Evaluating Systems to Reduce Road Improvement Impacts on Mountain Streams

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16. Abstract

Sediment is the most common pollutant affecting North Carolina's waterways, impacting a range of aquatic organisms, reducing reservoir capacity, and hurting their aesthetic value. Construction activities, including roadway projects, are a significant contributor of state-wide sediment loading. The NC DOT program of widening and paving rural roads in the mountain region provided an opportunity to evaluate new types of roadside erosion control BMPs with the goal of protecting the particularly sensitive trout streams commonly found there.

Two roadway paving projects were each divided into experimental sections installed with either 1) the standard DOT BMPs consisting of narrow sediment traps and rock checks, 2) the new fiber wattle check dams (consisting of a mix of straw wattles and coir logs) with 100 grams of granulated polyacrylamide (anionic PAM 705) added to each, or 3) the new wattle check dams alone (no PAM added).

The results suggest a significant advantage to the use of the new BMPs. At the first site, from June 2006 to March 2007, the average turbidity values (in NTUs) for the stormwater runoff for were 4,198 for the Standard BMPs, 30 for the Experimental BMPs with PAM, and 187 for the Exp. BMPs alone. The second site showed similar results with average turbidity values of 64 for the Exp. BMPs with PAM, as compared to 852 for the Standard BMPs. Sediment loading at both sites was similarly skewed with dramatic decreases in sediment discharged off site from the new BMPs. At the first site, the Standard BMPs lost an average of 944 lbs (428 kg) of sediment per storm event as compared to just 1.93 lbs (0.88 kg) for the BMPs with PAM and 6.53 lbs (2.96 kg) for the Exp. BMPs alone. At the second site, the Standard BMPs lost an average of 8.84 lbs (3.63 kg) per storm event compared with 1.67 lbs (0.76 kg) for the Exp. BMPs with PAM.

As a result, we recommend that the new BMPs be implemented on a wider basis by the DOT on similar roadway improvement projects, particularly in areas adjacent to sensitive habitat waters.

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Erosion control, Polyacrylamide(PAM), Wattles, Trout streams, Sediment loading

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Executive Summary

Standard DOT Best Management Practices (BMPs) for erosion and sediment control were compared to an alternative system. Standard BMPs involved Type B silt traps and rock check dams, while the alternative system involved coir log and straw wattle check dams installed at closer spacing. In addition, polyacrylamide (PAM) powder was added to the alternative system. The results suggest there is a significant advantage in the use of the new BMP systems, particularly those with polyacrylamide (PAM) added.

- Average turbidity values (in NTU) for the stormwater runoff at the Steeltown Road site were 4,198 for the Standard BMPs, 30 for the Experimental (Exp.) BMPs with PAM, and 187 for the Exp. BMPs alone. The Curley Maple Road site showed similar results with average turbidity values of 64 for the Exp. BMPs with PAM, as compared to 852 for the Standard BMPs.

- Sediment loading at both sites was similarly skewed with dramatic decreases in sediment discharged off site from the new BMPs. At Steeltown, the Standard BMPs lost an average of 944 lbs (428 kg) of sediment per storm event as compared to just 1.93 lbs (0.88 kg) for the Exp. BMPs with PAM and 6.53 lbs (2.96 kg) for the Exp. BMPs alone. At Curley Maple, the Standard BMPs lost an average of 8.84 lbs (3.63 kg) per storm event compared with 1.67 lbs (0.76 kg) for the Exp. BMPs with PAM.

The wattle and log check dams plus PAM system was the closest to achieving the target 10 NTU standard for trout streams, while the standard system was several orders of magnitude higher.

Despite the difficulty in comparing estimates of cost per device between the various BMPs, it would appear that the new BMPs are not significantly more expensive than the Standard BMPs, based on overall average costs. In fact, the differences for each project would likely be less than a few hundred dollars, which is very small in comparison to the total project costs. It also appears that the new BMPs are a reasonable substitute to the standard BMPs with regards to their overall water storage volume capacity, as their calculated storage volumes for the two project sites were equal to or exceeded those of the standard BMPs.

As a result, we recommend that the new BMPs be implemented on a wider basis by the DOT on similar roadway improvement projects, particularly in areas adjacent to sensitive habitat waters. This system of fiber check dams and PAM is likely to be applicable to other construction sites as well, and could lead to significant reductions in stormwater impacts on adjacent streams and lakes.

Table of Contents

page

List of Tables

Page

List of Figures

page

Introduction

Sediment is the most common pollutant affecting North Carolina's waterways, impacting a range of aquatic organisms, reducing reservoir capacity, and hurting their aesthetic and economic value. Construction activity, including roadway projects, is a significant contributor of state-wide sediment loading. The NC DOT program of widening and paving rural roads in the mountain region provided an opportunity to evaluate new types of roadside erosion control BMPs. Current regulations have established maximum allowable discharge turbidities to normal surface waters at 50 NTU (Nephelometric Turbidity Units), to lakes and reservoirs at 25 NTU and to sensitive waters (to include the trout streams common in the mountains) at just 10 NTU. However, these thresholds, particularly for the sensitive waters, have proven quite difficult to meet and new structures and practices are needed to achieve this requirement.

Erosion control Best Management Practices (BMPs) for construction sites are designed to reduce the amount of sediment leaving the project in water runoff. For roadway projects in the mountains with their frequently narrow, more restricted right-of-ways, they typically include small sediment basins and rock check dams placed in the roadside drainage ditch, which are designed to detain or slow water runoff, allowing suspended sediment more time to settle out before leaving the site. In steeper areas, the ditch channel is lined with an erosion control blanket as well. The alternatives tested in this study are a variety of straw and coir wattles and logs, which are simply cylindrical fiber or plastic mesh bags filled with either straw or coir fibers to use as a check dam for stormwater flow. Additionally, granular polyacrylamide was added to some of these wattles/logs to determine any added effect it might have on water treatment.

Polyacrylamide (PAM) is a water soluble, synthetic polymer that has been commonly used for years in a variety of water treatment processes including municipal water supplies, wastewater, and as a food processing aid. PAM can be manufactured in a variety of charged forms to be either cationic, anionic, or non-ionic (neutral), but each is intended to increase the rate of flocculation, or particle binding, that occurs in treated water. This significantly increases the rate of sedimentation by increasing the effective particle size. Concerns about PAM's potential toxic effects to aquatic organisms have been raised in the past. In fact, while the cationic PAM has been determined in the lab to be somewhat toxic to fish by binding to their gills (though under typical stream conditions, this toxicity is greatly reduced), the anionic PAM has not been found to be toxic (Tobiason et al. 2000). As a result, anionic PAM 705 was used in this study, which has been approved for stormwater treatment by the NC Div. of Water Quality. A good review of toxicological tests and concerns can be found at the Washington State Department of Transportation website.

The use of PAM for environmental or stormwater treatment is not new, and has been increasingly studied in the past several years. One of the most widely published uses is in furrow irrigation systems, in which PAM is added to the irrigation water to prevent erosion of the furrows (Lentz et al., 1992; Lentz and Sojka, 1995; Lentz et al., 1998). By adding PAM to the irrigation water, furrow erosion was reduced by up to 94%. This has become a standard practice among growers in many states in the western U. S. More recently, PAM is being tested for use for erosion control on exposed soil surfaces (Tobiason et al., 2000; Roa-Espinosa et al., 1999; Flanagan and Chaudhari, 1999). Erosion was reduced up to 93% and turbidity was reduced up to 82% in these test plots compared to bare soil. We have also demonstrated reductions in erosion and runoff turbidity with surface applications of PAM (Hayes et al., 2005; McLaughlin and Brown, 2006). Polyacrylamide is now a common addition to erosion control products such as hydromulch, and even to some newer check dam devices.

The objective of this study was to evaluate the effectiveness of alternative check dams (straw wattles and coir logs), with and without PAM, as compared to Standard DOT erosion control designs, consisting primarily of rock checks and small basins, for reducing turbidity and sediment losses during road improvement projects.

Project Description

This study was conducted on three DOT roadway paving projects located in the mountains. The first was located along Steeltown Rd, north of Lenoir in Caldwell County, the second was located along Curley Maple Rd, north of Boone in Watauga County, and the third was located along Fleming Chapel Church Rd, west of Lenoir in Caldwell County. Each roadway improvement included the installation of a drainage ditch adjacent to the road, where the DOT placed erosion and sediment control measures to reduce the amount of sediment discharged from the site. These ditches were partitioned into experimental sections, each one hydrologically distinct from the others by the periodic placement of drainage culverts that run under the road, discharging stormwater off the project site. The sections were then installed with various treatments as described below.

The Steeltown Rd site consisted of three separate treatment type sections:

Table 1. Steeltown Rd Site Section Descriptions

Treatment Section	Length (ft)	Slope (%)	BMP spacing (ft)
DOT Standard BMPs	450	5	63
Experimental BMPs with PAM	668	7	32
Experimental BMPs alone (no PAM)	461	6	25

The Curley Maple Rd site consisted of two separate treatment types:

Table 2. Curley Maple Rd Site Section Descriptions

Treatment Section	Length (ft)	Slope (%)	BMP spacing (ft)
DOT Standard BMPs	507	3	85
Experimental BMPs with PAM	489	3	27

The Fleming Chapel Church Rd consisted of four separate treatment type sections:

Table 3. Fleming Chapel Church Rd Site Section Descriptions

Treatment Section	Length (ft)	Slope (%)	BMP spacing (ft)
DOT Standard BMPs	375	3	80
Experimental BMPs with PAM	300	4	30
Experimental BMPs alone (no PAM)	524	3	30
Experimental BMPs alone (no PAM)	165	3	60

Materials and Methods

NC DOT Standard BMPs

The standard DOT BMPs found on these sites consisted primarily of small sediment basins (Temporary Sediment Basins – Type B) followed by rock check dams (Temporary Rock Silt Checks – Type B) located in the ditch channel, though at Steeltown and Fleming Chapel the entire ditch was also lined with Excelsior-brand erosion control blanket.

Figures 1 and 2. Examples of standard DOT BMPs.

Experimental BMPs

Coir Logs

The largest and stiffest of the experimental types, the coir logs are made of woven coir fibers made from coconut husks. The logs used were 10’ long and 12” diameter, costing around $55 each. Approximately 5 of these logs were placed per experimental section at the Steeltown Rd and Curley Maple Rd sites. They were fairly difficult to manipulate, owing to their very stiff form, often resulting in inadequate surface contact with the bottom or sides of the ditch.

Figures 3 and 4. Examples of coir logs.

Straw Wattles

Smaller, lighter, and more malleable than the coir logs, the straw wattles simply consist of straw packed into a plastic mesh casing. The wattles used were 10’ long and 9” in diameter, costing around $20 each. Approximately 15 of these wattles were placed per experimental section at the Steeltown Rd and Curley Maple Rd sites, where the coir logs were interspersed among them at even intervals. These wattles were very easy to manipulate and faster to install as compared to the coir logs.

Figures 5 and 6. Examples of straw wattles.

Coir Wattles

These wattles were made of coir fibers like the coir log but were much smaller, lighter, and much less stiff than the coir logs. The wattles used were 6’ long and were 6” and 9” in diameter (which were alternated during installation), but also had 1’ wide ‘wings’ on the bottom to help secure them to the ground. They cost around $25 each. These wattles were used exclusively in the experimental sections at the Fleming Chapel Rd site.

Figures 7 and 8. Examples of coir wattles.

Installation of all of the products was relatively simple and took an average of about 15 minutes each. A combination of wooden stakes and metal sod staples were used to secure the wattles/logs onto the ditch and sidewall surface as snugly as possible. In particular, the ‘wings’ on the coir wattles made for a quick, secure installation. As noted above, however, the stiff coir logs were somewhat more difficult to make fit onto the ditch contour and were placed at angles to the ditch in order to ensure better contact with the ground. Excess erosion control matting was also placed in any gaps where contact between the log and ground was not fully made. After a storm or two, these narrow areas tended to clog with sediment and debris, and did not seem to become a problem. For road safety reasons, the middle portion of each wattle/log above the ditch centerline was always made significantly lower than the adjacent roadway to help prevent water from backing up onto the road and becoming a hazard.

Once installed, these BMPs can simply remain in place in perpetuity. Consisting of primarily plant derived biodegradable materials, they will all eventually break down over time. It’s another of the benefits offered by these wattles and logs.

Polyacrylamide (PAM)

Additionally, for those sections that required it, 100 g of granulated PAM 705 was sprinkled over the lower, center portion of the wattle/log, so that when water flows over the top, it would mix into the runoff and begin to flocculate finer-sized sediment. This same amount of PAM was placed out after every major storm event, roughly once a month for these projects. The estimated cost of the PAM is about $1.67 per 100 gram application.

Figure 9. 100g of granulated PAM 705.

Runoff was collected by Teledyne ISCO brand 6712 portable water samplers programmed to collect samples after a set volume of water had passed. At Steeltown, they collected the samples from the front side of constructed weirs located at the end of each experimental section by the entrance to the discharge culvert. At Curley Maple, the samples were collected from the interior of the culverts themselves at the point of discharge off the site. At Fleming Chapel, samples were taken from small weirs that were placed over the discharge end of the culverts.

Figures 10. ISCO water sampler.

Figure 11. Weir at Steeltown Rd.


Figure 12. Pipe sampling at Curley Maple.


Figure 13. Weir at Fleming Chapel.

Cost Estimate Comparison

Estimating the cost of installation for the NC DOT standard BMPs is challenging as the cost per device will vary by site, depending on the number of devices to be installed, how frequently they require maintenance, etc. However, the website for the DOT Contracts Office contains a database of Statewide 2006 bid averages, where it was calculated that the average cost of Class B erosion control stone (installed) was $39.23/ton, while the initial cost to dig a sediment basin (and to periodically maintain it by digging it out when it fills up) was $6.01/yd^2. Assuming average conditions on a given site, we can give a general estimate of about $95.00 per basin and rock check combination, with a clean-out maintenance cost of about $15.00 per basin every month or so. For the Steeltown Rd site, there were 6 of these BMPs in the 450’ long DOT standard section, resulting in an estimated cost of $570 to install and $90 to maintain per month. This translates to $1.26 per foot for installation costs.

By comparison, the Experimental BMPs plus PAM section (668’ long) had 15 straw wattles ($20 each) and 5 coir logs ($55 each), each one requiring about $3 in sod staples and wooden stakes, for a total material cost of $635. At 15 minutes installation time each, assuming $15/hour for labor, the installation labor cost is about $75. The cost of the PAM, estimated to be about $1.67 per 100 gram application, would be $33 initially and every month thereafter for maintenance, plus the cost of 30 minutes of labor. This comes to a total estimated cost of $734 to install and $41 to maintain per month. This translates to $1.10 per foot for installation costs.

The Experimental BMPs alone section (461’ long) had 15 straw wattles ($20 each) and 4 coir logs ($55 each), each with $3 in staples and stakes, for a total material cost of $577 plus $75 of labor for installation. This comes to a total estimated cost of $652 to install with no monthly maintenance costs, or $1.41 per foot to install. This is more than the other Experimental section because the spacing of the checks was closer.

At the Curley Maple Rd site, the Experimental BMPs plus PAM section (489’ long) had 13 straw wattles ($20 each) and 5 coir logs ($55 each), each with about $3 in staples and stakes and $1.67 per 100 gram PAM application, for a total material cost of $749. At 15 minutes installation time each, labor cost should be around $67, for a total estimated cost of $816 to install and $37 to maintain per month. This is $1.67 per foot for installation alone.

For the DOT standard section (507' long), there were 6 basin and rock check BMPs. At a cost of $95 each, this section cost an estimated $570 to install and $90 to maintain per month, or $1.12 per foot to install.

In summary, the newer BMPs appear to be an economically viable alternative as the relative cost differences are very minimal, especially if one considers the maintenance costs over time. Also, if the rock checks and/or silt basins have to been removed or filled in, that would sharply increase the overall cost of the standard BMPs, as the wattles/logs can simply remain in place to slowly and harmlessly disintegrate over time.

We did not determine if the expensive coir logs could have been replaced by the straw wattles or other alternatives to bring costs down. The straw wattles did tend to settle and flatten over time, while the coir logs maintained their structure and continued to back up water during the period of observation. It is possible that the coir logs provided a needed "backup" system as the straw wattles disintegrated. There are many other materials and even types of check dam alternatives. It is likely that many of them would work as well, but our results suggest that straw wattles will perform for short periods and the inclusion of longer-lasting checks, such as coir logs, adds some insurance in case projects are open longer than 3-6 months.

Table 4. BMP Cost Estimate Comparison

Section	Section Length	Installation Cost	Maintenance Cost	Cost per linear foot
Steeltown Rd				
Standard BMPs	450'	$570	$90	$1.26
Exp. BMPs + PAM	668'	$734	$41	$1.10
Exp. BMPs only	461'	$652	None	$1.41 (BMP spacing closer here)
Curley Maple Rd				
Standard BMPs	450'	$570	$90	$1.12
Exp. BMPs + PAM	489'	$816	$37	$1.67

Results and Discussion

Steeltown Rd

The Steeltown Rd site was fully instrumented in June of 2006. Before site grading began, we obtained samples from one storm which averaged 589 NTU and 560 mg L^{-1}, representing runoff water quality from the unpaved road. The section of the Steeltown Road project with standard BMPs had a total of 21 storms where samples were obtained. Average storm discharge turbidities ranged from 337 to more than 14,000 NTU, generally higher toward the beginning of the grading, with an overall average of 1,737 NTU. An average 428 kg was discharged per storm and a total of 9,400 kg over the entire period.

In contrast, the section with experimental BMPs and PAM had discharge turbidities ranging from 7 to 335 NTU and an average of 30 NTU. Nine of the 27 storms monitored had average discharge turbidity of 10 NTU or less. Less than 24 kg of sediment was discharged over the entire nine months of monitoring. The section with the same check dam system but no PAM had higher turbidity compared to the section with PAM, but the numbers were still much lower than the standard section.

The road was paved between the October 5 and 17 events, and there is a general reduction in turbidity after that. However, the standard section continued to have much higher turbidity than either of the experimental sections, even though the vegetation was becoming well established. The source of the sediment was likely the traps, which continued to be maintained and therefore were continually disturbed. The experimental sections did not have any traps, so these completely vegetated after paving. Even before the paving, it appeared that the traps were the main source of sediment in the standard section.

Table 5. Steeltown Rd: Standard DOT BMPs

Date	# of Samples	Rainfall (in)	Average Turbidity (NTU)	Sediment Load (kg)
6/26/2006	12	1.17	14756	1128.16
6/27/2006	23	1.29	14768	6473.01
8/12/2006	24	1.49	2015	199.44
8/30/2006	3	1.10	2706	69.27
8/31/2006	4	1.05	2488	41.58
9/5/2006	9	1.68	4684	200.94
9/7/2006	4	0.60	3993	85.49
9/24/2006	4	0.72	13271	468.29
10/5/2006	4	0.73	4740	52.43
10/17/2006	8	1.48	1310	29.05
10/19/2006	2	0.28	1530	1.95
10/27/2006	2	0.79	913	0.60
11/8/2006	5	1.54	2516	31.26
11/11/2006	3	0.52	2566	13.96
11/16/2006	19	1.54	4669	477.43
12/22/2006	18	2.11	1568	61.07
12/25/2006	3	0.77	337	2.74
12/31/2006	3	1.58	673	6.45
1/8/2007	10	1.28	1656	40.02
2/25/2007	1	0.71	297	0.66
3/1/2007	24	1.81	895	18.73
3/16/2007	24	1.86	270	12.32

Total Sediment Load (kg)	9414.85
Average Sediment Load per Storm (kg)	427.95

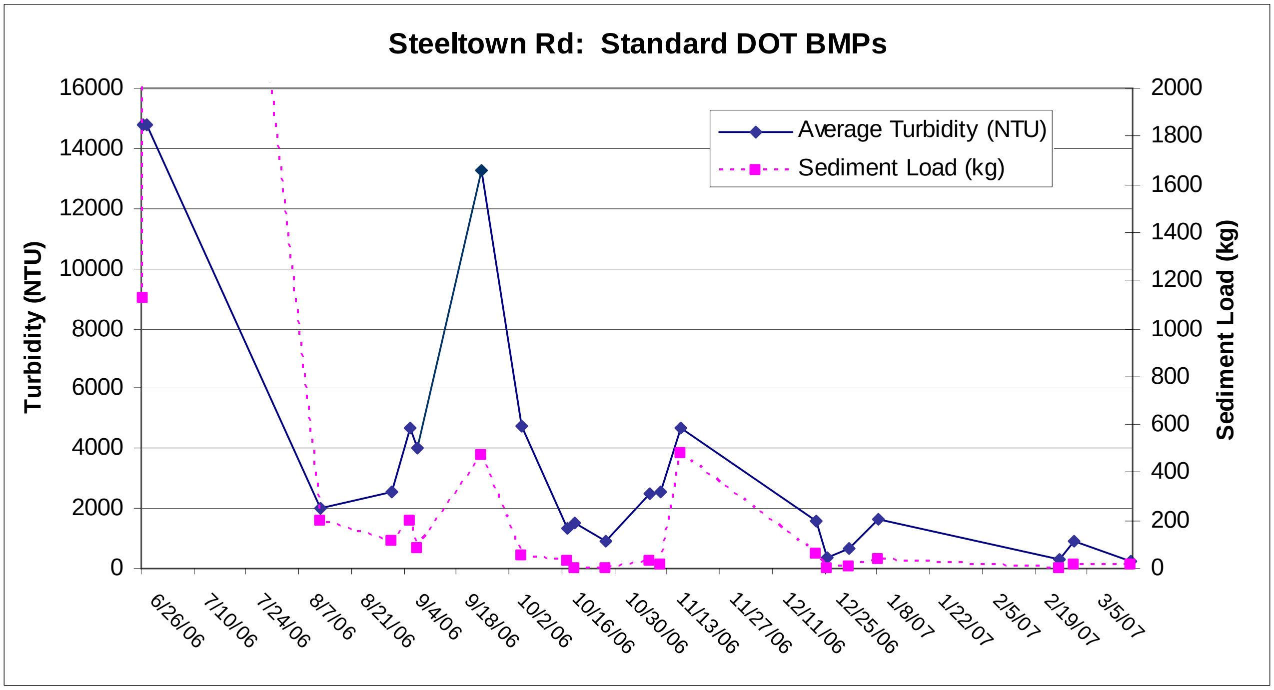

Figure 14. Steeltown Rd: Standard DOT BMPs

Table 6. Steeltown Rd: Experimental BMPs with PAM

Date	# of Samples	Rainfall (in)	Average Turbidity (NTU)	Sediment Load (kg)
6/27/2006	22	1.29	109	3.54
7/25/2006	6	0.37	335	0.87
8/9/2006	2	0.44	24	0.07
8/11/2006	13	1.21	24	0.96
8/12/2006	9	1.49	40	1.55
8/30/2006	11	1.10	43	2.70
8/31/2006	10	1.05	38	1.25
9/4/2006	3	1.68	40	0.78
9/7/2006	9	0.60	16	0.88
9/13/2006	7	0.99	9	0.09
9/23/2006	4	0.35	77	1.98
9/24/2006	4	0.72	18	0.00
10/5/2006	11	0.73	15	2.41
10/17/2006	13	1.48	4	0.18
10/20/2006	11	0.28	3	0.14
11/8/2006	11	1.54	13	0.46
11/11/2006	9	0.52	17	0.18
11/16/2006	12	1.54	5	0.93

11/22/2006	2	0.31	9	0.00
12/1/2006	22	0.16	3	0.01
12/22/2006	17	2.11	12	1.35
12/25/2006	7	0.77	8	0.28
1/5/2007	24	0.59	7	0.26
1/21/2007	2	0.70	10	0.16
2/25/2007	3	0.71	16	0.25
3/1/2007	24	1.81	19	0.75
3/16/2007	24	1.86	16	1.60

Total Sediment Load (kg)	23.63
Average Sediment Load per Storm (kg)	0.88

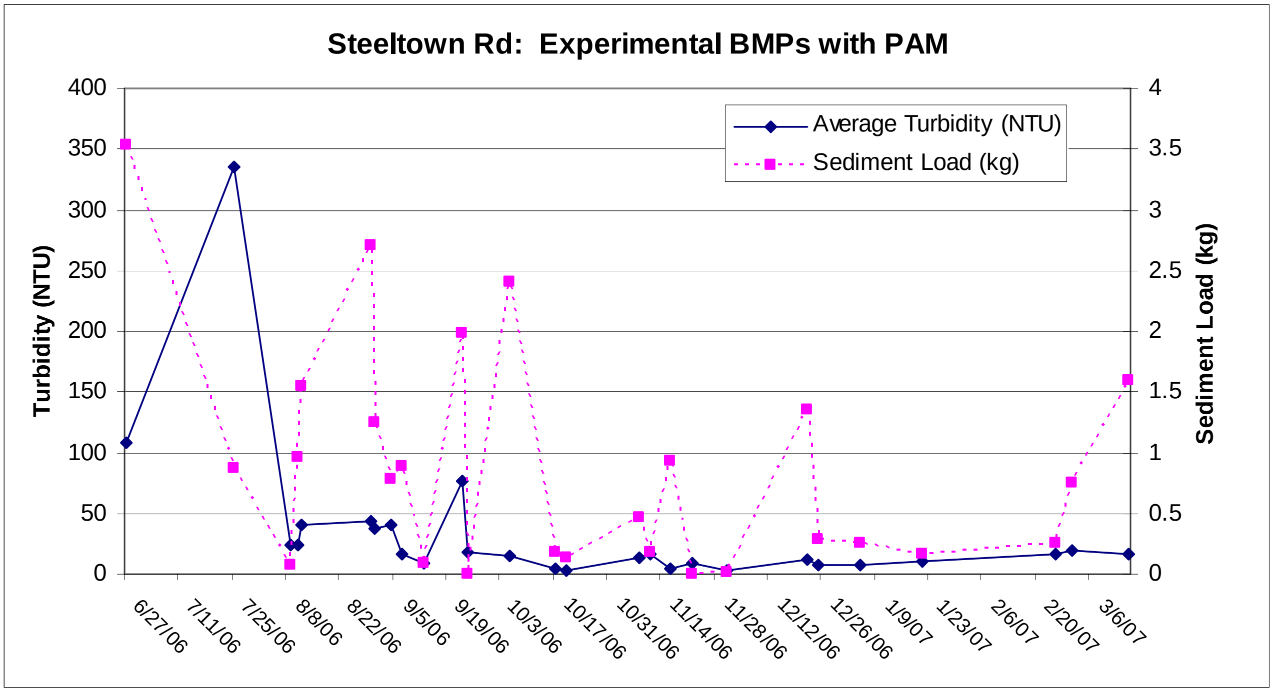

Figure 15. Steeltown Rd: Experimental BMPs with PAM

Table 7. Steeltown Rd: Experimental BMPs alone (no PAM)

Date	# of Samples	Rainfall (in)	Average Turbidity (NTU)	Sediment Load (kg)
6/27/2006	16	1.29	201	0.06
7/6/2006	24	0.74	919	0.12
7/25/2006	2	0.37	793	0.24
8/30/2006	9	1.10	570	10.49
8/31/2006	15	1.05	114	1.82
9/7/2006	8	0.60	274	5.14
9/13/2006	12	0.99	24	0.15

9/23/2006	4	0.35	414	1.69
10/5/2006	24	0.73	208	12.29
10/17/2006	13	1.48	69	1.75
10/20/2006	11	0.28	60	0.03
11/7/2006	24	1.13	37	0.09
11/16/2006	23	1.54	50	4.41
11/22/2006	2	0.31	36	0.00
12/1/2006	14	0.16	20	0.01
12/22/2006	12	2.11	21	1.36
12/25/2006	4	0.77	22	0.13
1/5/2007	24	0.59	44	2.83
1/21/2007	2	0.71	75	5.11
3/16/2007	24	1.86	89	11.49

Total Sediment Load (kg)	59.21
Average Sediment Load per Storm (kg)	2.96

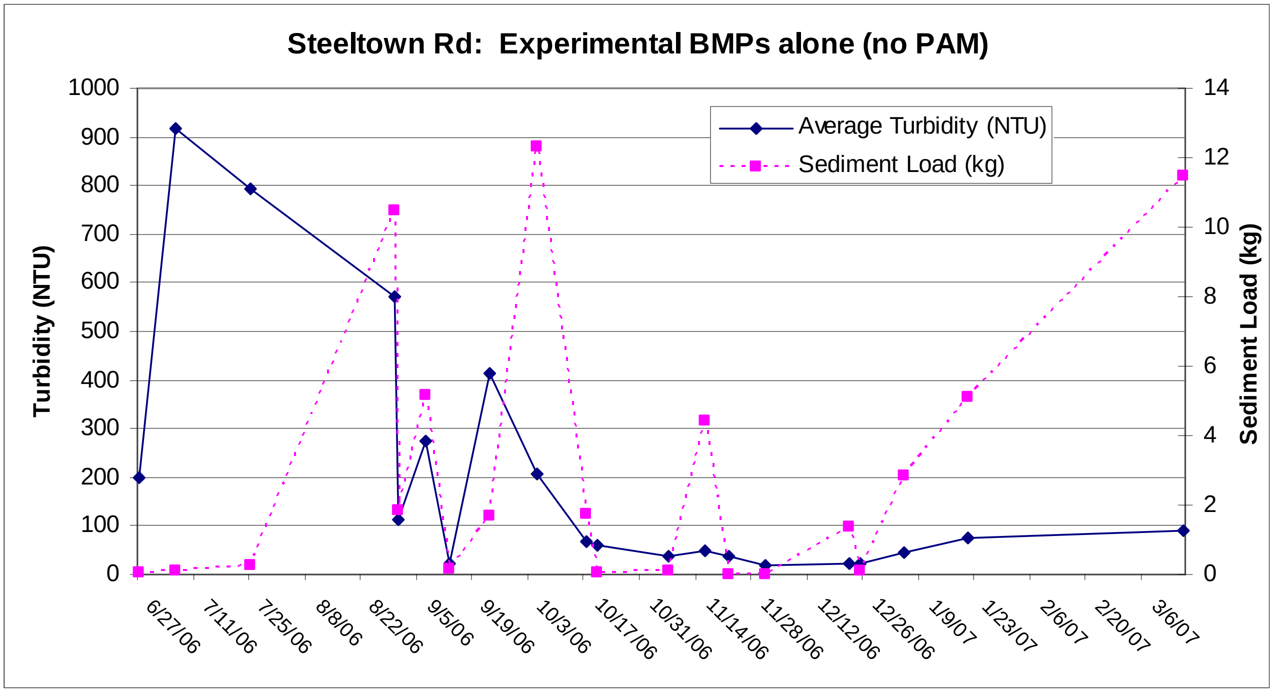

Figure 16. Steeltown Rd: Experimental BMPs alone (no PAM).

Table 8. Steeltown Rd Summary

	DOT Standard BMPs	Exp. BMPs with PAM	Exp. BMPs alone (no PAM)
Turbidity Values (NTU)			
Average	4198	30	187
Standard Deviation	6552	120	426
Median	1737	12	65
Sediment Loading Rates (kg)			
Total Sum	9414.85	23.63	59.21
Average Load per Storm	427.95	0.88	2.96

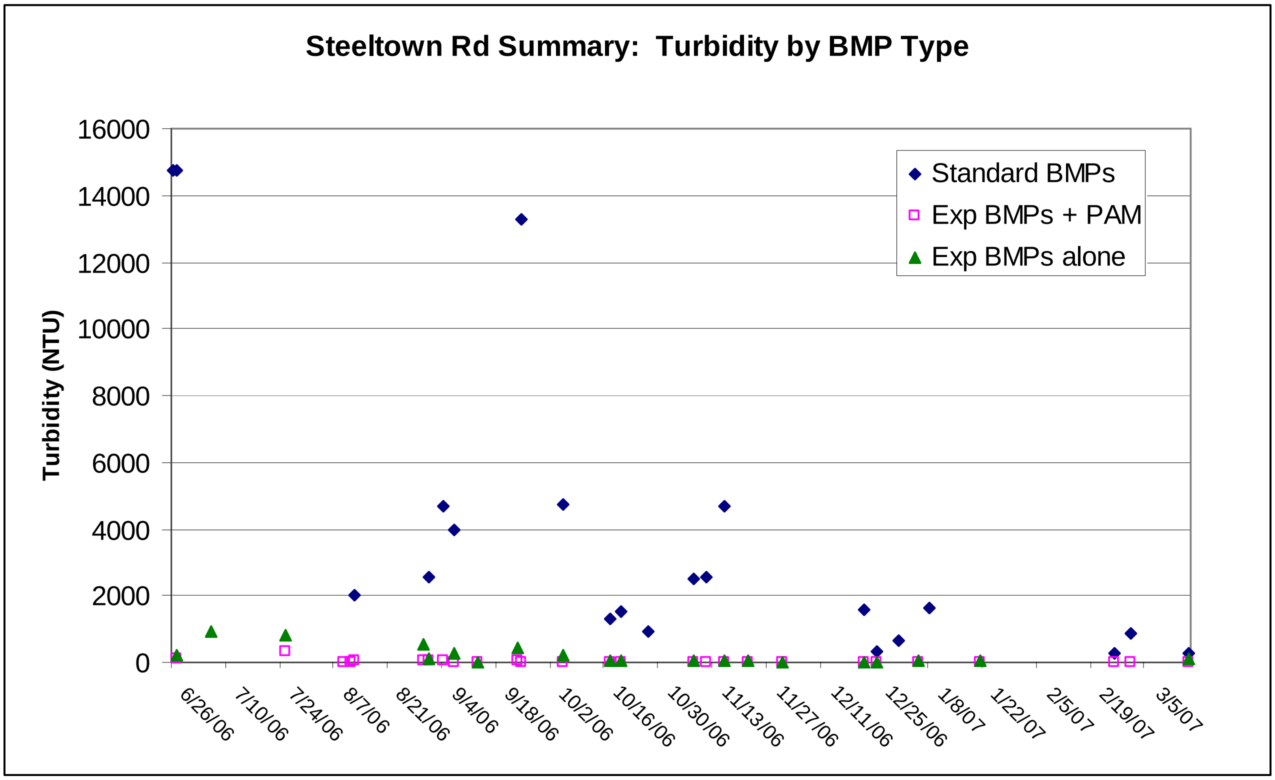

Figure 17. Steeltown Rd Summary: Turbidity by BMP Type.

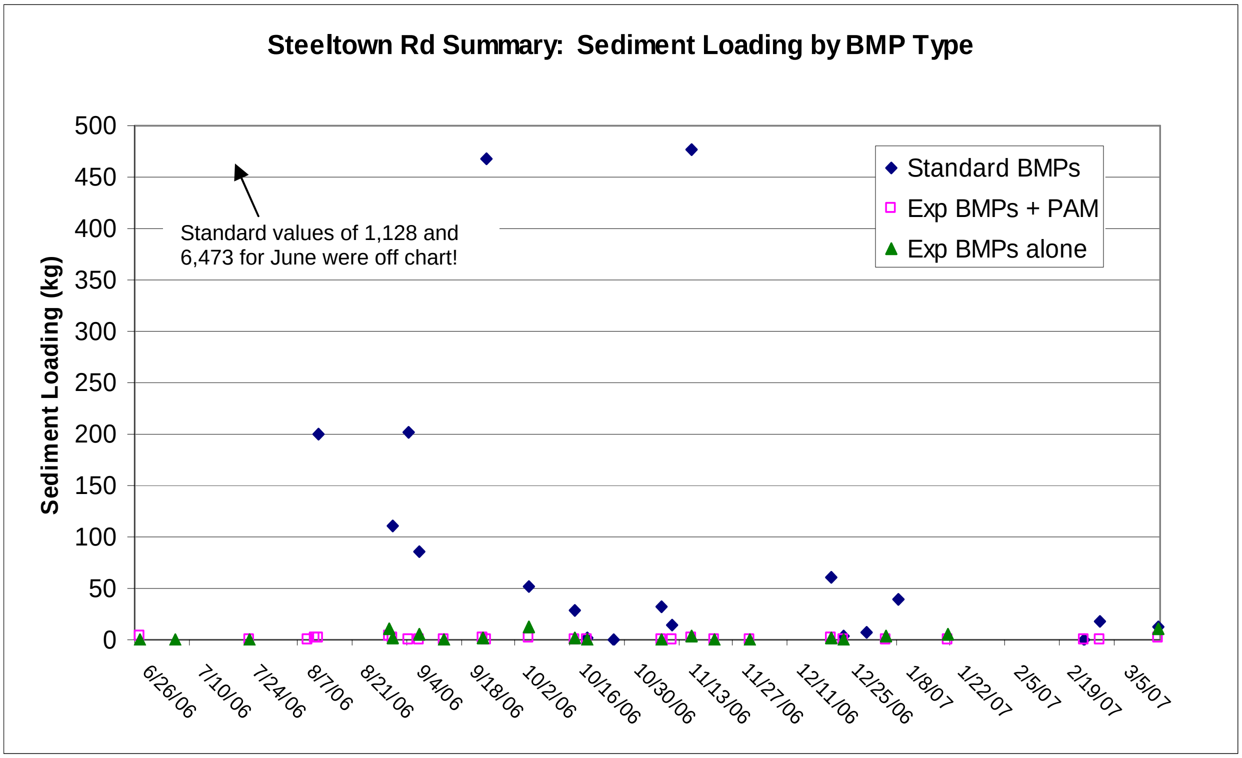

Figure 18. Steeltown Rd Summary: Sediment Loading by BMP Type.

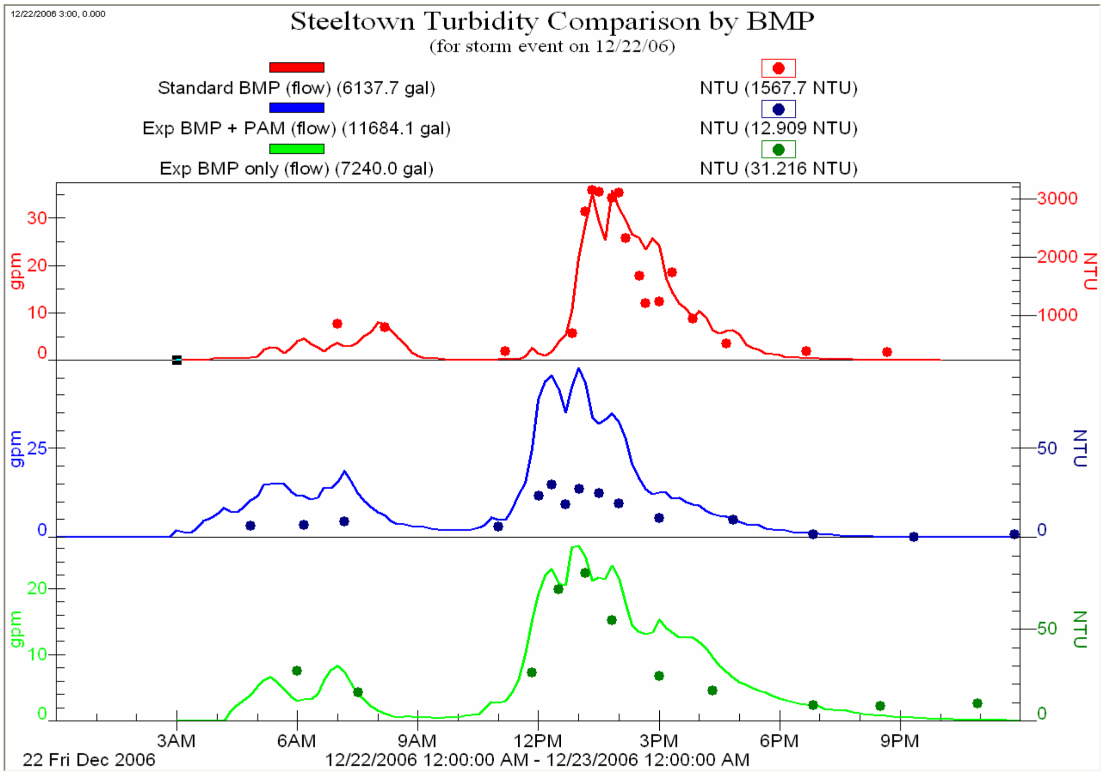

Figure 19. Sample Steeltown Rd Storm Event.

A sediment trap was also located at the very bottom of the roadway section, complete with a separate small forebay and two rows of coir baffles in the main bay. It was intended to be used to study the effects of the baffles on water quality, but due to the awkward curve of the trap, a design quirk due strictly to unavoidable right-of-way constraints, the relatively small flow volume bypassed most of the baffle, instead just concentrating in a narrow channel to one side. As a result, it was abandoned for the original purpose, but the results are still interesting in comparison to the second experimental BMP section (without PAM), which discharged directly into the trap.

In evaluating the two sets of data, the trap outfall was considerably more turbid compared to the runoff flowing into the basin from the experimental BMP section. For the seven storms from which data was collected at both locations, we found an average increase in turbidity of 416 NTU as the water flowed through the trap. We did not determine flows from this basin so we did not calculate sediment losses.

Table 9. Steetltown Rd: Basin outlet

Date	# of Samples	Rainfall (in)	Average Turbidity (NTU)	Average TSS (mg/L)
6/25/2006	4	1.17	1078	1204.55
7/6/2006	3	0.74	1080	1137.80
8/12/2006	13	1.49	411	307.55
8/31/2006	10	1.05	514	470.92
9/4/2006	10	1.68	468	350.60
9/7/2006	7	0.60	686	654.91
10/5/2006	6	0.73	2110	1751.40
10/17/2006	24	1.48	65	78.02
11/7/2006	24	1.13	67	47.47
11/16/2006	16	1.54	61	74.55

Figures 20 and 21. Steeltown Rd Basin.

Curley Maple Rd

The Curley Maple Rd site was fully instrumented in July of 2006. Not as many storms were captured at this site due to a range of technical and field challenges. Located high in the mountains, it was much colder and shadier here than at Steeltown, resulting in more rapidly draining batteries, frozen bubbler and suction tubes, inefficient solar panels, etc. The placement of the sampler tubing directly in the outfall pipe, while certainly a successful design on other projects, proved less reliable here, perhaps due to the much smaller flow volumes at these sites as compared to much larger stormwater basins on the bigger construction sites we usually monitor. Prior to grading, samples were obtained from six storm events and averaged 1,613 NTU and TSS of 738 mg L^{-1}. During the construction period, we obtained samples from 19 storms on the standard section and 9 storms on the experimental section.

The road was paved between September 29 and October 1, 2006, and there is a general reduction in turbidity after that time. However, the standard section still had higher turbidities than the experimental with PAM.

The overall results were similar to the Steeltown Road site, although the actual turbidity and sediment load numbers were much smaller in both sections. The standard BMP section had average turbidity and overall sediment losses roughly 10 times higher than the experimental BMP + PAM section. We did not have room to have a section with experimental BMPs alone.

Table 10. Curley Maple Rd: DOT Standard BMPs

Date	# of Samples	Rainfall (in)	Average Turbidity (NTU)	Sediment Load (kg)
7/13/2006	24	0.34	877	5.34
7/21/2006	15	0.95	3419	19.81
7/23/2006	1	-	163	0.36
8/31/2006	6	3.08	1871	6.85
9/5/2006	12	2.30	829	7.08
9/10/2006	1	0.43	3304	1.97
9/13/2006	2	1.19	1169	1.58
9/24/2006	2	0.47	1777	2.60
12/1/2006	2	0.91	110	2.11
12/22/2006	1	0.97	308	5.28
12/26/2006	2	0.49	24	0.10
1/8/2007	16	0.65	116	2.29
1/22/2007	2	0.58	98	4.50
2/14/2007	8	0.28	56	0.44
2/21/2007	16	0.44	112	1.51
3/1/2007	21	0.86	207	1.10
3/2/2007	3	0.23	1351	1.17
4/16/2007	2	0.41	133	0.51
4/19/2007	4	0.53	550	0.76

Total Sediment Load (kg)	65.36
Average Sediment Load per Storm (kg)	3.63

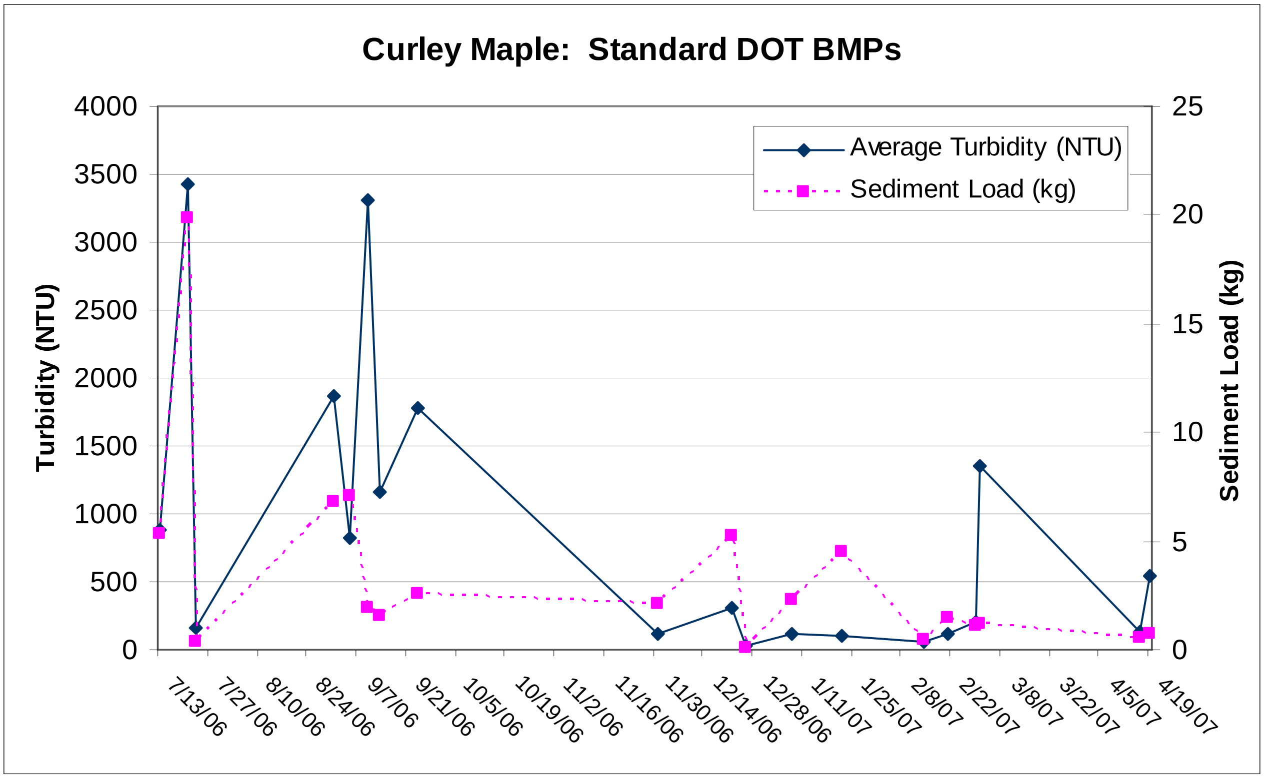

Figure 22. Curley Maple: Standard DOT BMPs.

Table 11. Curley Maple Rd: Experimental BMPs with PAM

Date	# of Samples	Rainfall (in)	Average Turbidity (NTU)	Sediment Load (kg)
7/13/2006	4	0.34	90	0.24
9/10/2006	1	0.43	15	0.09
9/13/2006	4	1.19	44	0.32
9/24/2006	2	0.47	533	0.84
1/22/2007	2	0.58	2	0.48
2/21/2007	24	0.44	1	0.29
3/1/2007	24	0.86	47	1.48
3/16/2007	24	0.71	45	2.48
4/19/2007	8	0.53	261	0.60

Total Sediment Load (kg) 6.82
Average Sediment Load per Storm (kg) 0.76

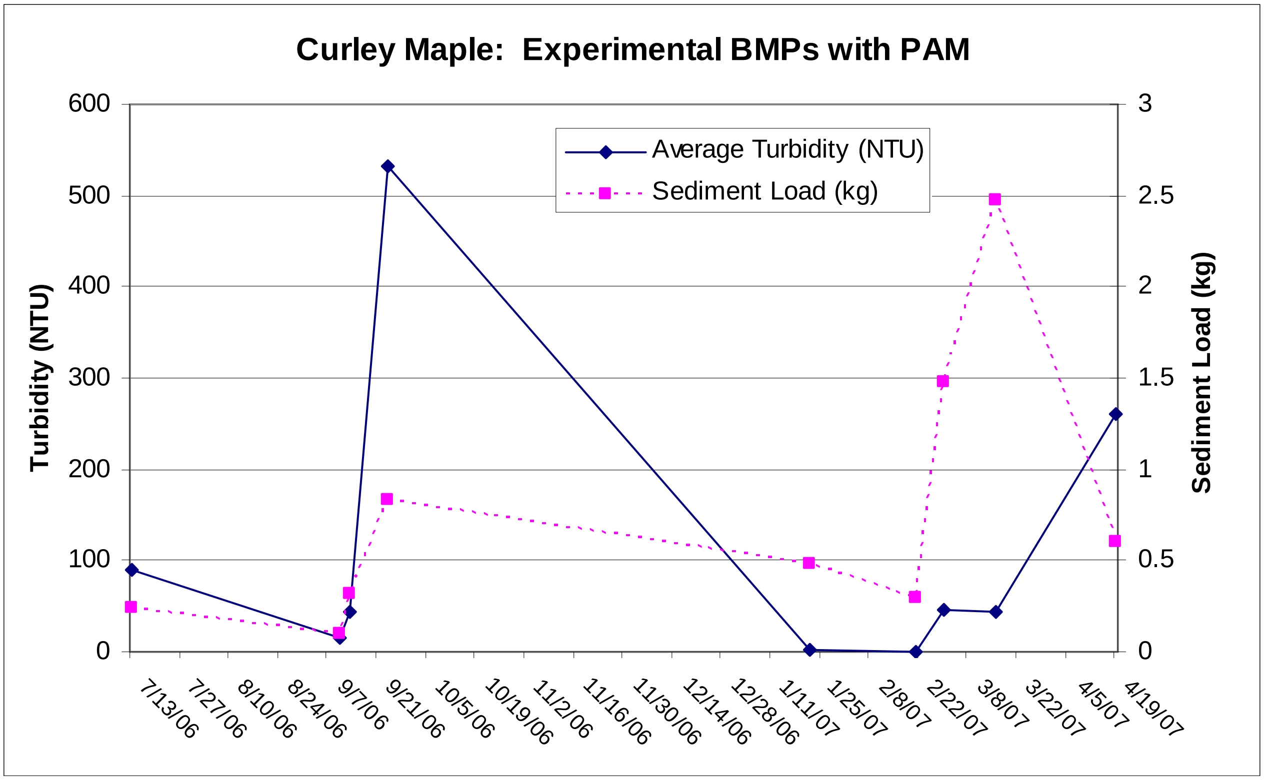

Figure 23. Curley Maple: Experimental BMPs with PAM.

Table 12. Curley Maple Rd Summary

	DOT Standard BMPs	Exp. BMPs with PAM
Turbidity Values (NTU)		
Average	852	64
Standard Deviation	1265	108
Median	305	40
Sediment Loading Rates (kg)		
Total Sum	65.36	6.82
Average Load per Storm	3.63	0.76

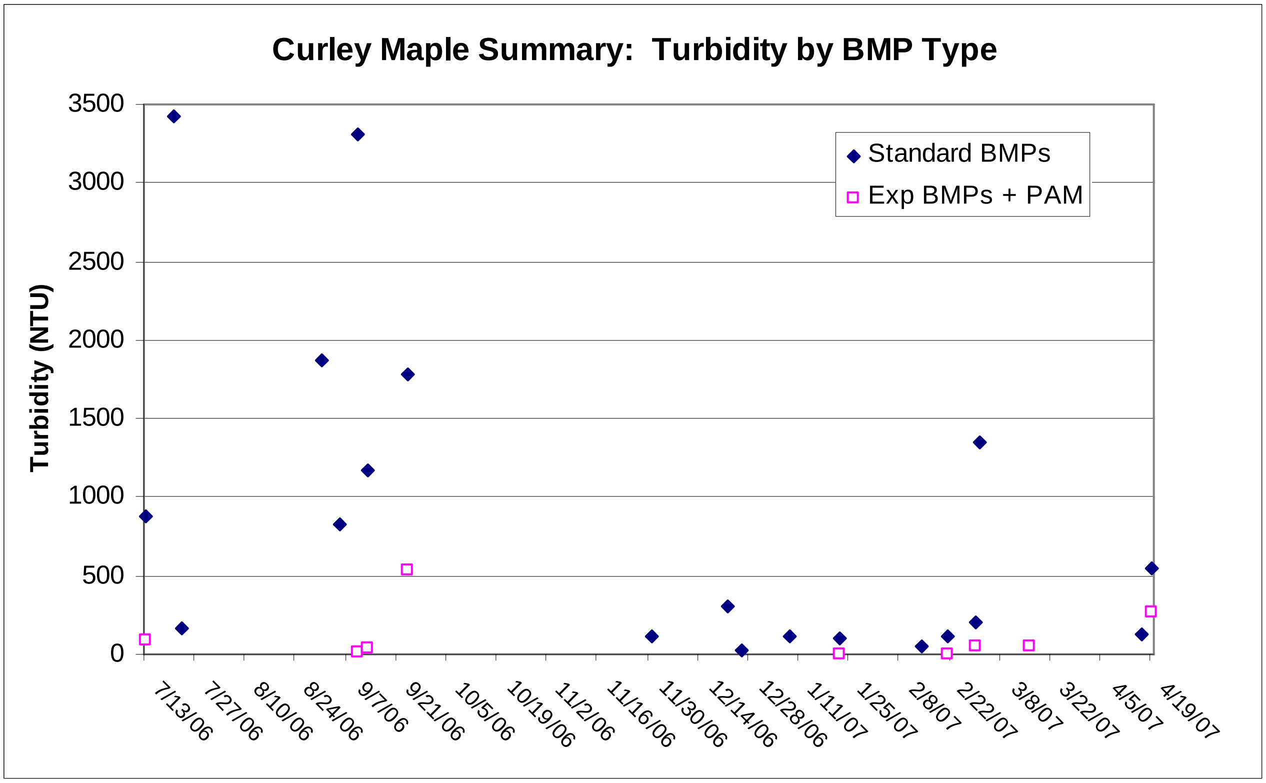

Figure 24. Curley Maple Summary: Turbidity by BMP Type.

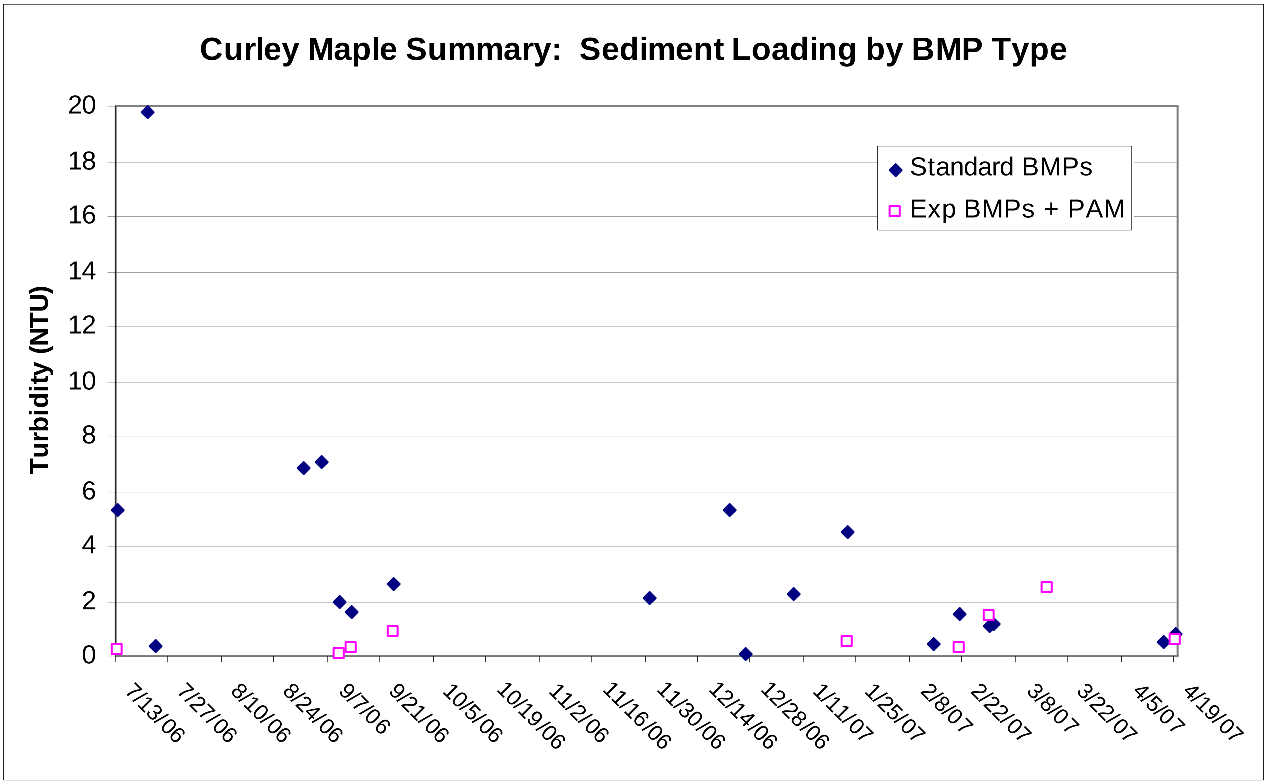

Figure 25. Curley Maple Summary: Sediment Loading by BMP Type.

Fleming Chapel Church Rd

The field study for this site is not yet complete and only a limited number of storms have been captured since it was fully instrumented in April 2007, primarily due to a lack of rainfall. The baseline data consisted of two samplers. The first was sampling a stretch of roadway that was partially disturbed by grading activity before the winter work cessation. The second sampler was from an undisturbed section and probably represents more accurate background data. The first sampler obtained samples from six storms with an average per storm turbidity of 4,249 NTU and TSS of 4,738 mg L^{-1}. The second sampler got data from six storms with an average per storm turbidity of 1,775 NTU and TSS of 1,776 mg L^{-1}.

We have four sections at this site, including the standard BMPs, experimental + PAM, experimental alone, and wide-spacing experimental alone. The only storm which has provided comparisons was on June 12. The experimental + PAM section had turbidity more than 20X lower than the standard BMP section. The wide-spacing experimental section had runoff turbidity relatively similar to the standard BMP section. No samples were obtained from the experimental alone section.

Table 13. Fleming Chapel Church Rd

Date	# of Samples	Rainfall (in)	Average Turbidity (NTU)	Sediment Load (kg)
Standard				
4/15/200	24	1.31	5744	323
6/12/2007	2	0.45	7310	12
6/14/2007	5	0.71	7915	30
Experimental plus PAM				
6/12/2007	24	0.45	304	16
Experimental alone (30’ spacing)				
4/15/2007	24	1.31	5335	100
Experimental alone (60’ spacing)				
4/15/2007	10	1.31	7474	51
6/12/2007	7	0.45	4796	17
6/14/2007	6	0.71	4992	11

Water Storage Volume Estimates

The potential water storage volumes were estimated for three common diameters of wattles/logs (9", 12", and 18"), and are given in the charts below for both the percent slope of the ditch (1%-10%) as well as ditch width (3'-5'). Note that over time, as any of these BMPs fill in with sediment, their water storage capacity would decrease.

In calculating the water storage volumes for the Steeltown Rd site, the standard DOT section, with six basins, held roughly 288 ft^3 of water. By comparison, the experimental with PAM section, with 15 straw wattles and 5 coir logs at a 7% slope and 3' wide channel, held roughly 289 ft^3 of water, while the experimental alone section, with 15 straw wattles and 4 coir logs at a 6% slope and 3' wide channel, held roughly 312 ft^3 of water.

At the Curley Maple Rd site, the standard DOT section with six basins held roughly 288 ft^3 of water, while the experimental with PAM section with 13 straw wattles and 5 coir logs at a 3% slope and 3' wide channel held roughly 615 ft^3 of water.

Thus, the new experimental BMPs appear to be a reasonable substitute to the standard BMPs with regards to their overall water storage volume capacity.

Table 14. 9" Wattle Water Storage

Slope (%)	Channel Width (ft)	Water Volume Storage (ft^3)
1	3	84.4
1	4	112.6
1	5	140.7
2	3	42.2
2	4	56.3
2	5	70.3
3	3	28.1
3	4	37.5
3	5	46.9
4	3	21.1
4	4	28.1
4	5	35.2
5	3	16.9
5	4	22.5
5	5	28.1
6	3	14.1
6	4	18.8
6	5	23.4
7	3	12.1
7	4	16.1
7	5	20.1
8	3	10.6
8	4	14.1
8	5	17.6
9	3	9.4
9	4	12.5
9	5	15.6
10	3	8.4
10	4	11.3
10	5	14.1

Table 15. 12" Wattle Water Storage

Slope (%)	Channel Width (ft)	Water Volume Storage (ft^3)
1	3	150.1
1	4	200.0
1	5	250.1
2	3	75.0
2	4	100.1
2	5	125.1
3	3	50.0
3	4	66.7
3	5	83.4
4	3	37.5
4	4	50.0
4	5	62.5
5	3	30.0
5	4	40.0
5	5	50.0
6	3	25.0
6	4	33.4
6	5	41.7
7	3	21.4
7	4	28.6
7	5	35.7
8	3	18.8
8	4	25.0
8	5	31.3
9	3	16.7
9	4	22.2
9	5	27.8
10	3	15.0
10	4	20.0
10	5	25.0

Table 16. 18" Wattle Water Storage

Slope (%)	Channel Width (ft)	Water Volume Storage (ft^3)
1	3	337.7
1	4	450.2
1	5	562.8
2	3	168.8
2	4	225.1
2	5	281.4
3	3	112.6
3	4	150.1
3	5	187.6
4	3	84.4
4	4	112.6
4	5	140.7
5	3	67.5
5	4	90.0
5	5	112.6
6	3	56.3
6	4	75.0
6	5	93.8
7	3	48.2
7	4	64.3
7	5	80.4
8	3	42.2
8	4	56.3
8	5	70.3
9	3	37.5
9	4	50.0
9	5	62.5
10	3	33.8
10	4	45.0
10	5	56.3

BMP Spacing Recommendations

The spacing distances between installed BMPs were determined for three diameters of wattles and for the percent slope of the ditch, as shown in the graphs below. These spacing were calculated for the formation of a step pool sequence. That is, when filled to capacity with water, a series of pools would be formed, each one beginning at roughly the base of the previous upslope wattle. This aids in the promotion of water infiltration as well as of sedimentation, and helps prevent erosion by reducing scouring in the ditch.

Note that at the three project sites, the experimental wattle spacing was much further apart than would be recommended in the guides below. For example, at Steeltown the wattle spacing was 32’ for the 7% slope section and 25’ for the 6% slope section, though the guides below would have recommended just 11’ and 13’ respectively. At Curley Maple, the actual spacing was much closer to the recommended, as the wattles were 27’ apart for the 3% slope, while the guide recommends 25’. Yet despite the differences, excellent results were obtained from both sites indicating that even under less than ideal wattle spacing, significant water quality improvements can be achieved.

Table 17.
9” Wattle Spacing

Slope (percent)	Distance Between Wattles (ft)
1	75
2	38
3	25
4	19
5	15
6	13
7	11
8	9
9	8
10	8

Table 18.
12” Wattle Spacing

Slope (percent)	Distance Between Wattles (ft)
1	100
2	50
3	33
4	25
5	20
6	17
7	14
8	13
9	11
10	10

Table 19.
18” Wattle Spacing

Slope (percent)	Distance Between Wattles (ft)
1	150
2	75
3	50
4	38
5	30
6	25
7	21
8	19
9	17
10	15

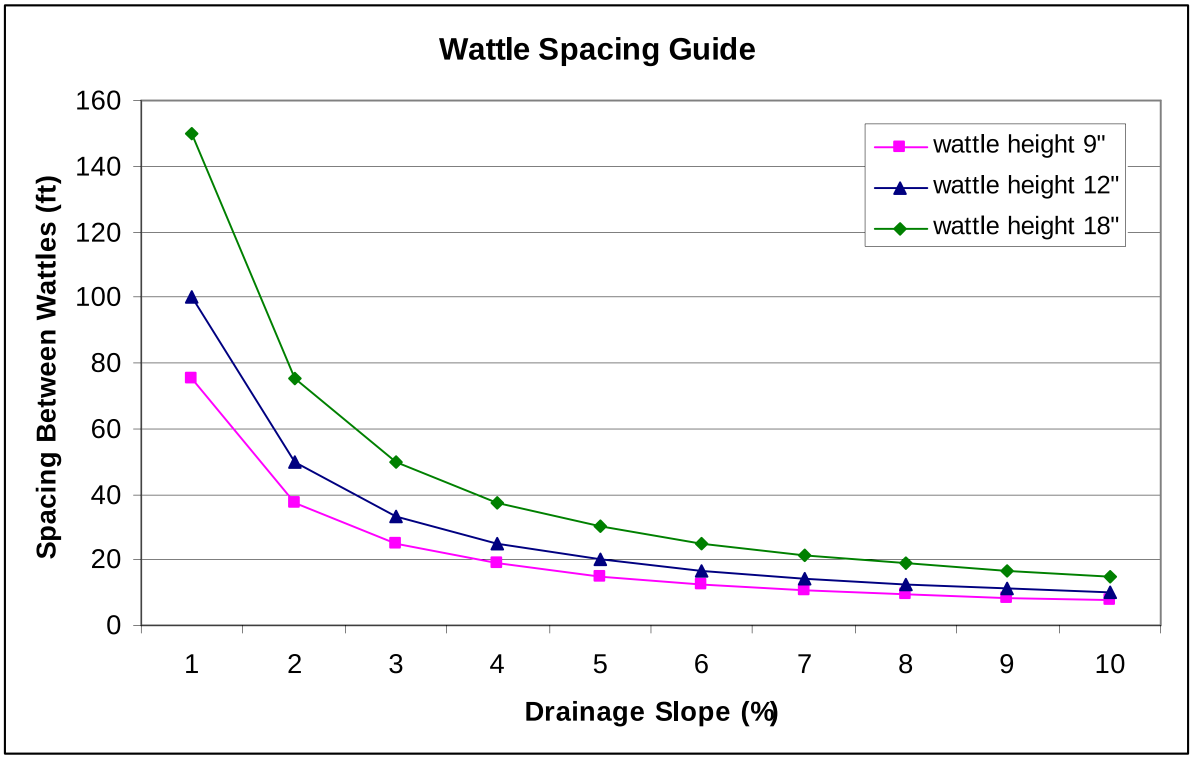

Figure 26. Wattle Spacing Guide by Wattle Height and Drainage Slope.

Conclusions and Recommendations

In comparing the alternate BMPs against the Standard DOT BMPs, the results suggest there is a significant advantage in the use of the new BMP types, particularly those with PAM 705 added.

At the Steeltown Road site the average turbidity values (in NTU) for the stormwater runoff were 4,198 for the Standard BMPs, 30 for the Exp. BMPs with PAM 705, and 187 for the Exp. BMPs alone. The Curley Maple site showed similar results with average turbidity values of 64 for the Exp. BMPs with PAM 705, as compared to 852 for the Standard BMPs.

Sediment loading at both sites was similarly skewed with dramatic decreases in sediment discharged off site from the new BMPs. At Steeltown, the Standard BMPs lost an average of 944 lbs (428 kg) of sediment per storm event as compared to just 1.93 lbs (0.88 kg) for the Exp. BMPs with PAM and 6.53 lbs (2.96 kg) for the Exp. BMPs alone. At Curley Maple, the Standard BMPs lost an average of 8.84 lbs (3.63 kg) per storm event compared with 1.67 lbs (0.76 kg) for the Exp. BMPs with PAM.

With regard to the sensitive habitat runoff turbidity limit of 10 NTU, a common restriction in the mountains with their significant number of trout streams, only the experimental BMPs with PAM 705 came close to successfully meeting this low threshold, though still slightly exceeding it.

It would appear that the new BMPs are not significantly more expensive than the Standard BMPs, based on average cost estimates performed. The differences in costs for each project would likely be less than a few hundred dollars, which is very small in comparison to the total project costs. It also appears that the new BMPs are a reasonable substitute to the standard BMPs with regards to their overall water storage volume capacity, as their calculated storage volumes for the two project sites were equal to or exceeded those of the standard BMPs.

We recommend that the new BMPs be implemented on a wider basis by the DOT on similar roadway improvement projects, particularly in areas adjacent to sensitive habitat waters, with the hopes of improving the quality of stormwater runoff from DOT projects.

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Appendix A

Prior to the experimental sites discussed in the main body of this report, there were two previous, eventually abandoned attempts at roadway construction monitoring. The first was located along Benge Ashe road in Wilkes County, while the second was located along Mulatto Mountain road in Ashe County.

Benge Ashe

The Benge Ashe site was established in Sept. 2004 and consisted of a single, large sediment trap complete with a coir baffle (Figure A.1) and a sizeable forebay (Figure A.2). To collect the initial pre-construction background samples, an automated sampler was setup to capture runoff from the pipe discharging into the forebay, and single-stage samplers, commonly referred to as 'bottles on a stick' were placed at the outlets of both the forebay and main basin to look at sediment and turbidity differences within the basin itself.


Figure A.1.


Figure A.2.


Figure A.3.

Figures A.1, A.2, and A.3 above show the sediment trap design and adjacent slope at Benge Ashe.

The automated sampler experienced significant technical difficulties during the sampling effort. The area was quite cool and shaded and, as a result, the sampler batteries died very quickly. Few samples were ever collected with the device. The single-stage samplers proved more reliable however, and they captured runoff from several storms.

Results from storms from Sept. and Dec. (Figures A.4 through A.7) show how high the turbidities can get within the basin and at the outlet, with initial values ranging from 500 to almost 3,500 NTU! In the graphs below, the ‘in’ samples were those collected from the forebay, while the ‘out’ or ‘exit’ samples were those collected at the spillway, or exit, of main basin. The ‘lower’/’bottom’, ‘middle’, and ‘upper’ designations refer to the bottles placement position on the post itself, thus they give us a snapshot of the turbidities present in the basin over the duration of the storm as the basin filled up with runoff. The summary graph for all six storms captured (Figure A.7) reveals a general pattern within the sediment trap. While the forebay often reduces turbidity somewhat from the very high initial values, the main basin does not appear to reduce the turbidity any further, in fact revealing consistent increases. However, the trap was effective in capturing sediment and in reducing the loading rates discharged out of the trap, it is only with regards to turbidity that it appears to have little important treatment effect.

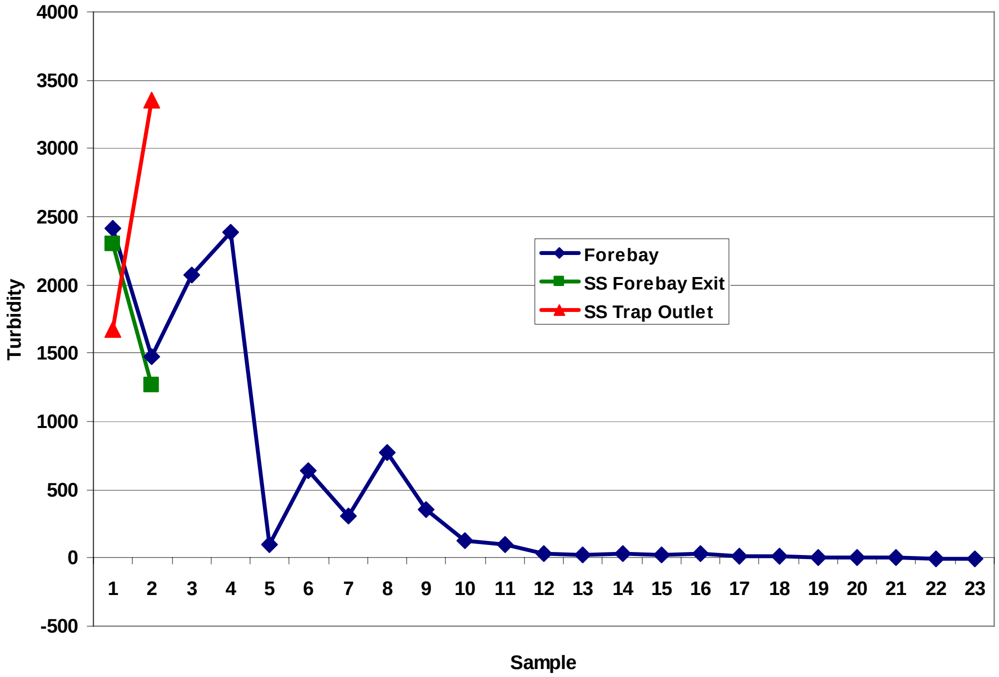


Figure A.4. Benge Ashe Storm Turbidity for 9/20/2004

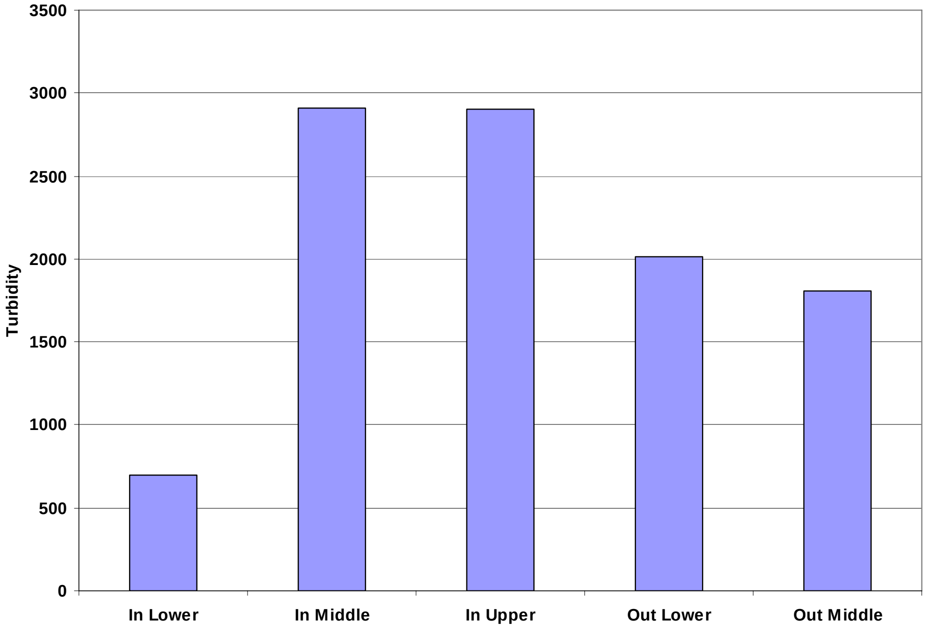


Figure A.5. Benge Ashe Single-Stage Sampler Turbidity for Storm on 9/30/2004

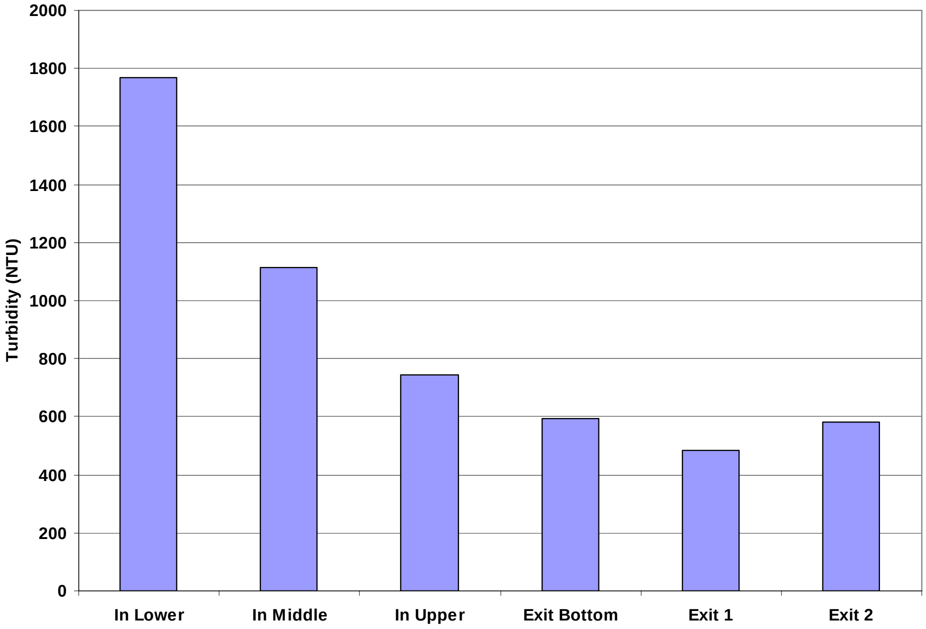


Figure A.6. Benge Ashe Single-Stage Sampler Turbidity for Storm on 12/8/2004

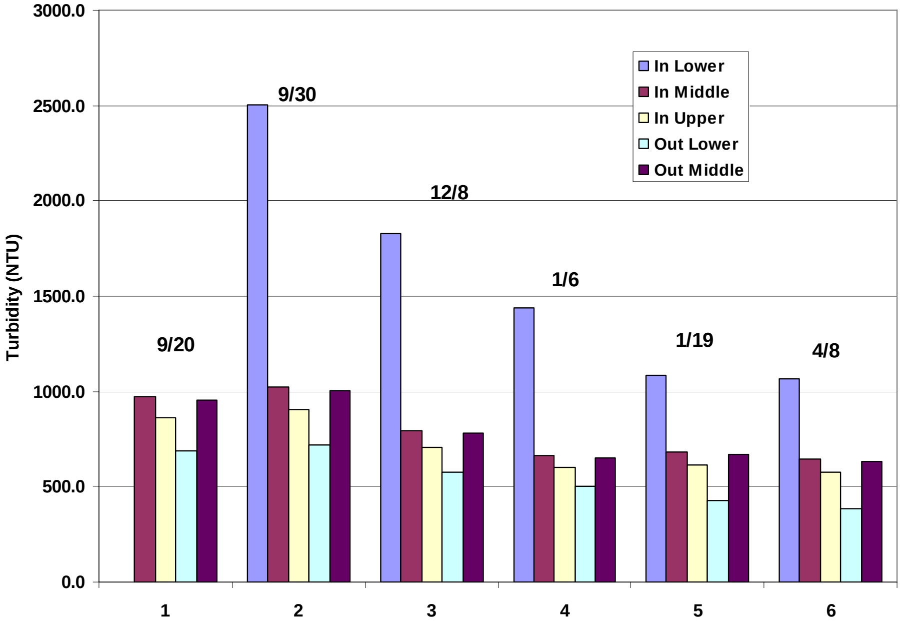


Figure A.7. Benge Ashe Single-Stage Sampler Turbidity by Storm Date

Mulatto Mountain

The Mulatto Mountain Rd site was monitored briefly from late 2004 to early 2005. This site consisted of a sediment trap with coir baffle (Figure A.10) as well as a second trap located a little farther downslope (Figure A.11) Automated water samplers were placed immediately adjacent to the road (Figures A.8 and A.9) and in both the traps to collect pre-construction background samples. However, samples in the traps ultimately proved quite difficult to capture here due to very high soil infiltration rates. For example, in the main trap (Figure A.10), the front of the coir baffle had a sizeable volume of sediment deposited on it, yet the rock spillway in the back was virtually clean and the sampler never recorded any runoff flowing overtop (and thus it captured no storm events).

The road surface samples collected revealed that there is a very large sediment load coming off these unpaved roads. The sampler intake tubing was often clogged up before it completed a full sample load. A view of the sample bottles taken from one storm event (Figure A.12) show how for many of the bottles, there was actually more sediment than water. The results were similar for the four storm events captured (Figure A.13), each revealing high sediment loading rates, though the runoff from the Jan. storm was particularly rich in sediment.

Ultimately, a vehicle crashed into the second sediment trap, damaging both the trap itself and, more importantly, the automated sampler. The DOT also notified us around this time that due to budget restrictions they were no longer planning on paving this road so the site was consequently abandoned.


Figure A.8.


Figure A.9.


Figure A.10.


Figure A.11.


Figure A.12.

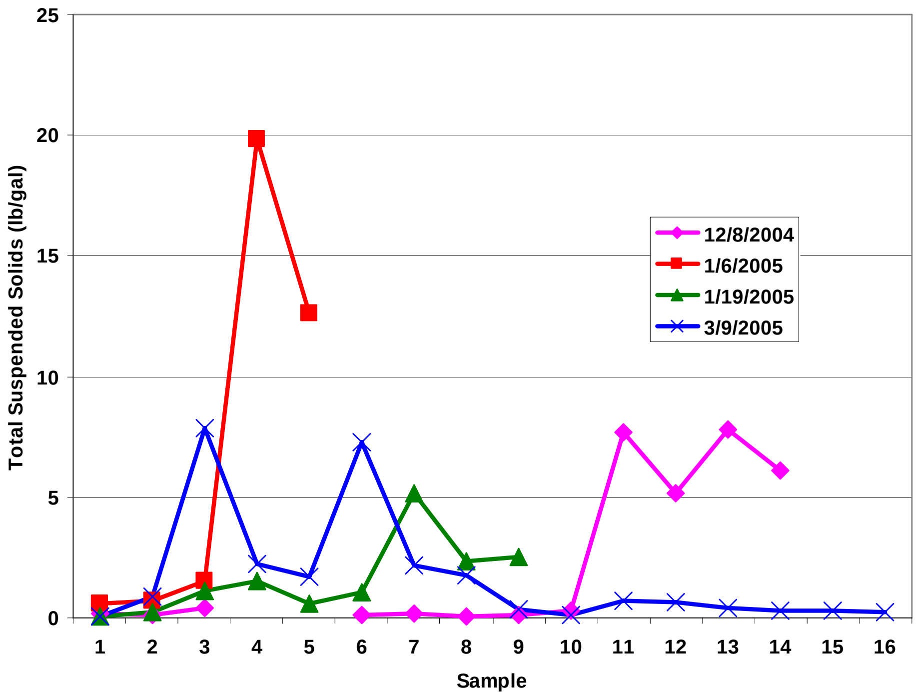
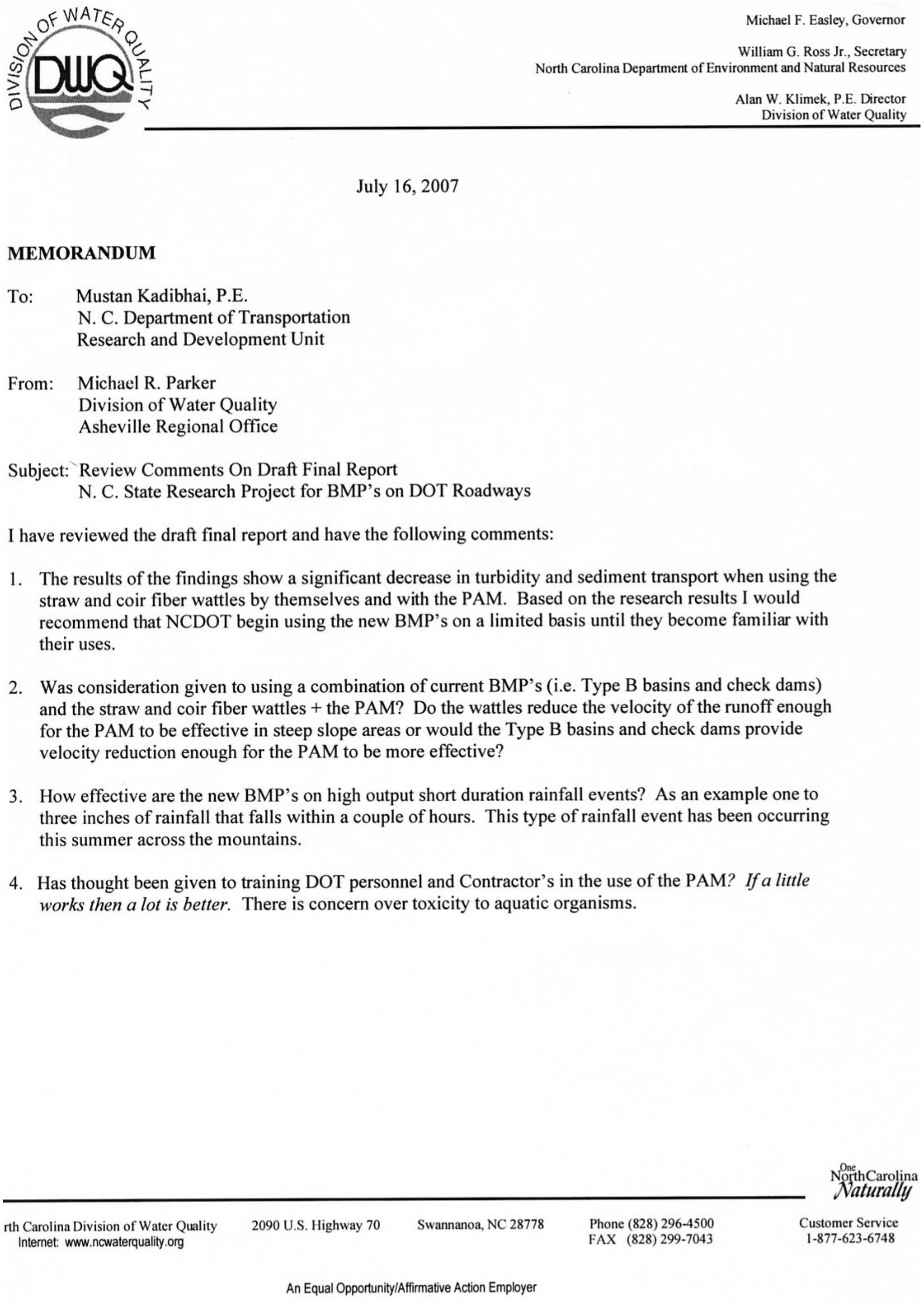


Figure A.13. Mulatto Mountain Pre-Construction Sediment Loading Rates for Four Storms.

Appendix B



Michael F. Easley, Governor

William G. Ross Jr., Secretary
North Carolina Department of Environment and Natural Resources

Alan W. Klimek, P.E. Director
Division of Water Quality

July 16, 2007

MEMORANDUM

To: Mustan Kadibhai, P.E.
N. C. Department of Transportation
Research and Development Unit

From: Michael R. Parker
Division of Water Quality
Asheville Regional Office

Subject: Review Comments On Draft Final Report
N. C. State Research Project for BMP's on DOT Roadways

I have reviewed the draft final report and have the following comments:

1. The results of the findings show a significant decrease in turbidity and sediment transport when using the straw and coir fiber wattles by themselves and with the PAM. Based on the research results I would recommend that NCDOT begin using the new BMP's on a limited basis until they become familiar with their uses.

2. Was consideration given to using a combination of current BMP's (i.e. Type B basins and check dams) and the straw and coir fiber wattles + the PAM? Do the wattles reduce the velocity of the runoff enough for the PAM to be effective in steep slope areas or would the Type B basins and check dams provide velocity reduction enough for the PAM to be more effective?

3. How effective are the new BMP's on high output short duration rainfall events? As an example one to three inches of rainfall that falls within a couple of hours. This type of rainfall event has been occurring this summer across the mountains.

4. Has thought been given to training DOT personnel and Contractor's in the use of the PAM*? If a little works then a lot is better.* There is concern over toxicity to aquatic organisms.

One NorthCarolina *Naturally*

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Response to comments from DWQ memorandum dated July 16, 2007:

2) Based on the results of this study, the fiber wattles do appear to adequately reduce the runoff velocity to allow for the sedimentation of PAM-flocculated particles, to at least as steep as the 7% slope for the center section at Steeltown. Significantly steeper slopes might result in a reduction in performance for the experimental wattles, but it seems unlikely that they would perform worse under similar conditions than the standard BMPs currently used. As long as the wattles are not washed away, and with adequate installation they should not, the wattles are at least as high as the rock checks and pond water upslope just as well, if not better. The small, vertical-walled basins appeared to act as much a generative source for sediment as for its deposition.

With regards to experimental design, the newer wattles were not used in conjunction with the standard DOT BMPs so as to better evaluate their individual performance, distinct from the standard. Also, for obvious economic reasons the DOT would prefer to replace a current structure or design with a superior one of comparable price as opposed to adding a new one on top of the current.

3) In the course of this project there were very few high output and short duration rainfall events as defined as one to three inches over a couple of hours. However, that type of storm event was recorded for the 6/27/06 and 8/30/06 sampling events and suggests that the experimental BMPs more than adequately hold up under those intense conditions, especially as compared to the standard BMPs (see Tables 10, 11, and 12 for further details).

4) Training DOT personnel and contractors in the proper installation of the wattles and application of the granulated polyacrylamide (PAM) is considered to be an important first step to the integration of the wattles into common DOT use, especially with regards to the concern over the potential toxicity of the polymer. An installation training presentation has already been assembled and is currently being reviewed for use for this exact purpose.