Using RUSLE2 to Determine Sediment Basin Size

Final Report

North Carolina Department of Transportation

PROJECT AUTHORIZATION NO. HWY- 2011-13

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Technical Report Documentation Page

1. Report No. FHWA/NC/2011-13	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Using RUSLE2 to Determine Sediment Basin Size		5. Report Date January 25, 2013
		6. Performing Organization Code
7. Author(s) Richard A. McLaughlin, Ryan Brown, and Gregory D. Jennings.		8. Performing Organization Report No.
9. Performing Organization Name and Address Department of Soil Science North Carolina State University Campus Box 7619 Raleigh, NC 27695		10. Work Unit No. (TRAIS) …
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address North Carolina Department of Transportation Research and Analysis Group 1 South Wilmington Street Raleigh, North Carolina 27601		13. Type of Report and Period Covered Final Report 08/16/2010 – 08/15/2012
		14. Sponsoring Agency Code 2011-13
Supplementary Notes:		

16. Abstract

The purpose of this project was to determine actual sediment yield at sediment basin inlets and to compare that to predicted yields estimated with RUSLE2. This involved monitoring four basins on a Piedmont project and one on a Coastal Plain project. Water samples were obtained during storm events at the inlet and outlet of each basin and analyzed for turbidity and total suspended solids (TSS). The flow data was used to calculate the amount of sediment reaching each basin. In addition, detailed surveys of the basin catchments were obtained using a LiDAR (Light Detection and Ranging) instrument. The amount of sediment delivered was highly related to storm intensity but not amount of rainfall. From observations of field operations, the presence of active grading also resulted in higher sediment yields. Peak flow was highly predictive of total sediment load, turbidity, and TSS. Total flow volume was also correlated with total sediment load and turbidity, but less with TSS. Peak flow was correlated with peak rain intensity but not with rainfall amount. Peak intensity was negatively correlated to basin performance in reducing TSS and turbidity. All of these results suggest that the current practice of using peak rain intensity for a design event to estimate runoff flow is appropriate. The relationship between actual sediment yield and RUSLE2 predicted sediment was very poor for 3 of the 5 basins studied due to erosion within the ditches. Tests of RUSLE2 sediment yield using either actual site surveys using LiDAR or slope factors from the clearing and grubbing (CG) or final grade (FG) were poorly correlated with measured sediment yield at the basin inlet. The CG slopes tended to overpredict and FG slopes underpredict actual sediment yields. The two basins where actual and RUSLE2 predicted sediment yield were similar had diversion ditches which were relatively stable and non-eroding. This suggests that stabilizing ditches and slopes quickly will greatly reduce sediment loading and may allow predictive models such as RUSLE2 to be used.

17. Key Words *Erosion, sediment, runoff, stormwater, basin*	18. Distribution Statement

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 57	22. Price

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

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Acknowledgments

Most of the data collection and analyses were conducted by Ryan Brown in the Department of Biological and Agricultural Engineering for his Master of Science degree. This information is included in Chapters 1 and 2. He was ably assisted by technician Jamie Luther, fellow graduate students Virginia Brown and Gina Lee, post-doctoral associate Jihoon Kang, and extension associates Melanie McCaleb and Scott King. Work on the Goldsboro site, described in Chapter 3, was conducted by Luther, Kang, Jacob Wiseman, and Rob Austin. We are always grateful for the assistance of the NC DOT Roadside Environmental Unit staff for finding potential sites for us that meet our requirements. We also greatly appreciated the assistance of project staff and contractors to find basins for monitoring in a timely manner. It is only through this type of cooperation that we can conduct research on “live” construction sites, which is one reason why North Carolina is considered a leader in erosion, sediment, and turbidity control.

Executive Summary

The purpose of this project was to determine actual sediment yield at the entrance to sediment basins and to compare that to predicted yields estimated with RUSLE2. This involved monitoring four basins on a Piedmont project and one on a Coastal Plain project. Water samples were obtained during storm events at the inlet and outlet of each basin and analyzed for turbidity and total suspended solids (TSS). The flow data was used to calculate the amount of sediment reaching each basin. In addition, detailed surveys of the basin catchments were obtained using a LiDAR (Light Detection and Ranging) instrument. RUSLE2 was run using the survey data as well as the plans at both the clearing and grubbing phase (natural topography) and the final grade phase.

The amount sediment delivered was highly related to storm intensity but not amount of rainfall. From observations of field operations, the presence of active grading also resulted in higher sediment yields. Peak flow was highly predictive of total sediment load, turbidity, and TSS. Total flow volume was also correlated with total sediment load and turbidity, but less with TSS. Peak flow was correlated with peak rain intensity but not with rainfall amount. Peak intensity was negatively correlated to basin performance in reducing TSS and turbidity. All of these results suggest that the current practice of using peak rain intensity for a design (10- and 25-year) event to estimate runoff flow is appropriate.

The relationship between actual sediment yield at the basin inlet and RUSLE2 predicted sediment was very poor for 3 of the 4 basins studied. Site activities and storm factors not included in the model appeared to be more important for sediment loading. Tests of RUSLE2 sediment yield using either actual site surveys using LiDAR or slope factors from the clearing and grubbing (CG) or final grade (FG) were poorly correlated with measured sediment yield at the basin inlet. The CG slopes tended to overpredict and FG slopes underpredict actual sediment yields. The one basin where actual and RUSLE2 predicted sediment yield were similar had diversion ditches which were relatively stable and non-eroding and little active grading. This suggests that stabilizing ditches and slopes quickly will greatly reduce sediment loading and may allow predictive models such as RUSLE2 to be used. Models that incorporate sediment transport and deposition would likely have better predictive ability for design needs. No model can accurately predict site activities and the landscape of a construction site at all times, however.

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Introduction

Accelerated erosion occurs whenever the soil surface is disturbed. Construction site preparation typically includes: removing the vegetative cover, altering the natural topsoil, and changing the shape of the slope. This can greatly increase the potential for erosion, increased runoff rates; and significant sediment delivery to rivers and lakes. Erosion decreases the productive value of the soil as well as reducing the quality of the waters that receive the sediment. Sediments created by accelerated erosion clog streams, fill lakes, and often can carry pollutants to these waters.

Individual construction sites can contribute massive loads of sediment to small areas in short periods of time (Kaufman 2000; Clark and Pitt 2004). Sediment runoff rates from construction sites are typically 10 to 20 times greater than those of agricultural lands, and 1,000 to 2,000 times greater than those of forest lands (US EPA 2000, revised 2005). The National Water Quality Inventory Report states that 12% of assessed rivers and streams (31% of the impaired rivers) and 9% of assessed lakes (21% of the impaired lakes) were affected by sedimentation. Sources of sedimentation include agriculture, urban runoff, construction and forestry. For example, excess sediment can quickly fill rivers and lakes, requiring dredging and destroying aquatic habitats. In urban areas construction sites are major sources of sediment. Typical sediment loading from construction sites varies from 250 to 500 Mg ha^{-1} year^{-1} and can range up to 2,500 Mg ha^{-1} year^{-1} (Broz et al. 2003).

Sediment runoff from construction sites to streams and lakes can negatively affect water quality, biodiversity and benthic habitats (Barton, 1977; Taylor and Roff, 1986). Regulations to protect water quality in North Carolina include the federal Clean Water Act (33 U.S.C. 1251 et seq.) and the NC Sedimentation Pollution Control Act of 1973, which established a permitting system requiring sediment and erosion control plans for all land-disturbing activities (North Carolina General Statues, 2002).

Sediment basins are a common best management practice (BMP) used on construction sites for trapping sediment and reducing off-site water quality impacts during stormwater runoff events. The current standard NCDOT sediment basin design guidance is based on disturbed catchment area and peak runoff discharge for a design storm. Several other hydrologic and land use parameters have been found to influence construction site sediment yields to basins and basin efficiency (Daniel et al, 1979; McLaughlin et al, 2009; Toy et al, 1999). These include stormwater runoff volume, rainfall intensity, and soil factors. In particular, the dynamic nature of land disturbance activities on highway construction sites would be expected to substantially affect sediment yield and basin efficiency throughout the project life.

NCDOT sediment basin design standards require that basins with surface outlet devices provide at least 126 m^3 of storage volume per hectare disturbed in the catchment. The design standards also require a minimum basin surface area proportional to the 10-year peak runoff discharge (or the 25-year peak discharge in sensitive watersheds) such that the minimum surface area is 1070 m^2 for each m^3/sec of design peak flow calculated using the rational method (NCDOT, 2010). This simple design approach for basin storage volume is based on the assumption of a linear relationship between sediment yield and disturbed catchment area. Furthermore, since basins are sized to promote sediment settling by requiring a minimum surface area, it is also expected that basin efficiency should be strongly related to peak flow and disturbed catchment area. Objectives of this research were to use measured sediment runoff data from a NCDOT highway construction site to (1) evaluate current sediment basin design parameters, and (2) identify alternative design parameters that are better predictors of basin efficiency and sediment yield during highway construction.

Materials and Method

Sediment Basin Monitoring

Four sediment basins on a NCDOT highway construction site were monitored for sediment inflow and outflow. The basins were located in the Piedmont on the I-540 construction project in western Wake County, North Carolina. The inlet and outlet of each basin were instrumented with ISCO 6700 automated samplers (or ISCO 6712) with a 730 bubbler modules (ISCO, Inc., Lincoln, NE, USA) to measure stormwater flow and to collect flow-weighted samples.

The standard inlet of a NCDOT basin is comprised of a 30.5-cm corrugated plastic slope pipe drain with an earthen berm to collect runoff from diversion ditches (NCDOT, 2010). The bubbler tube for flow measurement and the sampling tube were glued into the inlet pipes. The length and average slope of the pipe was determined for each basin and the samplers were programmed to calculate the flow rate using Manning's equation and the volume of water that had passed for a specific period of time (ISCO, 2008). The samplers were programmed to collect a 200-mL sample of stormwater for a defined volume that had passed after reaching an enable level. The enable level was set to 1.06 mm, which was the level of stormwater in the inlet pipe before sampling was initiated. Samples were taken after a known volume of stormwater had entered the basin (Table 1.1). This volume of stormwater was selected for each basin based on expected flows in each catchment and experience during the monitoring period.

Table 1.1 Volume of stormwater required to pass to initiate the collection of one 200-mL sample by the ISCO sampler at the inlet and outlet of each basin.

Basin	Inlet Passing Volume (L)	Outlet Passing Volume (L)
11.4 B	1890	1890
9.2 C	2840 (front inlet) 1890 (side inlet)	2840
10.3 B	1890	945
5.10 B	1890	2840

The samplers were programmed to collect four 200-mL aliquots per bottle, which would represent that portion of the hydrograph and sedigraph. Composite sampling allowed for more samples to be taken over the course of a storm, providing a better estimate of the true average total suspended solids (TSS) concentration over time. A 120° V-notch weir was installed near the outlet of the basins in order to measure the flow from the skimmer and emergency spillway. The flow over the weir was determined from the level given by the ISCO 730 bubbler module and the weir program in the sampler. Table 1 shows the volumes of water having passed before a sample was taken at each of the basins.

An ISCO 674 Rain Gage (ISCO, 2008) was attached to one of the samplers to monitor rainfall to an accuracy of 0.254 mm and was assumed to represent the rainfall for other basins that were monitored on the project at the same time. The amount of rainfall was recorded every five minutes by the sampler. The rain gage was initially set up on Basin 11.4 B. Once monitoring concluded there, the rain gage was moved to Basin 10.3 B and finally to Basin 5.10 B after monitoring on Basin 10.3 B was completed. Site and basin descriptions are presented in Table 1.2 later section.

After storms, samples were collected and analyzed for TSS and turbidity. Every sample was analyzed for turbidity, while TSS was measured only for every fourth sample due to time and expense. Turbidity was measured using an Analite portable turbidity meter (McVan Instruments, Melbourne, Australia; Figure 1.1). The measured values were corrected with a standard curve based on a series of formazin standards. Following the Standard Methods for the Examination of Water and Wastewater (Clesceri et al., 1998), TSS samples were filtered with 47-mm glass fiber filters (ProWeigh, Environmental Express, Mt. Pleasant, SC) and dried overnight at 103°C to 105°C (Figure 1.2).

Figure 1.1. ANALITE NEP-160 portable turbidity meter.

Figure 1.2. Vacuum filter device – TSS.

In order to obtain an estimate of TSS of each sample, a linear relationship between TSS and turbidity was developed for each site using the samples that were analyzed for both turbidity and TSS. The data were graphed with turbidity being the independent variable and TSS the dependent variable. A regression equation was calculated based on the graphed data and used to estimate the TSS based on turbidity for the other samples (Gippel, 1989). Using the flow and time data, the representative volume that went into the basin during the time when a sample was collected was determined. By using the volume and the TSS of each sample, the mass of sediment entering the basin was calculated.

For each storm, the average turbidity, average TSS, stormwater volume, peak flow, total rainfall, total sediment yield, intensity, time since last storm, and storm duration were calculated and compiled into tables to analyze how and which parameters influenced turbidity, sediment yield, and TSS entering the basin for a specific storm. Other factors such as whether polyacrylamide (PAM) for flocculation was used, whether grading was occurring, and whether discharge over the emergency spillway of the basin occurred were also recorded for evaluation.

Spillway discharge was assumed when the outflow at the weir exceeded the maximum flow rate of the skimmer, as provided by the manufacturer (J.W. Faircloth & Son, Inc., Hillsborough, NC). For each storm where inlet and outlet samples were collected, basin efficiency based on average TSS, average turbidity, and total sediment were also calculated using the respective values and a standard equation for calculating efficiency based on the values entering and exiting the basin. The equation used in calculating efficiency was:

$$\text{Basin Efficiency (\%)} = \left(\frac{\text{Value In} - \text{Value Out}}{\text{Value In}}\right) * 100\% \qquad (1)$$

During some storms, low flows and malfunctions were recorded by the sampler and as a result, the data from these storms were not used in the analysis. The basins were monitored for as long as possible to estimate long term erosion rates for their catchments and to see how sediment delivery to the basins changed with the changes in topography and groundcover.

Site and Basin Descriptions

Table 1.2 lists the design dimensions and calculations for the four basins monitored. Topographic surveys of the catchments for each basin were conducted using ground-based LiDAR (ScanStation2, Leica Geosystems 2012, San Ramon, CA) periodically during the grading process. On 14 September 2010 and 30 November 2010, surveys were collected with a Topcon Total Station (GTS 211D, Topcon Electronic Total Station, Livermore, CA) because of malfunctions with the LiDAR scanner. All of the surveys were processed in ArcGIS to determine catchment size (ESRI, 2010).

Table 1.2. Design dimensions and calculations for the basins monitored.

	Site Name			
Design Property	11.4 B-C&G 300,000 L	9.2 C-C&G 720,000 L	10.3 B-F* 220,000 L	5.10 B-C&G 260,000 L
Length (m)	29.0	39.6	9.15	24.4
Width (m)	12.2	19.8	13.7	12.2
Depth (m)	0.915	0.915	0.915	0.915
25-Year Peak Flow (m^3 s^{-1})	0.315	0.766	0.229	0.231
Disturbed Area (ha)	1.05	2.35	0.769	0.708
Intensity Used in Rational Method (mm hr^{-1})	198	198	198	198
C-factor Used in Rational Method	0.55	0.60	0.55	0.60
Skimmer Orifice Diameter (mm)	41.3	63.5	31.8	41.9
Emergency Spillway Weir Length (m)	9.76	17.4	6.71	9.76

C&G – Clearing and Grubbing Phase
F – Final Grade Phase
*Basin 10.3 B was a two-chambered basin with the dimensions of the top and bottom chambers being the same.

Basin 11.4 B

This basin was monitored from 14 September 2010 to 5 May 2011, from soon after its installation through the end of the clearing and grubbing phase and ended when the catchment was at final grade (Fig. 1.3). The catchment area in the final phase is reduced and as a result the dimensions of the basin are the same as the clearing and grubbing phase. Another basin upslope from Basin 11.4 B drained into its watershed, so we set up a sampler to monitor the outlet in order to later remove that sediment load from the total entering 11.4 B. Since we were only taking into account the activities in the catchment for Basin 11.4 B it was appropriate to eliminate the upper basin's contributions. The upper basin was removed on 3 February 2011.

Figure 1.3. Basin 11.4 B in December 2010.

Basin 9.2 C

This basin was monitored from 22 March 2011 to 16 September 2011, from the clearing and grubbing phase through a portion of the mass grading phase (Fig. 1.4). Since there were two inlets on this basin, both inlets were monitored using automated samplers and the data combined to characterize sediment and stormwater flow into the basin. For description purposes, the 'front' inlet was oriented parallel to the length of the basin, and the 'side' inlet was oriented perpendicular to the length of the basin. Heavy erosion and sidewall failings in the silt ditches seen on Basin 11.4 B suggested that a majority of sediment yield was from the ditches rather than the catchment. On Basin 9.2 C, we attempted to reduce the influence that erosion and failures in the silt ditch had on sediment yield. On 14 June 2011, the ‘sumps’ typically dug out in front of rock check dams in the silt ditch were filled in and smoothed out, and jute fabric and wattles were installed in the ditch to limit erosion (Fig. 1.5). Monitoring concluded as the catchment reached final grade because it was scheduled to be removed according to the plans.

Figure 1.4. Basin 9.2 C in March 2011.

Figure 1.5. Basin 9.2 C inlet before (left) and after (right) removal of the sump.

Basin 10.3 B

This two-chambered basin was monitored from 5 May 2011 to 14 November 2011, during the final grading and post-paving phases of construction (Fig. 1.6). This section of the project was at final grade and it was not anticipated that much grading would occur and therefore most of the sediment movement would be a result of erosion and not disturbance (Fig. 1.7).

Figure 1.6. Basin 10.3 B upper (left) and lower (right) chanber.

Figure 1.7. Basin 10.3 B watershed and inlet sump (foreground).

Basin 5.10 B

This basin was monitored from 4 August 2011 to 16 December 2011. In order to limit channel and gully erosion, the silt ditches leading to this basin were lined with Posi-Shell® (Posi-Shell, 2011; Fig. 1.8 & Fig. 1.9). Posi-Shell is a mixture of water, fibers, a mineral setting agent, and Portland cement and which mixed and hydraulically applied, much like hydromulch. It is a very durable material and in theory should prevent erosion in the silt ditches.

Figure 1.8. Basin 5.10 B watershed showing diversion ditches lined with Posi-shell and check dams in place.

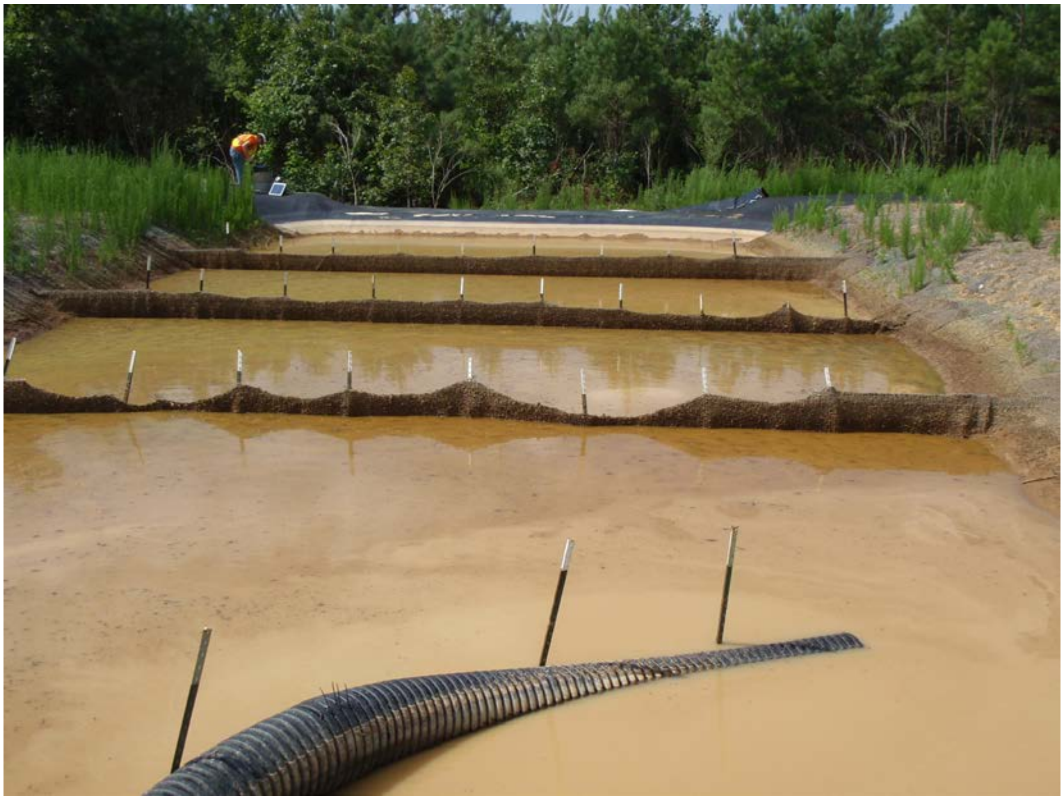


Figure 1.9. Basin 5.2 B in August 2011.

Results and Discussion

The data collected from the outlet of Basin 10.3 were questionable because the stormwater volume leaving the basin was consistently higher than the amount entering the basin. The data were checked for errors and consistency and the storm volume entering the basin seemed to be consistent for the catchment basin as determined by the surveys, intensity of storms, and the rainfall amount. The amount of stormwater leaving the basin tended to be four to ten times higher than what was entering the basin with the difference becoming larger as the monitoring came closer to an end. Upon inspection of the data, errors in programing (either in the pipe slope, pipe length, or in weir dimensions at inlet or outlet) were not apparent. The only explanation was that the error resulted from stormwater bypassing the inlet to enter into the lower basin from an area outside of the defined catchment. However, there was no conclusive evidence of this occurrence. Because of this anomaly, data collected from Basin 10.3 B were not included when determining basin efficiency, but the sediment yield data at the inlet were included in our analyses.

Changes in Sediment Load Over Time

The sediment load and TSS from all storms collected on Basin 11.4 B are graphed over time with the respective storm depth and intensity (Fig. 1.10). On 18 October 2010 some grading began in the basin catchment that removed much of the groundcover. On 23 November 2010, the site was strawed and tacked to re-establish groundcover in the catchment. In the period between these two dates, there was a large spike in the TSS and a small spike in total sediment entering the basin. The spike in TSS was likely due to the lack of groundcover while the low spike in sediment loading was due to the low rainfall depths for these storms. Between the two storms which occurred on 28 October 2010, the average TSS and sediment yield decreased in spite of the fact that the second storm on that day was larger and more intense. This may have been due to newly graded and disturbed soil being easily eroded by the first storm. This was also apparent from the storm on 16 November 2010 which had a smaller volume and intensity than either of the previous storms but had a higher sediment yield. From 23 November 2010 to 15 March 2011, the site was relatively dormant with a groundcover present on most of the catchment. This is evident in the graph for this period having low TSS and sediment yields coupled with the fact that these were low intensity storms. After 15 March 2011, grading progressed through the catchment which removed most of the groundcover. The trend in the graph shows the sediment yield and TSS increasing after this date, with some variation due to the intensity and size of the storms.

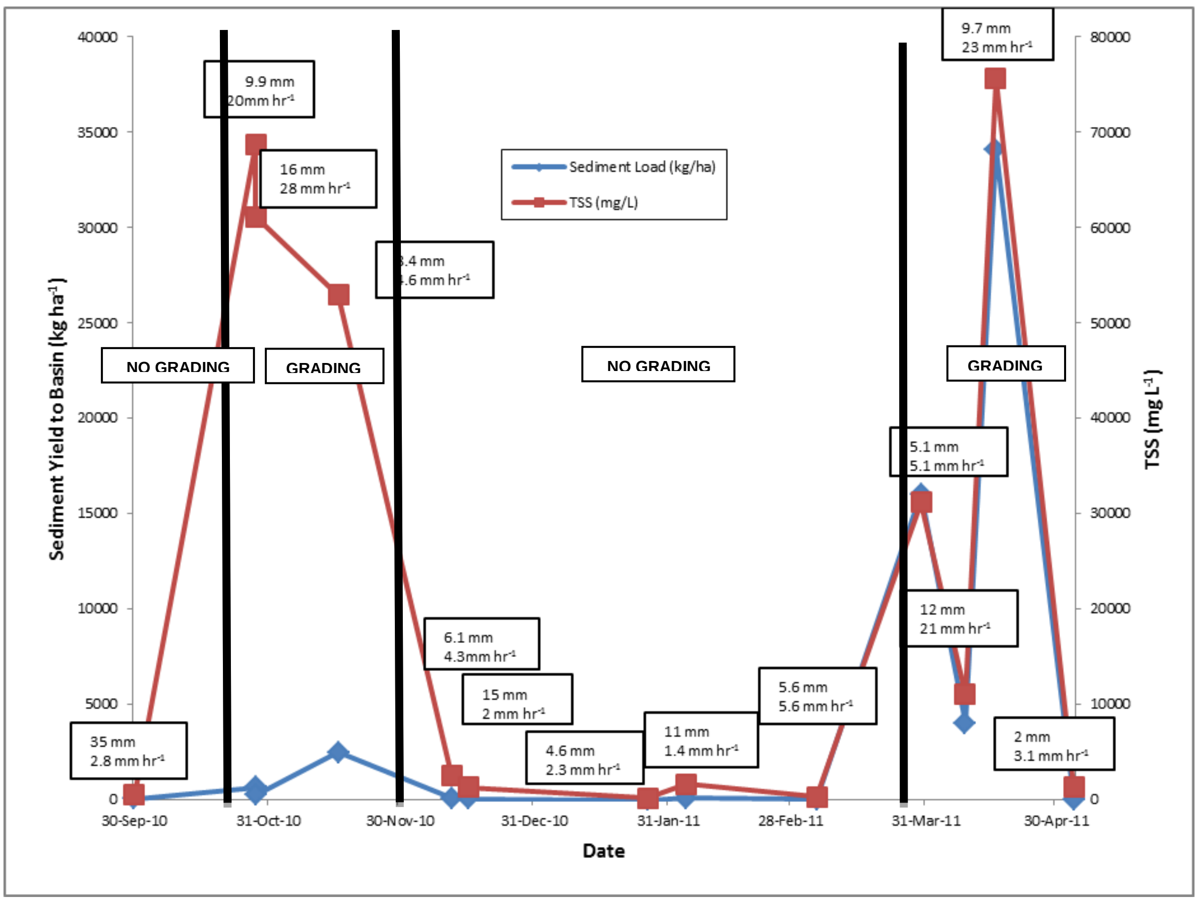


Figure 1.10. Sediment yields and TSS from each storm collected on Basin 11.4 B. The points indicate a storm with the boxes displaying rainfall depth and intensity from storms respectively. The left most box correlates to the left most point(s). Vertical lines indicate a point of major change to groundcover in the catchment due to earthwork.

The catchment for Basin 9.2 C was fairly dormant for a majority of the time it was monitored with groundcover and vegetation present on the catchment before grading started (Fig. 1.11). Grading in the catchment began on 17 August 2011. For the entire monitoring period, a haul road was located adjacent to the basin and heavy hauling traffic and periodic grading produced large quantities of loose soil which were unintentionally pushed into the diversion ditch leading to the basin. Subsequently, this sediment would be washed into the basin during storms. This may explain the lack of an obvious pattern between rainfall quantity and intensity, sediment yield, and TSS.

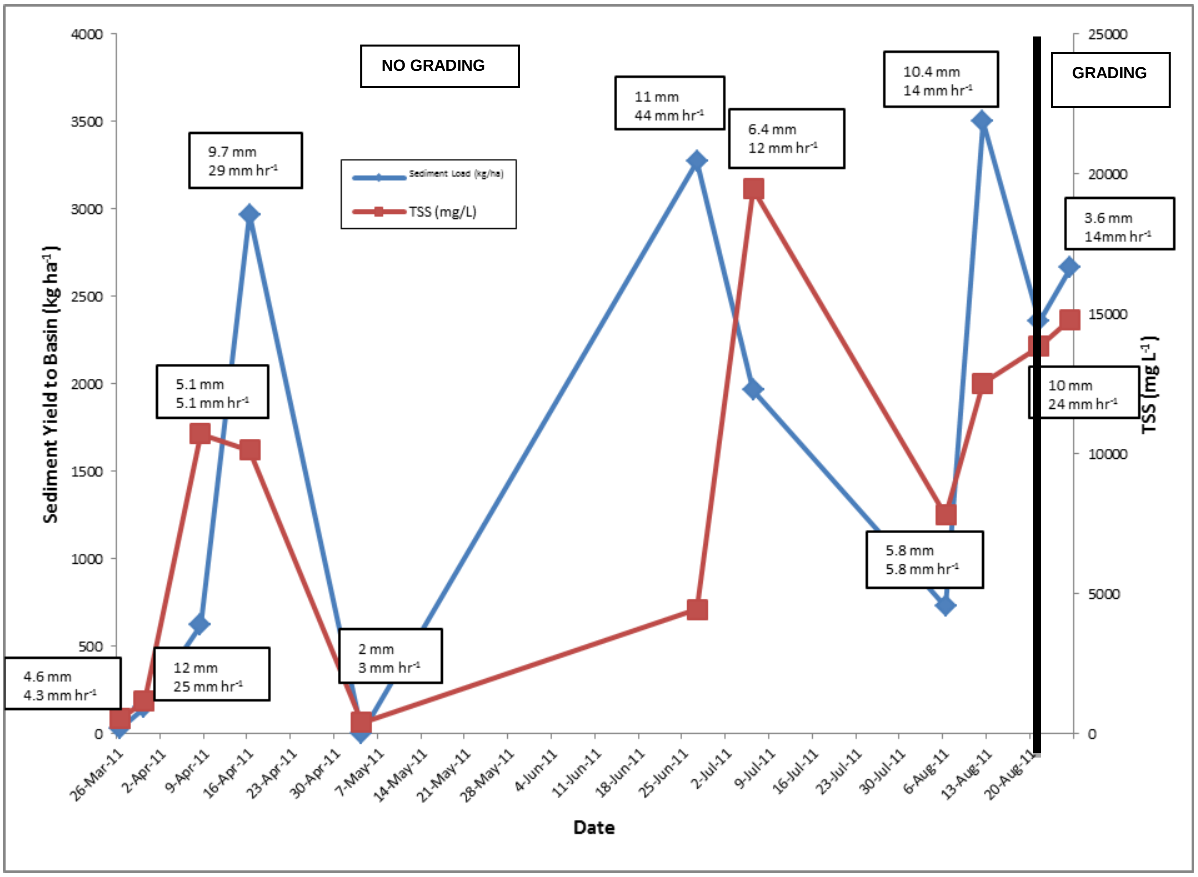


Figure 1.11. Sediment yields and TSS from each storm collected on Basin 9.2 C. The points indicate a storm with the boxes displaying rainfall depth and intensity from storms. The left most box correlates to the left most point(s). Vertical lines indicate a point of major change to groundcover in the catchment due to earthwork.

Basin 10.3 B was monitored during the final grade and post paving periods (Fig. 1.12). On 26 July 2011, a new silt ditch was installed which substantially reduced the drainage area to this basin. This was later confirmed by surveys of the area. On 10 August 2011 a berm was built which effectively blocked any runoff from the adjacent road bed from entering the basin. The resulting catchment was a small, well-grassed swale. This is apparent after 10 August 2011 when sediment yield and TSS decreased dramatically relative to the previous storms. The sediment yields and average TSS stayed relatively low for all of the storms compared to the 11.4 B and 9.2 C basins, with the exception of the one on 28 September 2011 where the TSS spiked. This was likely due to the high intensity of the storm.

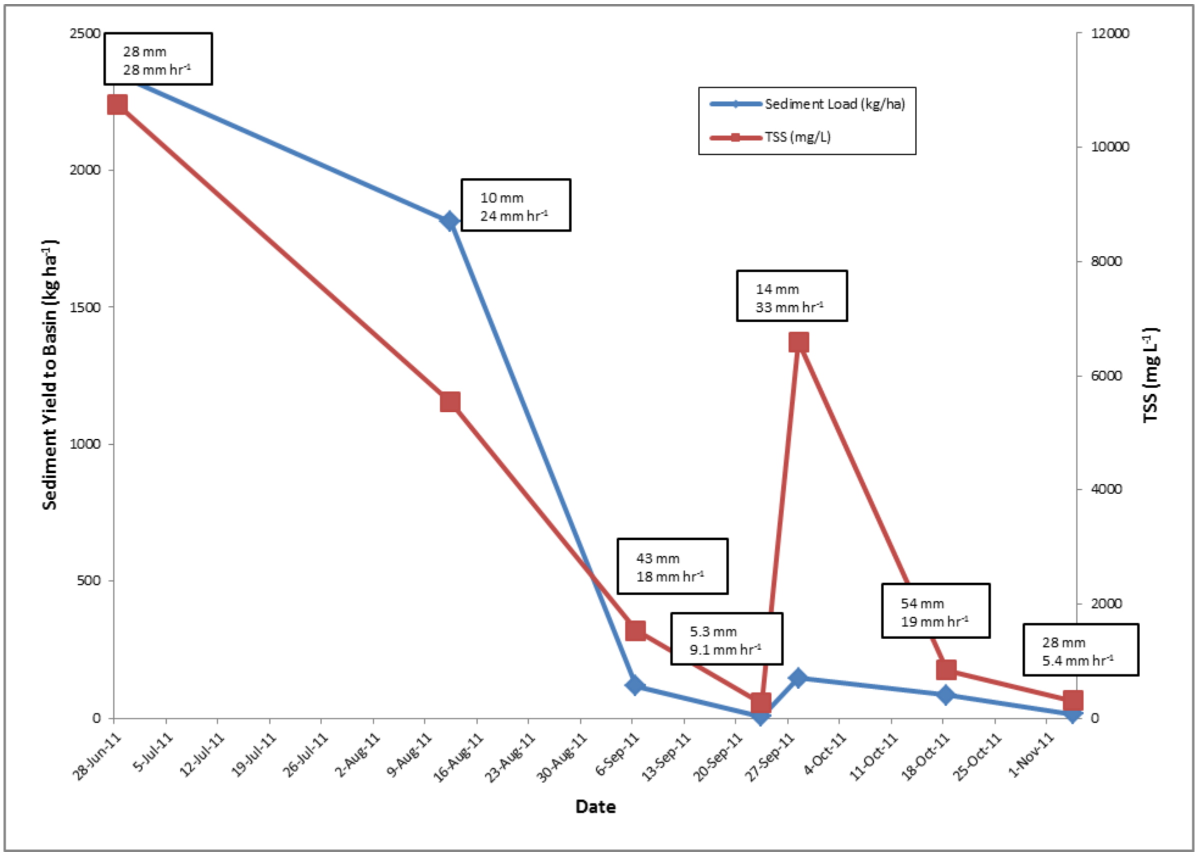


Figure 1.12. Sediment yields and TSS from each storm collected on Basin 10.3 B. The points indicate a storm with the boxes displaying rainfall depth and intensity from storms. The left most box correlates to the left most point(s). Vertical lines indicate a point of major change to groundcover in the catchment due to earthwork.

Basin 5.10 B was monitored after the clearing and grubbing phase. The area was mostly dormant with some minor disturbances. Prior to 14 November 2011, the catchment for the basin was stable with heavy weed growth and straw groundcover. After this date, large piles of soil were placed in the catchment near the silt ditch due to a culvert being buried in another area on the project. These piles were removed on 25 November 2011 leaving a bare area in the catchment until 5 December 2011 when the area straw groundcover was applied to the area. The TSS and sediment yield trends showed a spike during the period when the bare stockpiles were present (Fig. 1.13).

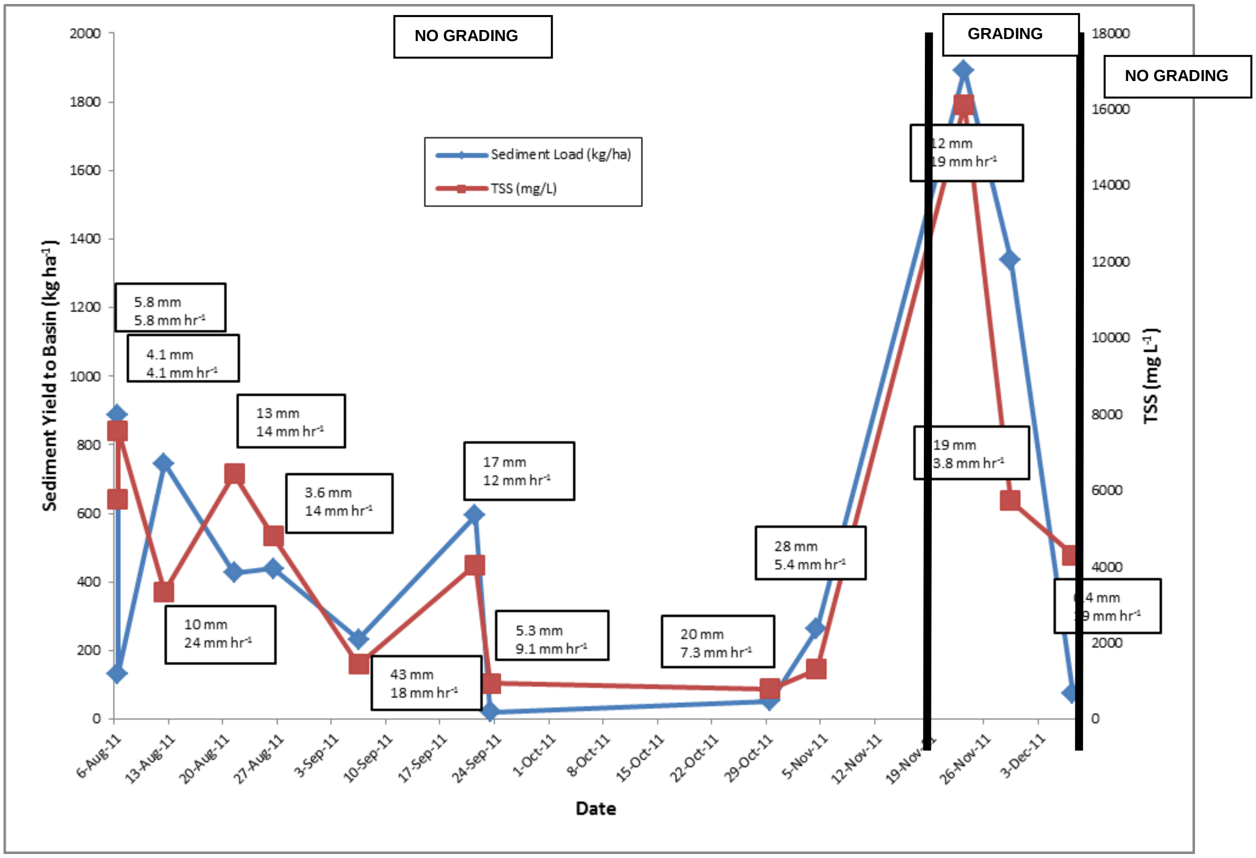


Figure 1.13. Sediment Yields and TSS from each storm collected on Basin 5.10 B. The points indicate a storm with the boxes displaying rainfall depth and intensity from storms. The left most box correlates to the left most point(s). Vertical lines indicate a point of major change to groundcover in the catchment due to earthwork.

The monitoring data on these basins provides strong evidence that groundcover and disturbances in a catchment have an important influence on the average TSS and sediment yield reaching the basin. This would indicate that as a project progresses into the mass grading phase, it can be expected sediment yields and average TSS will dramatically increase for similar runoff volumes and storm intensities. When ground cover is re-established, sediment yields will tend to decrease. However, as was evident with the haul road on 9.2 C, other factors can override the expected erosion and sediment delivery rates in a basin catchment. This is an indication to the difficultly in reliably predicting sediment yields based solely on expected physical features in the catchment.

Basin Efficiency by Reduction of Sediment Load, Average Turbidity, and Average TSS

The efficiency and performance of each of the basins and each storm collected was calculated based on the reduction in average TSS and turbidity at the inlet and outlet of the basins and the total amount of sediment entering and exiting them (Table 1.3).

Table 1.3. Basin efficiency and performance for each applicable storm collected.

Basin Name	Date	Average Intensity (mm/hr) /Total Rain (mm)	Stormwater Volume In/Out (L *10^3)	Basin Efficiency Total Sediment (%)	Basin Efficiency Average Turbidity (%)	Basin Efficiency Average TSS (%)
11.4 B	30 Sept. 2010**#	2.80/35	90/117	68.1	86.5	73.8
	16 Nov. 2010**#	4.60/8.40	59/112	98.6	99.4	99.4
	30 Mar. 2011**	5.10/5.10	243/32	99.9	99.3	99.2
	9 Apr. 2011**	21.3/12.4	204/9	99.8	90.1	92.0
	16 Apr. 2011**	23.2/9.65	331/57	83.4	1.04	6.55
9.2 C	6 July 2011#	11.6/6.4	448/206	99.2	94.7	96.0
	12 Aug 2011#	23.8/10.2	311/25	91.6	77.2	81.7
	26 Aug 2011**	14.2/3.56	244/129	91.7	70.5	80.5
5.10 B	E 6 Aug 2011#	5.84/5.84	111/99	73.6	61.8	65.6
	L 6 Aug 2011#	4.06/4.06	15/72	*	76.3	78.1
	12 Aug 2011#	23.8/10.2	167/168	*	-14.3	3.21
	21 Aug 2011#	14.0/12.7	55/104	*	72.3	58.1
	26 Aug 2011#	14.2/3.56	64/128	*	73.4	64.3
	6 Sept 2011**#	17.5/42.9	113/255	*	39.4	11.2
	21 Sept 2011**#	11.8/16.8	148/198	41.8	85.8	64.0
	4 Nov 2011**#	27.7/5.36	175/179	49.3	69.0	51.6
	23 Nov 2011**	19/11.7	87/40	94.4	86.2	87.6
	29 Nov 2011**	3.76/19.1	181/127	77.4	73.3	68.2
	7 Dec 2011**	19.1/6.35	13/12	92.3	27.4	91.5

*storms where most of runoff from catchment bypassed inlet pipe
**storms when PAM was used
#storms when groundcover was present.

In a number of cases, the amount of water leaving the basin exceeded that coming into it, most likely due to bypass flows that did not pass through the corrugated pipe inlet where flow was measured. This was obvious in the field for five storms on Basin 5.10 B and sediment retention is not presented for those storms. Basin 11.4 B had very high sediment retention for the three middle storms, somewhat less for the first, and much less for the fifth. The trend was similar for turbidity and average TSS reductions, except that during the last storm the turbidity and average TSS were essentially the same entering as exiting. For this storm it was observed that the flow into the basin exceeded the capacity of the 30 cm corrugated pipe forcing an overflow down the bank on the inside of the basin. The high runoff flow from the storm resulted in the high sediment and average TSS values at the inlet. The additional erosion from inside the basin would generate more turbidity and TSS, and would explain the poor reduction of these values. Sediment retention and turbidity and TSS reduction were fairly consistent for basin 9.2C for the three storms monitored, although not as high as was achieved in 11.4 B. This could have been the result of the use of polyacrylamide (PAM) on Basin 11.4 B to aid with flocculation and settling finer sediments. As is indicated in the table, PAM was put out for treatment prior to the storms. However it is not clear whether the PAM performed as desired due to smaller storms washing some away or poor distribution of the product.

Basin 5.10 B had a relatively stable watershed during most of our monitoring, but the construction of berm at the inlet was faulty and much of the runoff did not pass through the inlet pipe until this was corrected after 12 August 2011. This was evident in the data when flow occurred at the outlet prior to the inlet. Without accurate measurement of flow for the storms when this occurred, we could not calculate total sediment retention. For the remaining six storms, two retained <50% of the sediment, but in both cases volume out was higher than in, suggesting bypass flow may have also occurred somewhere around the basin. The retention rate for the remaining four events ranged from 74%-94%. The reduction in turbidity and TSS for this basin was highly variable, but the lowest occurred on 12 August when the storm intensity was the highest of those during the monitoring period.

Relationships between Weather, Runoff, and Basin Performance

The statistical relationships between storm characteristics and runoff values measured varied between expected and relatively surprising. Turbidity at the basin inlet was positively correlated with volume, peak flow, and total sediment load, and weakly correlated to total rain. All of these relationships were expected (Table 1.4). However, it was not correlated with storm intensity, the time interval between storms, or length of storm. Runoff TSS was only correlated to peak flow and total sediment load. This suggests that water quality was not greatly affected by storm characteristics but instead was influenced by peak flow during the storm. Peak flow was highly, positively correlated to two storm characteristics, intensity and storm length, but not to total rainfall. In fact, total rainfall was not correlated to any other storm or runoff characteristic except length of storm. The current practice in many states, including North Carolina, is to design the basin based on the peak flow rate for a design storm, such as a 10- or 25-year recurrence. Our results appear to support that approach since the correlations of peak flow to average TSS, average turbidity, and total sediment suggest that they can be predicted for a given storm given the peak flow of that storm.

Table 1.4. P-values from the Pearson's Correlation Coefficient between storm and basin data (n=23). Bold indicates significance (p<0.05).

	Peak Flow (cms)	Sediment Load (kg/ha)#	Average Inlet Turbidity (NTU)	Average Inlet TSS (mg/L)	Reduction of Total Sediment (%)**	Reduction of Turbidity (%)##	Reduction of TSS (%)##
Peak Flow to Inlet (cms)	-	0.0011	0.0162	0.0144	0.2073	0.4226	0.1504
Sediment Load (kg/ha) #	0.0011	-	0.0039	<0.0001	0.3562	0.1170	0.0268*
Average Inlet Turbidity (NTU)	0.0162	0.0039	-	<0.0001	0.0163	0.6807	0.5196
Average Inlet TSS (mg/L)	0.0144	<0.0001	<0.0001	-	0.1211	0.7607	0.8819
Total Inlet Volume (L)	0.0006	0.0930	0.0133	0.1717	0.0904	0.9054	0.8797
Rain (mm)	0.9946	0.4314	0.0927	0.2111	0.5500	0.8817	0.2035
Intensity (mm/hr)	0.0055	0.2994	0.2996	0.7639	0.9511	0.0056*	0.0466*
Time Since Last Storm Event (days)	0.9950	0.6552	0.4809	0.8633	0.9615	0.8472	0.9608
Length of Storm(hr)	0.0297	0.2985	0.1535	0.2852	0.5297	0.3029	0.7239

*Negative correlation. All other significant (p<0.05) correlations are positive.
**n =14, due to bypass flows on Basin 5.10 B and sampling errors at outlet
#n = 18, due to bypass flows on Basin 5.10 B
##n = 19, due to sampling errors at outlet

Storm and runoff characteristics were also correlated with sediment basin function in some instances, but not in many others. The reduction in turbidity and TSS were only correlated with storm intensity, with lower turbidity and TSS reduction occurring with higher intensity storms. This may relate to lower retention times during more intense storms, although the relationship to peak flow was not significant. The reduction in TSS alone was negatively correlated with the sediment load which is expected. The efficiency of the basins in retaining sediment was positively correlated to turbidity, with a weaker correlation to storm volume ($p = 0.0904$) and TSS ($p = 0.1211$). This suggests that the basins were more effective when the runoff water had higher levels of sediment, possibly because more of the entrained sediment was of sufficient size to settle in the basin. The results of correlations between storm and runoff characteristics for turbidity and TSS reduction compared to sediment retention are somewhat contradictory.

Chapter 2.Evaluation of RUSLE2 to Predict Sediment Yields on Highway Construction Sites: Piedmont

Introduction

One of the most well-known methods for estimating soil erosion is the universal soil loss equation (USLE). It is an empirical equation originally developed to estimate soil erosion from agricultural fields (Wischmeier and Smith, 1978). The basic empirical equation has been incorporated into a computer application with a graphical interface known as version two of the revised universal soil loss equation (RUSLE2) (Foster et al., 2003). Along with the progression from USLE to RUSLE2, the developers incorporated further research of the conditions associated with construction sites to be able to expand its use to non-agricultural areas (Toy et al., 1998).

The equation structure used in RUSLE2 is similar to that of USLE and RUSLE using a similar framework equation (equation 1).

$$a_i = r_i k_i l_i s c_i p_i, \tag{1}$$

The average annual soil loss on the *i*th day (a) is calculated using the erosivity factor on the *i*th day(r), soil erodibility factor on the *i*th (k), soil length factor on the *i*th day (l), slope steepness factor (s), cover-management factor on the *i*th day (c), and supporting factors on the *i*th day (p) (Foster et al., 2003). These factors are calculated internally using the user inputs of location, managements, soil type, and topography (Foster et al., 2003).

RUSLE2 has been cited to be misused by engineers, planners, and officials (Boomer et al., 2008). This is due to extrapolation from the data used in development, incorrectly modeling catchments (gully erosion, etc.), and misusing the results. These factors can have a significant impact on the sediment yield reaching a basin and cause the RUSLE2 estimate for the catchment to be far from the true yield (Dabney et al., 2011; Posen et al., 2003).

There has been limited verification of RUSLE2 estimates to the sediment yields coming from construction sites, and were inconclusive due to sampling techniques and poor BMP design (Kalainesan et al., 2007). Typically, evaluations of the model have been limited to revisions to the interface of the program and sensitivity tests of different BMPs and covers within RUSLE2 (Yoder et al., 2007; Wachal et al., 2008). The objectives of this research were to (1) evaluate RUSLE2's ability to predict sediment yields on highway construction sites using plan sets and surveys of the catchments, and (2) analyze how the sediment yield estimates in RUSLE2 change as the catchment topography changes due to grading.

Materials and Methods

Runoff monitoring procedures and site descriptions were provided in Chapter 1. The following is a discussion of the modeling effort. During the course of monitoring the basin, the management and operations from each of these sites were observed and recorded to be inputted to RUSLE2. When major changes in the topography occurred due to grading, surveys of the catchments were conducted throughout the monitoring period using ground based light detection and ranging (LiDAR: Scanstation2, Leica Microsystems GmbH, Wetzlar, Germany). The first two surveys on Basin 11.4 B were conducted using a TopCon Total Station (GTS 211D, Topcon Electronic Total Station, Livermore, CA) because of malfunctions with the LiDAR unit. The surveys were processed in ArcGIS 10 (ESRI, 2010) to develop the catchment basins and flow path profiles to be used in the RUSLE2 calculations.

Since RUSLE2 is a long term erosion model, the catchments were monitored for as a long as possible and separated into periods based on the major activity or grade occurring at the time. These periods were defined as clearing and grubbing (CG), mass grading (MG), final grade (FG), and post paving (PP). The sediment yield calculated using the automated samplers for these periods were compared to the corresponding result from RUSLE2.

The catchments were separated into areas with profiles of similar length and steepness. A typical profile from each area was selected to use in the RUSLE2 topography calculation (Fig. 2.1). For comparison, profiles were also selected from the CG and FG plans in a similar way to run in RUSLE2. These represent the data typically used to develop erosion and sediment control plans.

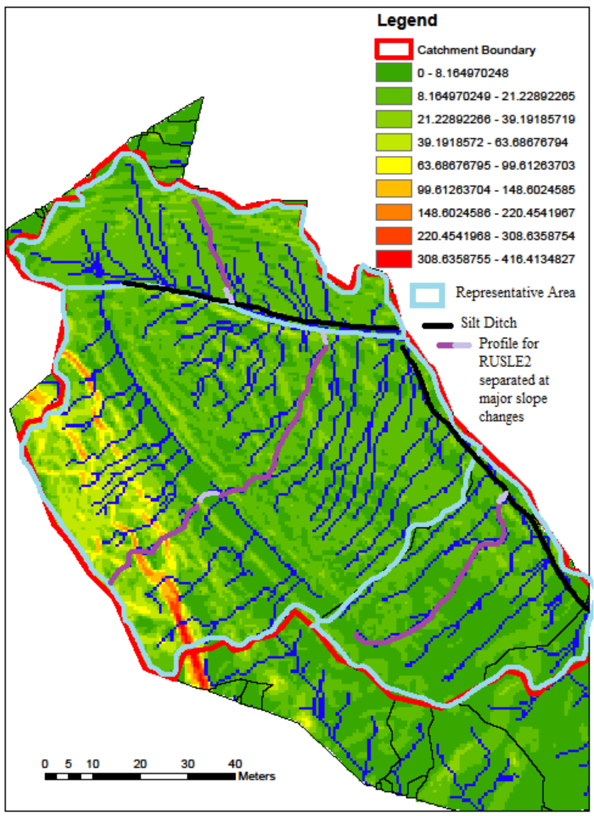


Figure 2.1. Example of LS profile development for RUSLE2 from ArcGIS processed survey. Scale is percent slope. Note: Extraneous points such as trees, grass, and construction equipment were also scanned during the LiDAR process.

Sensitivity of the LS Factor in RUSLE2

Through our monitoring on the basins, the topography on site would change suddenly, dramatically, and could deviate from the topography given on the plans. Since the basins on site are designed for one scenario or set of topography, it was important to evaluate how the sediment yield would change as the topography on site changes, and find at which point in the grading the highest sediment yield would occur.

From the profiles of the different surveys taken on each basin's catchments, the sediment yield for the entire monitoring period was estimated using RUSLE2. These estimates were compared to each other to find how the sediment yield changed through the different points of grading, and at which point the sediment yield would be highest. By using RUSLE2 estimates, field factors such as differences in the storm intensities, cover, and managements could be eliminated. To understand how different the estimates could be over the course of a construction project, the range and standard deviations of the estimates were found (Ott and Longnecker, 2008).

Statistical analysis

Using SAS® software (SAS, 2009), the field sediment yields were compared to those estimates using RUSLE2. In this, the difference (hereafter referred to as 'difference') between field sediment yield and RUSLE2 sediment yield estimate was set up as a variable and was regressed on the model predictions (equation 2).

$$\text{Difference} = A + B^*(\text{RUSLE2}) + \text{error}. \qquad (2)$$

In SAS, an F-test procedure was written to test whether the slope and intercept of this equation were both zero, and therefore if the difference between the field sediment yield and RUSLE2 estimate were zero. The level of significance was set to 0.05, so if the F-test of the parameter estimates in the regression model had probabilities greater than 0.05 it would mean that the difference in the RUSLE2 and field estimates was zero would not be rejected. In other words, there would be evidence that RUSLE2 could be used to reliably predict the sediment yield from these construction sites.

Results and Discussion

RUSLE2 Sediment Yield Estimation Using Surveys

There is a large discrepancy between the sediment yields at most sites and compared to estimates using RUSLE2 and topographic surveys of the sites (Table 2.1). However, the differences were not significant ($p = 0.152$) when all seven sites and stage conditions are included. The Basin 5.10 B site had relatively good agreement between measured and predicted sediment yields over a relatively long period, but it also was the only one with the diversion ditches lined with a spray-on concrete product to greatly reduce erosion. When this site is removed from the data set, the difference between the measured and predicted is significant ($p = 0.0220$) for the remaining six sites and stages.

Table 2.1. Results from field sediment yield and RUSLE2 calculations using survey profiles and planed profiles.

Basin ID	Days	Number of Storms	Total Precipitation (mm)	Field Sediment Yield (Mg)	RUSLE2 Representative Slopes from Surveys (Mg)	RUSLE2 Representative Slopes from Plans (Mg)
11.4 B (CG)	52	4	69	0.674	0.651	1.96
11.4 B (MG)	181	9	89	28.0	2.64	4.95
9.2 C (CG)	146	9	67	30.2	1.74	1.89
9.2 C (MG)	32	2	14	14.5	0.330	1.26
10.3 B (FG)	175	6	154	1.37	0.178	0.948
10.3 B (PP)	18	1	28	0.00227	0.000267	0.00207
5.10 B (CG)	134	10	150	5.74	3.31	7.62

For good reason, by including the data point from Basin 5.10 B, the model was found to be a good estimator of sediment yield on the construction sites, when otherwise the difference between field and RUSLE2 yield would be considered significantly different. Since the channelized areas were heavily protected with Posi-Shell on Basin 5.10 B, there was a much fairer comparison between the field sediment yield and the RUSLE2 estimate because channelized erosion was limited. Basin 5.10 B had among the highest field sediment yield and had a RUSLE2 estimation which was remarkable similar. At the other basins, the differences were much higher for the periods with high sediment yields and are most likely because channel erosion had a high influence on the sediment yield.

It should be noted that this is a relatively small sample size and the ranges of sediment yields, RUSLE2 estimations, and the differences thereof were wide. There was also evidence during the monitoring period that flow overtopped the earthen berm instead of entering the corrugated plastic inlet pipe where the flow was being measured and sample were being taken. This would suggest there was an even larger difference between the sediment yields and sediment estimations since some of the sediment inflow would have bypassed the sampler. Due to these reasons, it is difficult to make definitive conclusions about the results.

When estimates from RUSLE2 were calculated using the profiles developed from planning sets, the statistical results suggested that RUSLE2 would be a good method for estimating the sediment yield on site (Table 2.1). This was the case when Basin 5.10 B was used in the analysis ($n = 7$, p-value = 0.3262) and when it was not ($n = 6$, p-value = 0.1242).

In contrast to the previous analysis, the estimates from RUSLE2 tended to be higher and as a result there was less of a difference between the field sediment yield and RUSLE2 estimate. The RUSLE2 estimate tended to be higher when the planning sets were used because the planned catchments were larger, there were steeper slopes, and there were fewer flat areas in the catchment for deposition before reaching the basin than what was actually found on site in the surveys. When estimates from RUSLE2 were calculated using the profiles from the plans, there was no statistical difference when compared to the measured sediment yield. This was the case when Basin 5.10 B was used in the analysis ($n = 7$, p-value = 0.3262) and when it was not ($n = 6$, p-value = 0.1242).

Throughout the course of monitoring each basin and the corresponding catchment, the landscape and level of disturbance would change quickly and drastically. The surveys taken during monitoring were used with RUSLE2 to estimate sediment yields and compare them to the actual sediment yields for 7-13 storm events at each of the four basins (Fig. 2.2). There is no clear pattern of over- or under-predicting sediment yield. For Basin 11.4, sediment yield for five of the thirteen events were relatively well predicted but the remaining storms were vastly different by up to an order of magnitude higher or lower. For these storms, there were typically erosion processes occurring on site that were not and could not be taken into account using RUSLE2. Most of the predictions at Basin 9.2 C were much lower than actual sediment yields, by as much as two orders of magnitude. An active haul road was adjacent to this basin and ran parallel to the diversion ditch entering the basin. The road was typically left bare and periodically graded which forced soil into the ditches and left a highly erodible surface in close proximity to the diversion ditch leading directly to the basin. The first couple of predictions on Basin 10.3 B were lower than the measured value while the later storms had predictions much higher than the amounts measured. Between this change the catchment was nearing completion and as a result the catchment appeared to be reduced to a small well grassed swale as opposed to the relatively large area that the survey showed was going to the basin. As a result, much of the sediment eroding in the catchment bypassed the basin. The closest sediment yield predictions to actual were in the Basin 5.10 B catchment. This was most likely because there was little active grading during most of the monitoring period and the diversion ditches, which typically have concentrated flow, had been largely stabilized areas of with the spray-on concrete product.

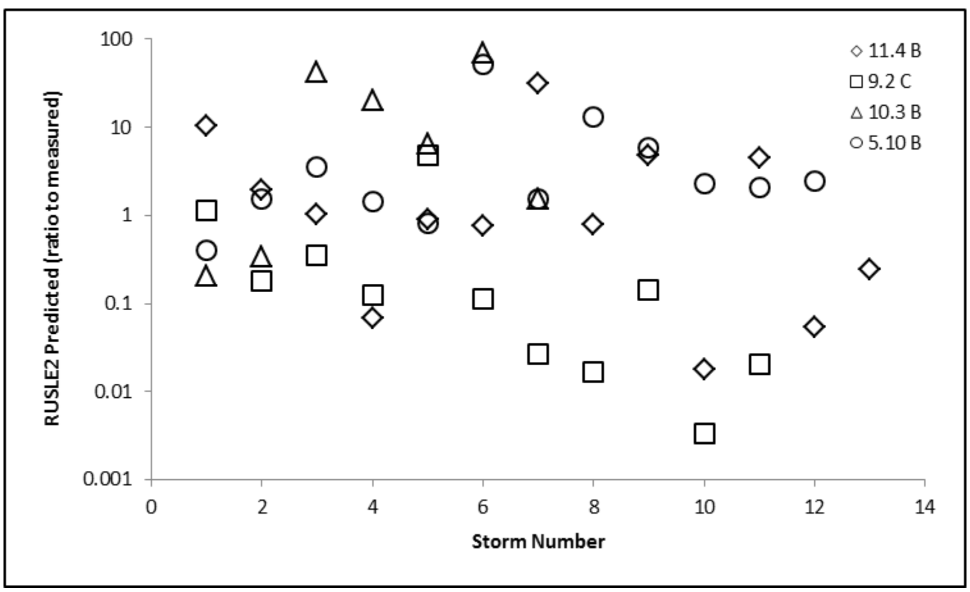


Figure 2.2. Ratio of RUSLE2 predicted sediment yield to measured yield at the inlet to four sediment basins.

The traditional method for estimating basin size is to use either the initial elevations at the clearing and grubbing (CG) phase or to use the final elevations (FG). At each basin monitored, there were many differences between either of these elevations as the areas went through various stages of grading. Furthermore, there were management differences between each of the sites and were unforeseen from the sets of plans. Lastly, RUSLE2 does not account for erosion in concentrated flow areas which resulted in some of the descrepencies as well. The differences or similarities between the RUSLE2 sediment yield and the measured sediment yield could typically be explained using these three factors, and is also a reason there was no clear pattern in whether RUSLE2 typically over- or under-predicted the sediment yield for individual storms.

Predictions Using Surveys Versus Plans

On Basin 11.4 B, the ratio between the RUSLE2 estimates using the survey topography and the CG topography ranged between 0.35 and 0.85. This ratio increased and approached one toward the third survey (Fig. 2.3). At this point, some grading in the catchment began, flattening areas which allowed for deposition and would limit soil loss. Subsequently the ratio started to decrease. Major grading began before the fifth survey and was nearly complete at the time the sixth survey collected. The ratio of survey to CG plan sediment yield predictions continued to decline. The ratio of the survey to the FG plan sediment yield had a similar trend, but had a range between 1.67 and 4.11 (Fig. 2.4). The higher ratios indicate that using the FG in the RUSLE2 plans will tend to under-predict the sediment yield given the topography at a given time in the catchment. However, at the fifth and six surveys, the ratio approaches one since these surveys were taken when the catchment was nearly at final grade.

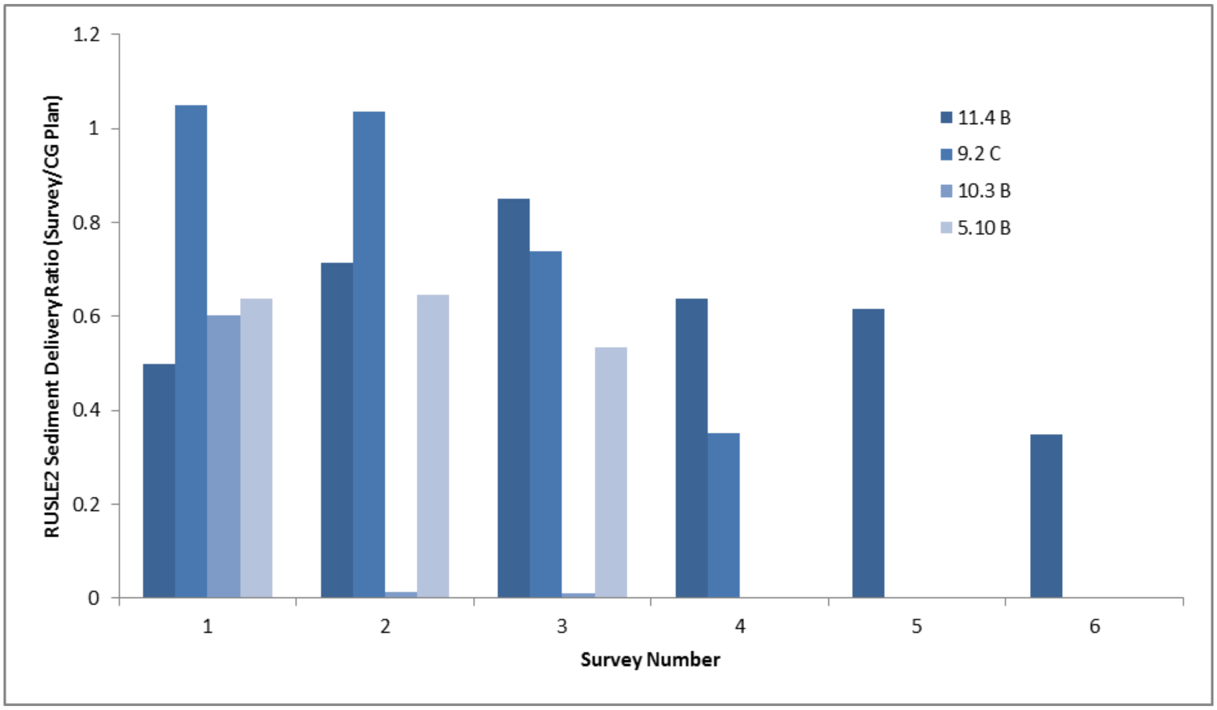


Figure 2.3. The ratio of the RUSLE2 sediment yield when predicted using the topography of a given survey to the RUSLE2 predicted sediment yield using the topography from the clearing and grubbing plans.

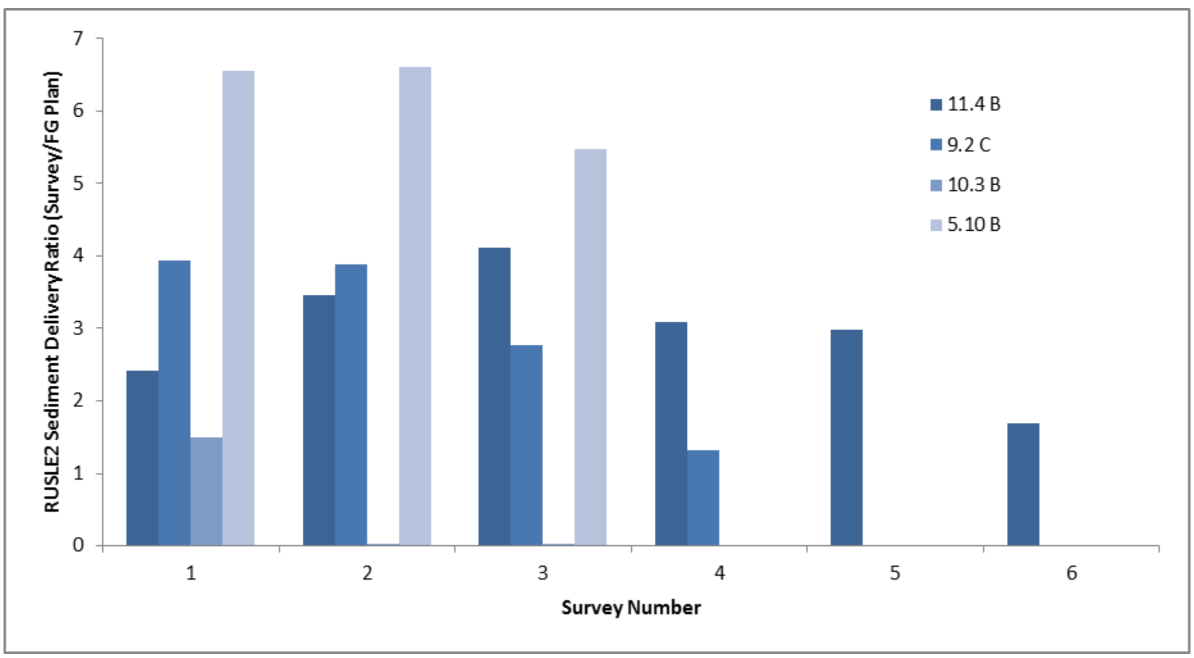


Figure 2.4. The ratio of the RUSLE2 sediment yield when predicted using the topography of a given survey to the RUSLE2 predicted sediment yield using the topography from the final grading plans.

On Basin 9.2 C, the ratio between the RUSLE2 estimates using the survey topography and the CG topography ranged between 0.35 and 1.05 (Fig. 2.3). The first two surveys on the Basin 9.2 C catchment were taken early in this portion of the project, and were similar to the topography from the clearing and grubbing plans. As a result the ratios of the survey to CG estimates were close to one. As the catchment was graded into a final phase, the ratio between the estimates decreased. The trend in the ratio between the survey and the FG plans was similar and ranged from 1.32 to 3.94 (Fig. 2.4). The ratio decreased and approached one on the latter surveys, 3 and 4, which were collected closer to when the catchment was at final grade.

On Basin 10.3 C, the ratio between the RUSLE2 estimates using the survey topography and the CG topography ranged between 0.01 and 0.60 (Fig. 2.3). This ratio shows that the CG estimate was consistently higher than the survey estimates yielded. This catchment was only monitored during the final grade phase and it was expected that the estimates based on the survey data would be closer to the estimate from the final grade topography. The ratios between the RUSLE2 estimates using the survey topography and the FG ranged between 0.03 and 1.49 (Fig. 2.4). As the portion of this project came closer to paving, a diversion ditch leading to the basin was flattened and blocked with a berm which re-routed the water further down the catchment. Due to this, the catchment for the FG was much smaller in the surveys than it was on the FG plans. As a result, the ratios were close to zero and suggest RUSLE2 greatly over-predicted using the FG plans given the intermediate topography.

On Basin 5.10 B, the ratio between the RUSLE2 estimates using the survey topography and the CG topography ranged between 0.53 and 0.65 (Fig. 2.3). The topography of the catchment did not change dramatically over the course it was being monitored. Therefore the difference in the ratios was small relative to the other basins. The ratios between the RUSLE2 estimates using the surveys and FGe plans ranged between 5.46 and 6.51 for Basin 5.10 B (Fig. 2.4). This basin was not monitored for a time which included a dramatic amount of grading and a survey was not collected when the catchment was nearing final grade. Due to this, the FG ratio did not approach one similar to some of the other basins for the later surveys.

The estimate of sediment yield was consistently lower when the topography from the surveys was used as opposed to the topography from the clearing and grubbing plans. Similar to Basin 11.4 B, this was most likely due to the fact that there were not flat areas within the catchment based on the topography in the CG or FG plans, but there were on site due to a haul road near the top third of the catchment. These flat areas create spots along the profile where sediment can deposit and therefore will not count toward the sediment yield at the bottom in the RUSLE2 calculation. The ratios with the FG plans tended to be higher than the other basins in the later surveys and did not decrease and approach one like the others did. This was because the catchment was not monitored and a survey was not taken when the catchment was nearing final grade.

Conclusion

The current method of design for sediment basins on NCDOT highway construction sites only takes into account a few of the factors that can affect true sediment yield from a catchment. Using an empirical or process based model could be a faster and more accurate method of sizing these sediment basins in order to achieve a desired performance.

Based on the observations and results of this research, RUSLE2 would not be a good method for estimating sediment yield and sizing sediment basins on NCDOT highway construction sites. The changing dynamic of the landscape, the differences in catchment management, and the lack of ability that RUSLE2 has in estimating channel erosion are all reasons that the estimate from RUSLE2 can be an over- or under- prediction of the sediment yield on site. Because of the landscape dynamics and unpredictable rain patterns, there was no clear evidence that RUSLE2 would typically under- or over-predict the measured sediment yield.

Furthermore, RUSLE2 can only estimate a sediment load and therefore would only be able to estimate the sediment storage volume. Neither sediment transport factors nor concentrated flow erosion are included in the model. The model also does not determine deposition in the channels due to the effects that BMPs, such as check dams, and the effects on sediment yield at the basin inlet.

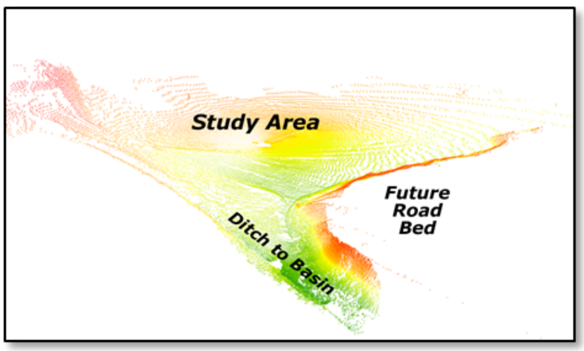
The similar sediment yield and RUSLE2 estimate on Basin 5.10 B and at Goldsboro emphasizes the importance of protecting the ditches leading into the basins, and that RUSLE2 can be more accurate when the topography is known.

The topography in clearing and grubbing plans tended to produce much higher sediment yields in RUSLE2 than that of the final grade. During the transition, the catchment tended to change from relatively steep slopes near the basin to shallow slopes near the basin, longer slopes, and smaller catchments. In construction scenarios similar to these, it may be more conservative to use the CG plan topography to estimate sediment yield with RUSLE2.

Chapter 3. Evaluation of RUSLE for a Coastal Plain (Goldsboro) Site

Introduction

After some difficulty, we located a suitable Coastal Plain site to test RUSLE under conditions where the soil was sandier and the topography was less steep than in the Piedmont or Mountains. The site was in Goldsboro and specifically the basin watershed was a fill area for an overpass ramp. Our first survey and initiation of runoff monitoring were in September 2012 (Fig. A.1 & A.2) with additional surveys on October 24, 2012, November 28, 2012 - January 8, 2013, and July 30, 2013. By the March-April period the site was at final grade and began to be stabilized (Fig. A.3). Automatic samplers were placed at the basin inlet and outlet, and occasionally at a point in the diversion to collect runoff prior to entering the diversion ditch. The description of conditions at the time of each survey and estimated erosion rates by slope class follows, with a final summary of the predicted and monitored erosion rates at the end of this chapter.



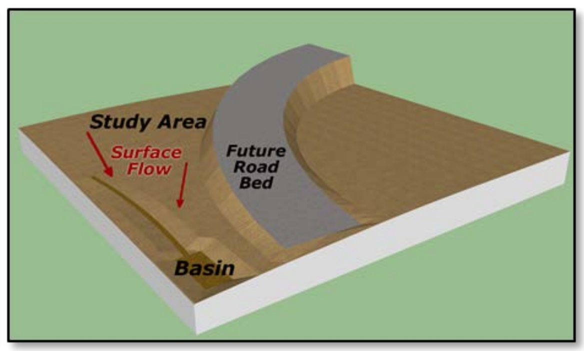


Figure 3.1. Project basin watershed as surveyed when monitoring begain (left) and as planned at the end of construction (right).

Figure 3.2. Study site at the beginning of basin monitoring. Note the beginning phase of fill process and how that corresponds to “Future Road Bed Site” in the survey in Fig. 3.1.

Figure 3.3. Study site in April 2013 as the watershed neared final grade.

Samples were collected periodically and may have represented multiple storms during the period. There were no runoff events in November and December due to relatively light rainfall during that period. There was a sharp drop in turbidity and TSS starting in March 2013 due to a combination of factors (Table 3.1). First, the site was approaching or reached final grade, which reduced the watershed for the basin by more than 50%. Second, the slopes draining to the basin were stabilized with mulch and vegetation, as opposed to the constant disturbance which was occurring up until that point. The disturbance included both the direct fill operation and a large part of the watershed which was used for staging and parking. Finally, the ditch check dams were treated with polyacrylamide, which was much more effective when the sediment loads were reduced.

Table 3.1. Water quality of samples obtained at the inlet of the sediment basin.

Sample Collection Date	Number of Samples	Average Turbidity (NTU)	Average TSS (mg L^{-1})
10/2/12	24	5692	4566
10/17/12	24	16264	13005
1/8/13	24	2110	1420
1/23/13	24	3484	2571
2/6/13	20	2443	1898
2/20/13	24	3010	2396

3/4/13	24	54	47
3/20/13	2	27	59
4/2/13	4	70	74
5/3/13	24	159	201

Results and Discussion

Goldsboro Biypass LIDAR Survey: Sept 25, 2012

On September 25, 2012 a Leica Scan Station 2 was used to collect LIDAR data for a 1.5 acre section of construction along the Goldsboro bypass. The area surveyed comprises the outside portion of a cloverleaf extending ~0.5 miles (Fig. 3.4). Three separate LIDAR scans were collected to develop an elevation model of the study area. Scans were co-registered using ground-based targets manually located at fixed locations. Over 500,000 elevation points were used to develop a 3-dimensional surface representation of the study site.

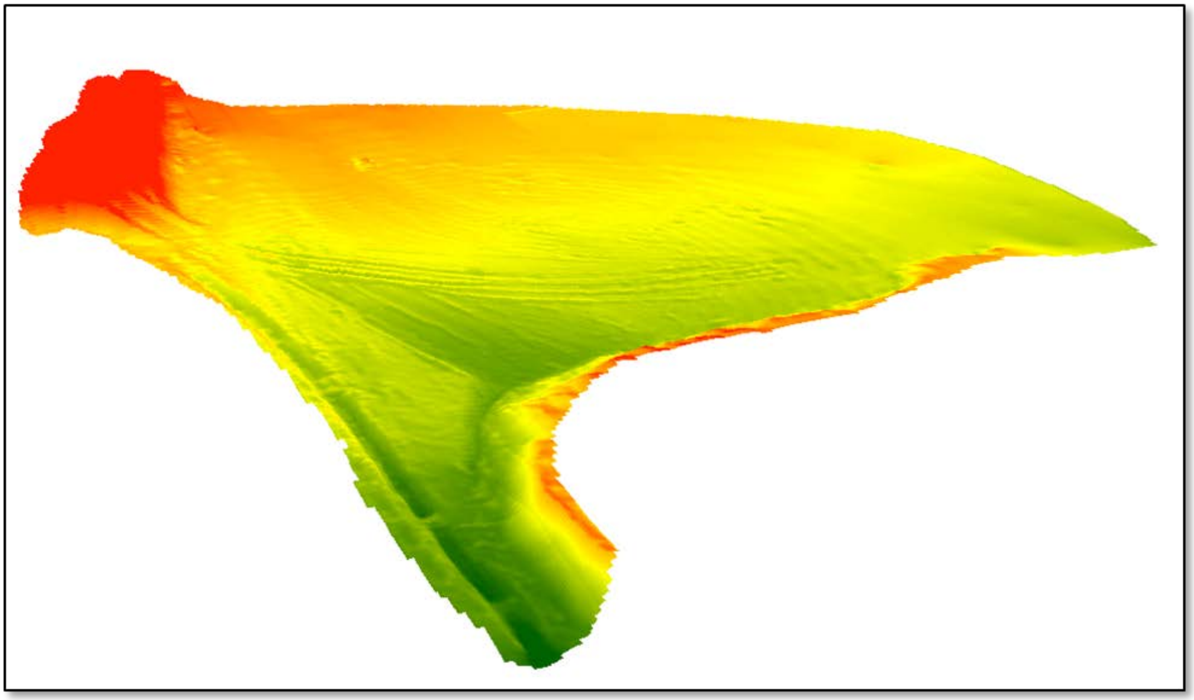


Figure 3.4. Interpolated surface from LIDAR data representing study area on September 25, 2012.

Using a combination of spatial processing tools including ESRI ArcGIS 10, GRASS, and R, the LIDAR points were manually edited to remove non-terrain features (e.g. construction equipment, trees, etc..) and interpolated to create a continuous surface representing the current surface topography. A thin-plate spline was used to smooth surface roughness common to high-resolution LIDAR data (Fig. 3.4). The smoothing operation provided a surface model better suited to surface flow and slope calculations.

The watershed boundaries were calculated using the LIDAR-derived topographic model. To identify the boundary the watershed analysis systematically works from the lowest elevation in the model up through the watershed until no cells in any adjacent direction are greater than the current analysis cell. At this spot a ridge exists between two watersheds and a line is placed to separate the basins. Figure 3.5 shows the resulting 1.5 acre watershed with three corresponding slope classes calculated from the digital elevation model are shown in Table 3.2.

Table 3.2. Area of each slope class on September 25, 2012.

Slope class (%)	Area (acres)
0-10	1.16
10-20	0.23
20-53	0.13

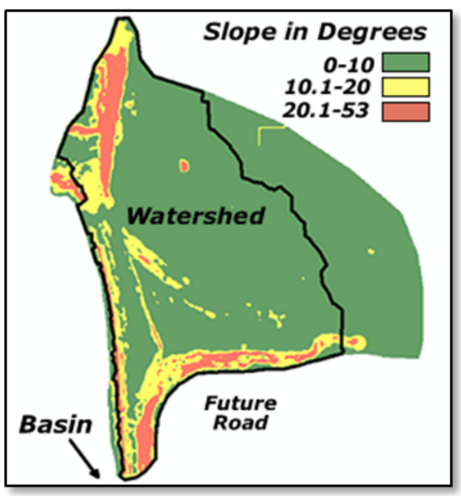


Figure 3.5. Map of the study area illustrating the location and extent of three major slope classes.

General surface flow paths were calculated from the LIDAR derived elevation model using the D8 method. Sinks in the elevation model were filled and a flow direction raster created. The flow direction raster was used to calculate a flow accumulation raster where high values represent an accumulation of surface flow and the convergence of flow across the surface (Figure 3.6).

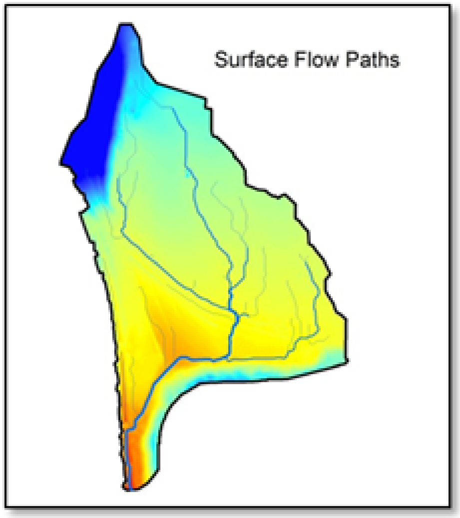
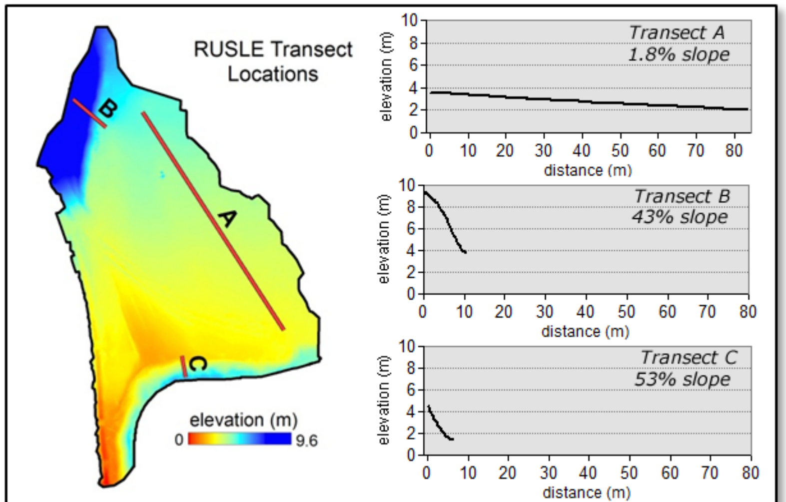


Figure 3.6. Modeled surface flow at the study site based on September 25, 2012 survey.

To examine the range of soil loss across the study site RUSLE was run for 3 transects within the study area (Fig. 3.7). Each transect represents a different slope condition and follows a surface flow path within the watershed. Transect A follows the main drainage pathway while transects B and C follow much shorter, steeper paths. Transects B and C overlay areas with significant slope resulting from both soil stockpiling and fill for the roadway, respectively. The factors used in this analysis are as follows; rainfall-runoff erosivity factor [R]=300 determined from an isoerodent map of the United States, the soil erodibility factor [K]=0.24 for a Goldsboro Loamy Sand, the slope length and steepness factor [LS] from the transect length [L] and slope [S] calculated from the LIDAR derived digital elevation model, and the cover-management factor [C] = 0.5 from online references. At this site, soil loss ranges in magnitude by almost 100 fold, with the LS factor the primary soil loss driver.



RUSLE

transect	R	K	L	S	LS	C	P	Soil Loss (ton/ac/yr)
A	300	0.24	82	1.8	0.18	0.5	1	6.4
B	300	0.24	13	43	11.30	0.5	1	406.9
C	300	0.24	6	53	12.06	0.5	1	434.0

Figure 3.7. RUSLE applied to transects along 3 major surface flow paths.

The modification of RUSLE for complex terrain and GIS is known as RUSLE3D. The primary difference between the models is the calculation of the LS factor. To incorporate the impact of flow convergence, the hillslope length factor [LS] is replaced by upslope contributing area A (Moore and Burch 1986; Mitasova et al. 1995, 1996; Desmet and Govers 1996). As with RUSLE, values for R,K,C, and P are constants and do not vary across the construction site. The LS factor is the primary driver for predicting the spatial distribution of soil loss as seen in Fig. 3.8.

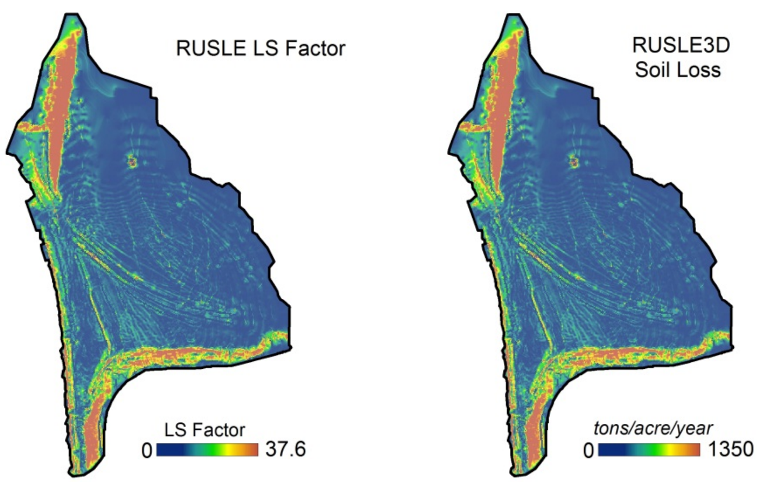


Figure 3.8. The LS factor as calculated for complex terrain and the resulting soil loss estimate. (SoilLoss = 300 * 0.24 * 0.5 * 1.0 * [LSFactor]) (1 ton of moist earth occupies approximately 22.2 cubic feet, or 0.629 cubic meters)

It is important to note that RUSLE is a detachment limited method. The equation assumes that water can transport an unlimited amount of sediment. The amount of erosion is limited only by the ability of water to detach soil. Consequently, deposition is not predicted and depositional areas should be excluded from the analysis. For that reason, applying RUSLE to complex terrain within a GIS is rather limited. However, RUSLE3D can be used to represent the extreme case where the maximum possible spatial extent of erosion is desired.

Goldsboro Bypass LIDAR Survey: October 24, 2012

On October 24, 2012 a second LIDAR survey was collected. Three scans were performed totaling over 1 million survey points. The 3 scans were co-registered using the same target locations established previously during the September 25th LIDAR scans. In general, grading for the cloverleaf has progressed with approximately 30 additional meters of soil added along the path of the future roadbed. However, no major topographic changes were observed in the main area drainage area leading to the sediment basin. As before, the raw LIDAR points were manually edited to remove non-topographic features (trees, construction equipment, etc.) and the points were interpolated to create a topographically accurate elevation surface (Figure 3.9). The watershed boundaries for the sediment basin were calculated in GRASS and the surface flow paths modeled using the D8 method.

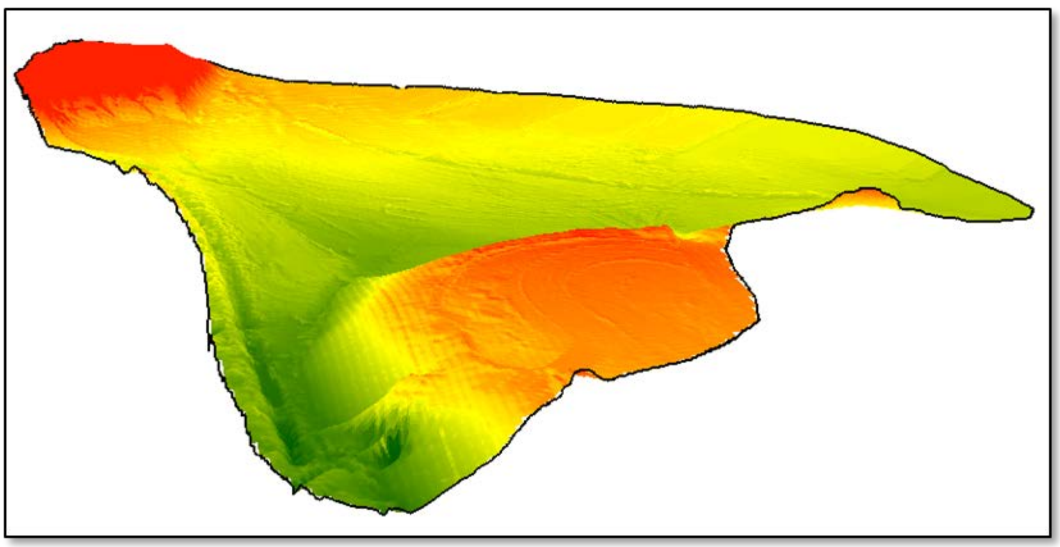


Figure 3.9. Interpolated surface from LIDAR data representing study area on October 24, 2012.

Figure 3.10. Basin and watershed view in early November 2012. Note the staging area and disturbed stockpile, the major sources of sediment, in the upper left of the photo.

Table 3.3. Area of each slope class for both the October 24 and September 25 surveys.

Slope class (%)	Area (ac) – Oct 24	Area (ac) – Sept 25
0-10	1.31	1.16
10-20	0.32	0.23
20-53	0.20	0.13

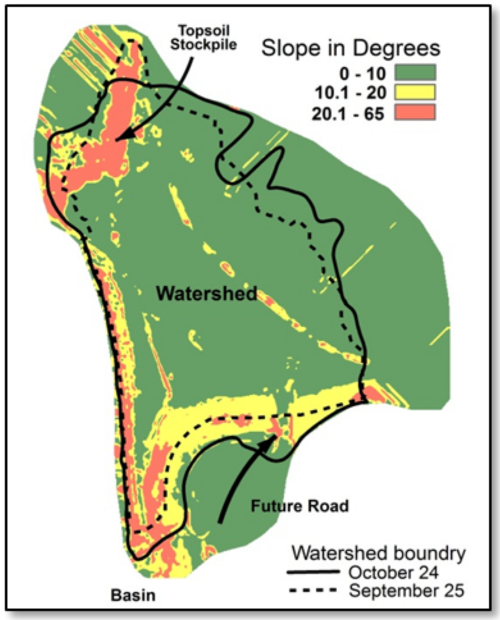


Figure 3.11. Map of the study area topography on October 24, 2012, showing the extent and location of three slope classes, and the change from September 25.

The roadbed was built a few meters higher resulting in a greater length of slope relative to September. Soil was removed from the lower portion of the stockpile creating very steep slopes (60%). Tire tracks from a bulldozer created a small ridge along the upper middle of the basin that directs flow toward the right before running along the toe slope of the roadbed. On Sept 24 there was a similar feature created that diverted the flow to the right as well, however this occurred along the middle left of the watershed, this feature was no longer present during the Oct 25 scan and as a result the main flow path on the left follows a 'more natural' downslope path (Fig. 3.11 & 3.12). While the majority of the area has slopes <10% and estimated erosion rates of 10 ton ac^{-1} yr^{-1}, the small areas of steeper slopes have potential erosion rates of 20-70 times that (Fig. 3.13).

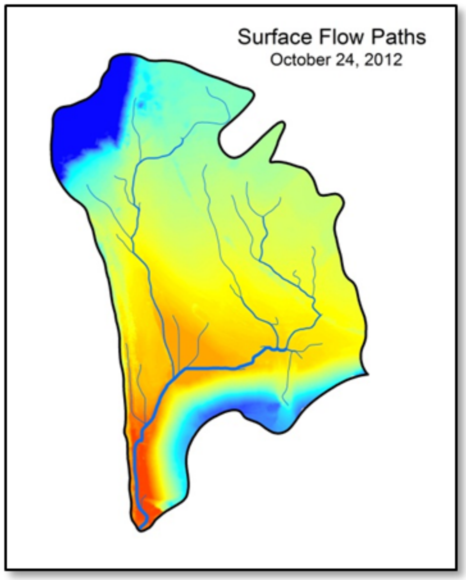
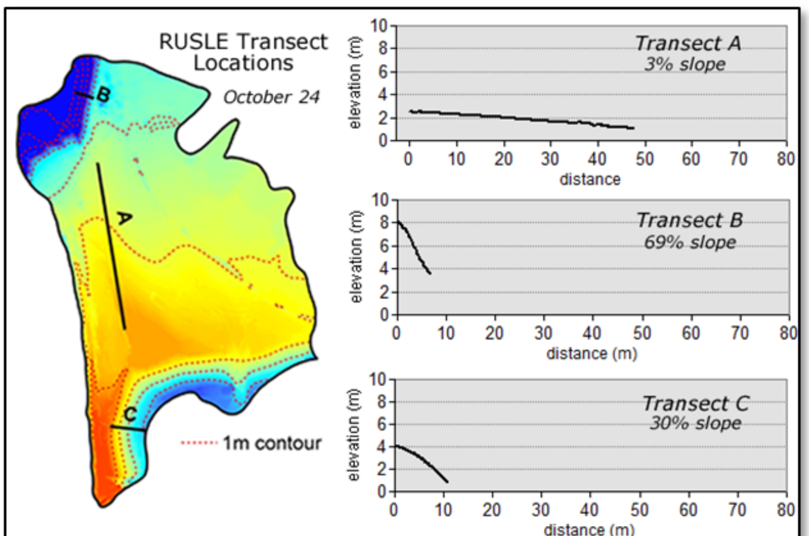


Figure 3.12. Flow-path analysis of the October 24 survey data.



transect	R	K	L	S	LS	C	P	Soil Loss (ton/ac/yr)
A	300	0.24	47.5	3.0	0.29	0.5	1	10.4
B	300	0.24	6.7	69.3	20.46	0.5	1	736.6
C	300	0.24	10.7	30.2	5.58	0.5	1	200.9

Figure 3.13. RUSLE applied to 3 transects that illustrate the full breadth of slope conditions at the site.

Goldsboro Bypass LIDAR Survey: November 28, 2012

On November 28, 2012 a third LIDAR survey was collected. Two scans were collected totaling over 500,000 survey points after processing. The scans were co-registered using the same target locations established during the prior 2 scans. In general, there were no major surface topography changes since the October scan (Fig. 3.14). The middle of the drainage area was being used primarily as a staging and construction vehicle parking area (Fig. 3.15). As such, vehicles were manually removed from the scan before the digital elevation model was created. The topsoil stockpile at the top of the drainage area was further depleted with approximately 1/3 to ½ of the stockpile removed from the original pile in September. The one notable change in surface drainage occurred in the middle of the drainage area where a temporary dirt road was built for the transport of soil to a roadbed being constructed outside the drainage area. Although < 1m high, this roadbed cut off approximately 1/4 of the drainage as compared to the September and October scans. The main flow paths remains similar where flow moves downslope toward the newly constructed roadbed then runs parallel to the foot slope of the roadbed until entering the ditch line. Almost no water enters the ditch line above this point.

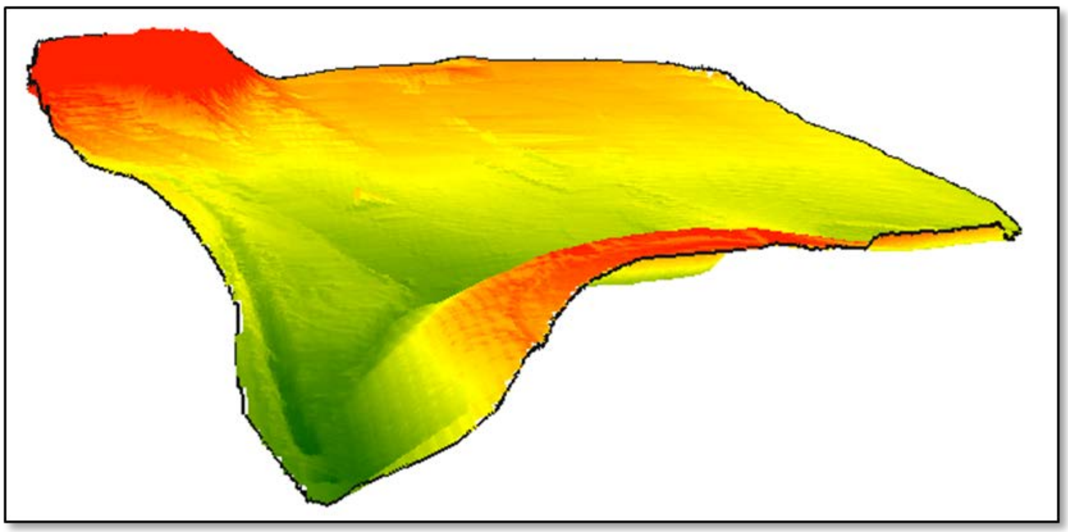


Figure 3.14. Interpolated surface from LIDAR data representing study area on November 28, 2012.

Figure 3.15. Watershed of basin in late November 2012. LIDAR unit evident at the top of the slope on right.

The total area in the watershed declined in the November survey due to landscape changes (Table 3.4). However, the majority of the watershed continued to be at relatively low slope (Fig. 3.16). The runoff continues to meander around the watershed on the low slope area and eventually finds its way into the diversion ditch near the basin inlet (Fig. 3.17). The potential erosion rates calculated using RUSLE range from around 20 ton ac^{-1} yr^{-1} on the low-slope area up to 450 ton ac^{-1} yr^{-1} on the stockpile area. Since the stockpile drains onto the low-slope area, little of that eroded sediment would be expected to reach the basin.

Table 3.4. Area in each slope class for all three surveys.

Slope class (%)	Area (ac) Sept. 25	Area (ac) Oct. 24	Area (ac) Nov. 28
0-10	1.16	1.31	1.01
10-20	0.23	0.32	0.29
20-53	0.13	0.20	0.07
Total	1.52	1.83	1.37

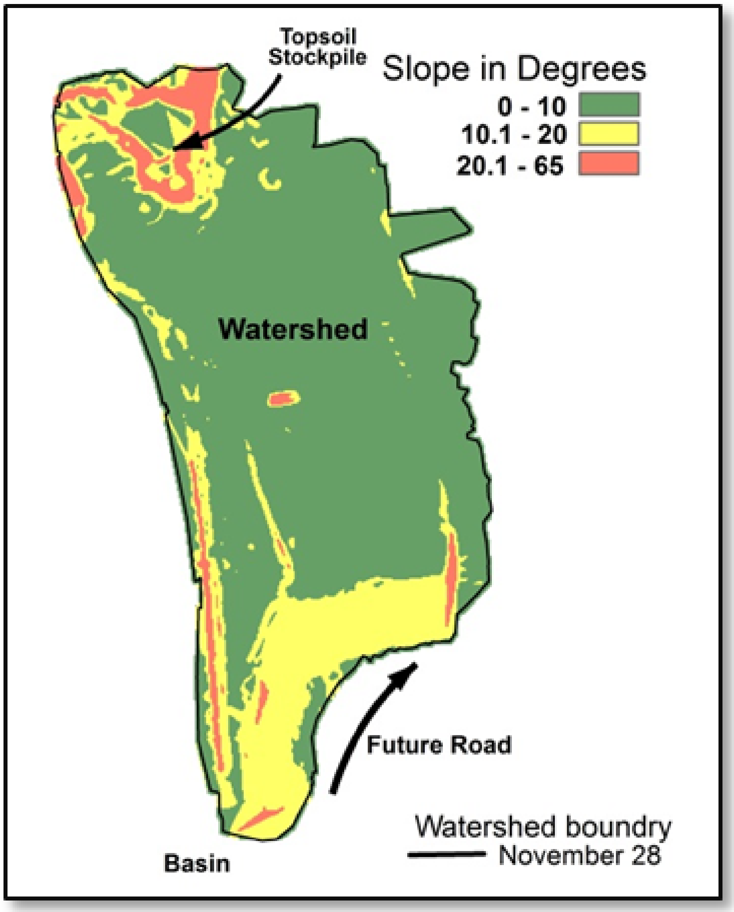
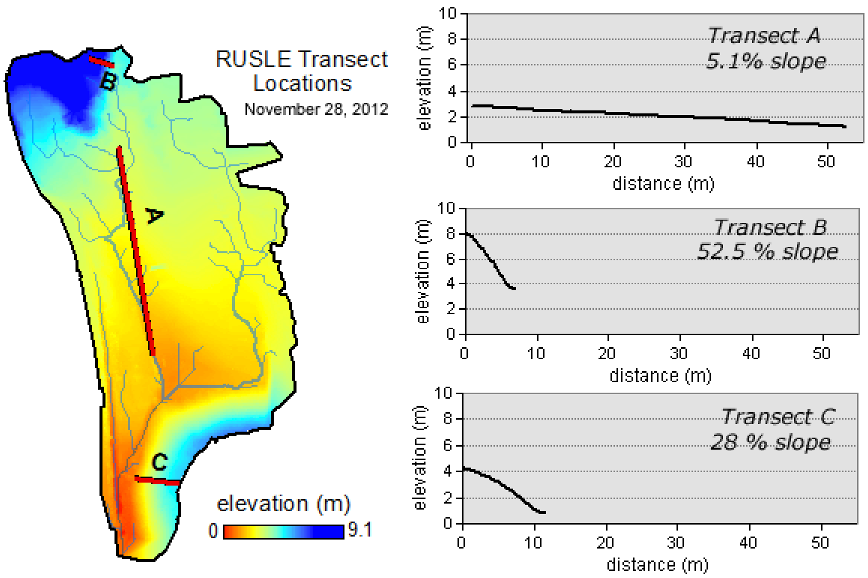


Figure 3.16. Map of the study area illustrating the location and area of three major slope classes derived from the November 28, 2012 survey.



RUSLE

transect	R	K	L	S	LS	C	P	Soil Loss (ton/ac/yr)
A	300	0.24	54	5.1	0.55	0.5	1	19.8
B	300	0.24	8	52.5	12.56	0.5	1	452.2
C	300	0.24	11	28	4.90	0.5	1	176.4

Figure 3.17. Flow paths, transects, and RUSLE applied to 3 transects that illustrate the three major slope conditions at the site on November 28, 2012.

Goldsboro Bypass LIDAR Survey: January 8, 2013

On January 8th, 2013 a fourth LIDAR survey was collected. Two scans were collected totaling over 400,000 survey points after processing. The scans were co-registered using the same target locations established during the prior 3 scans. In general, only minor surface topologic changes were observed (Fig. 3.18). The main watershed area remains a staging and parking area for construction vehicles (Fig. 3.19). There were two main visible differences from the Nov 28th scan. First, the temporary road that is used by the dump trucks to transport soil from the stockpile to the main roadbed was newly graded and re-routes a small volume of surface flow. The watershed area is reduced by approximately 600 square meters (0.15 acres). Second, a ditch was cut that runs alongside the soil stockpile. The new ditch does not extend into the existing ditch that runs parallel to the outside of the basin. The new ditch runs into the main body of the watershed. As in previous scans, the main flow path moves downslope toward the newly constructed roadbed, then runs parallel to the foot slope of the roadbed until entering the ditch line. As before, little surface water enters the ditch line above this point.

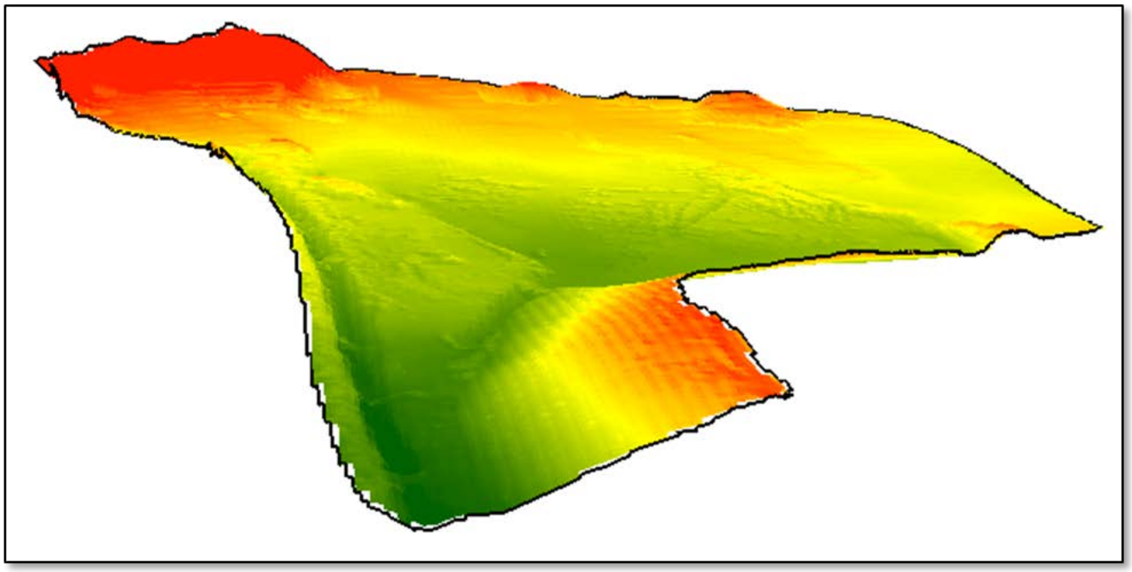


Figure 3.18. Interpolated surface from LIDAR data representing study area on January 8, 2013.

Figure 3.19. Basin watershed in early January 2013. Note the deposition in the diversion ditch.

The total area in the watershed continued to decrease due to the changing topography, with most of the change in the low-slope area (Table 3.5; Fig. 3.20). The flow path continued to be primarily across the flat area, reaching the diversion ditch near the inlet to the sediment basin (Fig. 3.21). Erosion estimates using RUSLE dropped for the flat area due to the decreased LS factor primarily, since the watershed size declined by about 25%.

Table 3.5. Area in three different slope classes for the four surveys completed through January 8, 2013.

	Area (acres)			
Slope Class (%)	Sept. 25	Oct. 24	Nov. 28	Jan. 8
0-10	1.16	1.31	1.01	0.76
10-20	0.23	0.32	0.29	0.30
20-53	0.13	0.2	0.07	0.08
Total	1.52	1.83	1.37	1.14

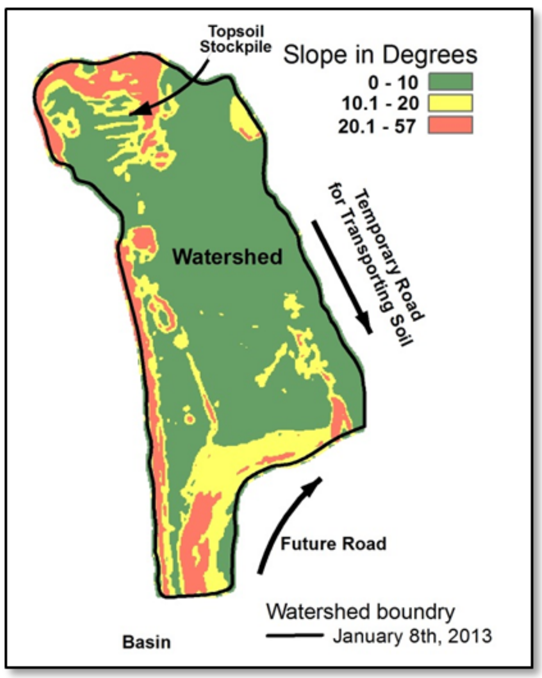
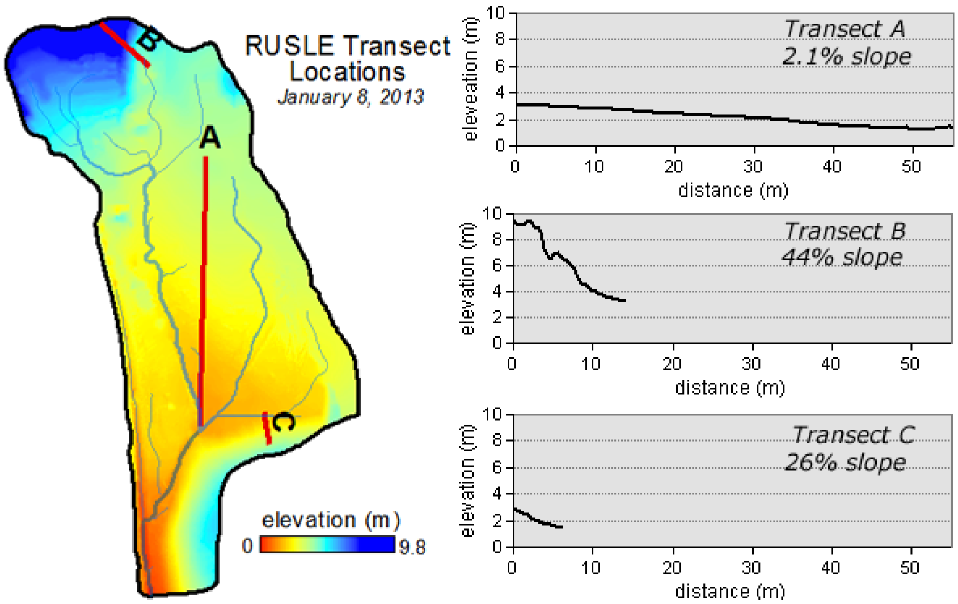


Figure 3.20. Map of the study area illustrating the location and area of three major slope classes derived from the January 8, 2013 survey.



RUSLE

transect	R	K	L	S	LS	C	P	Soil Loss (ton/ac/yr)
A	300	0.24	56	2.1	0.21	0.5	1	7.6
B	300	0.24	14	44	12.15	0.5	1	437.4
C	300	0.24	7	26	3.74	0.5	1	134.6

Figure 3.21. Flow paths, transects, and RUSLE applied to 3 transects that illustrate the three major slope conditions at the site on January 8, 2013.

Goldsboro Bypass Final LIDAR Survey: July 30th, 2013

On July 30th, 2013 the fifth and final LIDAR survey was collected. Two scans were collected totaling around 475,000 survey points after processing. Due to significant changes in the landscape the scans were co-registered using a set of temporary targets. The original targets used during the prior scans were also acquired and this insured all scans are referenced to a common coordinate system. As noted, drastic changes in the surface drainage had occurred (Fig. 3.22, 3.23). The area previously used to stage construction vehicles was filled to a level consistent with the future roadbed. An area of about 0.25 acres was filled and re-graded with approximately 3-5 meters of soil. This re-grading included a new temporary dirt road used to transport soil and equipment, clearly delineated in Fig. 3.24. A berm at the top of the slope runs parallel to the ditch designed to catch the surface flow for discharge into the sediment basin. As a result, most of the flow to the basin originates on the overpass slope, and the drainage area is less than half of that of the last survey (Table 3.6). Flow into the basin originates from an area between the ditch and the adjacent ridge. The catchment area drains into the ditch over a relative uniform slope between 35-45%. Unlike previous scans, the slope into ditch was covered in vegetation (grass) at this time which appeared to offer good slope stabilization. Given the substantial slope and greater than average rainfall during the last 2 months, there were few rills observed. As a final note, two drainage pipes were observed along the path of the dirt road. The first pipe is located at the bottom of a low-spot in the road and drains a small portion of the surface area from the roadbed into the ditch. The other drainage pipe is located further down the dirt road and although necessary to avoid ponding, only drains an area a few square meters. Overall, significant changes have occurred to the sediment basins catchment area but the most severe slopes (> 30%) appeared stabilized with vegetation. The ditch and surrounding area were also now covered with thick vegetation. While most of the drainage area for the basin had the potential of high erosion rates (Fig. 3.25), there was no evidence of it due to the good vegetative cover.

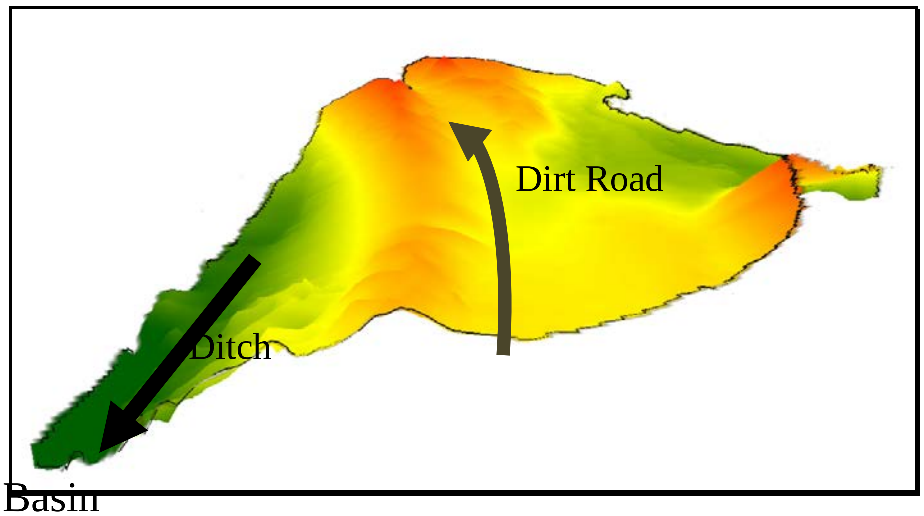


Figure 3.22. Interpolated surface from LIDAR data representing study area on July 30th, 2013.

Figure 3.23. Panoramic view of construction site. Viewer position is approximate to the survey point in Figure 3.21, on the ridge separating the watersheds.

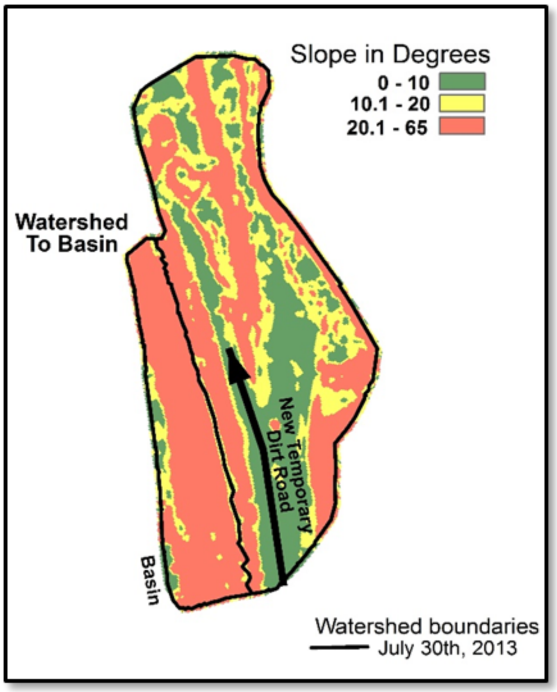
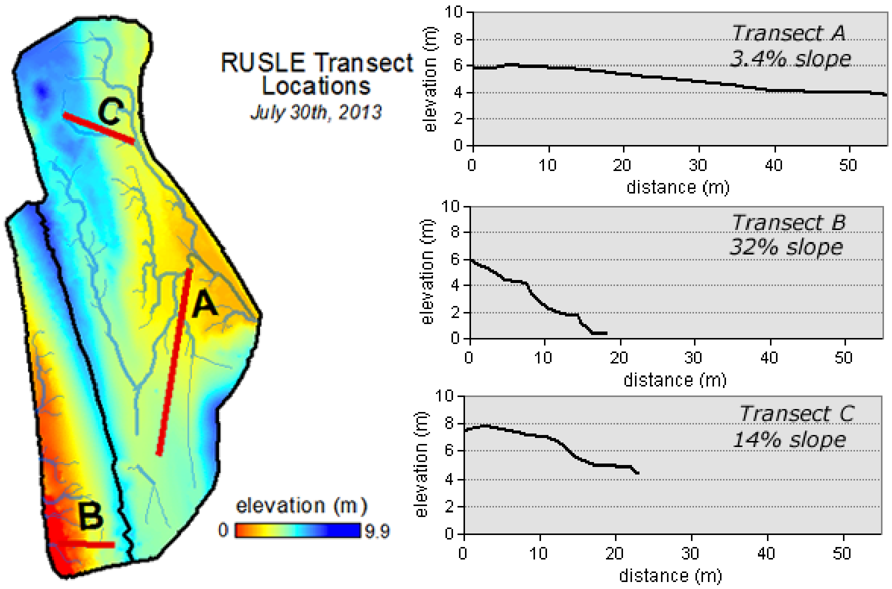


Figure 3.24. Map of the area with three different slope classes as of July 30, 2013.

Table 3.6. Area in each slope class for all five surveys.

	Area (acres)				
Slope Class (%)	Sept. 25	Oct. 24	Nov. 28	Jan. 8	July 30
0-10	1.16	1.31	1.01	0.76	0.02
10-20	0.23	0.32	0.29	0.30	0.05
20-53	0.13	0.20	0.07	0.08	0.43
Total	1.52	1.83	1.37	1.14	0.50



RUSLE

transect	R	K	L	S	LS	C	P	Soil Loss (ton/ac/yr)
A	300	0.24	56	3.4	0.34	0.5	1	12.2
B	300	0.24	14	32	7.57	0.5	1	272.5
C	300	0.24	7	14	2.04	0.5	1	73.4

Figure 3.25. Flow paths, slopes, and RUSLE applied to 3 transects that illustrate the range of slope conditions at the site from the July30th 2013 survey.

Goldsboro Site Comparison Summary

The site was surveyed five times during the course of the project, from the initial fill period and high level of watershed disturbance to the completion of the fill and stabilization of the slopes. During that period, 10 storms were monitored for runoff volume and TSS so we could calculate actual sediment delivery to the basin inlet. Other storms occurred during the period but were not monitored due to their low flow, and it is likely that the amount of sediment was relatively small. During the first period, the RUSLE estimate underestimated sediment delivery (Table 3.7). There were no samples during the 2nd period, but RUSLE overestimated erosion during the 3rd period. For the 4th period, which had the most storms and lasted the longest, the RUSLE-predicted and actual sediment delivery were very similar. Overall, the total sediment delivery predicted by RUSLE and the measured amount were both 83 tons.

These results are remarkable in that the overall prediction of sediment delivery was identical to the monitored amount, a very different result than at the Piedmont sites. There are a number of possible explanations. First, the diversion leading to the basin was relatively stable and contributed little, if any, sediment to the runoff. In fact it was likely somewhat of a sink. Second, the landscape changes were relatively constant with the fill slope building over the period. The disturbed area, primarily a parking area for construction vehicles, was relatively constant and the slope that was building was periodically stabilized with temporary cover. The RUSLE calculations used a C factor of 0.5, which would normally be somewhat low for areas which were highly disturbed as was this watershed. The Goldsboro site also has very sandy soils which may not have been as prone to erosion, both overland and rill/gully types, which were relatively common on the Piedmont sites. Finally, the ditches were actively maintained on the Piedmont sites and therefore were constantly disturbed.

Table 3.7. RUSLE-predicted and actual sediment delivery to the basin in Goldsboro.

	Number of Sampled Storms	Number of Storms > 0.5"	RUSLE Survey Estimate	Actual Sediment Delivery
LiDAR Survey Date			Tons/period	
9/25-10/24/2012	2	2	4.91	25.45
10/24-11/28/2012	0	0	21.60	No samples
11/28/2012 – 1/8/2013	1	2	11.55	1.20
1/8-7/30/2013	7*		45.13	57.03
Totals	10		83	83

*Sampling ended 5/28, but the site was nearly at the same final grade as on 7/30.

Chapter 4. Recommendations

The current method of design for sediment basins on NCDOT highway construction sites only takes into account a few of the factors that can affect true sediment yield from a catchment. Using an empirical or process based model could be a faster and more accurate method of sizing these sediment basins in order to achieve a desired performance.

Based on the observations and results of this research, RUSLE2 would not be a good method for estimating sediment yield and sizing sediment basins on NCDOT highway construction sites. The changing dynamic of the landscape, the differences in catchment management, and the lack of ability that RUSLE2 has in estimating channel erosion are all reasons that the estimate from RUSLE2 can be an over- or under- prediction of the sediment yield on site. There was no clear evidence that RUSLE2 would typically under- or over-predict the measured sediment yield because of the constant changes in the landscape and management.

Furthermore, RUSLE2 can only estimate a sediment load and therefore would only be able to estimate the sediment storage volume. The model does not consider basin design or give any indication of the efficiency a basin might have for reducing sediment discharge from a catchment. The model also does not consider deposition in the channels due to the effects that BMPs, such as rock check dams or wattles, would have on the sediment yield.

The similar sediment yield and RUSLE2 estimate on Basin 5.10 B and the Goldsboro site emphasizes the importance of protecting the ditches leading into the basins, and that RUSLE2 may be more accurate when ditch erosion is eliminated. Where RUSLE2 is used for basin design in Wisconsin, the assumption is that all ditches are lined and non-eroding.

The clearing and grubbing plans tended to produce the highest sediment yields in RUSLE2 model runs. The basins monitored tended to change from a catchment with relatively steep slopes near the basin to having shallow slopes near the basin, longer slopes, and smaller catchments which resulted in the CG plan estimates to be higher than those from the FG plans. In construction scenarios similar to these, it may be more conservative to use the CG plan topography to estimate sediment yield with RUSLE2.

This research presents a relatively small data set and sometimes applies RUSLE2 in scenarios where it is not applicable. Further research should be conducted to confirm these results and to develop a better method for applying RUSLE2 to basin design.

Chapter 5. Implementation and Technology Transfer Plan

1. This study determined that a significant amount of sediment generated during road construction comes from ditches and diversions.
2. Because RUSLE2 does not incorporate concentrated flow erosion and sediment transport, sediment loading estimates will be inaccurate unless water conveyances are fully protected from erosion.
3. Staff and contractors should be trained to properly evaluate and adjust the application of straw and tackifier to achieve successful erosion prevention and grass growth.
4. There should be an evaluation of methods to economically and effectively stabilize water conveyances during active grading on road construction sites.

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Appendix

A = the predicted average annual soil loss from interrill (sheet) and rill erosion from rainfall and associated overland flow. Units for factor values are usually selected so that "A" is expressed in tons per acre per year.

R = Rainfall-Runoff Erosivity Factor. "R" is an indication of the two most important characteristics of storm erosivity: (1) amount of rainfall and (2) peak intensity sustained over an extended period of time. Erosivity for a single storm is the product of the storm's energy E and its maximum 30 minute intensity I30 for qualifying storms. A value of R for a location is the average of EI30 values summed for each year of a 22-year record. The aim of this exercise is to illustrate the use of LIDAR in RUSLE; therefore, a constant *R-factor* of 300 was used in the model. The *R-factor* used in this exercise was visually determined from an isoerodent map of the United States

R Factor: 300

K = Soil Erodibility Factor. "K" values represent the susceptibility of soil to erosion and the amount and rate of runoff, as measured under the standard unit plot condition. The unit plot is an erosion plot 72.6 feet long on a 9 percent slope, maintained in continuous fallow, tilled up and down hill periodically to control weeds and break crusts that form on the surface of the soil.

Goldsboro Loamy Sand: 0.24 – 0.28

L = Slope Length Factor . "L" represents the effect of slope length on erosion. "L" is the ratio of soil loss from the field slope length to that from a plot slope 72.6 feet long under otherwise identical conditions. Slope length is the distance from the origin of overland flow along its flow path to the location of either concentrated flow or deposition. Computed soil loss values are not as sensitive to slope length as to slope steepness, thus differences in slope length of + or - 10% are not important on most slopes. This is especially true in flatter landscapes.

S = Slope Steepness Factor . "S" represents the effect of slope steepness on erosion. "S" is the ratio of soil erosion from the field slope gradient to that from a 9% slope under otherwise identical conditions. Computed soil erosion rates are more sensitive to slope steepness than to slope length.

LS = Slope Length and Steepness Factor. The slope length "L" and steepness "S" factors are combined into the "LS" factor in the RUSLE equation. A "LS" value represents the relationship of the actual field slope condition to the unit plot. A "LS" value of 1.0 represents the unit plot condition of 72.6 feet in length and 9% slope steepness.

Build an expression in the Raster Calculator

Pow([flowacc] * resolution / 22.1, 0.4) * Pow(Sin([slope]) / 0.09, 1.4) * 1.4
1.4 * exp(flowacc2*0.25/22.1,0.4)*exp(sin(slope) / 0.09, 1.4)

C = Cover-Management Factor. "C" represents the effect of plants, soil cover, soil biomass, and soil disturbing activities on soil erosion. RUSLE uses a subfactor method to compute soil loss ratios, which are the ratios of soil loss at any given time in a cover-management sequence to soil loss from the unit plot. Soil loss ratios vary with time as canopy, ground cover, soil biomass and consolidation change. A "C" factor value is an average soil loss ratio weighted according to the distribution of "R" during the year. The subfactors used to compute a soil loss ratio value are canopy, surface cover, surface roughness, and prior land use.

P = Support Practices Factor. "P" represents the impact of support practices on erosion rates. "P" is the ratio of soil loss from an area with supporting practices in place to that from an identical area without any supporting practices. Most support practices affect erosion by redirecting runoff or reducing its transport capacity. Support practices include contour farming, cross-slope farming, buffer strips, stripcropping, and terraces.