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Performance Testing of Reinforced Turf-Lined Channels

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Biography

C. Joel Sprague, Sr. Engineer - Mr. Sprague is a Senior Engineer for TRI/Environmental, Inc., Austin, TX. Mr. Sprague is based in Greenville, South Carolina where he also consults for Sprague & Sprague Consulting Engineers. He is a registered professional engineer in North and South Carolina, Georgia, and Texas. He has authored numerous articles and technical papers on the development, testing, and application of erosion and sediment control materials.

Peter Kemp, P.E., Sr. Engineer - Mr. Kemp is a licensed Professional Engineer with the Wisconsin Department of Transportation. Mr. Kemp chairs the AASHTO National Transportation Product Evaluation Program, Erosion Control Products Technical Committee which has developed and oversees NTPEP's erosion control product testing programs. Current programs include index and bench-scale quality assurance testing and large-scale performance testing.

Jay Sprague, Lab Director – Mr. Sprague supervises a staff of technicians, directs all site operations and testing, and is responsible for implementation of TRI's Quality Systems throughout all lab operations. Mr. Sprague's background includes developing markets and technologies associated with agricultural and erosion and sediment control products.

Abstract

Grass-lined channels have been widely used in roadway drainage systems for many years, in many climates and in a wide range of soil conditions. This is because a grass lining can be selected for the specific climate and soil to provide relatively good erosion protection while also potentially trapping sediments and related contaminants in the channel section. Yet, the long-term behavior of any grass in an open channel lining is directly affected by the health and integrity of the individual plants. Thus, the overall reliability of a vegetative lining may be compromised by "patches" of weak, dead, or up-rooted vegetation.

To minimize the potential for these localized vulnerabilities to lead to overall liner failure, a class of rolled erosion control product (RECP) called a turf reinforcement mat (TRM) has been used to integrate soil, lining material and grass/stems roots within a single, continuous matrix. To make this a long-term solution, the TRM consists of non-degradable materials. Still, the ability of the reinforced turf lining to provide erosion protection changes over time – providing increasing protection as the grass germinates and matures or decreasing protection as storm events degrade the vegetative stand.

This paper presents the performance characteristics for a range of TRMs and unvegetated/vegetated conditions using standardized large-scale test method, ASTM D 6460.

Keywords: RECPs, turf reinforcement mat, TRM, erosion control testing, NTPEP, ASTM D 6460

1 Background

Grass-lined channels have been widely used in roadway drainage systems for many years, in many climates and in a wide range of soil conditions. This is because a grass lining can be selected for the specific climate and soil to provide relatively good erosion protection while also potentially trapping sediments and related contaminants in the channel section. Yet, the long-term behavior of any grass in an open channel lining is directly affected by the health and integrity of the individual plants. Thus, the overall reliability of a vegetative lining may be compromised by “patches” of weak, dead, or up-rooted vegetation.

2 Erosion Control Products (ECPs) and Standardized Performance Testing

To minimize the potential for these localized vulnerabilities to lead to overall liner failure, a class of rolled erosion control product (RECP) called a turf reinforcement mat (TRM) has been used to integrate soil, lining material and grass/stems roots within a single, continuous matrix. To make this a long-term solution, the TRM consists of non-degradable materials. Still, the ability of the reinforced turf lining to provide erosion protection changes over time – providing increasing protection as the grass germinates and matures or decreasing protection as storm events degrade the vegetative stand.

Recent standardized large-scale vegetated channel erosion testing has been carried out through the National Transportation Product Evaluation Program. Test reports from independent testing of turf reinforcement mats (TRMs) are readily available on-line (www.ntpep.org). Thus, authoritative performance data is now available to regulatory agencies and site designers to qualify and compare candidate reinforced-turf channel lining alternatives.

3 Testing of TRMs

3.1 Standard Test Method for Channel Erosion – ASTM D 6460

Reported herein are performance characteristics for a range of TRMs and unvegetated/vegetated conditions. The performance was measured using large-scale test method, ASTM D 6460, *Standard Test Method for Determination of Rolled Erosion Control Product (RECP) Performance in Protecting Earthen Channels from Stormwater-Induced Erosion*.

3.1.1 Unvegetated RECP Testing

Unvegetated large-scale channel testing is commonly performed in rectangular flumes having a 10% bed slope using a loamy soil test section. The concentrated flow is produced by raising gates to allow gravity flow from an adjacent pond. At least four sequential, increasing flows are applied to each test section for 30 minutes each to achieve a range of hydraulic shear stresses in order to define the permissible, or limiting, shear stress, τ_{limit}, which is the shear stress necessary to cause an average of 0.5 inch of soil loss over the entire channel bottom. Testing is performed in accordance with ASTM D 6460 protocol which requires three replicate flumes be tested. Tables and graphs of shear versus soil loss are generated from the accumulated data for all three flumes.

3.1.2 Vegetated RECP (TRM) Testing

Vegetated RECP large-scale testing is performed much less often than testing of unvegetated RECPs and typically uses flumes having a steeper bed slope. This enables higher shear stresses to be achieved with the available water supply. Yet, bed slopes that are too steep (> 20%) may be subject to seepage induced bed soil instability, so there is a practical limit to how steep a flume can be. As with unvegetated tests, at least four sequential, increasing flows are applied to each test section, but instead of the flows lasting for 30 minutes they are maintained for 1 hour. And, the flows are considerably higher in order to achieve a range of hydraulic shear stresses that will define the permissible, or limiting, shear stress, τ_{limit}. The permissible shear stress is still considered as that shear stress that causes an average of 0.5 inch of soil loss over the entire channel bottom. The testing reported herein was performed in accordance with ASTM D 6460, <u>except that only single replicate flumes were run at each duration of vegetation growth</u>. Tables and graphs of shear versus soil loss are generated from the accumulated data for each flume tested.

3.2 Turf Reinforcement Mats (TRMs)

This paper reports on the testing of turf reinforcement mats –relatively nondegradable mattings that tie together, or "reinforce", vegetation. Table 1 provides information and index properties on the tested TRMs.

3.3 Test Soil

The test soil used in the test plots had the following characteristics.

Table 2. TRI-Loam Characteristics

Soil Characteristic	Test Method	Value
% Gravel	ASTM D 422	0
% Sand		45
% Silt		35
% Clay		20
Liquid Limit, %	ASTM D 4318	41
Plasticity Index, %		8
Soil Classification	USDA	Loam
Soil Classification	USCS	Sandy silty clay (ML-CL)

3.4 Preparation of the Test Channels

The initial channel soil veneer (12-inch thick minimum) is placed and compacted. Compaction is verified to be 90% (± 3%) of Proctor Standard density. The test channels undergo a "standard" preparation procedure prior to each test. Any rills or depressions resulting from previous testing are filled in with test soil and the soil surface is renewed to a depth of 1 inch. Then the channel is recompacted. Finally, the channel is finely groomed to create a channel bottom that is level side-to-side and at a smooth slope top-to-bottom and hand-compacted. If a vegetated condition is to be tested, grass seed (tall fescue) is applied to the plot at the rate of 500 seeds per square foot. The submitted erosion control product is then installed using the anchors and anchorage pattern directed by the client.

3.5 Installation of Erosion Control Product in Test Channel

As noted, the submitted erosion control product is installed as directed by the client. For the tests reported herein, the erosion control product was anchored using a "diamond" anchorage patterns. Typically, the anchorage consisted of 2"x 8" steel staples to create an anchorage density of approximately 3.8 staples per square yard, though some tests were done with other anchorage frequencies.

3.6 Specific Test Procedure

Immediately prior to testing, the initial soil surface elevation readings are made at predetermined cross-sections. The channel is then exposed to sequential 30-minute (unvegetated condition) or 1-hour (vegetated condition) flows having target hydraulic shear stresses selected to create at least three flow events below and one flow event above the shear stress level that results in a cumulative average soil loss of ½-inch. During the testing, flow depth and corresponding flow measurements are taken at the predetermined cross-section locations. Between flow events, the flow is stopped and soil surface elevation measurements are made to facilitate calculation of soil loss. The flow is then restarted at the next desired flow (shear) level. Pictures of typical channel flows and resulting soil/vegetation loss are shown in Figures 1 thru 12.

Table 1. Tested Product Information, including Index and Performance Properties

Product Information and Index Property / Test	Units	Values							
Product Identification*	-	2NFF	2NFF	3NFF	2NFF	3NFF-3D	2NFF	3NC-3D	3NSC-3D
Fiber	-	polyester	Poly-propylene	Poly-propylene	Poly-propylene	Poly-propylene	Poly-propylene	100% Coconut	70% Straw 30% Coconut
Netting Openings (approximate)	in	0.75 x 0.75	0.5 x 0.5	0.5 x 0.5	0.75 x 0.75	0.5 x 0.5	0.5 x 0.5	0.5 x 0.5	0.5 x 0.5
Stitching Spacing (approximate)	in	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Tensile Strength MD x XD (ASTM D 6818)	lb/in	24.5 x 14.5	41 x 25	104 x 116	35.4 x 25.2	91.7 x 75.3	41.1 x 17.9	81.9 x 60.5	62.3 x 66.1
Tensile Elongation MD x XD (ASTM D 6818)	%	32.4 x 45.9	25 x 18	33 x 19	25.7 x 28.1	31.2 x 24.7	29.1 x 27.3	29.3 x 18.8	33.3 x 22.1
Thickness (ASTM D 6525)	mils	360	288	345	231	588	384	582	620
Light Penetration (ASTM D 6567)	% cover	38.3	79.8	83.8	79.6	84.4	74.5	93.8	95.5
Density – Net Only (ASTM D 792, Method A)	g/cm^3	0.91	0.915	0.914	0.908	0.915	0.916	0.916	0.918
Mass / Unit Area (ASTM D 6475)	oz/sy	8.95	10.41	18.37	10.43	19.35	11.48	15.16	13.95
Anchorage Rate	staples per yd^2	3.8	4.5	4.5	3.8	2.5	3.8	3.8	3.8
Permissible Shear – Unvegetated	lb/ft^2	2.0	2.5	3.3	2.1	2.5	2.8	3.2	3.02
Permissible Shear: 6-8 Wks of Vegetation Growth	lb/ft^2	3.2	4.2	6.4	3.2	5.3	8.8	8.8	7.7
Permissible Shear: 20-22 Wks of Vegetation Growth	lb/ft^2	not tested	not tested	not tested	not tested	not tested	10.1	10.2	9.8
Permissible Shear: 60-65 Wks of Vegetation Growth	lb/ft^2	13.0	12.5	12.3	13.3	13.2	to be tested	to be tested	to be tested
Permissible Shear: 75+ Wks of Vegetation Growth	lb/ft^2	13.3	13.4	not tested	not tested	not tested	not tested	not tested	not tested

* KEY: 2NFF = Double net poly fiber filled; 3NFF = Triple net poly fiber filled; 3NFF-3D = Triple net poly fiber filled + 3-dimensional inner net; 3NC-3D = Triple net coconut fiber filled + 3-dimensional inner net; 3NSC-3D = Triple net straw-coconut fiber filled + 3-dimensional inner net.

Figure 1. Typical 10% (Unvegetated Shear) Flumes on Left; 20% Flumes on Right

Figure 2. 6+ Week Vegetated Shear in 20% Flumes; Recirculation Pump in Background

Figure 3. Typical 20% Temporary Flume Set Up 1+ Year Vegetated Shear Plots

Figure 4. Unvegetated RECP

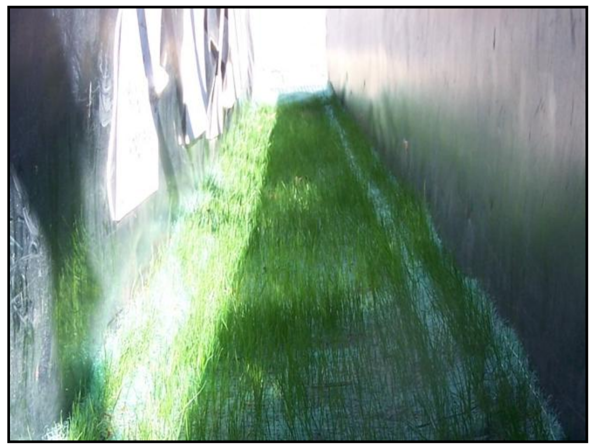

Figure 5. 6+ Week Vegetated RECP

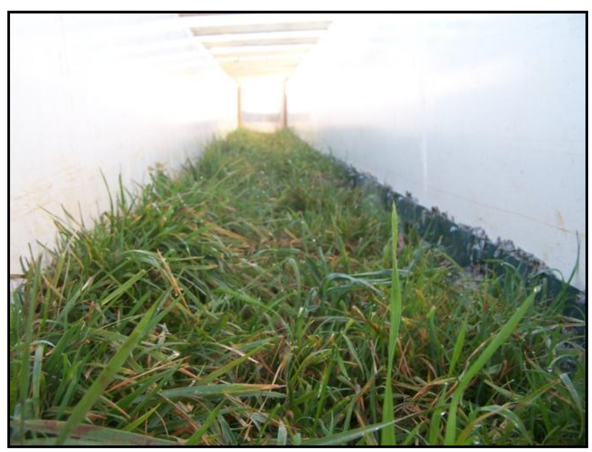

Figure 6. 1+ Year Vegetated RECP

Figure 7. Typical Flow in Unvegetated Channel

Figure 10. Unvegetated Channel after Test with Product Removed (typical)

Figure 8. Typical Flow in 6+ Week Vegetated Channel

Figure 11. 6+ Week Vegetated Channel after Test (typical)

Figure 9. Typical Flow in 1+ Year Vegetated Channel

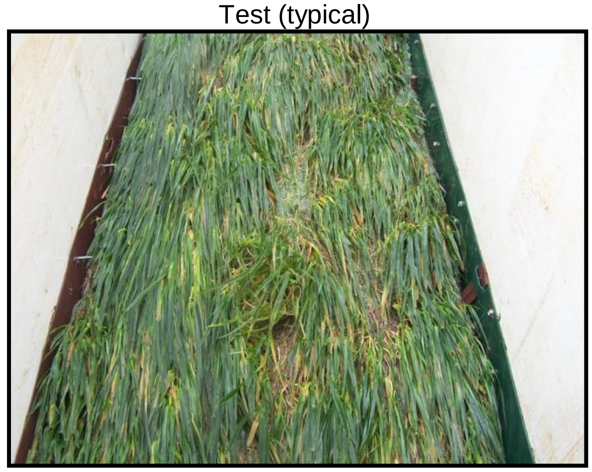

Figure 12. 1+ Year Vegetated Channel after Test (typical)

3.7 Typical Test Results

Average soil loss and the associated hydraulic shear calculated from flow and depth measurements made during the testing are the principle data used to determine the performance of the product tested. This data is entered into a spreadsheet that transforms the flow depth and velocity into an hydraulic shear stress and the soil loss measurements into an average Clopper Soil Loss Index (CSLI). Typical measured and calculated data is summarized in Table 3 for a range of growing periods. The test data is then plotted in a graph of shear versus soil loss for the protected condition is shown in Figure 13. The graph includes the best regression line fit to the test data to facilitate a determination of the limiting shear stress, τ_{limit},, at the 0.5-inch soil loss intercept. Typically, testing has been done unvegetated and at two vegetated conditions – approximately 6 weeks and 1 year of growth. Figure 14 represents a product with an additional test at a fourth state of vegetative density. The additional test, performed for the Wisconsin Department of Transportation, was on a channel that had previously been tested and was allowed to recover and continue growing until retested.

Table 3. Typical Summary Data Table – Protected Test Reach

Test # (Shear Level)	Actual Growth Period (wks)	Flow depth (in)	Flow velocity (fps)	Flow (cfs)	Manning's roughness, n	Max Bed Shear Stress (psf)	Cumm. CSLI (in)
S1, Unvegetated	0	1.42	2.78	0.65	0.041	0.74	0.05
S2, Unvegetated		2.21	3.97	1.46	0.039	1.15	0.17
S3, Unvegetated		3.15	6.22	3.26	0.031	1.63	0.35
S4, Unvegetated		4.02	8.12	5.43	0.028	2.09	0.53
S1, 6-wk Vegetated	8	1.05	3.35	0.58	0.040	1.09	0.06
S2, 6-wk Vegetated		2.06	5.95	2.04	0.034	2.13	0.19
S3, 6-wk Vegetated		3.12	9.04	4.69	0.030	3.22	0.51
S4, 6-wk Vegetated		4.33	12.29	8.86	0.028	4.48	1.13
S1, 1-yr Vegetated	65	2.62	6.23	2.70	0.039	2.71	0.05
S2, 1-yr Vegetated		4.51	12.13	9.09	0.029	4.66	0.12
S3, 1-yr Vegetated		7.60	16.82	21.22	0.029	7.86	0.19
S4, 1-yr Vegetated		10.85	22.86	41.20	0.027	11.21	0.30
S5, 1-yr Vegetated		12.64	24.92	52.34	0.028	13.06	0.50

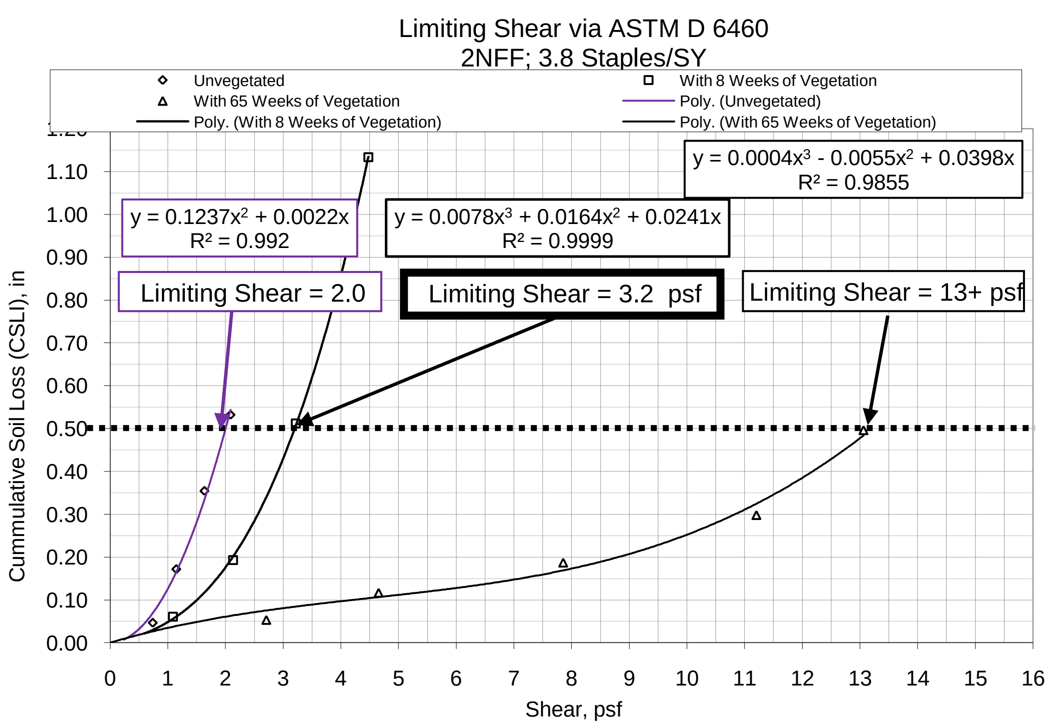

Figure 13. Shear Stress vs. Soil Loss – Tested Product

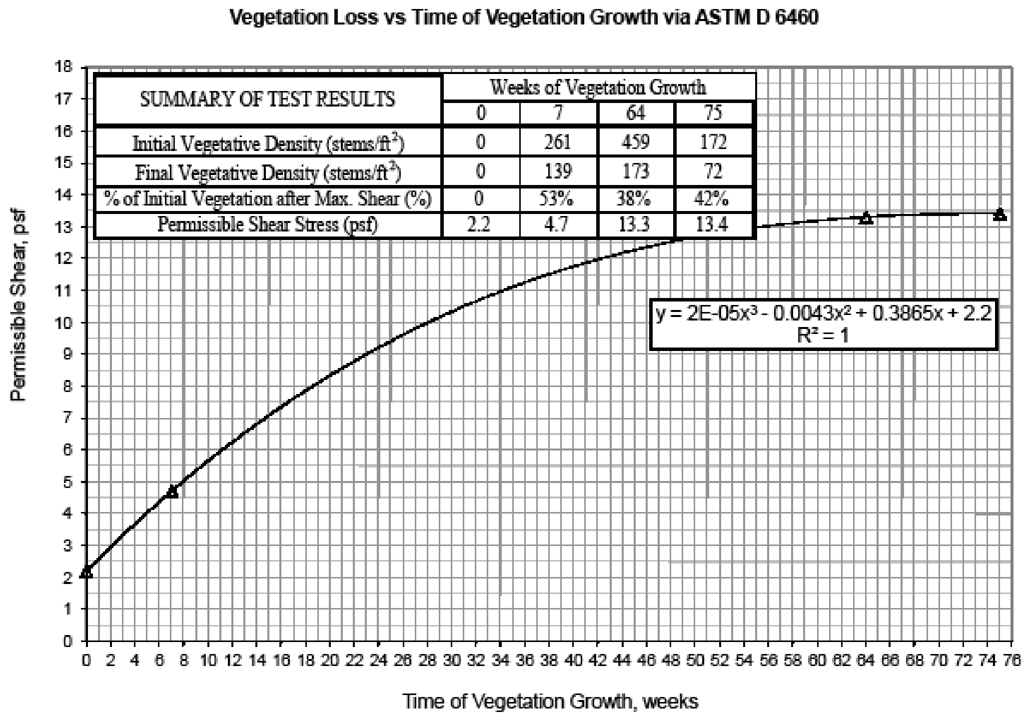

Figure 14: Shear Stress vs. Time of Growth with Associated Vegetative Density

4 RECP / TRM Performance via ASTM D 6460

As noted earlier, a significant body of independently developed performance data on ECPs is available at www.ntpep.org. Figure 15 combines the results of the testing of vegetated turf reinforcement mats reported herein with the large-scale results to-date from the NTPEP program for unvegetated RECPs per Sprague, et.al. (2012). Along with the vegetated results detailed herein, the summary includes a range of RECPs, including double net straw, straw-coconut, excelsior, and coconut (2NS, 2NSC, 2NX, and 2NC), along with the TRMs detailed in Table 1.

Figure 15 makes clear that over a wide range of unvegetated RECPs, including TRMs, the products can dependably provide no more than approximately 3 lb/ft^2 hydraulic shear stress protection. Conversely, when vegetation is allowed to grow through and mature, the potential hydraulic shear stress protection can potentially quadruple! Yet, the increase is very dependent on how long the vegetation is allowed to grow and whether the reinforced turf liner has previously undergone high shear levels. The 20-22 week growth data and the 75+ week growth data are both taken after the channel had been taken beyond its limiting shear at the previous duration of growth (i.e. 6-8 week and 60-65 week, respectively).

Figure 16 clearly shows that the mass/area of the TRM has an important effect on the performance of the unvegetated installation and, to a lesser degree, the 6-8 week vegetated performance. But, as the growth period increases the difference in TRMs seems to make little difference in the permissible shear stress achieved. This suggests that at some point in time, the maturity of the vegetation controls the performance. Another interesting detail that can be gleaned from Figure 15 is the difference in performance provided by a TRM anchored at 2.5 $staples/yd^2$ versus a TRM anchored at the more typical 3.8 to 4.5 $staples/yd^2$. Yet, this difference goes away, as well, as the vegetation matures.

Both before and after vegetation conditions are presented in Figure 17. Clearly, substantial amounts/percentages of the vegetation are lost during the testing, but what remains apparently continues to mature and become more firmly rooted. As a result, when the same channel is retested at a later date (i.e. 6-8 week channel retested at 20-22 weeks; and 60-65 week channels retested at 75+ weeks – such as is shown in Figure 14) it shows as good if not better hydraulic shear protection. This suggests that an important part of the TRM system is to protect the root mass. For example, Figure 14 shows there was significant stem loss during the 75 week test, yet the shear performance remained essentially equivalent to the 64 week performance.

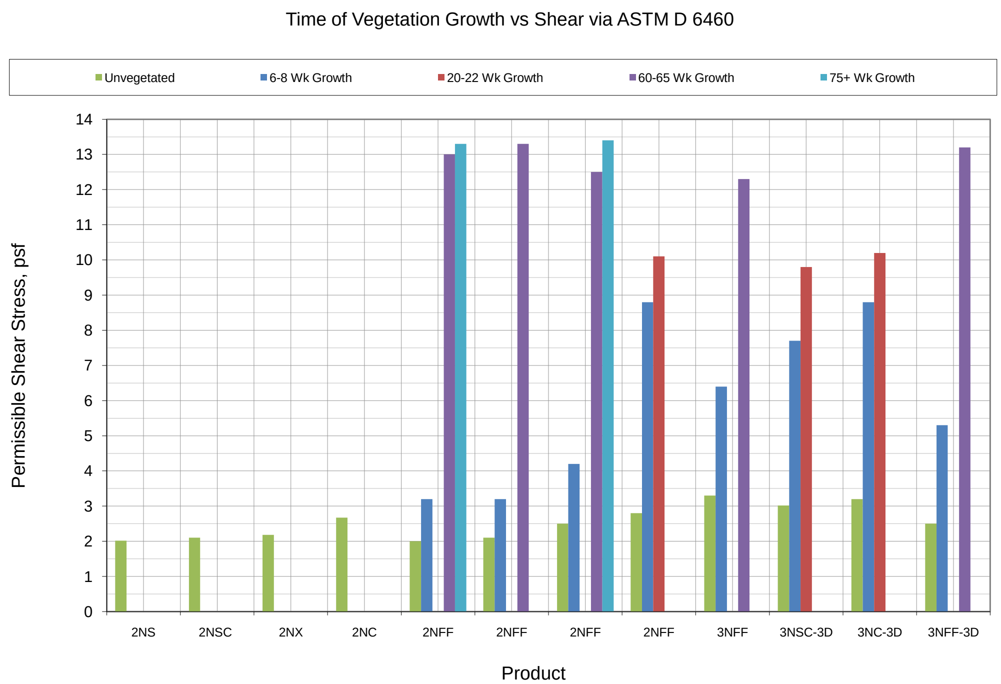

Figure 15. Summary of Large-scale Channel Test Results, including NTPEP Testing 2009-2011+

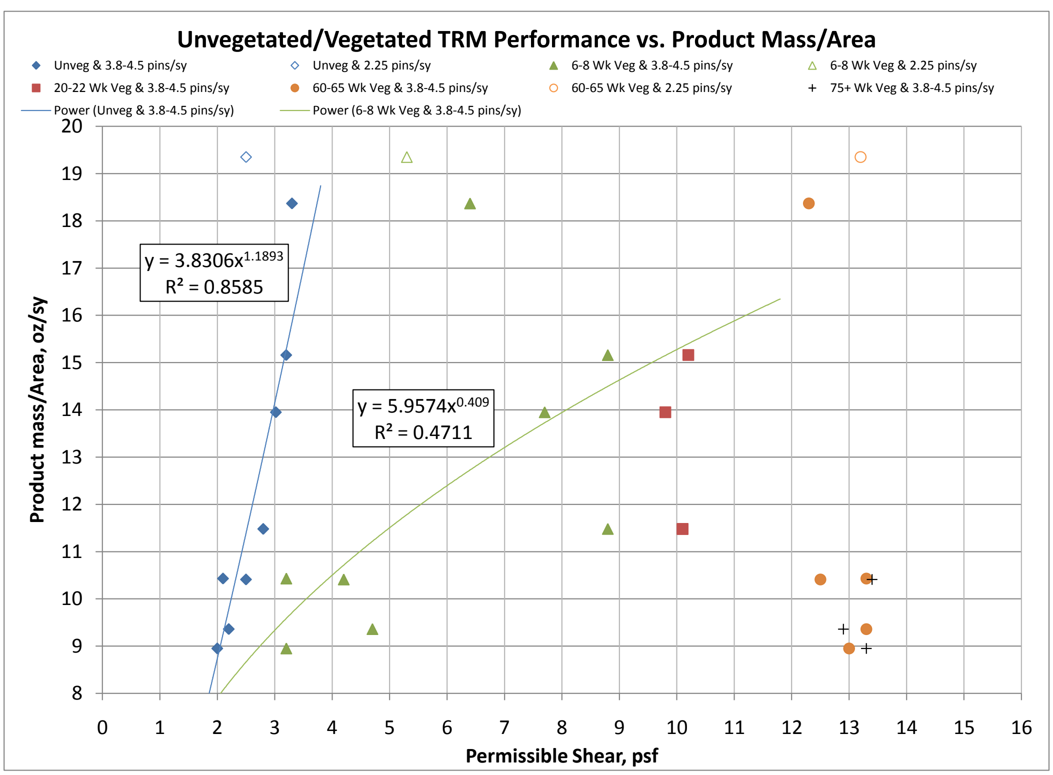

Figure 16. Unvegetated and Vegetated TRM Permissible Shear vs. TRM Mass/Area

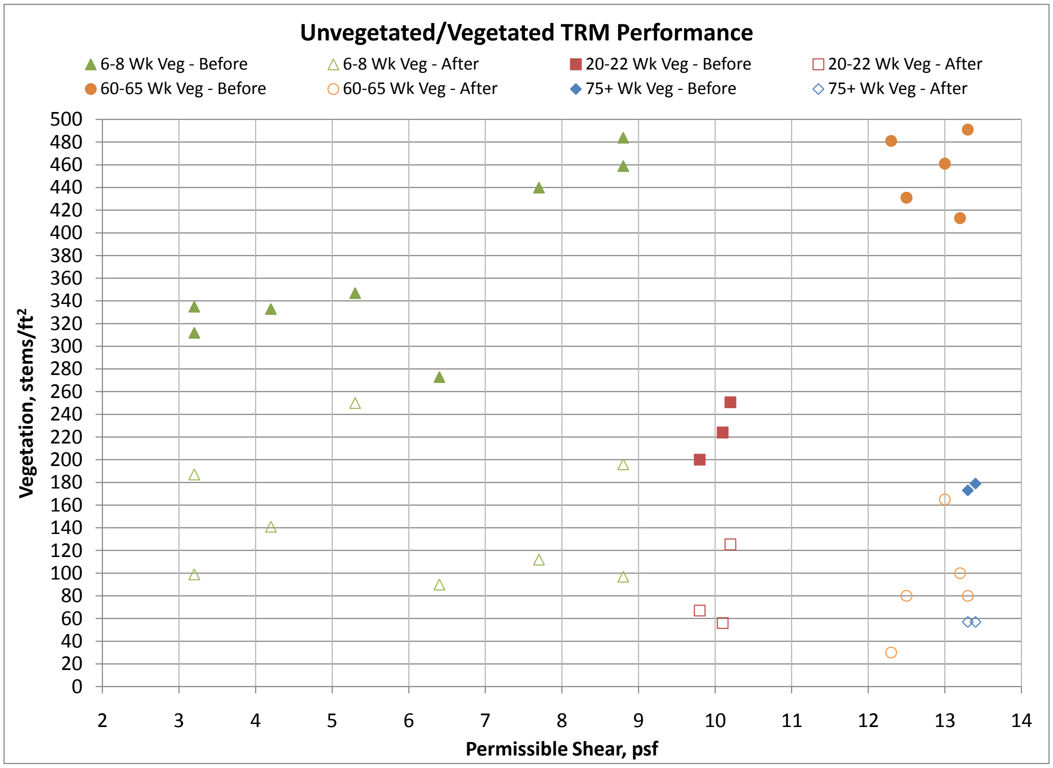

Figure 17. Before and After Vegetation for TRM Runs – Stem Count

5 Conclusions

This paper has presented the results of large-scale standardized performance tests on a range of unvegetated and vegetated TRMs, as well as, a summary of unvegetated RECP test results using the same large-scale testing procedure, ASTM D 6460.

This full-scale testing is useful in establishing the maximum benefit of a range of candidate rolled erosion control products (RECPs), including both unvegetated and vegetated turf reinforcement mats (TRMs). These large-scale performance tests are able to assess the ability of the reinforced turf lining to provide erosion protection over time – providing increasing protection as the grass germinates and matures or decreasing protection as storm events degrade the vegetative stand.

6 Reference

ASTM D 6460, *Standard Test Method for Determination of Rolled Erosion Control Product (RECP) Performance in Protecting Earthen Channels from Stormwater-Induced Erosion*. ASTM, Conshohocken, PA.

Sprague, C.J., Sprague, J.E., and Allen, S.R. (2012), “Large-scale Performance Testing of Erosion Control Products,” Proceedings of GeoAmericas 2012, Lima, Peru, IFAI.