Drivable Grass®

Report for Hydraulic Performance Testing

Prepared for

Soil Retention Products, Inc.

Prepared by

Michael D. Turner
Amanda L. Cox
Christopher I. Thornton

March 2011

Colorado State University
Daryl B. Simons Building *at the*
Engineering Research Center
Fort Collins, Colorado

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbols

Cumulative Soil Loss	total soil loss (in.)
i	number of discharges conveyed for test
n	Manning's coefficient of hydraulic resistance
Soil $Loss_i$	incremental soil loss (in.)
Z_{final}	final bed elevation or point-gage reading (ft)
$Z_{initial}$	initial bed elevation or point-gage reading (ft)

Abbreviations

acre/ft	acre(s) per foot
ASTM	American Society for Testing and Materials
cfs	cubic feet per second
cfs/ft	cubic feet per second per foot
CSLI	Clopper Soil Loss Index
CSU	Colorado State University
ECB	Erosion Control Blanket
ERC	Engineering Research Center
ft	feet or foot
ft/ft	feet per foot
ft/s	feet per second
ft^2/s	square feet per second
H:V	Horizontal:Vertical
hr(s)	hour(s)
ID	identification
in.	inch(es)
lb	pound(s)
lb/ft^3	pound(s) per cubic foot
min	minute(s)
n/a	not available
No.	Number
psf	pound(s) per square foot
psi	pound(s) per square inch
®	registered (trademark)
USCS	Unified Soil Classification System

1 INTRODUCTION

Between May 2009 and January 2011, hydraulic performance testing was conducted by Colorado State University (CSU) on Drivable Grass®, manufactured by Soil Retention Products, Inc. A total of forty tests on five unvegetated installations were conducted under the test program. All configurations consisted of Drivable Grass® paver mats installed over an erodible soil bed. Information presented within this report documents the construction, testing procedures, resulting database and data analysis. In addition, this report provides information from the hydraulic testing of full-scale Drivable Grass® systems under controlled laboratory conditions for the identification of stability threshold conditions.

2 TEST PROGRAM

2.1 TEST FACILITIES

Performance testing of the Drivable Grass® system was conducted at the Hydraulics Laboratory of Colorado State University, located at the Engineering Research Center (ERC). Colorado State University's ERC is comprised of laboratories and offices encompassing virtually all engineering disciplines. Within the ERC, the Hydraulics Division, a subdivision of the Civil and Environmental Engineering Department, operates the Hydraulics Laboratory which has multiple indoor and outdoor facilities.

Outdoor facilities are gravity fed from Horsetooth Reservoir with a capacity of approximately 170,000 acre-ft of water and a maximum static pressure of approximately 110 pounds per square inch (psi) in the ERC pipe network. Each outdoor facility has an independent water delivery system. Indoor facilities are fed by a variety of pumps, as well as a gravity feed from Horsetooth Reservoir. Figure 2-1 presents a photograph of the Engineering Research Center and Horsetooth Reservoir.

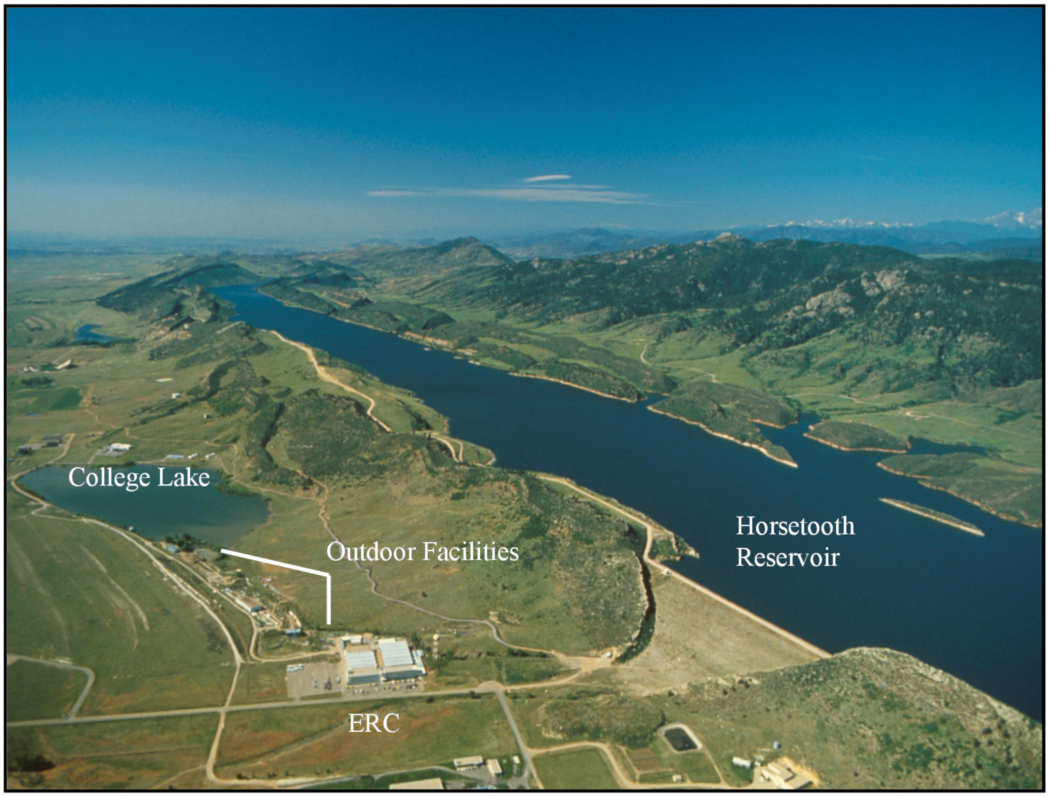


Figure 2-1: CSU's Engineering Research Center and Horsetooth Reservoir

For this testing program, two facilities were used. An existing adjustable-slope flume measuring 4-ft wide by 30-ft long was used for the first four configurations. The slope of the 4-ft wide flume was adjustable between 0 and 50 percent. Figure 2-2 presents a schematic of the 4-ft adjustable-slope flume used for the first four configurations. Head and toe plates contained an erodible bed, 12 inches deep, over which Drivable Grass® mats were installed. Water was supplied to the flume using a 125 horsepower centrifugal pump, and was measured by a combination of instrumentation, including an in-line annubar and an orifice plate. The second facility, which was used for the fifth configuration, was also an existing adjustable-slope flume measuring 2-ft wide by 40-ft long. The slope of the 2-ft wide flume was adjustable between 0 and 10 percent. Figure 2-3 presents a photograph of the 2-ft adjustable-slope flume used for the fifth configuration. Modified wooden transitions contained an erodible bed, over which Drivable Grass® mats were installed. Water was supplied to the flume using a variable-speed pump and was measured by a magnetic flow meter.

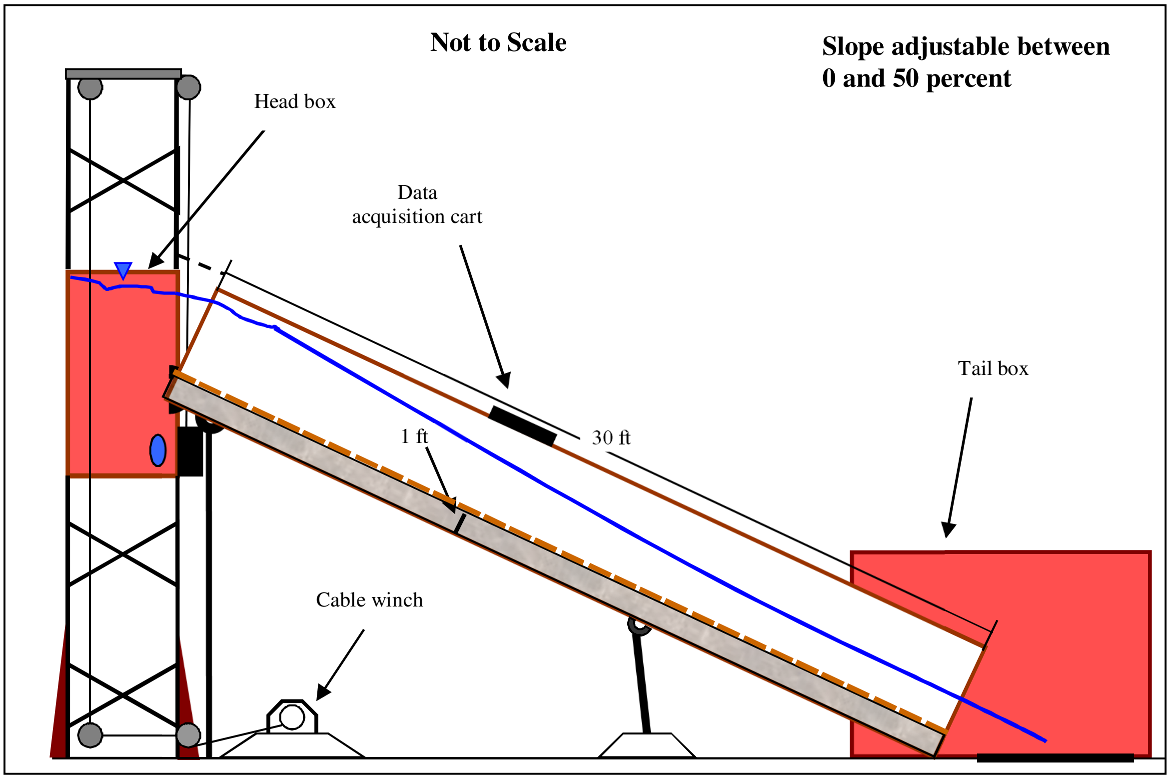


Figure 2-2: Four-foot wide adjustable-slope flume

Figure 2-3: Two-foot wide adjustable-slope flume

2.2 PRODUCT

The Drivable Grass® system, manufactured by Soil Retention Products, Inc., was tested to provide data consistent with the current methodologies for calculating hydraulic performance thresholds. The Drivable Grass® mats delivered to the Engineering Research Center were two feet square, and consisted of thirty-six four-inch square blocks measuring 1.5 inches in height. The blocks are cast together with polymer cord. Photographs of the uninstalled Drivable Grass® product are presented in Figure 2-4. Appendix A provides the product data sheet for the Drivable Grass® system.

Figure 2-4: Drivable Grass® paver mat from Soil Retention Products, Inc.

2.3 CONSTRUCTION

To determine hydraulic performance thresholds, five configurations of the Drivable Grass® system were tested. All configurations were installed to the specifications of Soil Retention Products, Inc. under the guidance of the Principal Investigator. The objective of testing five configurations was to examine the performance of unvegetated reinforced and unreinforced plots utilizing the Drivable Grass® system. A summary of the tested configurations is presented in Table 2-1.

Table 2-1: Configuration matrix

Configuration No.	Facility	Reinforcement	Concrete Paver	Mat Configuration
1	4-ft indoor adjustable-slope flume	None	Drivable Grass®	A
2	4-ft indoor adjustable-slope flume	None	Drivable Grass®	B
3	4-ft indoor adjustable-slope flume	W.E. Excel R-1	Drivable Grass®	B
4	4-ft indoor adjustable-slope flume	Miramesh® GR	Drivable Grass®	B
5	2-ft indoor adjustable-slope flume	W.E. Excel R-2	Drivable Grass®	C

For each configuration, soil was installed in the test section in 6-in. lifts and compacted using a plate compactor and steel hand tamp. For Configurations 1 through 4, soil moisture content and in-situ dry unit weight were determined by nuclear density gage along the centerline of the embankment as determined by Terracon, Inc. (ASTM D6938). Compaction verifications for Configurations 1 through 4 are provided in Appendix B. For Configuration 5, the in-place soil water content and compaction were determined by ASTM 2216 and 1556, respectively. A clayey sand, SC, as classified by the Unified Soil Classification System (USCS) was used for all embankments. Subgrade properties are located in Appendix C.

Following soil compaction, Drivable Grass® mats were installed in the facility. For Configurations 1 and 2, Drivable Grass® mats were placed directly on the compacted embankment without any ancillary reinforcement. For Configuration 3, an erosion control blanket (ECB), Western Excelsior Excel R-1, was placed between the compacted embankment and Drivable Grass®. For Configuration 4, a geosynthetic mesh, Miramesh® GR, was installed between the compacted embankment and Drivable Grass®. For Configuration 5, the Western Excelsior R-2 ECB was placed between the compacted embankment and Drivable Grass®. Appendix A provides product data sheets for both ECBs and the geosynthetic mesh.

Three mat placements were used during installation, and schematics of mat placement configurations are presented in Figure 2-5. Configuration 1 utilized mat placement Configuration A which was a non-staggered installation; and Configurations 2, 3, and 4, utilized Configuration B which was a staggered installation. Configuration 5 utilized Configuration C, which was also a non-staggered installation, although the Drivable Grass® mats were trimmed to dimensions of 2 ft by 1.67 ft for installation into the 2-ft facility. For Configurations 3 and 4, the reinforcement materials were attached to the upstream and downstream transitions using silicone adhesive, and the final two Drivable Grass® mats on each embankment were fixed in place with turf staples. For Configuration 5, 12-inch turf spikes were placed at a density of one per 0.83 ft^2 of mat along the entire length of the embankment. The position of the turf spikes for Configuration 5 is presented in Figure 2-5 (C).

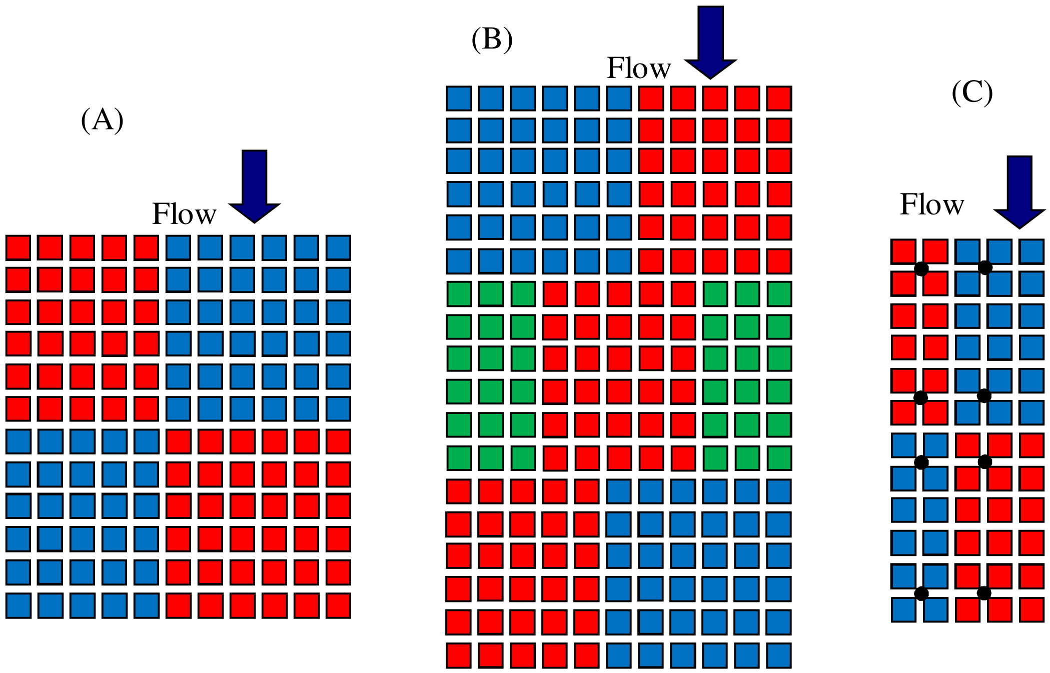


Figure 2-5: Block installation for Configuration 1 (A), Configurations 2, 3, and 4 (B), and Configuration 5 (C) (with anchoring)

2.4 TEST PROCEDURE

A test was defined as a continuous 1.0-hr flow over the system at a uniform discharge. The performance threshold for the Drivable Grass® system was defined as 0.5 inches of soil loss as computed using the Clopper Soil Loss Index (CSLI). Appendix D summarizes the CSLI computation procedure. A secondary performance threshold was identified as movement of the Drivable Grass® mats, or when the system was mechanically compromised. If the system endured the 1.0-hr flow without surpassing the defined thresholds, the procedure was repeated at a larger discharge or at a greater slope. Prior to each test, the system was seasoned with nominal flow before increasing the discharge to the target flow rate.

For each test, water-surface elevations were recorded at the beginning of each 1.0-hr long flow along the centerline of the flume at approximately 2-ft station intervals along the slope. Bed elevations (top of embankment surface) were established prior to the test at the same measurement stations as the water-surface readings. Bed and water-surface elevation measurements were recorded to the nearest 0.01 ft using a total station and point gage. Upon successful completion of the predefined 1.0-hr long continuous flow, the system was inspected and bed readings were recorded for each station.

3 TESTING SUMMARY AND DATABASE

Hydraulic testing of the Drivable Grass® system was completed between May 11th, 2009 and January 6th, 2011; resulting data were entered into a database for analysis. Table 3-1 presents the test matrix for the Drivable Grass® configurations which includes 40 total tests with five system configurations. Subsequent sections present data, describe conditions during testing, and provide testing photographic documentation.

Table 3-1: Drivable Grass® test matrix

Configuration	Description	Test Number	Unit Discharge (cfs)	Bed Slope (ft/ft)
1	Drivable Grass® mats w/o staggered installation	1	1.25	0.0035
	Drivable Grass® mats w/o staggered installation	2	2.45	0.0035
2	Drivable Grass® mats staggered installation	3	1.25	0.0022
	Drivable Grass® mats staggered installation	4	2.50	0.0022
3	Drivable Grass® mats with Excel R-1	5	1.25	0.0025
	Drivable Grass® mats with Excel R-1	6	2.50	0.0025
	Drivable Grass® mats with Excel R-1	7	3.13	0.0025
	Drivable Grass® mats with Excel R-1	8	3.75	0.0025
	Drivable Grass® mats with Excel R-1	9	4.38	0.0025
	Drivable Grass® mats with Excel R-1	10	5.00	0.0025
	Drivable Grass® mats with Excel R-1	11	6.18	0.0025
	Drivable Grass® mats with Excel R-1	12	1.25	0.0270
	Drivable Grass® mats with Excel R-1	13	2.50	0.0270
	Drivable Grass® mats with Excel R-1	14	3.13	0.0270
	Drivable Grass® mats with Excel R-1	15	3.75	0.0270
	Drivable Grass® mats with Excel R-1	16	4.38	0.0270
	Drivable Grass® mats with Excel R-1	17	5.00	0.0270
	Drivable Grass® mats with Excel R-1	18	6.10	0.0270
	Drivable Grass® mats with Excel R-1	19	1.25	0.1000
	Drivable Grass® mats with Excel R-1	20	2.50	0.1000
4	Drivable Grass® mats with Miramesh® GR	21	1.25	0.0040
	Drivable Grass® mats with Miramesh® GR	22	2.50	0.0040
	Drivable Grass® mats with Miramesh® GR	23	3.13	0.0040
	Drivable Grass® mats with Miramesh® GR	24	3.75	0.0040
	Drivable Grass® mats with Miramesh® GR	25	4.38	0.0040
	Drivable Grass® mats with Miramesh® GR	26	5.00	0.0040
	Drivable Grass® mats with Miramesh® GR	27	6.15	0.0040
	Drivable Grass® mats with Miramesh® GR	28	1.25	0.0270
	Drivable Grass® mats with Miramesh® GR	29	2.50	0.0270
	Drivable Grass® mats with Miramesh® GR	30	3.13	0.0270
	Drivable Grass® mats with Miramesh® GR	31	3.75	0.0270
5	Drivable Grass® mats with Excel R-2	32	0.22	0.0250
	Drivable Grass® mats with Excel R-2	33	0.75	0.0250
	Drivable Grass® mats with Excel R-2	34	1.48	0.0250
	Drivable Grass® mats with Excel R-2	35	1.50	0.0750
	Drivable Grass® mats with Excel R-2	36	2.50	0.0750
	Drivable Grass® mats with Excel R-2	37	4.05	0.0750
	Drivable Grass® mats with Excel R-2	38	2.50	0.1010
	Drivable Grass® mats with Excel R-2	39	3.50	0.1010
	Drivable Grass® mats with Excel R-2	40	4.68	0.1010

3.1 CONFIGURATION 1: DRIVABLE GRASS® WITH MAT CONFIGURATION A

Testing conducted on Configuration 1 utilized the Drivable Grass® system, arranged according to Mat Configuration A. A total of two tests with a 0.35 percent bed slope were performed on Configuration 1. During Test 2, the system became mechanically compromised, indicating that the performance threshold had been exceeded; however, test-reach averaged CSLI exceeding 0.5 inches was not measured. Test 2 was shutdown prior to the designated 1-hr duration. Figure 3-1 presents a photograph of Test 1 (Configuration 1) and Figure 3-2 presents a photograph of the test section following Test 2. Hydraulic and soil loss data collected during the testing of Configuration 1 are located in Appendix E.

Figure 3-1: Drivable Grass® system during Test 1 (Configuration 1)

Figure 3-2: Drivable Grass® system following final test of Configuration 1 (Test 2)

3.2 CONFIGURATION 2: DRIVABLE GRASS® WITH MAT CONFIGURATION B

Testing conducted on Configuration 2 utilized the Drivable Grass® system, arranged according to Mat Configuration B. A total of two tests with a 0.22 percent bed slope were performed on Configuration 2. During Test 4, the system became mechanically compromised, indicating that the performance threshold had been exceeded; however, test-reach averaged CSLI exceeding 0.5 inches was not measured. Test 4 was conducted for the full 1-hr duration. Figure 3-3 presents a photograph of Test 3 (Configuration 2) and Figure 3-4 presents a photograph of the test section following Test 4. Hydraulic and soil loss data collected during the testing of Configuration 2 are located in Appendix E.

Figure 3-3: Drivable Grass® system during Test 3 (Configuration 2)

Figure 3-4: Drivable Grass® system following final test of Configuration 2 (Test 4)

3.3 CONFIGURATION 3: ECB REINFORCED DRIVABLE GRASS® WITH MAT CONFIGURATION B

Configuration 3 was composed of the Drivable Grass® mats reinforced with an erosion control blanket: Excel R-1 manufactured by Western Excelsior. Technical documentation for the Excel R-1 is provided in Appendix A. Testing of Configuration 3 included a total of sixteen tests conducted on three bed slopes 0.25, 2.7, and 10.0 percent. At the onset of Test 20 of Configuration 3, mat movement was observed at the end of the test section. The discharge was terminated and investigation of the test section determined that the system had become mechanically compromised. Test 20 was shutdown prematurely of the designated 1-hr duration. During Test 20, material failure occurred prior to the collection of hydraulic data. Figure 3-5 presents a photograph of Test 19 (Configuration 3) and Figure 3-6 presents a photograph of the test section following Test 20.

Figure 3-5: Drivable Grass® system during Test 19 (Configuration 3)

Figure 3-6: Drivable Grass® system following final test of Configuration 3 (Test 20)

3.4 CONFIGURATION 4: GEOSYNTHETIC REINFORCED DRIVABLE GRASS® WITH MAT CONFIGURATION B

Configuration 4 was composed of Drivable Grass® mats reinforced with a biaxial, woven geosynthetic fabric, Miramesh® GR, manufactured by TenCate. Technical documentation for the Miramesh® GR is provided in Appendix A. Testing of Configuration 4 included a total of eleven tests conducted on two bed slopes 0.40 and 2.7. At the conclusion of Test 31, soil loss resulting in mat deformation was observed. Figure 3-7 presents a photograph of Test 30 (Configuration 4) and Figure 3-8 presents a photograph of the test section following Test 31. Hydraulic and soil loss data collected during the testing of Configuration 4 are provided in Appendix E.

Figure 3-7: Drivable Grass® system during Test 30 (Configuration 4)

Figure 3-8: Drivable Grass® system following final test of Configuration 4 (Test 31)

3.5 CONFIGURATION 5: ECB REINFORCED DRIVABLE GRASS® WITH MAT CONFIGURATION C

Configuration 5 was composed of the Drivable Grass® mats reinforced with an erosion control blanket: Excel R-2 manufactured by Western Excelsior. Technical documentation for the Excel R-2 is provided in Appendix A. Testing of Configuration 5 included a total of nine tests conducted on three bed slopes 2.5, 7.5, and 10.1 percent. The Drivable Grass® mat and Excel R-2 system reached the discharge and slope facility limits without the test-reach averaged CSLI exceeding 0.5 inches or mechanical failure. Figure 3-9 presents a photograph of Test 40 (Configuration 5) and Figure 3-10 presents a photograph of the test section following Test 40.

Figure 3-9: Drivable Grass® system during Test 40 (Configuration 5)

Figure 3-10: Drivable Grass® system following final test of Configuration 5 (Test 40)

4 ANALYSIS

Hydraulic and soil loss analyses were conducted for all collected water surface and bed elevation data. Average shear stress and average flow velocity were computed and compared to the computed CSLI. Both supercritical and subcritical flow regimes were observed during testing. Subcritical tests were analyzed using a standard-step backwater model, while supercritical tests were analyzed using a standard-step forewater model. Representative flow profiles for the subcritical model and supercritical model are presented below in Figure 4-1 and Figure 4-2. Flow depths from the respective model outputs were used with the momentum equation to calculate shear stress using Equation 4.1:

$$\boldsymbol{\tau_o = \frac{\gamma}{2}(y_1 + y_2)sin\theta + \frac{1}{L}\left[\frac{\gamma}{2}\left(y_1^2 + y_2^2\right)cos\theta - \rho q^2\left(\frac{1}{y_2} + \frac{1}{y_1}\right)\right]}$$ Equation 4.1

where:

τ_o = control volume shear stress (lbs/ft^2);

γ = unit weight of water (62.4 lbs/ft^3);

y_1 = upstream vertical flow depth of control volume (ft);

y_2 = downstream vertical flow depth of control volume (ft);

θ = angle of the embankment with respect to horizontal (ft/ft);

L = control-volume length (ft);

ρ = density of water (1.94 slugs/ft^3); and

q = unit discharge (cfs/ft).

Additionally, flow velocity was computed using the continuity equation, presented in Equation 4.2:

$$\boldsymbol{V = Q/A}$$ Equation 4.2

where:

V = local cross-sectional averaged flow velocity (ft/s);

Q = volumetric flow rate (cfs); and

A = flow area (ft^2).

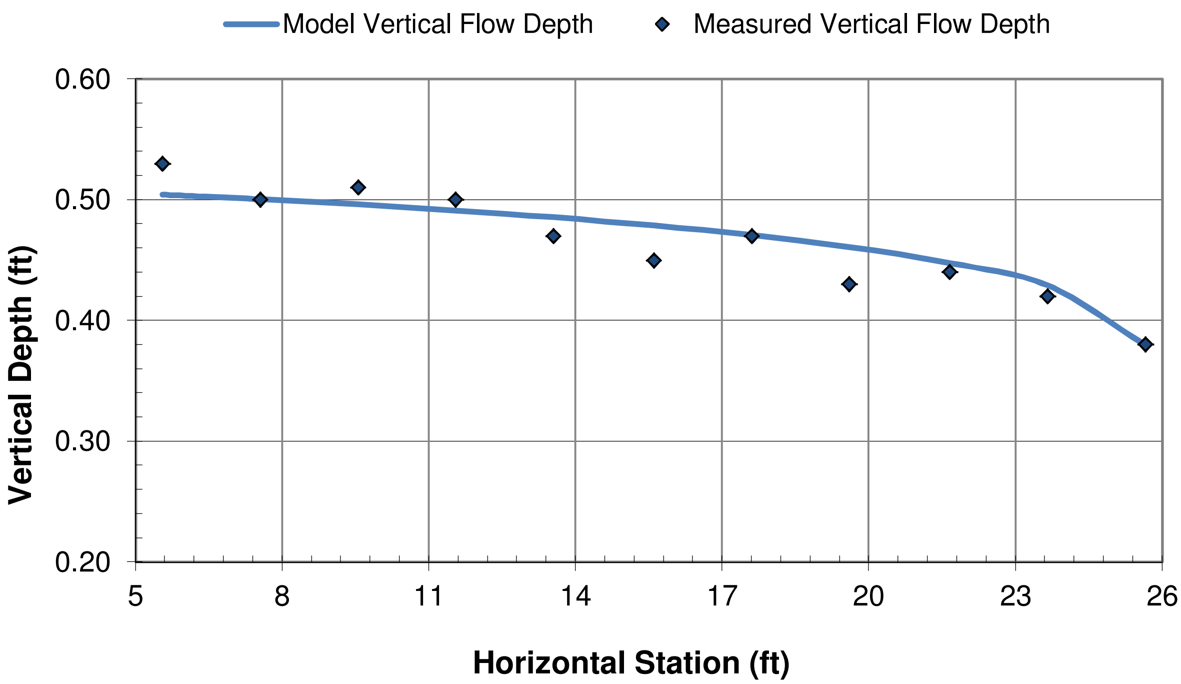


Figure 4-1: Subcritical model and measured vertical flow depths for Test 1 (Configuration 1, M2 profile)

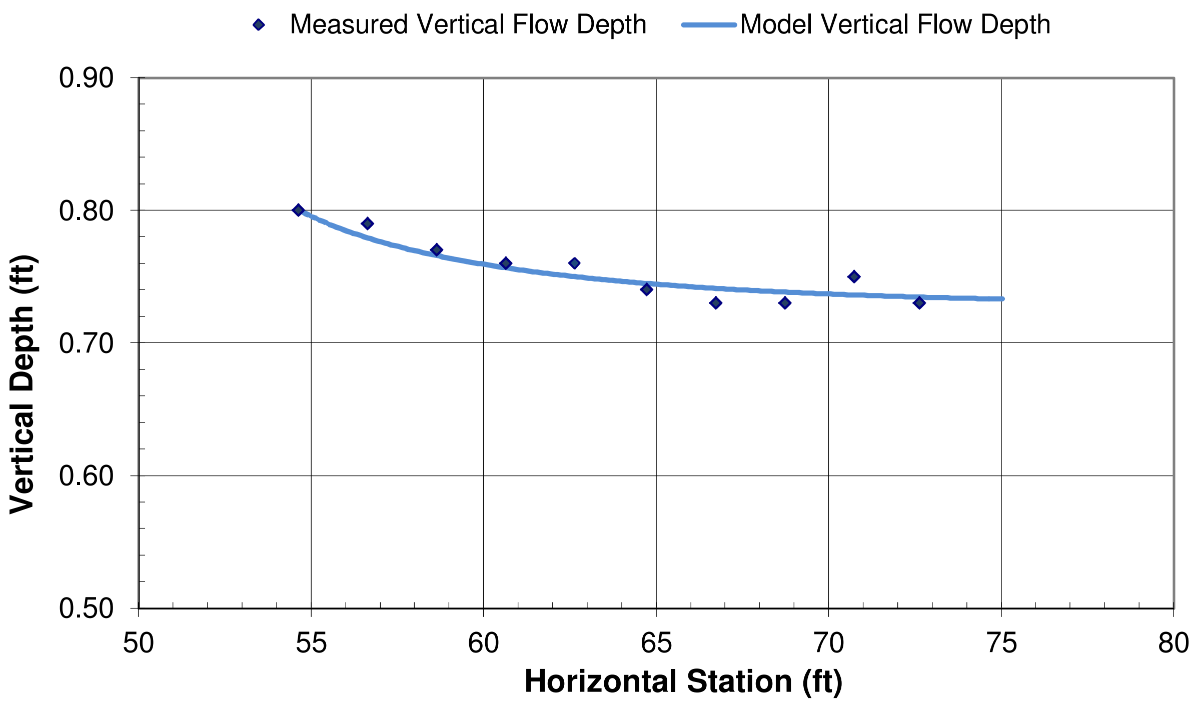


Figure 4-2: Supercritical model and measured vertical flow depths for Test 17 (Configuration 3, S2 profile)

For each test, the shear stress and flow velocity averaged over the entire test section were calculated and plotted against the CSLI. Figure 4-3 and Figure 4-4 present average flow velocity and average shear stress versus CSLI, respectively, for Configuration 1 and Configuration 2; Figure 4-5 and Figure 4-6 present average flow velocity and average shear stress versus CSLI, respectively, for Configuration 3 and Configuration 4; and Figure 4-7 and Figure 4-8 present average flow velocity and average shear stress versus CSLI, respectively, for Configuration 5. When applicable, computed soil loss near the transition from the headbox to the embankment was neglected due to entrance effects. Additionally represented in the flow velocity and shear stress versus CSLI plots are the results for bare-soil testing. Table 4-1 provides a summary of bare-soil testing results for comparison.

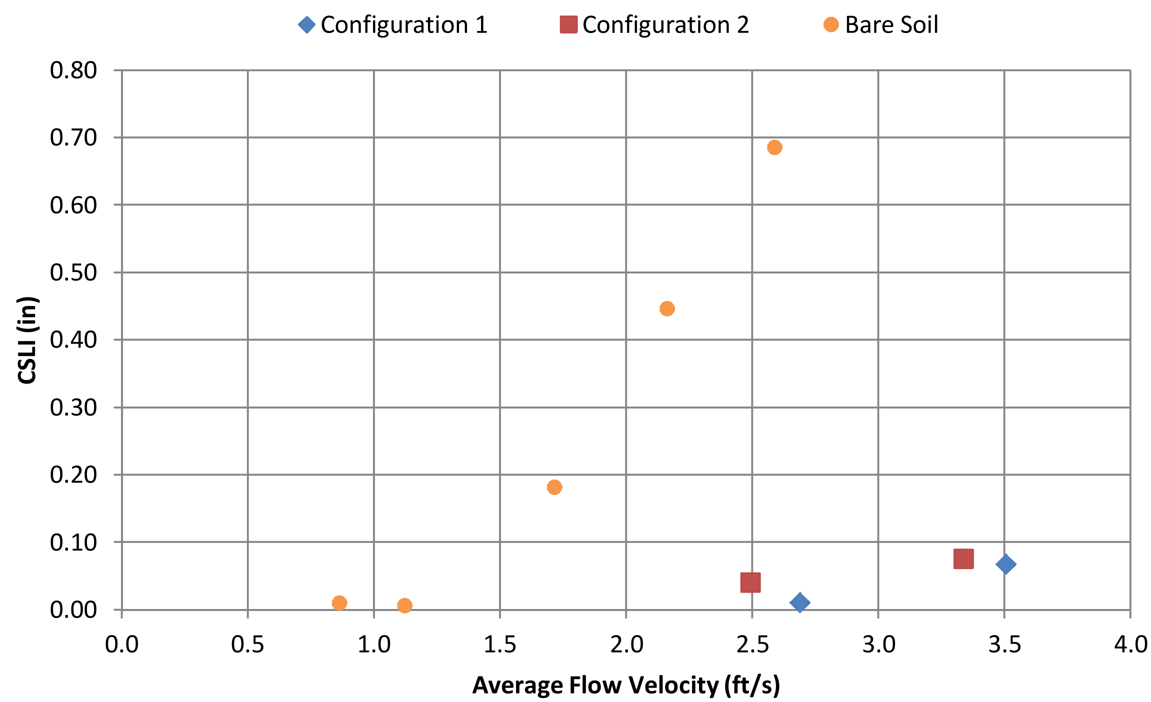


Figure 4-3: Average flow velocity vs. CSLI for Configuration 1 and Configuration 2

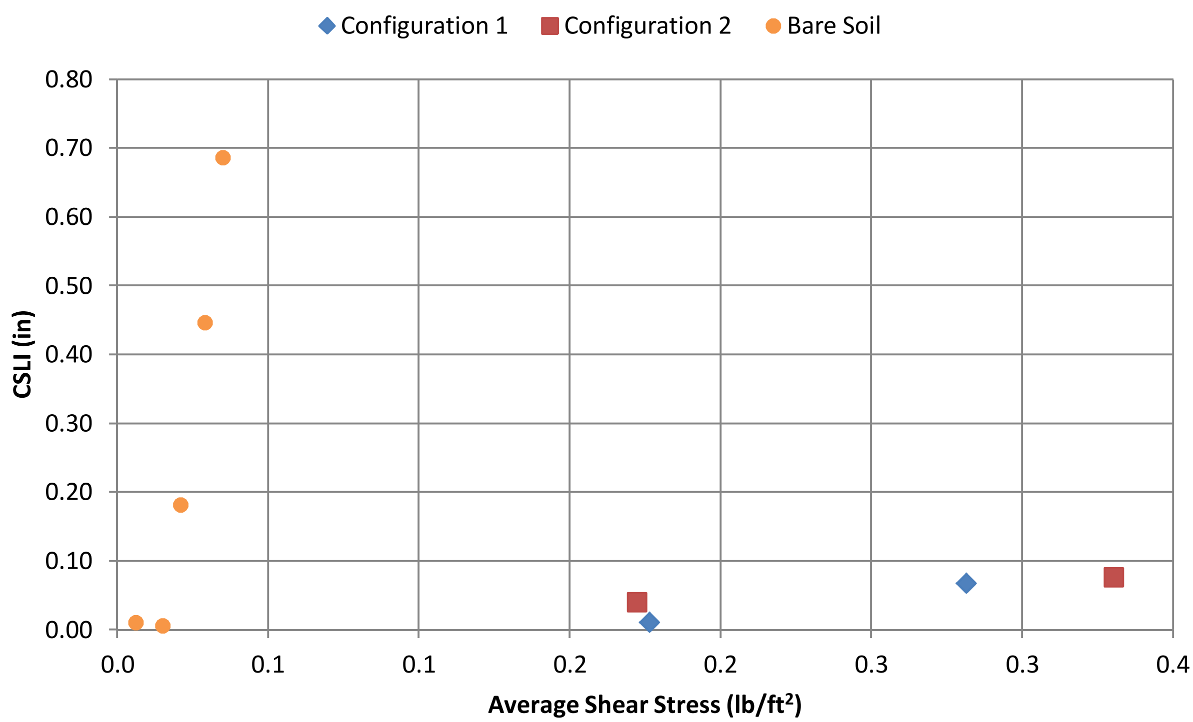


Figure 4-4: Average shear stress vs. CSLI for Configuration 1 and Configuration 2

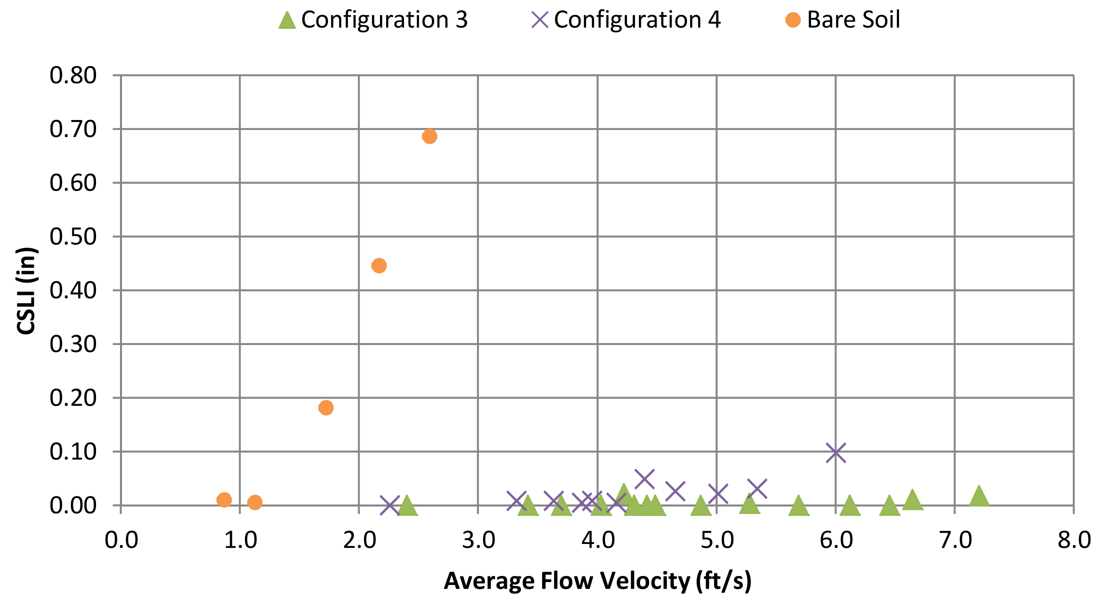


Figure 4-5: Average flow velocity vs. CSLI for Configuration 3 and Configuration 4

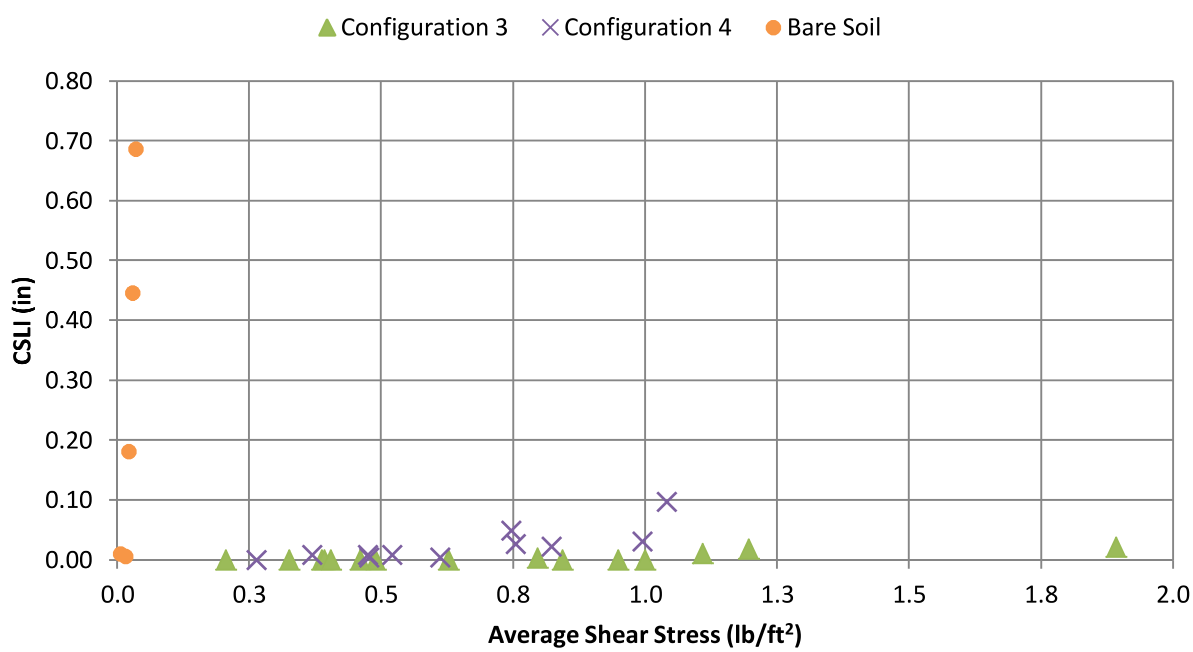


Figure 4-6: Average shear stress vs. CSLI for Configuration 3 and Configuration 4

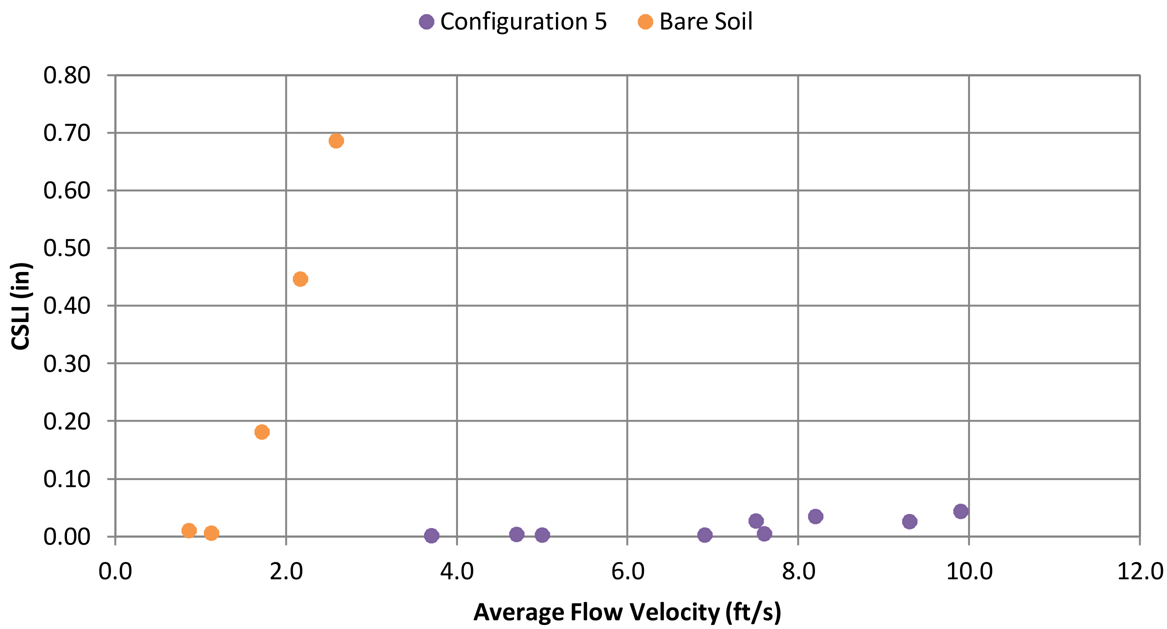


Figure 4-7: Average flow velocity vs. CSLI for Configuration 5

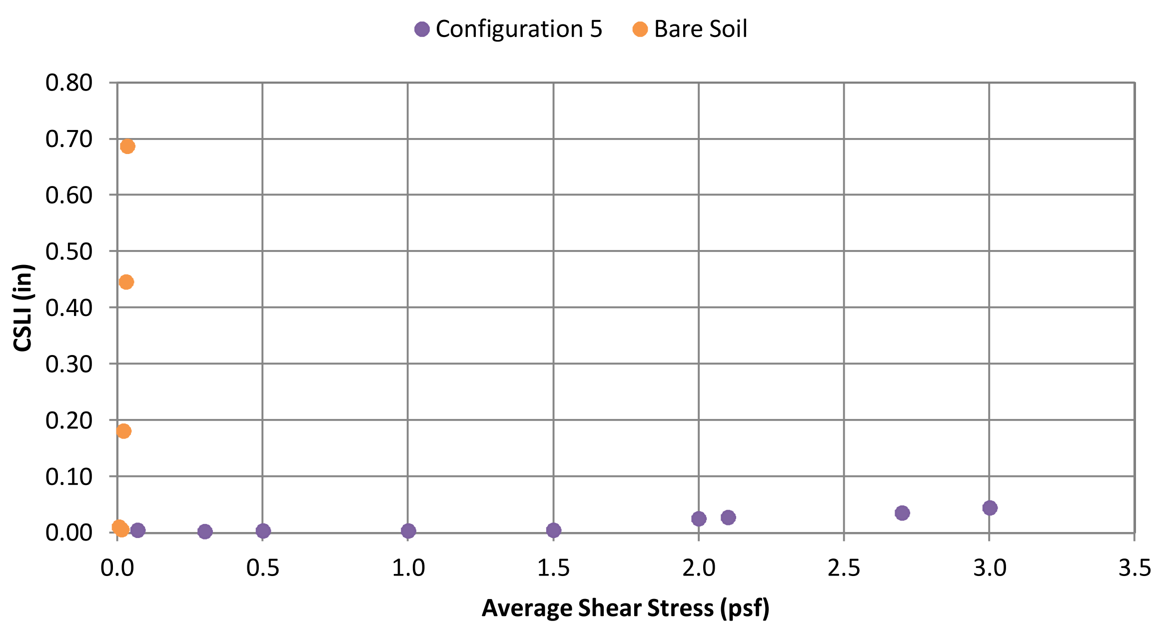


Figure 4-8: Average shear stress vs. CSLI for Configuration 5

Table 4-1: Summary of bare-soil performance

Shear Stress (lb/ft^2)	Velocity (ft/s)	CSLI (in)
0.006	0.86	0.01
0.015	1.12	0.01
0.021	1.72	0.18
0.029	2.16	0.45
0.035	2.59	0.69

Manning's *n* was computed for each configuration using the standard step hydraulic models. Table 4-2 presents a summary of unit discharge, bed slope, average velocity, average shear stress, Manning's *n*, and system condition for the Drivable Grass® system for each test. The bed slopes presented in Table 4-2 represent the initial bed slope, and do not present test-to-test variations incurred through erosion and deposition, although these considerations were taken into account in the hydraulic models. Figure 4-9 displays the relationship between Manning's *n* and the unit discharge for Configurations 1 and 2 (Drivable Grass® mats with bare soil), Figure 4-10 displays Manning's *n* versus unit discharge for Configuration 4 (Drivable Grass® mats with Miramesh® GR), and Figure 4-11 displays Manning's *n* versus unit discharge for Configurations 3 and 5 (Drivable Grass® mats with ECB).

Table 4-2: Hydraulic summary data for all configurations

Configur-ation	Description	Test	Discharge (cfs)	Unit Discharge (cfs)	Froude Number	Initial Bed Slope (ft/ft)	Actual Bed Slope (ft/ft)	Average Velocity (ft/s)	Average Shear Stress (lb/ft^2)	Maximum Velocity (ft/s)	Maximum Shear Stress (lb/ft^2)	Manning's n	CSLI (in)	Condition
1	Drivable Grass® Mats with Bare Soil	1	5.0	1.3	0.70	0.0035	0.0035	2.7	0.2	3.1	0.2	0.026	0.01	Stable
	Drivable Grass® Mats with Bare Soil	2*	9.8	2.5	0.75	0.0035	0.0033	3.5	0.3	3.7	0.3	0.027	0.07*	Unstable
2	Drivable Grass® Mats, offset, with Bare Soil	3	5.0	1.3	0.63	0.0022	0.0022	2.5	0.2	2.8	0.2	0.028	0.04	Stable
	Drivable Grass® Mats, offset, with Bare Soil	4	10.0	2.5	0.69	0.0022	0.0021	3.3	0.3	3.4	0.3	0.031	0.08	Unstable
3	Drivable Grass® Mats with Excel R-1	5	5.0	1.3	0.59	0.0025	0.0026	2.4	0.2	2.7	0.3	0.032	0.00	Stable
	Drivable Grass® Mats with Excel R-1	6	10.0	2.5	0.71	0.0025	0.0030	3.4	0.3	3.9	0.4	0.030	0.00	Stable
	Drivable Grass® Mats with Excel R-1	7	12.5	3.1	0.71	0.0025	0.0025	3.7	0.4	4.3	0.5	0.031	0.00	Stable
	Drivable Grass® Mats with Excel R-1	8	15.0	3.8	0.74	0.0025	0.0023	4.0	0.4	4.6	0.5	0.029	0.00	Stable
	Drivable Grass® Mats with Excel R-1	9	17.5	4.4	0.76	0.0025	0.0020	4.3	0.4	4.9	0.5	0.028	0.00	Stable
	Drivable Grass® Mats with Excel R-1	10	20.0	5.0	0.75	0.0025	0.0022	4.5	0.5	5.1	0.6	0.030	0.00	Stable
	Drivable Grass® Mats with Excel R-1	11	24.7	6.2	0.77	0.0025	0.0028	4.9	0.6	5.6	0.8	0.032	0.00	Stable
	Drivable Grass® Mats with Excel R-1	12	5.0	1.3	1.46	0.0270	0.0265	4.4	0.5	4.4	0.5	0.023	0.00	Stable
	Drivable Grass® Mats with Excel R-1	13	10.0	2.5	1.37	0.0270	0.0281	5.3	0.8	5.4	0.8	0.028	0.00	Stable
	Drivable Grass® Mats with Excel R-1	14	12.5	3.1	1.36	0.0270	0.0262	5.7	0.8	5.8	0.9	0.027	0.00	Stable
	Drivable Grass® Mats with Excel R-1	15	15.0	3.8	1.39	0.0270	0.0265	6.1	0.9	6.2	1.0	0.028	0.00	Stable
	Drivable Grass® Mats with Excel R-1	16	17.5	4.4	1.38	0.0270	0.0262	6.5	1.0	6.6	1.0	0.027	0.00	Stable
	Drivable Grass® Mats with Excel R-1	17	20.0	5.0	1.35	0.0270	0.0260	6.6	1.1	6.8	1.2	0.028	0.01	Stable
	Drivable Grass® Mats with Excel R-1	18	24.4	6.1	1.38	0.0270	0.0258	7.2	1.2	7.4	1.3	0.028	0.02	Stable
	Drivable Grass® Mats with Excel R-1	19	5.0	1.3	1.37	0.1000	0.1036	4.2	1.9	4.2	1.9	0.050	0.02	Stable
	Drivable Grass® Mats with Excel R-1	20	10.0	2.5	n/a	0.1000	0.1000	n/a	n/a	n/a	n/a	n/a	n/a	Unstable
4	Drivable Grass® Mats with Miramesh® GR	21	5.0	1.3	0.53	0.0040	0.0045	2.3	0.3	2.5	0.3	0.039	0.00	Stable
	Drivable Grass® Mats with Miramesh® GR	22	10.0	2.5	0.67	0.0040	0.0044	3.3	0.4	3.6	0.4	0.033	0.01	Stable
	Drivable Grass® Mats with Miramesh® GR	23	12.5	3.1	0.69	0.0040	0.0050	3.6	0.5	4.0	0.6	0.035	0.01	Stable
	Drivable Grass® Mats with Miramesh® GR	24	15.0	3.8	0.69	0.0040	0.0054	3.9	0.6	4.3	0.8	0.038	0.00	Stable
	Drivable Grass® Mats with Miramesh® GR	25	17.5	4.4	0.71	0.0040	0.0054	4.2	0.5	4.6	0.6	0.037	0.00	Stable
	Drivable Grass® Mats with Miramesh® GR	26	20.0	5.0	0.72	0.0040	0.0054	4.4	0.7	4.9	0.9	0.038	0.05	Stable
	Drivable Grass® Mats with Miramesh® GR	27	24.6	6.2	0.71	0.0040	0.0054	4.6	0.8	4.9	0.9	0.037	0.03	Stable
	Drivable Grass® Mats with Miramesh® GR	28	5.0	1.3	1.22	0.0270	0.0270	4.0	0.5	4.0	0.5	0.028	0.01	Stable
	Drivable Grass® Mats with Miramesh® GR	29	10.0	2.5	1.25	0.0270	0.0273	5.0	0.8	5.1	0.8	0.030	0.02	Stable
	Drivable Grass® Mats with Miramesh® GR	30	12.5	3.1	1.24	0.0270	0.0278	5.3	1.0	5.4	1.0	0.032	0.03	Stable
	Drivable Grass® Mats with Miramesh® GR	31	15.0	3.8	1.33	0.0270	0.0284	6.0	1.0	6.1	1.1	0.030	0.10	Unstable
5	Drivable Grass® Mats with Excel R-2	32	0.4	0.2	3.84	0.0250	0.0252	4.7	0.1	4.7	0.1	0.006	0.00	Stable
	Drivable Grass® Mats with Excel R-2	33	1.5	0.8	1.43	0.0250	0.0254	3.7	0.3	3.7	0.3	0.022	0.00	Stable
	Drivable Grass® Mats with Excel R-2	34	3.0	1.5	1.62	0.0250	0.0251	5.0	0.4	5.0	0.5	0.021	0.00	Stable
	Drivable Grass® Mats with Excel R-2	35	3.0	1.5	2.56	0.0750	0.0747	6.8	1.0	6.9	1.0	0.021	0.00	Stable
	Drivable Grass® Mats with Excel R-2	36	5.0	2.5	2.25	0.0750	0.0746	7.4	1.5	7.6	1.5	0.026	0.01	Stable
	Drivable Grass® Mats with Excel R-2	37	8.1	4.1	2.34	0.0750	0.0743	8.9	1.8	9.3	2.0	0.025	0.03	Stable
	Drivable Grass® Mats with Excel R-2	38	5.0	2.5	2.25	0.1010	0.1008	7.4	2.0	7.5	2.1	0.030	0.03	Stable
	Drivable Grass® Mats with Excel R-2	39	7.0	3.5	2.18	0.1010	0.1009	8.1	2.6	8.2	2.7	0.032	0.04	Stable
	Drivable Grass® Mats with Excel R-2	40	9.4	4.7	2.43	0.1010	0.1010	9.6	2.7	9.9	3.0	0.029	0.04	Stable

n/a = not available due to failure prior to data collection,
*Test conducted for a duration of 43 minutes instead of the total hour

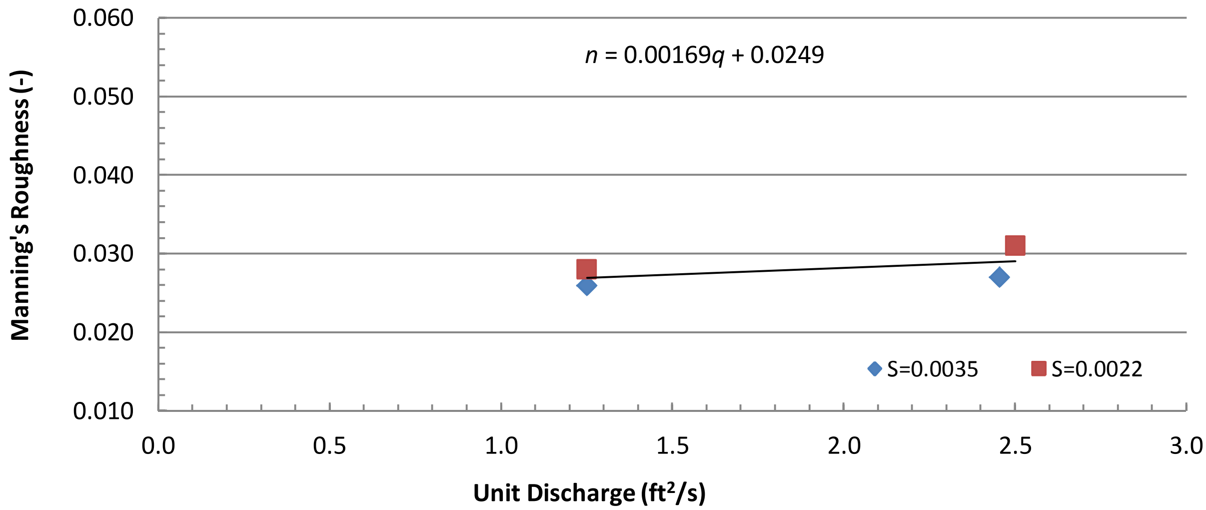


Figure 4-9: Manning's *n* vs. unit discharge for Configurations 1 and 2 (Drivable Grass® mats with bare soil)

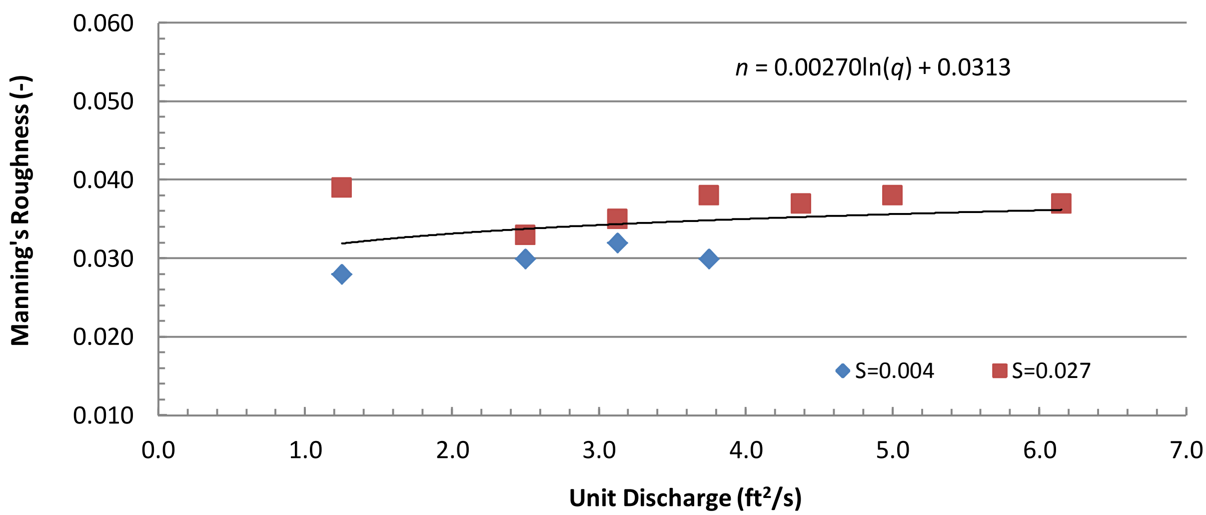


Figure 4-10: Manning's *n* vs. unit discharge for Configuration 4 (Drivable Grass® mats with Miramesh® GR)

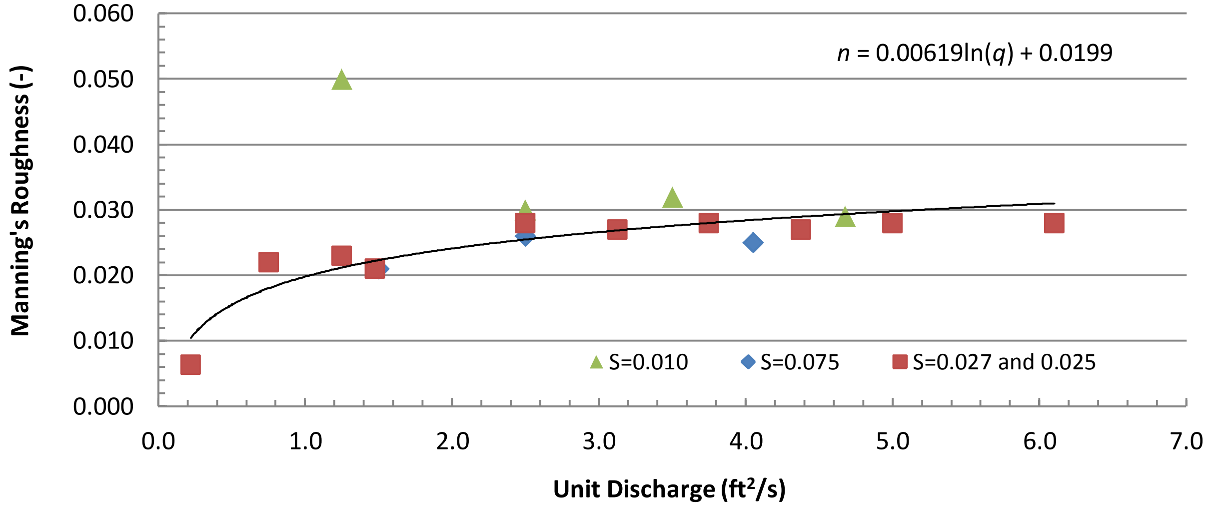


Figure 4-11: Manning's *n* vs. unit discharge for Configurations 3 and 5 (Drivable Grass® mats with ECB)

5 SUMMARY

Between May 2009 and January 2011, unvegetated reinforced erodible soil beds were tested to examine the performance of the Drivable Grass® systems, manufactured by Soil Retention Products, Inc. Tests were conducted on five distinct installations, including two testing series with Drivable Grass® mats on a bare-soil bed, two testing series with Drivable Grass® with an underlying erosion control blanket, and one testing series with Drivable Grass® with an underlying open mesh geotextile. The revetment systems were tested in two of CSU's adjustable-slope flumes. The test matrix incorporated varied discharges over several bed slopes to adequately determine the performance thresholds of the Drivable Grass® product. The following summarizes the performance of each configuration:

- Configuration 1 – Drivable Grass® mats installed on bare soil:
    - Maximum stable flow velocity equal to 3.1 ft/s
    - Maximum stable shear stress equal to 0.2 psf
- Configuration 2 – Drivable Grass® mats installed on bare soil with staggered installation:
    - Maximum stable flow velocity equal to 3.4 ft/s
    - Maximum stable shear stress equal to 0.3 psf
- Configuration 3 – Drivable Grass® mats reinforced with Excel R-1 ECB:
    - Maximum stable flow velocity equal to 7.4 ft/s occurred during Test 18 with a corresponding shear stress of 1.3 psf
    - Maximum stable shear stress equal to 1.9 psf occurred during Test 19 with a corresponding flow velocity of 4.2 ft/s
- Configuration 4 – Drivable Grass® mats reinforced with Miramesh® GR geosynthetic fabric:
    - Maximum stable flow velocity equal to 6.1 ft/s

    - Maximum stable shear stress equal to 1.1 psf
- Configuration 5 – Drivable Grass® mats reinforced with Excel R-2 ECB and 12-inch turf spikes:
    - Maximum stable flow velocity equal to 9.9 ft/s
    - Maximum stable shear stress equal to 3.0 psf
    - Not tested to failure

Testing was terminated on each configuration when 0.5 inches of CSLI was achieved, when the system became mechanically compromised, or when the maximum conditions available in the facility were reached. Data provided within this report offer a foundation for performance analysis and comparison of the Drivable Grass® system.

REFERENCES

ASTM Standard Test Method for Particle-Size Analysis of Soils. American Society for Testing and Materials, Standard D422.

ASTM (2000). Standard Test Method for Density and Unit Weight of Soil in Place by the Sand-Cone Method. American Society for Testing and Materials, Standard D1556.

ASTM Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass. Standard D2216 developed by Subcommittee D18.08 of the American Society for Testing and Materials.

ASTM Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System). American Society for Testing and Materials, Standard D2487.

ASTM Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils. American Society for Testing and Materials, Standard D4318.

ASTM (2000). Standard Test Method for Determination of Erosion Control Blanket (ECB) Performance in Protecting Earthen Channels from Stormwater-Induced Erosion. American Society for Testing and Materials, Standard D6460.

ASTM Standard Test Method for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth). Standard D6938 developed by Subcommittee D18.08 of the American Society for Testing and Materials.

APPENDIX A PRODUCT DATA SHEETS

LEED Credits and Potential Point Contributions

Section	Intent/Application	Example Uses	Credit	Points
Sustainable Sites				
Alternative Transportation	Parking Capacity	DRIVABLE GRASS® allows for overflow parking that would not count for excess of local zoning requirements	4.4	1
Site Development	Protect/Restore Habitat	Overflow Parking Stalls, Bioswale	5.1	1
Site Development	Maximize Open Spaces	Parking Stalls, Access Roads, Walkways /Pathways	5.2	1
Storm Water Design	Quantity Control	Bioswale, Trickle Channels, Parking Areas, Vegetated Roof	6.1	1
Storm Water Design	Quality Control Credit	Bioswale, Trickle Channels, Parking Areas, Vegetated Roof	6.2	1
Heat Island Effect	Non-Roof	Parking Areas and Access Roads	7.1	1
Heat Island Effect	Roof	Green Roof Pathways/Erosion Control	7.2	1
Water Efficiency				
Water Efficient Landscaping	Reduce by 50% or No Potable Water Use or Irrigation	Use as a permeable surface/filter to collect water which can then be used for landscaping Use with alternative infills or drought tolerant groundcovers or as part of a Xeriscape w/gravel infill for erosion control	1	2-4
Materials and Resources				
Recycled Content	10% / 20% (Post-Consumer + 1/2 Pre-Consumer)	45% Cement Replacement with Fly Ash in Concrete Mix	4	1-2
Regional Materials	10% / 20% Extracted Processed and Manufactured Regionally	We currently manufacture in several states. Please contact us for locations.	5	1-2
Innovation & Design Process				
Innovation in Design			1	1-5

Figure A-1: Drivable Grass® brochure information

WESTERN EXCELSIOR CORPORATION

IECA Member

QDOR Performance Verified

Material Properties and Dimensions

Description

Western Excelsior manufactures a full line of Rolled Erosion Control Products (RECPs). Excel R-1 temporary Erosion Control Blanket is composed of a 100% machine produced High Altitude Rocky Mountain Aspen Excelsior matrix mechanically (stitch) bonded on two inch centers to a single photodegradable, synthetic net. The excelsior matrix consists of curled, machine produced fibers with greater than eighty percent longer than six inches. Excel R-1 blanket is available in natural color or dyed green and is recommended for use in channels or slopes requiring erosion protection for a period up to eighteen months. Actual field longevity is dependent on soil and climatic conditions.

Specifications

Each roll of EXCEL R-1 is manufactured under Western Excelsior's Quality Assurance Program to ensure a continuous distribution of fibers and consistent thickness. Verified values are provided in Table 1 and product characteristics are provided in Tables 2 and 3. Values provided in Tables 1, 2 and 3 represent expected values at the time of manufacture. Installation instructions and performance data are available from Western Excelsior's Technical Support Division.

Table 1 - Verified Values

Tested Property	Test Method	Value	Units
Tensile Strength	ASTM D6818	5.0 (MD), 4.0 (TD)	lb/in
Elongation	ASTM D6818	15 (MD), 15 (TD)	%
Mass per Unit Area	ASTM D6475	11.5	oz/yd^2
Thickness	ASTM D6525	12.0	mm
Light Penetration	ASTM D6567	28	% open
Water Absorption	ASTM D1117	275	%

Table 2 - Netting

Top Net	Synthetic Photo-degradable
Bottom Net	N/A
Top Net Opening	1.00 in x 0.75 in (Nominal)
Bottom Net Opening	N/A

Table 3 - Roll Dimensions

Style	Narrow	Wide
Roll Width	4 ft	8 ft
Roll Length	180 ft	90 ft
Coverage	80 yd^2	80 yd^2
Roll Weight	65 lbs	65 lbs

Document # WE_EXCEL_R1_SPEC. This document has been developed to provide the characteristic properties of the product described. For questions, to request performance data or installation recommendations, contact Western Excelsior at 800-967-4009 or wexcotech@westernexcelsior.com. Updated 2/09.

Figure A-2: Western Excelsior Excel R-1 data sheet

Specifications

Western Excelsior manufactures a full line of Rolled Erosion Control Products (RECPs). Excel R-2 temporary Erosion Control Blanket is composed of a 100% machine produced High Altitude Rocky Mountain Aspen Excelsior matrix mechanically (stitch) bound on two inch centers between two photodegradable, synthetic nets. The excelsior matrix consists of curled, machine produced fibers with greater than eighty percent longer than six inches. Excel R-2 blanket is intended for use in channels or slopes requiring erosion protection for approximately eighteen to twenty-four months and is available in natural color or dyed green. Actual field longevity is dependent on soil and climatic conditions.

Each roll of EXCEL R-2 is manufactured under Western Excelsior's Quality Assurance Program to ensure a continuous distribution of fibers and consistent thickness. Verified index properties are provided in Table 1 and product characteristics are provided in Table 2.

Table 1- Specified Expected Values

Tested Property	Test Method	Value
Tensile Strength (MD) x (TD)	ASTM D6818	10.0 lb/in (1.8 kN/m) x 7.5 lb/in (1.3 kN/m)
Elongation (MD) x (TD)	ASTM D6818	15 % x 11 %
Mass Per Unit Area	ASTM D6475	9.1 oz/yd^2 (308 g/m^2)
Thickness	ASTM D6525	331 mils (8 mm)
Light Penetration	ASTM D6567	37 % open
Water Absorption	ASTM D1117	275 %

Table 2 - Netting

Top Net Type	Synthetic, Photodegradable
Bottom Net Type	Synthetic, Photodegradable
Top Net Opening Dimensions	0.8 in (20 mm) x 1.0 in (25 mm)
Bottom Net Opening Dimensions	0.8 in (20 mm) x 1.0 in (25 mm)

Excel R-2 is available in multiple roll sizes ranging in width from 4.0 ft to 16.0 ft. and 45 ft to 600 ft in length. Standard roll sizes are 80 square yards, measureing 4.0 ft wide by 180.0 ft long or 8.0 ft wide by 90 ft long. Custom roll sizes are available upon request.

Document # WE_EXCEL_R2_SPEC. This document has been developed to provide the characteristic properties of the product described. For questions, to request performance data or installation recommendations, contact Western Excelsior at 800-967-4009 or wexcotech@westernexcelsior.com. Updated 03/10/11.

Figure A-3: Western Excelsior Excel R-2 data sheet

TENCATE

Mirafi

Erosion Protection
Soil Reinforcement

Miramesh® GR

Miramesh® GR is composed of green high-tenacity monofilament polypropylene yarns that are woven together to produce an open mesh geotextile. Miramesh® GR is inert to biological degradation and resistant to naturally encountered chemicals, alkalis, and acids.

Mechanical Properties	Test Method	Unit	Minimum Average Roll Value	
			MD	CD
Tensile Strength (at ultimate)	ASTM D 4595	kN/m (lbs/ft)	21.0 (1440)	25.3 (1733)
Creep Reduced Strength	ASTM D 5262	kN/m (lbs/ft)	6.9 (471)	8.3 (566)
Long Term Allowable Design Load[1]	GRI GG-4	kN/m (lbs/ft)	5.9 (407)	7.2 (490)
UV Resistance (at 500 hours)	ASTM D 4355	% strength retained	90	

[1]NOTE: Long Term Allowable Design values are for sand, silt and clay.
Creep Reduction Factor based on 75-year design life.

Physical Properties	Test Method	Unit	Typical Value
Aperture Size (machine direction)	--	mm (in)	2 (0.08)
Aperture Size (cross machine direction)	--	mm (in)	2 (0.08)
Color	--	--	Green
Mass/Unit Area	ASTM D 5261	g/m^2 (oz/yd^2)	197 (5.8)
Roll Dimensions (width x length)	--	m (ft)	2.4 (8) x 40.7 (150)
Roll Area	--	m^2 (yd^2)	110 (133)
Estimated Roll Weight	---	kg (lbs)	23 (51)

TENCATE
materials that make a difference

FGS000084
ETQR11

Figure A-4: Mirafi Miramesh® GR data sheet

APPENDIX B COMPACTION VERIFICATION

Table B-1: Compaction testing results

Configuration Number	Test Date	Test Location	Wet Density (pcf)	Water Content (%)	Max. Dry Unit Wt. (pcf)	Dry Unit Weight (pcf)	Percent Compaction (%)
1	4/21/2009	S Side of Flume	118.3	5.6	122.2	112.0	92
1	4/21/2009	Middle of Flume	109.4	7.7	122.2	101.6	83
1	4/21/2009	N Side of Flume	110.2	6.8	122.2	103.2	84
1	4/21/2009	Middle of Flume	115.2	8.3	122.2	106.4	87
2	5/19/2009	Bottom	117.6	8.4	122.2	108.5	89
2	5/19/2009	Middle	122.1	8.7	122.2	112.3	92
2	5/19/2009	Top	120.1	10.7	122.2	108.5	89
3	6/1/2009	Bottom	116.2	8.7	122.2	106.9	87
3	6/1/2009	Middle	118.0	9.6	122.2	107.7	88
3	6/1/2009	Top	124.7	10.4	122.2	113.0	92
4	8/5/2009	Bottom	122.4	6.8	122.2	114.6	94
4	8/5/2009	Middle	125.2	11.1	122.2	112.7	92
4	8/5/2009	Bottom	122.8	8.1	122.2	113.6	93
4	8/5/2009	Top	114.1	6.8	122.2	106.8	87

ASTM D6938 testing conducted by Terracon

APPENDIX C SUBGRADE PROPERTIES

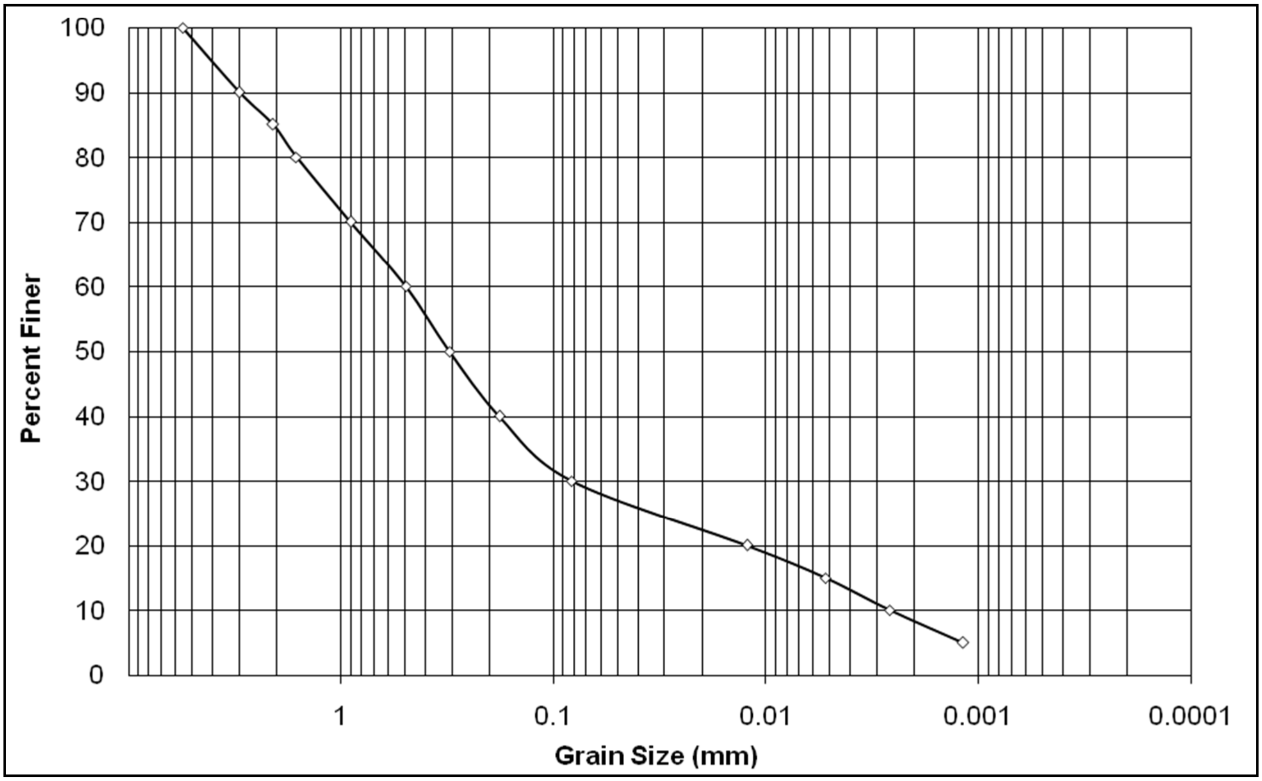


Figure C-1: Sub-grade grain size distribution

LABORATORY COMPACTION CHARACTERISTICS OF SOIL

Terracon

Report Number: 20041063.0071
Service Date: 08/12/08
Report Date: 08/20/08

301 N Howes
Ft Collins, CO 80521
970-484-0359

Client

Colorado State University
Attn: Amanda Cox
Engineering Research Center
1372 Campus Delivery
Fort Collins, CO 80523

Project

Engineering Research Center
4451 West Laporte Ave
Fort Collins, CO

Project Number 20041063

Material Information

Source of Material: Client Provided
Proposed Use: Flowfill Testing Soil

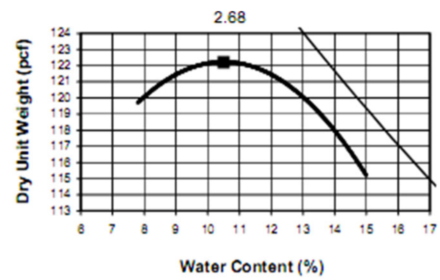
Sample Information

Sample Date: 08/12/08 **Sample Time:** 1630
Sampled By: James C. Bekins
Sample Location: Onsite Stockpile

Sample Description: Clayey sand

Laboratory Test Data

Test Procedure: ASTM D698
Test Method: Method A
Sample Preparation: Wet
Rammer Type: Manual
Maximum Dry Unit Weight (pcf): 122.2
Optimum Water Content (%): 10.5



Laboratory Test Data

	Result	Requirements
Liquid Limit:	30	
Plastic Limit:	20	
Plasticity Index:	10	
In-Place Moist. (%):		

Liquid Limit Method: Method A
Sample Preparation: Dry

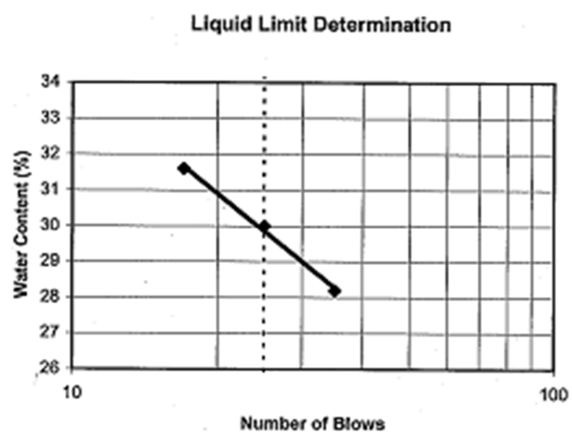


Figure C-2: Sub-grade material properties

APPENDIX D CLOPPER SOIL LOSS INDEX

SOIL-LOSS ANALYSIS

Soil loss at a given point was calculated for each test by computing the difference between the initial and final elevations. A cumulative soil loss was obtained by summing the previous test's soil loss with the current test. Equations D-1 and D-2 demonstrate the soil-loss calculations:

$$\text{Soil Loss}_i = (Z_{initial} - Z_{final}) * 12 \qquad \textbf{Equation D-1}$$

where: Soil Loss_i = incremental soil loss (in.);
$Z_{initial}$ = initial bed elevation or point-gage reading (ft); and
Z_{final} = final bed elevation or point-gage reading (ft).

$$\text{Cumulative Soil Loss} = \sum_1^i \text{Soil Loss}_i \qquad \textbf{Equation D-2}$$

where: Cumulative Soil Loss = total soil loss (in.);
Soil Loss_i = incremental soil loss (in.); and
i = number of discharges conveyed for test.

The method for estimating soil loss used a procedure based on the Clopper Soil Loss Index (CSLI) (as outlined in the ASTM (2000) D6460 Standard). The CSLI assigns a value of zero to any point in the control volume demonstrating a soil gain. The zero value is then averaged in with all other points in the control volume. This procedure is a compromise between including the increase in elevation as a gain and disregarding the point entirely.

Once the soil loss and hydraulic conditions were computed, a preferred method of calculating shear stress and soil loss was determined. The CSLI was used in conjunction with Equation D-2, using regressed values for flow depth and cross-section average velocity. The CSLI was chosen as a more conservative alternative to including soil gain and less extreme as discounting soil gain altogether.

APPENDIX E TEST DATA

Table E-1: Configuration 1 – Test 1 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
5.55	93.54	0.53	0.53	2.5	0.60	-	0.00
7.55	93.53	0.50	0.50	2.5	0.62	0.1	0.00
9.55	93.52	0.51	0.51	2.5	0.62	0.1	0.00
11.55	93.51	0.50	0.50	2.5	0.63	0.2	0.12
13.55	93.49	0.47	0.47	2.6	0.66	0.2	0.00
15.60	93.48	0.45	0.45	2.6	0.69	0.2	0.00
17.60	93.48	0.47	0.47	2.7	0.68	0.2	0.00
19.60	93.48	0.43	0.43	2.7	0.73	0.2	0.00
21.65	93.48	0.44	0.44	2.8	0.74	0.2	0.00
23.65	93.47	0.42	0.42	2.9	0.79	0.2	0.00
25.65	93.47	0.38	0.38	3.3	0.94	0.3	0.00

Table E-2: Configuration 1 – Test 2 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
5.55	93.55	0.76	0.76	3.2	0.65	-	0.00
7.55	93.54	0.77	0.77	3.3	0.65	0.2	0.00
9.55	93.53	0.79	0.79	3.3	0.65	0.2	0.00
11.55	93.52	0.76	0.76	3.3	0.67	0.2	0.12
13.55	93.50	0.74	0.74	3.4	0.69	0.3	0.00
15.60	93.48	0.71	0.71	3.4	0.71	0.3	0.00
17.60	93.49	0.70	0.70	3.4	0.73	0.3	0.00
19.60	93.50	0.63	0.63	3.5	0.78	0.3	0.00
21.65	93.50	0.63	0.63	3.6	0.80	0.3	0.00
23.65	93.48	0.60	0.60	3.7	0.85	0.3	0.24
25.65	93.48	0.55	0.55	4.5	1.06	0.4	0.38

Table E-3: Configuration 2 – Test 3 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
54.65	85.48	0.51	0.51	2.3	0.56	-	0.00
56.65	85.46	0.54	0.54	2.3	0.55	0.1	0.00
58.65	85.43	0.56	0.56	2.3	0.55	0.1	0.00
60.65	85.44	0.54	0.54	2.4	0.57	0.2	0.28
62.65	85.41	0.56	0.56	2.4	0.56	0.2	0.00
64.75	85.40	0.56	0.56	2.4	0.57	0.2	0.00
66.75	85.43	0.49	0.49	2.5	0.63	0.2	0.00
68.75	85.44	0.47	0.47	2.6	0.66	0.2	0.00
70.75	85.45	0.43	0.43	2.6	0.71	0.2	0.00
72.65	85.42	0.40	0.40	2.7	0.76	0.2	0.00
74.65	85.40	0.43	0.43	2.9	0.78	0.2	0.08

Table E-4: Configuration 2 – Test 4 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
54.65	85.49	0.74	0.74	3.0	0.62	-	0.00
56.65	85.46	0.81	0.81	3.1	0.60	0.3	0.00
58.65	85.44	0.81	0.81	3.1	0.61	0.3	0.00
60.65	85.43	0.83	0.83	3.1	0.61	0.3	0.00
62.65	85.42	0.84	0.84	3.2	0.61	0.3	0.00
64.75	85.40	0.85	0.85	3.2	0.62	0.3	0.00
66.75	85.44	0.75	0.75	3.3	0.67	0.3	0.00
68.75	85.45	0.73	0.73	3.4	0.70	0.3	0.00
70.75	85.45	0.67	0.67	3.5	0.76	0.4	0.08
72.65	85.43	0.59	0.59	3.7	0.84	0.4	0.32
74.65	85.40	0.61	0.61	4.1	0.92	0.5	0.28

Table E-5: Configuration 3 – Test 5 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
54.65	88.50	0.52	0.52	2.2	0.54	-	0.00
56.65	88.47	0.57	0.57	2.2	0.52	0.2	0.00
58.65	88.47	0.55	0.55	2.2	0.53	0.2	0.00
60.65	88.46	0.56	0.56	2.3	0.54	0.2	0.00
62.65	88.46	0.55	0.55	2.3	0.55	0.2	0.00
64.75	88.46	0.57	0.57	2.3	0.55	0.2	0.00
66.75	88.45	0.58	0.58	2.4	0.55	0.2	0.00
68.75	88.48	0.51	0.51	2.5	0.61	0.2	0.00
70.75	88.46	0.45	0.45	2.5	0.66	0.2	0.00
72.65	88.42	0.46	0.46	2.6	0.68	0.2	0.00
74.65	88.42	0.45	0.45	2.8	0.73	0.3	0.00

Table E-6: Configuration 3 – Test 6 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
54.65	88.49	0.77	0.77	3.1	0.63	-	0.00
56.65	88.46	0.82	0.82	3.1	0.61	0.3	0.00
58.65	88.45	0.80	0.80	3.2	0.63	0.3	0.00
60.65	88.45	0.80	0.80	3.2	0.63	0.3	0.00
62.65	88.44	0.78	0.78	3.3	0.65	0.3	0.00
64.75	88.44	0.77	0.77	3.3	0.67	0.3	0.00
66.75	88.42	0.83	0.83	3.4	0.65	0.3	0.00
68.75	88.46	0.68	0.68	3.5	0.74	0.3	0.00
70.75	88.44	0.59	0.59	3.6	0.82	0.4	0.00
72.65	88.40	0.59	0.59	3.7	0.85	0.4	0.00
74.65	88.41	0.60	0.60	4.2	0.95	0.5	0.00

Table E-7: Configuration 3 – Test 7 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
54.65	88.49	0.91	0.91	3.4	0.62	-	0.00
56.65	88.46	0.93	0.93	3.4	0.62	0.3	0.00
58.65	88.45	0.92	0.92	3.4	0.63	0.3	0.00
60.65	88.45	0.93	0.93	3.5	0.64	0.3	0.00
62.65	88.44	0.90	0.90	3.5	0.66	0.3	0.00
64.75	88.44	0.88	0.88	3.6	0.67	0.4	0.00
66.75	88.43	0.86	0.86	3.7	0.70	0.4	0.00
68.75	88.47	0.80	0.80	3.7	0.74	0.4	0.00
70.75	88.45	0.79	0.79	3.9	0.77	0.4	0.00
72.65	88.41	0.70	0.70	4.0	0.85	0.5	0.00
74.65	88.41	0.69	0.69	4.5	0.96	0.6	0.00

Table E-8: Configuration 3 – Test 8 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
54.65	88.48	0.97	0.97	3.7	0.66	-	0.00
56.65	88.46	1.04	1.04	3.7	0.64	0.3	0.00
58.65	88.45	1.03	1.03	3.8	0.65	0.3	0.00
60.65	88.45	1.03	1.03	3.8	0.66	0.3	0.00
62.65	88.44	0.98	0.98	3.9	0.69	0.4	0.00
64.75	88.44	0.96	0.96	3.9	0.71	0.4	0.00
66.75	88.43	0.94	0.94	4.0	0.73	0.4	0.00
68.75	88.47	0.89	0.89	4.1	0.76	0.4	0.00
70.75	88.45	0.80	0.80	4.2	0.83	0.4	0.00
72.65	88.41	0.78	0.78	4.4	0.87	0.5	0.00
74.65	88.41	0.77	0.77	4.9	0.98	0.6	0.00

Table E-9: Configuration 3 – Test 9 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
54.65	88.48	1.10	1.10	4.0	0.66	-	0.00
56.65	88.45	1.12	1.12	4.0	0.67	0.3	0.00
58.65	88.45	1.12	1.12	4.0	0.67	0.3	0.00
60.65	88.44	1.09	1.09	4.1	0.69	0.4	0.00
62.65	88.44	1.11	1.11	4.1	0.69	0.4	0.00
64.75	88.44	1.04	1.04	4.2	0.73	0.4	0.00
66.75	88.43	1.06	1.06	4.3	0.73	0.4	0.00
68.75	88.47	0.97	0.97	4.4	0.78	0.4	0.00
70.75	88.45	0.88	0.88	4.5	0.84	0.4	0.00
72.65	88.41	0.85	0.85	4.6	0.89	0.5	0.00
74.65	88.41	0.84	0.84	5.2	1.00	0.6	0.00

Table E-10: Configuration 3 – Test 10 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
54.65	88.48	1.14	1.14	4.1	0.68	-	0.00
56.65	88.45	1.24	1.24	4.2	0.66	0.4	0.00
58.65	88.45	1.23	1.23	4.2	0.67	0.4	0.00
60.65	88.45	1.21	1.21	4.3	0.68	0.4	0.00
62.65	88.44	1.19	1.19	4.3	0.70	0.4	0.00
64.75	88.44	1.19	1.19	4.4	0.71	0.5	0.00
66.75	88.43	1.14	1.14	4.5	0.74	0.5	0.00
68.75	88.47	1.08	1.08	4.6	0.77	0.5	0.00
70.75	88.44	1.00	1.00	4.7	0.82	0.5	0.00
72.65	88.41	0.94	0.94	4.8	0.88	0.6	0.00
74.65	88.41	0.94	0.94	5.3	0.97	0.7	0.00

Table E-11: Configuration 3 – Test 11 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
54.65	88.48	1.25	1.25	4.5	0.71	-	0.00
56.65	88.45	1.52	1.52	4.5	0.65	0.5	0.00
58.65	88.45	1.28	1.28	4.6	0.71	0.5	0.00
60.65	88.45	1.44	1.44	4.6	0.68	0.6	0.00
62.65	88.44	1.36	1.36	4.7	0.71	0.6	0.00
64.75	88.44	1.29	1.29	4.7	0.74	0.6	0.00
66.75	88.43	1.33	1.33	4.8	0.74	0.6	0.00
68.75	88.47	1.28	1.28	4.9	0.76	0.6	0.00
70.75	88.45	1.09	1.09	5.0	0.85	0.7	0.00
72.65	88.37	1.04	1.04	5.2	0.90	0.7	0.00
74.65	88.41	1.03	1.03	6.0	1.04	0.9	0.00

Table E-12: Configuration 3 – Test 12 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
54.63	88.87	0.26	0.26	-	-	-	0.00
56.63	88.79	0.29	0.29	4.3	1.41	-	0.00
58.63	88.75	0.27	0.27	4.4	1.48	0.4	0.00
60.63	88.69	0.29	0.29	4.4	1.44	0.5	0.00
62.63	88.64	0.28	0.28	4.4	1.47	0.5	0.00
64.73	88.59	0.29	0.29	4.4	1.45	0.5	0.00
66.73	88.54	0.28	0.28	4.4	1.48	0.5	0.00
68.73	88.51	0.30	0.30	4.4	1.43	0.5	0.00
70.73	88.45	0.28	0.28	4.4	1.48	0.5	0.00
72.62	88.37	0.28	0.28	4.4	1.48	0.5	0.00
74.62	88.31	0.28	0.28	4.4	1.48	0.5	0.00

Table E-13: Configuration 3 – Test 13 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
54.63	88.87	0.46	0.46	-	-	-	0.00
56.63	88.79	0.50	0.50	5.0	1.25	-	0.00
58.63	88.75	0.46	0.46	5.1	1.34	0.7	0.00
60.63	88.69	0.50	0.50	5.2	1.30	0.8	0.00
62.63	88.64	0.47	0.47	5.3	1.36	0.8	0.00
64.73	88.59	0.46	0.46	5.3	1.38	0.8	0.00
66.73	88.54	0.48	0.48	5.3	1.36	0.8	0.04
68.73	88.51	0.47	0.47	5.3	1.37	0.8	0.00
70.73	88.45	0.46	0.46	5.4	1.39	0.8	0.00
72.62	88.33	0.43	0.43	5.4	1.44	0.8	0.00
74.62	88.27	0.41	0.41	5.4	1.47	0.8	0.00

Table E-14: Configuration 3 – Test 14 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
54.63	88.87	0.54	0.54	-	-	-	0.00
56.63	88.79	0.58	0.58	5.4	1.25	-	0.00
58.63	88.75	0.52	0.52	5.5	1.35	0.8	0.00
60.63	88.69	0.55	0.55	5.6	1.34	0.8	0.00
62.63	88.64	0.55	0.55	5.7	1.35	0.8	0.00
64.73	88.59	0.53	0.53	5.7	1.39	0.8	0.00
66.73	88.57	0.56	0.56	5.8	1.35	0.9	0.00
68.73	88.51	0.56	0.56	5.8	1.36	0.9	0.00
70.73	88.45	0.52	0.52	5.8	1.41	0.9	0.00
72.62	88.38	0.54	0.54	5.8	1.39	0.9	0.00
74.62	88.31	0.51	0.51	5.8	1.43	0.9	0.00

Table E-15: Configuration 3 – Test 15 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
54.63	88.87	0.61	0.61	-	-	-	0.00
56.63	88.79	0.64	0.64	5.9	1.29	-	0.00
58.63	88.75	0.60	0.60	6.0	1.36	0.9	0.00
60.63	88.69	0.62	0.62	6.1	1.35	0.9	0.00
62.63	88.65	0.63	0.63	6.1	1.36	0.9	0.00
64.73	88.59	0.60	0.60	6.1	1.40	0.9	0.00
66.73	88.54	0.60	0.60	6.2	1.41	1.0	0.00
68.73	88.52	0.62	0.62	6.2	1.39	1.0	0.00
70.73	88.45	0.60	0.60	6.2	1.41	1.0	0.00
72.62	88.37	0.57	0.57	6.2	1.45	1.0	0.00
74.62	88.31	0.58	0.58	6.2	1.44	1.0	0.00

Table E-16: Configuration 3 – Test 16 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
54.63	88.87	0.70	0.70	-	-	-	0.00
56.63	88.79	0.72	0.72	6.1	1.26	-	0.00
58.63	88.75	0.70	0.70	6.2	1.31	0.9	0.00
60.63	88.69	0.68	0.68	6.3	1.36	0.9	0.00
62.63	88.65	0.72	0.72	6.4	1.33	1.0	0.00
64.73	88.59	0.67	0.67	6.5	1.40	1.0	0.00
66.73	88.56	0.67	0.67	6.5	1.41	1.0	0.00
68.73	88.52	0.68	0.68	6.6	1.40	1.0	0.00
70.73	88.46	0.66	0.66	6.6	1.43	1.0	0.00
72.62	88.37	0.63	0.63	6.6	1.47	1.0	0.00
74.62	88.31	0.64	0.64	6.6	1.46	1.0	0.00

Table E-17: Configuration 3 – Test 17 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
54.63	88.87	0.80	0.80	6.2	1.23	-	0.00
56.63	88.79	0.79	0.79	6.4	1.27	1.0	0.00
58.63	88.75	0.77	0.77	6.5	1.31	1.0	0.00
60.63	88.68	0.76	0.76	6.6	1.34	1.1	0.00
62.63	88.65	0.76	0.76	6.7	1.35	1.1	0.00
64.73	88.59	0.74	0.74	6.7	1.37	1.1	0.00
66.73	88.56	0.73	0.73	6.7	1.39	1.1	0.04
68.73	88.52	0.73	0.73	6.8	1.40	1.1	0.00
70.73	88.46	0.75	0.75	6.8	1.38	1.2	0.04
72.62	88.38	0.73	0.73	6.8	1.40	1.2	0.04
74.62	88.31	0.68	0.68	6.8	1.46	1.2	0.00

Table E-18: Configuration 3 – Test 18 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
54.63	88.87	0.9200	0.92	6.8	1.22	-	0.00
56.63	88.80	0.85	0.85	7.0	1.31	1.1	0.04
58.63	88.75	0.88	0.88	7.1	1.31	1.1	0.00
60.63	88.68	0.86	0.86	7.1	1.34	1.2	0.00
62.63	88.65	0.83	0.83	7.2	1.38	1.2	0.00
64.73	88.59	0.82	0.82	7.3	1.40	1.2	0.00
66.73	88.57	0.87	0.87	7.3	1.37	1.2	0.08
68.73	88.52	0.84	0.84	7.3	1.40	1.2	0.00
70.73	88.47	0.86	0.86	7.4	1.39	1.3	0.04
72.62	88.39	0.84	0.84	7.4	1.41	1.3	0.04
74.62	88.31	0.81	0.81	7.4	1.44	1.3	0.00

Table E-19: Configuration 3 – Test 19 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
54.36	90.07	0.26	0.26	-	-	-	0.00
56.35	89.83	0.31	0.31	4.0	1.28	-	0.04
58.34	89.66	0.27	0.27	4.2	1.44	1.9	0.00
60.33	89.45	0.29	0.29	4.2	1.39	1.9	0.00
62.32	89.23	0.29	0.29	4.2	1.39	1.9	0.00
64.41	89.05	0.29	0.29	4.2	1.39	1.9	0.00
66.39	88.79	0.32	0.32	4.2	1.32	1.9	0.08
68.38	88.64	0.31	0.31	4.2	1.34	1.9	0.04
70.37	88.42	0.30	0.30	4.2	1.37	1.9	0.04
72.26	88.19	0.30	0.30	4.2	1.37	1.9	0.04
74.25	87.99	0.28	0.28	4.2	1.41	1.9	0.00

Table E-20: Configuration 4 – Test 21 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
54.70	88.52	0.43	0.43	2.1	-	-	0.00
56.75	88.50	0.56	0.56	2.1	0.50	0.2	0.00
58.75	88.48	0.60	0.60	2.1	0.49	0.2	0.00
60.80	88.44	0.63	0.63	2.2	0.48	0.2	0.00
62.80	88.46	0.61	0.61	2.2	0.50	0.2	0.00
64.75	88.45	0.61	0.61	2.2	0.50	0.3	0.00
66.80	88.44	0.60	0.60	2.3	0.51	0.3	0.00
68.85	88.44	0.58	0.58	2.3	0.53	0.3	0.00
70.85	88.43	0.53	0.53	2.3	0.57	0.3	0.00
72.85	88.42	0.54	0.54	2.4	0.58	0.3	0.00
74.85	88.42	0.50	0.50	2.5	0.62	0.3	0.00

Table E-21: Configuration 4 – Test 22 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
54.70	88.54	0.73	0.73	3.1	0.64	-	0.00
56.75	88.50	0.77	0.77	3.1	0.63	0.3	0.00
58.75	88.48	0.80	0.80	3.2	0.62	0.3	0.04
60.80	88.43	0.83	0.83	3.2	0.62	0.3	0.00
62.80	88.46	0.80	0.80	3.2	0.63	0.3	0.00
64.75	88.44	0.77	0.77	3.3	0.66	0.3	0.00
66.80	88.43	0.77	0.77	3.3	0.67	0.4	0.00
68.85	88.43	0.77	0.77	3.4	0.68	0.4	0.00
70.85	88.44	0.74	0.74	3.5	0.71	0.4	0.00
72.85	88.43	0.72	0.72	3.6	0.74	0.4	0.00
74.85	88.43	0.67	0.67	3.7	0.80	0.5	0.04

Table E-22: Configuration 4 – Test 23 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
54.70	88.55	0.89	0.89	3.4	0.63	-	0.00
56.75	88.50	0.88	0.88	3.4	0.64	0.4	0.00
58.75	88.49	0.94	0.94	3.4	0.63	0.4	0.04
60.80	88.43	0.92	0.92	3.5	0.64	0.4	0.00
62.80	88.46	0.89	0.89	3.5	0.66	0.4	0.00
64.75	88.44	0.89	0.89	3.6	0.67	0.5	0.00
66.80	88.43	0.88	0.88	3.6	0.68	0.5	0.00
68.85	88.43	0.86	0.86	3.7	0.70	0.5	0.04
70.85	88.44	0.82	0.82	3.8	0.74	0.5	0.00
72.85	88.42	0.78	0.78	3.9	0.78	0.5	0.00
74.85	88.43	0.76	0.76	4.1	0.83	0.6	0.00

Table E-23: Configuration 4 – Test 24 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
54.70	88.57	1.02	1.02	3.6	0.63	-	0.00
56.75	88.50	1.01	1.01	3.6	0.63	0.5	0.00
58.75	88.49	1.05	1.05	3.7	0.63	0.5	0.04
60.80	88.43	1.04	1.04	3.7	0.64	0.5	0.00
62.80	88.46	1.06	1.06	3.7	0.64	0.6	0.00
64.75	88.44	1.00	1.00	3.8	0.67	0.6	0.00
66.80	88.43	0.91	0.91	3.9	0.71	0.6	0.00
68.85	88.43	0.95	0.95	3.9	0.71	0.6	0.00
70.85	88.43	0.94	0.94	4.0	0.73	0.7	0.00
72.85	88.43	0.88	0.88	4.2	0.79	0.7	0.00
74.85	88.43	0.84	0.84	4.5	0.86	0.8	0.00

Table E-24: Configuration 4 – Test 25 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
54.70	88.57	1.06	1.06	3.9	0.66	-	0.00
56.75	88.50	1.08	1.08	3.9	0.66	0.4	0.00
58.75	88.49	1.12	1.12	3.9	0.66	0.4	0.04
60.80	88.43	1.13	1.13	4.0	0.66	0.4	0.00
62.80	88.46	1.10	1.10	4.0	0.68	0.4	0.00
64.75	88.44	1.09	1.09	4.1	0.69	0.5	0.00
66.80	88.43	1.08	1.08	4.1	0.70	0.5	0.00
68.85	88.43	1.06	1.06	4.2	0.72	0.5	0.00
70.85	88.44	1.01	1.01	4.3	0.76	0.5	0.00
72.85	88.42	0.96	0.96	4.5	0.80	0.5	0.00
74.85	88.43	0.92	0.92	4.8	0.87	0.6	0.00

Table E-25: Configuration 4 – Test 26 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
54.70	88.57	1.11	1.11	4.1	0.68	-	0.00
56.75	88.51	1.26	1.26	4.1	0.64	0.6	0.00
58.75	88.49	1.17	1.17	4.1	0.67	0.6	0.04
60.80	88.43	1.27	1.27	4.2	0.65	0.7	0.04
62.80	88.46	1.18	1.18	4.2	0.69	0.7	0.04
64.75	88.44	1.21	1.21	4.3	0.69	0.7	0.08
66.80	88.43	1.17	1.17	4.4	0.71	0.7	0.00
68.85	88.43	1.11	1.11	4.5	0.74	0.8	0.16
70.85	88.44	1.14	1.14	4.6	0.75	0.8	0.00
72.85	88.43	1.07	1.07	4.7	0.81	0.9	0.04
74.85	88.43	0.97	0.97	5.2	0.92	1.0	0.04

Table E-26: Configuration 4 – Test 27 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
54.70	88.57	1.23	1.23	4.4	0.70	-	0.00
56.75	88.51	1.40	1.40	4.5	0.66	0.7	0.00
58.75	88.49	1.43	1.43	4.5	0.66	0.7	0.08
60.80	88.43	1.31	1.31	4.5	0.70	0.7	0.04
62.80	88.46	1.46	1.46	4.6	0.67	0.7	0.00
64.75	88.44	1.35	1.35	4.6	0.70	0.7	0.00
66.80	88.43	1.39	1.39	4.7	0.70	0.8	0.00
68.85	88.43	1.37	1.37	4.7	0.71	0.8	0.00
70.85	88.44	1.23	1.23	4.8	0.76	0.8	0.08
72.85	88.43	1.28	1.28	4.9	0.76	0.8	0.04
74.85	88.43	1.23	1.23	5.0	0.79	0.9	0.00

Table E-27: Configuration 4 – Test 28 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
54.68	100.00	0.30	0.30	-	-	-	0.00
56.73	99.94	0.32	0.32	-	-	-	0.00
58.73	99.89	0.34	0.34	3.7	1.11	-	0.04
60.78	99.84	0.31	0.31	3.9	1.24	0.5	0.00
62.78	99.78	0.33	0.33	4.0	1.22	0.5	0.00
64.73	99.73	0.31	0.31	4.0	1.26	0.5	0.00
66.78	99.67	0.31	0.31	4.0	1.27	0.5	0.00
68.82	99.62	0.31	0.31	4.0	1.27	0.5	0.00
70.82	99.56	0.35	0.35	4.0	1.19	0.5	0.04
72.82	99.51	0.34	0.34	4.0	1.21	0.5	0.00
74.82	99.46	0.32	0.32	4.0	1.25	0.5	0.00

Table E-28: Configuration 4 – Test 29 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
54.68	100.00	0.50	0.50	-	-	-	0.00
56.73	99.95	0.53	0.53	4.7	1.14	-	0.00
58.73	99.88	0.49	0.49	4.9	1.24	0.8	0.08
60.78	99.83	0.48	0.48	5.0	1.27	0.8	0.00
62.78	99.78	0.50	0.50	5.0	1.26	0.8	0.00
64.73	99.73	0.47	0.47	5.1	1.30	0.8	0.00
66.78	99.67	0.47	0.47	5.1	1.30	0.8	0.00
68.82	99.62	0.50	0.50	5.1	1.27	0.8	0.00
70.82	99.55	0.52	0.52	5.1	1.24	0.8	0.04
72.82	99.50	0.51	0.51	5.1	1.25	0.8	0.04
74.82	99.46	0.50	0.50	5.1	1.27	0.8	0.04

Table E-29: Configuration 4 – Test 30 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
54.68	100.01	0.62	0.62	-	-	-	0.00
56.73	99.98	0.63	0.63	5.2	1.16	0.9	0.00
58.73	99.89	0.59	0.59	5.3	1.21	1.0	0.08
60.78	99.83	0.55	0.55	5.3	1.27	1.0	0.00
62.78	99.78	0.58	0.58	5.3	1.24	1.0	0.04
64.73	99.73	0.56	0.56	5.4	1.26	1.0	0.00
66.78	99.67	0.52	0.52	5.4	1.31	1.0	0.04
68.82	99.62	0.57	0.57	5.4	1.25	1.0	0.00
70.82	99.55	0.60	0.60	5.4	1.22	1.0	0.04
72.82	99.51	0.58	0.58	5.4	1.24	1.0	0.04
74.82	99.47	0.59	0.59	5.4	1.23	1.0	0.04

Table E-30: Configuration 4 – Test 31 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
54.68	100.02	0.68	0.68	-	-	-	0.00
56.73	100.00	0.72	0.72	5.7	1.19	0.9	0.00
58.73	99.89	0.66	0.66	5.9	1.27	1.0	0.12
60.78	99.83	0.60	0.60	5.9	1.35	1.0	0.00
62.78	99.79	0.65	0.65	6.0	1.31	1.0	0.08
64.73	99.73	0.61	0.61	6.0	1.36	1.1	0.08
66.78	99.68	0.60	0.60	6.1	1.38	1.1	0.04
68.82	99.62	0.61	0.61	6.1	1.37	1.1	0.04
70.82	99.55	0.67	0.67	6.1	1.31	1.1	0.32
72.82	99.51	0.60	0.60	6.1	1.39	1.1	0.16
74.82	99.47	0.63	0.63	6.1	1.35	1.1	0.04

Table E-31: Configuration 5 – Test 32 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
10.45	93.69	0.05	0.05	4.7	3.84	0.1	0.06
12.45	93.64	0.05	0.05	4.7	3.84	0.1	0.00
14.50	93.59	0.05	0.05	4.7	3.84	0.1	0.00
16.50	93.54	0.05	0.05	4.7	3.84	0.1	0.00
18.50	93.48	0.05	0.05	4.7	3.84	0.1	0.00
20.55	93.43	0.05	0.05	4.7	3.84	0.1	0.00
22.60	93.38	0.05	0.05	4.7	3.84	0.1	0.00
24.60	93.33	0.05	0.05	4.7	3.84	0.1	0.00
26.60	93.28	0.05	0.05	4.7	3.84	0.1	0.00
28.65	93.23	0.05	0.05	4.7	3.84	0.1	0.00
30.70	93.18	0.05	0.05	4.7	3.84	0.1	0.00
32.35	93.14	0.05	0.05	4.7	3.84	0.1	0.00
34.40	93.08	0.05	0.05	4.7	3.84	0.1	0.00
36.40	93.03	0.05	0.05	4.7	3.84	0.1	0.00
38.40	92.98	0.05	0.05	4.7	3.84	0.1	0.00
40.45	92.93	0.05	0.05	4.7	3.84	0.1	0.04
42.50	92.88	0.05	0.05	4.7	3.84	0.1	0.00
44.50	92.83	0.05	0.05	4.7	3.84	0.1	0.00
46.50	92.78	0.05	0.05	4.7	3.84	0.1	0.00
47.55	92.75	0.05	0.05	4.7	3.84	0.1	0.01

Table E-32: Configuration 5 – Test 33 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
10.40	93.69	0.21	0.21	3.6	1.38	0.3	0.05
12.40	93.64	0.21	0.21	3.6	1.42	0.3	0.00
14.40	93.59	0.20	0.20	3.7	1.43	0.3	0.00
16.49	93.54	0.20	0.20	3.7	1.44	0.3	0.00
18.49	93.49	0.20	0.20	3.7	1.44	0.3	0.00
20.49	93.44	0.20	0.20	3.7	1.44	0.3	0.00
22.59	93.38	0.20	0.20	3.7	1.44	0.3	0.00
24.59	93.33	0.20	0.20	3.7	1.44	0.3	0.00
26.59	93.28	0.20	0.20	3.7	1.44	0.3	0.00
28.59	93.23	0.20	0.20	3.7	1.44	0.3	0.00
30.69	93.18	0.20	0.20	3.7	1.44	0.3	0.00
32.29	93.14	0.20	0.20	3.7	1.44	0.3	0.00
34.39	93.09	0.20	0.20	3.7	1.44	0.3	0.00
36.39	93.03	0.20	0.20	3.7	1.44	0.3	0.00
38.29	92.99	0.20	0.20	3.7	1.44	0.3	0.00
40.39	92.93	0.20	0.20	3.7	1.44	0.3	0.00
42.39	92.88	0.20	0.20	3.7	1.44	0.3	0.00
44.39	92.83	0.20	0.20	3.7	1.44	0.3	0.00
46.39	92.78	0.20	0.20	3.7	1.44	0.3	0.00
47.49	92.75	0.20	0.20	3.7	1.44	0.3	0.01

Table E-33: Configuration 5 – Test 34 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
10.40	93.68	0.31	0.31	4.7	1.49	0.4	0.05
12.40	93.63	0.31	0.31	4.8	1.54	0.4	0.00
14.40	93.58	0.30	0.30	4.9	1.57	0.4	0.00
16.49	93.53	0.30	0.30	4.9	1.59	0.4	0.00
18.49	93.48	0.30	0.30	5.0	1.61	0.4	0.00
20.49	93.43	0.30	0.30	5.0	1.62	0.4	0.00
22.59	93.38	0.29	0.29	5.0	1.63	0.4	0.00
24.58	93.33	0.29	0.29	5.0	1.63	0.5	0.00
26.58	93.28	0.29	0.29	5.0	1.64	0.5	0.00
28.57	93.23	0.29	0.29	5.0	1.64	0.5	0.00
30.65	93.18	0.29	0.29	5.0	1.64	0.5	0.00
32.25	93.13	0.29	0.29	5.0	1.64	0.5	0.00
34.35	93.08	0.29	0.29	5.0	1.64	0.5	0.00
36.35	93.03	0.29	0.29	5.0	1.64	0.5	0.00
38.35	92.98	0.29	0.29	5.0	1.64	0.5	0.00
40.35	92.93	0.29	0.29	5.0	1.64	0.5	0.02
42.45	92.88	0.29	0.29	5.0	1.64	0.5	0.00
44.45	92.83	0.29	0.29	5.0	1.64	0.5	0.00
46.45	92.78	0.29	0.29	5.0	1.64	0.5	0.00
47.45	92.75	0.29	0.29	5.0	1.64	0.5	0.01

Table E-34: Configuration 5 – Test 35 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
10.39	93.62	0.25	0.25	6.1	2.16	0.7	0.05
12.39	93.47	0.24	0.24	6.4	2.31	0.8	0.00
14.39	93.32	0.23	0.23	6.6	2.42	0.9	0.00
16.38	93.17	0.22	0.23	6.7	2.49	0.9	0.00
18.38	93.02	0.22	0.22	6.8	2.53	0.9	0.00
20.49	92.87	0.22	0.22	6.8	2.57	1.0	0.00
22.49	92.72	0.22	0.22	6.9	2.59	1.0	0.00
24.48	92.57	0.22	0.22	6.9	2.60	1.0	0.00
26.48	92.42	0.22	0.22	6.9	2.61	1.0	0.00
28.47	92.27	0.22	0.22	6.9	2.62	1.0	0.00
30.57	92.11	0.22	0.22	6.9	2.62	1.0	0.00
32.17	92.00	0.22	0.22	6.9	2.62	1.0	0.00
34.28	91.84	0.22	0.22	6.9	2.62	1.0	0.00
36.28	91.69	0.22	0.22	6.9	2.62	1.0	0.00
38.28	91.54	0.22	0.22	6.9	2.62	1.0	0.00
40.28	91.39	0.22	0.22	6.9	2.62	1.0	0.00
42.28	91.24	0.22	0.22	6.9	2.62	1.0	0.00
44.28	91.09	0.22	0.22	6.9	2.62	1.0	0.00
46.28	90.94	0.22	0.22	6.9	2.62	1.0	0.02
47.38	90.86	0.22	0.22	6.9	2.62	1.0	0.01

Table E-35: Configuration 5 – Test 36 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
10.38	93.62	0.37	0.38	6.7	1.92	1.1	0.05
12.38	93.47	0.36	0.36	7.0	2.04	1.3	0.00
14.39	93.32	0.35	0.35	7.1	2.13	1.3	0.00
16.39	93.17	0.34	0.34	7.3	2.18	1.4	0.00
18.38	93.03	0.34	0.34	7.4	2.22	1.4	0.00
20.48	92.87	0.34	0.34	7.4	2.25	1.5	0.00
22.48	92.72	0.33	0.34	7.5	2.27	1.5	0.00
24.48	92.57	0.33	0.33	7.5	2.29	1.5	0.00
26.49	92.42	0.33	0.33	7.5	2.30	1.5	0.00
28.49	92.27	0.33	0.33	7.5	2.31	1.5	0.00
30.59	92.11	0.33	0.33	7.5	2.31	1.5	0.00
32.19	91.99	0.33	0.33	7.6	2.31	1.5	0.00
34.20	91.84	0.33	0.33	7.6	2.32	1.5	0.00
36.20	91.70	0.33	0.33	7.6	2.32	1.5	0.00
38.20	91.55	0.33	0.33	7.6	2.32	1.5	0.00
40.30	91.39	0.33	0.33	7.6	2.32	1.5	0.00
42.30	91.24	0.33	0.33	7.6	2.32	1.5	0.00
44.30	91.09	0.33	0.33	7.6	2.32	1.5	0.00
46.30	90.94	0.33	0.33	7.6	2.32	1.5	0.06
47.40	90.86	0.33	0.33	7.6	2.32	1.5	0.01

Table E-36: Configuration 5 – Test 37 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
10.39	93.62	0.54	0.54	7.5	1.80	1.2	0.05
12.39	93.47	0.51	0.51	7.9	1.95	1.3	0.00
14.39	93.32	0.49	0.49	8.2	2.07	1.5	0.00
16.39	93.17	0.48	0.48	8.5	2.16	1.6	0.00
18.38	93.02	0.47	0.47	8.6	2.23	1.7	0.00
20.48	92.87	0.46	0.46	8.8	2.29	1.7	0.00
22.48	92.72	0.45	0.46	8.9	2.33	1.8	0.00
24.49	92.57	0.45	0.45	9.0	2.37	1.8	0.00
26.49	92.42	0.45	0.45	9.1	2.40	1.9	0.00
28.49	92.27	0.44	0.44	9.1	2.42	1.9	0.00
30.59	92.11	0.44	0.44	9.2	2.44	1.9	0.00
32.19	92.00	0.44	0.44	9.2	2.45	1.9	0.00
34.29	91.84	0.44	0.44	9.2	2.46	1.9	0.00
36.29	91.69	0.44	0.44	9.3	2.47	1.9	0.00
38.29	91.54	0.44	0.44	9.3	2.48	2.0	0.00
40.29	91.39	0.43	0.44	9.3	2.49	2.0	0.00
42.38	91.24	0.43	0.44	9.3	2.49	2.0	0.00
44.28	91.10	0.43	0.44	9.3	2.50	2.0	0.00
46.29	90.95	0.43	0.43	9.3	2.50	2.0	0.49
47.39	90.87	0.43	0.43	9.3	2.50	2.0	0.02

Table E-37: Configuration 5 – Test 38 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
10.37	97.57	0.36	0.36	7.0	2.05	1.8	0.05
12.37	97.37	0.35	0.35	7.2	2.14	1.9	0.00
14.37	97.17	0.34	0.34	7.3	2.20	2.0	0.00
16.37	96.96	0.34	0.34	7.4	2.23	2.0	0.00
18.37	96.76	0.34	0.34	7.4	2.25	2.0	0.00
20.38	96.56	0.34	0.34	7.4	2.27	2.1	0.00
22.47	96.35	0.33	0.34	7.5	2.27	2.1	0.00
24.38	96.16	0.33	0.34	7.5	2.28	2.1	0.00
26.39	95.95	0.33	0.34	7.5	2.28	2.1	0.00
28.49	95.74	0.33	0.34	7.5	2.28	2.1	0.00
30.49	95.54	0.33	0.34	7.5	2.28	2.1	0.00
32.19	95.37	0.33	0.34	7.5	2.28	2.1	0.00
34.19	95.17	0.33	0.34	7.5	2.28	2.1	0.00
36.19	94.97	0.33	0.34	7.5	2.28	2.1	0.00
38.19	94.77	0.33	0.34	7.5	2.28	2.1	0.00
40.19	94.56	0.33	0.34	7.5	2.28	2.1	0.00
42.19	94.36	0.33	0.34	7.5	2.28	2.1	0.00
44.19	94.16	0.33	0.34	7.5	2.28	2.1	0.00
46.19	93.96	0.33	0.34	7.5	2.28	2.1	0.53
47.29	93.85	0.33	0.34	7.5	2.28	2.1	0.01

Table E-38: Configuration 5 – Test 39 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
10.37	97.57	0.47	0.47	7.5	1.93	2.1	0.05
12.37	97.37	0.45	0.45	7.7	2.03	2.3	0.00
14.37	97.16	0.44	0.44	7.9	2.09	2.4	0.00
16.37	96.96	0.44	0.44	8.0	2.14	2.5	0.01
18.37	96.76	0.43	0.43	8.1	2.17	2.6	0.00
20.37	96.56	0.43	0.43	8.1	2.19	2.6	0.00
22.47	96.35	0.43	0.43	8.2	2.20	2.6	0.00
24.47	96.15	0.43	0.43	8.2	2.21	2.6	0.00
26.46	95.94	0.43	0.43	8.2	2.21	2.6	0.00
28.47	95.74	0.43	0.43	8.2	2.22	2.6	0.00
30.46	95.54	0.43	0.43	8.2	2.22	2.7	0.00
32.16	95.37	0.43	0.43	8.2	2.22	2.7	0.00
34.16	95.17	0.43	0.43	8.2	2.22	2.7	0.00
36.16	94.97	0.43	0.43	8.2	2.22	2.7	0.00
38.16	94.76	0.43	0.43	8.2	2.22	2.7	0.00
40.16	94.56	0.43	0.43	8.2	2.22	2.7	0.00
42.26	94.35	0.43	0.43	8.2	2.22	2.7	0.00
44.26	94.15	0.43	0.43	8.2	2.22	2.7	0.01
46.26	93.95	0.43	0.43	8.2	2.22	2.7	0.67
47.26	93.85	0.43	0.43	8.2	2.22	2.7	0.01

Table E-39: Configuration 5 – Test 40 hydraulic model and CSLI data

Horizontal Station (ft)	Bed Elevation (ft)	Flow Depth (ft)	Vertical Depth (ft)	Continuity Velocity (ft/s)	Froude Number	Shear Stress (lb/ft^2)	Cross-sectional CSLI (in)
10.37	97.57	0.55	0.55	8.5	2.02	2.1	0.05
12.37	97.37	0.53	0.53	8.8	2.14	2.3	0.00
14.37	97.17	0.51	0.52	9.1	2.24	2.4	0.00
16.37	96.97	0.50	0.51	9.3	2.31	2.5	0.00
18.37	96.76	0.50	0.50	9.4	2.36	2.6	0.00
20.37	96.56	0.49	0.49	9.5	2.40	2.7	0.00
22.48	96.35	0.49	0.49	9.6	2.44	2.8	0.00
24.38	96.16	0.48	0.48	9.7	2.46	2.8	0.00
26.38	95.95	0.48	0.48	9.7	2.48	2.8	0.00
28.48	95.74	0.48	0.48	9.8	2.49	2.9	0.00
30.48	95.54	0.48	0.48	9.8	2.51	2.9	0.00
32.18	95.37	0.48	0.48	9.8	2.51	2.9	0.00
34.18	95.17	0.47	0.48	9.8	2.52	2.9	0.00
36.17	94.96	0.47	0.48	9.9	2.52	2.9	0.00
38.18	94.76	0.47	0.48	9.9	2.53	2.9	0.00
40.17	94.56	0.47	0.48	9.9	2.53	2.9	0.00
42.28	94.35	0.47	0.48	9.9	2.53	2.9	0.00
44.21	94.15	0.47	0.48	9.9	2.54	3.0	0.00
46.21	93.95	0.47	0.48	9.9	2.54	3.0	0.90
47.21	93.85	0.47	0.48	9.9	2.54	3.0	0.00