16 State House Station
Augusta, Maine 04333

MaineDOT

Transportation Research Division

Technical Report 06-01

Field Testing of a Low-Cost Retrofit Filter Berm to Treat Stormwater Runoff Contaminants

Final Report

December 2008

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16. Abstract (Limit 200 words)

The goal of this cooperative effort between MaineDOT and the University of New Hampshire was to test a low-cost retrofit filter berm that would reduce non-point pollution from highway runoff. The retrofit berm would be easy to construct using readily available materials and construction equipment and would be designed to treat and remove certain constituents of the incoming stormwater runoff.

The UNH Stormwater Research Center field research facility was ideally suited for this trial project. The center is located on the Durham, NH campus, and consists of an experimental facility that includes an upstream watershed area of approximately nine acres of student parking lot area.

On this project an "engineered filter berm" was constructed and tested during several storm events. The research showed that this particular design did not perform as expected. The primary weaknesses of the design are high maintenance associated with clogging by leaf litter. Conclusions from the research are that the filter berm has some potential for a low cost retrofit in areas where leaf litter is not anticipated.

Data collection for the project was cut short, however, due a 100 year storm event that caused the structure to fail. During the failure, the 8 inch stone outer casing was washed away. This allowed the core material, crushed stone and wood chips, to rapidly erode. The structural failure from overtopping by hydraulic overload could be addressed by using larger stone or by encasing the stone armor in wire wraps such as gabions.

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FINAL REPORT ON FIELD VERIFICATION TESTING OF THE MAINE DEPARTMENT OF TRANSPORTATION FILTER BERM SWALE

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FINAL REPORT ON FIELD VERIFICATION TESTING OF THE MEDOT FILTER BERM SWALE
BY THE UNIVERSITY OF NEW HAMPSHIRE STORMWATER CENTER

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FINAL REPORT ON FIELD VERIFICATION TESTING OF THE MEDOT FILTER BERM SWALE
SEPTEMBER 2008

1.0 INTRODUCTION

Under an agreement from Maine Department of Transportation (MEDOT), field verification testing of a ***filter berm*** stormwater treatment unit was conducted at University of New Hampshire Stormwater Center, Durham NH. Testing consisted of determining the water quality performance for the following parameters:

- Total Suspended Sediment (TSS)
- Total Petroleum Hydrocarbons-Diesel Range (TPH-D)
- Nitrogen as Nitrate (DIN)
- Total Zinc (TZn)
- Total Phosphorus (TP)

Efficiency tests were conducted under normalized conditions at various ambient rainfall intensities, flow rates, and pollutant concentrations; all variables reflective of natural field performance conditions. The filter berm swale treatment unit is one of 10 devices that are configured and tested in parallel, with a single influent source providing uniform loading to all devices. All treatment strategies were uniformly sized to target a rainfall-runoff depth equivalent to 90% of the annual volume of rainfall. Under the parallel and uniformly sized configuration, a normalized performance evaluation is possible because different treatment strategies of the same scale receive runoff from events of the same duration, intensity, peak flow, volume, antecedent dry period, and watershed loading.

This report reflects analyses performed from September 2006 through May 2007. This included monitoring of 10 rainfall runoff events in total, 4 more events than contracted for.

Primary funding for the Center program has been provided by the Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET) and the National Oceanic and Atmospheric Administration (NOAA).The UNH Stormwater Center is housed within the Environmental Research Group (ERG) at the University of New Hampshire (UNH) in Durham, New Hampshire.

2.0 TEST FACILITY DESCRIPTION

The UNH Stormwater Center studies stormwater-related water quality and quantity issues. The Stormwater Center's field facility is designed to evaluate and verify the performance of stormwater management devices and technologies in a parallel, event normalized setting. Ten different management systems are currently undergoing side-by-side comparison testing under strictly monitored natural conditions (figure 1).

The site was designed to function as numerous, uniformly sized, isolated, parallel treatment systems. Rainfall-runoff is evenly divided at the head of the facility in a distribution box, designed with the floor slightly higher than the outlet invert elevations to allow for scour across the floor and into the pipe network. Effluent from all systems is piped into a central sampling gallery, where system sampling and flow monitoring conveniently occurs. The parallel configuration normalizes the treatment processes for event and watershed-loading variations.

The Center is located on the perimeter of a 9 acre commuter parking lot at the University of New Hampshire in Durham. The parking lot is standard dense mix asphalt that was installed in 1996, and is used to near capacity throughout the academic year. The sub-catchment area is large enough to generate substantial runoff, which is gravity fed to the parallel treatment processes. The lot is curbed and entirely impervious. Activity is a combination of passenger vehicles and routine bus traffic. The runoff time of concentration for the lot is 22 minutes, with slopes ranging from 1.5-2.5%. The area is subject to frequent plowing, salting, and sanding during the winter months. Literature reviews indicate that contaminant concentrations are above or equal to national norms for parking lot runoff. The climatology of the area is characterized as a coastal, cool temperate forest. Average annual precipitation is 48 inches uniformly distributed throughout the year, with average monthly precipitation of 4.02 in +/- 0.5. The mean annual temperature is 48°F, with the average low in January at 15.8°F, and the average high in July at 82°F.

2.1 Filter Berm Configuration and Sizing

An engineered filter berm was tested in an online configuration at the UNHSC as per specifications provided by MEDOT (see appendix 1). The filter berm was sized by MEDOT personnel for a 1 cfs treatment flow rate. The filter berm was constructed 2 feet high at the crest, 7’9” wide longitudinally, within an approximately 12’ wide stone lined channel as indicated in Figure 1 and Figure 2. Desgin modifications were made to protect the filter material. The filter material was installed as the core and encased by larger stone. The core of the filter berm was comprised of a 50% blend of common wood chips and ½” angular stone (Figure 3). The outer layer of filter berm was encased in 6-8” angular stone (Figure 4). The completed filter berm is shown in Figure 5 and during a rain event. Wood chips used were presumed to be a comprised of a combination of soft and hard woods. Guidance on composition of wood chips was not available so common wood chips were used.

Figure 1: Design Profile of MEDOT Filter Berm Tested at the UNHSC Field Facility

(Drawing by P. Newkirk, 8/06)

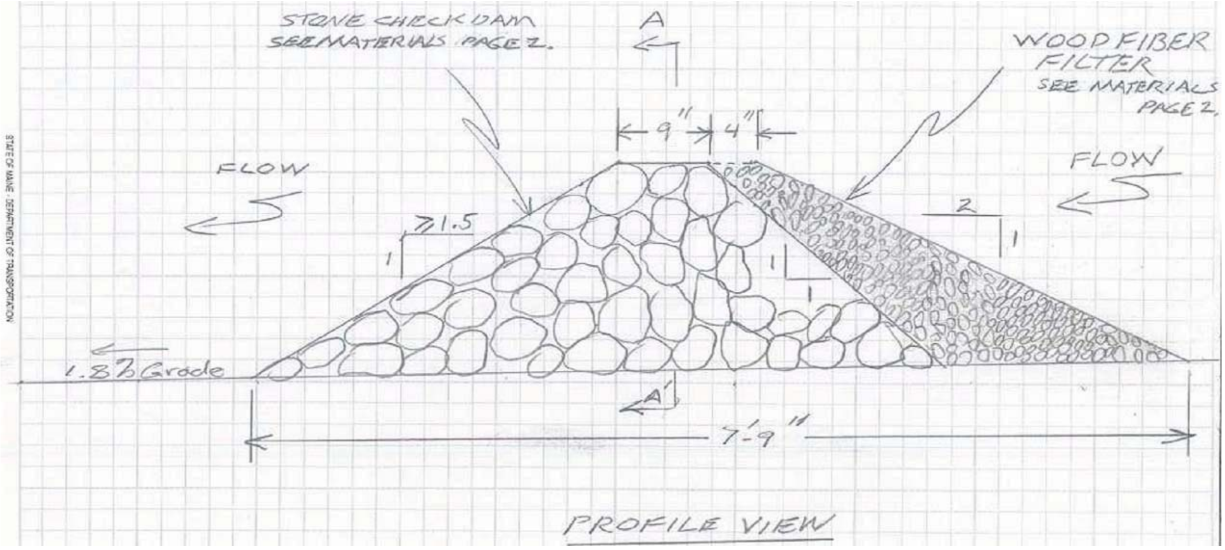


Figure 2: Design Cross-Section of MEDOT Filter Berm Tested at the UNHSC Field Facility; Wood fiber filter was used as core of berm, and stone rip rap as outer casing.

(Drawing by P. Newkirk, 8/06)

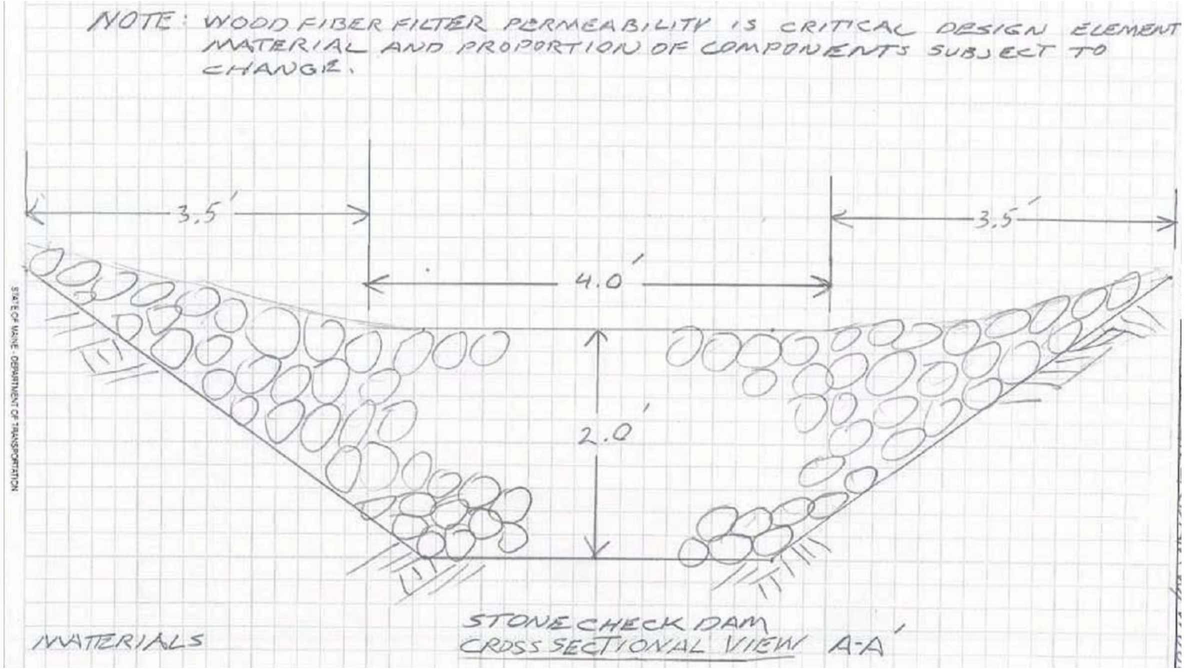

NOTE: WOOD FIBER FILTER PERMEABILITY IS CRITICAL DESIGN ELEMENT MATERIAL AND PROPORTION OF COMPONENTS SUBJECT TO CHANGE.

Figure 3: Inner Filter Core Comprised of 50% Wood Chips and 50% ½" Angular Stone

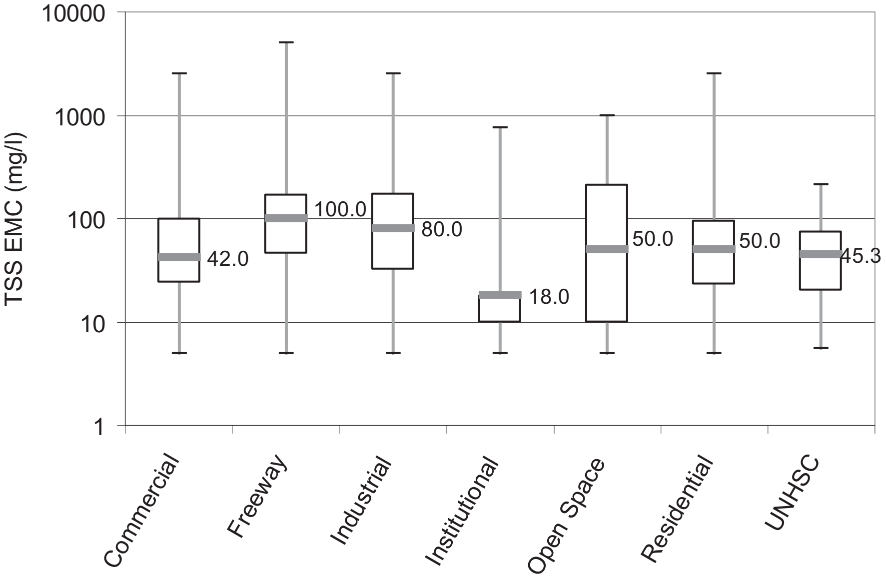
Figure 4: Outer Layer 6-8" Diameter Stone Casing for Filter Berm

Figure 5: Filter Berm Installation at UNHSC (Top left to right clockwise; Filter core placement; Looking downstream after installation; Looking downstream during rain event; Looking upstream during rain event); (Culvert is not part of berm structure and is located downstream of installation)

2.2 Reference TSS Information

Comparisons of the TSS concentrations for varied land uses are presented in Figure 6. Urban highways pollutant concentrations tend to be twice the mean measured concentrations for parking lots and residential uses. The UNH facility data is within the national norm for parking lots and is within the range of typical concentrations observed for a range of land uses.

Figure 6: Total Suspended Solids (TSS) for varied land uses and at the UNH Stormwater Center (mg/L); (Source: National Stormwater Quality Database, 2005[1])



3.0 INSTRUMENTATION AND MEASURING TECHNIQUES

3.1 Flow

Influent and effluent flow levels were measured using Teledyne Isco 6712 Automated samplers accompanied by Teledyne Isco 730 Bubbler Flow Modules in combination with Thelmar compound weirs.

3.2 Other Measurements

Temperature, pH, Specific Conductivity, and Dissolved Oxygen, are collected by a YSI 600XL sonde. These parameters are monitored real-time the treatment unit but are not included under this contract.

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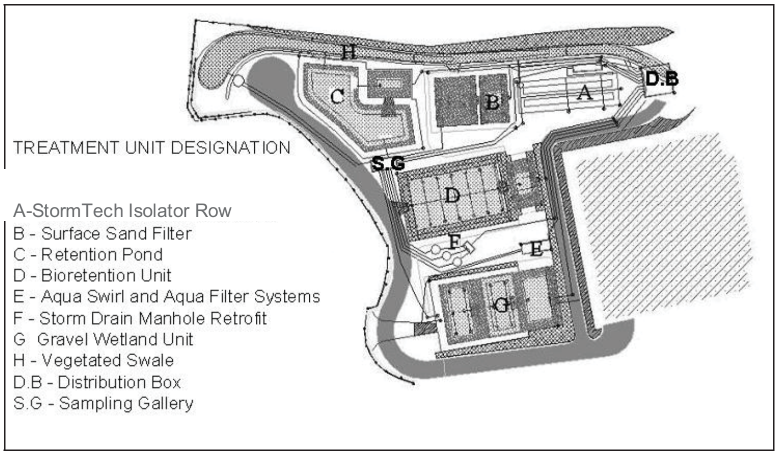
[1] Pitt, R. E., Maestre, A., and Center for Watershed Protection. (2005) "The National Stormwater Quality Database (NSQD, version 1.1)." USEPA Office of Water, Washington, D.C.

Figure 7: Site Plan: Plan view of the University of New Hampshire field research facility



3.3 Water Quality Analysis

Samples were processed and analyzed by an EPA certified laboratory using the standard methodologies outlined in Table 1.

Table 1: Laboratory analytical methods and detection limits for each analyte.

Analyte	Analytical Method	Sample Detection Limit (mg/L)	Method Detection Limit (mg/L)[a]
Nitrate/Nitrite in water	EPA 300.0A	0.1	0.008
Total Suspended Solids	EPA 160.2	10	0.4
Total Phosphorus	EPA 300.0A	0.01	0.008
Zinc in water	EPA 6010b	0.01	0.001-0.05
Total Petroleum Hydrocarbons –Diesel Range	EPA 8015B	0.4	0.1-3.0 ug/L

[a] Method detection limit is different than sample detection limit which will be less and is based on sample volume available for analyses.

4.0 TEST PROCEDURES

4.1 Rainfall Collection and Measurement.

A rainfall collection system consisting of a 6”diameter 2 foot high anodized aluminum housing, funnel, debris screen, and tipping bucket mechanism is installed at a controlled site within the research complex. Specified components are the ISCO Model 674 Tipping Bucket Rain Sensor with Rain Gauge. The precipitation event data is stored in the ISCO 6712 and the accumulated rainfall is retrieved through FlowLink 4.21 via a desktop computer located on-site.

4.2 Field Sampling Procedures.

Discrete samples are taken for influent and effluent waters by automated samplers. Automatic samples are programmed to take samples at uniform time intervals that are determined prior to each independent rain event. Generally at least 10 samples will be taken for each rain event; five discrete samples are taken within the time of concentration and the remaining samples (up to 19 more, 24 in total) taken over the remainder of the hydrograph. Influent time of concentration is approximately 22 minutes. Effluent time of concentrations vary for each device depending on conveyance lengths and treatment strategies. All samples are stored in thermostatically controlled conditions at 39°F.

One Liter disposable LDPE sample bags are used to assure clean, non-contaminated sample containers. Prior to a sampling event, each bag is labeled with a unique, water proof, adhesive bar code that corresponds with a field identification number containing information relating to the stormwater treatment unit, the sample number (1-24) and the date of sampling. Records are kept that correlate sample number with sample time, date, flow, and other real time water quality parameters. Detailed written and electronic records are kept identifying the technician who loaded each sampler, the date, time, and unique bar code and field identification numbers. This begins the chain-of-custody record that accompanies each sample to track handling and transportation of each sample throughout the sampling process.

Analyses substantially comply with the Technology Acceptance and Reciprocity Partnership (TARP), and the Technology Acceptance Protocol – Ecology (TAPE) guidelines. We operate under a detailed Quality Assurance Project Plan (QAPP) which is available on request.

4.3 Characterization of Influent Solids

Two distinct methods where employed to assess influent PSD, a total solids method and an autosampler method. The total solids method refers to actual sediments existing in a full volume sample of influent first flush. Autosampler PSD is reflective of the particle size range obtained from a composite sample analyzed by laser diffraction. The two methods are not directly comparable. The autosampler method represents the industry standard and that referred to in the TARP protocol. The total solids method represents actual PSD for the contributing watershed. Method consistency is needed for PSD to be comparable.

5.0 DATA EVALUATION

Data analyses include a range of approaches. Analyses include:

- evaluation of storm characteristics
- construction of pollutographs
- event mean concentrations
- normalized performance efficiencies

Pollutographs are based on time versus concentration for influent and effluent from discrete sample monitoring. Pollutographs can be used to assess the efficacy of the sampling programs by determining whether the bulk of the mass-load wash-off was monitored. This is determined by the observation of diminishing concentrations over time.

Event mean concentrations (EMC’s) are a parameter used to represent the flow-proportional average concentration of a given parameter during a storm event. It is defined as the total constituent mass divided by the total runoff volume. When combined with flow measurement data, the EMC can be used to estimate the pollutant loading from a given storm.

$$EMC = \frac{\sum_{i}^{n} V_i C_i}{V_{total}} \quad \text{where } n \text{ is the number of samples}$$

$$\text{Performance efficiency for individual storms} = 100 \quad X \quad \frac{EMC_{influent} - EMC_{effluent}}{EMC_{influent}}$$

$$\text{Method 1:} \qquad \text{Removal Efficiency (RE)=} \qquad \frac{\text{Sum of all Storm Efficiencies}}{\text{Number of Storms}}$$

$$\text{Method 2:} \qquad \text{Efficiency Ratio (ER)=} \qquad \frac{\text{Average } EMC_{influent} - \text{Average } EMC_{effluent}}{\text{Average } EMC_{influent}}$$

Pollutant loadings adjusted for event mean concentrations, are compared for each pollutant parameter using simple statistics. The data provides a basis to evaluate the primary study question; i.e., to discern whether stormwater treatment unit BMP's have served to produce observable (and perhaps statistically significant) improvement in quality and reduction in volume of stormwater runoff.

6.0 RESULTS

Table 2 displays rainfall event characteristics for the 10 monitored storm events plus the 11th storm during which time the berm failed but was not monitored. The June 5th, 2007 storm was a 100-year storm, prior to which the swale had functioned. Storms ranged in size from low intensity to high intensity, small volume to large volume. The results for the 11th storm are also included.

Table 2: Rainfall-Runoff event characteristics for 11 storm events (10 monitored, 6/5/07 event led to system failure)

Rainfall Event	Peak Intensity (in/hr)	Storm Duration (min)	Total Depth (in)	Peak Flow (gpm)	Volume (gal)	Season
9/15/2006	0.24	300	0.34	105	21036	Fall
10/17/2006	0.12	620	0.34	94	27924	Fall
11/8/2006	0.24	465	0.31	143	24836	Fall
12/23/2006	0.36	1020	1.21	225	80300	Winter
1/6/2007	0.36	760	0.50	346	43404	Winter
3/2/2007	0.48	535	1.02	200	52718	Winter
3/11/2007	0.12	430	0.28	85	23324	Winter
4/12/2007	0.12	590	0.37	115	30421	Spring
4/27/2007	0.24	450	0.54	146	31004	Spring
5/11/2007	0.60	125	0.26	488	13150	Spring
6/5/2007	5.04	280	1.55	3067	75981	Spring

6.1 Event Mean Concentrations and Removal Efficiencies

Performance statistics and EMC values are presented for each storm for the 5 contaminants in Table 3, Table 4,Table 5,Table 6,Table 7. These events are heavily biased to cold weather months as the system failed early June 2007. Figure 8 presents the distribution of influent and effluent EMCs. Use of removal efficiencies in this setting is appropriate as the systems are all receiving the same stormwater from the same watershed. TSS performance was below that observed for a vegetated swale with no berm at 50% and 60% removal efficiency respectively filter berm and the vegetated swale. The same was true for TZn, at 50% and 88% removal efficiency respectively. For TPH-D the swale appears to be slightly better at 81% and 67% respectively. For DIN no improvement in performance was observed at -12% RE. TP is observed to be 8% versus the -95% observed for the vegetated swale. This is a small data set (n=6-10) and it should be noted that 4 of the TSS events were eliminated during data set quality assurance procedures. It appears that the filter berm is not enhancing water quality for TSS and TZn when compared with a vegetated swale with slight improvements observed for TP and TPH-D.

Table 3: Total Suspended Solids EMC and Performance Statistics for 6 storm events

Date	Analyte	Units	TSS	
	Process		Influent	Effluent
9/15/2006	RE	%		
	EMC	mg/l		
10/17/2006	RE	%		
	EMC	mg/l		
11/8/2006	RE	%		
	EMC	mg/l		
12/23/2006	RE	%		
	EMC	mg/l		
1/6/2007	RE	%		23%
	EMC	mg/l	18.096	14.017
3/2/2007	RE	%		34%
	EMC	mg/l	128.683	84.513
3/11/2007	RE	%		42%
	EMC	mg/l	65.661	38.096
4/12/2006	RE	%		57%
	EMC	mg/l	36.234	15.444
4/27/2007	RE	%		90%
	EMC	mg/l	15.555	1.481
5/11/2007	RE	%		76%
	EMC	mg/l	123.364	30.180
Process			**TSS**	
Ave RE			**54%**	
Median RE			**50%**	
ER			**53%**	

Table 4: Total Petroleum Hydrocarbons-Diesel Range EMC and Performance Statistics for 10 storm events

Date	Analyte	Units	TPH-D	
	Process		Influent	Effluent
9/15/2006	RE	%		98%
	EMC	ug/l	643.599	15.690
10/17/2006	RE	%		99%
	EMC	mg/l	309.428	2.821
11/8/2006	RE	%		77%
	EMC	ug/l	283.803	65.039
12/23/2006	RE	%		85%
	EMC	ug/l	378.692	57.820
1/6/2007	RE	%		99%
	EMC	ug/l	1094.223	9.474
3/2/2007	RE	%		41%
	EMC	ug/l	2239.940	1322.947
3/11/2007	RE	%		58%
	EMC	ug/l	1647.889	692.115
4/12/2006	RE	%		53%
	EMC	ug/l	631.229	295.730
4/27/2007	RE	%		89%
	EMC	ug/l	455.725	49.529
5/11/2007	RE	%		64%
	EMC	ug/l	969.972	347.379
Process			**TPH-D**	
Ave RE			**76%**	
Median RE			**81%**	
ER			**67%**	

Table 5: Dissolved Inorganic Nitrogen EMC and Performance Statistics for 10 storm events

Date	Analyte	Units	DIN	
	Process		Influent	Effluent
9/15/2006	RE	%		0%
	EMC	mg/l	0.273	0.273
10/17/2006	RE	%		
	EMC	mg/l		
11/8/2006	RE	%		-15%
	EMC	mg/l	0.214	0.245
12/23/2006	RE	%		-30%
	EMC	mg/l	0.259	0.338
1/6/2007	RE	%		-3%
	EMC	mg/l	0.383	0.395
3/2/2007	RE	%		-12%
	EMC	mg/l	0.193	0.216
3/11/2007	RE	%		28%
	EMC	mg/l	0.429	0.308
4/12/2006	RE	%		-96%
	EMC	mg/l	0.050	0.097
4/27/2007	RE	%		-49%
	EMC	mg/l	0.111	0.165
5/11/2007	RE	%		-10%
	EMC	mg/l	0.258	0.284
Process			**DIN**	
Ave RE			**-21%**	
Median RE			**-12%**	
ER			**-7%**	

Table 6: Total Zinc EMC and Performance Statistics for 10 storm events

Date	Analyte	Units	TZn	
	Process		Influent	Effluent
9/15/2006	RE	%		63%
	EMC	mg/l	0.023	0.009
10/17/2006	RE	%		99%
	EMC	mg/l	0.037	0.000
11/8/2006	RE	%		50%
	EMC	mg/l	0.027	0.013
12/23/2006	RE	%		
	EMC	mg/l		
1/6/2007	RE	%		30%
	EMC	mg/l	0.027	0.019
3/2/2007	RE	%		49%
	EMC	mg/l	0.163	0.083
3/11/2007	RE	%		39%
	EMC	mg/l	0.077	0.047
4/12/2006	RE	%		39%
	EMC	mg/l	0.046	0.028
4/27/2007	RE	%		63%
	EMC	mg/l	0.021	0.008
5/11/2007	RE	%		59%
	EMC	mg/l	0.087	0.036
Process			**TZn**	
Ave RE			**55%**	
Median RE			**50%**	
ER			**52%**	

Table 7: Total Phosphorus EMC and Performance Statistics for 10 storm events

Date	Analyte Process	Units	TP	
			Influent	Effluent
9/15/2006	RE	%		-51%
	EMC	mg/l	0.062	0.094
10/17/2006	RE	%		-69%
	EMC	mg/l	0.060	0.101
11/8/2006	RE	%		-137%
	EMC	mg/l	0.042	0.099
12/23/2006	RE	%		-108%
	EMC	mg/l	0.033	0.068
1/6/2007	RE	%		16%
	EMC	mg/l	0.081	0.068
3/2/2007	RE	%		20%
	EMC	mg/l	0.240	0.192
3/11/2007	RE	%		0%
	EMC	mg/l	0.175	0.175
4/12/2006	RE	%		27%
	EMC	mg/l	0.069	0.050
4/27/2007	RE	%		26%
	EMC	mg/l	0.051	0.038
5/11/2007	RE	%		54%
	EMC	mg/l	0.198	0.092
Process			**TP**	
Ave RE			**-22%**	
Median RE			**8%**	
ER			**3%**	

Figure 8: Effluent EMC box and whisker plot comparisons for the range of contaminants. (Box reflects the 25th and 75th percentile, the line reflects the median and the whiskers reflect minimum and maximum)

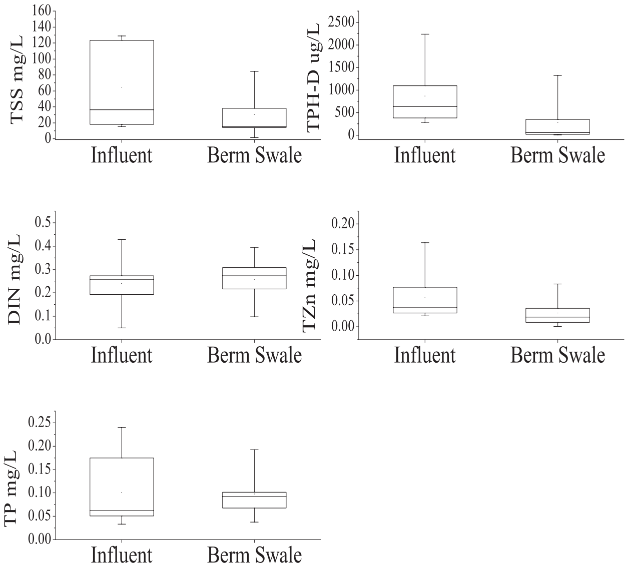


Table 8: Seasonal performance comparison statistics for TSS, TPH-D, DIN, TZn, and TP from 2004-2006

		Annual	
Analyte	Process	ER	RE (med)
TSS	Retention Pond	56%	72%
	Stone Swale	68%	50%
	Veg Swale	52%	60%
	Berm Swale	53%	50%
TPH-D	Retention Pond	89%	95%
	Stone Swale	28%	33%
	Veg Swale	53%	67%
	Berm Swale	67%	81%
DIN	Retention Pond	46%	54%
	Stone Swale	-2%	-72%
	Veg Swale	65%	-13%
	Berm Swale	-7%	-12%
TZn	Retention Pond	80%	93%
	Stone Swale	48%	64%
	Veg Swale	72%	88%
	Berm Swale	52%	50%
TP	Retention Pond	-26%	16%
	Stone Swale	0%	61%
	Veg Swale	-38%	-95%
	Berm Swale	3%	8%

6.2 Particle Size Distributions (PSD)

Two distinct methods where employed to assess influent PSD, a total solids method and an autosampler method. Particle size information for 3 influent events determined by autosampler and laser diffraction are presented in Figure 9. The total solids method refers to actual sediments existing in a full volume sample of influent first flush. Autosampler PSD is reflective of the particle size range pulled by a sampler using a 3/8th ID sampling line and a peristaltic pump. Total solids PSDs were quantified using wet sieving and hydrometer (ASTM Standard D 422 – 63). The two methods are not directly comparable. The autosampler method represents the industry standard and that referred to in the TARP protocol. The total solids method represents actual PSD for the contributing watershed. Particle size ranges represented by the auto sampler are the same sampling method representative of the TSS sediment characterization used to report water quality performance.

Table 9: Particle Size Summary for Parking Lot Runoff 2006-2008

Particle	Influent Total Capture (mm)	Influent Autosampler (mm)
d15	0.028	0.015
d50	0.150	0.038
d85	0.650	0.103

Figure 9: Influent particle size distributions by autosampler and laser diffraction for 3 storms in 2007

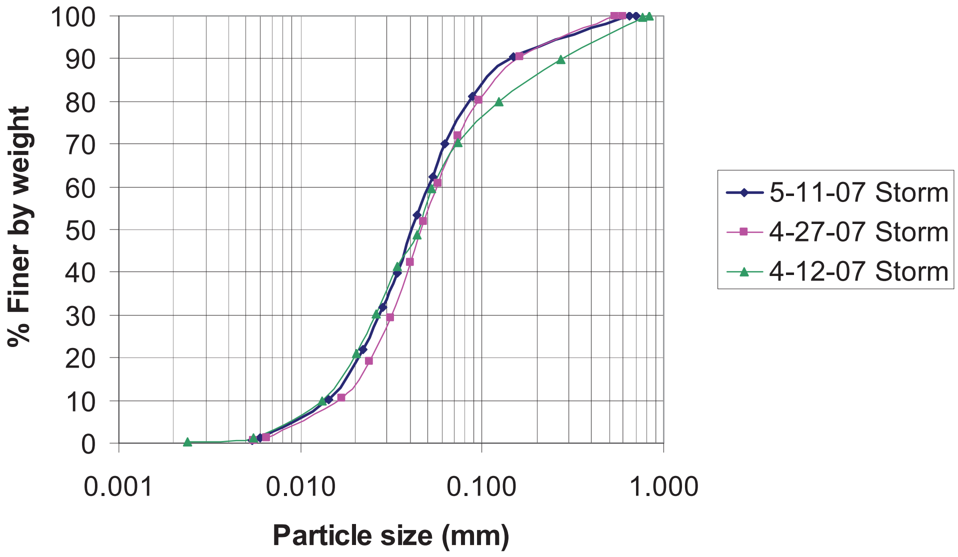
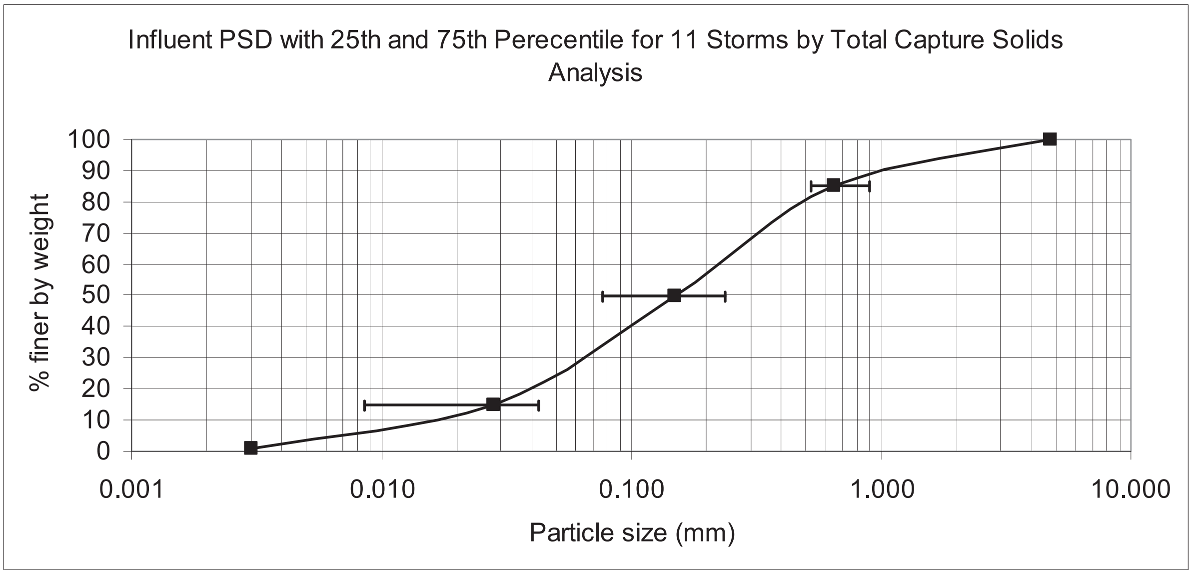


Figure 10: Total solids particle size distributions by wet-sieving and hydrometer analyses for influent (n= 11 storms, 25th and 75th percentile)



7.0 SUMMARY AND CONCLUSIONS

The swale filter berm failed after a 100 year flow event. The swale conveyed a 6.8 cfs peak flow. The 8 inch stone outer casing washed off the downward side of the swale exposing the smaller stone filter core which then eroded rapidly. Prior to this failure, it had largely been concluded that the filter berm was not working effectively primarily due to high maintenance sensitivity. The poor performance was immediately noticeable in the fall season from quickly accumulating leaves that resulted in clogging of the berm and subsequent over-topping. This is evident in Figure 5. Regular removal of leaves and debris was a standard maintenance routine. This could potentially be avoided in roadway areas where substantial leaf litter is not expected such as highways with large right of ways and median strips with grasses.

Another element of failure began a few months after installation when water began to pond routinely for extended periods of time behind the filter berm. Presumably the fines were accumulating within the core and clogging from the bottom up. Prior to the storm during which failure occurred, the permanent pond behind the berm was about 12” deep. After the extreme storm it was the entire depth of the berm at 2 feet deep.

The poor performance of the filter berm is consistent with what has been observed from the range of other systems tested at the UNHSC in that filtration with fine grained materials is needed for marked water quality improvements. It is likely that the swale performance would improve seasonally as the bulk of the testing was in the winter months when swales generally do very poorly. However the coarse grained filtration combined with settling are not strong mechanisms for water quality performance. Unit operations involving filtration with fine grained materials achieve the highest degree of removal.

7.1 Future Recommendations

The filter berm has some potential for a low cost retrofit in areas where leaf litter is not anticipated. Its primary failings were the high maintenance associated with clogging by leaf litter and the hydraulic structural failure from over-topping by large flows. This could be solved by use of a larger stone outer layer or encasing in a gabion like wrap.

APPENDIX 1: System Drawings for the MEDOT Filter Berm