EFFICIENCIES OF TEMPORARY SEDIMENT TRAPS ON TWO NORTH CAROLINA CONSTRUCTION SITES

D. E. Line, N. M. White

ABSTRACT. *Sediment export from construction sites is receiving increasing scrutiny, and correspondingly the efficiencies of sediment controls are being questioned. Sediment or total suspended solids (TSS) and total phosphorus (TP) concentrations in outflow from, as well as sediment accumulation, in three temporary sediment traps located on North Carolina construction sites were monitored to assess the efficiencies of the traps. The trapping efficiency of the trap located on a Coastal Plain site (Woodsong) was 69%, while the efficiencies of two traps located on a Piedmont site (Carpenter) averaged 59%. In addition, the Carpenter trap retained 30% of the TP coming off the site, while the Woodsong trap retained 9%. Sediment size analyses of a limited number of samples indicated that the Woodsong trap retained 91%, 43%, and 21% of the sand, silt, and clay primary particles entering the trap, while the Carpenter traps retained 68%, 72%, and 40% of the sand, silt, and clay particles entering it. The turbidity of outflow samples was also measured and correlated to TSS concentrations. A relatively strong linear correlation was found for data from the Carpenter traps (r^2 = 0.96), and a weaker correlation was documented for the Woodsong trap (r^2 = 0.64). These data indicate that for sites with high TSS concentrations in runoff and relatively little organic matter left on the site, TSS may be computed from turbidity; however, more data is needed to confirm this assertion.*

Keywords. *Sediment, Sediment detention, Construction, Sediment size.*

Sediment is generally accepted as the most pervasive pollutant in rivers and streams of the United States in terms of volume (Clark et al., 1985). In response to sediment pollution, billions of dollars have been spent on soil and water conservation projects. Most of the funds and effort have focused on controlling erosion and sediment loss from agricultural land. However, relatively recently, many states and municipalities have expanded erosion and sediment control efforts to include controlling sediment loss from urban–related sources such as construc– tion sites (Mertes, 1989).

North Carolina has one of the strongest sediment and erosion control programs for construction sites in the U.S. in terms of its comprehensiveness, financing, and staffing levels (Paterson et al., 1993). The program requires anyone who intends to disturb one acre or more of landto have an erosion and sediment controlplan detailing the area to be disturbed and the measures to be used to control sediment export from the site throughout the life of the project. Despite an ambitious program, sediment remains the primary pollutant affecting the quality of North Carolina's surface waters. While there are many sources of sediment in the state, construction–related activities were cited by the state as a major source of degradation to lakes (NC DENR, 1992). Further, Burby et al. (1990) reported that one–third or more of urban construction sites in the state release sediment to neighboring property and nearby streams.

Sediment from urban areas received public notoriety in North Carolina in 1997 when a plume of red, muddy runoff, thought to be from construction sites, was photographed on its way down the Neuse River. Following this incident, the governor called on the North Carolina Department of Environment and Natural Resources (NC DENR) to begin stricter enforcement of erosion and sediment control regulations on construction sites. In addition, the governor asked for a review of standards and needs for the erosion and sediment control program. One of the identified needs was to develop a better understanding of the limitations and efficiency of erosion and sediment control practices.

A review of the literature indicates that the sediment trapping efficiency of many devices depends on factors such as the intensity and duration of storm events, topography and extent of construction sites, soil type, and the system of practices implemented. For example, a study that examined the effectiveness of sediment traps and basins found that total suspended solids (TSS) measured in runoff from construction sites ranged up to four times the median value of 680 mg TSS/L for varying storm conditions (Schueler and Lugbill, 1990). These differences in concentrations were shown to effect trapping efficiency of the device. Device trapping efficiency also varies by soil type. Data collected from outflows of sediment trapping devices found instantaneous removal of only 46% of incoming sediment (Schueler and Lugbill, 1990). This low trapping efficiency was partially attributed to the incoming sediment being relatively fine–grained, consisting of silts, clays, and colloidal material (Hainley, 1980; Garcia, 1988; Schueler and Lugbill, 1990).

While there is considerable data on the TSS trapping efficiency of stormwater detention and retention ponds, there is little data on the efficiency of temporary sediment basins

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The authors are **Daniel E. Line,** ***ASAE Member Engineer***, Extension Specialist, Biological and Agricultural Engineering Department, and **Nancy M. White**, Director Research, Extension and Sponsored Programs, College of Design, North Carolina State University, Raleigh, North Carolina. **Corresponding author:** Daniel E. Line, NCSU Water Quality Group, Box 7637, Raleigh, NC 27695; phone: 919–515–8243; e–mail: dan_line@ncsu.edu.

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located on construction sites and even less on temporary sediment traps. Sediment basins, which are enclosed ponds with a type of riser outlet, have been evaluated by several researchers. A study of sediment basins in the Piedmont region of Maryland documented an average instantaneous TSS removal efficiency of 65% over nine storm events for four basins and two sediment traps (Schueler and Lugbill, 1990). When using only the data from storms that produced outflow, the efficiency decreased to 46%. These data are valuable; however, they were collected for only a limited number of storms and were based on only one sample per event and on only concentrations. More extensive testing at a research site documented a 93% efficiency on a mass–of–sediment basis for a basin with a perforated riser, and a 94.6% efficiency for the same basin with the addition of flow barriers to the basin (Millen et al., 1996).

The effectiveness of these sediment basins for a variety of soils and storm types and over a period of time is not well documented, but it is thought to be relatively low. So new techniques and modifications to existing practices are being evaluated. For example, using expanded polystyrene chips and gravel as filters enveloped in the spillway in a laboratory–scale sedimentation basin, Engle and Jarrett (1995) achieved average sediment removal of 78.3% and 87.5% for two devices with 1.5 and 3.0 hour de–watering times. Przepiora et al. (1998) found that molding plaster applied at the rate of 350 to 700 mg/L reduced fine–grained suspended sediment in basins within 3 hours of adding the flocculate. Adding baffles to sediment basins to slow the movement of water may also hold promise for improving trapping efficiency.

While some research has been conducted on sediment or TSS trapping efficiency of basins and the effects of modifications of basins, much less is known about the efficiency of temporary sediment traps. Sediment traps are similar to basins in that they are an enclosure for temporarily ponding runoff, but a section of the dam is made of rocks covered on the upstream side with a layer of wash stones (12 to 19 mm in diameter) to allow water to pass through. Sediment traps with their wash rock outlets have different hydraulic characteristics than basins, and therefore, sediment trapping efficiencies should be different. The objective of this study was to monitor, for at least a year, the sediment trapping efficiency of two sediment traps located on active construction sites with different soil types. Secondary objectives were to document the trapping efficiency by size of sediment and for phosphorus.

Site Descriptions and Methods

Sediment traps were evaluated on two different soil types and topographies. The first was located on a 9–ha development site in the Shallotte River watershed of southeastern North Carolina in the Coastal Plain. The Village of Woodsong, an intensive, neo–urban, multi–use development, was being constructed on the site. The portion of the site that drained to the trap was approximately 2 ha, two–thirds of which was cleared. Streets and houses were being constructed on the cleared land.

The soils at Woodsong were mapped as well–drained Goldsboro fine sandy loam, Baymeade fine sandy loam, Foreston loamy fine sand, and Lynchburg fine sandy loam. Particle size analysis of soil samples collected in the drainage area to the trap documented an average size distribution of 77% sand, 13% silt, and 10% clay. Prior to clearing, the site was forested with shortleaf, longleaf, and pond pines. The understory contained myrtle, bay, and species uniquely indigenous to the Coastal Plain such as flytraps, pitcher plants, and sundews. The site is relatively flat with slopes ranging from 0% to 2%. A ditch across the site was constructed during clearing to enhance the drainage of the main ditch that defined one side of the site. This cross ditch supplied most of the sediment to the trap, which was located 9 m downstream of the confluence of the cross ditch and the main ditch.

This sediment trap (referred to as Woodsong) consisted of a wash stone and rock checkdam across the drainage ditch (fig. 1). As shown in figure 1, the rock checkdam was 2.5 m wide at the base and 1.3 m high, with wash stone covering the upstream face of the dam. Because the slope of the ditch was <1.0%, runoff water often backed up in the sediment trap more than 15 m until the end of the monitoring period when the trap was nearly full of sediment. Two months after the start of monitoring, a hurricane dumped more than 300 mm of rain on the site, and sediment in the subsequent runoff filled the trap. Although the trap was dredged and unintentionally deepened by about 0.6 m a month later, sediment remained along the upstream side of the rock dam outlet, thereby clogging part of the outlet and creating a nearly permanent pool of water about 30 cm deep. Data collected prior to the hurricane was not used.

The second and third traps (referred to as Carpenter 1 and Carpenter 2) were located on a 160–ha development site in the Crabtree Creek watershed of central Piedmont North Carolina. Carpenter Village, an intensive, neo–urban, multi–use development, was being constructed on the site. The first trap, Carpenter 1, was installed in a small intermittent stream channel that drains approximately 4 ha, all of which was cleared, graded, and developed for residential housing during the period of monitoring.

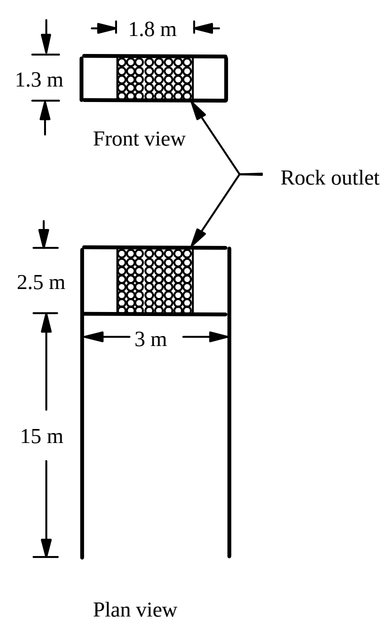

Figure 1. Plan and front (looking upstream) views of the Woodsong trap.

Carpenter 1 (fig. 2) consisted of a horseshoe–shaped berm centered over the intermittent stream channel draining the site, with the open side facing upstream. Centered in the downstream side of the berm was the rock and wash stone outlet. The rock outlet had a 3.7–m wide (at the bottom) and 0.3–m high trapezoidal emergency spillway formed in the middle. The rock dam was covered with a 305–mm thick layer of wash rock on the upstream side and over the top side. Because the berm was quite high, runoff water would often back up to more than 1.0 m deep in the trap and onto the area upstream of the trap. The trap had a design storage volume of 200 m^3. After three months of monitoring, the trap was dredged to remove the accumulated sediment. During the dredging, the trap was unintentionally deepened by approximately 0.5 m, which resulted in a continuous pool of water standing in the trap. Data collected both before and after cleaning were used in the analysis of the trap's efficiency.

The third trap, Carpenter 2, was installed at the outlet of a storm drain that drains an area of unknown size but was comparable to the drainage to Carpenter 1 in topography and soil type. Clearing, grading, and installation of roads were occurring in the drainage area during monitoring. Carpenter 2 was similar in size, shape, and configuration to Carpenter 1, with the same size and type of wash stone and rock outlet and the same height of berm.

The soils in the drainage areas to both traps are derived from Triassic mudstone and sandstone and are some of the most erodible in North Carolina. Soils were mapped as Whitestore clay loam and Creedmoor fine sandy loam, both of which have clayey subsoils that have very slow permeability. Particle size analysis of topsoil and near–surface subsoil samples collected from the drainage area indicated that the soil consisted of 62% sand, 22% silt, and 16% clay–sized particles. The slopes in the drainage area to the trap ranged from 3% to 15%. Prior to clearing, land use was mixed between secondary succession pine and hardwood stands and farm fields. Bottomland hardwood stands along the streams contain an understory of blueberry, deciduous azaleas, ferns, jack–in–the–pulpit, and endemic orchids.

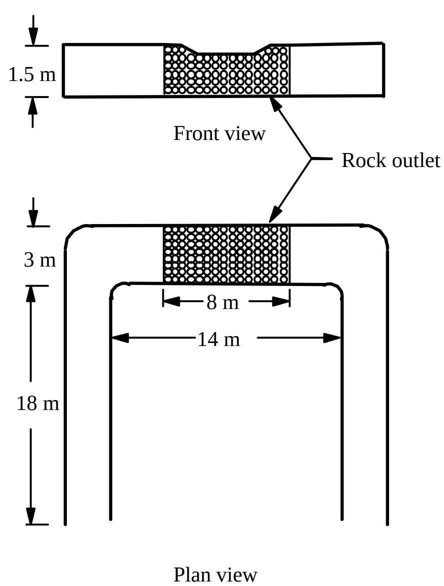

Figure 2. Plan and front (looking upstream) views of the Carpenter 1 trap.

Flow–weighted samples were collected from the outflow of each trap via automated samplers. The samplers continuously measured water depth over sharp–crested, v–notch or rectangular weirs and converted the water depth to discharge using standard weir equations. Sampler intakes were located immediately upstream of weirs and were fitted with floats to raise the intake when water levels rose so that all the samples were not drawn from the bottom of the water column. The float maintained the sampler intake about 100 mm below the water surface during high water levels, and a stake in the ground maintained the intake 25 mm below the weir and 50 mm above the channel bottom during periods of low flow. There was little evidence of sediment deposited in the sampling pool just upstream of the weirs over the duration of monitoring, possibly because the traps removed nearly all of the larger sediment.

Individual flow–weighted samples were combined into one sample per storm for laboratory analysis. When more than four individual runoff samples were collected, some of the samples were saved for later sediment size analysis. A sufficient amount of sediment was required for size analysis; therefore, when only a small amount was collected in the runoff samples from a storm, the samples were combined with sediment from other storms or discarded. All sediment size analysis samples were placed on a table for at least 3 days to allow the sediment to settle. After settling, most of the water was drained off and the remaining slurry was combined with slurry from other samples to make a composite sediment sample for one or more storms, depending on the amount of sediment in the samples and the number of samples collected for the storms.

Rainfall accumulation at 15–minute intervals was measured at each site using recording raingages. For snow and ice storms, equivalent rainfall amounts from a nearby (<10 km) weather station raingage were used. For the few storms when rainfall was missed due to equipment malfunction, rainfall amounts were obtained from a nearby raingage or the local weather station.

Outflow samples were analyzed for total suspended solids (TSS) and total phosphorus (TP) using methods 2540D (APHA et al., 1989) and 365.4 (USEPA, 1983), respectively. Samples were also analyzed for turbidity using a turbidimeter measuring in Nephelometric turbidity units (NTUs). For high turbidities (>1000 NTU) the sample was diluted and a linear extrapolation of the measured value and dilution ratio was used to estimate the turbidity of the runoff sample.

Ideally, flow–weighted samples of inflow and inflow rates would have been collected during every storm and used to compute the incoming sediment load. However, most sediment traps, including the three in this study, do not have one, well defined channel providing inflow to the trap but instead receive some input via overland flow and several channels. Therefore, short of modifying the trap, the incoming runoff and sediment could not be monitored. Thus, the amount of sediment remaining in the trap was tracked.

The volume of sediment deposited in the trap was determined by a series of surveys conducted during the duration of the monitoring to track the buildup of sediment in the trap. Cross–sections of each trap every 1–3 m along the length were surveyed using a standard surveying level. Distances between points along the cross section varied from 0.1 to 0.5 m depending on differences in the elevations of the surface. Shorter distances were used when more abrupt changes in the soil or sediment surface were encountered. A grid of surveyed points was established for each trap. The survey data was entered into a statistical package, which created a surface using a kriging method. Each successive surface from later surveys was compared to the original surface to estimate the change in volume resulting from deposition of sediment during the period.

The accuracy of using surveying to determine sediment accumulation in the trap may be questionable given the precision (0.3 cm) of land surveying and the often variable nature of land surfaces. The precision of surveying instruments becomes less significant as the sediment accumulates, thereby making the error in depth less as a percentage of the total depth measured. For this reason, the traps were surveyed after several storms had deposited sediment in the traps to allow time for a significant increase in the depth of sediment deposited. The variable nature of the land or sediment surface was only a factor at the beginning because the sediment was deposited in relatively flat, smooth layers.

During several of the surveys, three sediment cores from different areas of the deposited sediment were collected, oven dried (104°C), and weighed to determine the bulk density of the deposited sediment. Sediment cores were taken at different depths to document vertical variability in sediment bulk density. Bulk densities for deposited sediment at Carpenter averaged 1.11 g/cm^3, while deposited sediment at Woodsong averaged 1.45 g/cm^3. Samples of sediment were also collected from at least three locations for later sediment size and total phosphorus analysis.

All soil and sediment size analyses were conducted using the hydrometer method (Klute, 1986). For primary particle size analyses, soil and sediment samples were oven dried (104°C), ground with a mortar and pestle, and dispersed using a sodium hexametaphosphate solution. For aggregated or undispersed sediment analysis, wet sediment samples were emptied into the hydrometer and analyzed using the standard technique. Following the analysis, the sample was poured into beakers and oven dried to obtain the mass of sediment. Undispersed sediment analyses occurred within several days after collection of samples to help ensure that sediment aggregates did not break down. Samples for dispersed or primary particle size analyses were stored for weeks or months until a convenient time.

Using the hydrometer or fall velocity method to determine the size of undispersed sediment may appear at first to be problematic due to differences in densities of sediment primary particles and aggregates. Primary particles of soil or sediment generally have a density of 2.6 to 2.75 g/cm^3, and sediment aggregates, which contain organic matter and voids, often have a lower density of between 1.2 to 1.4 g/cm^3 (Haan et al., 1994). The lower density of aggregates would tend to increase their settling time and therefore cause the sediment to appear finer or smaller than it actually is. This discrepancy may not be inappropriate considering that the sediment aggregate, from a hydraulic settling perspective, is the same as a smaller particle.

RESULTS AND DISCUSSION

Because of the variability in storms and construction activities, monitoring many storms and using a relatively high percentage of all storms occurring were necessary to represent overall trapping efficiency. Runoff rate and volume were monitored for more than 76% of the storms during the study period, and flow–weighted samples were collected from more than 62% of the storms (table 1). For storms in which there was an equipment malfunction, flooding, or freezing condition, runoff volume was estimated. The runoff estimates were computed by assuming a linear relationship between rainfall and runoff and using regression to develop the relationship from monitoring data. The relationship between rainfall and runoff for both Carpenter (r^2 = 0.86) and Woodsong (r^2 = 0.87) were relatively strong. For storms without sample data, the TSS and TP concentrations were estimated from data for storms with similar characteristics that occurred relatively close in time to the storm with the missing data. While the missing data adds some uncertainty to the results, the relatively strong relationship between rainfall and runoff and the large number of sampled storm events help to minimize the uncertainty.

Sediment and phosphorus loads in outflow for each significant storm event were computed by multiplying the total outflow volume by the flow–weighted TSS and TP concentrations. For many larger storm events, individual flow–weighted samples were combined into three composite samples for laboratory analysis: one each from the rising, peak, and falling sections of the storm hydrograph. This involved combining samples that were collected before the discharge rate had reached about 80% of the peak rate (rising), while the discharge was greater than 80% (peak), and after it had dropped below 80% (falling). Analysis of variance (ANOVA) on samples from 17 storms at Carpenter indicated that there was no significant difference at the 0.05 level between the means of the concentrations of the rising, peak, and falling samples. Although the mean concentration for the rising samples was greater than the peak and falling, it was not statistically significant due to considerable variability. This variability was expected, given the wide range of precipitation intensities and storm types. At Woodsong, the rising, peak, and falling samples were not separated, and therefore the analysis was not conducted.

EFFECTIVENESS OF SEDIMENT TRAPS AT CARPENTER

Monitoring data and trapping effectiveness for trap 1 at Carpenter are shown in table 2. As shown in columns 1 and 2, the overall duration of monitoring (6/26/98 to 3/3/00) was divided into nine periods. The trapping effectiveness during the 10/15/98 to 12/6/98 period could not be determined due to the trap being dredged and repaired during this time. The last day of a period corresponded to the day the trap was surveyed to determine the accumulation of sediment deposited in the trap. The number of storms, rainfall, and discharge during the period are shown in columns 3 through 5 of table 2. These values include only storms that produced a high enough rate of and volume of runoff, usually greater than about 15 mm, to monitor. The total accumulation of

Table 1. Number of runoff–producing storms occurring and monitored.

Trap	Period	No. of storms	Runoff No. (%)	Sampled No. (%)
Carpenter 1	7/98 – 2/2000	43	34 (79)	32 (74)
Carpenter 2	8/99 – 10/99	13	12 (92)	10 (77)
Woodsong	11/98 – 6/2000	34	26 (76)	21 (62)

rainfall including all storms was 1720 mm, which means the rainfall for the monitored events was 82% of the total. The low accumulation and intensity storms are insignificant from a sediment perspective because relatively little sediment was transported from low–intensity storms, which produce little, if any, runoff. Additionally, one sleet and two snow events were not included in the totals as these events caused little sediment movement and low discharge rates. The 43 total storms monitored and included in the totals in table 2 encompassed a wide variety of storm types, rainfall intensities, and total accumulations, including two hurricane–sized (>100 mm) storms. Peak storm discharges from 7 to 390 L/s and total storm discharge volumes from 65 to 5,100 m^3 were documented. These discharges and volumes came from storms ranging in accumulation from 12 to 155 mm.

The mass of sediment passing through the trap (TSS out) and the trapping efficiency are also shown in table 2. Sediment passing through the trap per storm event decreased considerably after 12/6/98. This was due to the decrease in incoming sediment associated with the establishment of a vegetative cover and the installation of streets and storm drains in the drainage area following the completion of rough grading. This decrease emphasizes the effect of temporary vegetation planted to stabilize soils. The total TSS passing through the trap during the 1.7 years of monitoring was 67,114 kg, which given that the drainage area was about 4 ha, amounted to 9,870 kg/ha of TSS export per year. The drainage area varied due to construction grading and piping of stormwater; however, several determinations of the area at different times ranged between 3.6 and 4.7 ha.

Sediment trapping efficiency was computed by dividing the mass of sediment deposited in the trap by the sum of the mass deposited and passing (TSS out), and then multiplying by 100 to convert to a percentage. The efficiency varied from 18% to 77% with no readily apparent trend. The relatively low efficiency (49%) of the 7/24/98 to 8/25/98 period may be attributed to the occurrence of an intense storm that produced discharge rates of more than 380 L/s, which overtopped the outlet and damaged part of the trap. Even with the inclusion of this storm, the overall efficiency prior to 10/14/98 was 64%, while overall efficiency for the period after was only 36%. The greater trapping efficiency can be attributed to the combination of higher concentrations of sediment and possibly larger sediment aggregates in the inflow. The higher incoming sediment concentrations and aggregate sizes were likely the result of more erodible surface area and the prevalence of concentrated flow channels in the drainage area. As rough grading was completed and the area seeded, the erodible area decreased and the concentrated flow channels were replaced by nonerodible storm drains. The grass and storm drains effectively eliminated concentrated flow erosion, thereby causing the majority of sediment to originate from interrill erosion, which results in finer sediment. The lower concentration and smaller sizes of sediment eroded after site stabilization resulted in lower trapping efficiencies of the sediment trap. Trapping efficiency for the period from 10/15/98 to 12/6/98 was not determined due to the dredging of the trap. As shown at the bottom of table 2, the overall sediment trapping efficiency, excluding the 10/15/98 to 12/6/98 period, was 59%.

The 58% and 59% trapping efficiencies for the Carpenter traps are similar to the 65% TSS removal efficiency for four sediment basins and two traps on a Piedmont Maryland construction site (Schueler and Lugbill, 1990). This indicates that sediment traps on Piedmont soils can be expected to retain about 60% of the sediment yield from construction sites.

The mass of phosphorus passing through the trap (TP out) increased considerably after the 10/15/98 to 12/6/98 period, even though the TSS out generally decreased. The increased export of TP was likely the result of topsoil and fertilizer entering the drainage area. During the fall of 1998, houses were built, yards established, and a vegetative cover over the inactive part of the drainage area was established. In conjunction with these activities, phosphorus was imported into the drainage area, thereby increasing the potential for export. The total TP export out of the trap for the duration of monitoring was 8.25 kg, which was equivalent to about 1.21 kg TP/ha per year.

The phosphorus trapping efficiency (TP efficiency) depended on determining the phosphorus content of the deposited sediment and then computing the efficiency the same way sediment trapping efficiency was computed. Two samples of deposited sediment collected before 10/15/98 had an average TP content of 0.03 mg TP/g of sediment, and two collected after 12/7/98 had an average of 0.06 mg TP/g of sediment. The average of these TP contents was combined with the mass of sediment deposited in the trap and the mass of TP passing through to compute the TP efficiencies shown

Table 2. Monitoring data and trapping efficiency for the Carpenter 1 trap.

Begin	End	No. of storms[a]	Rain (mm)	Discharge (m^3)	TSS out (kg)	TSS efficiency (%)	TP out (kg)	TP efficiency (%)
6/26/98	7/23/98	1	38.9	1,160	8,899	77	0.41	84
7/24/98	8/25/98	5	128.3	2,525	27,009	49	0.46	64
8/26/98	10/14/98	4	130.2	1,857	11,872	71	0.65	59
10/15/98	12/6/98	5	24.9	1,314	1,931	NA	0.50	NA
12/07/98	1/8/99	4	116.8	3,518	2,253	24	1.24	3
1/9/99	2/16/99	4	93.2	2,432	2,315	69	0.55	36
2/17/99	5/12/99	6	157.7	3,172	2,772	18	1.33	3
5/13/99	9/3/99	3	92.5	1,280	2,414	47	0.17	42
9/4/99	3/3/00	16	645.4	18,995	9,580	18	2.94	4
Total		43	1403	34,939	67,114		8.25	
Overall						59		30

[a] Includes only storms that produced significant discharge.

in table 2. The efficiencies varied considerably, with those during the first two monitoring periods being slightly greater than the sediment trapping efficiency and the rest less. The decrease in TP efficiency was likely due to the addition of fertilizer to the drainage area, resulting in some of the TP being in soluble form and therefore independent of sediment trapping. The overall TP trapping efficiency was 31%, which was about half the sediment trapping efficiency.

Monitoring data and sediment trapping efficiency for trap 2 at Carpenter are shown in table 3. The overall trapping efficiency for the period of monitoring (8/31/99 to 10/27/99) was 58%, which is similar to that for Carpenter 1. Sediment accumulated to a level higher than the inlet storm drain during the period of monitoring, thereby necessitating dredging. Frequent and unpredictable dredging of this trap prevented the continued monitoring of its effectiveness. Due to funding limitations, runoff and retained sediment samples from this trap were not analyzed for TP.

Effectiveness of the Sediment Trap at Woodsong

Monitoring data and trapping efficiency for the Woodsong sediment trap are shown in table 4. The monitoring duration (11/1/98 to 6/7/00) was divided into seven periods ending on the days the sediment trap was surveyed to determine sediment accumulation in the trap. Like the Carpenter traps, the data includes only significant storms, those of sufficient intensity and accumulation to produce adequate runoff for monitoring. The 34 storms monitored encompassed rainfall accumulations from 17 to 385 mm, including two hurricane–sized (>100 mm) events. Peak storm event rainfall intensities reached more than 75 mm/hr, resulting in peak discharges of up to 190 L/s. After 8/99, when streets and storm drains were completed, some of the runoff to the trap was diverted, thereby increasing the size of storm needed to produce adequate runoff for monitoring.

Table 3. Monitoring data and trapping efficiency for the Carpenter 2 trap.

Begin	End	No. of storms[a]	Rain (mm)	Discharge (m^3)	TSS out (kg)	TSS efficiency (%)
8/13/99	8/24/99	2	46.0	2.3	867	59
8/25/99	10/27/99	11	502.2	2,525	27,009	58
Total		13	548.2	2,527	27,876	
Overall						58

[a] Includes only storms that produced significant discharge.

The mass of sediment passing through the trap (TSS out) and the trapping efficiency are also shown in table 4. Sediment in the outflow dropped considerably after 10/29/99 due to completion of rough grading and the storm drain system and the stabilization of roadside swales with vegetation. Due to flat slopes and grading, the drainage area to the trap could not be accurately determined but was estimated to be between 1.6 and 2.4 ha. Given this area, the sediment export was 2850 to 4280 kg/ha per year, which was less than half the export at Carpenter 1.

The trapping efficiencies were relatively consistent throughout the monitoring period, compared to Carpenter 1, varying only from 52% to 86%. This consistency was unexpected, given the variability in storms and the more than 50% reduction in the trap's storage capacity. The accumulation of sediment in the trap removed the standing pool of water and came within about 0.6 m of the top of the outlet dam. However, the trapping efficiencies during the last two periods were greater than several of the previous periods. This maintenance of efficiency was likely due to reduced discharge rates as the trap was filling and sediment dynamics. The relatively coarse sediment from the site settles out of runoff rapidly, and therefore only a small amount of storage is needed to slow the runoff enough for sediment deposition. The overall sediment trapping efficiency was 69%, which was 10% greater than the Carpenter 1 trap.

The mass of phosphorus passing through the trap (TP out) exhibited no apparent trend. Only two houses had been constructed in the drainage area, and these did not have landscaping or lawns installed yet. Little fertilizer or topsoil input of TP occurred during the period of monitoring to increase TP export. The TP trapping efficiency (TP efficiency) was relatively low compared to Carpenter 1, likely due to the aggregation properties of the sediment. The soils and sediment at Carpenter were more highly aggregated than those at Woodsong. Considering that the traps predominantly remove only larger sediment, which could be large soil primary particles or aggregates of smaller primary particles, the Carpenter trap probably removed a greater percentage of fine or clay–sized particles than the Woodsong trap. Since most of the phosphorus in sediment is attached to finer particles, the Carpenter trap would likely be more effective at removing TP and should have a higher efficiency, as the data indicates. The loss in storage volume may explain

Table 4. Monitoring data and trapping efficiency for Woodsong.

Begin	End	No. of storms[a]	Rain (mm)	Discharge (m^3)	TSS out (kg)	TSS efficiency (%)	TP out (kg)	TP efficiency (%)
11/1/98	3/1/99	9	105.2	1,950	1,520	75	0.96	12
3/2/99	3/31/99	3	23.5	810	1,530	86	1.09	19
4/1/99	5/5/99	3	74.0	5,310	2,350	52	0.98	7
5/6/99	8/6/99	4	67.5	650	1,780	54	0.85	6
8/7/99	10/29/99	10	319.9	6,540	3,410	59	2.10	6
10/30/99	2/7/00	2	46.3	1,030	330	79	0.60	5
2/8/00	6/7/00	3	31.4	180	30	60	0.04	3
Total		34	667.8	16470	10,950		6.62	
Overall						69		9

[a] Includes only storms that produced significant discharge.

the decrease in TP trapping over the duration of monitoring, given that as the volume decreased the probability of removing any fine sediment from runoff also decreased.

Sediment Size Analyses

Because sediment size often effects the efficiency of sediment traps, the size distributions of sediment deposited in the trap and transported in the outflow were determined (figure 3). Size analysis of sediment in seven outflow samples from Carpenter is represented by the first two bars in figure 3. Sediment sizes in aggregated or undispersed (U) sediment samples were nearly evenly distributed between sand (31%), silt (32%), and clay (37%), while those for primary particles or dispersed (D) were skewed toward a greater percentage of clay. The greater percentage of clay indicates that many of the silt–sized and some of the sand–sized sediment were actually aggregates containing clay–sized particles. The percentage of sand–sized aggregates and primary particles in the outflow (~30%) was higher than expected; however, sieving of several samples indicated that the sand was very fine. Because a significant amount of sediment in runoff samples was required to perform this analysis, samples from only larger and more intense storms were included. This may have biased the data toward larger size sediment in the samples, given that higher flow rates through the trap tend to have the energy to transport larger sediment.

Analysis of deposited sediment taken from the trap indicated that greater than 50% of the sediment was sand–sized, and sand– and silt–sized sediment composed more than 90% of the sediment remaining in the trap. Dispersing the sediment samples showed that some of the sand– and silt–sized sediment included clay–sized particles. The clay and silt particles deposited in the trap likely held some TP, which contributed to the TP trapping efficiency.

Sediment in five samples of outflow from the Woodsong trap contained an average of 22% sand, 29% silt, and 49% clay–sized sediment, as shown in the fifth bar of figure 3. Dispersing the samples revealed that some of the silt–sized sediment was aggregates containing clay particles. The lower percentage of clay–sized sediment in outflow samples indicated that the Woodsong trap was more effective than the Carpenter traps at trapping sand–sized sediment. The better trapping efficiency could be expected, given the low gradient of the ditch where the trap was located.

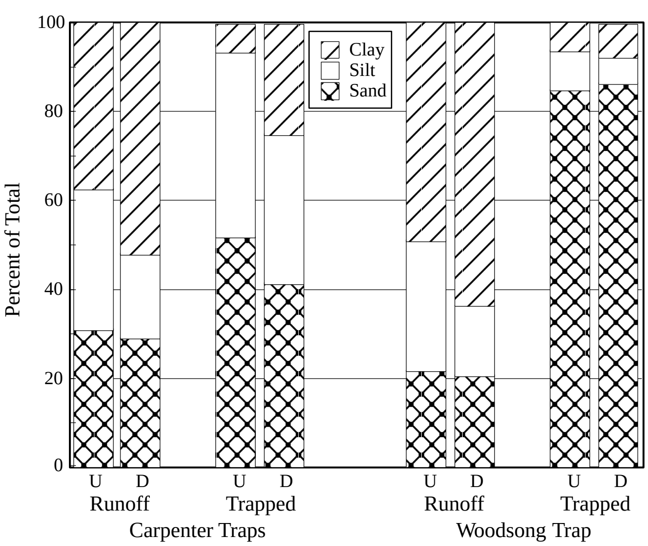

Figure 3. Size distributions of dispersed (D) and undispersed (U) sediment.

Analysis of samples collected from the deposited sediment indicated that the sediment retained by the trap was more than 85% sand–sized. Dispersed samples contained a slightly high percentage of sand, which was likely a product of variability in samples or analysis error. Only three samples of undispersed sediment and only four samples of dispersed sediment were analyzed; therefore, slight variability was likely not significant. Both dispersed and undispersed samples analyzed suggest that a low percentage of silt and clay were retained in the trap. This result suggests a relatively low trapping efficiency for silts and clays, which tends to agree with the low trapping efficiency of TP for this trap.

The percentages of sand, silt, and clay particles in outflow and deposited sediment can be used to partition the overall trapping efficiency into primary particle sizes, as shown in table 5. While 52% of the sediment passing through the trap consisted of clay particles, a considerable amount consisted of sand and silt particles also. The considerable percentage of sand particles in the outflow indicates that additional trapping of sediment may be relatively easily obtained by increasing the size of the trap or implementing some other modification. The Carpenter traps were nearly equally efficient at trapping sand (68%) and silt (72%) particles, but were less efficient at trapping clay particles. Many of the silt and clay particles were likely aggregated to form larger sediment, which facilitated deposition in the trap.

The Woodsong trap was very efficient at trapping sand particles (91%), but was much less efficient at trapping silt and clay particles. The low trapping efficiencies for silt and clay particles were likely due to weak soil/sediment aggregation. The soils at Woodsong were not highly aggregated; therefore, the sediment primary particles were transported more easily by runoff, even at generally low velocities, because they were not in larger aggregates. The significant portion of sand (21%) in outflow sediment indicates that the efficiency of the trap may be increased relatively easily with modifications that facilitate deposition of sediment, such as a silt fence baffle.

The sediment size data provides an indication of the sizes of sediment in outflow and the trapping efficiency by size; however, the limited number of samples analyzed limits the results. The results are also somewhat biased because only larger and more intense storms produced enough sediment in outflow samples for size analysis, while sediment deposited in the trap from all storms was included in the size analysis for deposited sediment.

Turbidity of Outflow

In many cases, the most visible effect of sediment from construction sites is cloudy or turbid runoff water. In a number of states, including North Carolina, water quality standards for receiving waters include turbidity. For this

Table 5. Primary particle sizes of sediment and trapping by particle size.

	Outflow sediment			Trapping efficiency		
Site	Sand (%)	Silt (%)	Clay (%)	Sand (%)	Silt (%)	Clay (%)
Carpenter	29	19	52	68	72	40
Woodsong	21	16	63	91	43	21

reason and because turbidity is often directly associated with sediment concentrations, the turbidity of outflow samples was monitored. Figure 4 shows turbidity versus TSS concentrations of samples of outflow collected from Carpenter. While the range in TSS concentrations was from 215 to 15,500 mg/L, all but 5 of the 43 samples had TSS concentrations less than 3,000 mg/L. Linear regression of the data identified the following best–fit equation:

$$\text{Turbidity} = 1.00 \times \text{TSS} + 162.9 \qquad r^2 = 0.96 \quad (1)$$

The equation and the r^2 of 0.96 indicate a relatively strong 1–to–1 relationship between turbidity and TSS for this site. A relationship between turbidity and TSS was expected, given that confounding factors such as the extent of springs or wetlands that might introduce other sources of turbidity were minimal. The very high TSS concentrations also contributed to the strong relationship between TSS and turbidity because the TSS tended to overshadow the effects of other sources of turbidity.

The turbidity and TSS concentrations for Woodsong are shown in figure 5. The TSS concentrations ranged from 95 to 6100 mg/L with all except 4 of the 64 samples being less than 4,000 mg/L. Linear regression of the data suggested the following best–fit equation:

$$\text{Turbidity} = 0.56 \times \text{TSS} + 81.93 \qquad r^2 = 0.64 \quad (2)$$

The scatter of the data and the relatively low r^2 of 0.64 indicate a poor relationship between TSS and turbidity. This was generally expected, given that a considerable wooded area with a substantial amount of organic matter remains on the site. Additionally, the TSS concentrations were much lower than at Carpenter, thereby increasing the probability that other factors can influence turbidity.

Few studies have been conducted on sediment loss and turbidity of runoff from construction sites; however, two studies provide information for comparison purposes. A study by Przepiora et al. (1998) documented turbidities ranging from 120 to 3200 NTUs and corresponding TSS concentrations from 90 to 2800 mg/L in outflow from sedimentation basins at two North Carolina construction sites. While the range of the TSS values was closer to those at Woodsong compared to Carpenter, the similarities in the endpoints of the TSS and turbidity ranges indicated a nearly 1–to–1 relationship, which was similar to the Carpenter data. The Przepiora et al. (1998) data could be expected to be like Carpenter considering they were collected from a site located in the Piedmont of North Carolina within 12 km of Carpenter site. Yorke and Herb (1978) also reported a strong linear relationship ($r^2 = 0.87$) between TSS (in mg/L) and turbidity (in NTUs) for construction runoff from a Piedmont Maryland site. This provides further evidence that either TSS or turbidity may be computed from monitoring the other parameter in runoff from construction sites in Piedmont locations.

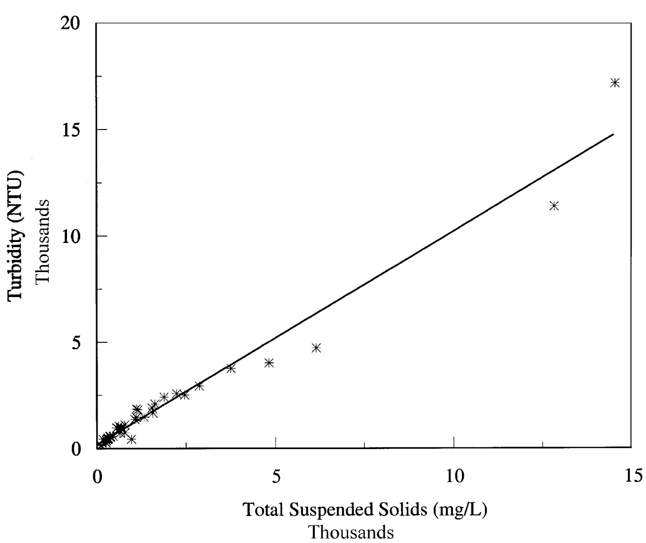

Figure 4. Turbidity versus total suspended solids concentrations for outflow from the Carpenter traps.

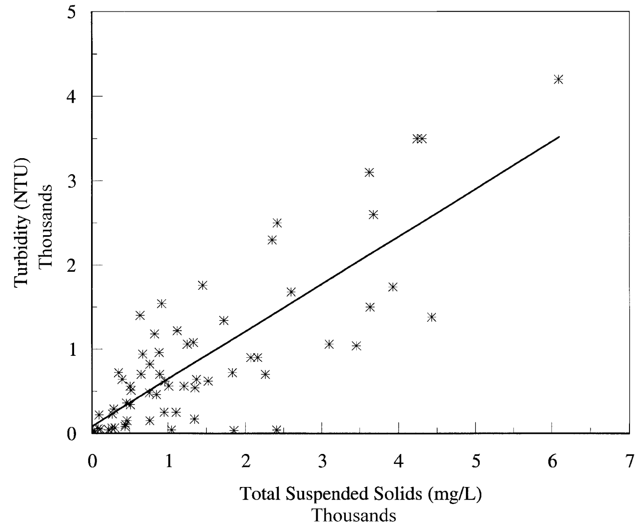

Figure 5. Turbidity versus total suspended solids concentrations for outflow from the Woodsong trap.

SUMMARY

Sediment (TSS) and phosphorus (TP) concentrations in outflow from, as well as sediment accumulation in, three temporary sediment traps were monitored to assess the efficiencies of the traps. One trap was located on a construction site (Woodsong) in the Coastal Plain and the other two on a site (Carpenter) in the Piedmont region of North Carolina. The overall sediment trapping efficiency of the Woodsong trap from 11/98 to 6/00 was 69%, while the average overall efficiencies of the Carpenter traps from 6/98 to 3/00 was 59%. The efficiency of the Carpenter trap tended to be higher during the early stage or rough grading phase of construction. Following the completion of rough grading and the establishment of temporary vegetation, sediment export from the sites decreased dramatically. Additionally, the Carpenter trap retained 30% of the TP coming off the site, while the Woodsong trap retained 9%.

Sediment size analyses of a limited number of samples indicated that the Woodsong trap retained 91%, 43%, and 21% of the sand, silt, and clay particles entering the trap, while the Carpenter trap retained 68%, 72%, and 40% of the sand, silt, and clay particles entering it. Size analyses of sediment in runoff and sediment retained in the trap indicated that a significant percentage of the silt and clay particles retained in the Carpenter trap were part of larger sediment aggregates. The greater efficiency at retaining silt and clay particles likely resulted in the increased TP trapping efficiency of the Carpenter trap (30%) as compared to the Woodsong trap (9%).

The turbidity of outflow samples was also measured and correlated to TSS concentrations. A relatively strong linear correlation was found for data from the Carpenter traps (r^2 = 0.96) and a much weaker correlation was documented for the Woodsong trap (r^2 = 0.64). These data indicate that for sites with high TSS concentrations in runoff and relatively little organic matter left on the site, TSS may be computed from turbidity; however, more data is needed to confirm this relationship.

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REFERENCES

APHA, AWWA, WPCF. 1989. *Standard Methods for the Examination of Water and Wastewater.* 17th ed. Washington, D.C.: American Public Health Association.

Burby, R. J., E. J. Kaiser, M. I. Lugar, R. G. Paterson, H. R. Malcom, and A. C. Beard. 1990. A report card on urban erosion and sedimentation control in North Carolina. *Carolina Planning* 16(2): 28–35.

Clark, E., J. Haverkamp, and W. Chapman. 1985. *Eroding Soils: The Off–Farm Impacts*. Washington, D.C.: The Conservation Foundation.

Engle, B. W., and A. R. Jarrett. 1995. Sediment retention effectiveness of sedimentation basin filtered outlets. *Trans. ASAE* 38(2): 435–439.

Garcia, K. T. 1988. Effect of erosion control structures on sediment and nutrient transport, Edgewood Creek drainage, Lake Tahoe basin, Nevada 1981–1983. USGS Water Resources Investigations Report No. 87–4072. Reston, Va.: U.S. Geological Survey.

Haan, C. T., B. J. Barfield, and J. C. Hayes. 1994. *Design Hydrology and Sedimentology for Small Catchments*. San Diego, Cal.: Academic Press.

Hainley, R. A. 1980. Effects of highway construction on sediment discharge into Blockhouse Creek and Stream Valley Run, Pa. Water Resources Investigations No. 80–68. Reston, Va.: U.S. Geological Survey.

Klute, A., ed. 1986. *Methods of Soil Analysis: Part 1. Physical and Mineralogical Methods*. 2nd ed. Madison, Wisc.: American Society of Agronomy and Soil Science Society of America.

Mertes, J. D. 1989. Trends in governmental control of erosion and sedimentation in urban development. *J. Soil and Water Conserv.* 44(6): 550–554.

Millen, J., A. R. Jarrett, J. W. Faircloth. 1996. Reducing sediment discharge from sedimentation basins with barriers and a skimmer. ASAE Paper No. 96–2056. St. Joseph, Mich.: ASAE.

NC DENR. 1992. Water quality progress in North Carolina, 1990–1991. 305(b) Report No. 92–06. Raleigh, N.C.: North Carolina Department of Environment and Natural Resources, Division of Environmental Management.

Paterson, R., M. Lugar, R. Burby, E. Kaiser, R. Malcom, and A. C. Beard. 1993. Costs and benefits of urban erosion and sediment control: The North Carolina experience. *Environmental Management* 17(2): 167–178.

Przepiora, A., D. Hesterberg, J. E. Parsons, J. W. Gilliam, D. K. Cassel, and W. Faircloth. 1998. Field evaluation of calcium sulfate as a chemical flocculant for sedimentation basins. *J. Environ. Quality* 27(3): 669–678.

Schueler, T. R., and J. Lugbill. 1990. Performance of current sediment control methods at Maryland construction sites. Washington, D.C.: Dept. of Environmental Programs, Metropolitan Washington Council of Governments.

USEPA. 1983. Methods for chemical analysis of water and waste. EPA–600/4–79–020. Cincinnati, Ohio: U.S. Environmental Protection Agency.

Yorke, T. H., and W. J. Herb. 1978. Effects of urbanization and streamflow on sediment transport in the Rock Creek and Anacostia River Basins, Montgomery County, Maryland, 1962–1974. USGS Professional Paper No. 1003. Denver, Colo.: U.S. Geological Survey.