FIELD VERIFICATION TESTING OF THE ADS WATER QUALITY UNIT™

By

University of New Hampshire Stormwater Center

Submitted to

Advanced Drainage Systems, Inc
April 2007

Prepared by
Dr. Robert M. Roseen[1], James P. Houle[2], Dr. Thomas P. Ballestero[3]

[1] Director, The UNH Stormwater Center, Ph.D., Department of Civil Engineering, 35 Colovos Road, University of New Hampshire, Durham, NH 03824; PH 603-862-4024; FAX 603-862-3957; e-mail: robert.roseen@unh.edu; web: www.unh.edu/erg/cstev/

[2] Facility Manager, The UNH Stormwater Center, 35 Colovos Road, University of New Hampshire, Durham, NH 03824; PH 603-767-7091; FAX 603-862-3957; e-mail: James.Houle@unh.edu; web: www.unh.edu/erg/cstev/

[3] Senior Scientist, Principal Investigator, Associate Professor, Department of Civil Engineering, P.E., Ph.D., P.H., C.G.W.P., P.G., Department of Civil Engineering; Principal Investigator, The UNH Stormwater Center, 35 Colovos Road, University of New Hampshire, Durham, NH 03824; PH 603-862-1405; FAX 603-862-3957; e-mail: tom.ballestero@unh.edu; web: www.unh.edu/erg/cstev/

FIELD VERIFICATION TESTING OF
THE ADS INFILTRATION ™ TREATMENT UNIT
BY THE UNIVERSITY OF NEW HAMPSHIRE STORMWATER CENTER
APRIL 2007

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1.0 INTRODUCTION

Under an agreement from ADS, Inc. (Advanced Drainage Systems), field verification testing of an ADS Water quality unit was conducted at University of New Hampshire Stormwater Center, Durham NH. This testing was performed as the first part of the treatment train followed by the ADS Infiltration unit, reported separately. 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 (N-NO3)
- Total Zinc (Zn)

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 ADS Water quality 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. An additional and separate monitoring location was designed for evaluation of stand-alone ADS Water Quality Unit in a similar fashion as described above.

Testing was performed from September 2004 to September 2006. This included monitoring of 20 rainfall runoff events in total, with 19 events analyzed for at least one contaminant for the ADS Water quality unit Treatment Train.

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 controlled 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.

3.0 INSTRUMENTATION AND MEASURING TECHNIQUES

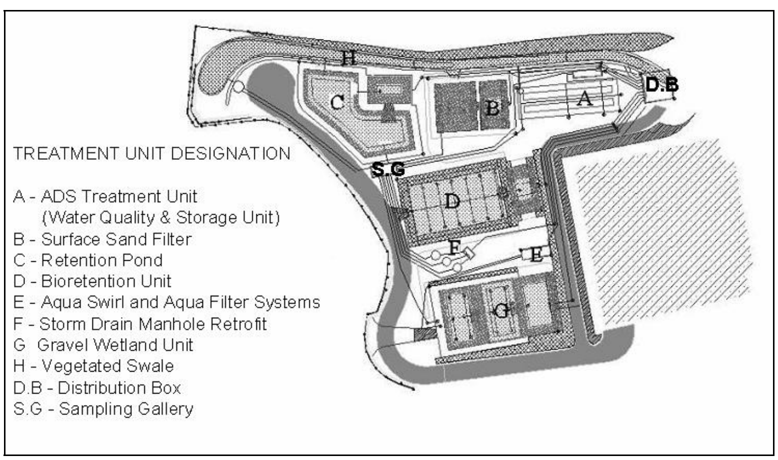
3.1 Flow

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, but are outside the scope of work identified under this contract.

Figure 1: 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	Method Detection Limit (mg/L)
Nitrate/Nitrite in water	EPA 300.0A	0.008
Total Suspended Solids	EPA 160.2	0.4
Zinc in water	EPA 6010b	0.001-0.05
Total Petroleum Hydrocarbons – Diesel Range	EPA 8015B	0.1-3.0 ug/L

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.

As a rule our analyses comply with the Technology Acceptance and Reciprocity Partnership (TARP) guidelines. We operate under a detailed Quality Assurance Project Plan (QAPP) which is available on request.

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.

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

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

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

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

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

Results of all tests are shown in tables 3 and 4, and figures 2 through 5.

Table 2: Rainfall-Runoff event characteristics for 20 storm events

Rainfall Event	Peak Intensity (in/hr)	Storm Duration (min)	Total Depth (in)	Peak Flow (gpm)	Volume (gal)	Anticedent Dry Period (days)	Season
9/8/2004	1.08	1590	2.3	463	48692	7.0	Fall
9/18/2004	0.60	1075	2.0	115	40030	7.0	Fall
10/30/2004	0.84	705	0.5	177	8250	13.0	Fall
11/24/2004	0.36	705	0.7	90	15551	3.5	Fall
1/14/2005	0.96	645	0.7	430	30329	1.3	Winter
2/10/2005	0.24	1520	1.3	90	23323	3.6	Winter
3/8/2005	0.12	1220	0.8	48	11914	5.7	Winter
3/28/2005	0.48	1685	2.3	156	90458	3.4	Winter
4/20/2005	0.48	480	0.6	87	29864	5.9	Spring
5/8/2005	0.12	965	0.6	38	22754	4.0	Spring
6/22/2005	0.60	95	0.3	186	7797	4.0	Summer
8/13/2005	0.96	765	0.5	375	15088	10.0	Summer
9/15/2005	0.72	30	0.20	393.11	9712	10.0	Fall
11/6/2005	0.48	100	0.28	213	16557	10.8	Fall
1/12/2006	0.60	320	0.59	220	26392	5.8	Winter
5/9/2006	0.12	565	0.56	26	5535	5.6	Spring
6/1/2006	4.92	485	1.99	1654	96340	10.7	Summer
6/21/2006	1.56	50	0.21	652	9066	4.7	Summer
7/21/2006	1.56	50	0.21	652	9066	7.5	Summer
9/5/2006	1.20	585	0.63	581	55750	4.5	Summer

6.1 Event Mean Concentrations and Removal Efficiencies

EMC values for influent and effluent pollutant concentrations, removal efficiencies, and efficiency ratios for 20 storms are presented in Table 3 and Table 4.

Table 3: Total Suspended Solids (TSS) and Total Petroleum Hydrocarbons- Diesel Range (TPH-D) EMC's and Performance Statistics for 20 storm events at influent and effluent points of the ADS Water Quality Unit™ (A1)

Date	Analyte		TSS		Date	Analyte		TPH-D	
	Device		Influent	A1		Device		Influent	A1
	RE	%		49.8%		RE	%		
9/8/2004	EMC	mg/l	22.710	11.401	**9/8/2004**	EMC	mg/l		
	RE	%		100.0%		RE	%		100.0%
9/18/2004	EMC	mg/l	36.577	0.000	**9/18/2004**	EMC	mg/l	797.922	0.000
	RE	%		66.3%		RE	%		60.7%
10/30/2004	EMC	mg/l	32.561	10.976	**10/30/2004**	EMC	mg/l	787.538	309.268
	RE	%		100.0%		RE	%		100.0%
11/24/2004	EMC	mg/l	13.264	0.000	**11/24/2004**	EMC	mg/l	448.463	0.000
	RE	%		91.3%		RE	%		
1/14/2005	EMC	mg/l	109.866	9.594	**1/14/2005**	EMC	mg/l		
	RE	%		55.0%		RE	%		13.0%
2/10/2005	EMC	mg/l	60.676	27.332	**2/10/2005**	EMC	mg/l	945.110	821.823
	RE	%		22.4%		RE	%		31.6%
3/8/2005	EMC	mg/l	49.559	38.448	**3/8/2005**	EMC	mg/l	996.196	681.767
	RE	%		38.0%		RE	%		100.0%
3/28/2005	EMC	mg/l	26.816	16.625	**3/28/2005**	EMC	mg/l	318.730	0.000
	RE	%		83.9%		RE	%		79.5%
4/20/2005	EMC	mg/l	45.265	7.302	**4/20/2005**	EMC	mg/l	711.984	145.856
	RE	%				RE	%		19.0%
5/8/2005	EMC	mg/l			**5/8/2005**	EMC	mg/l	338.461	274.078
	RE	%		61.5%		RE	%		15.9%
6/22/2005	EMC	mg/l	65.057	25.052	**6/22/2005**	EMC	mg/l	773.770	650.957
	RE	%		76.5%		RE	%		32.7%
8/13/2005	EMC	mg/l	80.310	18.848	**8/13/2005**	EMC	mg/l	1068.027	719.224
	RE	%				RE	%		100.0%
9/15/2005	EMC	mg/l	11.74		**9/15/2005**	EMC	mg/l	709.50	0.00
	RE	%		100.0%		RE	%		
11/6/2005	EMC	mg/l	13.683	0.000	**11/6/2005**	EMC	mg/l		
	RE	%				RE	%		
1/12/2006	EMC	mg/l	52.058		**1/12/2006**	EMC	mg/l	2155.156	
	RE	%		97.2%		RE	%		72.0%
5/9/2006	EMC	mg/l	94.027	2.647	**5/9/2006**	EMC	mg/l	757.973	212.044
	RE	%		82.9%		RE	%		
6/1/2006	EMC	mg/l	187.568	32.008	**6/1/2006**	EMC	mg/l		
	RE	%		64.4%		RE	%		72.1%
6/21/2006	EMC	mg/l	75.870	27.037	**6/21/2006**	EMC	mg/l	598.497	166.691
	RE	%		71.6%		RE	%		36.0%
7/21/2006	EMC	mg/l	45.308	12.870	**7/21/2006**	EMC	mg/l	1008.020	645.400
	RE	%		100.0%		RE	%		21.7%
9/5/2006	EMC	mg/l	10.188	0.000	**9/5/2006**	EMC	mg/l	475.893	372.625
	Average EMC	**mg/l**	**57.018**	**14.126**		**Average EMC**	**mg/l**	**805.703**	**333.316**
	Efficiency Ratio	**%**		**75%**		**Efficiency Ratio**	**%**		**59%**
	Average RE	**%**		**74.2%**		**Average RE**	**%**		**57.0%**

Table 4: Nitrate-Nitrogen (NO3) and Total Zinc (Zn) EMC's and Performance Statistics for 20 storm events at influent and effluent points of the ADS Water Quality Unit™ (A1)

Date	Analyte		NO3		Date	Analyte		Zn	
	Device		Influent	A1		Device		Influent	A1
	RE	%		28.0%		RE	%		30.6%
9/8/2004	EMC	mg/l	0.820	0.591	**9/8/2004**	EMC	mg/l	0.093	0.065
	RE	%		47.5%		RE	%		100.0%
9/18/2004	EMC	mg/l	0.343	0.180	**9/18/2004**	EMC	mg/l	0.062	0.000
	RE	%		-12.8%		RE	%		100.0%
10/30/2004	EMC	mg/l	0.376	0.424	**10/30/2004**	EMC	mg/l	0.076	0.000
	RE	%		-62.6%		RE	%		
11/24/2004	EMC	mg/l	0.205	0.334	**11/24/2004**	EMC	mg/l	0.023	
	RE	%		-175.3%		RE	%		98.8%
1/14/2005	EMC	mg/l	0.020	0.055	**1/14/2005**	EMC	mg/l	0.046	0.001
	RE	%		21.3%		RE	%		40.1%
2/10/2005	EMC	mg/l	0.937	0.738	**2/10/2005**	EMC	mg/l	0.079	0.047
	RE	%		-14.0%		RE	%		25.6%
3/8/2005	EMC	mg/l	0.421	0.480	**3/8/2005**	EMC	mg/l	0.105	0.078
	RE	%				RE	%		100.0%
3/28/2005	EMC	mg/l	0.015		**3/28/2005**	EMC	mg/l	0.015	0.000
	RE	%		-40.1%		RE	%		49.8%
4/20/2005	EMC	mg/l	0.618	0.866	**4/20/2005**	EMC	mg/l	0.104	0.052
	RE	%				RE	%		
5/8/2005	EMC	mg/l			**5/8/2005**	EMC	mg/l		
	RE	%		90.3%		RE	%		100.0%
6/22/2005	EMC	mg/l	4.319	0.419	**6/22/2005**	EMC	mg/l	0.009	0.000
	RE	%		-20.6%		RE	%		38.6%
8/13/2005	EMC	mg/l	0.897	1.082	**8/13/2005**	EMC	mg/l	0.105	0.064
	RE	%		53.2%		RE	%		48.7%
9/15/2005	EMC	mg/l	0.26	0.12	**9/15/2005**	EMC	mg/l	0.03	0.02
	RE	%				RE	%		64.9%
11/6/2005	EMC	mg/l	0.500		**11/6/2005**	EMC	mg/l	0.040	0.014
	RE	%				RE	%		
1/12/2006	EMC	mg/l	0.346		**1/12/2006**	EMC	mg/l	0.034	
	RE	%		-307.4%		RE	%		79.9%
5/9/2006	EMC	mg/l	0.105	0.429	**5/9/2006**	EMC	mg/l	0.040	0.021
	RE	%		-148.1%		RE	%		89.3%
6/1/2006	EMC	mg/l	0.230	0.571	**6/1/2006**	EMC	mg/l	0.062	0.025
	RE	%		-134.2%		RE	%		96.7%
6/21/2006	EMC	mg/l	0.379	0.887	**6/21/2006**	EMC	mg/l	0.049	0.013
	RE	%		-29.3%		RE	%		94.9%
7/21/2006	EMC	mg/l	0.479	0.620	**7/21/2006**	EMC	mg/l	0.047	0.025
	RE	%		-804.1%		RE	%		66.8%
9/5/2006	EMC	mg/l	0.031	0.280	**9/5/2006**	EMC	mg/l	0.003	0.010
	Average EMC	**mg/l**	**0.595**	**0.505**		**Average EMC**	**mg/l**	**0.054**	**0.025**
	Efficiency Ratio	**%**		**15%**		**Efficiency Ratio**	**%**		**53%**
	Average RE	**%**		**-94.3%**		**Average RE**	**%**		**72.0%**

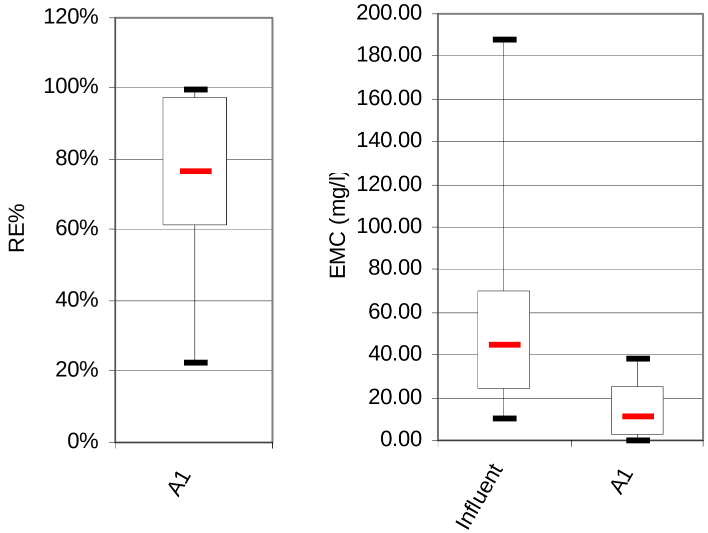


Figure 2: Total Suspended Solids Performance Data: Removal Efficiency and EMC

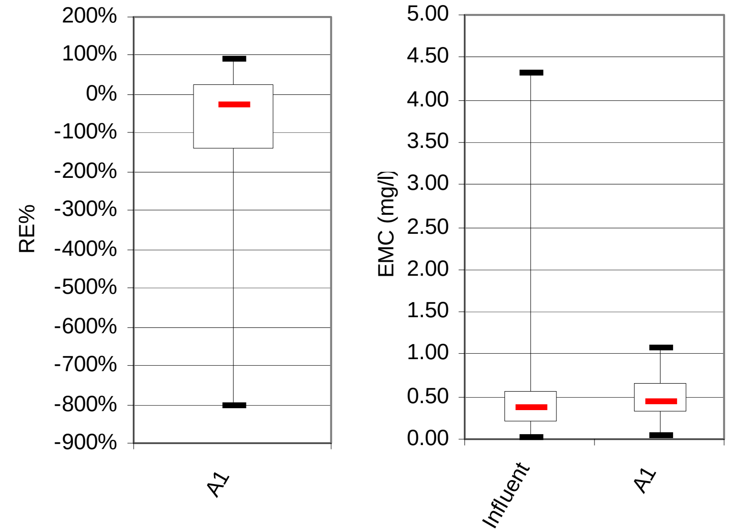


Figure 4: Nitrate Performance Data: Removal Efficiency and EMC

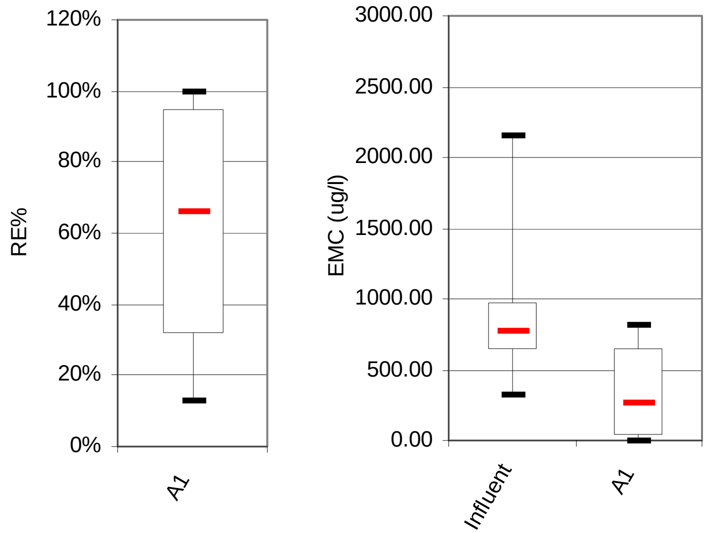


Figure 3: Total Petroleum Hydrocarbons Diesel Range Data: Removal Efficiency and EMC

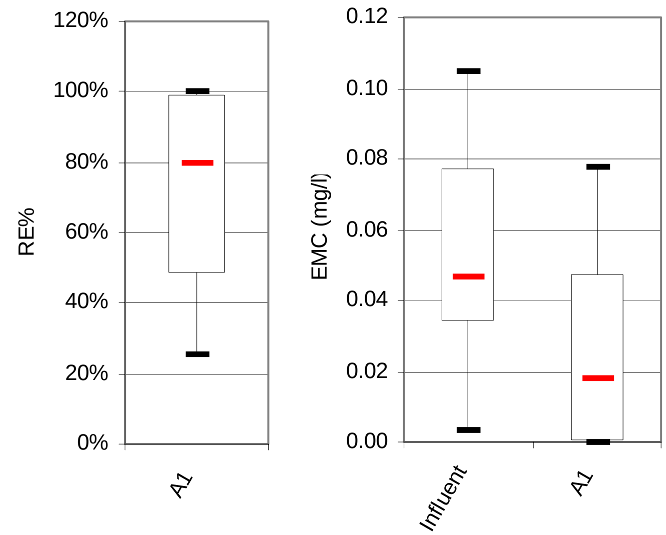


Figure 5: Zinc Performance Data: Removal Efficiency and EMC

6.2 Particle Size Distributions

Three distinct types of particle size distributions are presented:

1) Parking lot runoff influent sampled by Total Capture Method (TC)
2) Automated sampler influent (AS)
3) Captured sediment sampled within the ADS Water Quality Unit

Particle size information for 5 influent events including automated sampler (AS) influent and total capture (TC) sediments in addition are presented in Table 5 and Figure 6. In addition, in-system sediments characteristics for the A1 Water Quality Unit are presented for two annual and one final sediment sampling events (2005- 2006) and included in figure 6. Each method is distinct from another. Sediment loading was measured for several storm events by flow weighted discrete samples collected by an automated sampler. In addition, large 4-6,000 gallon complete samples were taken during the concurrent monitored storm volume, thereby capturing the entire sediment load for the respective sampling period. From this total capture (TC), actual particle size distributions (PSD) were determined for each event and compared with the PSD by auto sampler. PSD for the samples collected by the automated sampler were developed using a Microtrac S3500 Tri-laser photo-detection device (ISO 13320-1) and were compared to the PSD for the total capture and the annual sediment survey quantified using dry sieves and hydrometer (ASTM Standard D 422 – 63).

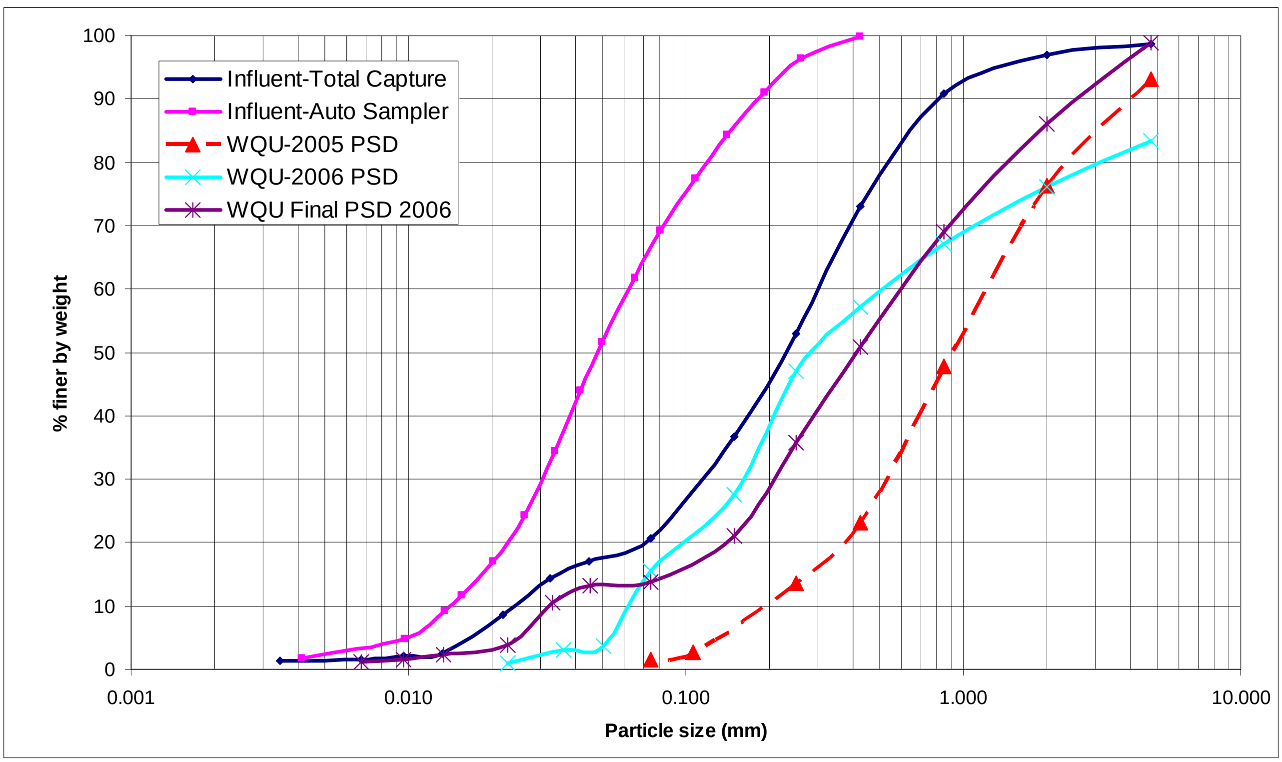


Figure 6: Particle size information for Influent by 2 methods (total capture and auto-sampler) and sediment retained by ADS water Quality Unit (WQU) for three events

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. Total capture particle ranges are most representative of the real particle size characterization of influent sediment as they result from 4-6,000 gallon full influent pipe water samples. Annual sediment survey events were performed using a sediment sampler. The analytical disparity between the total capture method and the auto sampler demonstrates sampling bias from the auto sampler towards finer particles.

Table 5: Particle Size Summary for Parking Lot Runoff (TC) and Auto Sampler Influent (AS) 2005-2006 and the ADS Water Quality Unit (WQU) for sediment retained for 3 events

Particle (mm)	Influent (AS)	Influent (TC)	WQU 2005	WQU 2006	WQU Final 2006
d15	0.016	0.035	0.29	0.075	0.093
d50	0.049	0.22	0.9	0.28	0.42
d85	0.142	0.65	3	6	1.8

7.0 Discussion

Two major factors must be considered when evaluating removal efficiencies: particle size distributions, and influent concentrations. The context of the testing environment and recommended applications are essential when evaluating treatment devices. Generally it is felt that high influent concentrations results in higher removal efficiencies. In this study there is a wide variation for the range of influent pollutant concentrations. It is well know that there is a direct relationship between particle size and removal efficiencies as small diameter particles are more difficult to remove from stormwater. Additionally, higher removal efficiencies due to high influent concentrations do not translate automatically to lower loading rates. For example, a highway with an influent event mean concentration of 200 mg/l TSS treated with a treatment device possessing an 80% removal efficiency would result in an effluent EMC of 40 mg/l. In contrast, a commercial parking lot, treated with the same device, with an influent EMC of 75 mg/l and a removal efficiency of 45% will have an effluent EMC of 40mg/l. Negative removal efficiencies denote pollutant exportation. While some negative removal efficiencies are reported, they often occur when influent concentrations are extremely low. In the case of Nitrate, the system appears to be exporting nitrate, as is observed for many non-vegetated systems tested at the Center. While the materials in from which the systems are not releasing nitrate which suggests that the measure of nitrate is not complete, and that other forms of nitrogen, most likely organic nitrogen must also be considered to fully understand the nitrogen balance. While some negative removal efficiencies are reported, they often occur when influent concentrations are extremely low and may or may not be representative of the performance standard and must be examined with care.

The range of statistical analyses presented reveal a range of performance trends. Clearly the treatment is quite effective in terms of serial water quality improvement. It can be seen in Figure 6 that the water quality unit (WQU) is removing the very fine sands and above. The WQU is working effectively as a pre-treatment system for the larger subsurface infiltration system, which is then responsible for the removal of fines and other contaminants.

Another point regarding performance and water quality treatment, is that this treatment device has an internal high flow bypass which discharges directly into the subsurface infiltration for non-WQV flows. It is likely that this factor, along with the size of the system, contributes to the high performance for sediment removal by minimizing resuspension for non-design flows.

Efficiency Ratio (ER) analysis was performed on the final dataset for both treatment devices. For this dataset ER is a more stable estimation of overall treatment performance as it minimizes the impact of low concentration values, or relatively clean storms with low influent EMC concentrations. Where Removal Efficiencies (RE) reflect treatment unit performance on a storm by storm basis, ERs weight all storms equally and reflect overall influent and effluent averages across the entire data set. As with all performance evaluations they are best understood on a total mass basis. A review of removal efficiencies (RE) on a per event basis, efficiency ratios (ER) for the entire period of monitoring, and event mean concentrations (EMC) for both an event basis and entire period of monitoring will reveal the measured performance variations attributable to season, flow, concentration, and other factors.

7.1 Reference TSS Information

Urban highways pollutant concentrations tend to be twice the national mean measured concentrations for parking lots and residential uses. The UNH facility data is within the national norm for parking lots. TSS median EMC (34 mg/l) at the UNH facility is greater than the national median EMC for commercial parking lots (27 mg/l). These are event mean concentrations, not direct concentrations. The one notable difference is the max concentration of 350 mg/l.

Table 4: Total Suspended Solids (TSS) Event Mean Concentrations (EMC) at Highway, NURP Runoff Sites, and UNH Stormwater Center (mg/L)

LOCATION	TSS mg/l
Commercial Parking Lot EMC*	27
Industrial Parking Lot EMC*	228
Commercial Street EMC*	468
Residential Street EMC*	172
Urban Highway EMC*	142
National stormwater median EMC*	67
UNH EMC Average	57
UNH EMC Min	10
UNH EMC Max	190
UNH non-EMC Median	24
UNH non-EMC Average	44
UNH non-EMC St deviation	63
UNH non-EMC Min	1
UNH non-EMC Max	350

*Reference FHWA 1990