WatershedGeo®
Unearthing Solutions

TECHNICAL NOTE

NON-HYDRAULIC TESTING AND EVALUATIONS OF THE HYDROTURF® ADVANCED REVETMENT TECHNOLOGY

Included in this technical note is a summary of the non-hydraulic technical testing and evaluations performed on the HydroTurf® Revetment System. This information is outlined as follows:

- Introduction to HydroTurf® Revetment System
- Benefits
- Aerodynamic Evaluation
- Weathering and Functional Longevity
- Flammability
- Vehicle Loading Evaluations
- Carbon Footprint for Various Revetment Systems

The hydraulic testing information is included in a separate technical note. Please contact Watershed Geosynthetics for this document.

INTRODUCTION TO HYDROTURF® REVETMENT SYSTEM

HydroTurf® was developed as an engineered revetment solution for use in preventing erosion in the following applications:

- Protection from Wave Overwash / Overtopping on the Landward Side of Levees and Embankments;
- Lining of Channels, Swales, Canals, and Spillways;
- Shoreline Protection within Basins, Impoundments, and Reservoirs; and
- Facings for Slopes and Mechanically Stabilized Earth Walls.

HydroTurf® is a unique flexible concrete erosion prevention solution consisting of a high-friction, impermeable geomembrane layer with an integrated drainage layer overlain by an engineered synthetic turf. The geomembrane is placed directly on the subgrade soil. It is covered with the engineered turf whose fibers provide reinforcement for the

HydroBinder® cementitious infill. This infill is placed dry to a thickness of ¾-inch minimum. After placement, it is then hydrated with a light spray of water. A cross section of HydroTurf® is shown in Figure 1.

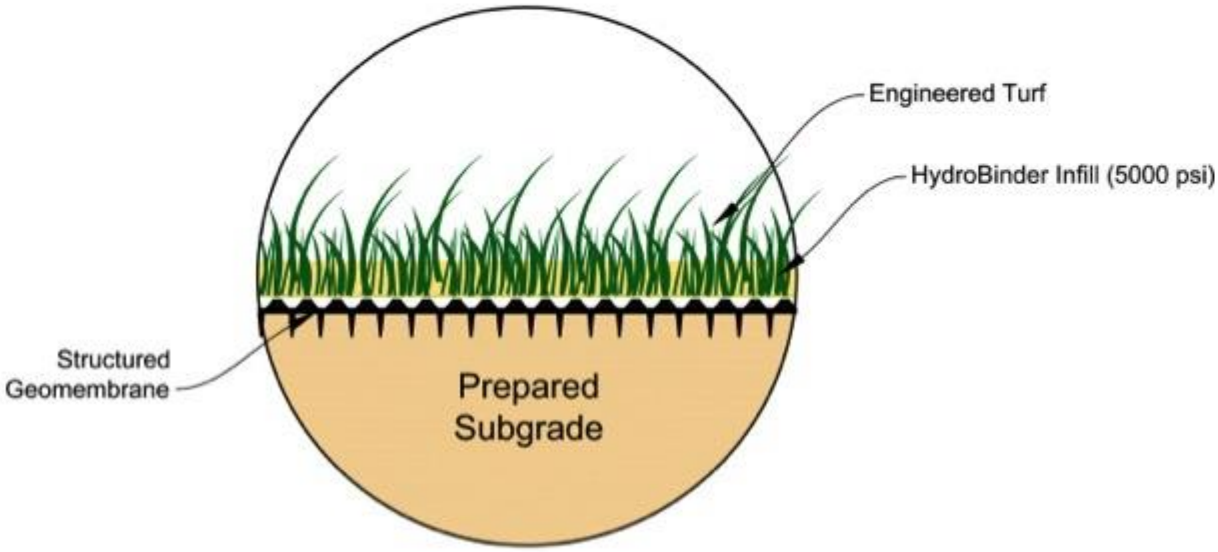

Figure 1 – Section of HydroTurf® Revetment System

BENEFITS

HydroTurf® has a number of benefits over other revetment solutions. These benefits include the following:

- ***Excellent Hydraulic Performance*** – HydroTurf® has been measured to have exceptional hydraulic performance over other hard armor revetment systems.
- ***50+ Year Functional Longevity –*** Through long term weathering tests, HydroTurf® is extrapolated to have a 50+ year functional longevity.
- ***Less Costly Construction*** – HydroTurf® is significantly less costly than hard armor revetment systems (i.e., concrete, rock riprap, and articulated concrete block (ACB)). The installed cost for HydroTurf® is typically up to 50% less than that for traditional hard armor systems.

- ***Rapid, Low Impact, and Scalable Construction*** – Construction and installation of the HydroTurf® System are rapid, low impact, and scalable. Only small, light construction equipment is needed to install the system. On large projects, one (1) experienced construction crew is able to install approximately 1 acre per day. Additional crews can be added to increase this rate.

- ***Significant Long Term Maintenance Cost Savings*** – Vegetation management and erosion control are significant maintenance costs for Anchored Turf Reinforcement Mats (TRMs) products. Maintenance costs for these TRMs may be as high as $1500/acre/year. HydroTurf® has minimal maintenance and will drastically lower long term maintenance costs.

- ***Reduction in Carbon Footprint*** - HydroTurf® has a significantly lower carbon footprint (1/4 to 1/8) than that of the other revetment solutions.

- ***Aesthetics*** – HydroTurf® looks and feels like natural vegetation.

AERODYNAMIC EVALUATION

HydroTurf will withstand high winds and not be lifted, dislodged or damaged. HydroTurf has features that help mitigate the forces of wind. These include a porous surface to break the vacuum, and turf blades that will increase the aerodynamic boundary conditions and react against the wind causing a resistance to the uplift component. Also, the infill of HydroTurf is cemented so it will not be dislodged.

In order to quantify these features, the HydroTurf System was evaluated in the Subsonic Model Test Facility Wind Tunnel at the Georgia Tech Research Institute (GTRI). Testing was performed to evaluate the aerodynamic properties and ballast requirements (infill thickness). The material was tested under two (2) different configurations - a perimeter condition (up to 18-in from the edge of the installation) and an interior condition (beyond 18-in from the edge). Wind speeds were increased up to 170 ft/s (approximately 120 mph). Figure 2 shows the test at 170 ft/s (120 mph).

Based on these hurricane force wind speeds, the minimum infill ballast requirements are 0.40-in for the perimeter condition and 0.038-in for the interior condition. Since HydroTurf® has a recommended HydroBinder® infill thickness of ¾-in, it will resist wind speeds greater than 170 ft/s (120 mph) when properly designed, constructed, and maintained.

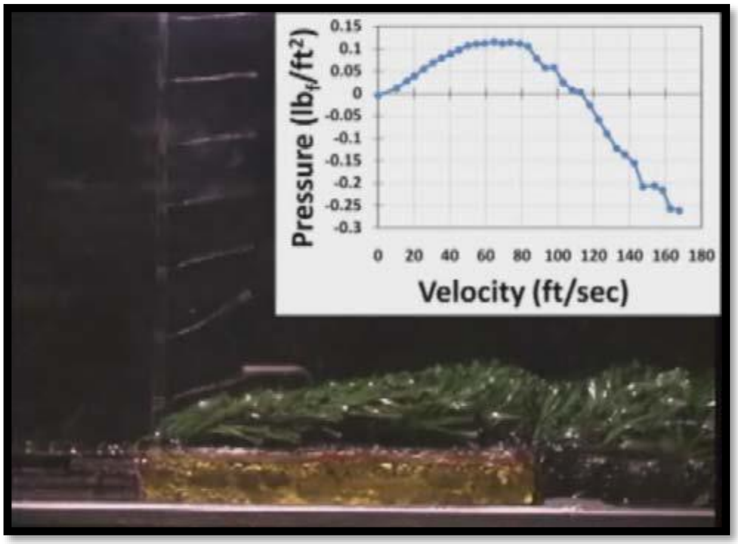

Figure 2 – Aerodynamic Evaluation of HydroTurf at GTRI

In addition to the testing that was performed at GTRI, WG had wind gust testing performed at Vigyan Laboratories. The synthetic component of the HydroTurf (no infill) was installed Vigyan's wind tunnel (see Figure 3). The starting wind speed was approximately 26 mph. Then it was subjected to a wind gust with the top speed being attained in 2 to 3 seconds. The maximum top speed for the gusts was approximately 110 mph. 22 test runs were performed. The turf did not lift or pull away. It remained in place for the 22 test runs.

Figure 3 – Wind Gust Evaluation of HydroTurf at Vigyan

WEATHERING AND FUNCTIONAL LONGEVITY

HydroTurf is comprised of three (3) components – structured geomembrane, engineered synthetic turf, and the HydroBinder infill. In order to evaluate the longevity of the system, we evaluate the longevity of its three (3) components. This evaluation is as follows:

Structured Geomembrane

The structured geomembrane in HydroTurf is manufactured from polyethylene. The longevity of high density polyethylene (HDPE) geomembranes has been extensively evaluated for many years by the Geosynthetics Institute (GSI). In the GRI White Paper #6[1], GSI projects that the half-life of a covered HDPE geomembrane is 445 years at an average annual temperature of 68 deg F (20 deg C). The structured geomembrane of the HydroTurf system has similar properties to the geomembranes researched by GSI, and therefore, it is projected to have a similar longevity of hundreds of years.

Engineered Synthetic Turf

The engineered synthetic turf fibers with the HydroBinder Infill is the protection layer of the HydroTurf System. These components shield the underlying backing geotextiles and geomembrane from exposure. The synthetic turf yarns are the only synthetic component of the system that is directly exposed to the elements, specifically ultraviolet light (UV). Weathering tests of these yarns have been performed in accordance with ASTM G147 and G7 at Atlas Material Testing Laboratories in New River, AZ. Samples were exposed to direct UV by fastening them to a panel which faces south at a 45 degree angle. A photograph of the weathering apparatus is shown in Figure 3.

Figure 3 – Weathering Apparatus at Atlas Material Testing Laboratories

[1] Koerner, R, G. Hsuan, and G. Koerner, "GRI White Paper #6 – Geomembrane Lifetime Prediction: Unexposed and Exposed Conditions", February 8, 2011.

The samples were exposed for a given period and then the retained tensile strength was measured. To date, four (4) samples have been tested for the exposure periods of 1.3, 5, 7, and 10 years. The retained tensile strength at these exposure periods is 97.2%, 89.7%, 83.8%, and 82.5%, respectively. Retained tensile strength was plotted against exposure duration as shown in Figure 4.

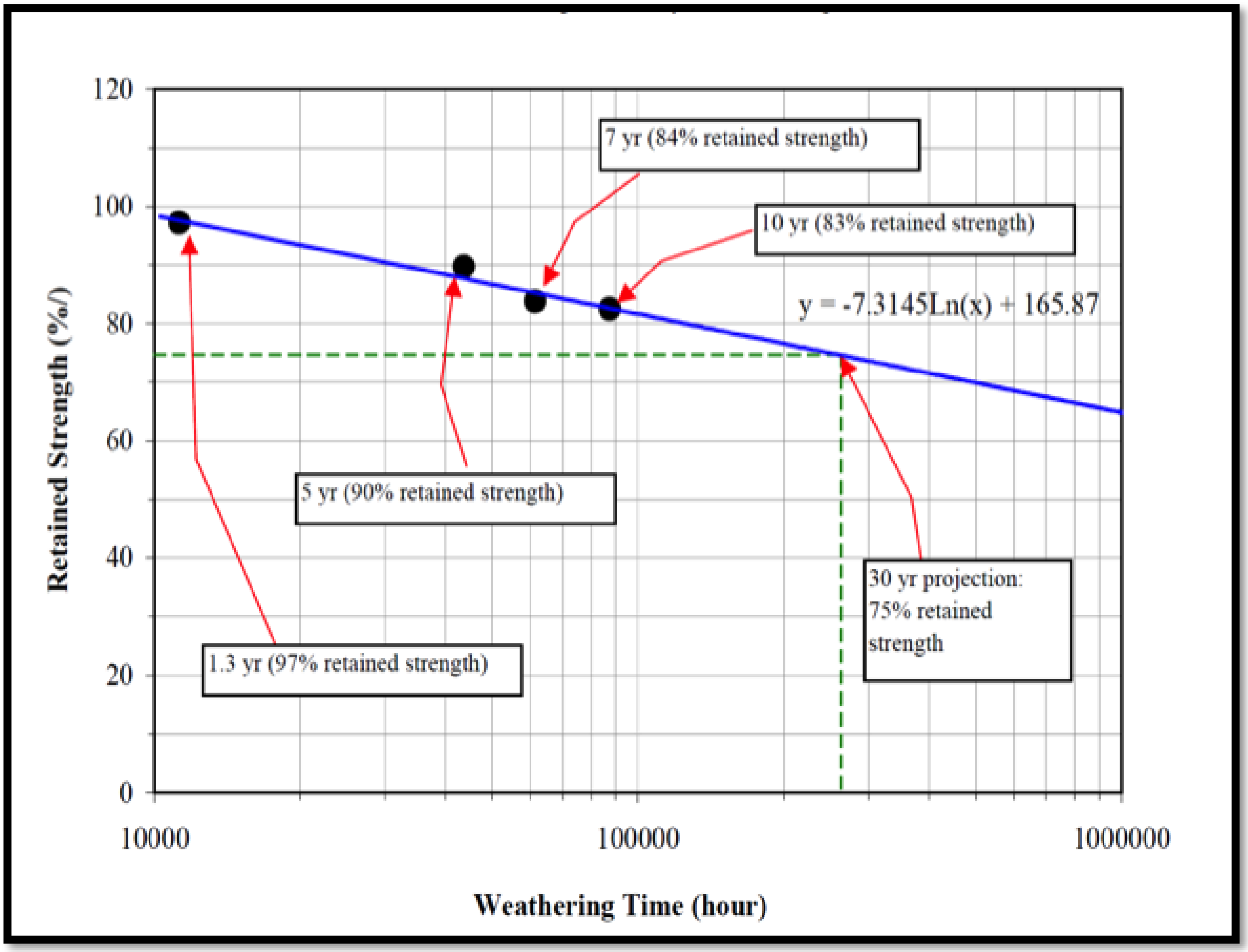

Figure 4 –Retained Tensile Strength of Synthetic Turf Fibers vs. Weathering Exposure Duration

A logarithmic line was fit to the four (4) points and extrapolated out to 1,000,000 hours. At 100 years (876,000 hours), the retained tensile strength of the synthetic turf yarn is projected out to approximately 65%. At 65% retained tensile strength, it will continue to function as designed and provide reinforcement for the infill, protection of the geotextile backing layers, and protection of the underlying geomembrane. Therefore, it can be projected that the engineered synthetic turf fibers will have a 100+ year functional longevity.

HydroBinder Infill

The American Concrete Institute (ACI) provides an average service life for reinforced (with steel) concrete of 75 years with a typical range between 50 and 100 years. The HydroBinder infill is a high-strength (5000 psi), cementitious concrete mortar which is reinforced with polyethylene fibers. These polyethylene fibers will not degrade / corrode in the applications where HydroTurf is used. Concrete with reinforcing steel will be more susceptible to degradation / corrosion in these applications. Therefore, the HydroBinder is conservatively predicted to have longevity of at least 50 years, if not up to 100 years, depending on exposure and environments.

It should also be noted that the HydroBinder is similar to a road repair mix which is formulated to be used as an overlay for patching, leveling, filling, repairing and topping concrete surfaces. On account of this, the HydroBinder is easily maintained, patched and repaired should it be damaged or degraded.

Summary of HydroTurf Longevity

The longevity of each of the components of HydroTurf is summarized as follows:

- Structured Geomembrane – 445 years to Half Life
- Engineered Synthetic Turf - 100 years to 65% Retained Strength
- HydroBinder Infill – 50 to 100 years for Reinforced Concrete

Therefore, based on the longevity of each of the components of HydroTurf, it can be conservatively estimated that the HydroTurf System will have at least a 50 year functional longevity, if not up to 100 years. As with any engineered system, in order to achieve its maximum functional longevity, it is suggested that the HydroTurf system be properly maintained. For detailed information on maintenance, the HydroTurf Maintenance Guidelines is available at the following link on our website:

http://watershedgeo.com/technical-downloads/

FLAMMABILITY

The HydroTurf® system was tested for surface flammability in accordance with ASTM D 2859 - Standard Test Method for Flammability of Finished Textile Floor Covering Materials. This is the standard test method that is required by U.S. Consumer Product Safety Commission for Carpets and Rugs.

Eight (8) 12-in by 12-in samples of HydroTurf® with HydroBinder® infill and eight (8) 12-in by 12-in samples of HydroTurf® without infill (engineered turf only) were prepared for testing. They were first preheated to dry them out. Then, a metal frame was placed over them. The metal frame has an 8-in diameter opening (See Figure 5).

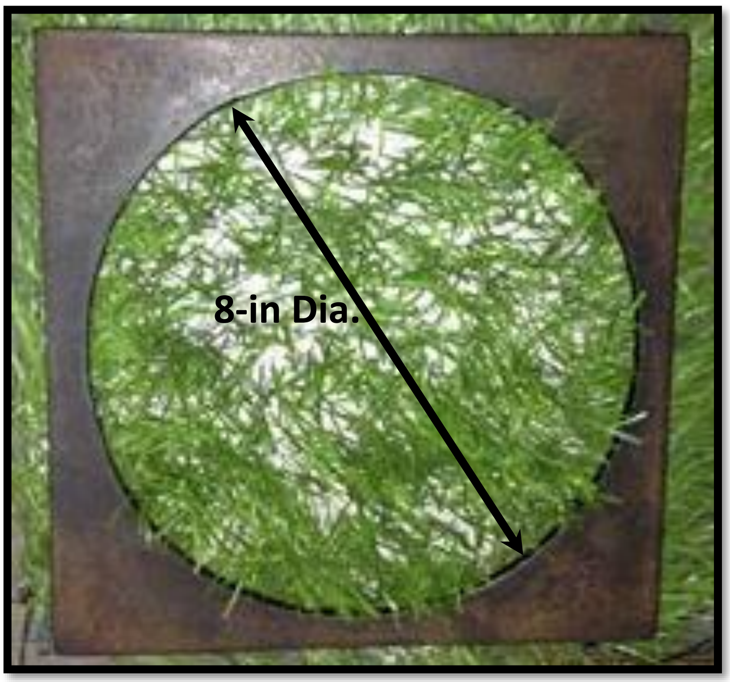

Figure 5 – HydroTurf® Sample Prepared for Flammability Testing

An ignition source (methenamine solid fuel tablet) was placed in the center of the sample. The methenamine tablet was then lit. It burned for approximately 2 minutes at over 700 deg F. After the flame had extinguished, the propagation of the flame was measured from the edge of the 8-in diameter metal frame. The criteria for a passing test is that the flame must self-extinguish before reaching a distance of 1-in from the frame in seven (7) out of the eight (8) samples tested.

Both the HydroTurf® with HydroBinder® infill and the HydroTurf® without the infill (engineered turf only) passed this flammability test. The HydroTurf® without the infill was evaluated as a worst case scenario. Pictures of one of the samples after testing are shown in Figure 6.

Figure 6 – HydroTurf® Sample after Flammability Testing

VEHICLE LOADING EVALUATIONS

Vehicle loading calculations have been performed on the HydroTurf® system. These calculations are intended to determine puncture and tear resistance of the system to support vehicle loads. The vehicles used in the evaluation consist of the following:

- Pickup Truck weighing 6,000 lbs with 45 psi tire pressure.
- Fire Engine weighing 55,000 lbs on dual rear axles / wheels (tire pressure of 120 psi).

Photos of these vehicles are show in Figure 7.

Figure 7 – Vehicles Used in Loading Evaluations

These calculations are based on the methodologies presented in Koerner (2005)[2]. The calculated results for the puncture and tear resistance of the geosynthetic components are presented in the Table 1.

[2] Koerner, Robert M. (2005), "Designing with Geosynthetics".

	Light Vehicle (Pick Up Truck)	Heavy Vehicle (Fire Engine)
Applied Pressure / Load – Deformation of Geotextile Backing*	4.37	1.64
Tensile Strength (Lateral Movement)*	1.85	1.90****
Puncture Resistance – Geotextile Backing Component*	239	90
Puncture Resistance on Roadways – Geomembrane Component	4 oz/sy GT	12 oz/sy GT

* Factor of Safety
** Methodology per Koerner (2005)
*** Reduction Factors of 1.5 for Installation Damage
**** 200 lb geotextile required

Table 1 – Results of Puncture and Tear Resistance Calculations

A braking evaluation was also performed. This evaluation was performed with the following assumed conditions:

- Pickup Truck was moving at 10 mph and stopped on a 3H:1V slope within 2 sec.
- Fire Engine was moving at 10 mph and stopped on an 8% slope within 2 sec.

Factors of Safety against static and dynamic movement of the geosynthetic layers were calculated. A schematic of the breaking forces used to calculate the Factors of Safety is shown in Figure 8. The results or the evaluation are shown in Table 2.

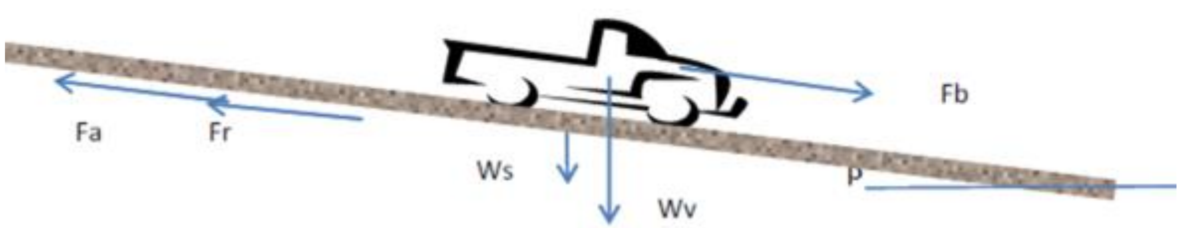

Figure 8 – Schematic of Breaking Forces

Vehicle	Slope Angle	Static FS	Dynamic FS
Fire Engine	8 Degrees	4.6	1.8
Pick Up Truck	18 Degrees (3H:1V)	2.0	1.2

Table 2 – Factors of Safety of Braking Resistance

Based on these evaluations, factors of safety against damage of the HydroTurf System on account of traffic loading with rubber tired vehicles were ≥1.2. Typically, on slopes we suggest vehicles with tire pressures less than 45 psi, and on flatter areas (8% or less) and designed access roads, we suggest vehicles with tire pressures less than 100 psi.

It should be noted that the resistance of HydroTurf to traffic / vehicle loading is more a function of the underlying subgrade conditions (i.e., soil type, bearing capacity, bearing ratio, particle size, etc.). Therefore, it is important to perform a site specific analysis and specify proper engineered compaction and grading of the subgrade surface. As long as the subgrade can support the vehicle loads, the HydroTurf will be able to support these loads.

CARBON FOOTPRINT FOR VARIOUS REVETMENT SYSTEMS

An estimated carbon footprint was evaluated for the following revetment systems:

- 24-inch Thick Rock Riprap
- 6-inch Thick Articulated Concrete Block (ACB) – Closed Cell
- 6-inch Thick ACB – Open Cell
- 6-inch Thick Concrete Paving
- 4-inch Thick Concrete Paving
- HydroTurf®

The evaluation included the calculation of the amount of CO_2 (lbs) per square foot (sf) of revetment surface area. For each system, the following CO_2 producing activities were analyzed:

- Subgrade preparation;
- Manufacture of the materials;
- Hauling of materials to the project site; and,
- Placing and installing the materials.

Values of CO_2 production were primarily derived from EPA (2005)[3] and University of Bath (2008)[4].

Based on this evaluation, HydroTurf® has a significantly lower carbon footprint (1/4 to 1/8) than that of the other revetment solutions. The graph in Figure 9 shows the carbon footprint for each of the various revetment systems. Also for every one (1) acre of revetment, the use of HydroTurf® will remove from the roads approximately 55 truck trips of ACB, 85 truck trips for concrete paving, or 200 truck trips for rock riprap.

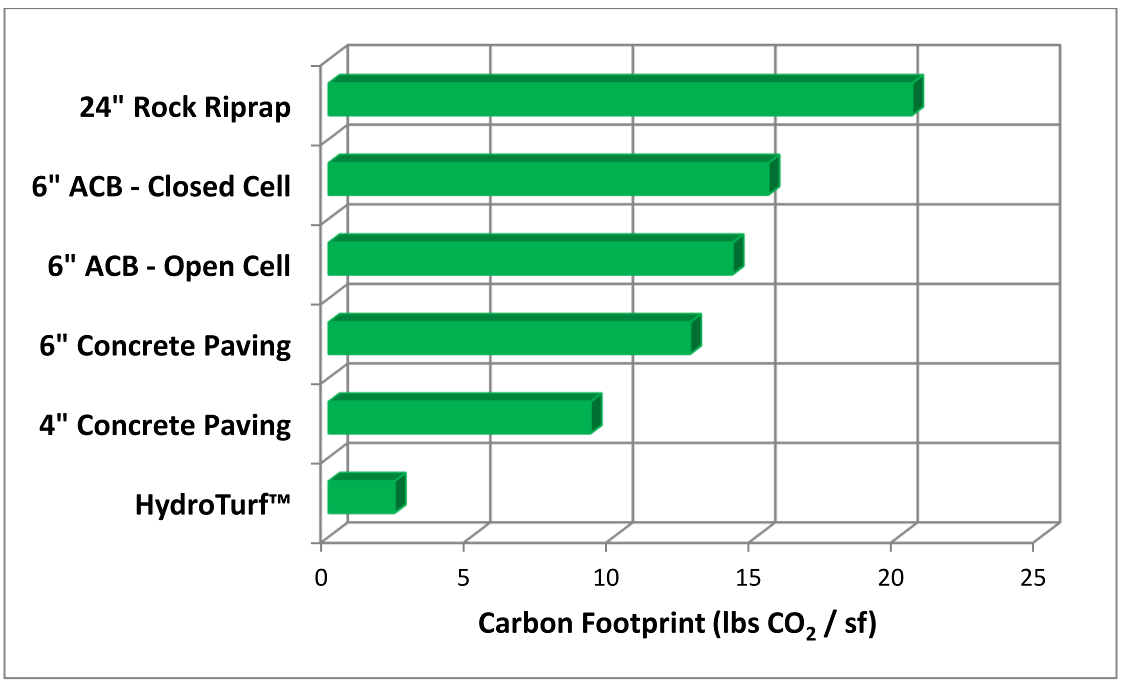

Figure 9 – Estimated Carbon Footprint for Various Revetment Systems

[3] U. S. EPA (2005), "Emission Facts," Office of Transportation and Air Quality, EPA 420-F-05-001, February.

[4] University of Bath (2008), Hammond, G.P. and C.I. Jones, "Inventory of Carbon and Energy," Version 1.6a.

LIMITATIONS

HydroTurf® product (US Patent No. 7,682,105; Canadian Patent No. 2,663,170; and other Patents Pending) and registered trademark are the property of Watershed Geosynthetics LLC. All information, recommendations and suggestions appearing in this letter concerning the use of our products are based upon tests and data believed to be reliable; however, this information should not be used or relied upon for any specific application without independent professional examination and verification of its accuracy, suitability and applicability. Since the actual use by others is beyond our control, no guarantee or warranty of any kind, expressed or implied, is made by Watershed Geosynthetics LLC as to the effects of such use or the results to be obtained, nor does Watershed Geosynthetics LLC assume any liability in connection herewith. Any statement made herein may not be absolutely complete since additional information may be necessary or desirable when particular or exceptional conditions or circumstances exist or because of applicable laws or government regulations. Nothing herein is to be construed as permission or as a recommendation to infringe any patent.