kN

Passive Wedge:

W_P = 9.18061 kN
U_V = 1.33687 kN

$$FS = \frac{-b + \sqrt{b^2 - 4ac}}{2a}$$

where a = 178.0
b = -182.9
c = 39.5

FS= 0.719

thickness of cover soil = h =	0.60	m		
length of slope measured along the geomembrane = L =	37	m		
soil slope angle beneath the geomembrane = β =	26.6	°	= 0.46	(rad.)
vertical height of the slope measured from the toe = H =	16.6	m		
parallel submergence ratio = PSR =	0.62			
depth of the water surface measured from the geomembrane = h_w =	0.37	m		
dry unit weight of the protective cover = γ_{dry} =	20.4	kN/m^3		
saturated unit weight of protective cover = $\gamma_{sat'd}$ =	20.4	kN/m^3		
unit weight of water = γ_w =	9.81	kN/m^3		
friction angle of protective cover = ϕ =	33.0	°	= 0.58	(rad.)
interface friction angle between geotextile and geomembrane = δ =	26.0	°	= 0.45	(rad.)

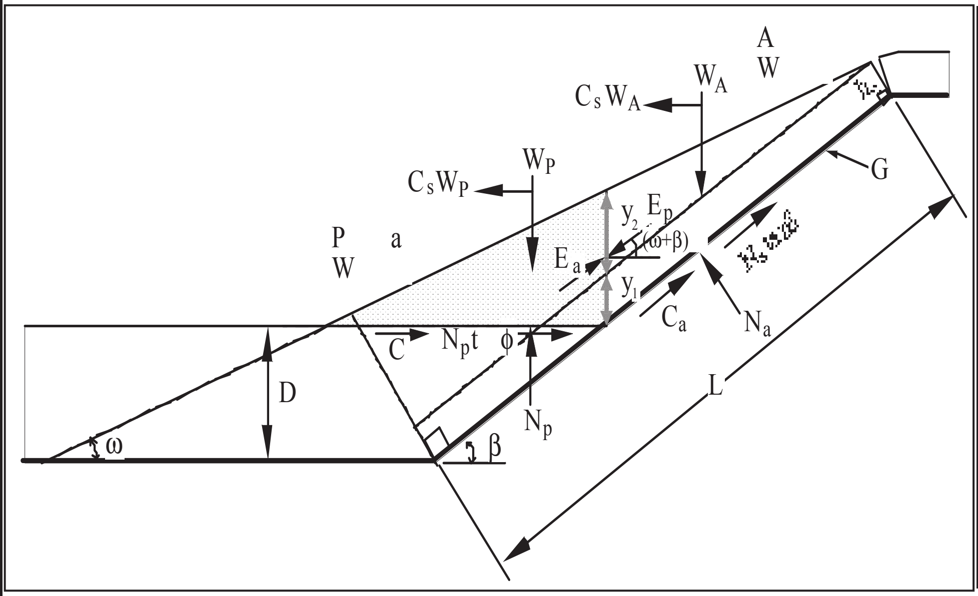
Note: numbers in boxes are input values

numbers in Italics are calculated values

Constructed by Te-Yang Soong

Final Cover Side Slope Veneer Stability Seismic

Uniform and/or Tapered Cover Soil with Consideration of Seismic Forces



Calculation of FS

Active Wedge:

Wa=	435.1	kN
Na=	389.0	kN
Ca=	0.0	kN

Passive Wedge:

Wp=	9.2	kN
C=	0.0	kN

F - b b^2 - 2 a

a=	473.5
b=	-309
c=	49.3

FS= 0.37

(Note: for uniform cover soil thickness the input value of $\omega = \beta$)

thickness of cover soil at top (crest) of the slope = hc =	0.60	m		
thickness of cover soil along the bottom of the site = D =	0.60	m		
soil slope angle beneath the geomembrane = β =	26.6	°	= 0.46	(rad.)
finished cover soil slope angle = ω =	26.6	°	= 0.46	(rad.)
length of slope measured along the geomembrane = L =	37.0	m		

y2=	0.00	(m)
y1=	0.67	(m)
$(\omega+\beta)/2$=	0.464	(rad.)
(=	26.6	°)

unit weight of the cover soil = γ =	20.4	kN/m^3		
friction angle of the cover soil = ϕ =	33.0	°	= 0.58	(rad.)
cohesion of the cover soil = c =	0.0	kN/m^2		
interface friction angle between cover soil and geomembrane = δ =	26.0	°	= 0.45	(rad.)
adhesion between cover soil and geomembrane = ca =	0.0	kN/m^2		

seismic coefficient = Cs = 0.80 g

Note: numbers in boxes are input values

numbers in Italics are calculated values

NOAA Atlas 14, Volume 4, Version 3
Location name: Hilo, Hawaii, USA*
Latitude: 19.7297°, Longitude: -155.09°
Elevation: 58.76 ft**
* source: ESRI Maps
** source: USGS

POINT PRECIPITATION FREQUENCY ESTIMATES

S. Perica, D. Martin, B. Lin, T. Parzybok, D. Riley, M. Yekta, L. Hiner, L.-C. Chen, D. Brewer, F. Yan, K. Maitaria, C. Trypaluk, G. M. Bonnin

NOAA, National Weather Service, Silver Spring, Maryland

PF_tabular | PF_graphical | Maps_&_aerials

PF tabular

PDS-based point precipitation frequency estimates with 90% confidence intervals (in inches/hour)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	6.30 (5.81-7.04)	7.68 (7.08-8.84)	9.54 (8.81-11.0)	10.9 (10.0-12.6)	12.7 (11.5-14.8)	14.0 (12.5-16.4)	15.2 (13.5-18.1)	16.5 (14.3-19.8)	18.0 (15.3-22.0)	19.2 (16.0-23.8)
10-min	4.67 (4.31-5.22)	5.69 (5.24-6.55)	7.07 (6.53-8.15)	8.10 (7.42-9.34)	9.39 (8.51-10.9)	10.4 (9.29-12.2)	11.3 (9.98-13.4)	12.2 (10.6-14.7)	13.4 (11.4-16.3)	14.3 (11.9-17.7)
15-min	3.91 (3.61-4.37)	4.76 (4.39-5.49)	5.92 (5.46-6.82)	6.78 (6.21-7.82)	7.86 (7.13-9.16)	8.67 (7.78-10.2)	9.45 (8.36-11.2)	10.2 (8.90-12.3)	11.2 (9.52-13.7)	11.9 (9.93-14.8)
30-min	2.75 (2.54-3.07)	3.35 (3.09-3.86)	4.17 (3.85-4.80)	4.77 (4.37-5.50)	5.53 (5.02-6.45)	6.10 (5.47-7.16)	6.65 (5.88-7.89)	7.20 (6.26-8.64)	7.88 (6.70-9.62)	8.40 (6.99-10.4)
60-min	1.81 (1.67-2.02)	2.21 (2.03-2.54)	2.74 (2.53-3.16)	3.14 (2.88-3.62)	3.64 (3.30-4.24)	4.01 (3.60-4.71)	4.38 (3.87-5.19)	4.74 (4.12-5.68)	5.18 (4.41-6.33)	5.53 (4.60-6.84)
2-hr	1.28 (1.16-1.43)	1.60 (1.48-1.84)	2.03 (1.86-2.33)	2.34 (2.15-2.71)	2.76 (2.50-3.21)	3.08 (2.76-3.62)	3.39 (3.00-4.02)	3.71 (3.23-4.46)	4.13 (3.51-5.05)	4.45 (3.70-5.52)
3-hr	0.998 (0.904-1.12)	1.28 (1.18-1.47)	1.62 (1.49-1.87)	1.88 (1.73-2.18)	2.23 (2.02-2.59)	2.49 (2.23-2.92)	2.75 (2.42-3.26)	3.01 (2.61-3.61)	3.36 (2.85-4.10)	3.62 (3.01-4.49)
6-hr	0.693 (0.624-0.781)	0.877 (0.809-1.01)	1.13 (1.03-1.30)	1.32 (1.20-1.52)	1.57 (1.42-1.83)	1.77 (1.58-2.08)	1.96 (1.73-2.33)	2.17 (1.88-2.60)	2.44 (2.07-2.98)	2.65 (2.20-3.28)
12-hr	0.466 (0.420-0.527)	0.594 (0.548-0.685)	0.767 (0.705-0.885)	0.901 (0.825-1.04)	1.08 (0.981-1.27)	1.23 (1.10-1.45)	1.38 (1.21-1.64)	1.53 (1.33-1.84)	1.75 (1.47-2.13)	1.91 (1.58-2.37)
24-hr	0.302 (0.272-0.338)	0.386 (0.346-0.430)	0.502 (0.448-0.561)	0.594 (0.529-0.665)	0.721 (0.637-0.811)	0.823 (0.721-0.930)	0.928 (0.805-1.05)	1.04 (0.892-1.19)	1.19 (1.01-1.38)	1.31 (1.09-1.53)
2-day	0.201 (0.183-0.221)	0.256 (0.232-0.282)	0.331 (0.300-0.366)	0.390 (0.352-0.432)	0.471 (0.423-0.524)	0.534 (0.476-0.598)	0.600 (0.530-0.674)	0.668 (0.584-0.755)	0.761 (0.655-0.869)	0.834 (0.708-0.960)
3-day	0.148 (0.135-0.164)	0.189 (0.172-0.209)	0.246 (0.223-0.272)	0.290 (0.262-0.321)	0.350 (0.314-0.389)	0.397 (0.354-0.444)	0.445 (0.393-0.500)	0.495 (0.433-0.560)	0.563 (0.485-0.642)	0.616 (0.523-0.709)
4-day	0.122 (0.111-0.135)	0.156 (0.142-0.172)	0.203 (0.184-0.225)	0.240 (0.217-0.266)	0.289 (0.260-0.322)	0.328 (0.292-0.367)	0.367 (0.325-0.413)	0.408 (0.357-0.462)	0.464 (0.400-0.529)	0.507 (0.431-0.583)
7-day	0.087 (0.079-0.097)	0.111 (0.101-0.123)	0.144 (0.130-0.159)	0.169 (0.152-0.187)	0.202 (0.180-0.225)	0.227 (0.202-0.255)	0.253 (0.223-0.285)	0.279 (0.243-0.317)	0.315 (0.270-0.360)	0.342 (0.289-0.394)
10-day	0.071 (0.064-0.078)	0.090 (0.081-0.099)	0.115 (0.104-0.127)	0.134 (0.121-0.149)	0.160 (0.143-0.178)	0.179 (0.159-0.200)	0.199 (0.175-0.223)	0.219 (0.190-0.247)	0.245 (0.210-0.280)	0.265 (0.224-0.305)
20-day	0.049 (0.044-0.054)	0.061 (0.055-0.067)	0.076 (0.069-0.084)	0.088 (0.079-0.098)	0.104 (0.093-0.116)	0.116 (0.103-0.129)	0.127 (0.112-0.143)	0.139 (0.122-0.158)	0.155 (0.133-0.177)	0.167 (0.142-0.193)
30-day	0.039 (0.036-0.043)	0.048 (0.044-0.053)	0.060 (0.054-0.067)	0.069 (0.062-0.077)	0.082 (0.073-0.091)	0.091 (0.081-0.102)	0.101 (0.089-0.113)	0.111 (0.096-0.125)	0.124 (0.106-0.141)	0.134 (0.113-0.154)
45-day	0.032 (0.029-0.035)	0.039 (0.035-0.043)	0.048 (0.044-0.054)	0.056 (0.050-0.062)	0.065 (0.058-0.073)	0.073 (0.065-0.082)	0.081 (0.071-0.091)	0.089 (0.077-0.101)	0.100 (0.085-0.115)	0.109 (0.092-0.126)
60-day	0.029 (0.026-0.031)	0.034 (0.031-0.038)	0.042 (0.038-0.047)	0.048 (0.044-0.054)	0.057 (0.051-0.063)	0.063 (0.056-0.071)	0.069 (0.061-0.078)	0.076 (0.066-0.086)	0.084 (0.072-0.097)	0.091 (0.077-0.105)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

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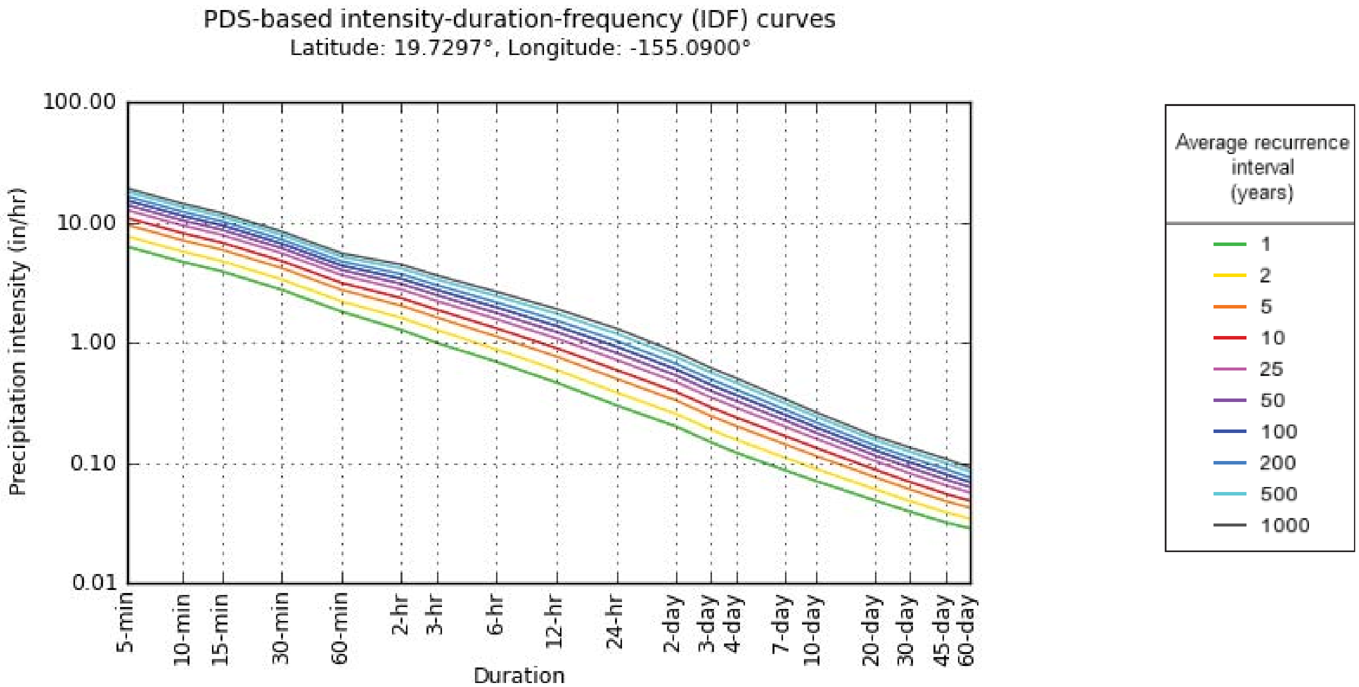
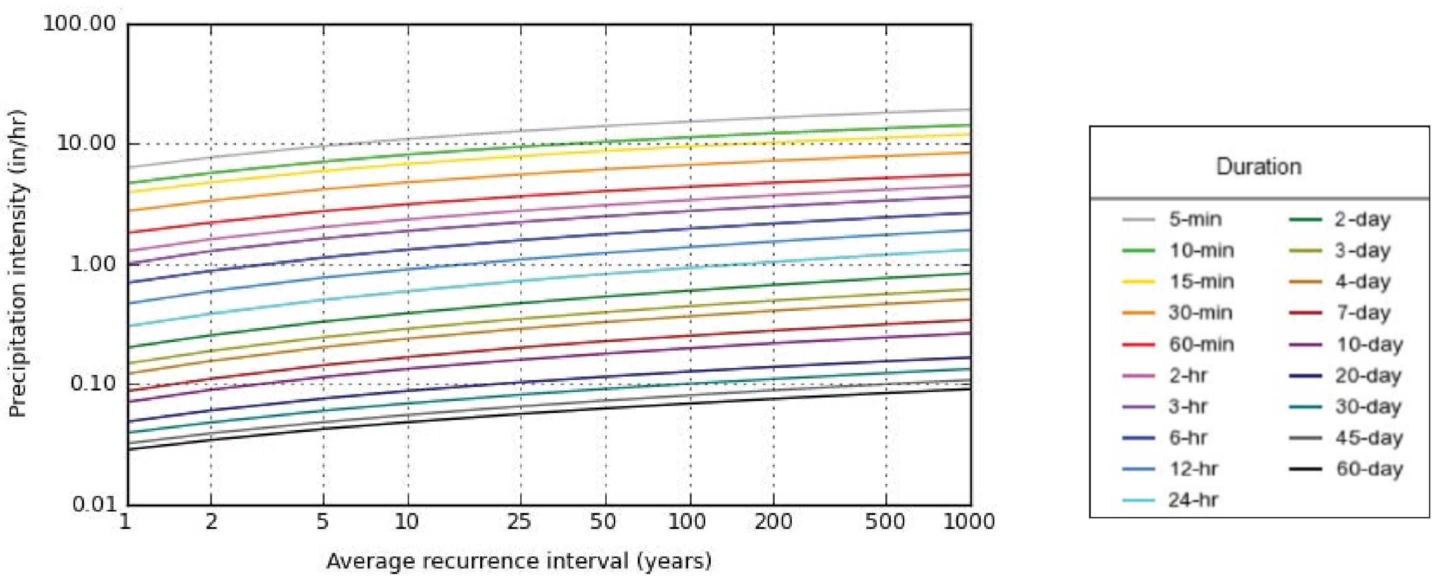
PF graphical





NOAA Atlas 14, Volume 4, Version 3 Created (GMT): Mon Feb 27 16:56:48 2017

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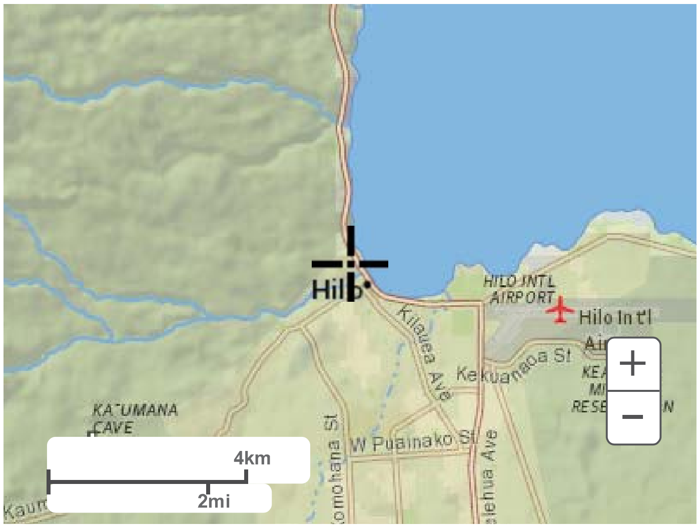
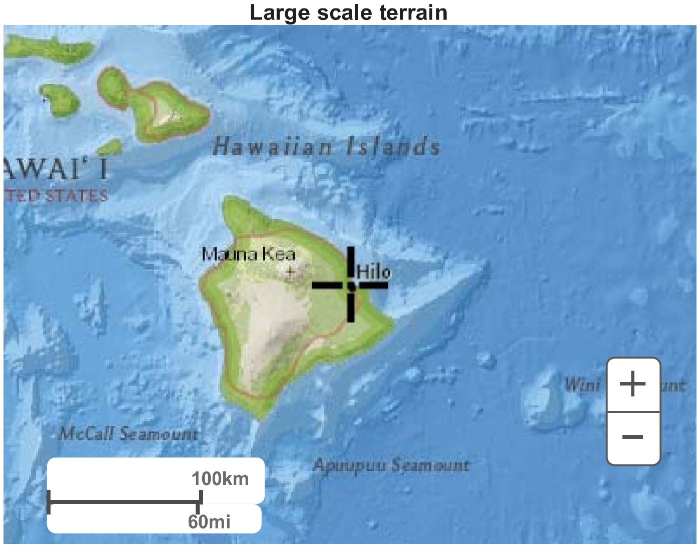
Maps & aerials

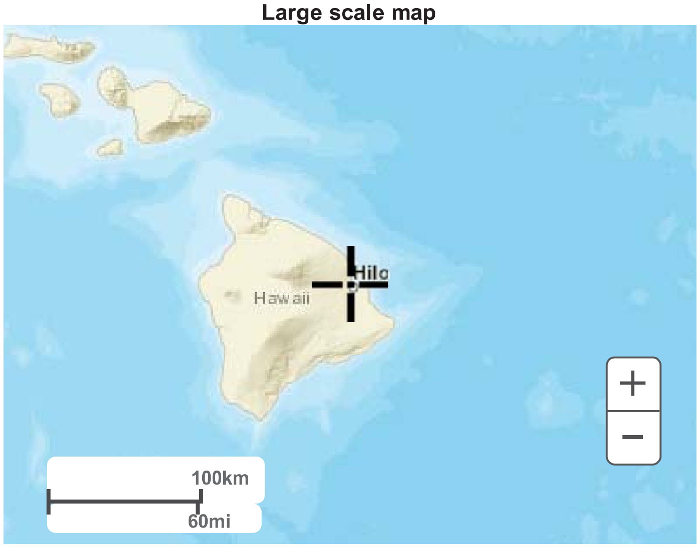
Small scale terrain



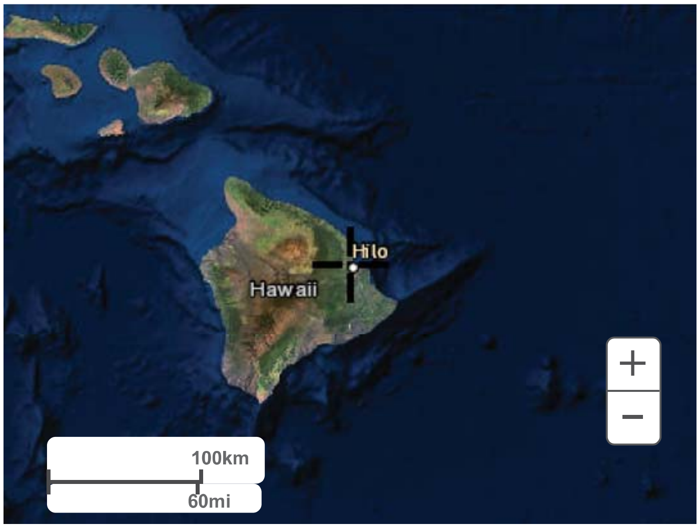
Large scale terrain



Large scale map



Large scale aerial



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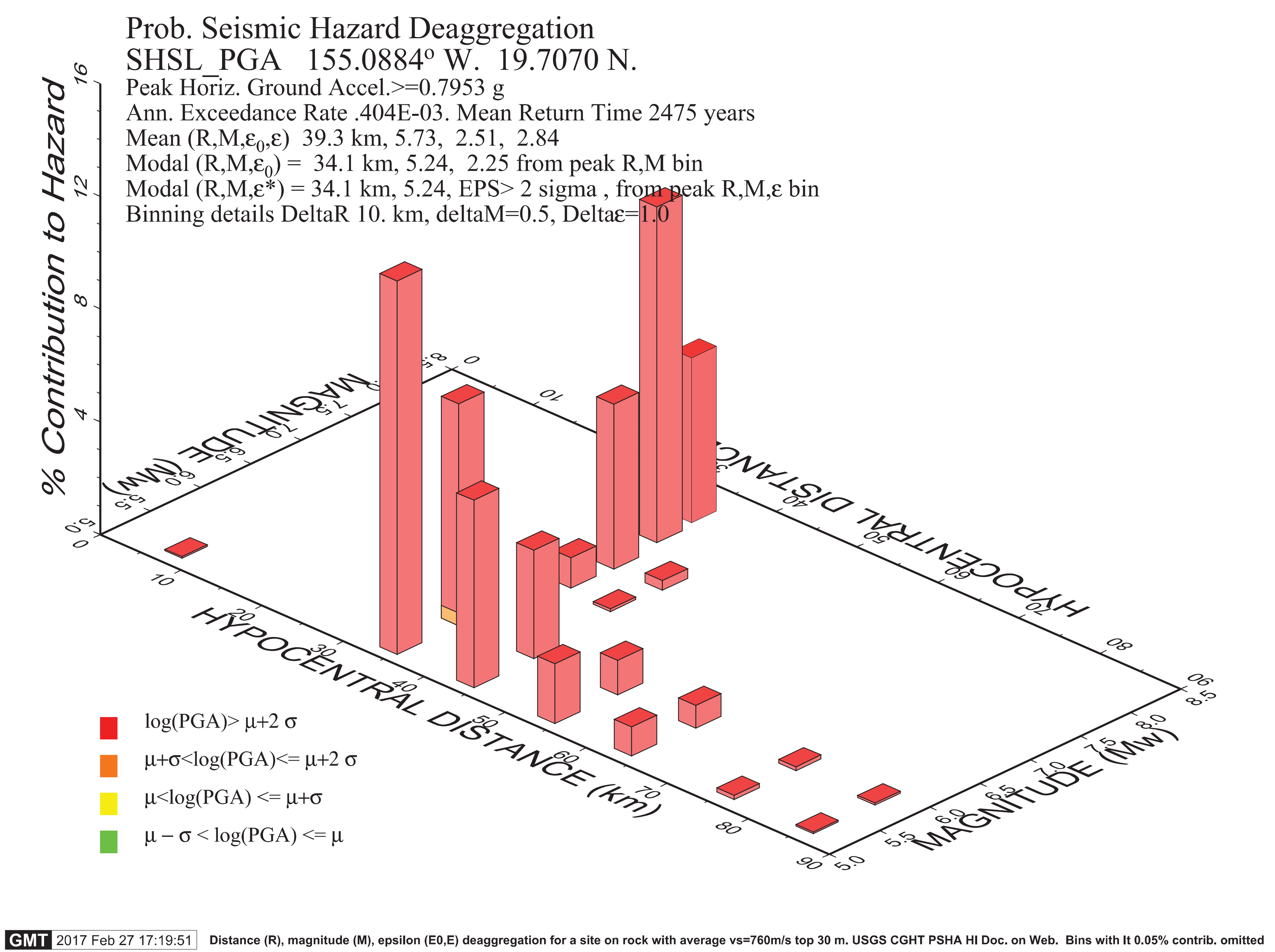
US Department of Commerce
National Oceanic and Atmospheric Administration
National Weather Service
National Water Center
1325 East West Highway
Silver Spring, MD 20910
Questions?: HDSC.Questions@noaa.gov

Disclaimer



Prob. Seismic Hazard Deaggregation
SHSL_PGA 155.0884° W. 19.7070 N.
Peak Horiz. Ground Accel.>=0.7953 g
Ann. Exceedance Rate .404E-03. Mean Return Time 2475 years
Mean (R,M,ε0,ε) 39.3 km, 5.73, 2.51, 2.84
Modal (R,M,ε0) = 34.1 km, 5.24, 2.25 from peak R,M bin
Modal (R,M,ε*) = 34.1 km, 5.24, EPS> 2 sigma , from peak R,M,ε bin
Binning details DeltaR 10. km, deltaM=0.5, Deltaε=1.0
% Contribution to Hazard
HYPOCENTRAL DISTANCE (km)
MAGNITUDE (Mw)
log(PGA)> μ+2 σ
μ+σ<log(PGA)<= μ+2 σ
μ<log(PGA) <= μ+σ
μ – σ < log(PGA) <= μ
GMT 2017 Feb 27 17:19:51
Distance (R), magnitude (M), epsilon (E0,E) deaggregation for a site on rock with average vs=760m/s top 30 m. USGS CGHT PSHA HI Doc. on Web. Bins with lt 0.05% contrib. omitted

Appendix C
Closure Cost Estimate for Side Slope

Comparison of Applicable Landfill Closure Costs for the Slopes

ClosureTurf™/Geomembrane Final Cover

Total Slope Area		27.4	ac
Synthetic Turf System: LLDPE (Super GripNet), relief valves, Turf, Sand in-fill and ArmorFill (35.73/sy material and installation)	$	172,933	/ac
6-inch thick- 3/8" minus cinder ($3.50/sy delivered + $2.35/sy installed)	$	28,338	/ac
Stormwater Control	$	2,500	/ac
Passive Gas Vents	$	4,500	/ac
Subtotal	**$**	**208,271**	**/ac**
Capital Contingency		**20%**	
Total	**$**	**249,925**	/ac
Cost of Closure Turf Cover	**$**	**6,857,946**	

Evapotranspiration Cover (ET Cover)

Total Slope Area					27.4	ac
36-inch ET monolithic layer ($34/sy delivered + $11.15/sy installed)				$	218,524	/ac
Hydroseeding				$	2,500	/ac
Maintenance Period (fertilize 2 times)				$	300	/ac
Stormwater System				$	1,750	/ac
Terrace Installation						
16 oz/sy Geotextile	0.30 /sf	$	13,068 /ac			
40 mil Geomembrane	0.73 /sf	$	31,799 /ac			
16 oz/sy Geotextile	0.30 /sf	$	13,068 /ac			
18-inch Cover Soil	1.83 /sf	$	79,503 /ac			
Total Cost		**$**	**137,438** /ac			
Total length of the Terraces			10,350 LF			
Total Area of the Terraces			4.3 ac			
Terrace Installation cost		$	587,804			
Subtotal Excluding Terraces				**$**	**223,074**	/ac
Area Excluding Terraces			23.2 ac			
Total Cost of ET Cover Excluding Terraces				**$**	**5,167,091**	
Terrace Installation Cost				**$**	**587,804**	
Capital Contingency					**20%**	
Cost of ET Cover				**$**	**6,905,874**	

Prescribed Cover System

Total Slope Area		27.4	ac
12-inch thick- bentonite amended pepeekeo dirt ($7.00/sy delivered + $4.65/sy installed+ $17.56/sy bentonite amend)	$	141,376	/ac
6-inch thick- bentonite amended pepeekeo dirt ($3.50/sy delivered + $2.35/sy installed+ $13.56/sy bentonite amend)	$	93,944	/ac
6-inch thick- 3/8" minus cinder ($3.50/sy delivered + $2.35/sy installed)	$	28,314	/ac
Stormwater Controls	$	2,500	/ac
Passive Gas Vents	$	4,500	/ac
Subtotal	**$**	**270,635**	/ac
Capital Contingency		**20%**	
Total	**$**	**324,762**	/ac
Cost of Prescribed Cover	**$**	**8,898,472**	

Notes:

1. Cost associated with grading the landfill per HDR revised final cover design is common for ET Cove and prescribed cover. The Closure Turf ™/Geomembrane require regrading to eliminate terraces so that storm water can flow directly to perimeter drainage network.
2. Cost estimates are for evaluation and comparison purposes. The costs also do not account for quality testing, design and permitting, on-site CQA representation, contract administration and additional efforts associated with regulatory approvals (i.e. establishment period reports).
3. It is assumed that the intermediate cover soil in-place is not suitable for liner subgrade due to large particle size. Based on our observations, select bedding material will be required as a foundation layer to meet geomembrane specifications.
4. A bulking factor of 1.3 is used where appropriate.

Appendix D
Closure Cost Estimate for Top Deck

Comparison of Applicable Landfill Closure Costs for the Top Deck

ClosureTurf^{TM}/Geomembrane Final Cover

Total Top Deck Area		13.86	ac
Synthetic Turf System: LLDPE (microspike), relief valves, Turf and Sand in-fill (26.19/sy material and installation)	$	126,760	/ac
16 oz/sy Geotextile ($2.70/sy installed)	$	14,636	/ac
Stormwater Control	$	2,500	/ac
Passive Gas Vents	$	4,500	/ac
Subtotal	**$**	**148,396**	**/ac**
Capital Contingency		**20%**	
Total	**$**	**178,075**	/ac
Cost of Closure Turf Cover	**$**	**2,468,118**	

Geosynthetic/Soil Composite Cover

Total Top Deck Area		13.86	ac
16 oz/sy Geotextile ($2.70/sy installed)	$	14,636	/ac
Install 40 mil LLDPE geomembrane ($0.73/sf)	$	35,615	/ac
16 oz/sy Geotextile ($2.70/sy installed)	$	14,636	/ac
18-inch thick- 3/8" minum cinder ($10.05/sy delivered + $5.31/sy installed)	$	77,325	/ac
6-inch thick- pepeekeo topsoil ($3.50/sy delivered + $2.35/sy installed)	$	28,338	/ac
Hydroseeding	$	2,500	/ac
Passive Gas Vents	$	4,500	/ac
Total Unit Cost to Install Top Deck	**$**	**177,550**	**/ac**
Capital Contingency		**20%**	
Total	**$**	**213,060**	**/ac**
Cost of Geosynthetic/Soil Composite Cover Top Deck	\	**2,953,015**	

Prescribed Cover System

Total Top Deck Area		13.86	ac
12-inch thick- bentonite amended pepeekeo dirt ($7.00/sy delivered + $3.72/sy installed+ $17.56/sy bentonite amend)	$	136,875	/ac
6-inch thick- bentonite amended pepeekeo dirt ($3.50/sy delivered + $2.08/sy installed+ $13.56/sy bentonite amend)	$	92,638	/ac
6-inch thick- 3/8" minus cinder ($3.50/sy delivered + $2.08/sy installed)	$	27,007	/ac
Stormwater Controls	$	2,500	/ac
Passive Gas Vents	$	4,500	/ac
Subtotal	**$**	**263,520**	/ac
Capital Contingency		**20%**	
Total	**$**	**316,224**	/ac
Cost of Prescribed Cover	**$**	**4,382,865**	

Notes:

1. Grading the top deck for all the cover options are similar.
2. Cost estimates are for evaluation and comparison purposes. The costs also do not account for quality testing, design and permitting, on-site CQA representation, contract administration and additional efforts associated with regulatory approvals (i.e. establishment period reports).
3. It is assumed that the intermediate cover soil in-place is not suitable for geomembrane liner due to large particle size. Based on our observations, a geotextilelayer will be required as a foundation layer to meet geomembrane specifications.
4. A bulking factor of 1.3 is used where appropriate.

Appendix E
Site Work Cost Estimate: ClosureTurf^{TM}/Geomembrane Cover

Site Work Cost- ClosureTurf^{TM}/Geomembrane

Description	Unit	Unit Cost	Quantity	Total
Mobilization and Demobilization	LS	326,638	1	$ 326,638
Surveying (2 Person Crew)	per day	1610	100	$ 161,000
Stormwater Detention Basin	LS	200,000	1	$ 200,000
Site Grading (Side Slopes)	SY	4.02	89,830	$ 360,939
Site Grading (Top Deck and Terraces)	SY	3.70	87,894	$ 324,858
Grade the Perimeter Road	SY	5.84	7,113	$ 41,528
Perimeter Road and Channel	LF	80.5	5,335	$ 429,468
Final Cover Access Road	LF	41.65	1,060	$ 44,149
Site Work Cost				$1,888,579
Capital Contingency				20%
Total Site Work Cost				**$2,266,294**

Notes:

1. Cost associated with grading the landfill per HDR revised final cover design is common for ET Cover, Geosynthetic/Soil Composite and Prescribed Cover. The ClosureTurf^{TM} require regrading to eliminate terraces so that stormwater can flow directly to perimeter drainage network.

2. Construction time for ClosureTurf^{TM}/gemembrane is less compared to other alternatives. This reduces survey cost.

Appendix F
Site Work Cost Estimate: Prescribed, Geomembrane/Soil Composite and ET Covers

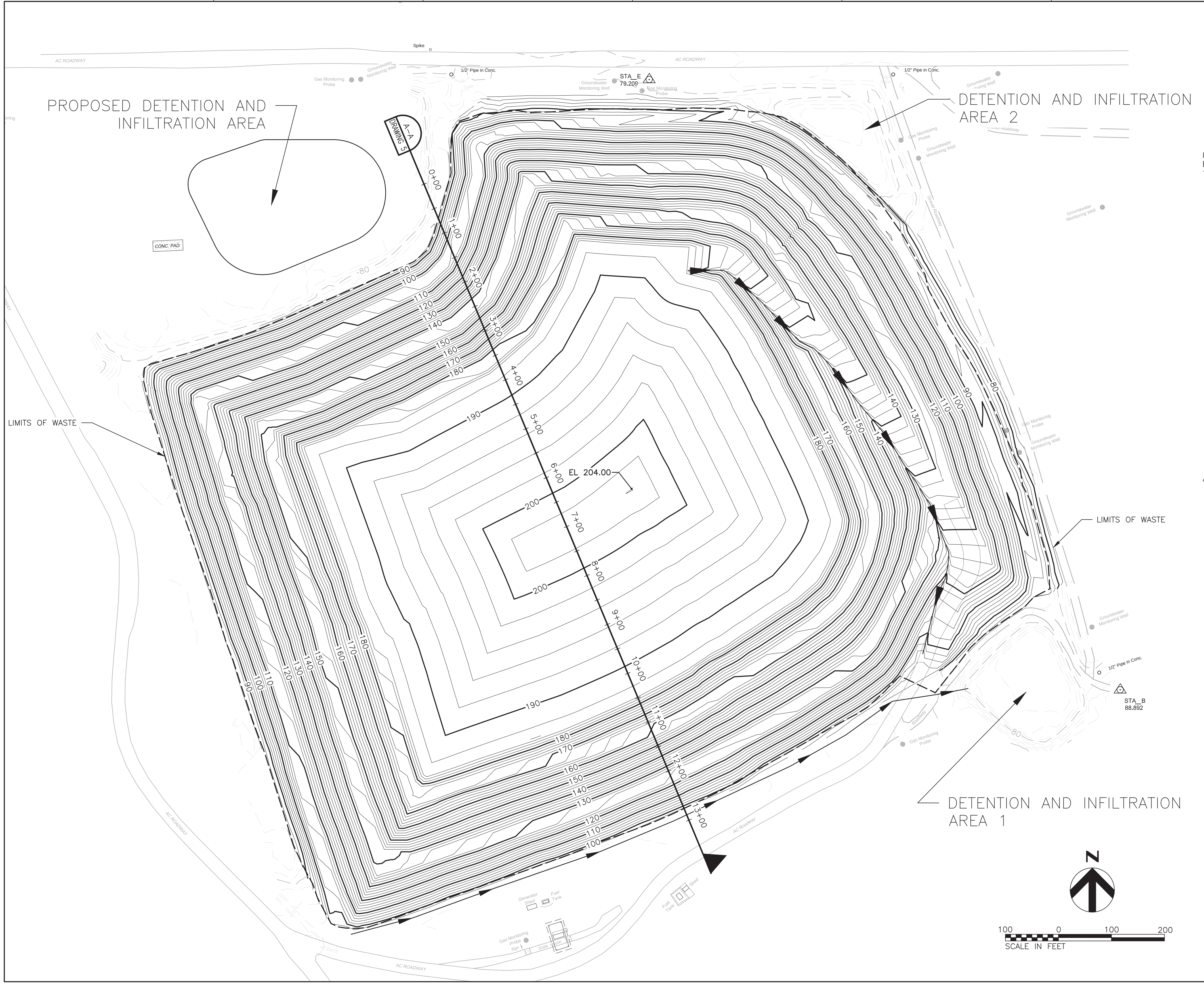
Site Work Cost- Prescribed, Geosynthetic/Soil Composite and ET Covers

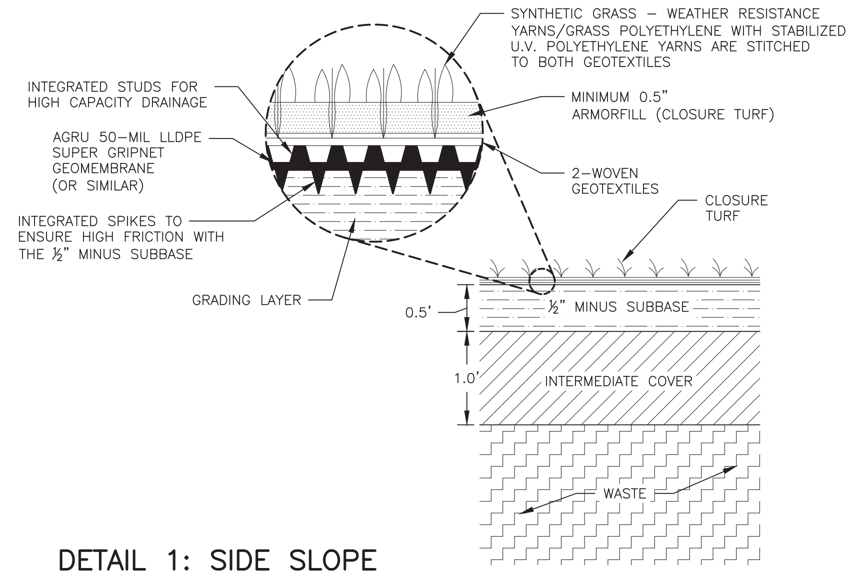
Description	Unit	Unit Cost	Quantity	Total
Mobilization and Demobilization	LS	330,553	1	$ 330,553
Surveying (2 Person Crew)	per day	1610	125	$ 201,250
Stormwater Detention Basin	LS	200,000	1	$ 200,000
Site Grading (Side Slopes)	SY	4.02	112,288	$ 451,173
Site Grading (Top Deck and Terraces)	SY	3.70	87,894	$ 324,858
Grade the Perimeter Road	SY	5.84	7,113	$ 41,528
Perimeter Road and Channel	LF	80.5	5,335	$ 429,468
Final Cover Access Road	LF	41.65	1,060	$ 44,149
Site Work Cost				$2,022,978
Capital Contingency				20%
Total Site Work Cost				**$2,427,573**

Notes:

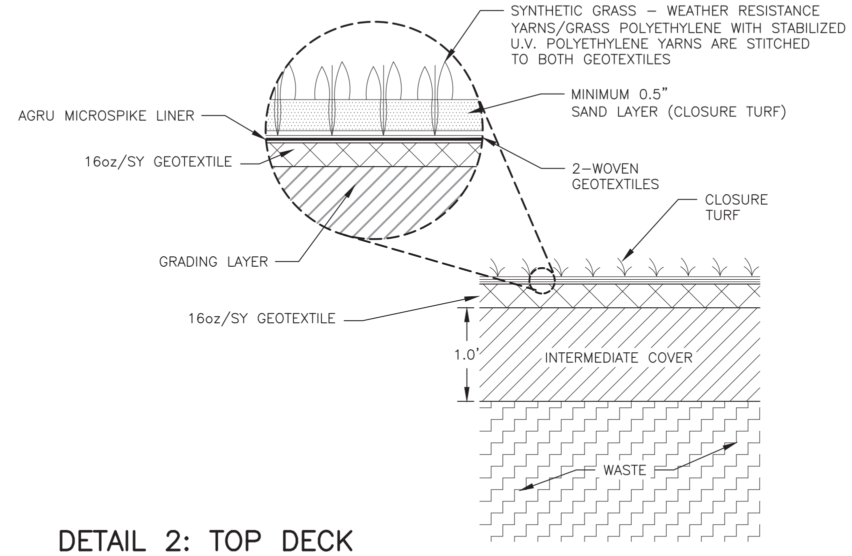
1. Cost associated with grading the landfill per HDR revised final cover design is common for ET Cover, Geosynthetic/Soil Composite and Prescribed Cover. The ClosureTurf™ require regrading to eliminate terraces so that stormwater can flow directly to perimeter drainage network.

Appendix G
Closure Alternatives Drawings





DETAIL 1: SIDE SLOPE
CLOSURE TURF™/GEOMEMBRANE COVER DETAIL
NOT TO SCALE



DETAIL 2: TOP DECK
CLOSURE TURF™/GEOMEMBRANE COVER DETAIL
NOT TO SCALE

LEGEND

- EXISTING CONTOURS (MINOR)
- 190 — EXISTING CONTOURS (MAJOR)
- FINAL COVER CONTOURS (MINOR)
- 190 — FINAL COVER CONTOURS (MAJOR)
- FLOW DIRECTION
- STA_B 88,892 CONTROL POINTS

NOTES:

1. WASTE LIMITS SHOWN ARE AS–BUILT LIMITS.
2. INTERMEDIATE COVER GRADES ARE MODIFIED TO MEET:
   - SIDE SLOPES ARE LESS THAN 2H:1V
   - TERRACES ARE MODIFIED TO SHEET FLOW AT 5% (MIN) SLOPE
   - TOP DECK IS 5% (MIN) SLOPE
   - ROAD AT 15.5% (MAX) SLOPE
3. THE PROPOSED GRADES WERE PREPARED WITH THE FOCUS OF MINIMIZING REGRADING/RELOCATION WHILE MEETING THE DESIGN INTENT.
4. FURTHER INSTRUCTIONS ARE NEEDED TO GRADE PERIMETER FLOW CHANNEL AND THE ROAD.
5. DRAINAGE FLOW PATTERN IS CONCEPTUAL AND TO BE FINALIZED PER COUNTY INSTRUCTIONS.

ISSUE	DATE	DESCRIPTION
B	2/16/17	DRAFT SUBMITTAL FOR REVIEW
A	11/4/16	ISSUED FOR CLIENT REVIEW

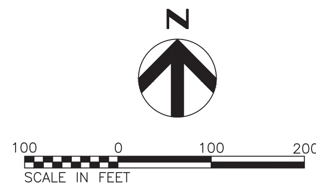
PROJECT MANAGER	A. KREITZER, P.E.
DESIGNED BY	K. PERERA
DRAWN BY	J. RAYMOND
CHECKED BY	M. ROBERTS
CHECKED BY	T. STEINBERGER, P.E.
PROJECT NUMBER	10040916

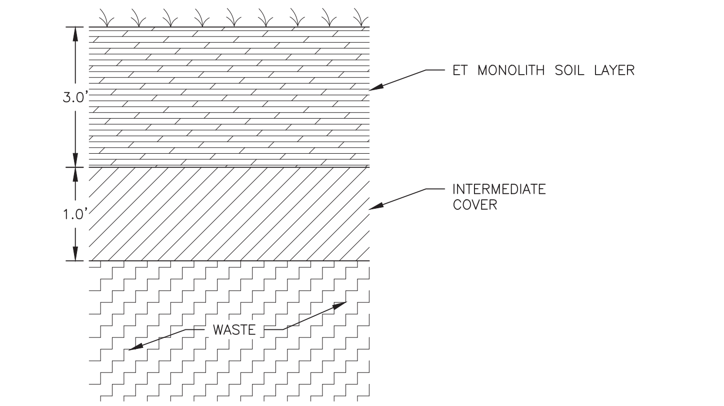
SOUTH HILO SANITARY LANDFILL
HILO, HAWAII
FINAL COVER SYSTEM OPTIONS EVALUATION

CLOSURE TURF™/GEOMEMBRANE COVER

0 1" 2"

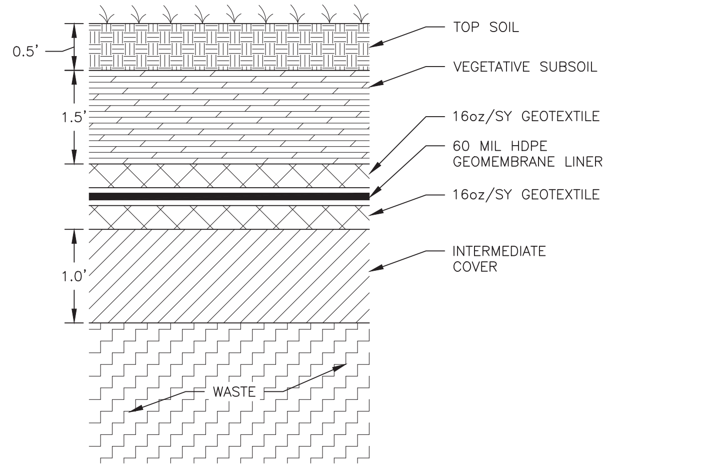
FILENAME Drawing 1.dwg
SCALE 1" = 100'
SHEET **Drawing 1**





DETAIL 1: SIDE SLOPE – EVAPOTRANSPIRATION COVER

NOT TO SCALE



DETAIL 2: TERRACE AND TOP DECK GEOSYNTHETIC/SOIL COMPOSITE COVER

NOT TO SCALE

LEGEND

- EXISTING CONTOURS (MINOR)
- 190 — EXISTING CONTOURS (MAJOR)
- FINAL COVER CONTOURS (MINOR)
- —190— FINAL COVER CONTOURS (MAJOR)
- LIMITS OF WASTE (SEE NOTE 1)
- FLOW DIRECTION
- DOWNCOMER PIPE
- STA_B 88,892 CONTROL POINTS

NOTES:

1. WASTE LIMITS SHOWN ARE AS-BUILT LIMITS.
2. INTERMEDIATE COVER GRADES ARE MODIFIED TO MEET:
   - SIDE SLOPES ARE LESS THAN 2H:1V
   - TERRACE FLOWS AT 1.5% (MIN) TO A LOW POINT
   - TOP DECK IS 5% (MIN) SLOPE
   - ROAD AT 15.5% (MAX) SLOPE
3. THE PROPOSED GRADES WERE PREPARED WITH THE FOCUS OF MINIMIZING REGRADING/RELOCATION WHILE MEETING THE DESIGN INTENT.
4. FURTHER INSTRUCTIONS ARE NEEDED TO GRADE PERIMETER FLOW CHANNEL AND THE ROAD.
5. DRAINAGE FLOW PATTERN IS CONCEPTUAL AND TO BE FINALIZED PER COUNTY INSTRUCTIONS.
6. THE TOP DECK CAN BE EITHER GEOSYNTHETIC/SOIL COMPOSITE COVER, EGC OR SYNTHETIC TURF COVER.

HDR

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CHECKED BY	T. STEINBERGER, P.E.
PROJECT NUMBER	10040916

SOUTH HILO SANITARY LANDFILL
HILO, HAWAII
FINAL COVER SYSTEM OPTIONS EVALUATION

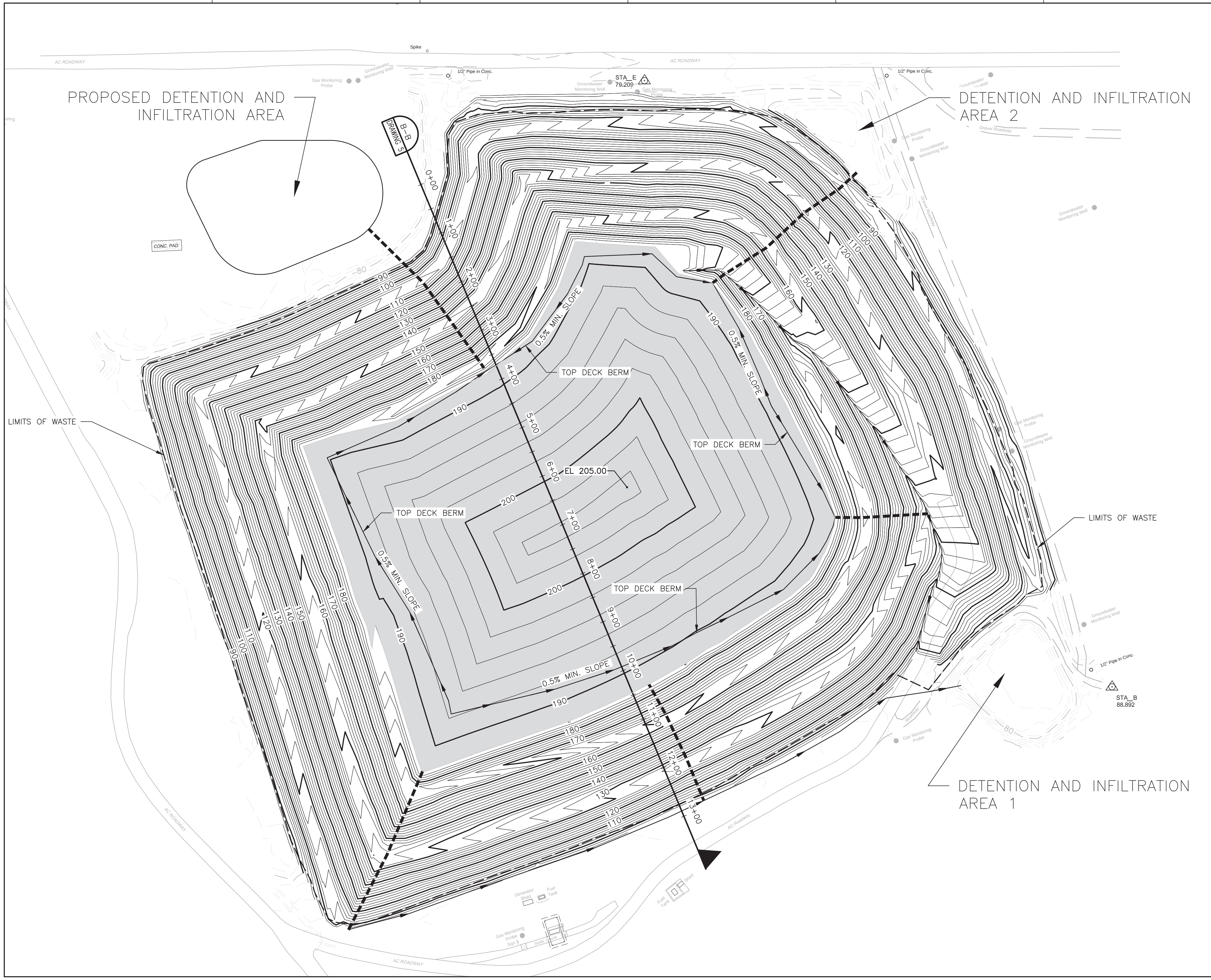
EVAPOTRANSPIRATION COVER

0 1" 2"

FILENAME Drawing 2.dwg

SCALE 1" = 100'

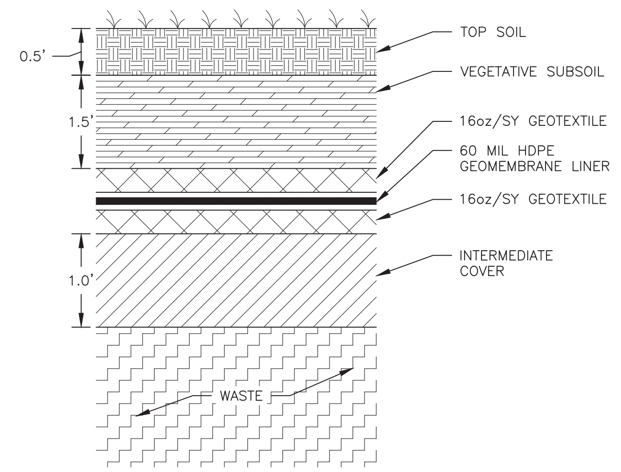
SHEET **Drawing 2**



100 0 100 200
SCALE IN FEET

LEGEND

- EXISTING CONTOURS (MINOR)
- 190 EXISTING CONTOURS (MAJOR)
- FINAL COVER CONTOURS (MINOR)
- 190 FINAL COVER CONTOURS (MAJOR)
- LIMITS OF WASTE (SEE NOTE 1)
- FLOW DIRECTION
- DOWNCOMER PIPE
- STA_B 88.892 CONTROL POINTS



TOP DECK GEOSYNTHETIC/SOIL COMPOSITE COVER

NOT TO SCALE

NOTES:

1. WASTE LIMITS SHOWN ARE AS-BUILT LIMITS.
2. INTERMEDIATE COVER GRADES ARE MODIFIED TO MEET:
   - SIDE SLOPES ARE LESS THAN 2H:1V
   - TERRACE FLOWS AT 1.5% (MIN) TO A LOW POINT
   - TOP DECK IS 5% (MIN) SLOPE
   - ROAD AT 15.5% (MAX) SLOPE
3. THE PROPOSED GRADES WERE PREPARED WITH THE FOCUS OF MINIMIZING REGRADING/RELOCATION WHILE MEETING THE DESIGN INTENT.
4. FURTHER INSTRUCTIONS ARE NEEDED TO GRADE PERIMETER FLOW CHANNEL AND THE ROAD.
5. DRAINAGE FLOW PATTERN IS CONCEPTUAL AND TO BE FINALIZED PER COUNTY INSTRUCTIONS.

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PROJECT NUMBER	10040916

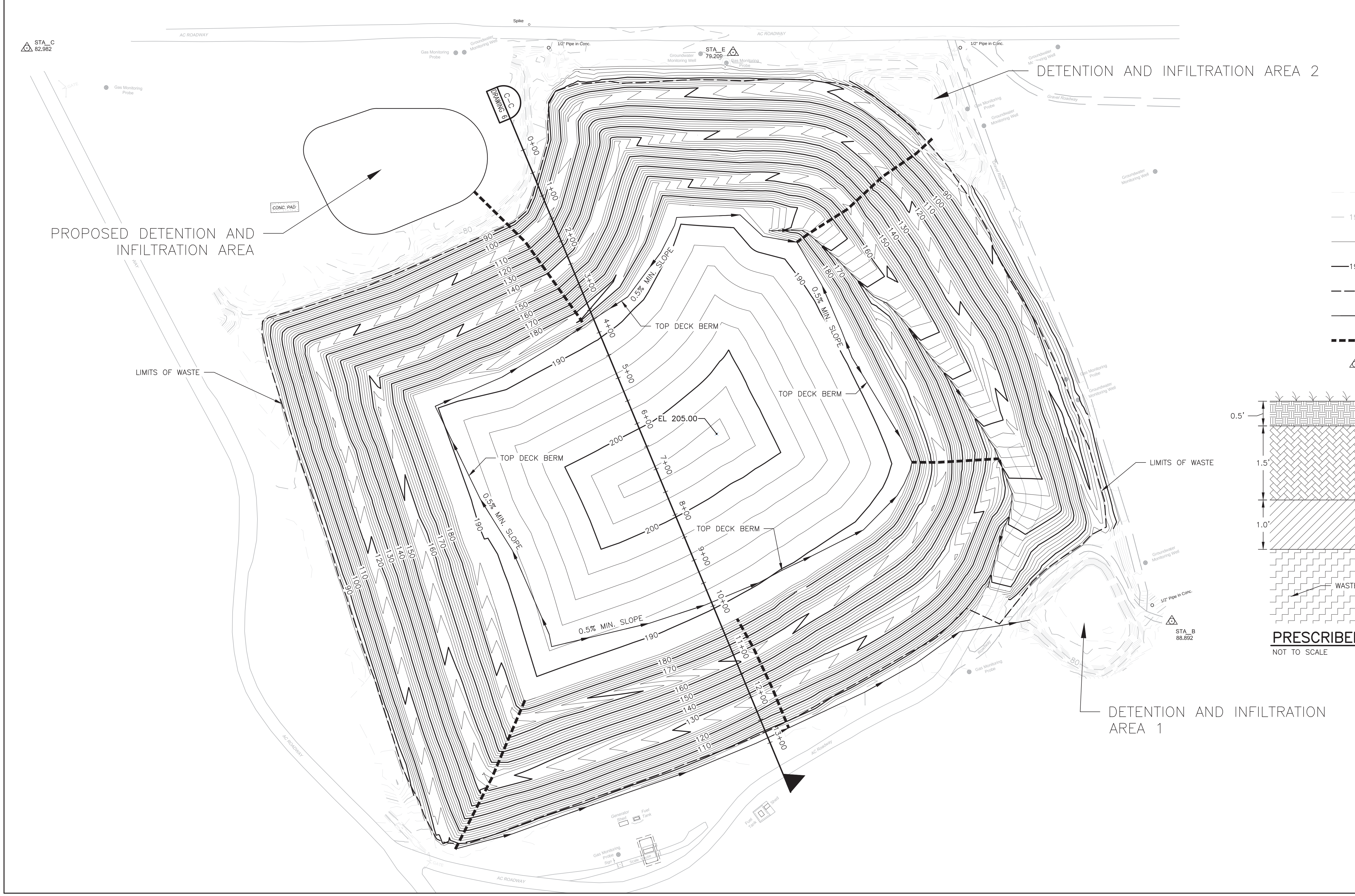
SOUTH HILO SANITARY LANDFILL
HILO, HAWAII
FINAL COVER SYSTEM OPTIONS EVALUATION

GEOSYNTHETIC/SOIL COMPOSITE COVER

0 1" 2"

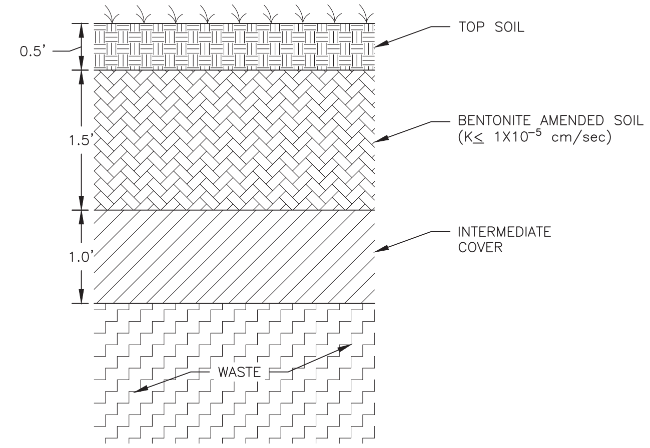
FILENAME Drawing 3.dwg
SCALE 1" = 100'

SHEET **Drawing 3**



LEGEND

- EXISTING CONTOURS (MINOR)
- 190 EXISTING CONTOURS (MAJOR)
- FINAL COVER CONTOURS (MINOR)
- 190 FINAL COVER CONTOURS (MAJOR)
- LIMITS OF WASTE (SEE NOTE 1)
- FLOW DIRECTION
- DOWNCOMER PIPE
- STA_B 88.892 CONTROL POINTS



PRESCRIBED COVER DETAIL

NOT TO SCALE

NOTES:

1. WASTE LIMITS SHOWN ARE AS-BUILT LIMITS.
2. INTERMEDIATE COVER GRADES ARE MODIFIED TO MEET:
   - SIDE SLOPES ARE LESS THAN 2H:1V
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PROJECT NUMBER	10040916

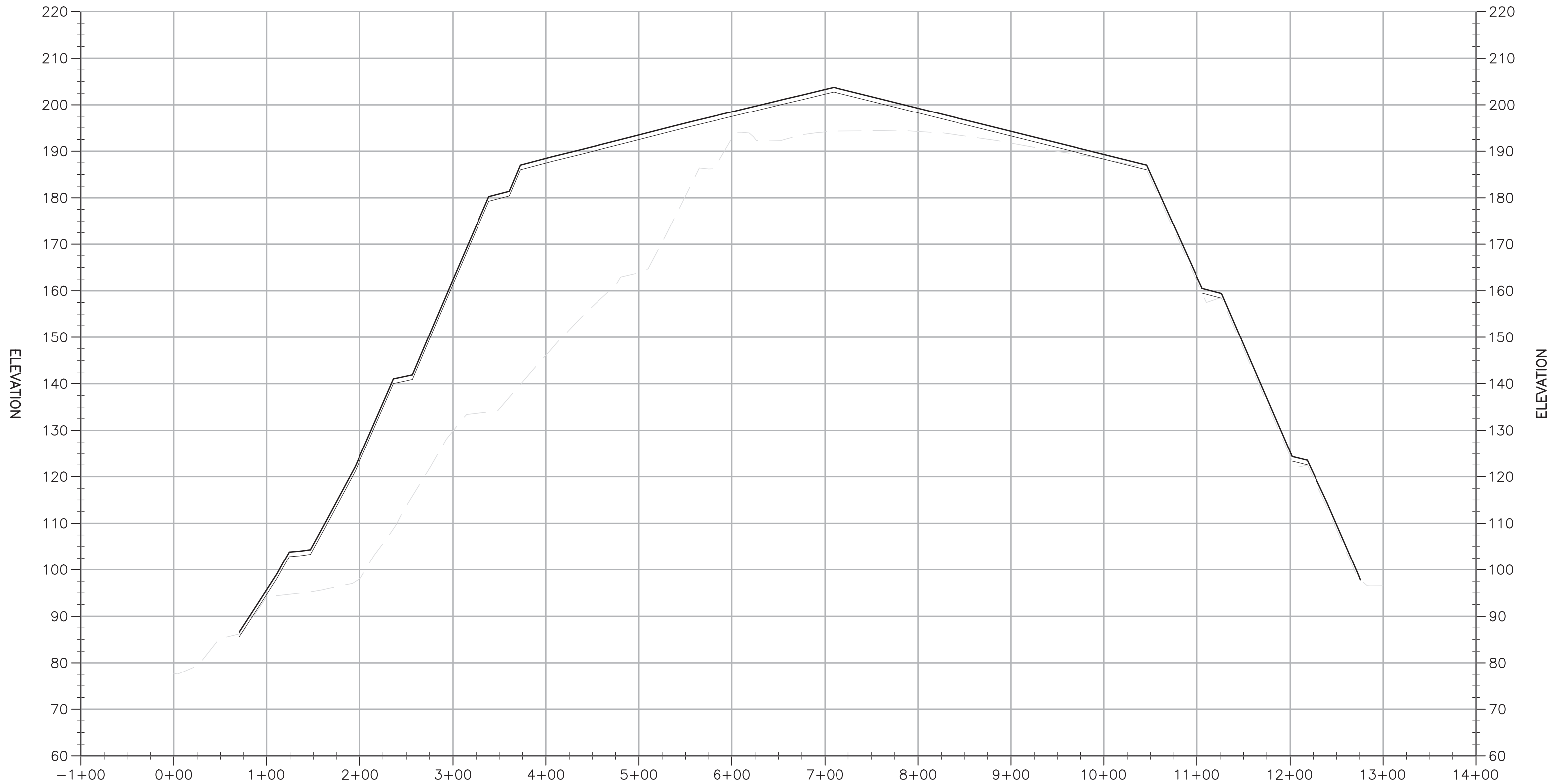
SOUTH HILO SANITARY LANDFILL
HILO, HAWAII
FINAL COVER SYSTEM OPTIONS EVALUATION

PRESCRIBED COVER

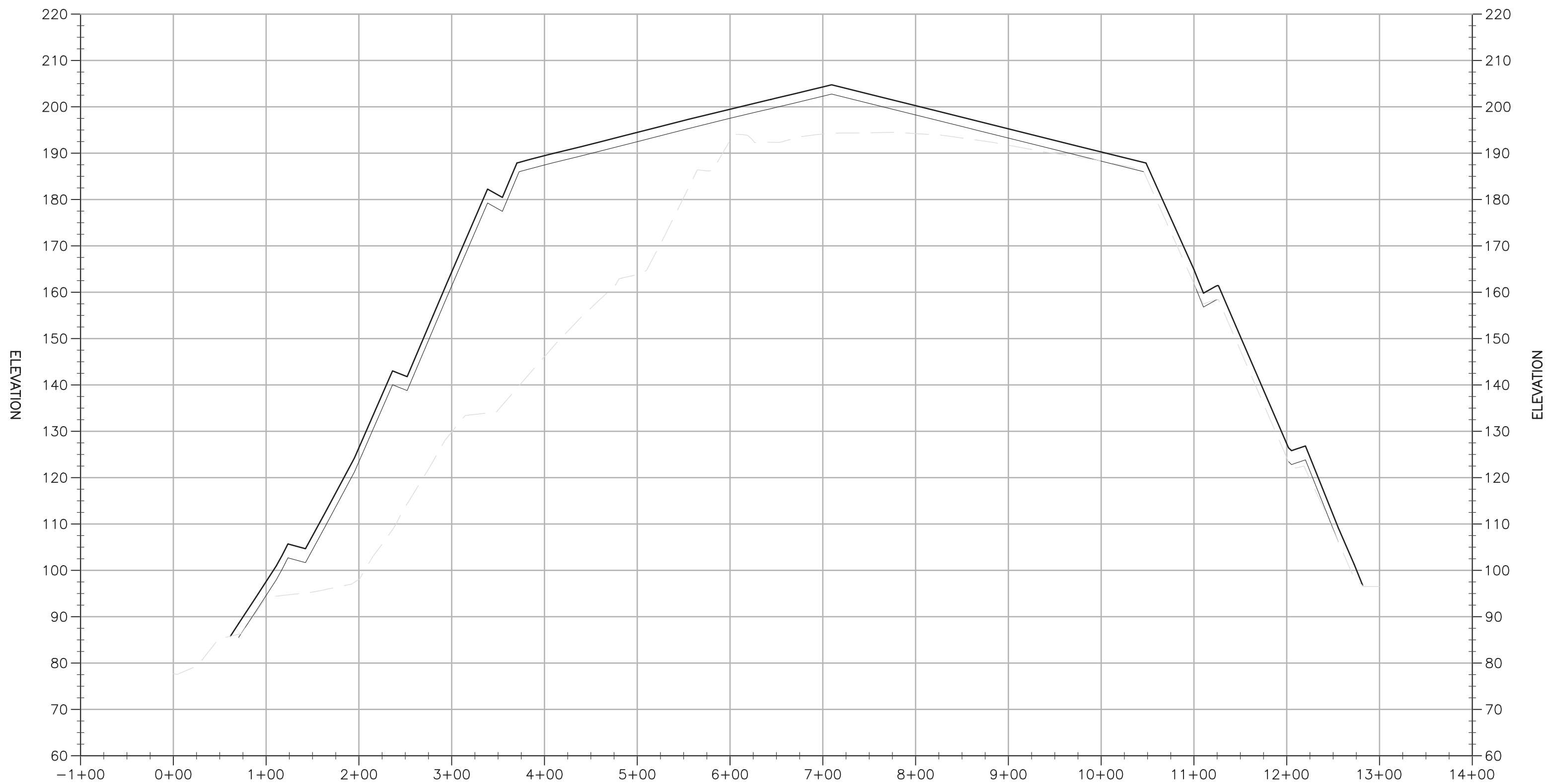
0 1" 2"

FILENAME Drawing 4.dwg
SCALE 1" = 100'

SHEET
Drawing 4



CLOSURE TURF™ COVER: SECTION A–A



EVAPOTRANSPIRATION COVER COMBINED WITH GEOSYNTHETIC/SOIL COMPOSITE COVER: SECTION B–B

LEGEND

EXISTING GRADE

PROPOSED INTERMEDIATE COVER

PROPOSED FINAL COVER

100 0 100 200
HORIZONTAL SCALE: 1" = 100'

20 0 20 40
VERTICAL SCALE: 1" = 20'

NOTES:

1. THE PERMITTED LIMITS OF WASTE OR APPROXIMATE LANDFILL BOUNDARY IS DEFINED IN BAS (2006) PERMIT DRAWINGS.

HDR

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SOUTH HILO SANITARY LANDFILL
HILO, HAWAII
FINAL COVER SYSTEM OPTIONS EVALUATION

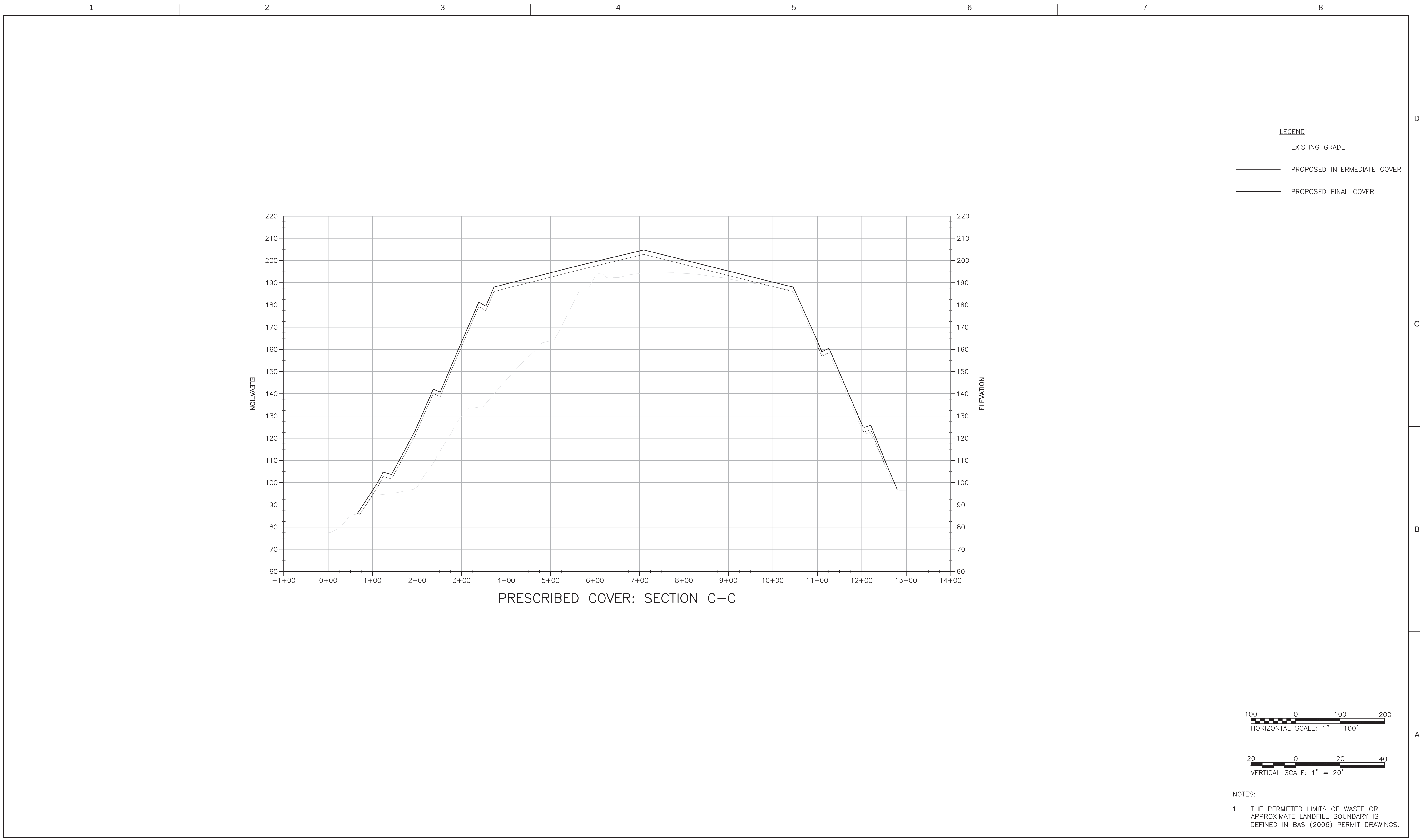
LANDFILL CROSS SECTIONS
(SHEET 1 OF 2)

0 1" 2"

FILENAME Drawing 5.dwg

SCALE H: 1" = 100' , V: 1" = 20'

SHEET
Drawing 5



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SOUTH HILO SANITARY LANDFILL
HILO, HAWAII
FINAL COVER SYSTEM OPTIONS EVALUATION

LANDFILL CROSS SECTIONS
(SHEET 2 OF 2)

0 1" 2"

FILENAME Drawing 6.dwg
SCALE H: 1" = 100' , V: 1" = 20'
SHEET
Drawing 6