ABSTRACT

BROWN, RYAN FRANCIS. An Evaluation of the Current Sediment Basin Designs in North Carolina and Evaluating the Applicability of Designing Sedimentation Basins on North Carolina Department of Transportation Highway Construction Sites with RUSLE2. (Under the direction of Dr. Greg Jennings and Dr. Rich McLaughlin).

The rapid population growth and the resulting construction of buildings and roads can result in increased erosion and sediment discharge into streams, lakes, and rivers. This sediment can dramatically decrease the water quality and impair the ecosystems within and around these bodies of water. To be incompliance with the Clean Water Act, North Carolina Department of Transportation is required to develop sediment and erosion control plans for highway construction projects. Sediment basins are a typical best management practice used on these sites, and in recent years there has been an interest in evaluating the current design, tracking the dynamic changes in the landscape over the course of the project, and applying a more process based approach. One option is to use the robust computer application for estimating soil erosion, RUSLE2, in order to determine sediment yields and appropriately size sediment basins.

Based on repeated surveys of a highway construction project site, there was a progression from the natural and original contours to a catchment with a flat interior for the road bed with relatively steep slopes at the edges and showed no relationship of changing sediment yields to the average slope of the catchment.

From monitoring the sediment yields through the progression of the project, there tended to be an increase in sediment yield and total suspended solids concentration as disturbances in the catchment occurred which removed the cover. The analysis from the data also suggested there is a relationship between the stormwater volume and peak flow of a

storm event and the sediment yield entering the basin. Furthermore, the data suggest there may be an independent or interactive relationship between sediment yield entering the basin and whether the catchment area is disturbed. The performance of the basin was dictated by the intensity of the storm event, and this basin performance in terms of removing sediment and turbidity may be more accurately predicted for lower intensity storms. This analysis suggests that intensity as a sole parameter may be an important consideration in establishing criteria for a desired basin performance in terms of a reduction of turbidity. The sediment yields were well correlated to the stormwater volume reaching the basin as well as the peak flow from a storm event. Most notably was the correlation of the presence of an uncovered, disturbed area to sediment yield entering the basin which indicates that cover is crucial in preventing soil erosion.

Based on a comparison of RUSLE2 sediment yield predictions to field measured sediment yield, it is not advised to use RUSLE2 as a reliable method for estimating sediment yields with the current practices on these construction sites. The estimates given by RUSLE2 tend to be much less than actual sediment yield measured in the field due to erosion in the unprotected ditches and diversions leading to the basins. A combination of channel erosion, maintenance practices, and site management increased sediment yields to the basins beyond what RUSLE2 is capable of predicting and how the model should be used. Either the use of another model which includes channel erosion or management practices that reduce or eliminate channel erosion with relatively stable catchments is recommended.

An evaluation of how the changing topography of a construction site would affect the RUSLE2 estimations of sediment yield showed that as the project moved toward the final grade contours, the sediment yield decreased. The topography from the clearing and grubbing plans produced the highest sediment yields and should be used to estimate sediment yields in order to properly size the basins.

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An Evaluation of the Current Sediment Basin Designs in North Carolina and Evaluating the Applicability of Designing Sedimentation Basins on North Carolina Department of Transportation Highway Construction Sites with RUSLE2

by
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DEDICATION

To my wife, and the Lord God Almighty

BIOGRAPHY

It was a dark, cold, and blizzard filled night in the winter of 1988 when Ryan Francis Brown was born to James and Frances Brown in Charlotte, NC. Earlier in the night, North Carolina and Duke squared off in an intense hoopfest. Duke inevitably won the contest, but in hind sight was probably a good thing so that Ryan didn't have to live through more UNC losses than was entirely necessary.

His family moved to Irmo, SC in on April Fool's Day in 1996 where he became a member of the Bands of Irmo, with whom he performed great works of music ranging from Hot Cross Buns to Carmina Burana in some of the greatest music halls in the country including the Atlanta Symphony Hall, Carnegie Hall, and the RCA Dome in Indianapolis.

After considering a wide range of professions through his life from a rock star to an orthopedic surgeon to a financial professional, he decided engineering focused on biology and the environment thanks to the influences of his teachers and brother, Justin.

He attended Clemson University where he received a BS in biosystems engineering in 2010. During his time there he met his lovely wife, Audrey, to whom he was wed to after they had graduated.

He attempted to find a job near his soon to be wife, but due to the great recession those ideas were stunted and therefore he ended up pursuing an MS in Biological and Agricultural Engineering at NC State University. To his surprise were the fulfillment of this endeavor and the lack of any regret for ending up on this path due to the many events that influenced his life.

ACKNOWLEDGMENTS

Audrey, for support; My family, for their belief and guidance; My teachers and advisors, for their inspiration and willingness; Society, for funding and having a genuine interest; Music, for its transcending power.

I would also like to thank all of the people with the set up and data collection for this project; Jamie Luther, Virginia Brown, Gina Lee, Kim Whitley, Melanie McCaleb, Rich McLaughlin, Rob Austin, and Paul Worthington.

The North Carolina DOT for funding the project and Raleigh-Durham Road Builders, specifically Mike Tuszynski, for their cooperation and aid.

And finally, I would like to thank my advisers, Rich McLaughlin and Greg Jennings, for the opportunity.

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CHAPTER 1: LITERATURE REVIEW

1.1 Erosion on Construction Sites: The Effects and Regulations

With the rapid growth and development of cities, the amount of construction for an area will increase at least to some degree. Most of these construction projects involve a high level of disturbance and periods of disturbed and exposed soil surfaces to the land which makes the soil highly susceptible to erosion. In recent decades there has been an increase in the number of regulations concerning erosion control from construction sites and for good reason. Wolman and Schick (1967) found that with every increase of 1000 people to a city or town, the sediment yield from the construction that occurs as a result is estimated between 700 and 1800 tons. The amount of sediment discharged from a construction site can be on the order of 20 times greater than that yields from agricultural lands (Daniel et al., 1979). Due to this increased sedimentation in the receiving streams, there can be changes in biodiversity and populations which can result in long-lasting effects on the ecosystem naturally in place before construction (Barton, 1977; Taylor and Roff, 1986). Furthermore, since the stormwater systems are typically installed on a construction site early in the development, uncontrolled erosion and the subsequent sediment transport could fill and clog the stormwater systems with sediment and have to be later cleaned out by the contractor. This is a costly situation which can be more expensive to clean up compared to proper sediment and erosion control measures established at the site throughout the progression of the project.

In compliance with the Clean Water Act, the Sedimentation Pollution Control Act of 1973 was passed (North Carolina General Statutes, 2002). The act established for land disturbing activities, permits would be required and in order to obtain a permit an erosion and sediment control plan is needed and the plan is required to be followed through the progression of the project. More recently, the US-EPA has attempted to establish an average turbidity discharge required on construction sites, that is for discharges from a site from storms less than a 2-year, 24-hour frequency, the average turbidity level must be below 280 NTU (Code of Federal Regulations, 2011). However, because of known errors in calculating the required average turbidity level and lawsuits from various contractors and groups, the passing and enforcement of the regulation has been delayed (Roder, 2011; US-EPA, 2010). The proposal for the average turbidity discharge limit is being looked into further taking into consideration the desires of the different building groups as well as a larger database.

1.2 Planning For and Controlling Erosion

Sediment basins are a commonly used best management practice (BMP) option for controlling and minimizing the amount of soil coming off of road and highway construction sites in North Carolina. Research has shown that the levels of total suspended solids (TSS) coming off of a construction site are variable and highly dependent on the site itself (Daniel et al., 1979; McLaughlin et al., 2009). Due to the usually simplistic methods for designing sediment basins, many of the basins used on highway construction sites may be over- or under-sized for the particular drainage area.

The reason the amounts of sediments coming from a site can be so variable include at a minimum differences in the soil types, the location/climate, the topography, and the land cover (Toy et al., 1999). On a construction site, the topography and land cover can change from day to day based on the stage of construction they are currently working. It is not uncommon for the catchment that a sediment basin is treating to have the cover, topography, catchment size, and potentially the soil type to change throughout the progression of the project. The different locations, and more importantly the different climates at those locations, have different intensities and frequency of rain as well as freezing and thawing cycles that can have dramatic effect on the amount of sediments being eroded (Foster et al., 2003). The texture of the soils affects the erodibility of them with silty soils being the most susceptible (Foster et al., 2003). The topography affects the level of erosion because of the length and steepness of a slope, but also the sediment yields and the enrichment of the soil texture due to concave sections within the topography. These areas will cause some larger particles to settle out and deposit (Foster et al., 2003). Alternately, when compared to a constant average slope a convex slope can yield more sediment. With there being a difference in almost all of these factors between construction sites and there being multiple factors influencing soil erosion, there would never be a direct relationship between a few design parameters and the amount of sediments coming from the site.

A method to begin designing these basins using a more process based approach would be to estimate the soil loss and enriched soil fraction at the end of a slope from the proposed construction site using empirical and theoretical relationships known to occur in soil erosion. The first most widely used equation like this to estimate soil loss was the universal soil loss equation developed by Wischmeier and Smith (1978) for the USDA-Agricultural Research Service (ARS) for use by farmers for conservation planning.

1.3 The Evolution of USLE

From the USLE, further research stemmed to be able to apply the equation to non-agricultural lands. With the advent of computers and the complicated and tedious calculations that are required by the equation as more factors were taken into account, it was integrated into a texted based computer program aptly named the revised universal soil loss equation (RUSLE) (Renard et al., 1997). As further progression in computing technology, further research in areas crucial to computing soil loss, and as weaknesses emerged from the first revision of the universal soil loss equation (USLE), the equation was developed into RUSLE2 (Foster et al., 2003). The framework of RUSLE2 is still rooted in the empirical relationships originally developed by USLE. The equation structure used in RUSLE2 is similar to that of USLE and RUSLE using a similar framework equation (1.1).

$$a_i = r_i k_i l_i s c_i p_i, \qquad [1.1]$$

where 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). Each of these factors are calculated internally by RUSLE2 using user inputs for location, management, soil type, and best management practices. Also from USLE to RUSLE2, there was refinement of the model to include process based models for deposition and transport capacity of sediment, developing division factors for erosion on a day-to-day basis rather than yearly averages, research and inclusion of factors needed for applying the model to construction sites, and expansion of the several of the factors involved in the calculation of soil loss, such as canopy cover (Foster et al., 2003;

Toy et al., 1998). Along with these improvements, there were also changes to the interface including a graphical windows based interface of the slope, the ability to input complex slopes, and the ability for it be used in every scenario where erosion would occur due to exposed soil and where runoff occurs due to the rainfall intensity being greater than the infiltration rate of the soil (Foster et al., 2003).

More recent developments include a friendlier construction planning look with accurate terms for construction managements and an accounting period function where the user can input a specific time period for soil loss. This, for instance, to be used with a municipality's rules regarding erosion control period to estimate soil loss in terms of tons per acre rather than on an annualized basis (Yoder et al., 2007). A method of including the runoff from a series of representative rainfall events was also added to RUSLE2 (Dabney et al., 2010). RUSLE2 does not generate runoff values since plot scale data suggested a higher correlation between intensity and erosion than runoff volume and erosion. Due to this, the Annualized Agricultural Non-Point Source Pollution Model (AnnAGNPS) (Binger and Theurer, 2001) was used to generate sets of rainfall and runoff information using the 30-year monthly mean climate data within RUSLE2. The rainfall and runoff data generated was included to provide a link, in the future, to estimating soil losses through gully erosion through the use of process based models such as the Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) model (Foster et al., 1980 a,b).

RUSLE2 has been seen as a premier tool for soil erosion estimation. This is because of the availability of the program itself, as it is free for use by the public, and the incorporation and availability of many of the inputs such as the climate, soils, cover and managements common on construction sites, and conservation practice data for use in the program that can make it applicable to almost any situation, anywhere. Furthermore, since the foundation of the program is in the empirical development of USLE and the 10,000 plot years of research data, it is very robust as far as erosion estimation equations are concerned (Yoder et al., 2007). RUSLE2 can also be easily changed which provides a quick look at different erosion control scenarios for a fast determination of the most effective and appropriate plan.

Even with its validation and large data set used to create the program, the results can be highly varied from the actual sediment yields on a modeled site. The authors of RUSLE2 note that the sediment yield estimates from the program can be larger or smaller than the actual field yields by fifty percent (USDA NRCS, 2003). The authors further emphasize the fact that RUSLE2 may have inherent errors, should be used to assist in erosion control planning, and professional judgment should also be used in the interpretation of the results (USDA-ARS, 2008).

1.4 Uses and Evaluations of RUSLE2 for Construction Site Erosion Control Planning

There has been limited research performed as to applicability of RUSLE2 to predicting erosion rates on construction sites. The program was used in Wisconsin in conjunction with previous projects to find how RUSLE2 compares with other methods as well as its predecessors, as a means of developing an erosion control plan with the use of BMPs (Yoder et al., 2007). The study provided insight to changes to the interface and terminology in the program that made it easier to use and more accurate to the erosion rates on construction sites, but did so by using previous studies along with an extensive literature review of erosion from constructions sites. There was no field verification of the values obtained through RUSLE2.

The program was also used on a Pennsylvania interstate highway construction site and compared to volumes of sediment deposited in basins and to grab sample concentrations of TSS collected at the inlet and outlets of those basins (Kalainesan et al., 2007). The study found that RUSLE2 produced values 25% to 30% greater than what was found through field samples. Although, it was noted that the concentrations coming out of the basins were greater than the concentrations going in to the basins due likely to the fact that the basins were not maintained well or filled faster than the rate at which they were designed to fill. The only information the authors concluded was that there is a great need for a process based model to be implemented to calculate sediment basin size so they do not fill faster than they are supposed to and that BMPs on construction sites need to be maintained properly. The implications and conclusions of this study are limited due to the suspect methods in calculating sediment yields and the use of BMPs in RUSLE2.

Similar to the case earlier in Wisconsin, RUSLE2 was used to model erosion from natural gas well sites (Wachal et al., 2008). The author modeled a number of different BMP scenarios in the program to evaluate the cost-benefit of certain BMPs as well as combinations of BMPs. But like the scenario in Wisconsin, no field verification of the program was attempted. The author found the program assumes the best case scenario for with BMPs, i.e. they are properly maintained and constructed, which isn’t always the case on construction sites. The author also stated that RUSLE2 was flexible in its uses and reiterated its ability to be used on a multitude of situations as a means of developing erosion and sediment control plans.

Caltrans (California's Department of Transportation) has begun to incorporate RUSLE2 into its erosion control plan as a means of estimating the amount of sediment to expect from a site and to be able to test the best method of how to limit rates of erosion (Caltrans, 2008). Caltrans used the RUSLE2 originally developed by the USDA-ARS and made modifications to some of the inputs and interface options to change and remove pieces in order to move the program away from something geared toward agricultural soil conservation to a program more applicable to soil conservation on a construction site. The modifications included additions of cover, climate, and soils, as well as modifications to the vernacular of the management/operation options so engineers using the program will accurately describe the processes occurring on the site. This ensures less misuse of the program and therefore more accurate estimations of soil loss. While this is a significant step to incorporate the program into erosion control plans, it was more so a modification to ensure the program was used correctly, and therefore there is still a need to see if the program is flexible and accurate to be able to model the levels of erosion coming from a construction site.

The North Carolina's Department of Transportation (NCDOT) currently uses RUSLE2 in estimating soil loss on some projects including road widening projects, secondary road construction, and from waste areas. The estimated soil loss calculated in the program is used to come up with a storage volume necessary in a sedimentation basin. From the soil delivery rate calculated in RUSLE2, the value given in ton/acre/year is divided by the bulk density of the soil found by the soil survey and multiplied against the constant 32.02 to convert the units from g/cm^3 to $tons/ft^3$. The area disturbed is then multiplied against this value and used as the storage volume necessary for the erosion control device being used (RUSLE2 Guide, 2009). This approach assumes no influence of sediment erosion from channelized flow, and assumes all sediment entering into these basins settles out in them.

1.5 Gully Erosion

RUSLE2 does not model gully erosion. This poses a significant problem when using RUSLE2 for estimating sediment yields from construction sites since it is common practice to channelize flows in silt ditches to direct stormwater into basins, and that ephemeral gully erosion can have a dramatic impact on the total sediment yields on a catchment (Dabney et al, 2010). Posen et al. (2003) has highlighted the great need for research in this area. Understanding, estimating, and predicting how gully erosion will occur, how much it will contribute to the overall sediment loss from the catchment, and threshold levels as to where channelized flow will begin is a very complex issue. All of these pieces that define gully erosion depend on a variety of different factors including time, environment, soil pedology, hydrology, soil texture, climate, land management, etc.

The current models available for estimating gully erosion are limited, with the major ones being Chemical, Runoff, and Erosion from Agricultural Management Systems (CREAMS) (Knisel, 1980), Ephemeral Gully Erosion Model (EGEM) (Merkel et al., 1988), and Water Erosion Prediction Project (WEPP) (Flanagen and Nearing, 1995). These are processed based models and work on the principle that a concentrated flow will create a shearing stress on the channel sides thus causing sediments to erode. Also associated with the flow are transport capacities to carry the sediment some length downstream. The authors of these methods claim the models have valid predictions for soil erosion in gullies, but these models have not be through field testing in a wide range of conditions (Posen et al., 2003). Furthermore, these models cannot predict the start of a gully in the landscape; something left to the user to assess on a field visit for the catchment being modeled.

The effects of gully erosion in a catchment can be dramatic and should not be ignored when estimating soil erosion and sediment yields. The current research in the areas of large scale spatially and temporally is limited and needs to be expanded to aid in erosion prediction.

1.6 Research Need

Even though the program itself is relatively robust in nature and the basis is the empirical relationships developed by 10,000 plot-years of data (Wischmeier and Smith, 1978), these models and equations are commonly misused by engineers, policy makers, and watershed modelers (Boomer et al., 2008). The model has been cited as being continually used to estimate soil loss in situations which were not originally researched in the development of USLE. Such extrapolation of the data may lead to poor sediment yield estimates. Cover factors, topography changes, gully erosion, and other nuances on construction sites have been cited to be very important and can have a significant change in the sediment yield predicted from a drainage area (Boomer et al., 2008).

The current regulations in North Carolina for designing sediment basins on highway construction sites is for there to be 1800 cubic feet of storage space for every acre disturbed and 325 square feet of surface area for every cubic foot per second of the peak flow off of the catchment for a ten year storm.

Using the logic presented here for designing a basin, there should be a linear relationship between the sediment yield from a catchment and the area of the catchment, and a linear relationship between the sediment yield per unit area of the basin and the peak flow from a rain event. In the development of USLE, Wischmeier and Smith (1978) found that when all other factors were held constant, the erosion index (EI) had the most effect on sediment yields. The EI is essentially a measure of a storm's intensity based on previous rainfall records. This suggests that sediment control structures should be designed based on the intensities of rain storms and not necessarily the volume of runoff from them. Since RUSLE2 uses this parameter when calculating the sediment yield estimate, the model will provide accurate and precise estimations of rill and interrill erosion.

The current regulations for designing sediment basins on highway construction sites are a simplification of what drives soil erosion taking into account only a few of the factors that impact sediment yields. By applying RUSLE2 and properly using the results, the program could be used to effectively and efficiently estimate soil yields and aid in the design of sediment basins.

CHAPTER 2: SURVEYS AND CHANGES IN TOPOGRAPHY

2.1 Introduction

In a typical highway construction project, the topography of the catchment is changed dramatically during the course of construction. However, typically only the initial, undisturbed and final design topographies are included in construction plans, so it is of interest to document the changes that occur between the beginning and end slopes and how that might affect the erosion in the catchment. This can be qualitatively analyzed by evaluating and comparing digital elevation models (DEMs) from surveys taken during the progression of grading in the catchment. The changes in topography can be quantitatively evaluated by comparing the average slope in the catchment of each survey and evaluating how much that influences the erosion and sediment yields during that portion of the project.

The objective of this portion of the research was to provide detailed documentation of the changes to the topography on a typical highway construction site from the initial rough grade through the final grade. This was accomplished by using ground based light detection and ranging (LiDAR) to collect surveys on each of the basins with the exception of the first two surveys of Basin 11.4 B. These surveys were taken with a TopCon total station on 9/14/10 and 11/30/10. The points were exported and processed in a similar way as the data points from LiDAR.

The level of speed and accuracy of LiDAR is unparalleled to that of a total station and the grid size able to be obtained using LiDAR would be unfathomable using a total station. The advantages to using a ground base LiDAR system include being able to obtain a smaller spacing of survey points, the speed of collecting a survey, and the consistency that offers by being able to gather a LiDAR scan at the same point spacing every time. Any small inconsistency such as removing extraneous points, taking a scan from a different position in the catchment, or reducing the point cloud grid spacing for processing in GIS is limited by the high level of precision and accuracy as indicated by the small point spacing that is obtained and be more accurate in tracking changes in the topography (Lokteff et al., 2011). The disadvantages of the system include the comparative cost, the extraneous points such as vegetation and machinery which have to be removed and block the view of any points directly behind, and shadowing effects that may result from the side orientation of the machine and contours in the catchment (Perroy et al., 2010).

The system has the position and distance accuracy of plus or minus six and four millimeters respectively for distances between 1 and 50 meters. The horizontal and vertical angle accuracy is plus or minus 60 microradians (Leica, 2007).

An attempt was also made to use the LiDAR to estimate the levels of erosion and deposition in the silt ditches. The intention was to take surveys periodically throughout the project of the silt ditches, and from those surveys a ‘flat’ surface could be created using only points outside of the ditch and compare it to a surface using all of the points. By comparing the two surfaces, the volume of the ditch could be found for a particular date and by comparing these volumes over time, the level of erosion or deposition could be found based on whether the volume of the ditch was getting larger or smaller. This proved to be difficult from a logistics standpoint since ditches were commonly cleaned out by crews and the ditches were re-graded or rerouted through the phases and progression of the project.

There are also technical issues surrounding this approach as well. The position of the LiDAR itself can create shadowing effects and therefore may alter the perception of the ditch when analyzing it for its volume. Perroy et al. (2010) found that the side looking orientation and limited footprint area provide limitations to estimating gully erosion. The authors also found this method for estimating erosion and deposition to be difficult as well, stating that the method was reasonable but could benefit from refinement and further research into this technique.

The purpose of the results documented in this portion of the thesis was to assess how the topography in the catchment changes as grading occurs through evaluation qualitatively of the surveys of the catchments and by analyzing how the average slope of the catchment changes, and make an evaluation on how the changes in average slope change the sediment yields to the basins.

2.2 Methods and Materials

2.2.1 Survey Techniques of Catchments

A ScanStation2 (Leica, 2009) was used to take ground based LiDAR surveys of the catchments for the basins. The ScanStation2 was generally set up near the same location on each basin site and set up to take surveys at point spacing between 0.05 m and 0.20 m. On Basins 11.4 B and 9.2 C multiple surveys were taken and combined because of the size of the catchments.

In conjunction with the ScanStation2 for collecting surveys, Cyclone 7.0 software for control of the scanner was used as well as for some processing (Leica, 2009). After scans were taken, the points were brought into the Model Space of the software and, as necessary, were combined with other scans and extraneous points (trees, machinery, vehicles, etc.) were removed. The remaining points were exported as a comma space delimited file to import to GIS for further processing.

2.2.2 Survey Post-Processing for Application to RUSLE2

All of the surveys for the catchments were processed in a similar way in ArcGIS 10 (ERSI, 2010). The X, Y, Z data were added to the workspace from a comma space delimited file and a boundary was created around the points and set as the mask. Within the spatial analyst tools, the inverted weighted distance (IDW) was used to develop a DEM. The DEM was then processed using the ‘fill’ function to smooth the contours. The ‘slope’ function was used on the fill layer to find the slope at points within the catchment. The flow direction was calculated using the filled DEM and then the flow accumulation was found using the flow direction layer. The flow length was then calculated using the flow direction. By creating a boundary around the catchment and setting it as a mask, the slope function was used again to create a slope layer where the average slope from which was used to compare the slopes from survey to survey.

2.2.3 Data Analysis

The information gathered was compared visually from survey to survey between basins and also quantitatively by using ArcGIS to calculate an average slope for the catchment and compare those by establishing patterns in them. The average slopes were also used as an independent variable in SAS® software by using the stepwise function (SAS, 2009). The stepwise function was set up with sediment yield (kg/ha) as a dependent variable and average slope as one of the independent variables; the other variables being those highlighted in section 3.3.4. The stepwise function adds and removes variables from a regression model that could be used to predict dependent variables based on the independent variables based on a significance level of 0.15. In this case, if average slope were to be picked in the stepwise function, this would give evidence that the average slope of a catchment would have an impact on the sediment yields reaching the basin.

2.3 Results and Discussion

The surveys taken on each basin are shown in the processed form in figures A2-1 through A2-16 in the appendix. By a visual comparison of the surveys, it was typical that the areas went from smooth, natural hills to areas of minor and shallow slopes in the middle where a road bed would be built with steeper slopes on the side areas. During the course of the projects there were generally limited points when oddities such as temporary fill soil piles or cut areas with steep slopes were left in the catchment.

The differences in the point density between a survey taken with the total station and LiDAR are apparent from comparison of the figures below.

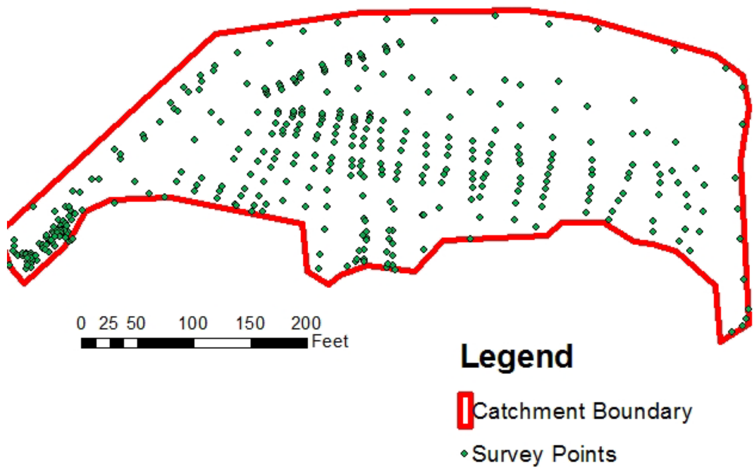

Figure 2-1. Points within catchment area taken with total station on Basin 11.4 B on 11/30/10.

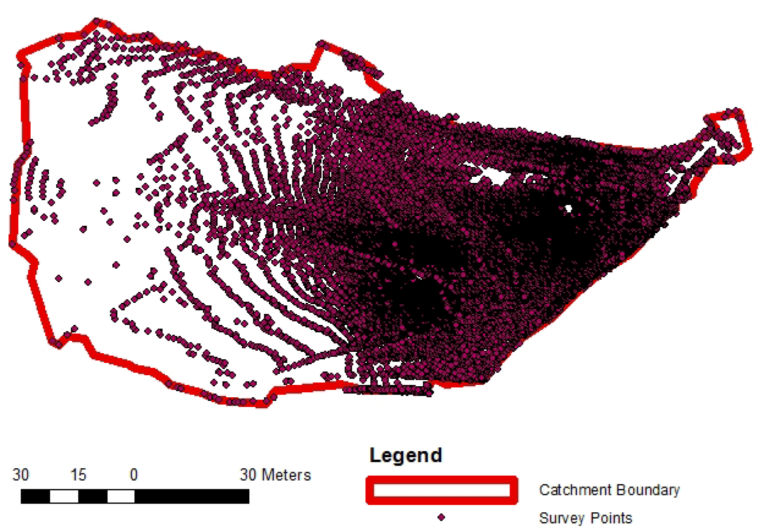

Figure 2-2. Points within catchment area taken with ground based LiDAR on Basin 11.4 B on 12/14/10.

The average density changed from 1.1 points per square meter when the total station was used on basin 11.4 B on 30 November 2010 to 20 points per square meter on Basin 11.4 B on 14 December 2010 when the LiDAR was used.

The average slopes from the processed surveys are displayed for each of the surveys taken on each basin in the tables below.

Table 2-1. Average slope in catchment of Basin 11.4 B for respective survey. Surveys taken with total station or LiDAR as noted.

Date of Survey	Average Slope (%)
09/14/2010 (Total Station)	13
11/30/2010 (Total Station)	11.9
12/14/2010 (LiDAR)	11.6
2/3/2011 (LiDAR)	11.4
3/15/2011 (LiDAR)	13.3
4/25/2011 (LiDAR)	18.6

Table 2-2. Average slope in catchment of Basin 9.2 C for respective survey. All surveys taken with LiDAR.

Date of Survey	Average Slope (%)
4/25/2011	9
6/08/2011	8.8
8/10/2011	7
9/16/2011	8.1

Table 2-3. Average slope in catchment of Basin 10.3 B for respective survey. All surveys taken with LiDAR.

Date of Survey	Average Slope (%)
6/8/2011	4.5
8/10/2011	13.1
11/14/2011	13.5

Table 2-4. Average slope in catchment of Basin 5.10 B for respective survey. All surveys taken with LiDAR.

Date of Survey	Average Slope (%)
8/10/2011	16.4
11/14/2011	19.5
12/13/2011	13.6

From the average slopes from the surveys taken on each of the basins, there does not appear to be a pattern and for some cases the average slope is generally constant. The DEM for each survey with correlating pictures and catchment descriptions are in figures A2-1 through A2-37 in the appendix.

Based on the development of a regression equation using the stepwise function in SAS software, when all of the storms were analyzed together, average slope was not selected as significant (Table C2-1). When the storms were split among their respective basins, the sample sizes was too small for an appropriate analysis and average slope was not selected as significant for any of the basins when entered to the regression (Tables C2-2 through C2-5).

The average slope in the catchment did not necessarily determine the sediment yields to the basins, but rather how the topography was developed and how the slopes connected to each other. Even though there were steep slopes in the final grade of the project, they are typically at the edges and transition to relatively flat areas before reaching the basin. It is likely that there may be large amounts of erosion in steep sloping areas, but most of this sediment is deposited on flat grades before it reaches basins.

2.4 Conclusions

The use of LiDAR increased the density of the points dramatically from 1.1 to 20 points per square meter. By increasing the point density, the accuracy of the slope and distance between two locations of relatively close proximity is increased. This increased accuracy is accomplished in a shorter period of time and with less man-power than by using a total station.

The system can be set to take survey points of particular grid spacing, and therefore delivers a consistent scan of the catchment each time.

Based on a visual comparison of surveys, the catchments of the basins generally progressed to having flat interiors where road beds would lay with steep slopes on the edges of the catchment, and there were no apparent patterns in the average slope of the catchment over time. Also, the average slope of the catchments collected in the surveys did not have a relationship to the sediment yields for corresponding storms.

CHAPTER 3: Analysis of Sediment Yields and Basin Performance with Relation to Current Skimmer Basin Sizing Methods

3.1 Introduction

The increase in population of an area tends to lead to rapid construction and development of housing and infrastructure which due to exposed soil surfaces can accelerate the rate of erosion from an area (Wolman and Schick, 1967). Allowing this sediment load to enter to streams and lakes can fill in these bodies of water and can affect the water quality impacting the biodiversity and benthic habitat of the water way (Barton, 1977; Taylor and Roff, 1986). Due to this, the Clean Water Act (33 U.S.C. 1251 et seq.) was passed by the United States Congress and subsequently the Sedimentation Pollution Control Act of 1973 was passed in North Carolina to establish a permitting system requiring sediment and erosion control plans for land disturbing activities (North Carolina General Statues, 2002).

Sediment basins are a common BMP used on construction sites. The sedimentation basins constructed on NCDOT sites are based on a few parameters having to do with the hydrology and sedimentology of the catchment the basin is treating. There are a wide variety of variables that have influence on the amount of sediment eroding and reaching a basin (Daniel et al. 1979; McLaughlin et al., 2009; Toy et al., 1999). This fact, along with the high level of change in the catchment and nuances typical of a highway construction project, a simple method for designing these sedimentation basins would not be a valid approach for ensuring good performance and control of sediment discharging from the site.

The current design methods for sizing sediment basins on NCDOT sites are based on the disturbed area of the catchment and the 10-year peak flow (25-year peak flow for sites in sensitive watersheds) for the basin volume and surface area. Sediment basins with surface outlet devices on highway construction sites require 126 cubic meters of storage space for every hectare disturbed and 1070 square meters of surface area for every cubic meter per second of the 10-year peak flow (or 25-year when applicable) (NCDOT, 2010). Since the storage volume is calculated based on the amount of disturbed area in the catchment, there should be a strong linear relationship between the sediment yields into the basin and the disturbed area in the catchment. Also, since the surface area is designed to ensure sufficient deposition in the basin and by relation efficiency of the basin, there should be a strong linear relationship between the peak flow and basin efficiency.

The objectives of this research were to:

- Measure sediment runoff concentrations and yields moving in and out of basins during different phases of construction on a NCDOT highway development project.
- Evaluate current sediment basin design for basin performance and sediment loading using storm event and management data from four disturbed catchments during all phases of highway construction.
- Identify appropriate design variables as better predictors of basin performance and sediment yield during NCDOT highway development.

3.2 Methods and Materials

3.2.1 Sediment Basin Monitoring

Four sediment basins on a North Carolina Department of Transportation (NCDOT) highway construction sites were monitored for sediment inflow and outflow. These basins were located in the Piedmont region on the I-540 extension construction project in Wake County, North Carolina.

The inlet and outlet of each basin were monitored with ISCO 6700 automated samplers (or ISCO 6712) with a 730 bubbler modules (ISCO, Inc., Lincoln, NE, USA) to measure the stormwater flow and collected samples on a volume weighted basis.

The standard inlet of a basin on NCDOT sites use a 30.5 cm corrugated plastic slope pipe drain (NCDOT, 2010). The bubbler tube and the sampling tube were glued into the inlet pipes. The length and average slope of the pipe was determined individually and the samplers were programmed to internally calculate the flow rate using Manning's equation and from that 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 is the level of stormwater in the inlet pipe before sampling was initiated. Samples were taken after a known volume had passed (Tables 3-1 and 3-2), which was selected based on expected flows in each catchment and experience during the monitoring period.

Table 3-1. Volume of stormwater required to pass to initiate the collection of one 200 mL sample by the sampler at the inlet of each basin.

Basin ID	Passing Volume (L)
11.4 B	1890
9.2 C Front	2840
9.2 C Side	1890
10.3 B	1890
5.10 B	1890

Table 3-2. Volume of stormwater required to pass to initiate the collection of one 200 mL sample by the sampler at the outlet of each basin.

Basin ID	Passing Volume (L)
11.4 B	1890
9.2 C	2840
10.3 B	945
5.10 B	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 TSS concentration over time.

A 120^0 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 730 bubbler module and the weir program in the sampler. Similarly to the inlet, samples were collected on a flow-weighted basis in four 200 mL aliquots per bottle.

An ISCO 674 Rain Gage (ISCO, 2008) was attached to one of the samplers to monitor rainfall depths 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 (Figure B3-1). Once monitoring concluded there, the rain gage was moved to Basin 10.3 B (Figure B3-2) and finally to Basin 5.10 B (Figure B3-3) after monitoring on Basin 10.3 B was completed.

After rain events, samples were collected and analyzed for total suspended solids (TSS) and turbidity. Every sample was analyzed for turbidity while the TSS was measured for every fourth sample due to time and expense.

Turbidity was measured using a TC-3000e portable turbidity meter (version 1.5, LaMotte, Chestertown, MD). The measured values were corrected with a standard curve based on a series of formulized 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 ProWeigh filters from Environmental Express (Mt. Pleasant, SC) and dried overnight at 103°C to 105°C.

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 being the dependent variable. A regression equation was calculated based on the graphed data and used to estimate the TSS based on the turbidity for the other samples (Gippel, 1989). These graphs are displayed in figures C3-1 through C3-4 in the appendix.

Using the flow and time data, the representative volume that went into the basin during the course of when a sample was collected was calculated. By using the volume and the TSS of each sample, the mass of sediment entering the basin was calculated.

For each storm collected during the basin monitoring period, the average turbidity, average TSS, stormwater volume, peak flow, total rainfall, total sediment yield, intensity, time since prior rain event, and length of storm were calculated and compiled into tables to analyze how and which parameters influenced the turbidity, sediment yield, and TSS entering the basin for a specific storm (Tables C3-1 through C3-8). Other factors such as whether polyacrylamide (PAM) for flocculation was used, whether grading was occurring, and whether discharge occurred over the emergency spillway of the basin occurred were also recorded.

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 collected, basin performance based on TSS, NTU, and total sediment were also calculated using equation 3.1.

$$Basin\ Performance\ (\%) = \frac{Value\ In - Value\ Out}{Value\ In} * 100\% \qquad [3.1]$$

The storms which included inlet samples and inlet and outlet samples were compiled with the properties as described and put into tables C3-1 through C3-4 and C3-5 through C3-8 respectively. During some storms, low flows and malfunctions were recorded by the sampler and as a result, the data from these events were not used in the analysis.

The basins were monitored for as long as possible to estimate long term erosion rates for the catchments of the basins and to see how sediment delivery to the basins changes as the topography and groundcover in the catchment change through the project's progression.

3.2.2 Site and Basin Descriptions

3.2.2.1-Basin ID 11.4 B

Basin ID 11.4 B from the erosion control plans (State Project Reference Number: R-2635B) was located on the I-540 extension off of Apex Barbeque Rd. near Apex, NC (Figure

3-1) and was monitored from 9/14/2010 to 5/5/2011. The description of this basin and the design numbers are listed in table 3-3 and 3-4.

Table 3-3. Design dimensions and calculations for Basin ID 11.4 B for clearing and grubbing phase.

Design Property	Value
Length (m)	29.0
Width (m)	12.2
Depth (m)	0.915
25-Year Peak Flow (m^3/s)	0.315
Disturbed Area/Drainage Area (ha)	1.05
Intensity for Rational Method (mm/hr)	198
C-factor for Rational Method	0.55
Skimmer Orifice Diameter (mm)	41.3
Emergency Spillway Weir Length (m)	9.76

Table 3-4. Design dimensions and calculations for Basin ID 11.4 B for final grade phase.

Design Property	Value
Length (m)	29.0
Width (m)	12.2
Depth (m)	0.915
25-Year Peak Flow (m^3/s)	0.206
Disturbed Area/Drainage Area (ha)	0.688
Intensity for Rational Method (mm/hr)	198
C-factor for Rational Method	0.55
Skimmer Orifice Diameter (mm)	41.3
Emergency Spillway Weir Length (m)	9.76

Figure 3-1. Basin ID 11.4 B

This basin was monitored from soon after its installation through the end of the clearing and grubbing phase and into the beginning of the mass grading phase for this portion of the project. Monitoring of this basin was terminated because of a majority of the sediment yield was originating from the silt ditch leading into the basin.

Another basin upslope from 11.4 B, Basin ID 11.3 C, appeared to drain into the watershed of Basin 11.4 B and was monitored at the outlet only. It was assumed the mass flow of sediment exiting from 11.3 C would enter into 11.4 B; therefore the sediment load was subtracted from that going into 11.4 B. Since RUSLE2 is only calculating the sediment load from the catchment leading into 11.4 B, it would not be a valid comparison without subtracting out this extra sediment load.

The monitoring of 11.3 C ended on 02/03/11 when the basin was removed in accordance to the plans.

On the dates 9/14/10 and 11/30/10, surveys were collected with a Topcon Total Station (GTS 211D, Topcon Electronic Total Station, Livermore, CA) because of malfunctions with the LiDAR scanner. The surveys for this basin were conducted and the data processed in ArcGIS as described in chapter 2. All surveys collected and processed on this basin are displayed in figures A2-2 through A2-7.

3.2.2.2-Basin ID 9.2 C

The inlet and outlet of basin ID 9.2 C (State Project Reference Number: R-2635A) east of Apex-Holly Springs Rd. (Figure 3-2), was monitored from 3/22/2011 to 9/16/2011. The description and design calculations for the basin are listed in table 3-5.

Table 3-5. Design dimensions and calculations for Basin ID 9.2 C for clearing and grubbing plans.

Design Property	Value
Length (m)	39.6
Width (m)	19.8
Depth (m)	0.915
25-Year Peak Flow (m^3/s)	0.766
Disturbed Area/Drainage Area (ha)	2.35
Intensity for Rational Method (mm/hr)	198
C-factor for Rational Method	0.6
Skimmer Orifice Diameter (mm)	63.5
Emergency Spillway Weir Length (m)	17.4

Figure 3-2. Basin ID 9.2 C, view of front. Side inlet is to the left in the photograph.

Since there were two inlets on this basin, both inlets were monitored using automated samplers and the data combined to characterize flow into the basin. For description purposes, the ‘front’ inlet was oriented parallel to the longest dimension of the basin, and the ‘side’ inlet was orient perpendicular to the longest dimension of the basin. This basin was monitored from the clearing and grubbing phase and through a portion of the mass grading phase.

Heavy erosion and sidewall failings in the silt ditches seen on Basin 11.4 B suggested that a majority of the sediment yield was from the ditches rather than the catchment. On basin 9.2 C, we attempted to reduce the influence erosion and failures in the silt ditch had on sediment yield. On 6/14/2011, 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 to limit erosion. The soil deposited in front of the wattles and check dams was estimated by measuring the length, width, and depth of the deposits, and obtaining the bulk density to convert to the volume estimated to mass.

All of the surveys were conducted using LiDAR and processed in GIS as described in chapter 2, and are displayed in figures A2-8 through A2-11.

3.2.2.3-Basin ID 10.3 B

The inlet and outlet of Basin ID 10.3 B (State Project Reference Number R-2635B; figure 3-3) was monitored from 5/5/2011 to 11/14/2011. This basin was located west of US highway 1. It was monitored during the final grading and post paving phases of construction. The description and design calculations for the basin are listed in table 3-6. The basin was tiered, therefore the dimensions of both top and bottom basin are given.

Table 3-6. Design specifications for Basin ID 10.3 B for final grade plans.

Design Property	Value
Width-Top (m)	9.15
Length-Top (m)	13.7
Depth-Top (m)	0.915
Width-Bottom (m)	9.15
Length-Bottom (m)	13.7
Depth-Bottom (m)	0.915
25-Year Peak Flow (m^3/s)	0.229
Disturbed Area/Drainage Area (ha)	0.769
Intensity for Rational Method (mm/hr)	198
C-factor for Rational Method	0.55
Skimmer Orifice Diameter (mm)	31.8
Emergency Spillway Weir Length (m)	6.71

Figure 3-3. Basin ID 10.3 B

This section of the project was at final grade and it wasn't anticipated that much grading would occur and therefore most of the sediment movement would be a result of erosion.

All of the surveys were conducted using LiDAR and processed in GIS as described in chapter 2, and are displayed in figures A2-12 through A2-14.

3.2.2.4-Basin ID 5.10 B

The inlet and outlet of basin ID 5.10 B (State Project Reference Number R-2635A; Figure 3-4) was monitored from 8/4/2011 to 12/16/2011. This basin was located west of the NC 55 by-pass near Holly Springs, NC. The description and design calculations for the basin are listed in table 3-7.

Table 3-7. Design dimension and calculations for Basin ID 5.10 B from clearing and grubbing plans.

Design Property	Value
Length (m)	24.4
Width (m)	12.2
Depth (m)	0.915
25-Year Peak Flow (m^3/s)	0.231
Disturbed Area/Drainage Area (ha)	0.708
Intensity for Rational Method (mm/hr)	198
C-factor for Rational Method	0.6
Skimmer Orifice Diameter (mm)	41.9
Emergency Spillway Weir Length (m)	9.76

Figure 3-4. Basin ID 5.10 B

In order to limit channel and gully erosion, the silt ditches leading to this basin were lined with Posi-Shell (Posi-Shell, 2011). 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 in the silt ditches. Wattles were also installed in these ditches and the level of sediment deposition was measured as described previously and subsequently removed by hand periodically. A sample was collected at the time sediment was removed for bulk density.

All of the surveys were conducted using LiDAR and processed in GIS as described in chapter 2 are displayed in figures A2-15 through A2-17.

3.2.3 Data Analysis

The properties for each storm were analyzed by calculating Pearson's correlation coefficient and constructing regression equations in SAS software (SAS, 2009).

The Pearson correlation coefficient was found between all possible combinations of the variables in the analysis simultaneously. The Pearson coefficient is a measure of the association between two variables and can range from -1 to 1 where a coefficient of 1 implies a perfect positive relationship between the dependent and independent variables. A correlation coefficient of -1 implies a perfect negative relationship between the two. From the coefficient, a probability could be found and used to establish whether the correlation between the two variables was significant. Any of the correlation coefficients with a p-value lower than 0.05 were considered significant.

A model regression between one variable or multiple variables was constructed. In other words, a model was constructed to find which of the independent variables had a significant ($p \leq 0.05$) influence in predicting the dependent variable. This was done using the stepwise functions.

The stepwise function systematically adds and deletes variables to create a regression model from the variables based on entry and stay significance levels of 0.15 (SAS, 2009). To start, the program adds in independent variables one at a time to build a regression model and test the significance using an F-test for significance. If it was seen as significant by the program at the 0.15 level in explaining the dependent variable, the variable was included in the regression model. As new variables were included in the regression model, the degrees of freedom change. Due to this, the p-value changes for all of the independent variables when they are entered into the regression model, and as a result the p-value is recalculated for all of the variables as new ones are entered into the regression model to test their significance. If the p-value of the F-test for the variable no longer met the 0.15 level for significance when the variable is included in the regression model, then it is removed.

The result from the stepwise function produces the linear regression model that, given the independent parameters in the model that is proposed (i.e. rainfall intensity, peak flow, etc.), will best predict the dependent variable.

The significance of the presence of PAM, whether discharge occurred over the emergency spillway, and whether disturbed and exposed areas were present in the catchment were found by establishing a dummy variable. In this, the ‘yes’ or ‘no’ answer to the question (i.e. Was PAM used on the basin during the storm?) was associated to a 1 or 0 respectively.

SAS was used to construct a regression model using a stepwise function to explain the variability of basin performance in terms of the reduction of turbidity from storm to storm. The stepwise function was written with the basin performance by reduction in turbidity was used as the dependent variable with total stormwater volume, peak flow, rainfall depth, sediment load (kg), sediment load per area of catchment (kg/ha), basin surface area sediment loading (kg/m^2), intensity of rainfall, time since last event, catchment area, and length of storm used as independent variables. The presence of PAM, disturbed surfaces in the catchment, and occurrence of discharge over the emergency spillway were included as independent ‘dummy variables’ to find whether they had a significant impact on the efficiency of the basin.

After the initial calculation in the program using these aforementioned dependent and independent variables was completed, the variable(s) selected by the stepwise function were multiplied against the 'dummy variables' to find whether there were any interactions between the property and the variable(s) chosen in the overall evaluation of the data.

A regression equation was also constructed in SAS with the sediment load per catchment area entering the basin (kg/ac) was the dependent variable and total stormwater volume, peak flow, rainfall, intensity, time since last event, and length of storm were used as the independent variables. As in the case with using basin efficiency as the dependent variable in the previous section, the program was set up to include whether the use of PAM was significant in determining sediment yield and whether grading and/or exposed area had was significant in explaining the sediment yield as 'dummy variables'.

Similar to the evaluation of basin performance above, after the initial calculation the program was set up with interactions between the 'dummy variables' and the selected variable(s) to find whether any interactions were present.

3.3 Results and Discussion

The data collected from the outlet of Basin ID 10.3 were questionable because the quantity of 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, the intensity of storms, and the rainfall amount. The amount of storm water 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. To the best of our knowledge the error came from stormwater by-passing the inlet to enter into the lower basin from an area outside of the defined catchment. However, there was no conclusive evidence of this occurring. Because of this, the data collected on Basin 10.3 was left out of data sets when basin efficiency was a variable, but otherwise, when only inlet data were being used, the data were included.

3.3.1 Changes in Sediment Load over Time

Below are graphs of the sediment load and TSS from all of the storms collected during the basin monitoring period.

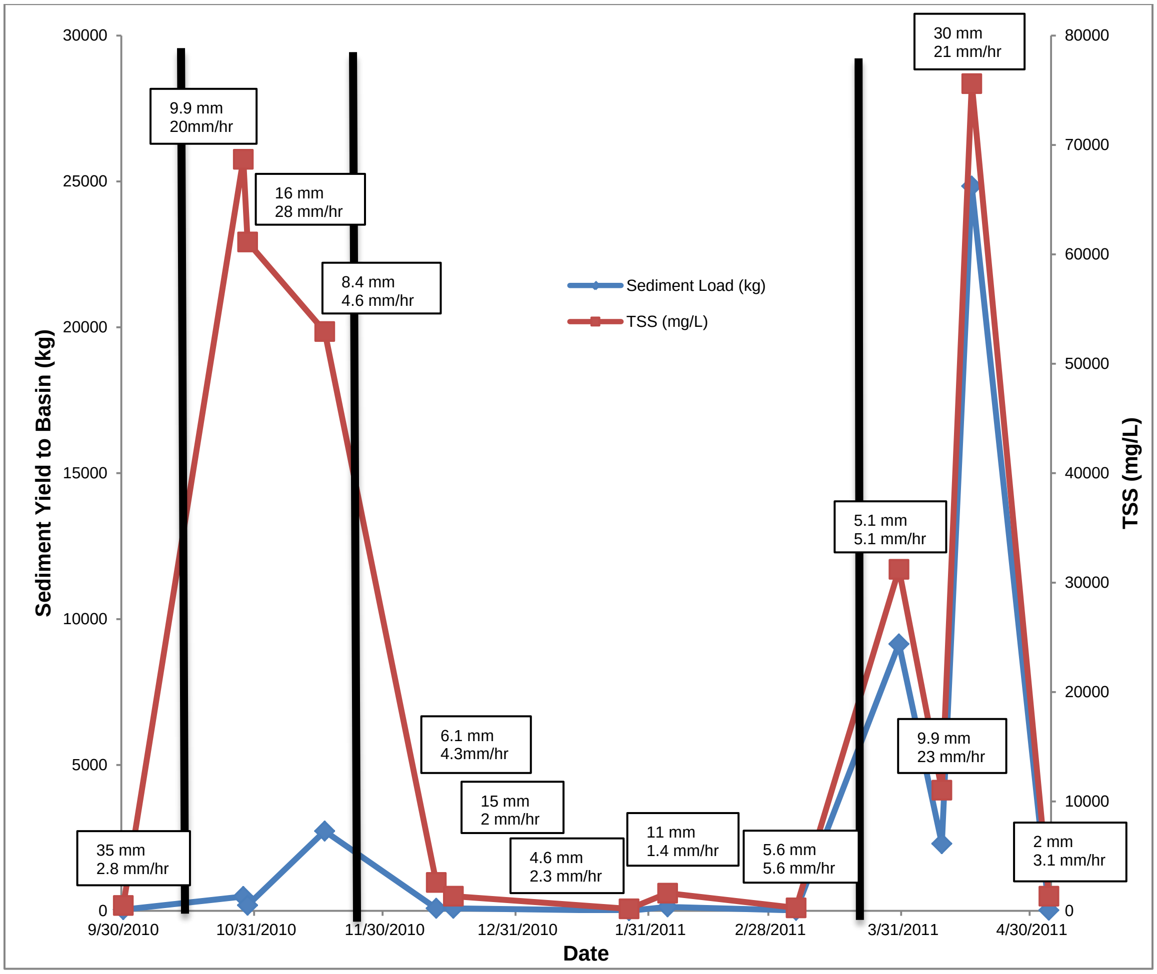

Figure 3-5. Sediment Yields and TSS from each storm collected on Basin 11.4 B. The points indicate a rain event with the boxes displaying rainfall depth and intensity from the storms. The left most box correlates to the left most point(s), etc. Lines were placed at specific dates of major grading and management events.

On 10/18/2010 some grading began in the basin catchment that removed much of the groundcover. On 11/23/2010, the site was strawed and tacked to re-establish groundcover in the catchment. In the period between these two dates, there is a large spike in the TSS and a small spike in the 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 events. There were two rain events on 10/28/10 where, from the first to the second event, the average TSS and sediment yield decreased. This was in spite of the fact that the later storm was more intense and had a greater rainfall depth. This may have been the result of loose materials due to grading being easily eroded by the first storm. This is also apparent from the storm after these on 11/16/2010 that had a smaller volume and intensity than either of the previous storms but had a higher sediment yield due to the loose soil from grading. From 11/23/2010 to 3/15/2011, 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 low intensity storms. After 3/15/2011, grading progressed through the catchment which removed most of the groundcover. This is evident in the graph as the sediment yield and TSS increase after this date, with the last point notably being less due to the low intensity and rainfall depth of this event.

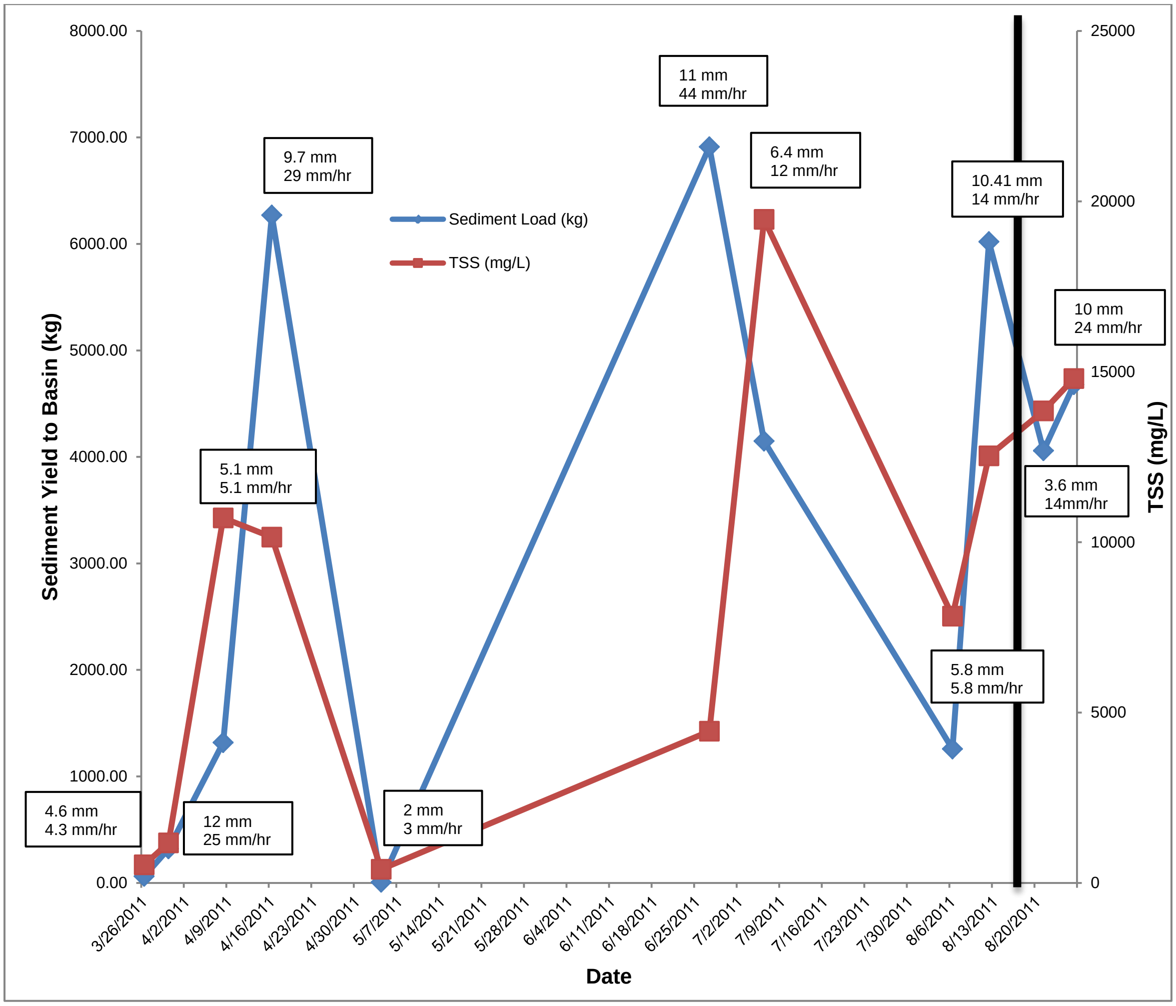

Figure 3-6. Sediment Yields and TSS from each storm collected on Basin 9.2 C. The points indicate a rain event with the boxes displaying rainfall depth and intensity from the storms. The left most box correlates to the left most point(s), etc. Lines were placed at specific dates of major grading and management events.

The catchment for this basin was fairly dormant for a majority of the time it was monitored with groundcover and vegetation present on the catchment before grading started. Grading in the catchment began on 8/17/2011.

For the entire monitoring period, a haul road was present adjacent to the basin and as it was used and graded, large quantities of loose soil were unintentionally pushed into the silt ditch. Subsequently, these masses would be washed into the basin during storm events. This, along with differences in rainfall depths and intensities seemed to drive the sediment yields and the resulting lack of trend or pattern in the graph.

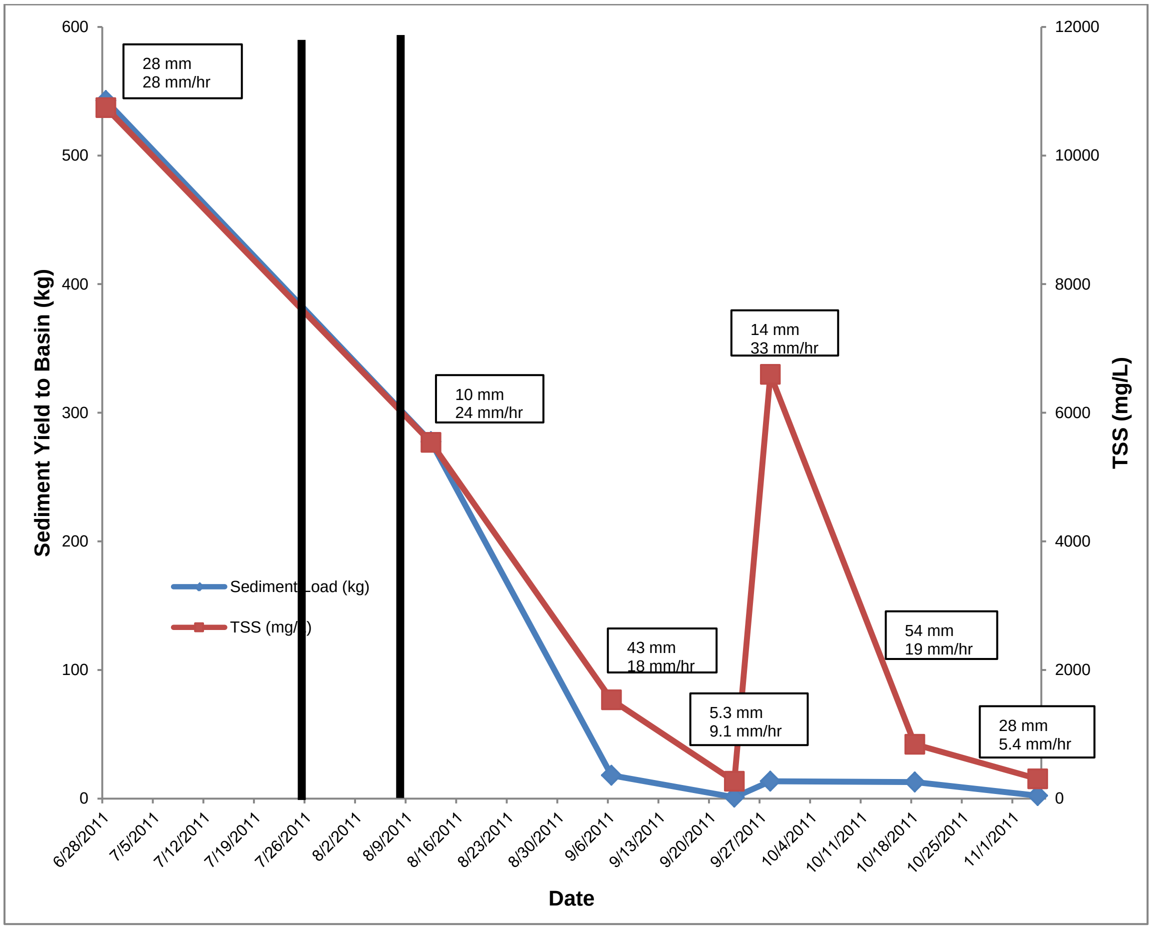

Figure 3-7. Sediment Yields and TSS from each storm collected on Basin 10.3 B. The points indicate a rain event with the boxes displaying rainfall depth and intensity from the storms. The left most box correlates to the left most point(s), etc. Lines were placed at specific dates of major grading and management events.

Basin 10.3 B was monitored during the final grade and post paving periods. As the project progressed, the catchment became confined to a small portion of a well-grassed swale.

On 7/26/2011 a new silt ditch was built and it appeared that a smaller catchment for the basin resulted. This was later confirmed from surveys collected of the area. On 8/10/11 a berm was built parallel to the road and perpendicularly to the silt ditch leading into Basin 10.3 B. This effectively blocked any runoff from the road bed from entering the basin. The resulting catchment was a small, well-grassed swale. This is apparent after 8/10/2011 when the sediment yield and TSS decrease dramatically relative to the previous storms. This is true with the exception of the storm on the storm on 9/28/2011 where the TSS spiked due to the high intensity of the storm.

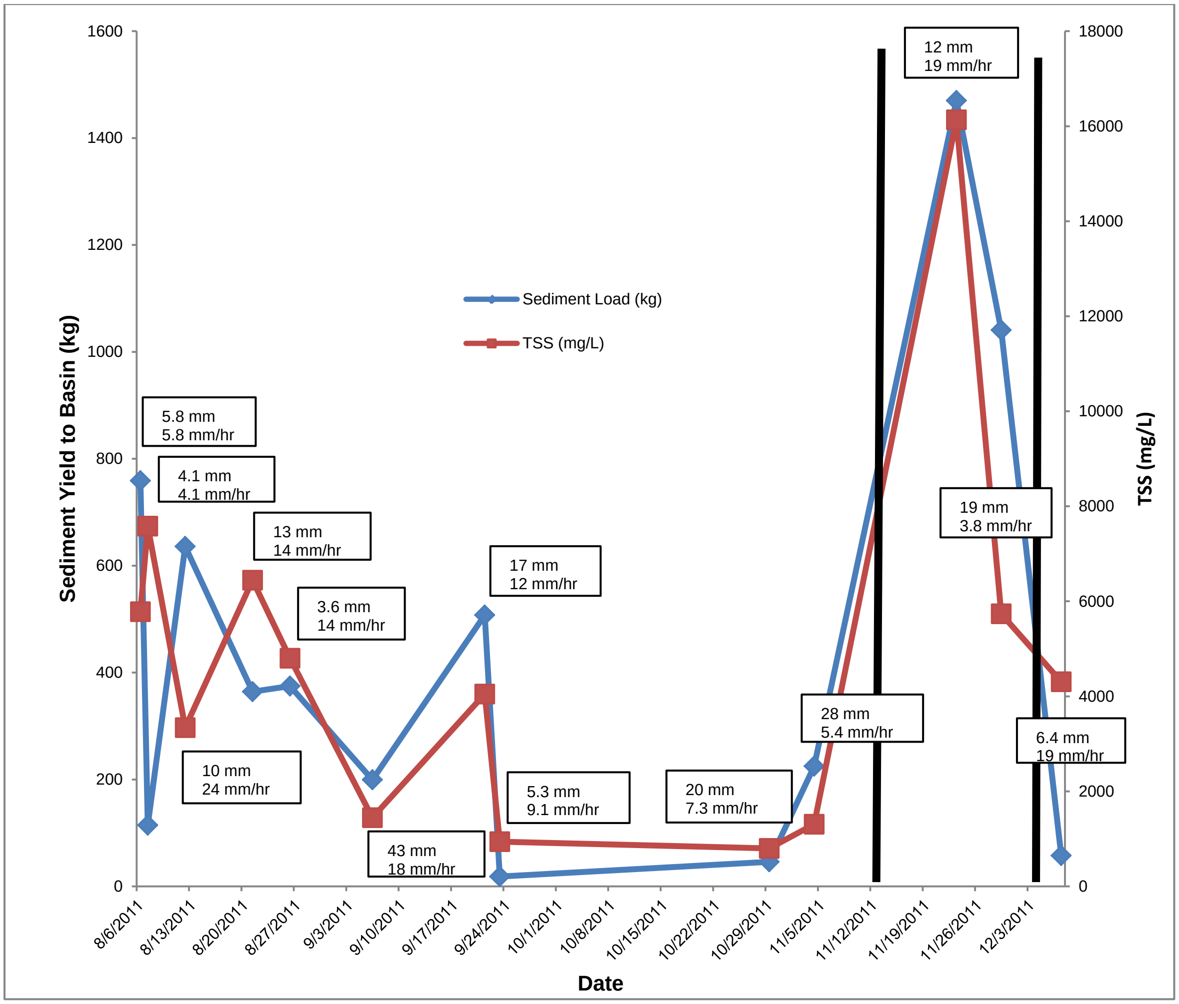

Figure 3-8. Sediment Yields and TSS from each storm collected on Basin 5.10 B. The points indicate a rain event with the boxes displaying rainfall depth and intensity from the storms. The left most box correlates to the left most point(s), etc. Lines were placed at specific dates of major grading and management events.

Basin 5.10 B was monitored after the clearing and grubbing phase when the catchment was dormant with some minor disturbances in the catchment. Until 11/14/2011 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 further up on the project. These piles were removed on 11/25/2011 leaving a bare area in the catchment until 12/05/2011 when the area was strawed and tacked. This is evident in the graph where the TSS and sediment yield spike between the dates when the area was bare and decreases once it is covered.

The monitoring data on these basins provide strong evidence that the groundcover in a catchment has a large influence on the average TSS and sediment yield with some variation related to intensity and rainfall depth. This would indicate that as the project progresses into the mass grading phase, it can be expected the sediment yields will increase dramatically along with the average TSS of the flow given the conditions with regard to the volume and intensity of storms and the level of loose soil present in the catchment. As the catchments become more stable and covered with grass, straw, and/or pavement, the sediment yields begin to decrease.

The results from basin 9.2 C, do not suggest a clear relationship between the groundcover or storm characteristics. The controlling factor seemed to be anthropogenic activities on the haul road more than any other variable. This is a testament to the difficultly in reliably predicting sediment yields based on physical features in the catchment or storm characteristics.

3.3.2 Using Pearson's Correlation Coefficient for Single Variable Relationships

SAS (N = 23) was used to find the Pearson's correlation coefficient and the p-value to determine significance between each of the variables (tables C3-9 through C3-11).

In summary, we found that the sediment load in terms of mass (kg), mass per unit area of the catchment (kg/ha), and mass per unit area of the basin (kg/m^2) were all significantly and positively correlated to peak flow of the storms and the total stormwater volume (Table C3-10). In other words, as the peak flow and stormwater volume increased, the sediment load would also increase.

The mass loadings were not significantly correlated to the rainfall depth, intensity, area, time since the last rain event, the length of the rain event, or the basin efficiency in terms of reduction of total sediment, reduction of TSS, or reduction of turbidity.

The average inlet turbidity was significantly and positively linearly correlated to the total stormwater volume, the peak flow from the storm, and the sediment loading (kg, kg/ha, kg/m^2) to the basin (Table C3-9).

This is consistent with the logic that as the average turbidity of a sample increases, so should the corresponding sediment; that the two generally have a positive linear relationship. Because of that relationship, it also makes sense the relationship between average inlet turbidity and stormwater volume and peak flow since these were found to be correlated to sediment loading. It was not correlated to the intensity, rainfall depth, the time since the last event, area, or the length of the storm.

The average inlet TSS concentration was significantly positively linearly correlated to the peak flow and the sediment loading (kg, kg/ha, kg/m^2) to the basin (table C3-9). This is similar to the results using average inlet turbidity but without stormwater volume being included. It was also not correlated to rainfall depth, area, storm intensity, time since the last storm event, or the length of the storm event.

The basin efficiency in terms of reduction of total sediment was significantly positively linearly correlated to average inlet turbidity (p-value = 0.0030), average inlet TSS (p-value =

0.0391), and total stormwater volume (p-value = 0.0135) (table C3-10). That is to say that as the average inlet turbidity, average inlet TSS, and the total storm volume increased the efficiency of the basin in terms of reduction of total sediment also increased. Based on observations of the ditches after high intensity events, it was apparent there were high energy and high velocity flows which would be capable of eroding the side walls and carrying larger particles. Upon entering the basin, the velocity of the flow decreases due to the much wider flow area and the larger particles can settle out quickly.

Also, because these particles have a large mass it would accentuate the difference between the mass entering the basin and the mass leaving the basin. Further research would need to be conducted (i.e. particle size analysis of samples) in order to confirm these findings.

Increasing TSS coupled with increasing stormwater volume indicates there will be an increase in sediment yield entering the basin simply because sediment yields were calculated in that way; TSS concentration of a sample multiplied against the stormwater volume passing which was represented by the sample. Even though a lot of the mass may be settling out in the basin, the turbidity exiting the basin can still be high. From the discharge limits from the EPA being imminent and the dramatic effect increased turbidity can have on the ecology of streams, lakes, and rivers it seems an evaluation of the efficiency in terms of reduction of turbidity is more useful than an evaluation of the reduction of total sediments.

The efficiency was not significantly correlated to the intensity of the storm, the time since the last storm, the peak flow, area, or the length of the storm.

The basin efficiency in terms of reduction of turbidity and reduction of TSS were negatively linearly correlated to the storm intensity (p-value = 0.0394, correlation coefficient = -0.432; p-value = 0.0024, correlation coefficient = -0.602, respectively). The higher intensity storms produce higher flow rates in the channels which encouraged erosion in channelized areas, and higher flow rates into the basin and make it more likely for discharge to occur over the emergency spillway since discharge through the skimmer is very limited. This is emphasized by the significant and positive correlation between intensity with peak flow (p-value = 0.0014, correlation coefficient = 0.560) and stormwater volume (p-value = 0.005, correlation coefficient = 0.627). During higher intensity events, the hydraulic retention time in the basin is decreased dramatically and sediments have less time to settle out in the basin. This drives down the efficiency of the basin for reduction in average TSS and average turbidity down as the intensity of a storm increases, as indicated by the negative correlation coefficients between basin performance (by turbidity and average TSS) and storm intensity. The rainfall depth, time since last event, length of storm, area, peak flow, or total stormwater volume did not correlate to the efficiency of the basin in terms of reduction of TSS or turbidity.

3.3.3 Basin Performance by Reduction in Turbidity as Dependent Variable

SAS was used to construct a regression equation where the full tables of p-values for the independent variables for each analysis can be found in tables C3-12 through C3-18 in the appendix.

To have an indication on how the different methods of accessing basin efficiency and performance, the respective values for each storm is shown in table 3-8.

Table 3-8. Basin efficiency in terms of reduction of turbidity, reduction of average TSS, and reduction of total sediment for each storm collected.

Basin Name/Storm		**Intensity (mm/hr)**	**Basin Efficiency – Reduction of Total Sediment (%)**	**Basin Efficiency – Reduction of Average Turbidity (%)**	**Basin Efficiency – Reduction of Average TSS (%)**
11.4 B	Storm 1	1.40	55.0	76.2	75.0
	Storm 2	2.80	68.1	86.5	73.8
	Storm 3	4.60	98.6	99.4	99.4
	Storm 4	5.10	99.9	99.3	99.2
	Storm 5	21.3	99.8	90.1	92.0
	Storm 6	23.2	83.4	1.04	6.55
9.2 C	Storm 1	11.6	99.2	94.7	96.0
	Storm 2	14.2	91.7	70.5	80.5
	Storm 3	23.8	91.6	77.2	81.7
	Storm 4	43.7	82.2	69.6	-5.79
5.10 B	Storm 1	3.76	77.4	73.3	68.2
	Storm 2	4.06	-4.51	76.3	78.1
	Storm 3	5.36	49.3	69.0	51.6
	Storm 4	5.84	73.6	61.8	65.6
	Storm 5	7.11	94.4	86.2	87.6
	Storm 6	7.29	68.4	90.1	60.2
	Storm 7	9.14	-18.0	68.8	46.1
	Storm 8	11.8	41.8	85.8	64.0
	Storm 9	14.0	22.2	72.3	58.1
	Storm 10	14.2	36.4	73.4	64.3
	Storm 11	17.5	-70.0	39.4	11.2
	Storm 12	19.1	92.3	27.4	91.5
	Storm 13	23.8	14.3	-14.3	3.21

Only the basin performance in terms of reduction of turbidity was used in the statistical analysis. Using all of the storms together in the stepwise function ($n = 23$), intensity (p-value = 0.0394) and area (p-value = 0.0302) were significant in predicting the performance of the basin in terms of a reduction of turbidity when entered into the model (Table C3-12).

The fact that the area was found to be significant when entered into the regression model is indicative of the way the basins are designed. The rational method is used to calculate the peak flow from the catchment and is multiplied against a constant to determine the surface area of the basin. Since the rational method is a coefficient for cover (a constant) multiplied by the area multiplied by the rainfall intensity, the surface area of the basin should increase as the area multiplied by the intensity increases. The volume increases because the surface area found is typically multiplied against the standard depth of 0.915 m. The larger volume increases the hydraulic retention time in the basin, which allows more time for the sediment particles to settle. Aside from the fact that short circuiting may occur (most of which is overcome by porous baffles), the volume of the basin is the only controllable factor that will drive the performance of the basin.

This was verified by including another independent variable describing interaction between the intensity and area of the catchment which multiplies the two together. The stepwise function was run again with this parameter along with all of the aforementioned independent variables. The results from this were that the intensity and the interaction term between intensity and area were seen as significant when entered into the regression model (Table C3-13).

The parameter estimate is the estimate of the slope for the regression for the respective parameter that was found to be significant when entered into the regression model. By analyzing these estimates of the intensity and the interaction of intensity and area in the regression model developed (table 3-9), we found that as intensity increased the performance of the basin decreased, while as the interaction of intensity and area increased the performance of the basin increased.

Table 3-9. Parameter estimates for selected variables within stepwise function with basin performance by reduction in turbidity for all storms with inflow and outflow.

Variable	Parameter Estimate	Standard Error
Intensity (mm/hr)	-4.72	1.08
Intensity (mm/hr) X Area (ha)	1.93	0.552

The fact that intensity was found to be significant when entered into the regression model using the stepwise function and was negatively related to the performance is consistent with the findings using of the Pearson correlation coefficients in the previous section where only intensity was seen to have a negative linear relationship to the performance of the basin by reduction in turbidity.

The positive relationship in the interaction term to basin performance is, again, related to the fact that this is used in the design of the volume of the basin. Increasing this parameter, increases the volume. An increased volume would increase the hydraulic retention time of the basin, in turn increasing the performance.

When the data was analyzed by separating the storms based on intensity, the storms that had an intensity less than 12.7 mm/hr (n = 13) the function selected sediment load into basin (kg) (p-value = 0.0226) (Table C3-14). For the storms intensities greater than 12.7 mm/hr (n = 9), no variables were selected by the stepwise function (Table C3-15).

When the data was separated by site and by storm greater or less than 12.7 mm/hr, it resulted in either one set or both sets being a low sample size for the number of independent variables and therefore nothing conclusive should be made on the results from the sites being separated by intensity.

These results suggest that it may be easier to predict the efficiency of a basin from lower intensity storms. In other words, with the lower intensity storms, it is suggested that sediment load (kg) could be used to predict basin efficiency in terms of reduction of turbidity; there is a parameter that defines how the basin will perform. Opposed to the case with the greater intensity storms where there were no variables seen as significant when entered into a regression model that could explain the variability of the basin efficiency from storm to storm. This could be for a variety of reasons including, but not limited to, less chance of channel erosion, that can be highly inconsistent and dependent on a large number of variables and as a result makes it difficult to find a parameter that defines the performance of the basin.

When the basins were analyzed individually, the significant variable selected by the stepwise function on Basin 11.4 B (n = 6) was sediment yield (kg) (p-value = 0.0305). The significance of the use of PAM and whether discharge occurred over the emergency spillway on basin 11.4 B could not be determined since all storms analyzed included the use of PAM and had discharge occur over the emergency spillway (Table C3-16). On Basin 5.10 B (n = 12) was the intensity (p-value = 0.0012) when the variables were entered into the regression model. The significance of area could not be determined since all of the storms analyzed had the same catchment area (Table C3-18). On Basin 9.2 C (n = 4) no variables were significant when entered into the regression model (Table C3-17). Since the basins are designed based on their catchment area and that efficiency is a relative measurement, it is a fair assessment to evaluate all storms together. Therefore due to the relatively small sample size for storms collected on each basin compared to the earlier evaluation with all storms, the conclusions and suggestions from this analysis is limited.

Some possible changes to the design of the basin to improve the performance of it would be to improve the retention time. This would be best accomplished by limiting the amount of water discharging over the emergency spillway. Since the typical basin does not completely de-water, the basin is not able to hold the design storms. Therefore, basins will more commonly discharge through the emergency spillway thus increasing the flow rate through the basin and reducing the retention time.

Another possibility would be to slope the bottom so that the water column near the outlet of the basin is shorter than at the inlet, but still maintain the volume of the basin. By having the bottom sloped like this creates a shorter height and therefore less time needed for particles to settle out in this area.

3.3.4 Sediment Entering Basin at Inlet as Dependent Variable

Full tables of all of the p-values found for each of the independent variables in the different analyses can be found in tables C3-19 through C3-25 in the appendix.

When all of the storms were evaluated together ($n = 44$), the stepwise function returned peak flow (p-value = <0.0001) and whether disturbed area was present (p-value = 0.0343) as a significant variables (Table C3-19).

From this, the program was set up to find whether there were interactions between the variable that was selected, peak flow, and the characteristics of the storm and the catchment which were set up as ‘dummy variables’.

When all of the storms were evaluated together (n = 44) with sediment yield being the dependent variable with everything aforementioned being the independent variable including the interactions, the interaction between peak flow and disturbed area (p-value = <0.0001), the total stormwater volume (p-value = 0.0267), and whether the catchment was disturbed (0.0341) were selected as significant when entered into the regression model (table C3-20).

The variable not included from the first analysis is peak flow. It was selected when the interaction variables were not included, but not when the interaction variables were included. This has to do with how the variables are selected in the stepwise function. Since the interaction of peak flow and disturbed area is tested first in the model and it was selected as significant, the probability values of the other variables when entered and tested in the regression model changes. This suggests that peak flow by itself may not be as important but was selected initially because it was part of an interaction. The interaction of peak flow and disturbed area in the catchment is significant in explaining the sediment yield entering the basin, and peak flow was probably initially selected because it was a part of an interaction term. This is evident in the graph (figure 3-9) where the relationship between peak flow and sediment yield results in different slopes and intercepts in the regression lines fitted to the data with and without disturbed areas in the catchment.

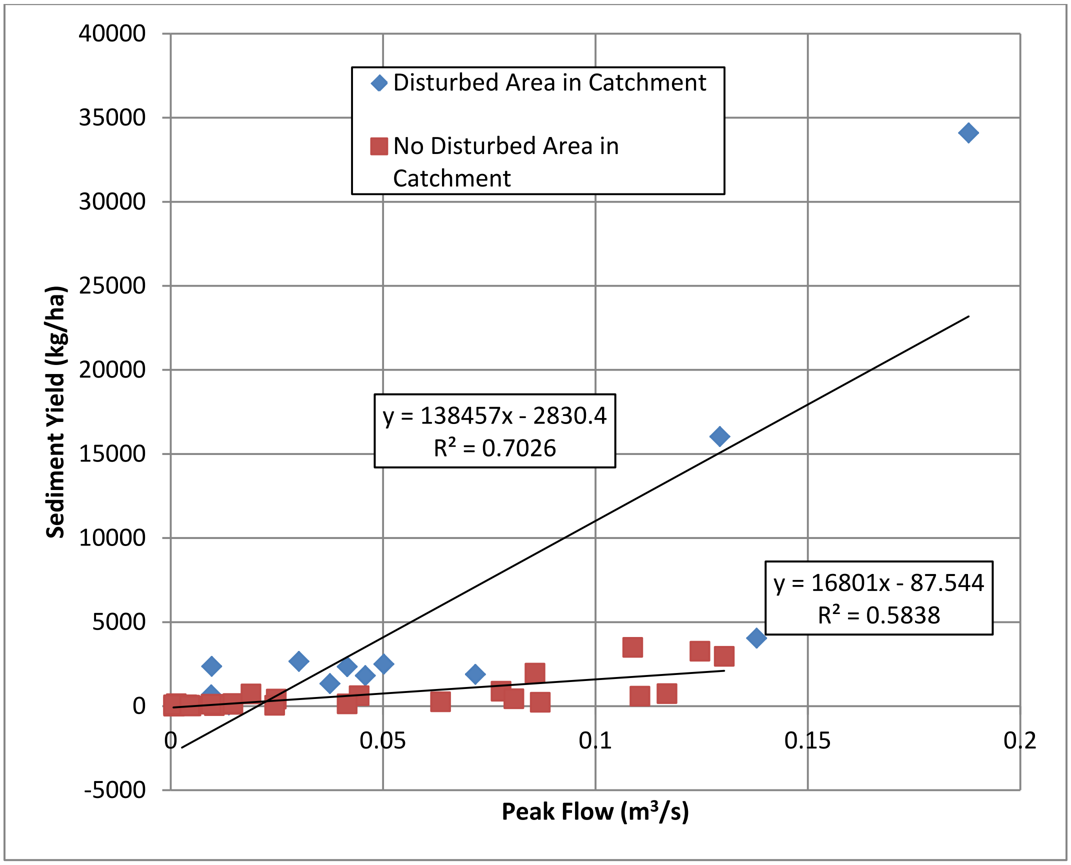

Figure 3-9. Graph of the independent variable, peak flow, and dependent variable, sediment yield per unit area (kg/ha), with equations of regression lines show the differences in slope with and without disturbed area for all storms.

Since peak flow as a single variable was not selected in the case when interaction between the ‘dummy variables’ were included, the program was run again with interactions between the ‘dummy variables’ and the total stormwater volume. The same interactions and variables were selected as before; total stormwater, presence of disturbed areas in the catchment, and interaction between disturbed area and peak flow.

In order to have a better idea of the impact area had on the sediment yield, the dependent variable was changed to sediment yield (kg) as opposed to sediment yield per unit area (kg/ha).

When all of the storms were evaluated together (n = 44) with sediment load (kg) as the dependent variable, the total stormwater (p-value = <0.0001) and the interaction between peak flow and disturbed area (p-value = <0.0001) were significant when entered into the regression model (table C3-21).

The parameter estimates for these variables selected are displayed in table 3-10.

Table 3-10. Parameter estimate for selected variables within the stepwise function with sediment yield as dependent variable for all storms with inflow samples collected.

Independent Variable	Parameter Estimate	Standard Error
Stormwater Volume (L)	0.0146	0.00262
Peak Flow (m^3/s) X Disturbed Area in Catchment	62300	8680

Based on the analysis of the parameter estimates, we found that as the stormwater volume increased, the sediment yield would increase as well. The parameter estimate of the interaction between peak flow and disturbed area in the catchment being positive suggests that a disturbed area in the catchment will dramatically increase the sediment yield due to an increase in peak flow. This effect that a disturbed area in the catchment have on the severity of increased sediment yield due to increase in peak flow is evident by figure 3-10, where the slopes and intercepts of the data separated by those storms with and without having a disturbed area in the catchment are different. This is similar to the interaction between peak flow and having a disturbed area in the catchment seen before in figure 3-9.

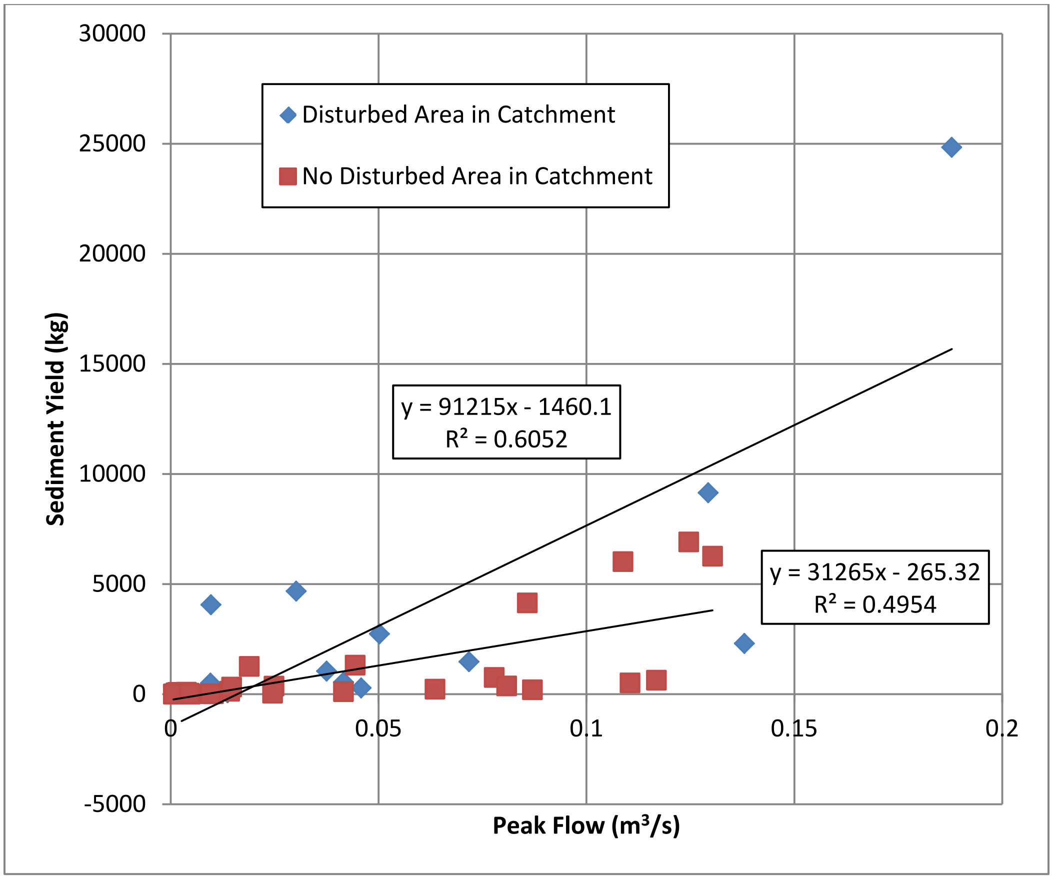

Figure 3-10. Graph of the independent variable, peak flow, and dependent variable, sediment yield (kg), with equations of regression lines to show the differences in slopes and intercepts with and without a disturbed surface in the catchment for all storms.

For Basin 11.4 B (n = 13) the total stormwater volume (p-value = 0.0001), the rainfall depth (p-value = 0.0196), intensity (p-value = 0.0360), and length of storm (p-value = 0.1310) were selected since they were significant when entered into the regression model (Table C3-22).

The parameter estimates for each of the selected variables is given in table 3-11.

Table 3-11. Parameter estimate for selected variables within the stepwise function with sediment yield as the dependent variable for all storms collected on Basin 11.4 B.

Variable	Parameter Estimate	Standard Error
Stormwater Volume (L)	0.0589	0.00840
Rainfall Depth (mm)	-431	148
Intensity (mm/hr)	346	138
Length of Storm (hrs)	743	442

The reason there is a negative relationship between the rainfall depth and the sediment yield is because many of the storms that had high depths were typically low intensity storms than thus would produce less erosion than the flashy storms associated with high intensities and relatively low rainfall depths.

The significance of PAM could not be determined since all of the storms included the use of PAM on Basin 11.4 B.

On Basin 9.2 C (n = 11), peak flow (p-value = <0.0001), the use of PAM (p-value = 0.0002), and the area (p-value = 0.1392) were significant when entered into the regression model (Table C3-23). Evaluation of the parameter estimates (table 3-12) showed the impact of peak flow and use of PAM had a positive relationship with sediment yield while area had a negative impact on the sediment yield. Even though the data suggest that the use of PAM increases the sediment yield, there was a large difference between the number of storms evaluated with PAM (n = 2) and without PAM (n = 9). Therefore these results are not conclusive and further evidence should be sought in order to confirm this finding.

Table 3-12. Parameter estimates for selected parameters in stepwise function on Basin 9.2 C. These are given for a relative sense of impact the selected independent variable had on the sediment yield.

Variable	Parameter Estimate	Standard Error
Peak Flow (m^3/s)	52700	2840
Use of PAM	3100	432
Area (ha)	-1500	886

The negative impact of area could be due incorporation of more concave slopes and allow for more deposition within the catchment, rather than it making it to the basin.

The significance of disturbed or graded areas on Basin 9.2 C could not be determined because all storms on this basin during the monitoring period did not have disturbed or graded areas.

On Basin 10.3 B (n = 7), total stormwater volume (p-value = 0.0311), the peak flow (p-value = 0.0048), the intensity (p-value = 0.0085), and the area (<0.0001) were selected as significant when entered into the regression model (Table C3-24). Due to the small sample size and the number of variables selected as significant when inputted to the regression model, the conclusions from this analysis are limited.

The significance of the use of PAM could not be found since PAM was never used on Basin 10.3 B.

On Basin 5.10 B (n = 13), the interaction between peak flow and the presence of a disturbed area in the catchment (p-value = <0.0001), the total stormwater volume (p-value = 0.0007), the time since the last event (p-value = 0.0649), and the use of PAM (p-value = 0.0045) were selected as significant when entered into the regression model (Table C3-25).

Upon inspection of the parameter estimates of each of these variables (table 3-13), total stormwater volume, time since the last event, and the interaction between peak flow and having a disturbed area in the catchment were positively related to the sediment yield. The use of PAM was found to be negatively associated with the sediment yield.

Table 3-13. Parameter estimates for selected parameters in stepwise function on Basin 5.10 B. These estimates are given for a relative sense of the impact the selected independent variables had on the dependent variable.

Variables	Parameter Estimates
Stormwater Volume (L)	0.00290
Time since last event (days)	9.64
Use of PAM	-285
Peak flow X Disturbed area	16600

The results from the analysis of this data suggest that the use of PAM decreases the sediment yield entering the basin. This is contradictory to what was found on Basin 9.2 C. However, these results are more substantiated due to the high number of storms and lower different between the number of storms with (n = 8) and without (n = 5) PAM. The significance of area could not be determined because the area of the catchment remained the same throughout the period monitored on Basin 5.10 B.

The interaction between peak flow and having a disturbed area in the catchment is similar to what was found when all the storms were evaluated together by sediment yield on an aerial basis. It is evident in the graph (figure 3-11) that the peak flow has a more dramatic impact on the sediment yield when there is a disturbed area in the catchment.

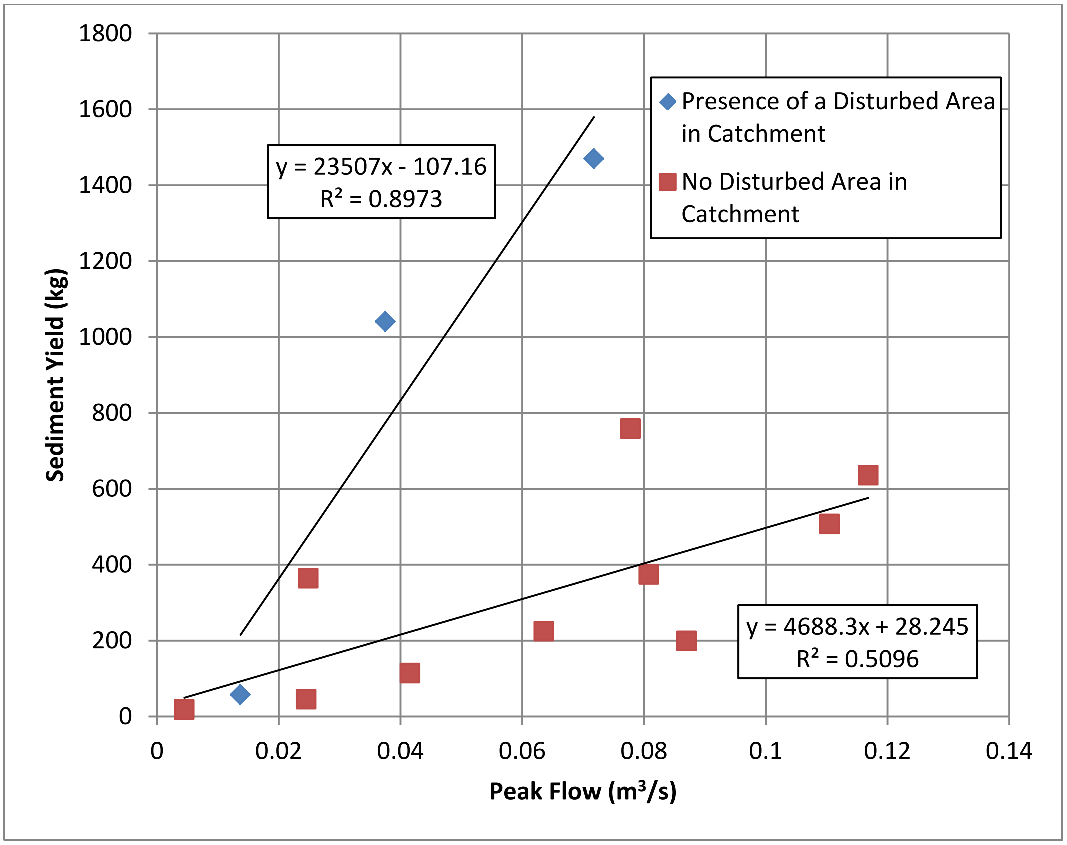

Figure 3-11. Graph of the independent variable, peak flow, and dependent variable, sediment yield (kg), with equations of regression lines show the differences in slope with and without a disturbed surface in the catchment on Basin 5.10 B.

3.4 Conclusion

3.4.1 Changes in Sediment Yields through Progression of Projects

As the projects moved from the clearing and grubbing phase to a mass grading phase, the average TSS and sediment yields would typically increase. The presence of a cover in the catchment as opposed to disturbed bare soil, generally provided lower average TSS and sediment yields, and varied by storm characteristics. After the catchments for the basins reached the final grade and post paving phases, the catchments were relatively stable and areas not in the road bed were straw, tacked, and seeded to add cover. This generally led to lower average TSS and sediment yields, again with variation due to storm characteristics. With grading and driving on the haul road near basin 9.2 C being typical and the lack of a pattern in the data collected on this basin suggests that these man-induced events influenced the sediment yields.

From this analysis, the results suggest that the addition of cover is a crucial part of limiting erosion in a catchment. Furthermore, when machinery is moving through the catchment and disturbances are typical, the sediment load can be high and is less predictable.

3.4.2 Basin Performance by Reduction in Turbidity

The inflow and outflow from three basins with different catchment areas on the same project site were monitored and analyzed for their performance measured as the reduction of turbidity. The current design uses the peak flow from the catchment calculated by the rational method to determine the surface area which is used to calculate the design volume of the basin. The volume results in a retention time for a particular flow rate and therefore the amount of time allowed for particles to settle in the basin.

Based on the stepwise analysis, the fact that the interaction between intensity and area was seen as significant when entered into the regression model and had a positive relationship with the efficiency of the basin is indicative of the methods used to design the volume of the basin.

Intensity was the other variable seen as significant when entered into the regression model. This suggests intensity is an important variable in predicting of the efficiency of a basin and may need to be analyzed independently to design a sediment basin in order to ensure desired design efficiency.

When the data were separated between storms with intensities greater and less than 12.7 mm/hr, the results suggested lower intensity storms may be easier to predict the sediment yield.

Some possible changes to the design for improved reduction of turbidity could be to slope the bottom of the basin to create a shorter height for sediment to settle from and improve the retention time in the basin.

Further research in this area could be to analyze the particle size of each sample entering and exiting the basin to understand what types of particles are settling out in the basin.

3.4.3 Sediment Entering Basin

In the analysis of all the storms, the results suggest the total stormwater entering the basin and that there is an interaction between the peak flow and whether a disturbed area is present. The findings are substantiated by the fact that stormwater volume is significant when entered into the regression model for two of the three sites monitored. For two of the three valid sites, either peak flow was selected independently as significant when entered into the regression model or the interaction was selected. The significance and influence that disturbed or graded areas have on the sediment yield is substantiated by the conclusions made in section 3.4.1.

This data suggests that total stormwater volume and the presence of a disturbed area in the catchment have an impact on the sediment yield, and there would be some interaction with having a disturbed area in the catchment and storm characteristics such as the peak flow or stormwater volume. In other words, the fact that there is a disturbed area in the catchment changes the severity of how much the sediment increases due to the increase in peak flow or stormwater volume in this case.

The current regulation for designing the sediment storage capacity of a basin is based on 3.14 cm of soil for every disturbed hectare (126 m^3/ha). When all of the storms were analyzed together with sediment yield (kg) as the dependent variable as opposed to sediment yield per unit area (kg/ha), area was not significantly correlated with sediment yield at the basin inlet.

Instead of focusing just the disturbed area of the catchment for designing the sediment storage volume of the basin, the conclusions made here suggest there are a variety of parameters define the volume of sediment entering the basin. These variables are but may not be limited to, peak flow, whether there are disturbed areas in the catchment, and stormwater volume. These need to be addressed to better estimate the level of soil erosion on a highway construction site basin catchment, and therefore a better method for designing the sediment storage space in a sediment basin.

Based on this analysis, cover in the catchment is a crucial part of preventing sediment yield, and is a similar conclusion from section 3.4.1. Also, since the peak flow and stormwater volume were significantly correlated to sediment yields as well, the management should be such that during times of the year when storms with high peak flow and volumes are typical or predicted, some type of cover should be installed and disturbances in the catchment should be limited in order to limit the amount of erosion.

CHAPTER 4: Evaluation of RUSLE2 Model for Predicting Sediment Yields on a Piedmont North Carolina Highway Construction Site

4.1 Introduction

The rate of erosion from an area can be greatly accelerated due to the land disturbances typically associated with constructing buildings and roads (Wolman and Schick, 1967). This sediment discharge from construction sites can have a negative impact on the biodiversity, macroinvertebrate population, and benthic habitats of the receiving streams (Barton, 1977; Taylor and Roff, 1986). To address the problem, the Clean Water Act of 1972 included provisions to require states to implement sediment and erosion control plans on construction sites (Clean Water Act, 1972). In response to this, the Sedimentation Pollution Control Act of 1973 was passed in North Carolina requiring erosion and sediment control plans to be developed and implemented for land disturbing activities (North Carolina General Statutes, 2002).

Sediment basins are a common best management practice (BMP) option for capturing sediment coming off construction sites in North Carolina. The levels of total suspended solids (TSS) coming off of a construction site and discharging from these basins are undoubtedly variable and highly dependent on the site itself (Daniel et al., 1979; McLaughlin et al., 2009). Differences in soil types, rainfall patterns, topography, and land cover are likely to create differences in the sediment yields from the site and the performance of these BMPs (Toy et al., 1999). Predicting the sediment erosion rate from a construction site would be difficult with only simple relationships.

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 2 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 as can be seen in equation 4.1.

$$a_i = r_i k_i l_i s c_i p_i, \tag{4.1}$$

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. An extensive overview of the changes between USLE and RUSLE2 are described by 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. The high level of variability these factors can have on sediment yield can cause the estimates from RUSLE2 to be far from the actual sediment yields (Dabney et al., 2010; 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:

- Evaluate the performance of RUSLE2 model to predict measured sediment yield from highway construction sites during all phases of a NCDOT highway construction project using topography from periodic surveys of the catchment in Piedmont North Carolina from four different sediment basins.
- Evaluate the performance of RUSLE2 model to predict measured sediment yield from highway construction sites from a planning perspective using various methods to determine topography including: Complex or representative slopes from clearing and grubbing, the average slopes from clearing and grubbing, and the average slope from final grade plans.
- Evaluate the performance of RUSLE2 model to predict measured sediment yields from highway construction sites on a storm-by-storm basis.
- Analyze the sensitivity of the topography parameter in RUSLE2 and how the sediment estimates change in relation to the topography changes to the catchment throughout the grading process on each site
- Establish which topographic planning prospective would be most conservative versus that which would be least conservative.

4.2 Methods and Materials

4.2.1 Sediment Basin Monitoring

Four sediment basins on a North Carolina Department of Transportation (NCDOT) highway construction site were monitored for sediment inflow. These basins were located in the Piedmont region of North Carolina on the I-540 extension construction project in Wake County, North Carolina. Each basin had an ISCO 6700 automated sampler with a 730 bubbler module (ISCO, 2008) to measure the stormwater flow into the basin and take samples on a volume weighted basis. The inlets for the basins were 30.5 corrugated plastic pipes which, along with the length and slope of the pipe, were used to program the automated sampler to measure the stormwater flow and take samples on a volume weighted basis. The samplers were programed to take a 200 mL sample for every 1890 L of stormwater passing (2840 L for the side of basin 9.2 C for a combined total of 4730 L). There were four aliquots per bottle to extend the sampling capacity for a storm.

An ISCO 674 Rain Gage (ISCO, 2008) was attached to one of the samplers to monitor rainfall depths to an accuracy of 0.0254 cm at 5 minute intervals and was assumed to represent the rainfall depth for the other basins being monitored on the project at the same time. After rain events, samplers were collected and analyzed for total suspended solids (TSS) and turbidity. Every sample was analyzed for turbidity while the TSS was measured for every fourth sample due to time and expense. In order to estimate the TSS of each sample, a linear relationship between TSS and turbidity was developed for each site using the samples which both properties were found. The resulting regression equation of the best fit line was used to calculate the TSS from the turbidity value of a sample (Gippel, 1989).

Turbidity was measure using a TC-3000e portable turbidity meter (ver. 1.5, LaMotte, Chestertown, MD). The measured valued were corrected with a standard curve based on a series of formulized standards. Following the Standard Methods for Examination of Water and Wastewater (Clesceri et al., 1998), TSS samples were filtered with 47 mm glass fiber ProWeigh filters from Environmental Express (Mt. Pleasant, SC) and dried overnight at 103°C to 105°C.

The RUSLE2 model is very robust in nature. If it could be used to aid in appropriately estimating sediment yields within one region of the United States, it would be able to be applied to any region in the United States by changing the parameters that are unique to a particular scenario that the user is trying to emulate. Therefore it isn't necessary to 'test' the model's applicability in a wide variety of climates, soils types, and projects.

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. Since RUSLE2 is best suited to estimating long term erosion, the sites were monitored for as long as possible. Surveys of the catchments were taken periodically throughout the monitoring period when major changes in the topography were apparent using ground based light detection and ranging (LiDAR) and processed in ArcGIS 10 (ESRI, 2010). These surveys were used to develop the catchment basins and flow path profiles to be used in the RUSLE2 calculations. An example of how profiles and area were determined to be inputted to RUSLE2 is in figure A4-1 in the appendix with more detail in section 4.2.3. As a note, the first two surveys on Basin 11.4 B were taken using a TopCon Total Station (GTS 211D, Topcon Electronic Total Station, Livermore, CA) because of malfunctions with the LiDAR unit.

The sediment yield into the basins calculated for each storm using the TSS and stormwater volume information associated with each sample and was summed for defined periods for comparison to the RUSLE2 calculation. Because RUSLE2 is a long term erosion model, definitions for the different periods of construction, defined as clearing and grubbing, mass grading, final grade, and post paving were created based on observations of the sites. The sediment yield seen on the site for these periods were compared to the corresponding result from RUSLE2.

4.2.2 Site Descriptions

Basin ID 11.4 B from the erosion control plans (State Project Reference Number: R-2635B) was located on the I-540 extension off of Apex BBQ Rd. near Apex, NC and was monitored from 9/14/2010 to 5/5/2011.

Monitoring of the basin began soon after its installation and through most of the mass grading phase of the catchment.

Basin ID 9.2 C from the erosion control plans (State Project Reference Number: R-2635A) was located east of Apex-Holly Springs Rd. and was monitored from 3/22/2011 to 9/16/2011. There were two inlets on this basin which were monitored and the sediment yields from each were summed for a total which was compared to the estimate from RUSLE2. In order to prevent erosion in channelized areas, on 6/14/2011 the ‘sumps’ typically dug out in front of rock check dams in the silt ditch were filled in and smoothed on this basin, and jute fabric was laid on top to resist shearing forces.

Basin ID 10.3 B (State Project Reference Number R-2635 B) was monitored from 5/5/2011 to 11/14/2011 and was located west of US highway 1. It was monitored during the final grade and post-paving phases of construction.

Basin ID 5.10 B (State Project Reference Number R-235 A) was monitored from 8/4/2011 to 12/16/2011, and was located west of the NC Highway 55 by-pass near Holly Springs, NC. As a method for limiting channelized erosion, the silt ditches leading into the basin were lined with Posi-Shell (Posi-Shell, 2011). Posi-Shell is a mixture of water, fibers, a mineral setting agent, and Portland cement which is mixed and hydraulically applied, much like hydromulch. Wattles were installed over the Posi-Shell to encourage deposition. The sediment deposited in these areas was periodically measured and manually removed.

4.2.3 Site Soil Analysis

At least two samples from different places within each of the catchments for the basins were collected for a soil texture analysis. The texture analysis was done using the hydrometer technique (Gee and Bauder, 1986). The average of the soil texture for the catchment was used in the RUSLE2 calculations. The textures found for each sample are listed in tables C4-1 through C4-9 in the appendix.

The bulk density of the sediments deposited in the silt ditches that were being monitored was obtained by inserting a metal core of known volume into the pile of sediment behind a wattle or check dam. The sample was then dried at 105^0C until a constant weight was reached and the sample massed. The dry mass divided by the volume gave the bulk density of the sediment.

4.2.4 RUSLE2 Profile Development from Processed Surveys

From the surveys collected and processed as described earlier, the profiles used in the RUSLE2 calculations were determined. In order to do this, portions of the catchment which enveloped similar slopes and flow paths were grouped together so that the area was defined by one profile. The length and slope of a portion was found. As dramatic changes in the slope occurred from where flow would begin and end, the length and slope for that next portion was found until a complete profile was created. The profiles developed for use in RUSLE2 start where flow begins and leads to a concentrated flow. On the construction site, this generally was from a break in the catchment to a silt ditch, if not earlier based on field observations. These methods for determining the profile for RUSLE2 calculations are the generally accepted method of applying the model (Yoder, Daniel, University of Tennessee, Personal Communication, 27 Sept 2011). These were taken to be representative flow paths of a similar area that could be used in the ‘topography’ tab of RUSLE2 (i.e. Representative LS for Areas), which is effectively used in the LS portion of the equation. An example of how the flow paths and profiles are developed can be found in figure 4-1.

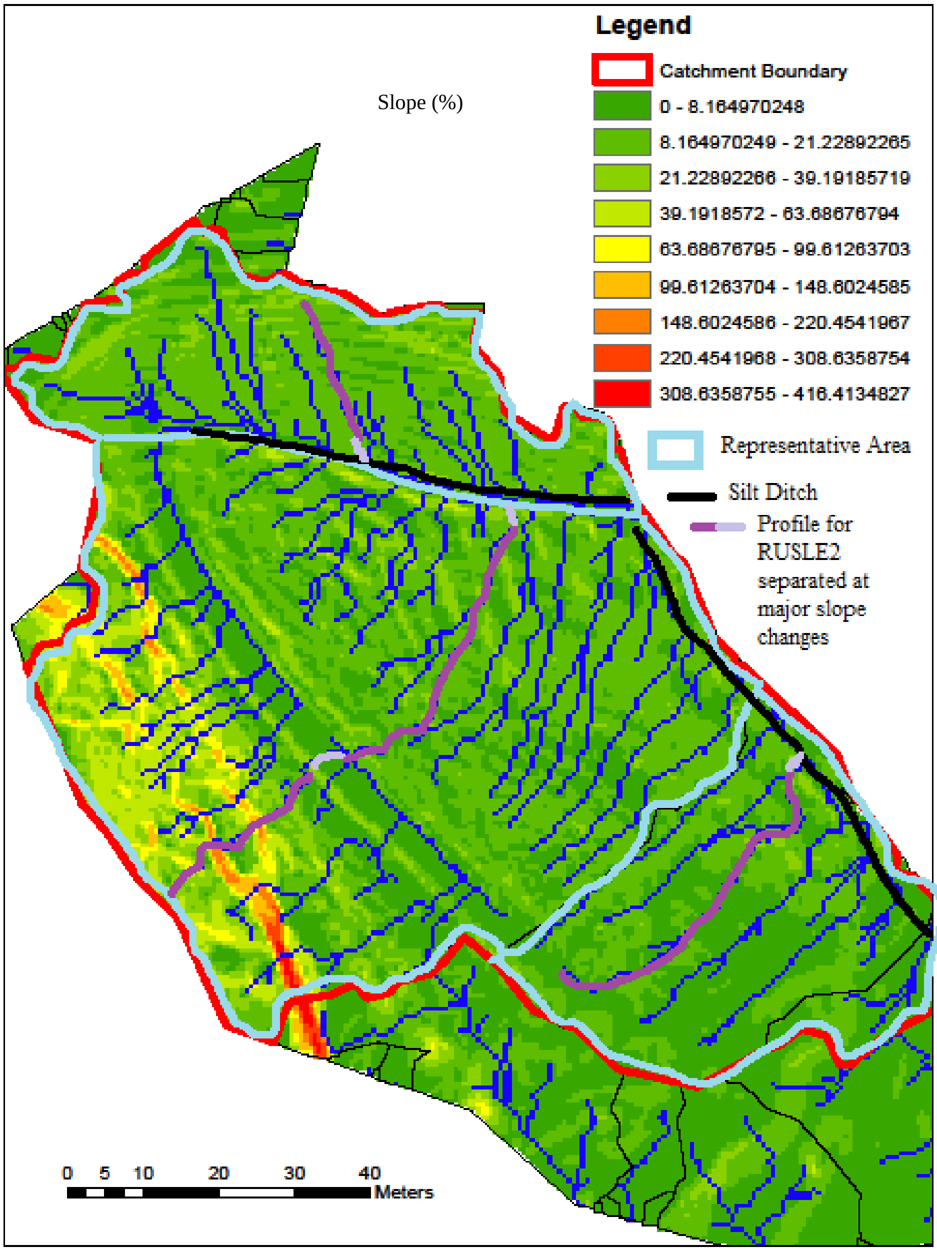

Figure 4-1. Example of LS profile development for RUSLE2 from ArcGIS processed survey. Points where dramatic changes in the slope prompted a different segment in the profile developed for RUSLE2. The flow length and elevation at the ends of the segment were used for calculating the length and slope for the segment and segments were put together for the complete profile used in RUSLE2 scenarios.

The number of profiles, the size of these representative areas, and the number of segments for each profile depended on the catchment characteristics. The profiles were disaggregated into length and slope segments and displayed in tables A4-8 through A4-74 in the appendix.

4.2.5 RUSLE2 Evaluation and Sensitivity Tests

4.2.5.1 Comparing RUSLE2 sediment yield estimates based on survey topography to field results

This scenario used the surveys obtained through the progression of the project for the topography element in RUSLE2. From the surveys, profiles were developed for representative areas in the catchment using the process described before. RUSLE2 was used to calculate the soil yield using the RUSLE2 climate database, the management/operations based on observations, and the soil texture determined from particle size analysis. The program calculated the sediment yield during the period that the topography from the survey best encompassed the topography in the catchment. The survey periods were further summed to give a sediment yield estimate for the period of construction; clearing and grubbing, mass grading, etc.

4.2.5.2 Comparing RUSLE2 sediment yield estimates based on planned topography to field results

The first of these scenarios used representative length, slopes, and areas from clearing and grubbing and final grade plans. Since plans are required and readily available when planning a construction project, using these plans would be the main method by which to develop an erosion control plan. These calculations were performed to determine whether it would be practical to use the contouring from these plans to come up with a sediment load, even though there are dozens of different landscapes in the intermediate between phases. The catchment for the basin was defined based on the clearing and grubbing plans and representative profiles for areas were developed and inputted to RUSLE2. The RUSLE2 climate, soil texture from site particle size analysis, and operations/managements from site observations were used in the calculation as well.

The second of these scenarios in RUSLE2 used one average slope for the entire catchment based on the topography from the plans. The municipalities currently using RUSLE2 will typically use this method for estimating sediment yield. This method also offers simplicity and consistency to the planning process. Essentially the longest length across the catchment was found and the elevation at the end points was used to find the slope. This profile was inputted to RUSLE2 along with the soil texture from particle size analysis, management/operations from observations, and using the RUSLE2 climate data, the sediment yield was determined for the period monitored.

4.2.5.3 Comparing RUSLE2 sediment yield estimates based on survey topography on a storm-by-storm basis

This scenario used the same profiles developed in the first scenario (Representative slopes from Surveys) but utilized the ability of inputting storms individually to compare the sediment yield of each storm based on the erositivity value. The rain gage data was used along with the techniques described by Foster et al. (2003) to develop an erositivity index (EI) for each storm, which along with the total rainfall, was inputted to RUSLE2. Again, like the first scenario, the management/operations from observations, the soil texture from particle size analysis, and the profiles from the surveys were used in RUSLE2 to calculate a sediment yield which was then compared to the sediment yield of the corresponding storm.

4.2.5.4 Sensitivity of the topography parameter in RUSLE2 and changes to sediment estimates

This scenario was a sensitivity test of the topography element in RUSLE2. Using the profiles developed from surveys, the RUSLE2 climate data, the management/operations, and soil texture from particle size analysis, RUSLE2 was used to calculate the sediment yield for the entire period the catchment was monitored. The climate, management/cover, and soils were the same for each run for the basin catchment. The profiles from the surveys were run for the entire monitoring period rather than the time that it best enveloped. In this approach, the topography was the only feature changing and therefore would be a fair comparison of the sediment yield differences due to changes in topography without influences from different storm events, climates, managements, or soil types. The period run in RUSLE2 for Basin 11.4 B was 14 September 2010 to 5 May 2011 (233 days), for Basin 9.2 C the period was 22 March 2011 to 16 September 2011 (178 days), for Basin 10.3 B 5 May 2011 to 14 November 2011 (193 days), and for Basin 5.10 B 10 August 2011 to 16 December 2011 (128 days).

4.2.6 Data Analysis

4.2.6.1 Comparing Field Sediment Yields to RUSLE2 Calculations

This was the analysis performed for all of the scenarios that compared a RUSLE2 estimated soil yield to the respective field sediment yield. The sediment yields from the field were compared to the respective periods or storms (hereafter referred to as ‘field’) for each of the scenarios run in RUSLE2 (hereafter referred to as ‘RUSLE2’). The results from this were analyzed using SAS software (SAS, 2009). In this, the difference (hereafter referred to as ‘difference’) between field and RUSLE2 was set up as a variable and was regressed on the model predictions. The regression model developed is displayed in equation 1.

$$\text{Difference} = A + B*(\text{RUSLE2}) + \text{error}. \quad [1]$$

The resulting F-test in the output from the procedure was to test the hypothesis that the slope (B) and intercept (A) are both zero so that the difference would be zero. This should be the case if RUSLE2 could be considered a good method for determining sediment yield on construction sites. If the estimate of the slope or the intercept in the regression model was significantly different from zero, this would give evidence there is some influence on the sediment yield that is not taken into account by RUSLE2.

The null hypothesis for the regression is that the parameter estimate for the slope and intercept of the regression model is zero and if not rejected would suggest that RUSLE2 is a good method for predicting sediment erosion. The level of significance chosen for this linear regression model was 0.05. Anything where the F-test of the regression model parameter estimates had a probability greater than 0.05 suggests the null hypothesis is not rejected. In other words, there is evidence that RUSLE2 could be used to reliably predict sediment yields on construction sites.

Along with this, plots and tables were created in order to display the information for visual and qualitative analysis.

4.2.6.2 Sensitivity of Topography in RUSLE2 Calculations

Tables and graphs were used to display how the RUSLE2 calculations change as the topography in the catchment changes and how the estimates deviate from each other. The variance and standard deviation of the data were found using a couple of different methods. The first of which used the mean of the RUSLE2 calculations used as the mean in the variance calculation (equation 4.2) to understand the level of dispersion of the sediment yield estimates at different grading points. The second and third methods were to assess the level of dispersion between what would be the sediment yield estimate from a planning perspective, using the clearing and grubbing and final grade plans. The second method used the sediment yield estimate from RUSLE2 using the representative LS from the plans for the site as the mean in the variance equation (equation 4.2), and the third method used the sediment yield estimates from RUSLE2 using the average LS from the plans for the site as the mean in the variance equation (equation 4.2).

The equations 4.2 and 4.3 were used to find the variance and standard deviation respectively.

$$Var = \frac{\Sigma(x - \bar{x})^2}{n - 1} \qquad [4.2]$$

$$Std\ Dev = \sqrt{Var} \qquad [4.3]$$

4.3 Results and Discussion

4.3.1 Comparing Field Sediment Yields to RUSLE2 Calculations

4.3.1.1 Using the RUSLE2 sediment yield estimates based on topography from periodic surveys

The results from using the representative profiles from the respective surveys in RUSLE2 and the sediment yield from the field are displayed below in table 4-1.

Table 4-1. Results from field sediment yield and RUSLE2 calculations using survey profiles for each basin. Basins 11.4 B and 9.2 C included a clearing and grubbing (CG) phase and mass grading (MG) phase. Basin 10.3 B included a final grade (FG) and post paving (PP) phase. Basin 5.10 B included a clearing and grubbing (CG) phase.

Basin ID	Field Sediment Yield (Mg)	RUSLE2 Representative Slopes from Surveys (Mg)
11.4 B (CG)	0.674	0.651
11.4 B (MG)	28.0	2.64
9.2 C (CG)	30.2	1.74
9.2 C (MG)	14.5	0.330
10.3 B (FG)	1.37	0.178
10.3 B (PP)	0.00227	0.000267
5.10 B (CG)	5.74	3.31

The p-value for the F-test using the difference between RUSLE2 and field sediment yields was found to be 0.152 (n=7). This does not reject the null hypothesis that the difference between field and RUSLE2 is zero and suggests that the model can predict the field sediment yield. The parameter estimate for the intercept and slope with respective standard errors (SE) and p-values from t-tests are in table 4-2.

Table 4-2. Parameter estimates of the slope and intercept of the regression model using data based on survey topography. Model is: DIFF = (Slope)*(RUSLE2 Estimate) + Intercept + error.

Parameter	Estimate	Standard Error	t-test p-value
Intercept	-5.99	7.53	0.463
Slope	-3.78	3.90	0.380

The probabilities found through the t-test for these estimates are above the 0.05 level of significance to indicate they are not significantly different from zero, as is desired, but the somewhat high standard errors indicate these parameter estimates may be far from the true values. It also emphasizes the wide ranging differences between the field and RUSLE2 and the fact there is a limited data set.

Due to the fact that on Basin 5.10 B Posi-Shell was used to limit channelized erosion and is an atypical practice on NCDOT construction sites, the analysis was run again without the data point from this basin. In this case, the probability drops below the 0.05 level of significance ($n = 6$, p-value = 0.0229) and therefore the null hypothesis is rejected; RUSLE2 is not a good predictor of sediment yields. The parameter estimate for the intercept and slope for this analysis are in table 4-3.

Table 4-3. Parameter estimates of the slope and intercept of the regression model using data based on survey topography without data point from Basin 5.10 B. Model is: DIFF = (Slope)*(RUSLE2 Estimate) + Intercept + error.

Parameter	Estimate	Standard Error	t-test p-value
Intercept	1.90	4.97	0.722
Slope	10.6	3.40	0.036

Based on the probabilities of these, the intercept is not statistically very far from zero while the slope is far from zero. This indicates as the RUSLE2 estimate increases, the difference increases as well. The SEs for the estimate of the slope using and not using the data from Basin 5.10 B are similar indicating the spread of data for both analyses is similar.

Even though there was some damage to the Posi-Shell at the inlet (figure B2-28) and portions of the Posi-Shell which were worn away (figures B2-23 through B2-27), the channels were much better protected than on any of the previous basins. As a result, the comparison of the field sediment yield and RUSLE2 calculations helped to provide evidence that RUSLE2 was good at predicting sediment loads whereas the data would suggest RUSLE2 is not good at predicting sediment yields.

The reason the data from Basin 5.10 B made a dramatic difference to the tested hypothesis was because it was among the highest RUSLE2 estimated sediment yields and had a field sediment yield which was remarkable close compared to others. The finding that the data from Basin 5.10 B helped to give evidence that RUSLE2 is a good method for predicting sediment yields was also evident by a visual inspection of the graphs of the data in figures 4-2 and 4-3. In these graphs, the points are the plotted results from the field with the corresponding RUSLE2 estimates. The solid line is a one-to-one, 45 degree angle line to give spatial reference since the scales on the x and y axes are different. The dashed line is the regression line of the data plotted.

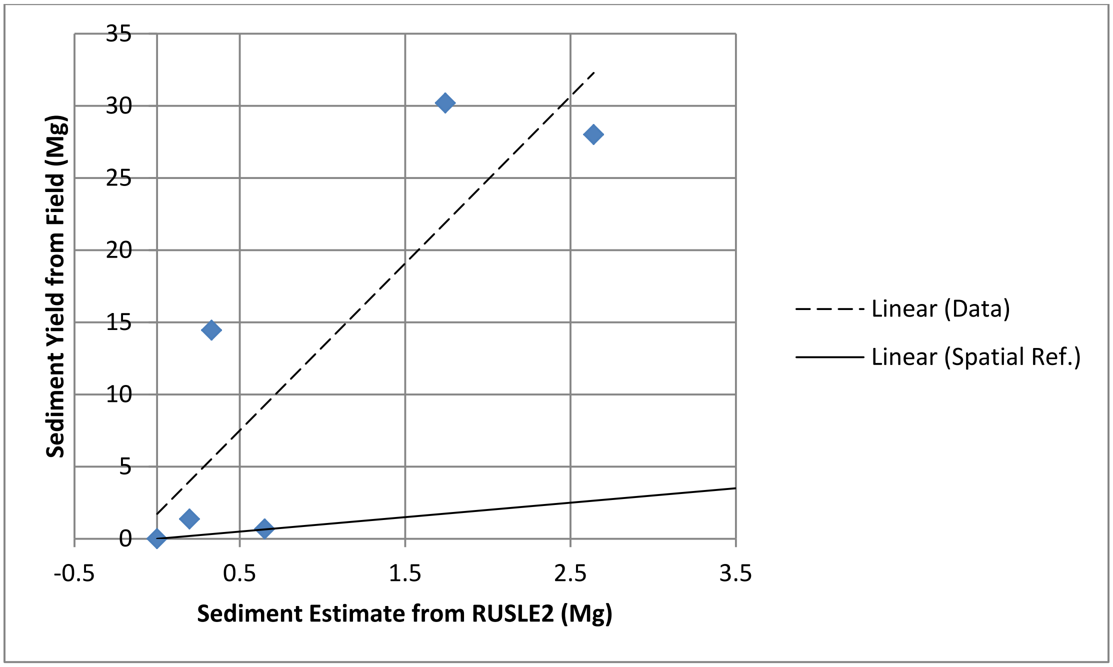

Figure 4-2. Graph of field sediment yield vs RUSLE2 estimate using survey topography without data point from Basin 5.10 B.

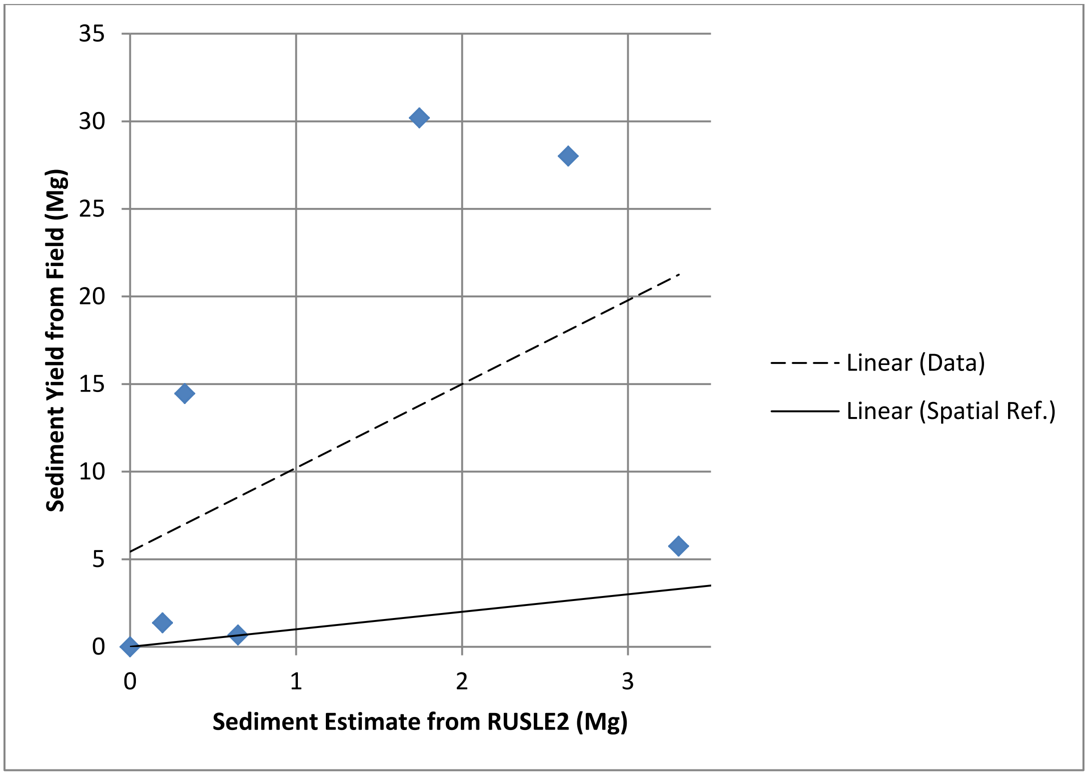

Figure 4-3. Graph of field sediment yield vs RUSLE2 estimate using survey topography with data point from Basin 5.10 B.

By including the final point from Basin 5.10 B to the graph, the slope of the regression line is brought closer the one-to-one line, which would result in the slope estimate in the regression model previously discussed being brought closer to zero.

4.3.1.2 Using the RUSLE2 estimates based on the topography from planning sets

The results from using the representative slope and area profiles and average slope profiles from plans in RUSLE2 and the sediment yield from the field are displayed in table 4-4.

Table 4-4. Results of the sediment yield from the field and RUSLE2 calculations using representative slopes and average slopes from plans. Basins 11.4 B and 9.2 C included a clearing and grubbing (CG) phase and mass grading (MG) phase. Basin 10.3 B included a final grade (FG) and post paving (PP) phase. Basin 5.10 B included a clearing and grubbing (CG) phase.

Basin ID	Field Sediment Yield (Mg)	RUSLE2 Representative Slopes from Plans (Mg)	RUSLE2 for Average Slope from Plans (Mg)
11.4 B (CG)	0.674	1.96	3.07
11.4 B (MG)	28.0	4.95	8.02
9.2 C (CG)	30.2	1.89	1.37
9.2 C (MG)	14.5	1.26	2.32
10.3 B (FG)	1.37	0.948	0.948
10.3 B (PP)	0.00227	0.00207	0.00207
5.10 B (CG)	5.74	7.62	6.83

In the analysis comparing the field sediment yields to the RUSLE2 estimates found using representative profiles and areas from the plans, the analysis suggested RUSLE2 was a good predictor of soil yields when the data point from Basin 5.10 B was (n = 7, p-value 0.3262) and was not (n = 6, p-value = 0.1242) included in the analysis. When the data point from Basin 5.10 B was removed from the data set, the p-value from the F-test increased indicating the linear regression model was statistically closer to zero than the model developed when all of the data was included.

The estimate of the slope and intercepts in the linear regression model tested with all of the data points is in table 4-5 and without Basin 5.10 B is in table 4-6.

Table 4-5. Parameter estimates of the slope and intercept of the regression model using data based on planning phase topography. Model is: DIFF = (Slope)*(RUSLE2 Estimate) + Intercept + error.

Parameter	Estimate	Standard Error	t-test p-value
Slope	-0.0809	2.12	0.971
Intercept	-9.49	8.50	0.315

Table 4-6. Parameter estimates of the slope and intercept of the regression model without using data point from Basin 5.10 B using data based on planning phase topography. Model is: DIFF = (Slope)*(RUSLE2 Estimate) + Intercept + error.

Parameter	Estimate	Standard Error	t-test p-value
Slope	-4.60	3.06	0.207
Intercept	-2.39	8.07	0.782

The p-values for each of the parameters are all significant at the 0.05 level and would be considered to be statistically close to zero.

The comparison of the average profiles slope and the field results with both approaches, (with and without the data point from Basin 5.10 B) both produced an F-test p-value above 0.05. The analysis suggested that RUSLE2 was a good method for predicting sediment yield with (n = 7, p-value = 0.253) and without (n = 6, p-value = 0.334) the data point from Basin 5.10 B. Also, the regression model tested using the data point from Basin 5.10 B produced an F-test p-value that is higher, again indicating the linear regression developed with the point from Basin 5.10 B was statistically closer to zero.

The estimates of the slope and intercept for the linear regression models using all of the data points is in table 4-7 and without the point from Basin 5.10 B is in table 4-8.

Table 4-7. Parameter estimates of the slope of the regression model using data based the on average slope of the catchment in the planning phase. Model is: DIFF = (Slope)*(RUSLE2 Estimate) + Intercept + error.

Parameter	Estimate	Standard Error	t-test p-value
Slope	-0.484	1.79	0.798
Intercept	-7.40	8.44	0.421

Table 4-8. Parameter estimates of the slope of the regression model without using data point from Basin 5.10 B using data based on the average slope of the catchment in the planning phase. Model is: DIFF = (Slope)*(RUSLE2 Estimate) + Intercept + error.

Parameter	Estimate	Standard Error	t-test p-value
Slope	-1.63	2.07	0.474
Intercept	-6.12	8.42	0.507

The p-values found for each of the parameters were all found to be significant at the 0.05 level and RUSLE2 would be considered a good method for predicting soil yield. The estimate of soil yield tended to be higher in these scenarios since the plans tended to have larger catchments, steeper slopes, and fewer areas for deposition than what was actually on the site.

4.3.1.3 Comparing on a storm-by-storm basis the RUSLE2 sediment yield estimate to the field sediment yield

The results from using RUSLE2 to calculate sediment yields from single storm events and the sediment yield from the field from the respective storm are displayed in table 4-9.

Table 4-9. Results from RUSLE2 sediment calculation using respective survey topography for individual storms and field sediment yields.

Basin ID	Date	RUSLE2 Sediment Estimate (kg)	Sediment Yield from Field (kg)
11.4 B	9/30/2010	466	44.4
11.4 B	10/28/2010 Early	968	494
11.4 B	10/28/2010 Late	200	192
11.4 B	11/16/2010	188	2730
11.4 B	12/12/2010	79.0	86.6
11.4 B	12/16/2010	65.8	85.6
11.4 B	1/26/2011	65.9	2.10
11.4 B	2/4/2011	106	136
11.4 B	3/6/2011	83.0	17.1
11.4 B	3/30/2011	163	9150
11.4 B	4/9/2011	10300	2300
11.4 B	4/16/2011	1360	24800
11.4 B	5/4/2011	5.60	22.9
9.2 C	3/26/2011	69.0	61.4
9.2 C	3/30/2011	58.3	320
9.2 C	4/8/2011	469	1320
9.2 C	4/16/2011	773	6270
9.2 C	5/4/2011	28.8	6.00
9.2 C	6/27/2011	779	6910
9.2 C	7/6/2011	109	4150
9.2 C	8/6/2011	21.1	1260
9.2 C	8/12/2011	870	6020
9.2 C	8/21/2011	13.7	4060
9.2 C	8/26/2011	96.5	4680
10.3 B	6/28/2011	111	543
10.3 B	8/12/2011	93.3	277
10.3 B	9/6/2011	760	18.0
10.3 B	9/23/2011	22.6	1.10
10.3 B	9/28/2011	86.3	13.5
10.3 B	10/18/2011	884	12.8
10.3 B	11/4/2011	3.50	2.30
5.10 B	Early 8/6/2011	310	759
5.10 B	Late 8/6/2011	174	114
5.10 B	8/12/2011	2250	636

Table 4-9. Continued

5.10 B	8/21/2011	521	364
5.10 B	8/26/2011	310	375
5.10 B	9/6/2011	10200	199
5.10 B	9/21/2011	778	508
5.10 B	9/23/2011	237	18.3
5.10 B	10/29/2011	273	45.8
5.10 B	11/4/2011	513	225
5.10 B	11/23/2011	3095	1470
5.10 B	11/29/2011	2600	1040

When all storms were analyzed in SAS, the results indicated that the null hypothesis should be rejected (p-value = 0.0046) and that RUSLE2 does not predict the actual field sediment yield based on the level of significance chosen of 0.05.

Table 4-10. Parameter estimates of the slope and intercept in the regression model using the RUSLE2 on an individual storm basis with the respective survey for topography. Model is: DIFF = (Slope)*(RUSLE2 Estimate) + Intercept + error.

Parameter	Estimate	Standard Error	t-test p-value
Slope	-0.952	0.296	0.0025
Intercept	1810	698	0.0129

Based on the estimate of the slope and intercept in the linear regression model, the t-test p-value indicates the estimate is far from the desired value of zero, and a relatively low SE value indicating the estimate is relatively close to the true parameter value (Table 4-10).

The intercept estimate was found to be positive while the estimate of the slope was found to be negative. This indicates that the difference (Field – RUSLE2) will be positive when RUSLE2 estimates are low and negative when RUSLE2 estimates are high. In other words, RUSLE2 will under-predict when the estimate is low and over predict when the estimate is high which is evident in figure 4-4.

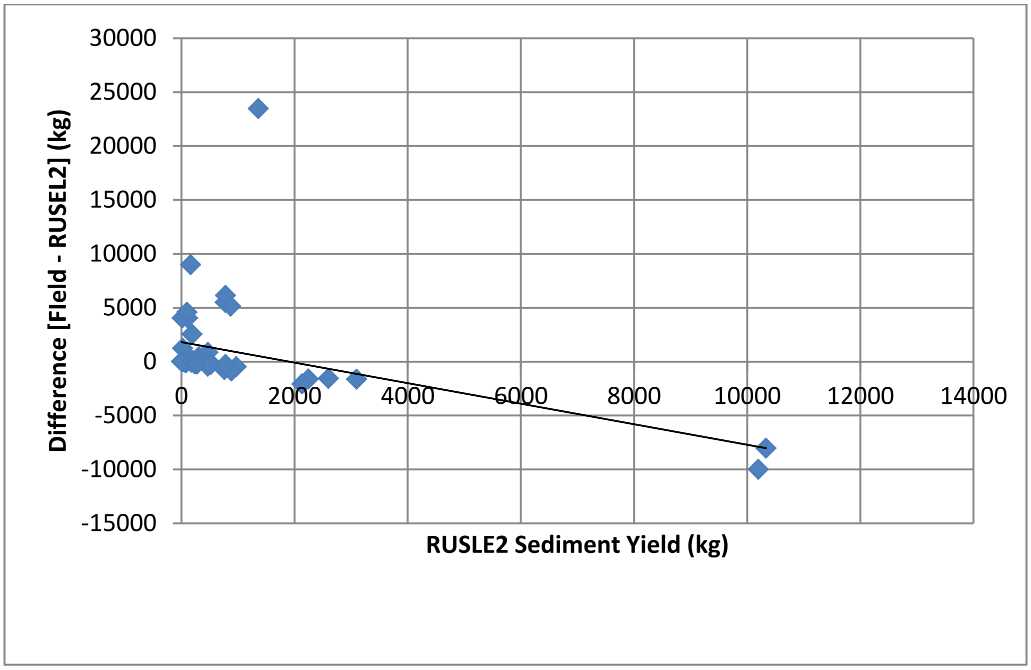

Figure 4-4. RUSLE2 sediment yield estimates plotted against the difference between the field and RUSLE2 sediment yields

It is also evident, the differences in the RUSLE2 estimates and field values, in figure 4-5 where the linear regression model on the sediment yield from each storm and the respective RUSLE2 value had a different slope and intercept than the desired 1:1 line, which is dotted in the figure.

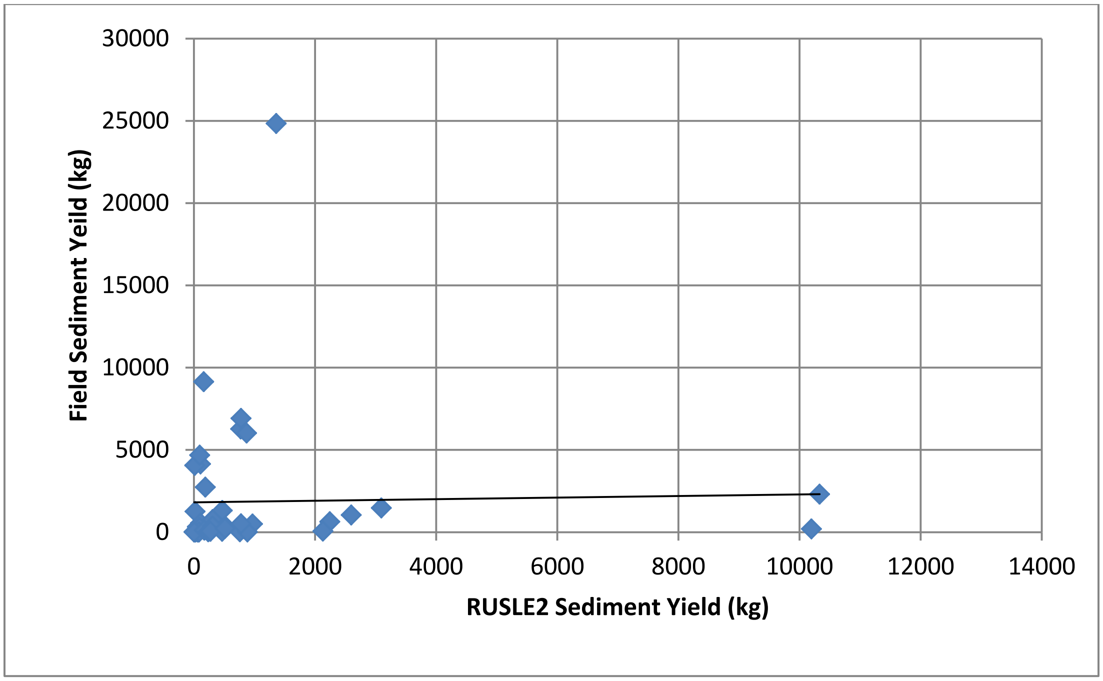

Figure 4-5. Plotted storms with field sediment yield and RUSLE2 calculated sediment yield on an individual basis.

An EI in RUSLE2 of zero would give an estimate of zero and would have zero sediment yields in the field. To understand whether the intercept was influencing the fact that the difference tended to be negative given the estimate from RUSLE2, the regression model was calculated again with the intercept forced to zero. The parameter estimate of the slope is listed in table 4-11.

Table 4-11. Parameter estimate of the slope and the intercept forced to be zero in the regression model using the RUSLE2 on an individual storm basis with the respective survey for topography. Model is: DIFF = (Slope)*(RUSLE2 Estimate) + error.

Parameter	Estimate	Standard Error	t-test p-value
Slope	-0.635	0.287	0.0323

The negative slope indicates the difference will become more negative as the RUSLE2 estimate increases. In other words, RUSLE2 will typically over-predict the actual sediment yield.

This is contrary to what the dependent mean indicates. The dependent mean of the difference for all of the storms is 886 kg. This being positive lends the idea that RUSLE2 will typically under-predict, and is a similar conclusion to what was found earlier when RUSLE2 was evaluated on a period basis.

In the figures, it is apparent there are a couple of points where RUSLE2 greatly over-predicted which could force the linear regression model to have a negative slope. One possible reason that these estimates were over-predicted by RUSLE2 is because there was an assumption that the rain gage collected a representative rainfall intensity and volume for all of the basins monitored. These values were used in the calculation of the erositivity value which the sediment yield calculated in RUSLE2 was highly dependent. Since the rain gage was only located on one basin and due to the nature of thunder storms, the intensity gathered at one location could have been much different than the actual intensity at another. If the intensity was much higher at the basin where the data was collected than one of the other basins being monitored, the RUSLE2 EI would be relatively high resulting in a high erosion estimate. If the intensity at the basin without a rain gage was relatively low, the same processes of erosion due to the high intensity event would not be apparent in the sediment yield collected for that storm at the ungagged basin.

Another possibility is the deposition of sediments in the silt ditches behind wattles and other BMPs. On Basin 5.10 B in particular, most of the estimates from RUSLE2 are greater than those found by the samplers. It was assumed that once the flow enters a channelized area, that the sediment will reach the basin because of a lack of ability to include depositional BMPs in RUSLE2 and take that into account. Since the sediment build-up wasn't accounted on a storm-by-storm basis, if a lot of sediment settled out in the ditch before reaching the basin, RUSLE2 would over-estimate in these instances.

Also, particularly during high intensity events, there was physical evidence flows were moving over top of the berm at the inlet. Flow moving over the berm would be largely unaccounted for by the sampler and means more sediment than what was collected using the automated samplers would have entered the basin. In other words, more sediment could have eroded from the catchment and entered the basin by by-passing the inlet and the amount of sediment load found using the sampler data would have been far less than the true amount of sediment.

A combination of these occurrences was responsible for the two cases where RUSLE2 over-predicted greatly. The first of these being, that the storm on 4/9/2011 at Basin 11.4 B had evidence of flow moving over the top of the berm. For the second point, there was evidence flow was moving over the top of the berm and the intensity for the site was assumed since the rain gauge was located on another site being monitored. Both sites probably had some level of deposition in the silt ditches before entering the basin.

Again, the thought that RUSLE2 may tend to over-predict is likely due to the two points where RUSLE2 greatly over predicted sediment yields on Basin 11.4 B on 4/9/2011 and on Basin 5.10 B on 9/6/2011. This was also confirmed by evaluating the data using Cook's D test (figure4-6) to find questionable data in a set. This test is a commonly used test in statistics applied to data to seek out points that might be questionable and worth checking for their validity (Bollen and Jackman, 1990).

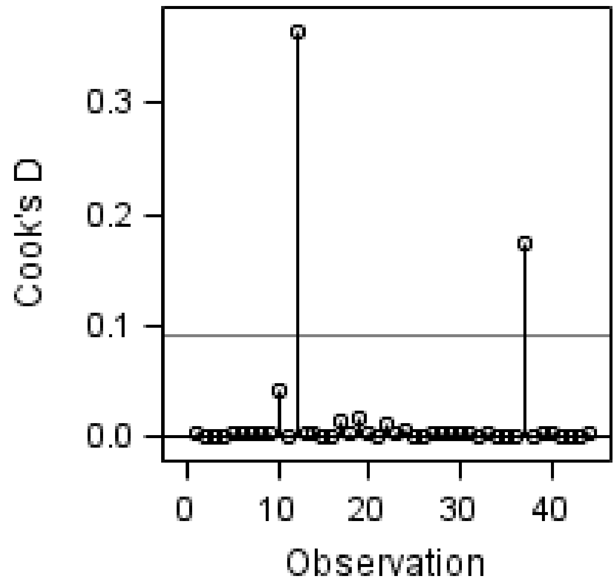

Figure 4-6. Cook's D test plot. Those points above the horizontal line are considered to be outliers.

Removing these points and forcing the intercept to zero, the parameter estimate for the slope becomes positive (table 4-12).

Table 4-12. Parameter estimate of the slope in the regression model using the RUSLE2 on an individual storm basis with the respective survey for topography. Model is: DIFF = (Slope)*(RUSLE2 Estimate) + error.

Parameter	Estimate	Standard Error	t-test p-value
Slope	0.857	0.745	0.257

The slope estimate for the regression model was positive without the two aforementioned data points and the dependent mean of the full data set being positive. This suggests that on an individual basis, RUSLE2 tends to under-predict the sediment yield from a storm. This is concurrent with the earlier findings when RUSLE2 was evaluated on a period basis.

In order to understand whether the data was site dependent, the data were separate by site and the same statistical test was performed. All but basin 11.4 B provided F-test p-values less than 0.05. The statistics calculated on the data for all of the basins in is table 4-13.

Table 4-13. P-values derived from an F-test of the regression models developed using the RUSLE2 on an individual storm basis and separating the data by site with the respective survey for topography. Model is: DIFF = (Slope)*(RUSLE2 Estimate) + Intercept + error.

Basin ID	Sample Number	F-test P-value	Mean Square Error
11.4 B	13	0.37	7300
9.2 C	11	0.014	1970
10.3 B	7	0.01	222
5.10 B	13	<0.0001	451

The reason the data on 11.4 B gave a value greater than 0.05 and therefore suggested RUSLE2 was a good method for predicting soil erosion was probably due to coincidence rather than anything else. There is evidence of the high level of randomness and inconsistency in the data for 11.4 B, or a wide spread in the data. This is apparent by looking at the relatively high root mean squared error compared to the others (table 4-13).

In order to understand whether the data was dependent on intensities of the storm, the data were separated and analyzed based on the rainfall intensity. The analysis of the storms with intensities greater than 12.7 mm/hr (n = 20) suggested that RUSLE2 was not a good method for predicting soil yields (p-value = 0.0045). The parameter estimates for intercept and slope are listed in table 4-14. Analyzing only the storms with intensities less than 12.7 mm/hr did suggest RUSLE2 was good at predicting sediment yields (p-value = 0.1516) (n = 24). The parameter estimates for the intercept and slope are listed in table 4-15.

Table 4-14. For storms collected with intensities greater than 12.7 mm/hr, Parameter estimates of the slope and intercept in the regression model using the RUSLE2 on an individual storm basis with the respective survey for topography. Model is: DIFF = (Slope)*(RUSLE2 Estimate) + Intercept + error.

Parameter	Estimate	Standard Error	t-test p-value
Intercept	3180	1490	0.0474
Slope	-1.12	0.443	0.0211

Table 4-15. For storms collected with intensities less than 12.7 mm/hr, Parameter estimates of the slope and intercept in the regression model using the RUSLE2 on an individual storm basis with the respective survey for topography. Model is: DIFF = (Slope)*(RUSLE2 Estimate) + Intercept + error.

Parameter	Estimate	Standard Error	t-test p-value
Intercept	877	474	0.0775
Slope	-0.874	0.55	0.127

This suggests that RUSLE2 may be better at predicting sediment yields from storms with lower intensities. Based on observations of the site after lower intensity versus higher intensity storms, lower intensities storms are more likely to have lower velocities and shear stress in the channels which would limit the level of gully erosion, and is not modeled by RUSLE2.

Overall RUSLE2 would not be a good predictor of soil erosion yields and tends to under-predict sediment yield estimates for individual storms with typical managements and operations on NCDOT construction sites. This is based on the positive dependent mean of the data, the high estimate of the intercept when all of the data was used in the regression model, and the positive estimate of the slope in the regression model when the questionable data points were removed from the data set. These findings also suggest that RUSLE2 may be better at predicting sediment yields from storms with intensities less than 12.7 mm/hr. The reason RUSLE2 tended to under-predict was because of the influence from channel erosion on the total sediment load entering the basin. This is similar to what was found when RUSLE2 was evaluated by period.

4.3.2 Sensitivity of Topographic Element in RUSLE2

Since the sediment yield can change based on the differences in the topography and through the progress of the project the topography can change dramatically and without warning, it was important to evaluate how different sediment yield could deviate from each other. In order to accomplish this while eliminating the environmental differences, the sensitivity of the topographic element in RUSLE2 was evaluated. This, as opposed to comparing sediment yields in the field at different points in the grading process, which could deviate based on differences in storm intensities, covers, etc.

Among the different surveys taken and the plans for each basin, the area of the catchment for the basin deviated. In order to eliminate the influence of differences in area to make a fair comparison among surveys and plans, the results from these calculations were presented in both Mg and Mg per hectare. The variance and standard deviation were all calculated in terms of Mg per hectare.

4.3.2.1 Basin ID 11.4 B

The tables 4-16 and 4-17 show the sediment yields calculated using RUSLE2 with the respective survey or plan set, and the variance and standard deviation for Basin 11.4 B respectively.

Table 4-16. The RUSLE2 calculation of sediment yield for the respective survey or plan set for Basin 11.4 B.

Survey Date	Area	RUSLE2 Calculations	
	(ha)	Mg/ha	Mg
9/14/2010	0.739	3.24	2.40
11/30/2010	1.09	4.65	5.07
12/14/2010	1.22	5.53	6.85
2/3/2011	1.19	4.15	4.95
3/15/2011	0.571	4.00	2.29
4/25/2011	0.728	2.27	1.55
CG Plans (Rep Slp)	1.05	6.50	6.84
CG Plans (Avg Slp)	1.05	10.5	11.1
FG Plans (Avg Slp)	0.688	1.35	0.925

Table 4-17. The variance and standard deviation of the RUSLE2 sediment yield estimates using survey data from each other and from the plans for Basin 11.4 B.

	Between Surveys (Mg/ha)	With CG Plans (Representative Slopes) as Mean (Mg/ha)	With CG Plans (Average Slopes) as Mean (Mg/ha)	With FG (Average Slopes) as Mean (Mg/ha)
Variance	0.81	8.94	53.0	9.55
Standard Deviation	0.90	2.99	7.28	3.09

The differences in sediment yield calculated by RUSLE2 suggest the sediment yields calculated from the surveys can vary dramatically as the topography changes in the catchment based on the range of 2.3 and 5.5 Mg/ha and the standard deviation being 0.9 Mg/ha. It is also evident that the sediment yield estimate in the field would deviate from the planning sets because of the differences in the topography between the two. This is seen by the large standard deviations from the means as defined as the RUSLE2 estimate from the using the topography from the different planning sets.

Figure 4-7 shows how the RUSLE2 predictions change over time as the topography changes in terms of tons, and how each of those would compare to the RUSLE2 calculation determined from the plans.

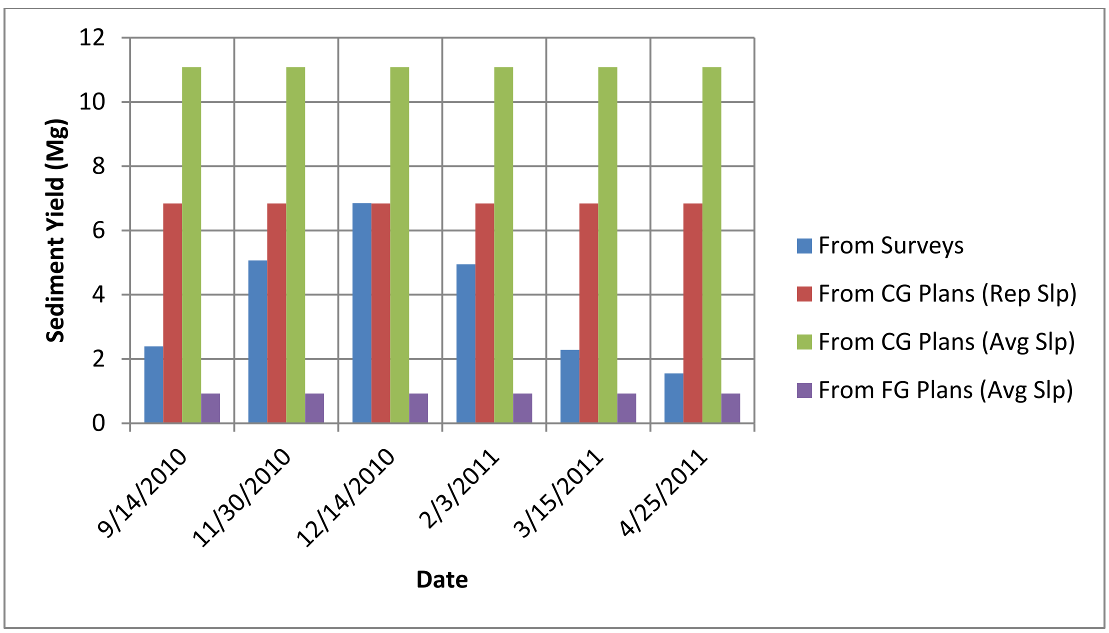

Figure 4-7. Comparison of sediment yields calculated by RUSLE2 in tons as the topography of the catchment for Basin 11.4 B changes.

By evaluation of the graph, it suggests that if the clearing and grubbing were used to estimate soil yield, it would typically be an over-estimate purely due to the differences in topography. Also, the sediment yield calculated using the representative slope was closer to the sediment yield estimate using the survey data than the than the sediment yield based on the average slope.

This is opposite of the case for the final grade plans where the estimates using this method were always an under-estimate compared to the estimate found using survey data.

4.3.2.2 Basin ID 9.2 C

The tables 4-18 and 4-19 below show the sediment yields calculated using RUSLE2 with the respective survey or plan set, and the variance and standard deviation for Basin 9.2 C respectively.

Table 4-18. The RUSLE2 calculated sediment yield for the respective survey or plan set for Basin 9.2 C.

Survey Date	Area	RUSLE2 Calculations	
	(ha)	Mg/ha	Mg
4/25/2011	2.20	1.41	3.10
6/8/2011	2.12	1.39	2.95
8/10/2011	1.72	0.992	1.71
9/16/2011	1.76	0.473	0.832
CG Plans (Rep Slp)	2.35	1.35	3.16
CG Plans (Avg Slp)	2.35	1.57	3.69

Table 4-19. The variance and standard deviation for the RUSLE2 sediment yields using survey data from each other and from the RUSLE2 sediment yield estimates using planning schemes for Basin 9.2 C.

	Between Surveys (Mg/ha)	With CG Plans (Representative Slope) as Mean (Mg/ha)	With CG Plans (Average Slope) as Mean (Mg/ha)
Variance	0.310	0.297	0.530
Standard Deviation	0.557	0.545	0.728

The range of RUSLE2 sediment yield estimates using survey data ranged between 0.47 and 1.4 Mg/ha. For the RUSLE2 estimates using the topography from plans, the range was between 1.3 and 3.7 Mg/ha. The narrow range of variances and standard deviations suggests there was not a lot of spread or variation in the data.

Figure 4-8 below shows how the RUSLE2 estimation changed over time as the topography of the catchment changed, and also compares that to the estimation obtained by using the planning schemes.

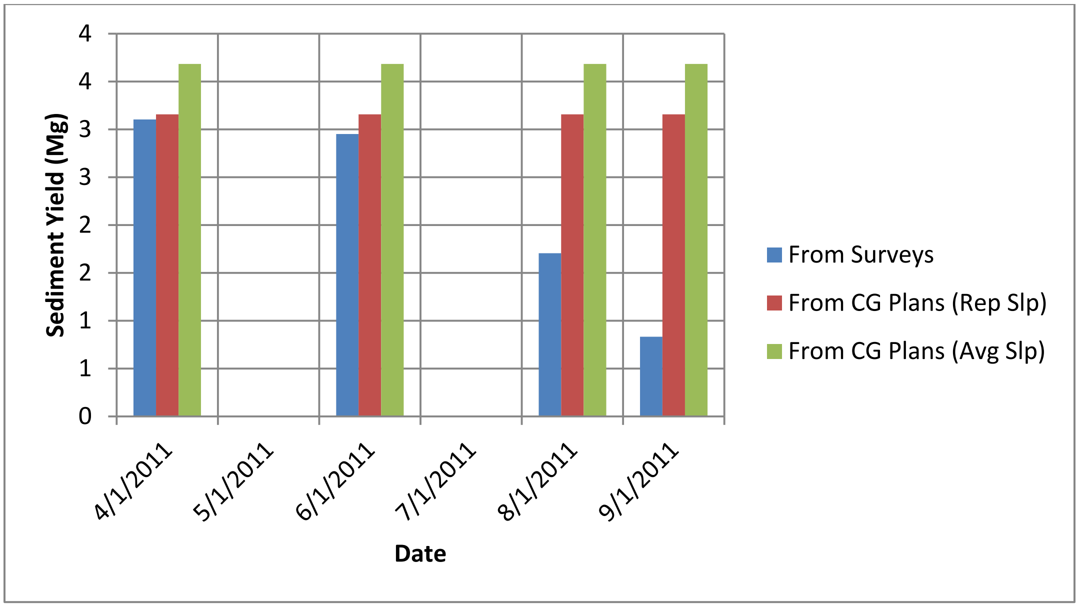

Figure 4-8. Comparison of sediment yields calculated by RUSLE2 in tons as the topography of the Basin 9.2 C changes over time.

The estimation of sediment yield based on the survey data is consistently below the estimation from the planning schemes. The variance and standard deviations found using this data were considerably less than those found using the data from Basin 11.4 B. The reason for this is because of the limited amount of change to the topography during course of monitoring. The surveys taken on 4/25/2011 and 6/8/2011 were very similar to what was given on the clearing and grubbing plans which is validated by the fact that the RUSLE2 estimates using those sets of topography are close to the estimate calculated for the representative slope from the clearing and grubbing plans and observations of the site during those survey dates.

4.3.2.3 Basin ID 10.3 B

The tables 4-20 and 4-21 show the sediment yield estimation using RUSLE2 with the respective survey or set of plans, and the variance and standard deviation confidence for Basin 10.3 B respectively.

Table 4-20. Sediment yields using RUSLE2 with the respective survey or plan set for Basin 10.3 B.

Survey Date	Area (ha)	RUSLE2 Calculations Mg/ha	Mg
6/8/2011	0.231	1.85	0.427
8/10/2011	0.153	0.0390	0.00600
11/14/2011	0.0920	0.0360	0.00300
CG Plans (Rep Slope)	1.58	3.06	4.84
CG Plans (Avg Slope)	1.58	2.91	4.60
FG Plans (Avg Slope)	0.769	1.23	0.948

Table 4-21. Variance and standard deviation of the RUSLE2 results for Basin 10.3 B.

	Between Surveys (Mg/ha)	With CG Plans (Representative Slope) as Mean (Mg/ha)	With CG Plans (Average Slope) as Mean (Mg/ha)	With FG (Average Slope) as Mean (Mg/ha)
Variance	0.804	9.90	8.85	1.62
Std Dev	0.897	3.15	2.97	1.27

The standard deviation from the estimates using the clearing and grubbing (CG) plans were much greater than the standard deviation from the estimates using the final grade (FG) plans, and were further from the standard deviation of sediment yield estimates from surveys.

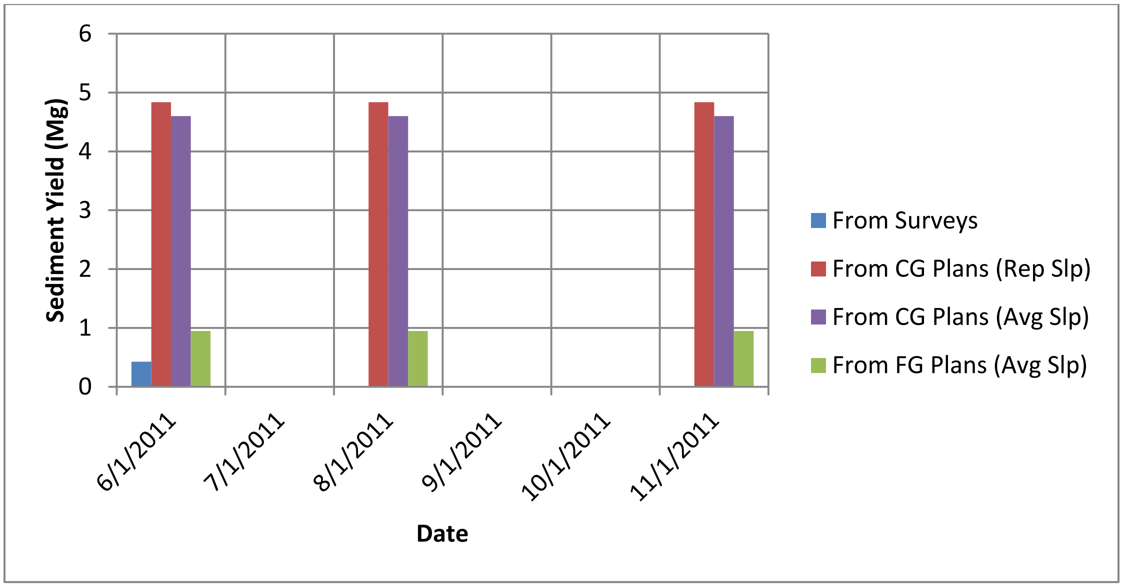

Figure 4-9. Comparison of RUSLE2 estimates of sediment yield over time as topography changes, and to planned estimates for Basin 10.3 B.

Since the surveys were taken at the point that the catchment was at final grade, the sediment yield estimates based on the survey data should be closer to the estimates based on the final grade contouring. The sediment yield using the survey data was consistently lower than the estimate found using any of the construction plans and decreased as the project progressed, and as expected closer to the sediment yield estimates based on the final grade contours.

The reason the sediment yield estimates from the surveys continued to decrease was due to the changing size of the catchment. Between the survey taken on 6/8/2011 and 8/10/2011, the silt ditch which captured run off from the future road bed was flattened which effectively re-routed a portion of the catchment into a basin further down the project. This forced the estimates down because of the smaller contributing area and shorter length slopes than what was in the plans.

4.3.2.4 Basin ID 5.10 B

In tables 4-22 and 4-23 are the results from using RUSLE2 to calculate sediment yields for different surveys taken over the monitoring period, and the variance and standard deviation for Basin 5.10 B respectively.

Table 4-22. The sediment yield estimates using RUSLE2 with various surveys and sets of plans for Basin 5.10 B.

Survey Date	Area	RUSLE2 Calculations	
	(ha)	Mg/ha	Mg
8/10/2011	0.854	6.88	5.76
11/14/2011	0.780	6.94	4.29
12/13/2011	0.657	5.74	3.77
CG Plans (Rep Slope)	0.708	10.8	7.62
CG Plans (Avg Slope)	0.708	16.4	11.6

Table 4-23. The variance and standard deviation between the RUSLE2 sediment yield estimations for various surveys and plans for Basin 5.10.

	Between Surveys (Mg/ha)	With CG Plans (Representative Slope) as Mean (Mg/ha)	With CG Plans (Average Slope) as Mean (Mg/ha)
Variance	0.518	27.43	146
Standard Deviation	0.720	5.24	12.1

The standard deviation among the different surveys was relatively low compared to the standard deviations from the sediment yield estimates using the any planning method.

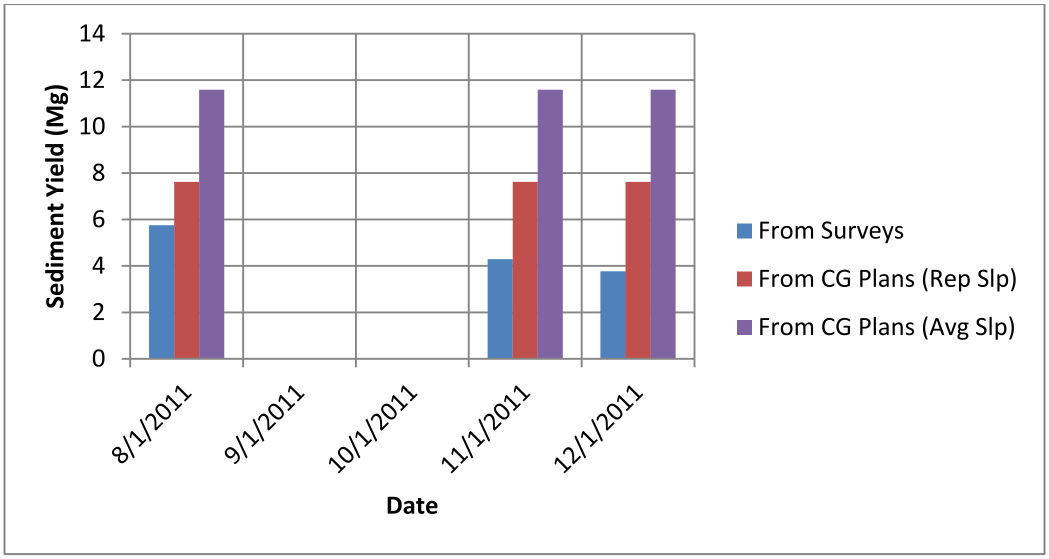

Figure 4-10. Comparison of the RUSLE2 sediment yield estimate over time as topography changes, and to plan sets of basin 5.10 B.

Based on figure 4-10, it is apparent that using the survey data to estimate sediment yield produces a consistently lower estimate of sediment from the catchment for the period that was monitored on Basin 5.10 than by using the clearing and grubbing plans; both representative slope and average slope. This is most likely due to the lack of depositional areas in RUSLE2 from the plans. There were more flat areas created in the catchment then what was provided in the plans which allowed for deposition in the RUSLE2 emulations.

4.4 Conclusion

4.4.1 Comparing RUSLE2 estimates using topography from surveys to field results

Based on these results, RUSLE2 would not give a reliable prediction of sediment yield on a highway construction site with management sequences typical on NCDOT highway construction. Even though the hypothesis that the RUSLE2 estimate and the actual field sediment yield are similar was not rejected, the fact that without the final basin being included, which had the channels well protected with a relatively stable catchment, the hypothesis was rejected. Furthermore physical evidence suggested the possibility that the amount of sediment collected by some of the samplers during some storm events suggests the field sediment yields are lower than the true amount of sediment that eroded and entered the basin. Documented evidence of this along with evidence of heavy channel erosion and sidewall failure in the silt ditches is in appendix B (figures B4-1 through B4-22).

At the very least, in order to use RUSLE2 to estimate sediment yield and calculate sediment storage volume, the channelized flow areas need to be protected in order to limit channel erosion. The data also suggest that RUSLE2 may be better at predicting sediment yields from lower intensity events.

These conclusions were based on a relatively limited data set for evaluating RUSLE2 over several periods of the construction process and overall applied RUSLE2 in scenarios that it was not intended to reliably predict sediment yields.

RUSLE2 would be best applied in a situation where the catchment has a limited amount of change and is relatively stable. In order to assure there is no under-prediction by RUSLE2, the worst case scenario of the plans would need to be modeled. Based on the results of this research, this would be the average slope from the catchment plans with the steepest slopes nearest the basin.

Since RUSLE2 is only capable of estimating rill and interrill erosion it is crucial that the erosion and failures typically seen in the silt ditches in this study is eliminated from a site. This was apparent do to the improved results for the basin where the silt ditches were well protected. Furthermore it may be best to apply RUSLE2 in areas where storms typically have lower intensities which may prevent major channel erosion.

Further research on construction sites could include removing wattles and rock check dams in the silt ditches since these BMPs cannot be modeled and are not accounted for in the RUSLE2 sediment prediction.

4.4.2 Comparing RUSLE2 estimates using planning set topography to the field sediment yields

Similar to the results using survey topography, even though the statistical test found that the null hypothesis should not be rejected, the evidence of channel and gully erosion along with high levels of variability in the sediment estimates suggest that RUSLE2 may not be a good predictor of sediment yields on NCDOT construction sites using the planning topography under the current practices. RUSLE2 tends to under-predict the actual sediment yield.

To reiterate, this is also a limited data set and further research should be conducted to confirm these findings.

4.4.3 Comparing RUSLE2 estimates on a storm-by-storm basis to the field sediment yields

In this case, the statistical analysis with all of the data included showed that the null hypothesis should be rejected and that RUSLE2 would not be a good method for estimating sediment yields on a storm-by-storm basis. From further evaluation of the data and eliminating some outlier points, the statistical analysis suggested that RUSLE2 would tend to under-predict the true sediment yields for similar reasons as in the previous sections. Further research should be performed to confirm these findings.

4.4.2 Sensitivity of Topography in RUSLE2 Calculations

The sediment yield tended to deviate as the topography changed in the catchment from what was planned. The sediment yield estimates were always lower using the topography from the surveys as opposed to the estimates calculated using the topography from planning sets, and also depended on what phase the site was closest to when the survey was taken; clearing and grubbing or final grade. The sediment yield estimates generally started high and decreased as the topography approached final grade. This is because as the catchment went from the topography in the clearing and grubbing phase to the final grade, the catchment slopes near the basin became much shallower. Even with steep slopes on the sides, the shallow slopes of the road bed area allowed for deposition to take place in the calculation of sediment yield in RUSLE2.

The sediment yield estimates tended to be lower when the representative slopes based off of the clearing and grubbing plans were used as opposed to the average slope from the plans due to the deposition that could take place in a representative profile. The sediment yield estimate using the topography from the representative slope method also tended to be closer to the estimate found from the survey. The most conservative estimate of sediment yield in terms of having the highest sediment yields tended to be when the topography from the average slope of the clearing and grubbing phase was used. The least conservative method tended to be when the topography from the final grade was used to estimate sediment yield in RUSLE2.

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APPENDICES

Appendix A

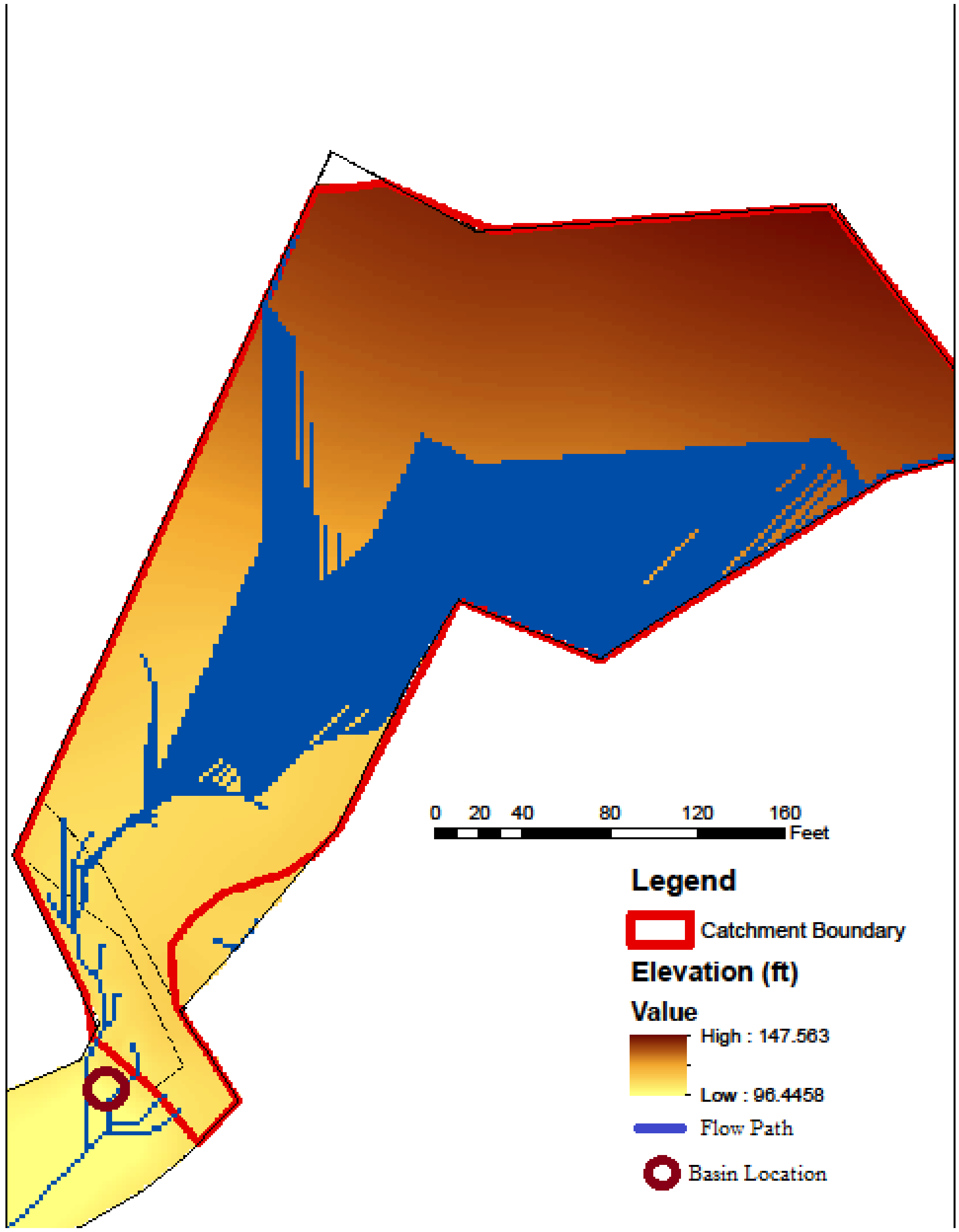

Figure A2-1. GIS processed survey from basin ID 11.4 B on 09.14.10

Figure A2-2. Photograph from 9.14.10 when the survey was taken on Basin 11.4 B. The orientation of the photograph was looking from the top of the catchment toward the basin in the top left corner of the image. The entire area was strawed and tacked soon after the clearing and grubbing stage of the project with some vegetation and piles of chipped trees.

Figure A2-3. Photograph from 9.14.10 when the survey was taken on Basin 11.4 B. The orientation of the photograph was looking up into the catchment near the basin's location.

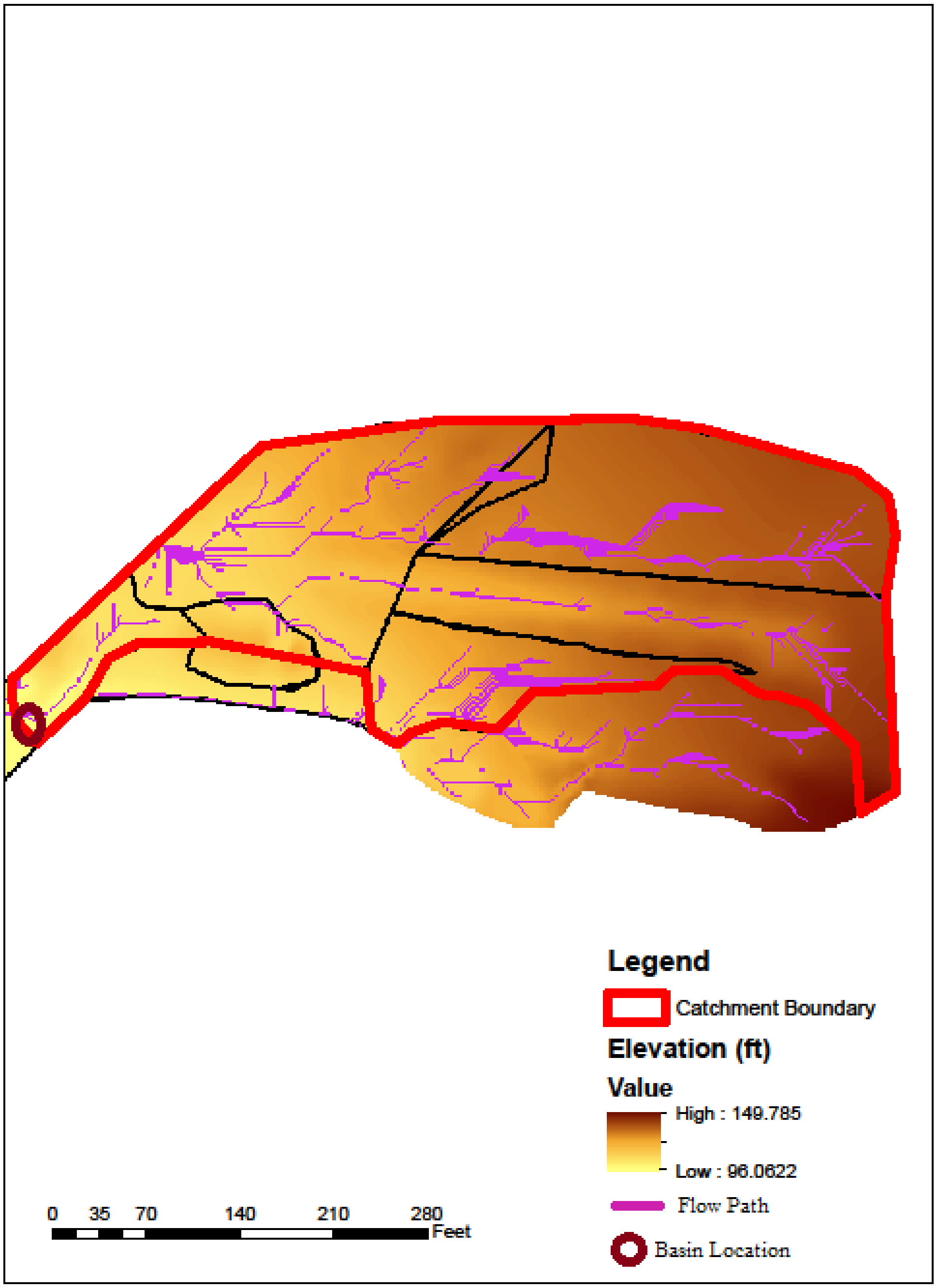

Figure A2-4. GIS processed survey from basin ID 11.4 B on 11.30.10

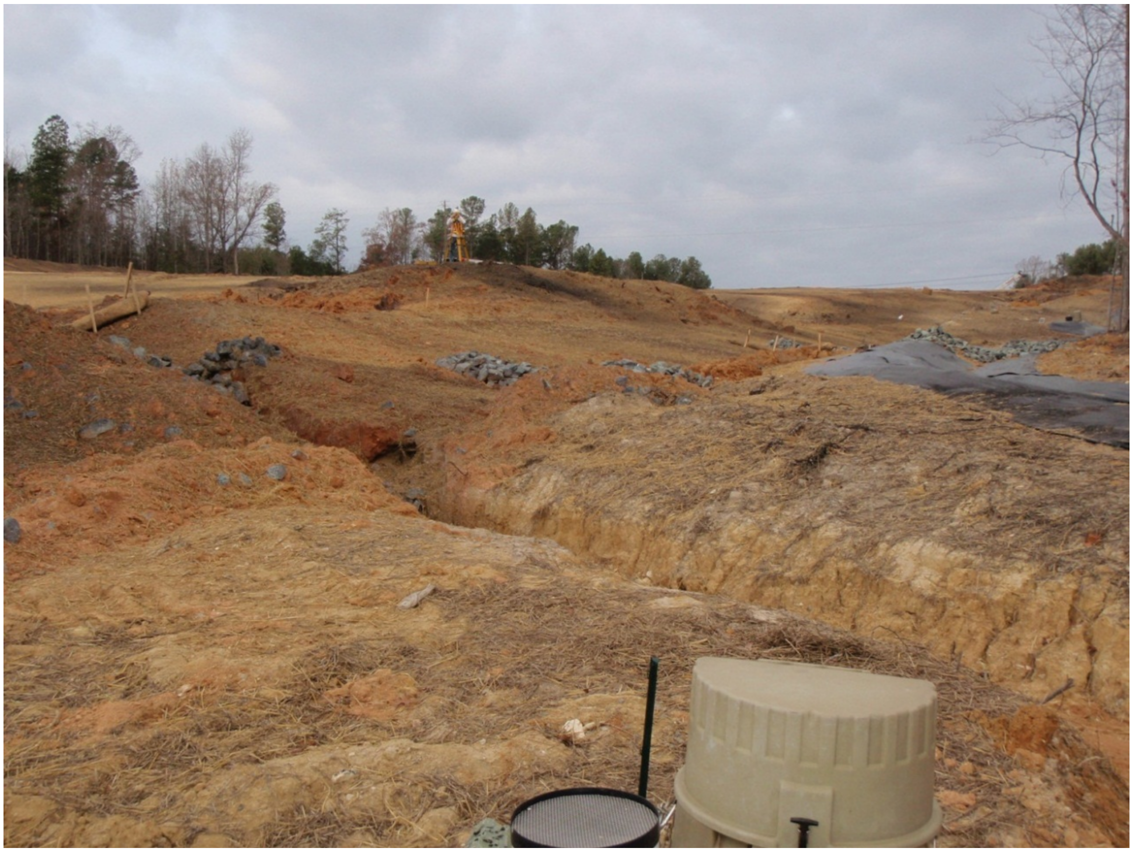

Figure A2-5. Photograph from 11.30.10 when the survey was taken on Basin 11.4 B. The orientation of the photograph is looking up into the catchment from the location of the basin's location. A fill pile (center, where total station set up is located in the photograph) was moved into catchment. There was some grading in the center of the catchment, but not dramatic. The entire area was strawed and tacked with no vegetation or chipped wood present.

Figure A2-6. Photograph from 11.30.10 when the survey was taken on Basin 11.4 B. The orientation of the photograph is looking up into the catchment from the opposite side of the catchment from the basin's location.

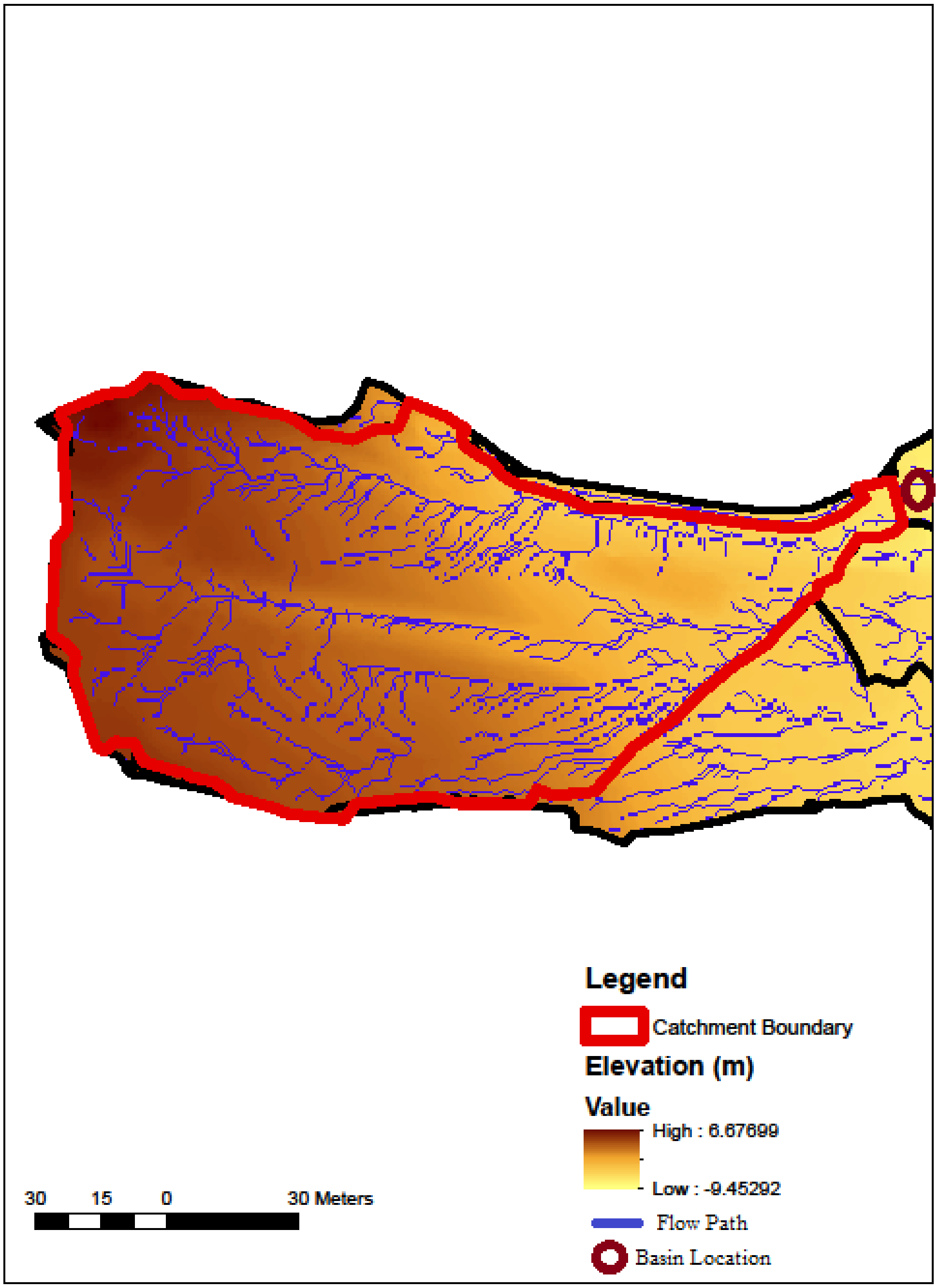

Figure A2-7. GIS processed survey from basin ID 11.4 B on 12.14.10.

Figure A2-8. Photograph from 12.14.10 when survey was taken. This is the first survey taken with LiDAR. The orientation of the photograph is from inlet of basin. The catchment was very similar to when previous survey was taken. There was very limited change to topography.

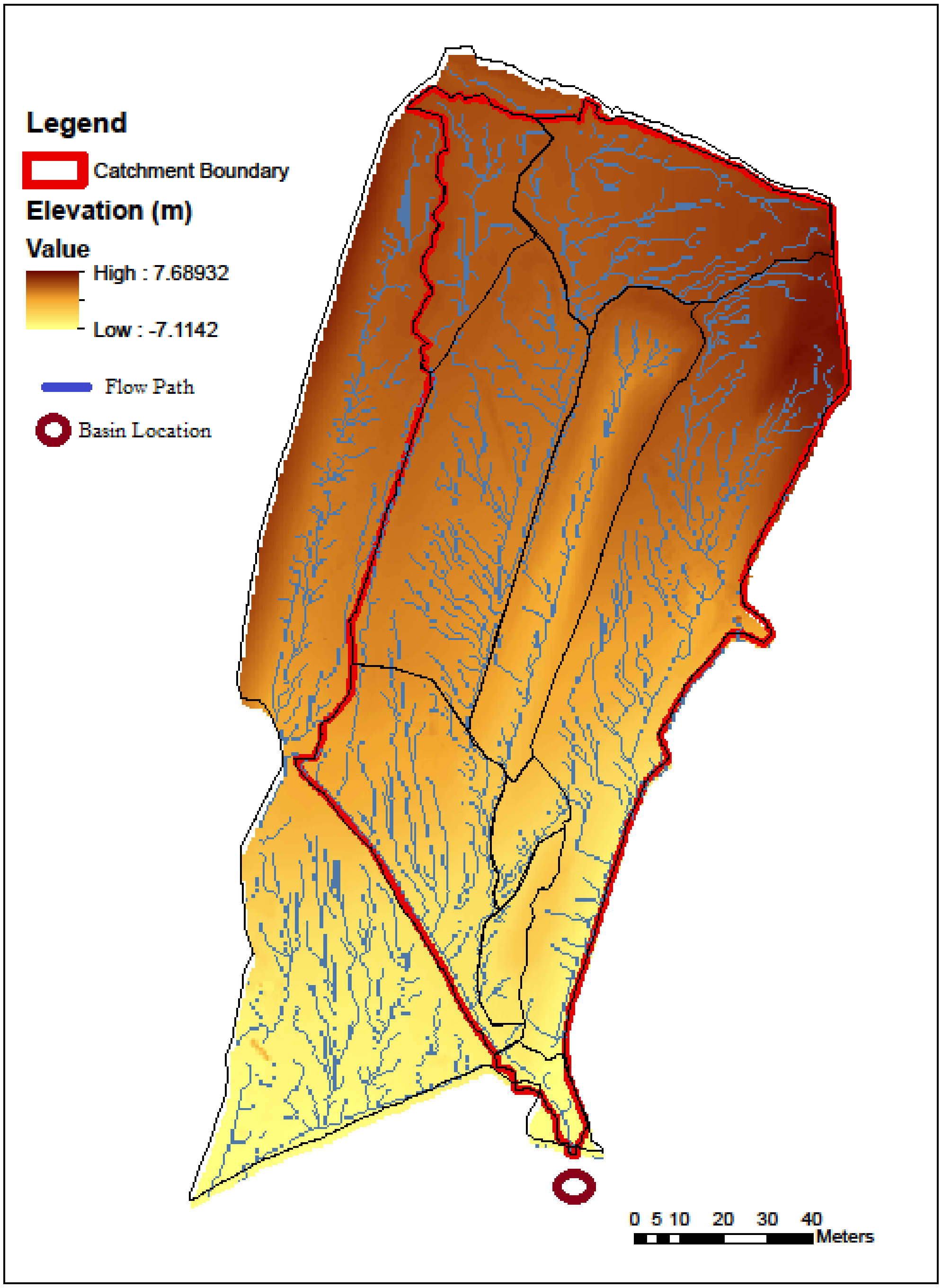

Figure A2-9. GIS processed survey from basin ID 11.4 B on 02.03.11

Figure A2-10. Photograph from 2.03.11 when survey was taken on Basin 11.4 B. The orientation is looking down the catchment where the basin was located in the top left corner of the photograph. The topography was very similar to the previous survey with some disturbances from equipment moving through catchment and straw moving due to rain and wind.

Figure A2-11. Photograph from 2.03.11 when survey was taken on Basin 11.4 B. The orientation is looking up into the catchment near the basin's location.

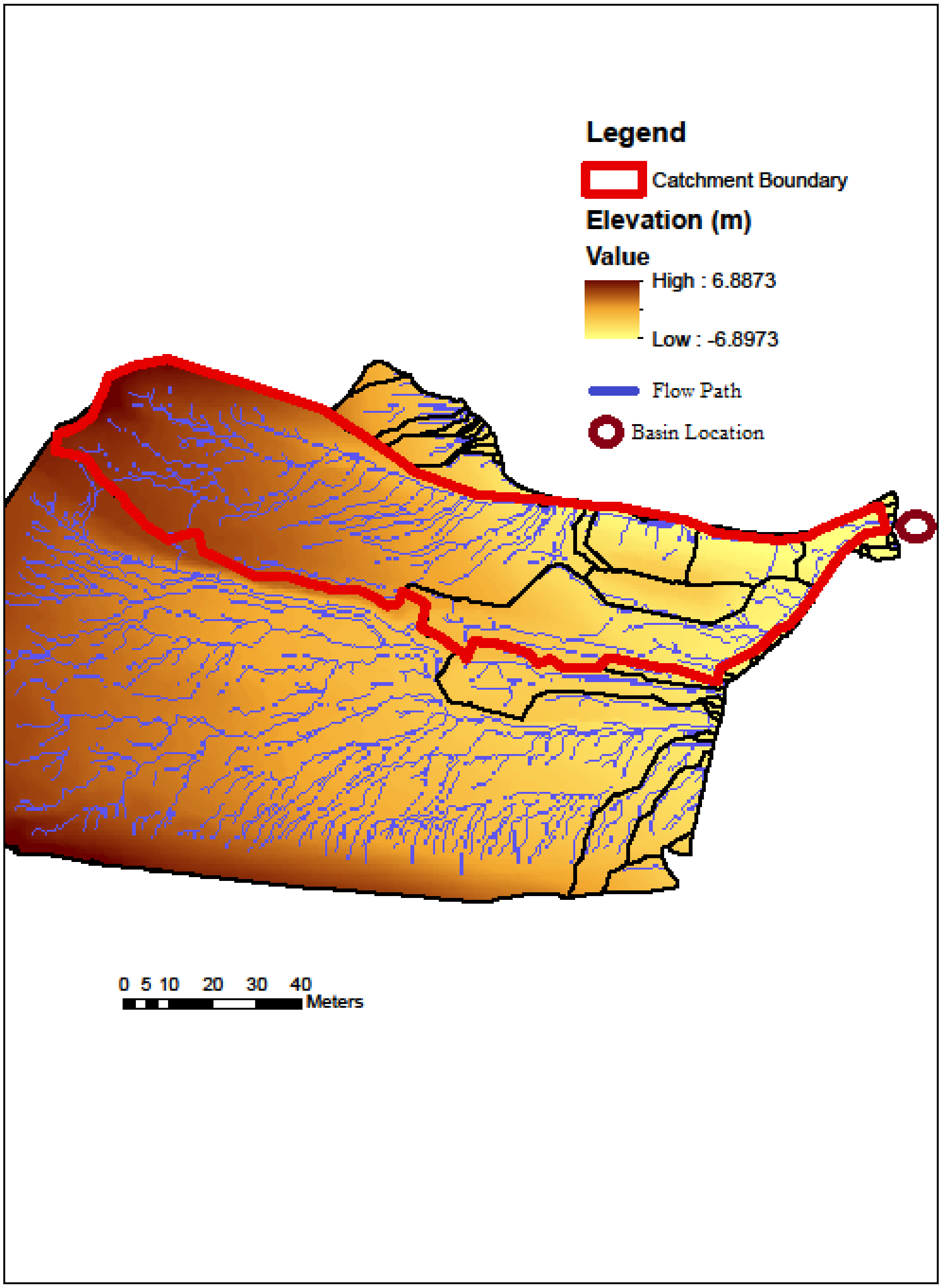

Figure A2-12. GIS processed survey from basin ID 11.4 B on 03.15.11

Figure A2-13. Photograph from 3.15.11 when survey on Basin 11.4 B was taken. The orientation is looking up into the catchment from near the basin's location. Major grading was beginning in the middle of what was the catchment for the basin. Catchment size was reduced due to the removal of silt/diversion ditches. Most of the catchment was left bare.

Figure A2-14. Photograph from 3.15.11 when the survey of Basin 11.4 B was taken. The orientation is looking down the catchment with the basin location being near the top left corner of the photograph.

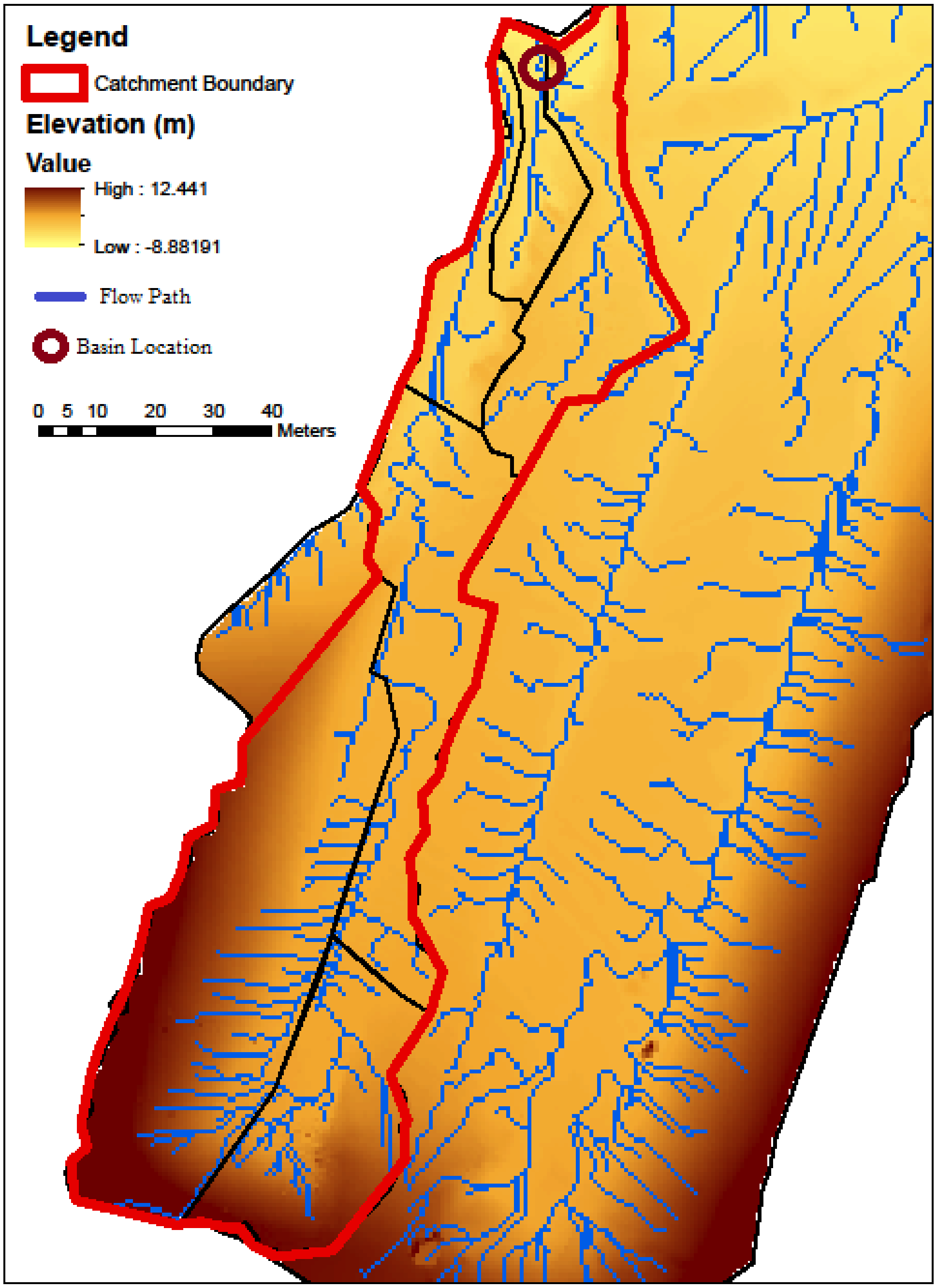

Figure A2-15. GIS processed survey from basin ID 11.4 B on 04.25.11

Figure A2-16. Photograph from 4.25.11 when the survey on Basin 11.4 B was taken. The orientation of the photography is looking up into the catchment from a location near the basin. The entire area was bare. The topography of the catchment was near final grade.

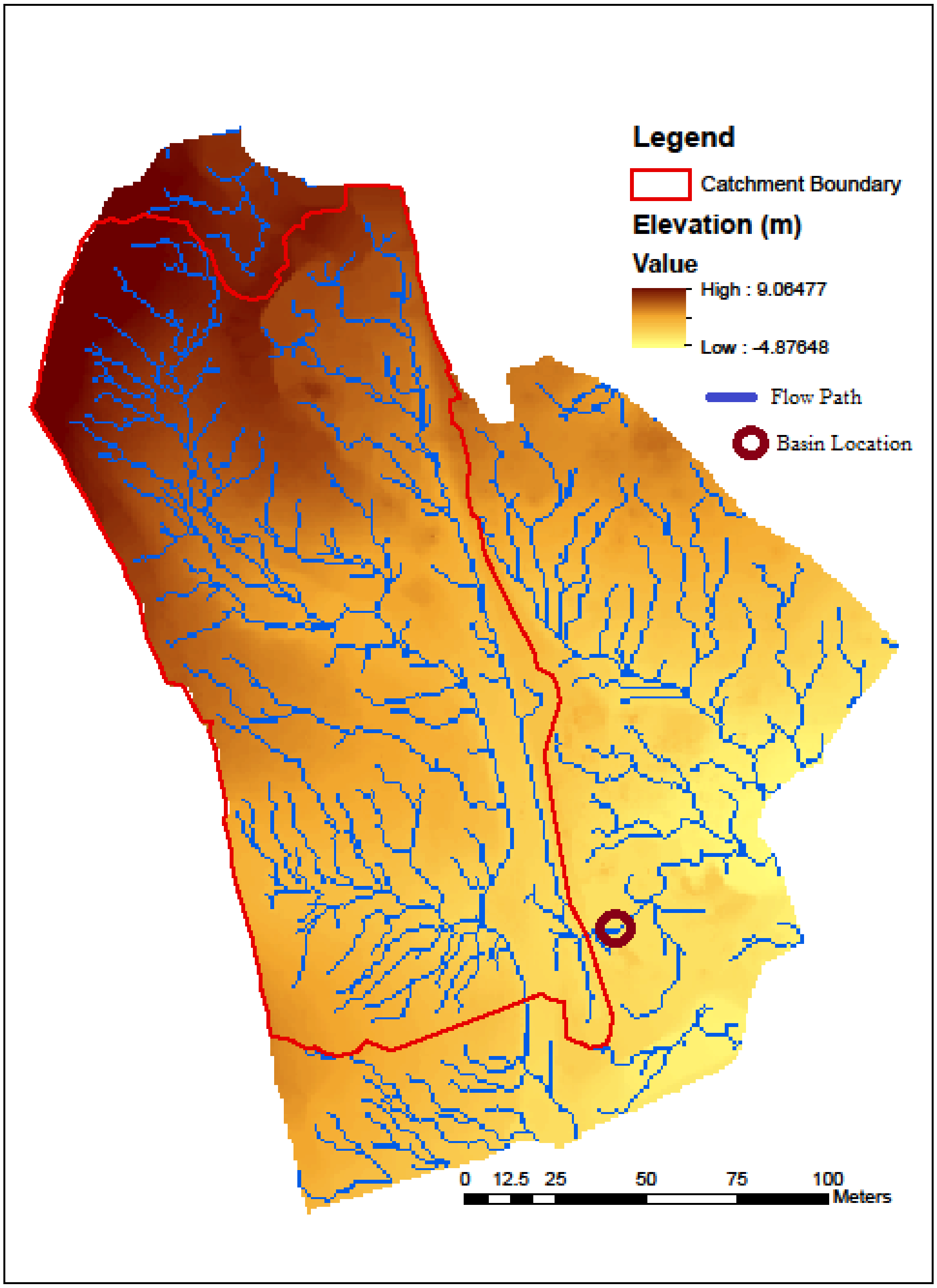

Figure A2-17. GIS processed survey from basin ID 9.2 C on 04.25.11

Figure A2-18. Photograph from 4.25.11 when the survey on Basin 9.2 C was taken. The orientation is looking up into the catchment taken at a location near the inlet of the basin. The entire area had cover (mulch, wood chips, or straw) with limited grading or topography changes from the original grade.

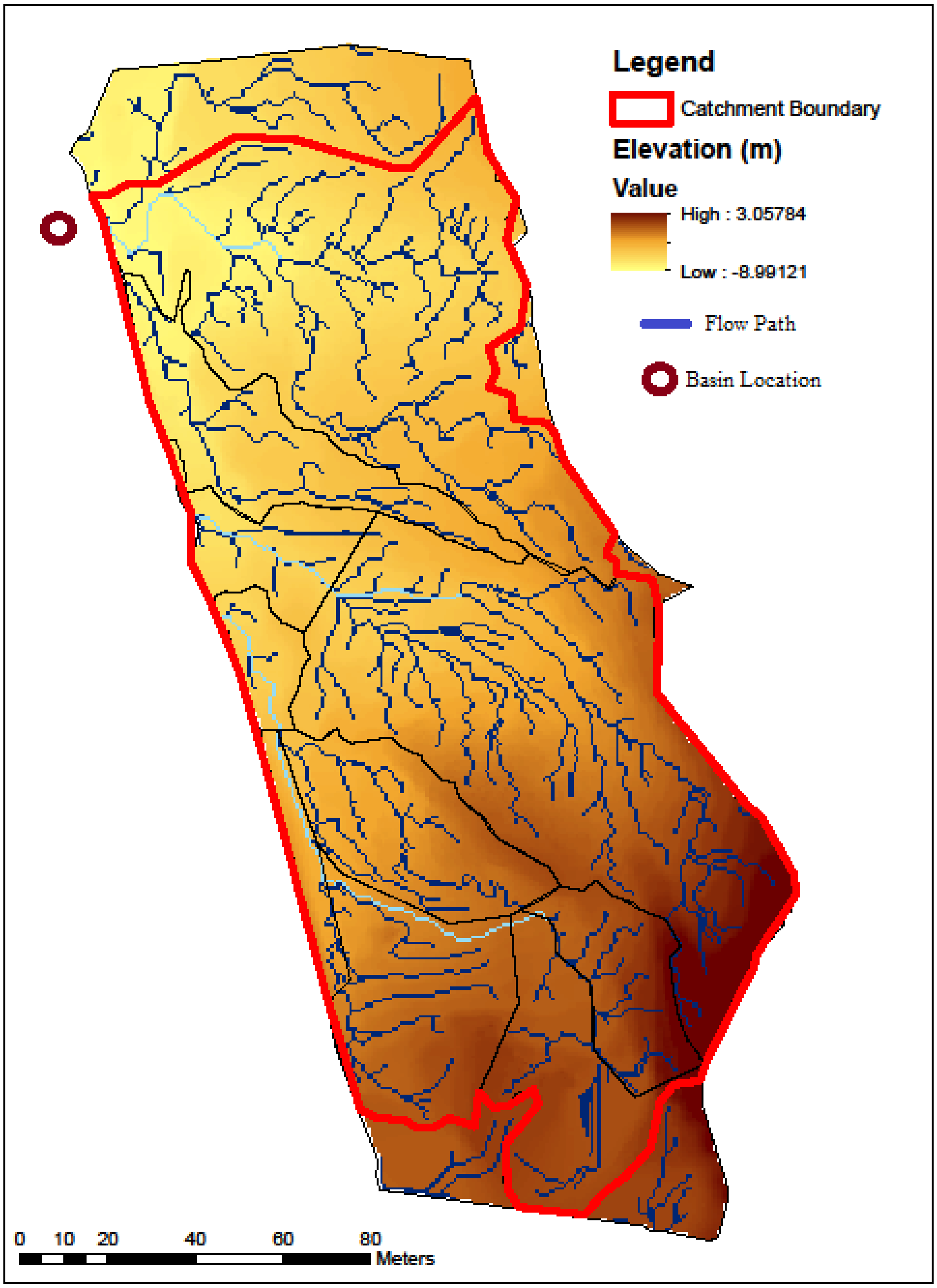

Figure A2-19. GIS processed survey from basin ID 9.2 C on 06.08.11

Figure A2-20. Photograph from 6.08.11 when the survey on Basin 9.2 C was taken. The orientation of the photograph is looking up into the catchment taken at a location near the inlet of the basin. There was limited change to the cover and topography since the previous survey was taken. A small portion at the top of the catchment had changed.

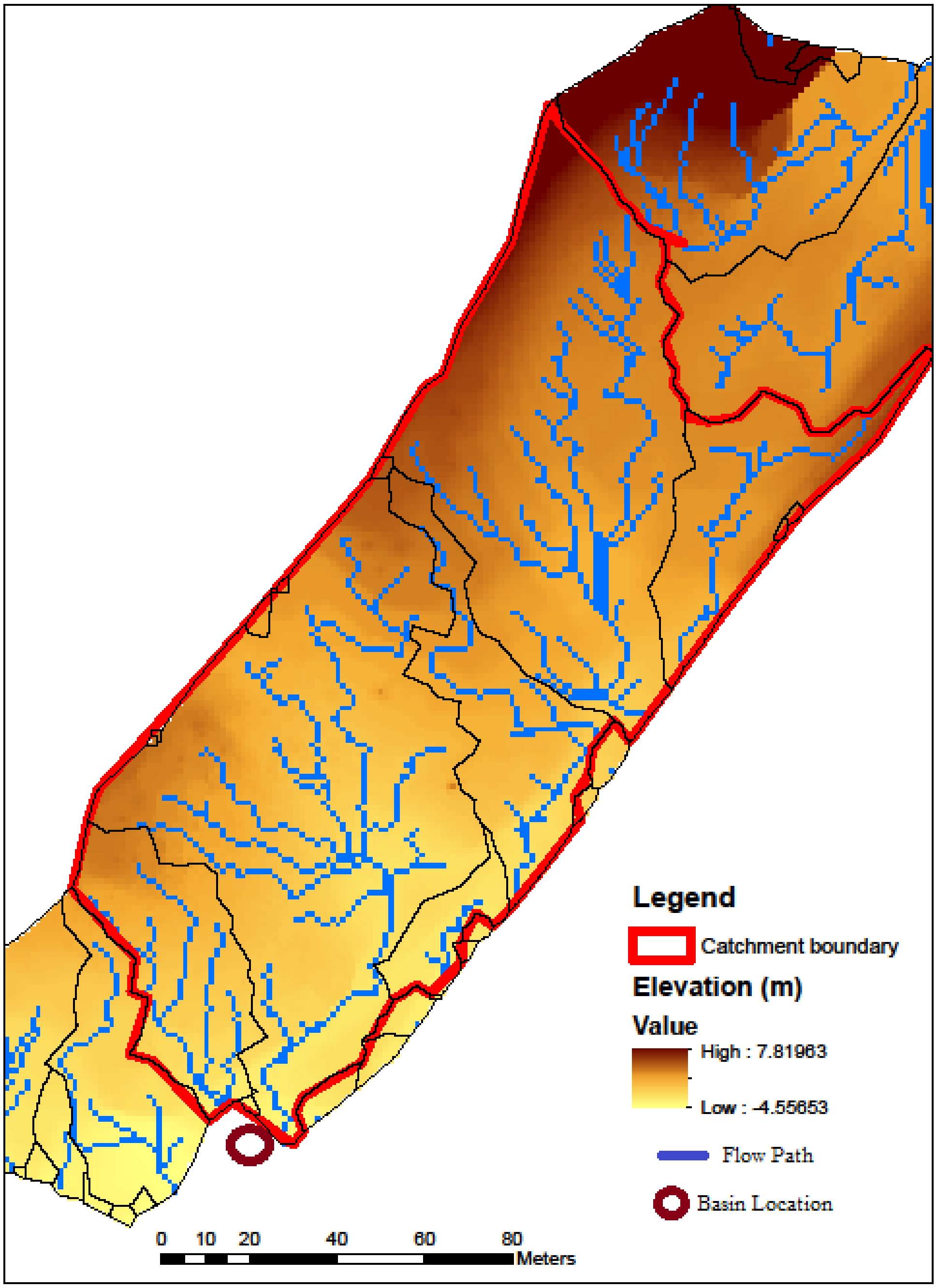

Figure A2-21. GIS processed survey from basin ID 9.2 C on 08.10.11

Figure A2-22. Photograph from 8.10.11 when the survey of Basin 9.2 C was taken. The orientation of the photo is looking up into the catchment at a location near the inlet of the basin. Grading had started, beginning at the top of the catchment. Other than the changes to the top of the catchment, little elsewhere in terms of cover or topography had changed.

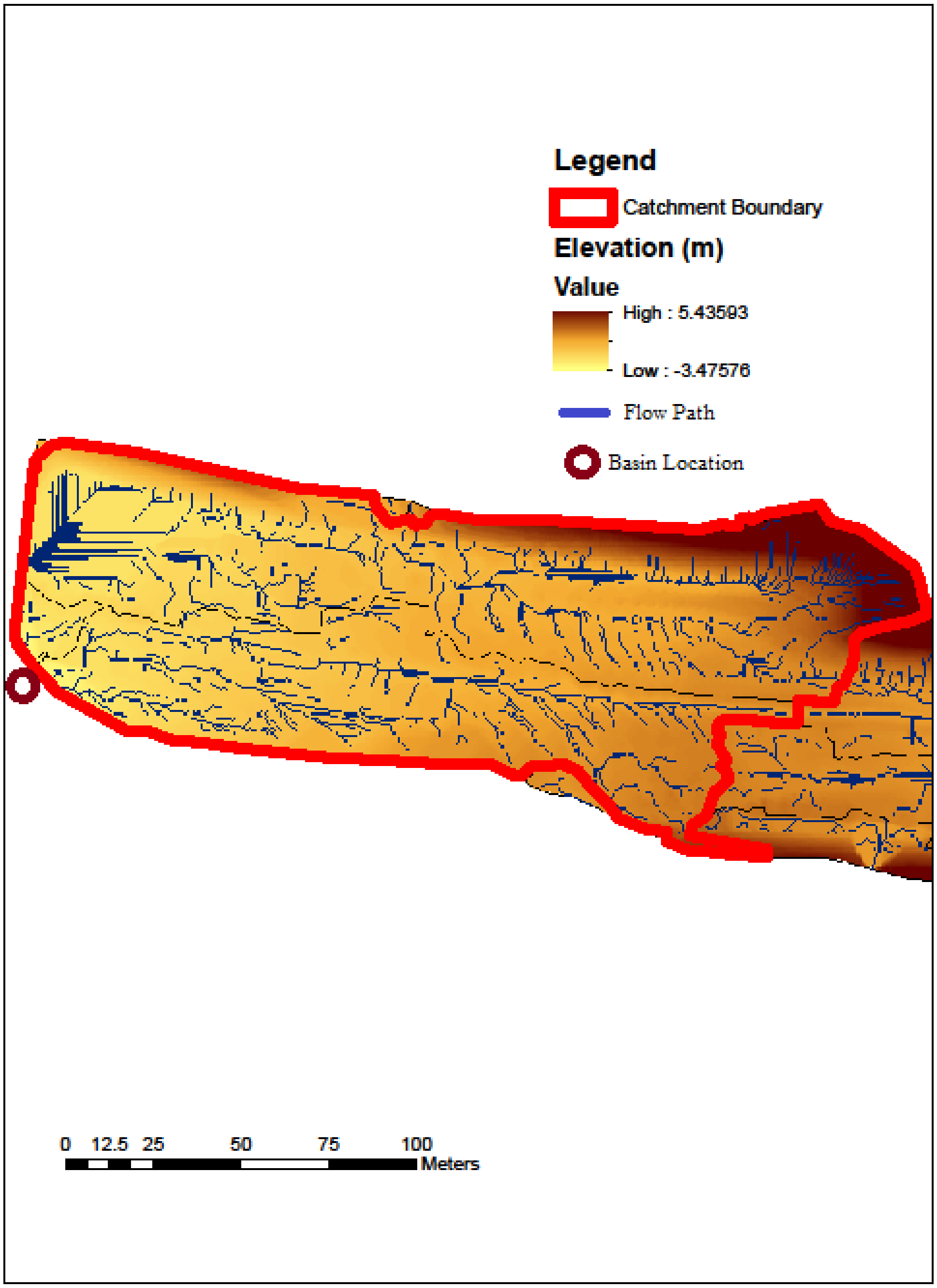

Figure A2-23. GIS processed survey from basin ID 9.2 C on 09.16.11

Figure A2-24. Photograph from 9.16.11 when the survey on basin 9.2 C was taken. The orientation is looking down the catchment from the top, where the location of the basin is in the left center, near the top. Grading had progressed through the rest of the catchment to approach final grade. Some areas were strawed and tacked while most areas were bare.

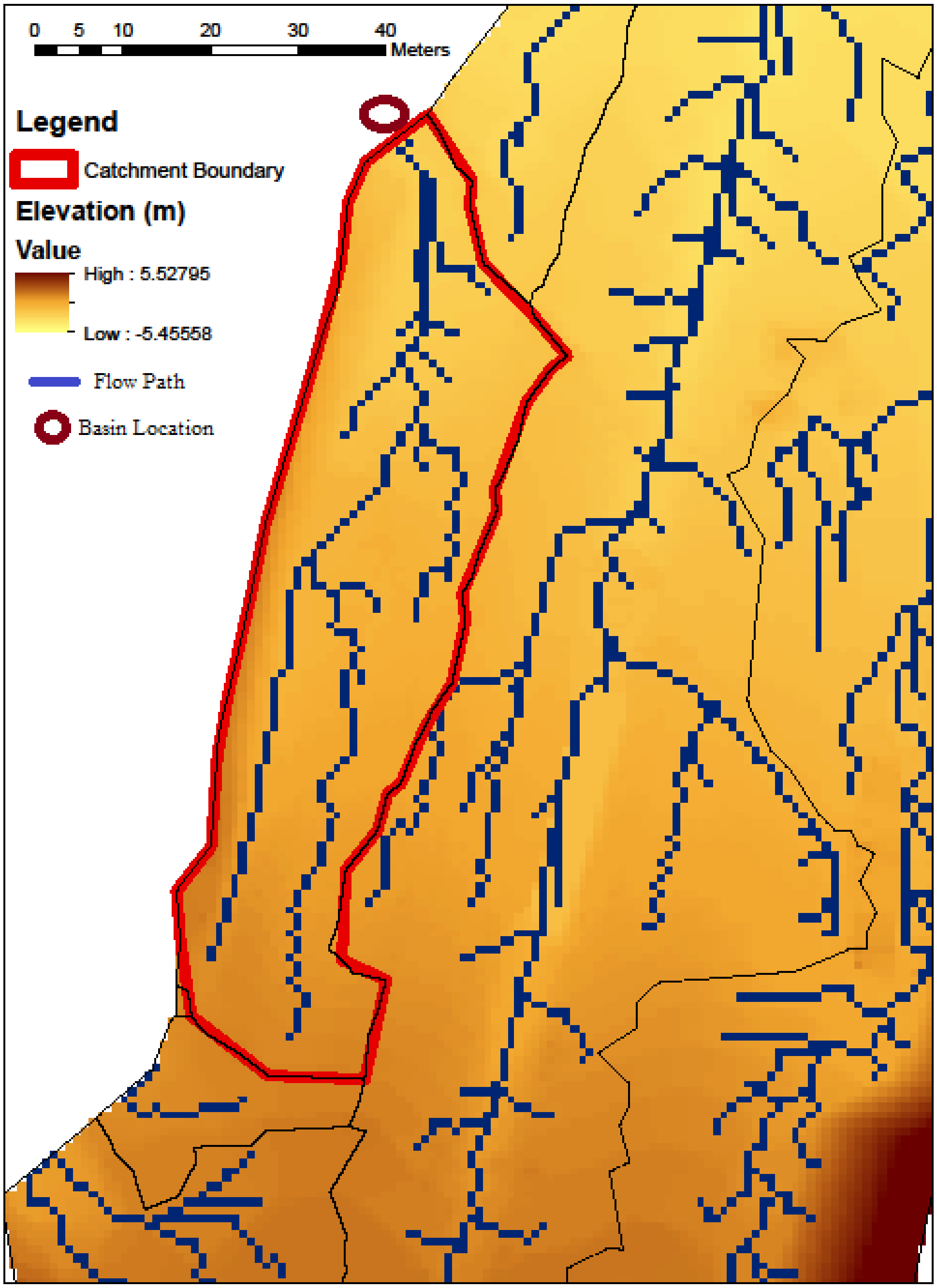

Figure A2-25. GIS processed survey from basin ID 10.3 B on 06.08.11

Figure A2-26. Photograph from 6.8.11 when the survey on Basin 10.3 B was taken. The orientation of the photograph is looking up into the catchment from a location near the inlet of the basin. The entire area was strawed and tacked. The catchment was at final grade when monitoring began. Notice on the left side of the photograph, a diversion ditch which captured a large amount of stormwater.

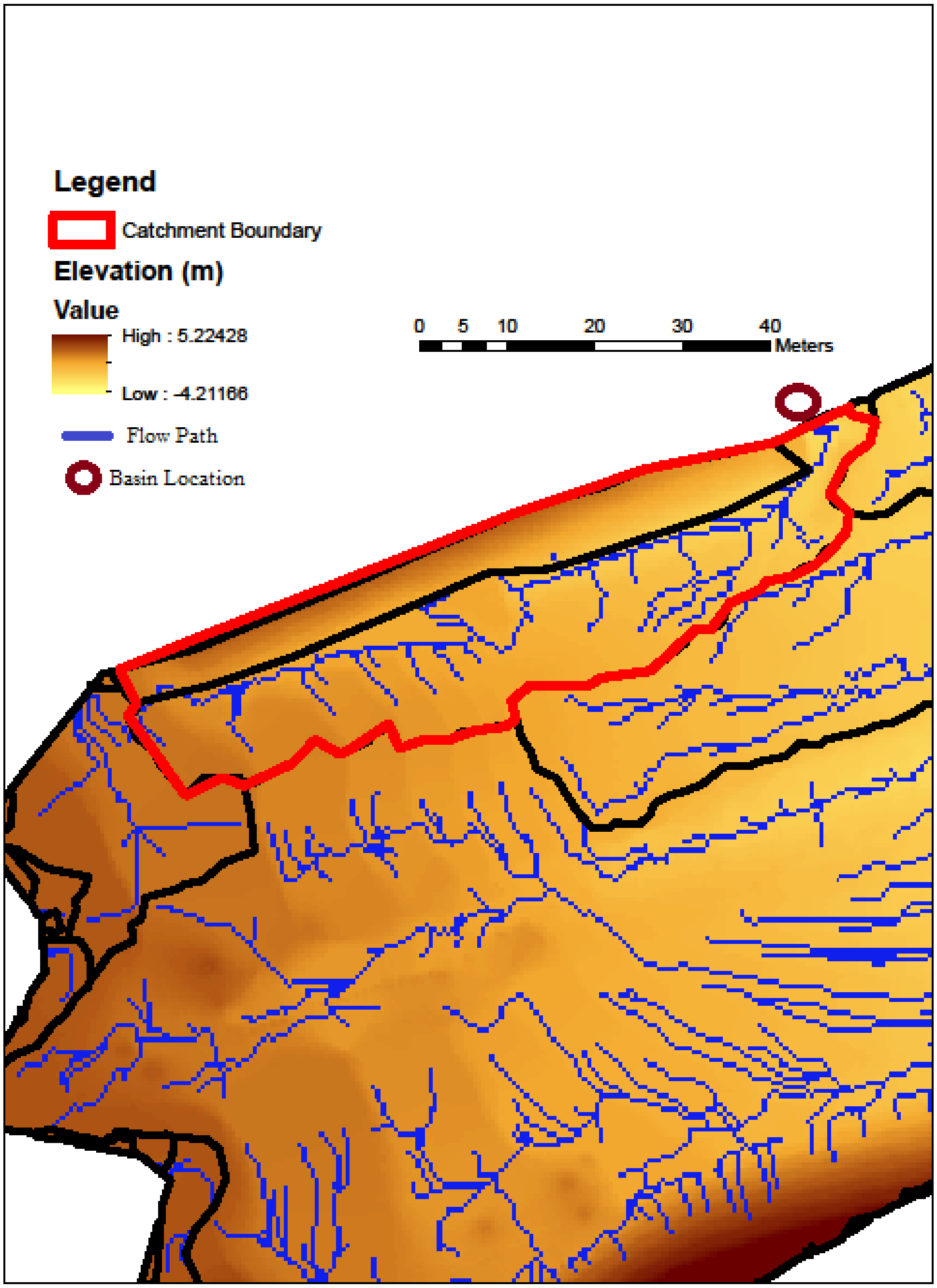

Figure A2-27. GIS processed survey from Basin ID 10.3 B on 08.10.11.

Figure A2-28. Photograph from 8.10.11 when the survey on Basin 10.3 B was taken. The orientation of the photograph is looking up into the catchment taken from a location near the inlet of the basin. There was little change to the topography since the last survey was taken. Most areas were strawed and tacked with the exception of the road beds which were heavily compacted soils. Notice the diversion ditch had been removed which limited the amount of stormwater entering the basin.

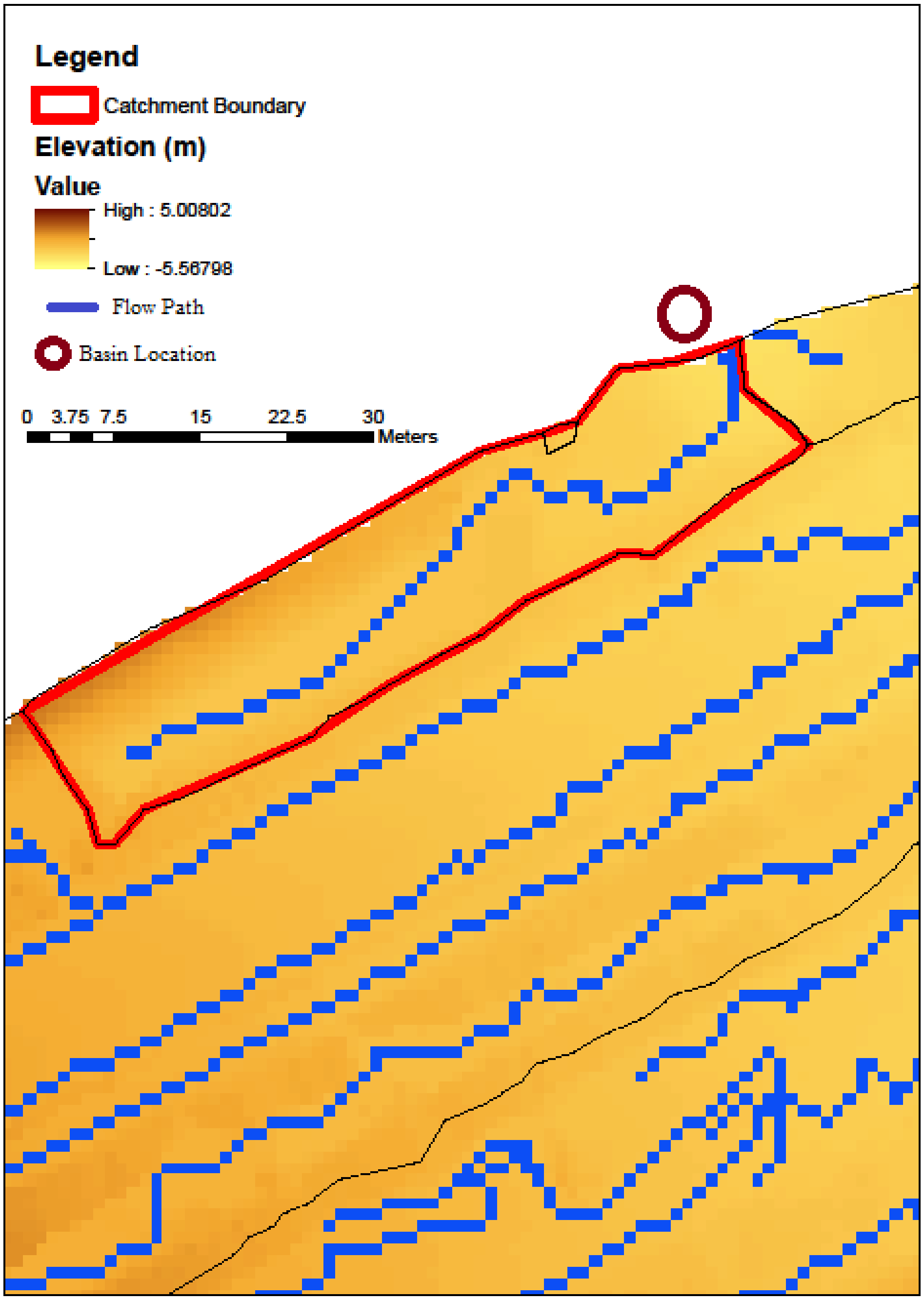

Figure A2-29. GIS processed survey from basin ID 10.3 B on 11.14.11

Figure A2-30. Photograph from 11.14.11 when the survey on Basin 10.3 B was taken. The orientation of the photograph is looking up the catchment at a location near the inlet of the basin. The topography had changed very little since the last survey. Notice the berm along the top left of the photograph which limited the catchment area to the grassed swale running along the road bed. This berm had been in place since 9.16.11.

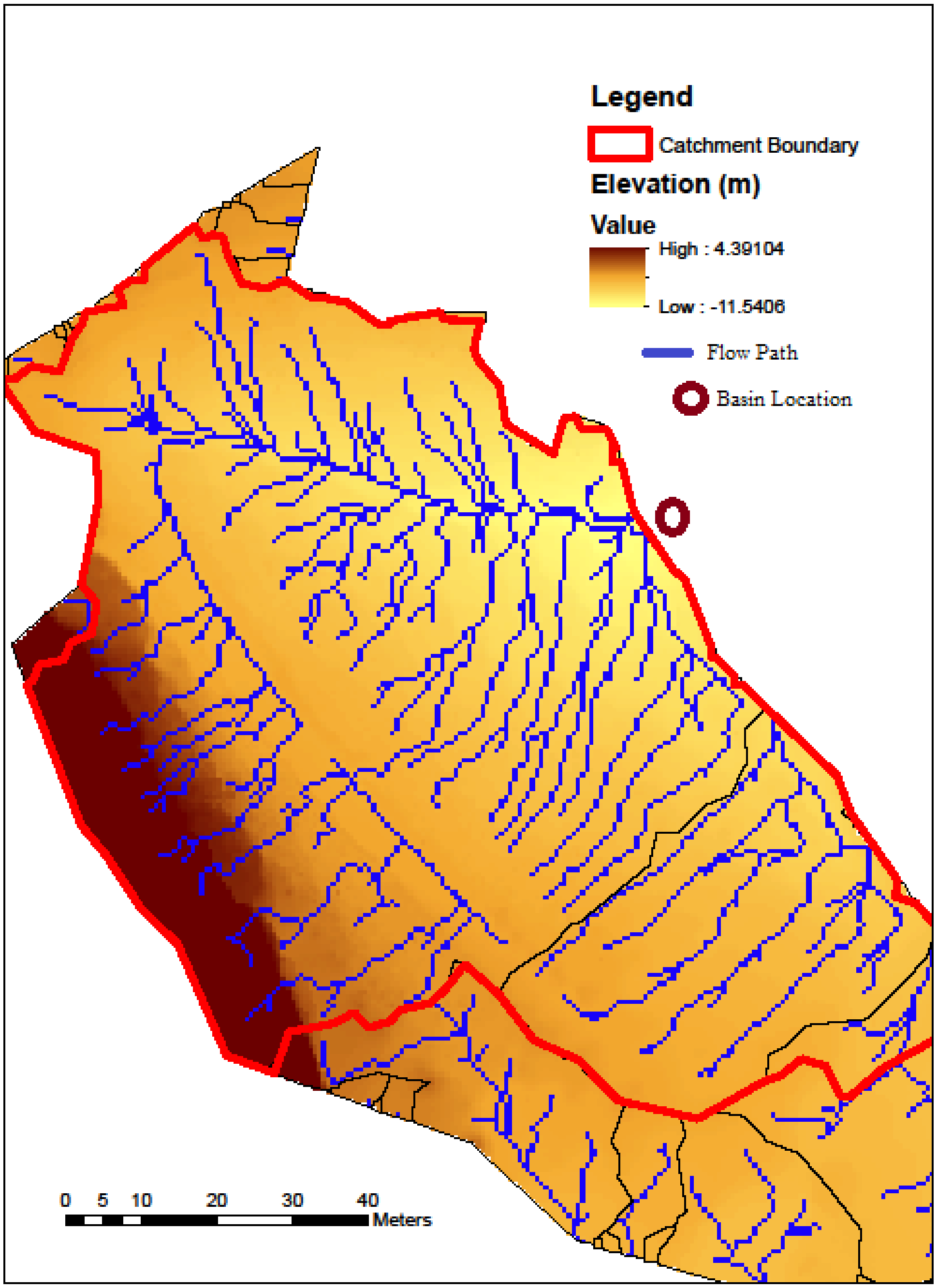

Figure A2-31. GIS processed survey from basin ID 5.10 B on 08.10.11

Figure A2-32. Photograph from 08.10.11 when the survey on Basin 5.10 B was taken. The orientation of the photograph is looking up into the catchment with the inlet pictured in the right center. The topography was nearly the same as the original grade where the only difference was a haul road located at the toe of the hill at the back of the catchment. The entire area was strawed and tacked with some vegetation growth.

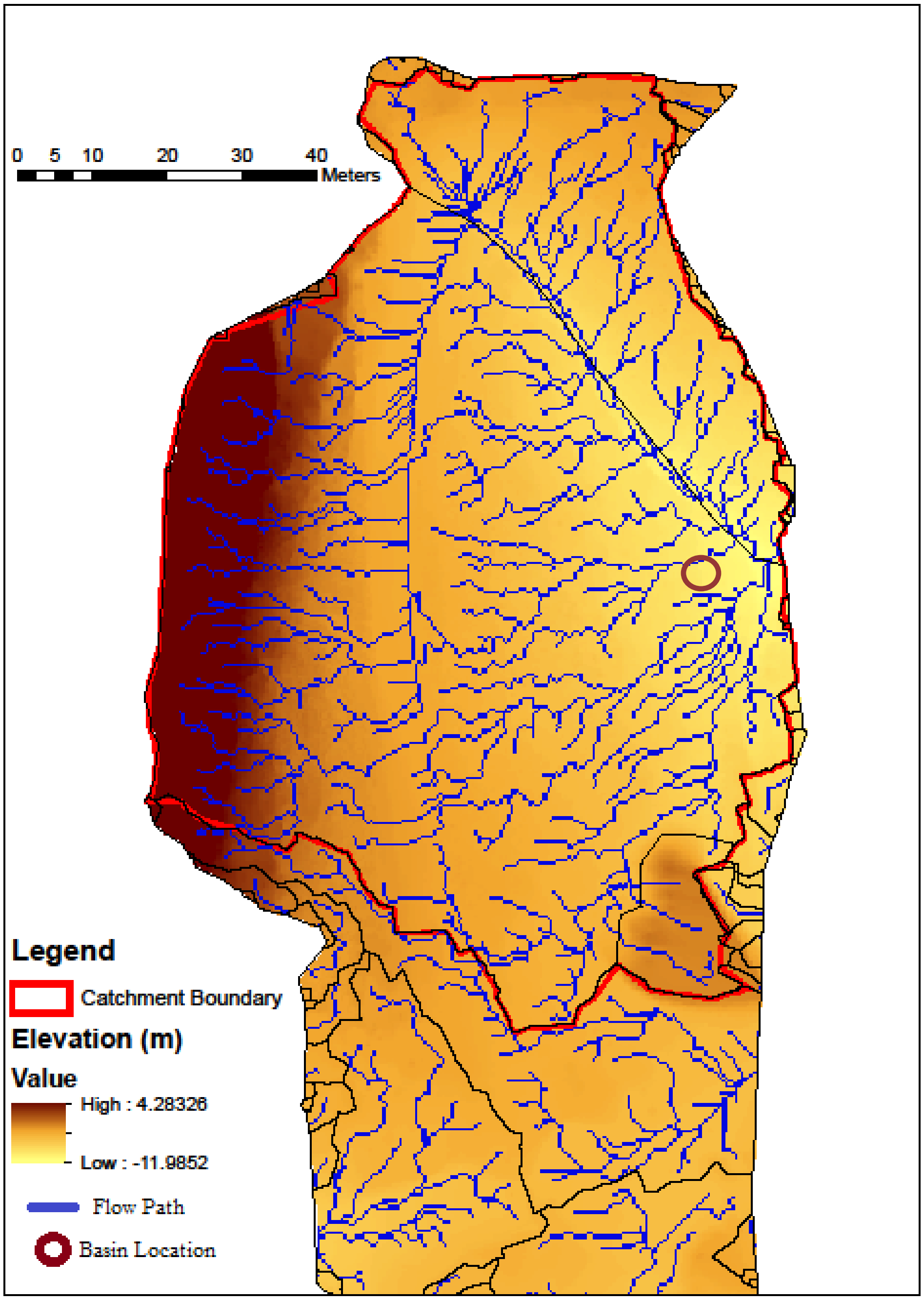

Figure A2-33. GIS processed survey from basin ID 5.10 B on 11.14.11

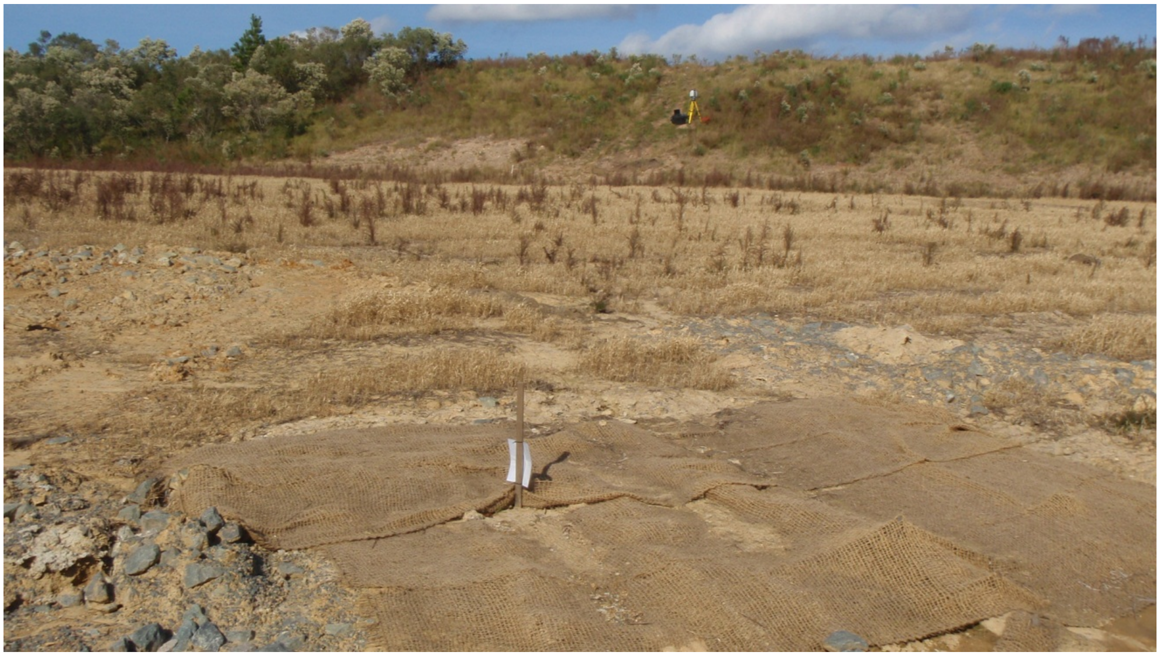

Figure A2-34. Photograph was taken on 11.14.11 when the survey on Basin 5.10 B was taken. The orientation of the photograph is looking up into the catchment at a location near the inlet of the basin. Little had changed in the catchment in terms of cover and topography except for a fill pile on the left side using this orientation.

Figure A2-35. Photograph was taken on 11.14.11 when the survey on Basin 5.10 B was taken. Based on the orientation of the photograph in figure A2-34, this is the left side of the catchment. This fill pile was located here from approximately 11.14.11 to 11.28.11 and no rainfall events occurred during this period.

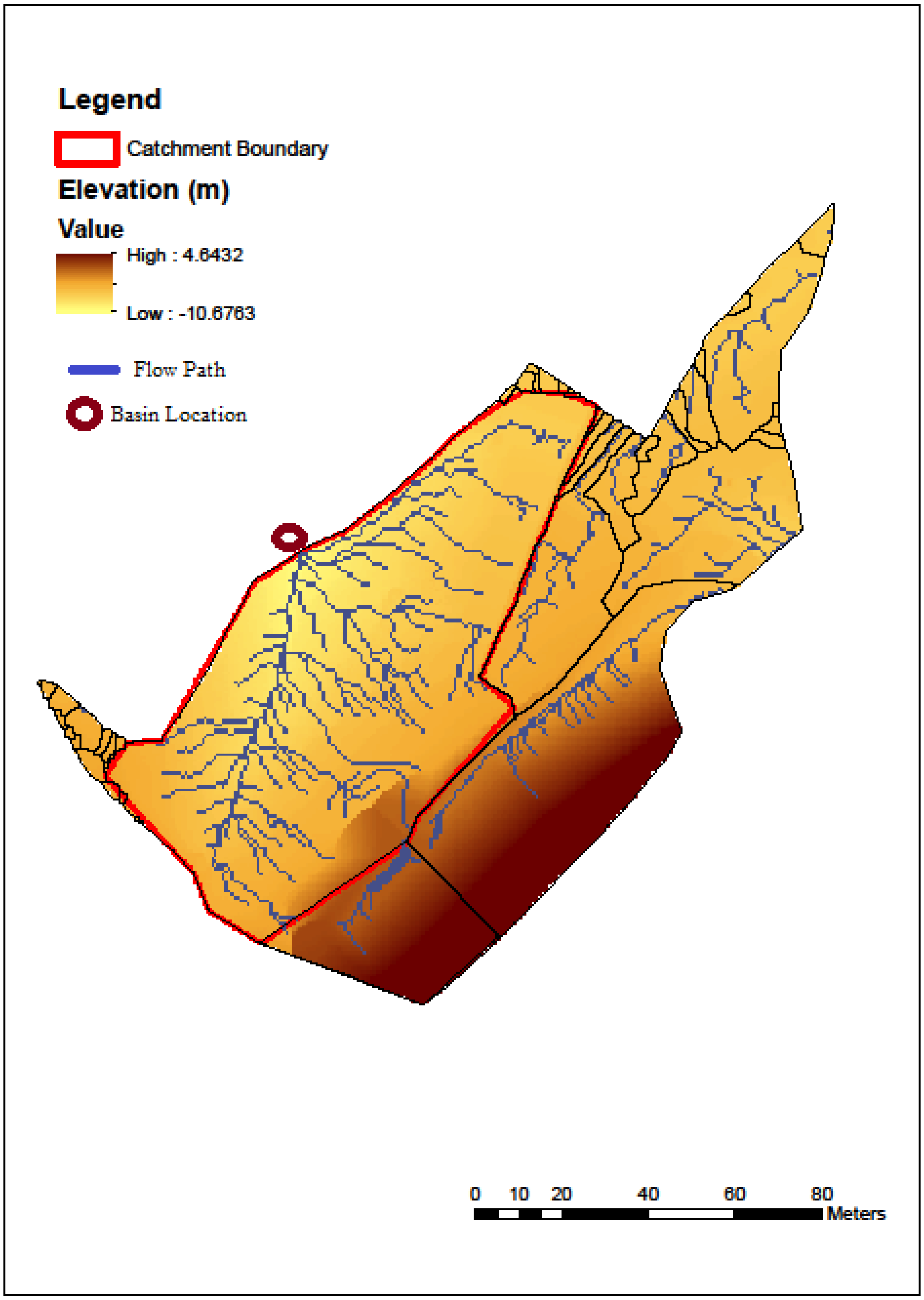

Figure A2-36. GIS processed survey from basin ID 5.10 B on 12.13.11

Figure A2-37. Photograph from 12.13.11 when the survey on Basin 5.10 B. The orientation of the photograph is looking up into the catchment from a location near the inlet of the basin. The fill pile on the left side of the catchment had been removed and grading had begun near the top of the catchment. Areas that were not actively being graded had been strawed and tacked.

Table A4-1. Sequence of managements/operations used in RUSLE2 calculations for basin 11.4 B

Date	Operation	Vegetation	Type of Cover Material	Cover Matl add/remove (lb/ac)	Cover from addition (%)
8/6/2010	Harvest, timber remove tops				
8/12/2010	Bulldozer, clearing/cutting				
9/1/2010	Root rake				
9/10/2010	Planting, broadcast seeder	Grass seed, fall seeding			
9/10/2010	Add mulch		Mulch\wheat straw	3000	83
11/5/2010	Bulldozer, filling/leveling			80.2	4.4
11/12/2010	Planting, broadcast seeder	Grass seed, fall seeding			
11/12/2010	Add mulch		Mulch\wheat straw	3000	83
3/15/2011	Bulldozer, filling/leveling			183	9.7
4/5/2011	Bulldozer, clearing/cutting light				
4/25/2011	Add mulch		Mulch\wheat straw	3000	83
4/25/2011	Highly disturbed land\broadcast seeder	Grass, cool season, spring seeded			

Table A4-2. Sequence of managements/operations used in RUSLE2 calculations for basin 9.2 C

Date	Operation	Vegetation	Type of Cover Material	Cover Matl add/remove (lb/ac)	Cover from addition (%)
3/22/2011	Add mulch		wood chips	2000	33
3/22/2011	Add mulch		Mulch\wheat straw	3000	83
3/22/2011	Planting, broadcast seeder	Grass seed, spring seeded			
8/4/2011	Add mulch		Mulch\wheat straw	3000	83
8/23/2011	Bulldozer, filling/leveling			2000	67
8/26/2011	Bulldozer, filling/leveling				
8/30/2011	Bulldozer, filling/leveling				

Table A4-3. Sequence of managements/operations used in RUSLE2 calculations for basin 10.3 B for road bed in 6/8/11 survey and final grade plans.

Date	Operation	Vegetation	Type of Cover Material	Cover Matl add/remove (lb/ac)	Cover from addition (%)
5/5/2011	Add mulch		Mulch\wheat straw	100	5.8
6/8/2011	Add mulch		Mulch\wheat straw	2000	70
6/22/2011	Land plane				
6/30/2011	Roller, smooth				
7/26/2011	Roller, smooth				
8/15/2011	Land plane				
8/15/2011	Roller, smooth				
8/20/2011	Roller, smooth				
10/27/2011	Paving				

Table A4-4. Sequence of managements/operations used in RUSLE2 calculations for basin 10.3 B for hillside in 6/8/11 survey and all areas after 7/26/11.

Date	Operation	Vegetation	Type of Cover Material	Cover Matl add/remove (lb/ac)	Cover from addition (%)
5/5/2011	basic/general\add mulch		Mulch\wheat straw	100	5.8
6/8/2011	basic/general\add mulch		Mulch\wheat straw	2000	70
6/8/2011	Planting, broadcast seeder	Grass seed, fall seeding			
7/26/2011	Add mulch		Mulch\wheat straw	2500	77
7/26/2011	Planting, broadcast seeder	Grass seed, fall seeding			

Table A4-5. Sequence of managements/operations used in RUSLE2 calculations for basin 5.10 B used for majority of areas in catchment

Date	Operation	Vegetation	Type of Cover Material	Cover Matl add/remove (lb/ac)	Cover from addition (%)
8/4/2011	Begin weed growth	Weeds, less than 3 mo growth			
9/8/2011	Add mulch		Mulch\wheat straw	1000	45

Table A4-6. Sequence of managements/operations used in RUSLE2 calculations for basin 5.10 B used for area disturbed on 11/14/11.

Date	Operation	Vegetation	Type of Cover Material	Cover Matl add/remove (lb/ac)	Cover from addition (%)
8/4/2011	Begin weed growth	Weeds, less than 3 mo growth			
9/8/2011	Add mulch		Mulch\wheat straw	1000	45
11/14/2011	Bulldozer, clearing/cutting light				
12/9/2011	Add mulch		Mulch\wheat straw	2000	70

Table A4-7. Storm erositivity values calculated for use in RUSLE2 for evaluation of single storm event sediment yields with corresponding dates.

Storm Date	Depth (in)	rs (storm erosivity)
9/30/2010	1.24	24.4
10/28/2010 Early	0.39	48.0
10/28/2010 Late	0.22	9.70
11/16/2010	0.33	9.06
12/12/2010	0.24	3.57
12/16/2010	0.16	2.51
1/26/2011	0.18	2.38
2/4/2011	0.44	3.65
3/6/2011	0.22	9.00
3/26/2011	0.18	3.10
3/30/2011	0.2	2.70
4/8/2011	0.59	24.78
4/9/2011	1.18	330
4/16/2011	0.39	48.2
5/4/2011	0.08	1.51
6/27/2011	0.43	68.5
6/28/2011	1.11	92.4
7/6/2011	0.19	10.3
8/6/2011 Early	0.23	7.26
8/6/2011 Late	0.16	4.13
8/12/2011	0.39	50.5
8/13/2011	1.07	359
8/21/2011	0.5	11.1
8/26/2011	0.18	6.44
9/6/2011	1.69	540
9/21/2011	0.66	45.9
9/23/2011	0.4	14.4
9/28/2011	0.54	54.7
10/18/2011	2.15	512
10/29/2011	0.31	20.6
11/4/2011	1.09	37.2
11/23/2011	0.46	26.3
11/29/2011	0.87	22.3
12/7/2011	0.36	22.9

Table A4-8. Profile (1) for Basin 11.4 B developed from survey taken on 9/14/2010.

Area represented by profile is 0.0229 ha.

Slope (%)	Length of Segment (m)
50.8	2.451189024

Table A4-9. Profile (2) for Basin 11.4 B developed from survey taken on 9/14/2010.

Area represented by profile is 0.716 ha

Slope (%)	Length of Segment (m)
8.19	32.9
8.61	90.2
10.6	8.99
3.01	46.5

Table A4-10. Profile (1) for Basin 11.4 B developed from survey taken on 11/30/2010.

Area represented by profile is 0.0617 ha.

Slope (%)	Length of Segment (m)
10.1	16.9
35.4	7.88

Table A4-11. Profile (2) for Basin 11.4 B developed from survey taken on 11/30/2010.

Area represented by profile is 0.0541 ha

Slope (%)	Length of Segment (m)
27.3	4.14
25.6	3.54
0.165	3.33
21.9	3.21

Table A4-12. Profile (3) for Basin 11.4 B developed from survey taken on 11/30/2010.

Area represented by profile is 0.0462 ha

Slope (%)	Length of Segment (m)
37.2	9.39
1.14	14.4
2.47	15.8

Table A4-13. Profile (4) for Basin 11.4 B developed from survey taken on 11/30/2010.

Area represented by profile is 0.299 ha

Slope (%)	Length of Segment (m)
2.50	101

Table A4-14. Profile (5) for Basin 11.4 B developed from survey taken on 11/30/2010.

Area represented by profile is 0.271 ha

Slope (%)	Length of Segment (m)
1.69	7.62
3.91	7.47
6.09	28.0
-0.792	8.09
12.5	36.1
13.3	1.10

Table A4-15. Profile (6) for Basin 11.4 B developed from survey taken on 11/30/2010.

Area represented by profile is 0.119 ha

Slope (%)	Length of Segment (m)
6.84	40.9
17.3	9.29
20.7	5.48
10.6	6.95
15.0	8.28

Table A4-16. Profile (7) for Basin 11.4 B developed from survey taken on 11/30/2010.

Area represented by profile is 0.240 ha.

Slope (%)	Length of Segment (m)
3.30	55.5
18.1	8.84
4.96	58.8

Table A4-17. Profile (1) for Basin 11.4 B developed from survey taken on 12/14/2010.

Area represented by profile is 0.0499 ha.

Slope (%)	Length of Segment (m)
7.33	3.41
41.7	4.33
15.5	5.71

Table A4-18. Profile (2) for Basin 11.4 B developed from survey taken on 12/14/2010. Area represented by profile is 0.0325 ha.

Slope (%)	Length of Segment (m)
4.01	15.2
26.7	2.41

Table A4-19. Profile (3) for Basin 11.4 B developed from survey taken on 12/14/2010. Area represented by profile is 0.0721 ha.

Slope (%)	Length of Segment (m)
3.05	34.9
7.27	2.91

Table A4-20. Profile (4) for Basin 11.4 B developed from survey taken on 12/14/2010. Area represented by profile is 0.425 ha.

Slope (%)	Length of Segment (m)
2.53	92.0
4.05	43.6
12.3	21.7

Table A4-21. Profile (5) for Basin 11.4 B developed from survey taken on 12/14/2010. Area represented by profile is 0.425 ha.

Slope (%)	Length of Segment (m)
4.40	13.4
9.24	12.5
5.39	48.7
8.51	17.5
8.26	20.2
12.0	18.3

Table A4-22. Profile (6) for Basin 11.4 B developed from survey taken on 12/14/2010.

Area represented by profile is 0.214 ha.

Slope (%)	Length of Segment (m)
13.6	11.4
0.0572	23.2
5.29	13.2
5.10	98.1

Table A4-23. Profile (1) for Basin 11.4 B developed from survey taken on 2/3/2011.

Area represented by profile is 0.199 ha.

Slope (%)	Length (m)
20.1	4.11
16.7	7.95
6.15	4.12
13.2	4.62
3.30	98.0

Table A4-24. Profile (2) for Basin 11.4 B developed from survey taken on 2/3/2011.

Area represented by profile is 0.709 ha.

Slope (%)	Length of Segment (m)
0.981	56.3
2.71	108
11.4	19.9
4.96	5.83

Table A4-25. Profile (3) for Basin 11.4 B developed from survey taken on 2/3/2011.

Area represented by profile is 0.0332 ha.

Slope (%)	Length of Segment (m)
15.9	13.9
1.76	28.6

Table A4-26. Profile (4) for Basin 11.4 B developed from survey taken on 2/3/2011.

Area represented by profile is 0.0355 ha.

Slope (%)	Length of Segment (m)
12.1	12.8
2.84	28.8

Table A4-27. Profile (5) for Basin 11.4 B developed from survey taken on 2/3/2011.

Area represented by profile is 0.0208 ha.

Slope (%)	Length of Segment (m)
11.7	7.04

Table A4-28. Profile (6) for Basin 11.4 B developed from survey taken on 2/3/2011.

Area represented by profile is 0.196 ha.

Slope (%)	Length of Segment (m)
4.28	27.2
7.31	20.4
14.8	19.5
5.86	10.9
12.1	1.71

Table A4-29. Profile (1) for Basin 11.4 B developed from survey taken on 3/15/2011. Area represented by profile is 0.355 ha.

Slope (%)	Length of Segment (m)
4.46	20.8
3.56	29.2
6.74	21.9

Table A4-30. Profile (2) for Basin 11.4 B developed from survey taken on 3/15/2011. Area represented by profile is 0.115 ha.

Slope (%)	Length of Segment (m)
3.50	5.71
29.4	3.62
4.84	5.83
0.418	5.50
5.30	58.9

Table A4-31. Profile (3) for Basin 11.4 B developed from survey taken on 3/15/2011. Area represented by profile is 0.0276 ha.

Slope (%)	Length of Segment (m)
10.5	4.92
19.5	7.95
4.06	8.04

Table A4-32. Profile (4) for Basin 11.4 B developed from survey taken on 3/15/2011. Area represented by profile is 0.0166 ha.

Slope (%)	Length of Segment (m)
15.0	3.91

Table A4-33. Profile (5) for Basin 11.4 B developed from survey taken on 3/15/2011. Area represented by profile is 0.0570 ha.

Slope (%)	Length of Segment (m)
31.0	7.41
20.2	3.21

Table A4-34. Profile (1) for Basin 11.4 B developed from survey taken on 4/25/2011. Area represented by profile is 0.528 ha.

Slope (%)	Length of Segment (m)
20.0	36.1
1.16	105
3.36	50.6
5.07	14.4

Table A4-35. Profile (2) for Basin 11.4 B developed from survey taken on 4/25/2011. Area represented by profile is 0.0495 ha.

Slope (%)	Length of Segment (m)
20.2	8.86
0.102	9.84

Table A4-36. Profile (3) for Basin 11.4 B developed from survey taken on 4/25/2011. Area represented by profile is 0.153 ha.

Slope (%)	Length of Segment (m)
3.56	81.7
5.19	14.2

Table A4-37. Profile (1) for Basin 11.4 B developed as a representative slope from clearing and grubbing plans. Area represented by profile is 1.05 ha.

Slope (%)	Length of Segment (m)
7.80	13.7
8.80	25.9
10.0	9.15
10.6	25.9
8.00	7.62
16.7	27.4
5.2	44.2

Table A4-38. Profile (1) for Basin 11.4 B developed as an average slope from clearing and grubbing plans. Area represented by profile is 1.05 ha.

Slope (%)	Length of Segment (m)
9.50	154

Table A4-39. Profile (1) for Basin 11.4 B developed as an average slope from final grade plans. Area represented by profile is 0.688 ha.

Slope (%)	Length of Segment (m)
2.25	122

Table A4-40. Profile (1) for Basin 9.2 C developed from survey taken on 4/25/2011. Area represented by profile is 1.59 ha.

Slope (%)	Length of Segment (m)
8.01	42.7
3.30	95.7
1.83	7.89
6.27	17.2

Table A4-41. Profile (2) for Basin 9.2 C developed from survey taken on 4/25/2011.

Area represented by profile is 0.167 ha.

Slope (%)	Length of Segment (m)
3.48	4.34
4.48	5.24

Table A4-42. Profile (3) for Basin 9.2 C developed from survey taken on 4/25/2011.

Area represented by profile is 0.438 ha.

Slope (%)	Length of Segment (m)
3.15	6.67
18.2	9.21
2.92	16.5
4.02	26.6
9.42	5.99
4.03	70.4

Table A4-43. Profile (1) for Basin 9.2 C developed from survey taken on 6/08/2011.

Area represented by profile is 0.431 ha.

Slope (%)	Length of Segment (m)
16.0	19.2
1.57	31.8
3.75	52.9

Table A4-44. Profile (2) for Basin 9.2 C developed from survey taken on 6/08/2011.

Area represented by profile is 0.0369 ha.

Slope (%)	Length of Segment (m)
23.3	4.37

Table A4-45. Profile (3) for Basin 9.2 C developed from survey taken on 6/08/2011.

Area represented by profile is 0.153 ha.

Slope (%)	Length of Segment (m)
9.98	8.04
9.35	14.8
3.25	29.0
10.4	7.33
2.36	6.77

Table A4-46. Profile (4) for Basin 9.2 C developed from survey taken on 6/08/2011.

Area represented by profile is 0.0406 ha.

Slope (%)	Length of Segment (m)
10.2	7.17
2.41	8.16

Table A4-47. Profile (5) for Basin 9.2 C developed from survey taken on 6/08/2011.

Area represented by profile is 0.0800 ha.

Slope (%)	Length of Segment (m)
5.00	22.3
10.4	5.19
4.21	3.09

Table A4-48. Profile (6) for Basin 9.2 C developed from survey taken on 6/08/2011. Area represented by profile is 0.601 ha.

Slope (%)	Length of Segment (m)
3.60	36.6
2.79	25.5
5.68	7.22
3.60	85.9

Table A4-49. Profile (7) for Basin 9.2 C developed from survey taken on 6/08/2011. Area represented by profile is 0.619 ha.

Slope (%)	Length of Segment (m)
6.08	40.8
5.08	45.3
4.94	48.7
2.66	32.3

Table A4-50. Profile (8) for Basin 9.2 C developed from survey taken on 6/08/2011. Area represented by profile is 0.158 ha.

Slope (%)	Length of Segment (m)
3.71	35.3
11.1	9.97

Table A4-51. Profile (1) for Basin 9.2 C developed from survey taken on 8/10/2011. Area represented by profile is 0.796 ha.

Slope (%)	Length of Segment (m)
2.79	171

Table A4-52. Profile (2) for Basin 9.2 C developed from survey taken on 8/10/2011.

Area represented by profile is 0.205 ha.

Slope (%)	Length of Segment (m)
3.08	87.8
7.30	15.4

Table A4-53. Profile (3) for Basin 9.2 C developed from survey taken on 8/10/2011.

Area represented by profile is 0.563 ha.

Slope (%)	Length of Segment (m)
12.5	37.2
1.68	104
9.75	7.69
2.17	20.8

Table A4-54. Profile (4) for Basin 9.2 C developed from survey taken on 8/10/2011.

Area represented by profile is 0.156 ha.

Slope (%)	Length of Segment (m)
4.42	31.7
2.90	58.4

Table A4-55. Profile (1) for Basin 9.2 C developed from survey taken on 9/16/2011.

Area represented by profile is 0.385 ha.

Slope (%)	Length of Segment (m)
23.6	13.4
0.174	46.5

Table A4-56. Profile (2) for Basin 9.2 C developed from survey taken on 9/16/2011. Area represented by profile is 0.646 ha.

Slope (%)	Length of Segment (m)
8.88	50.5
1.02	230.

Table A4-57. Profile (3) for Basin 9.2 C developed from survey taken on 9/16/2011. Area represented by profile is 0.696 ha.

Slope (%)	Length of Segment (m)
5.29	15.4
1.86	37.3

Table A4-58. Profile (4) for Basin 9.2 C developed from survey taken on 9/16/2011. Area represented by profile is 0.0317 ha.

Slope (%)	Length of Segment (m)
2.12	15.1
8.87	5.41

Table A4-59. Profile (1) for Basin 9.2 C developed as representative areas from clearing and grubbing plans. Area represented by profile is 2.35 ha.

Slope (%)	Length of Segment (m)
5.00	95.3

Table A4-60. Profile (1) for Basin 9.2 C developed as average slope from clearing and grubbing plans. Area represented by profile is 2.35 ha.

Slope (%)	Length of Segment (m)
4.50	273

Table A4-61. Profile (1) for Basin 10.3 B developed from survey taken on 6/8/2011.

Area represented by profile is 0.0626 ha.

Slope (%)	Length of Segment (m)
34.97610063	3.975

Table A4-62. Profile (2) for Basin 10.3 B developed from survey taken on 6/8/2011.

Area represented by profile is 0.168 ha.

Slope (%)	Length of Segment (m)
1.93	60.8
2.36	55.5

Table A4-63. Profile (1) for Basin 10.3 B developed from survey taken on 8/10/2011.

Area represented by profile is 0.0481 ha.

Slope (%)	Length of Segment (m)
27.6	7.66
1.62	31.0

Table A4-64. Profile (2) for Basin 10.3 B developed from survey taken on 8/10/2011.

Area represented by profile is 0.105 ha.

Slope (%)	Length of Segment (m)
2.42	94.5

Table A4-65. Profile (1) for Basin 10.3 B developed from survey taken on 11/14/2011.

Area represented by profile is 0.0917 ha.

Slope (%)	Length of Segment (m)
22.7	10.1
0.513	46.4
3.65	27.3

Table A4-66. Profile (1) for Basin 10.3 B developed as representative area slope from clearing and grubbing plans. Area represented by profile is 0.526 ha.

Slope (%)	Length of Segment (m)
4.8	114.3293

Table A4-67. Profile (2) for Basin 10.3 B developed as representative area slope from clearing and grubbing plans. Area represented by profile is 1.05 ha.

Slope (%)	Length of Segment (m)
3.55	103
6.50	80.0

Table A4-68. Profile (1) for Basin 10.3 B developed as an average slope from clearing and grubbing plans. Area represented by profile is 1.58 ha.

Slope (%)	Length of Segment (m)
4.80	183

Table A4-69. Profile (1) for Basin 10.3 B developed as an average slope from the final grade plans. Area represented by profile is 0.769 ha.

Slope (%)	Length of Segment (m)
2.50	110.

Table A4-70. Profile (1) for Basin 5.10 B developed from survey taken on 8/10/2011. Area represented by profile is 0.679 ha.

Slope (%)	Length of Segment (m)
12.1	74.3
5.55	10.0
7.72	56.4

Table A4-71. Profile (2) for Basin 5.10 B developed from survey taken on 8/10/2011.

Area represented by profile is 0.157 ha.

Slope (%)	Length of Segment (m)
5.17	59.3

Table A4-72. Profile (1) for Basin 5.10 B developed from survey taken on 11/14/2011.

Area represented by profile is 0.146 ha.

Slope (%)	Length of Segment (m)
9.36	37.2
9.60	0.897

Table A4-73. Profile (2) for Basin 5.10 B developed from survey taken on 11/14/2011.

Area represented by profile is 0.0243 ha.

Slope (%)	Length of Segment (m)
0.456	6.36
15.6	11.3
5.60	46.3
27.1	1.70

Table A4-74. Profile (3) for Basin 5.10 B developed from survey taken on 11/14/2011.

Area represented by profile is 0.448 ha.

Slope (%)	Length of Segment (m)
35.8	27.8
11.6	6.03
2.60	17.1
7.74	34.8
26.7	3.30

Table A4-75. Profile (4) for Basin 5.10 B developed from survey taken on 11/14/2011.

Area represented by profile is 0.162 ha.

Slope (%)	Length of Segment (m)
6.33	51.6
21.6	2.26

Table A4-76. Profile (1) for Basin 5.10 B developed from survey taken on 12/13/2011.

Area represented by profile is 0.210 ha.

Slope (%)	Length of Segment (m)
50.7	4.61
6.37	22.7
14.1	18.3
13.1	3.93

Table A4-77. Profile (2) for Basin 5.10 B developed from survey taken on 12/13/2011.

Area represented by profile is 0.130 ha.

Slope (%)	Length of Segment (m)
11.3	26.5
3.52	1.82

Table A4-78. Profile (3) for Basin 5.10 B developed from survey taken on 12/13/2011.

Area represented by profile is 0.0367 ha.

Slope (%)	Length of Segment (m)
27.7	3.93
5.78	33.1
67.6	0.748

Table A4-79. Profile (1) for Basin 5.10 B developed as representative slope from clearing and grubbing plans. Area represented by profile is 0.708 ha.

Slope (%)	Length of Segment (m)
0	38.1
34.3	26.7
10.7	57.2

Table A4-80. Profile (1) for Basin 5.10 B developed as representative slope from clearing and grubbing plans. Area represented by profile is 0.708 ha.

Slope (%)	Length of Segment (m)
12.5	122

Appendix B

Figure B3-1. Rain gauge set up at basin 11.4 B.

Figure B3-2. Rain gauge set up at Basin 10.3 B

Figure B3-3. Rain gauge set up at Basin 5.10 B

Figure B3-4: Inlet of Basin 11.4 B

Figure B3-5. Outlet of Basin 11.4 B.

Figure B3-6. Inlet of Basin 9.2 C Front

Figure B3-7. Inlet of Basin 9.2 C Side

Figure B3-8. Outlet of Basin 9.2 C

Figure B3-9. Inlet of Basin 10.3 B

Figure B3-10. Outlet of Basin 10.3 B

Figure B3-11. Inlet of Basin 5.10 B

Figure B3-12. Outlet of Basin 5.10 B

Figure B4-1: Waddle Leading into Basin 11.4 B on 01/04/11

Figure B4-2: Waddle Leading into Basin 11.4 B on 01/27/11

Figure B4-3: Waddle Leading into Basin 11.4 B on 03/22/11

Figure B4-4: Silt Ditch Leading into Basin 11.4 B on side of catchment on 01/04/11

Figure B4-5: Silt Ditch Leading into Basin 11.4 B on side of catchment on 04/08/11

Figure B4-6: Silt Ditch Leading into Basin 11.4 B on side of catchment on 04/25/11

Figure B4-7: Silt Ditch Leading into Basin 11.4 B into catchment on 12/14/10

Figure B4-8: Silt Ditch Leading into Basin 11.4 B into catchment on 03/15/11

Figure B4-9: Silt Ditch Leading into Basin 11.4 B looking at basin on 01/04/11

Figure B4-10: Silt Ditch Leading into Basin 11.4 B looking at basin on 4/13/11

Figure B4-11: Failure of Silt Ditch Leading into Basin 11.4 B on 9/15/10

Figure B4-12: Failure of Silt Ditch Leading into Basin 11.4 B on 9/29/10

Figure B4-13: Silt Ditch Leading into Basin 11.3 C on 11/30/10

Figure B4-14: Silt Ditch Leading into Basin 11.3 C on 01/27/11

Figure B4-15: Waddle in Silt Ditch Leading into Basin 9.2 C on 4/13/11

Figure B4-16: Waddle in Silt Ditch Leading into Basin 9.2 C on 4/25/11

Figure B4-17: Silt Ditch Leading into Basin 9.2 C on 6/22/11

Figure B4-18: Silt Ditch Leading into Basin 9.2 C on 7/11/11

Figure B4-19: Silt Ditch Leading into Basin 9.2 C on 7/26/11

Figure B4-20: Silt Ditch Leading into Basin 9.2 C on 8/10/11

Figure B4-21: Culvert in Silt Ditch covered by haul road grading leading to basin 9.2 C

7/26/11

Figure B4-22: Culvert in Silt Ditch uncovered leading to basin 9.2 C 7/26/11

Figure B4-23: Posi-Shell in silt ditch leading to basin 5.10 B 8/10/11

Figure B4-24: Posi-Shell in silt ditch leading to basin 5.10 B 01/05/12

Figure B4-25: Hole in Posi-Shell due to wear 11/01/11

Figure B4-26: Hole in Posi-Shell due to wear 12/09/11

Figure B4-27: Deep rill in Posi-Shell due to wear 11/01/11

Figure B4-28: Damage to Posi-Shell at inlet of basin 5.10 B from clean out 9/26/11

Appendix C

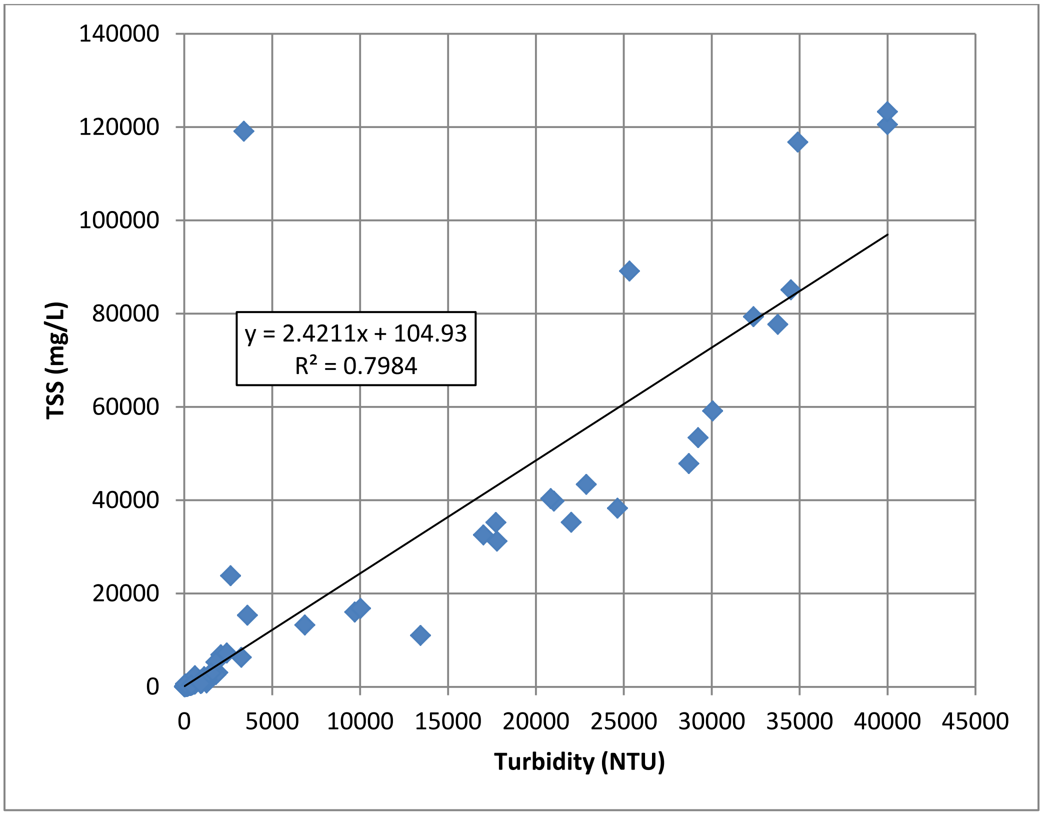

Figure C3-1. TSS vs Turbidity for samples collected on basin 11.4 B

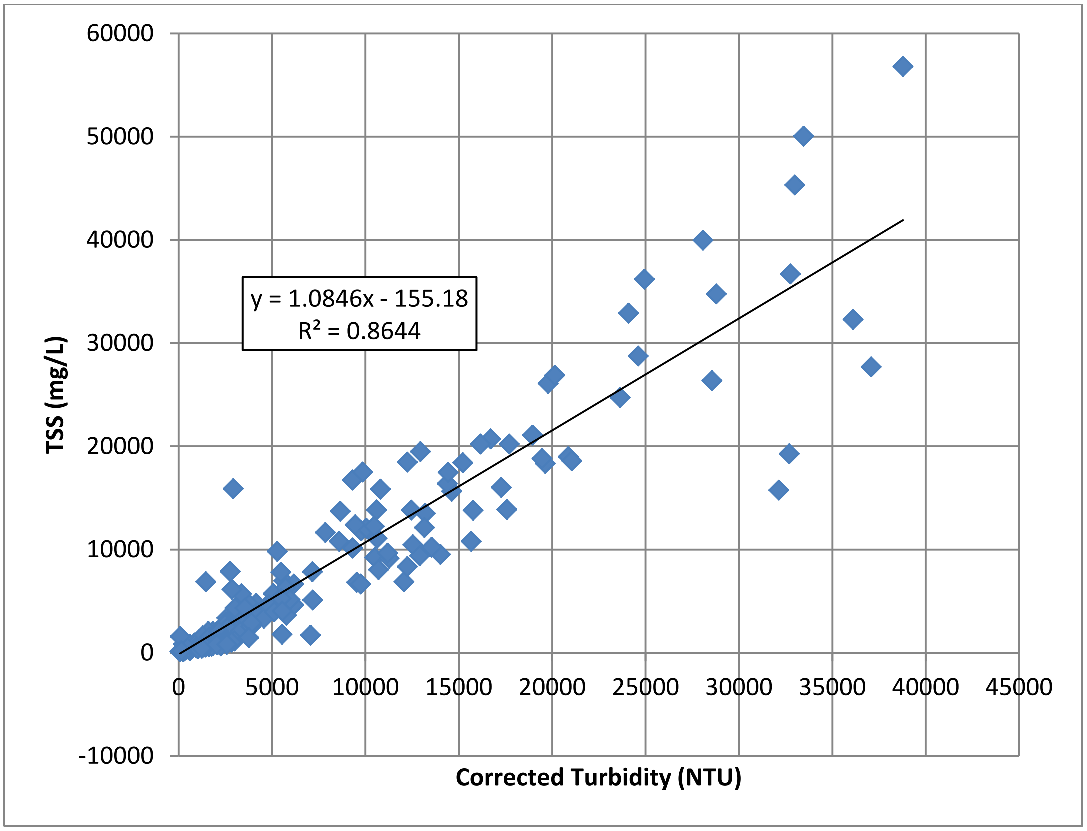

Figure C3-2. TSS vs Turbidity for samples collected on basin 9.2 C

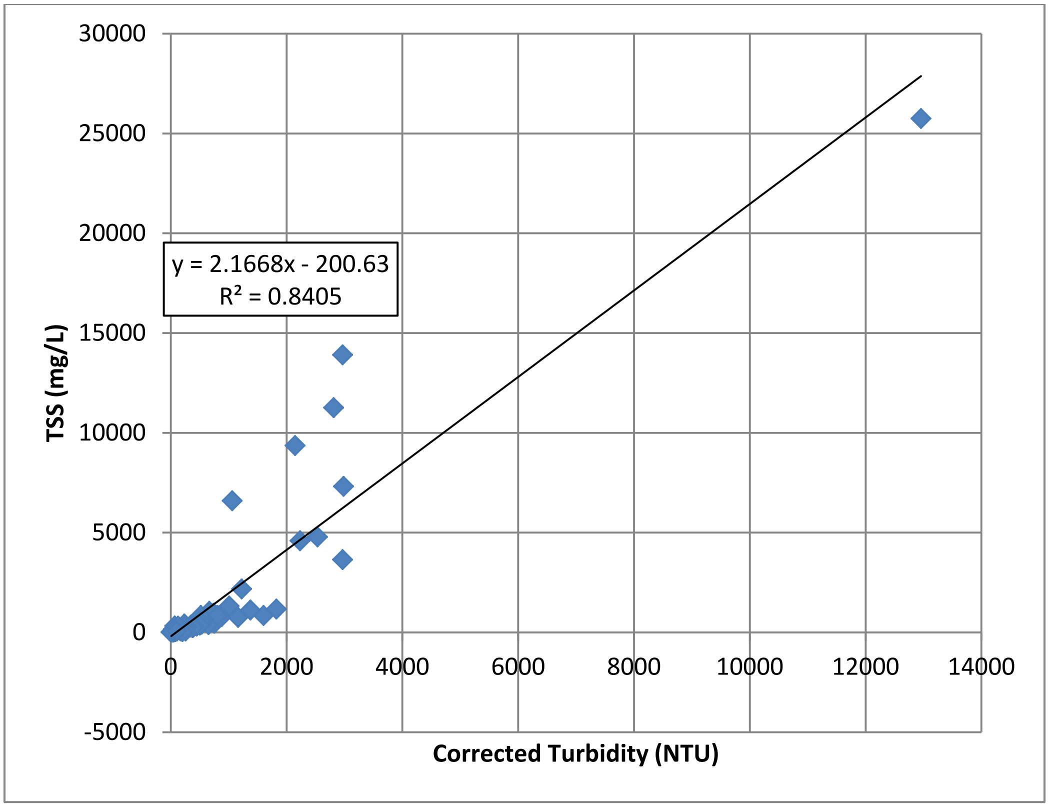

Figure C3-3. TSS vs Turbidity for samples collected on basin 10.3 B

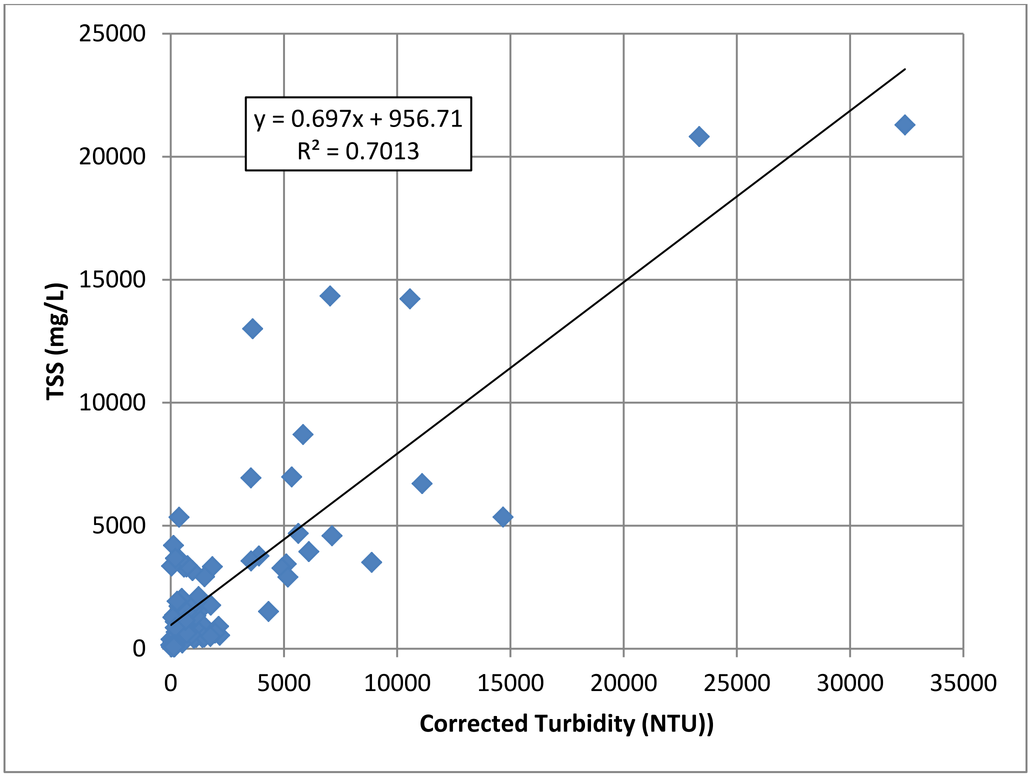

Figure C3-4. TSS vs Turbidity for samples collected on basin 5.10 B

Table C2-1. Using sediment yield per unit area as dependent variable and including average slope calculated from surveys as an independent variable using all of the storms with inlet samples collected. Listed are the associated p-values at the final step in the stepwise function if the variables were included in the regression model. Variables above bolded line were selected as significant when entered into the regression model. Model R-square = 0.761. N = 44. Model p-value = <0.0001. Model Intercept = -410.

Variable	P-Value
Peak Flow X Disturbed Area In Catchment	<0.0001
Stormwater Volume (L)	0.0267
Disturbed Area in Catchment	0.0341
Peak Flow (cms)	0.832
Rainfall Depth (mm)	0.192
Intensity (mm/hr)	0.757
Time Since Last Event (days)	0.512
Length of Storm (hrs)	0.574
Use of PAM	0.931
Area (ha)	0.966
Average Slope in Catchment (%)	0.847

Table C2-2. Using sediment yield per unit area as dependent variable and including average slope calculated from surveys as an independent variable using all of the storms on Basin 11.4 B with inlet samples collected. Listed are the associated p-values at the final step in the stepwise function if the variables were included in the regression model. Variables above bolded line were selected as significant when entered into the regression model. The significance of the use of PAM could not be found since PAM was used on every storm in this set. Model R-square = 0.926. N = 13. Model p-value = 0.0001. Model Intercept = -3170.

Variable	P-Value
Peak Flow X Disturbed Area In Catchment	<0.0001
Stormwater Volume (L)	0.0267
Disturbed Area in Catchment	0.0341
Peak Flow (cms)	0.832
Rainfall Depth (mm)	0.192
Intensity (mm/hr)	0.757
Time Since Last Event (days)	0.512
Length of Storm (hrs)	0.574
Use of PAM	0.931
Area (ha)	0.966
Average Slope in Catchment (%)	0.847

Table C2-3. Using sediment yield per unit area as dependent variable and including average slope calculated from surveys as an independent variable using all of the storms on Basin 9.2 C with inlet samples collected. Listed are the associated p-values at the final step in the stepwise function if the variables were included in the regression model. Variables above bolded line were selected as significant when entered into the regression model. Model R-square = 0.979. N = 11. Model p-value = 0.0001. Model Intercept = 3360.

Variable	P-Value
Use of PAM	0.0003
Peak Flow (cms)	<0.0001
Area (ha)	0.0112
Stormwater Volume (L)	0.654
Rainfall Depth (mm)	0.679
Intensity (mm/hr)	0.897
Time Since Last Event (days)	0.681
Length of Storm (hrs)	0.633
Disturbed Area in Catchment	N/A
Peak Flow X Use of PAM	0.543
Peak Flow X Disturbed Area in Catchment	0.543
Average Slope in Catchment (%)	N/A (Small Sample Size)

Table C2-4. Using sediment yield per unit area as dependent variable and including average slope calculated from surveys as an independent variable using all of the storms on Basin 10.3 B with inlet samples collected. Listed are the associated p-values at the final step in the stepwise function if the variables were included in the regression model. Variables above bolded line were selected as significant when entered into the regression model. Model R-square = 1. N = 7. Model p-value = 0.0009. Model Intercept = -671.

Variable	P-Value
Peak Flow (cms)	0.0227
Rainfall Depth (mm)	0.0484
Intensity (mm/hr)	0.0071
Disturbed Area in Catchment	0.0057
Area (ha)	0.0027
Stormwater Volume (L)	<0.0001
Time Since Last Event (days)	<0.0001
Length of Storm (hrs)	<0.0001
Use of PAM	N/A
Disturbed Area in Catchment	N/A
Peak Flow X Use of PAM	N/A
Peak Flow X Disturbed Area in Catchment	N/A
Average Slope in Catchment (%)	N/A

Table C2-5. Using sediment yield per unit area as dependent variable and including average slope calculated from surveys as an independent variable using all of the storms on Basin 5.10 B with inlet samples collected. Listed are the associated p-values at the final step in the stepwise function if the variables were included in the regression model. Variables above bolded line were selected as significant when entered into the regression model. Model R-square = 0.960. N = 13. Model p-value = <0.0001. Model Intercept = 127.

Variable	P-Value
Peak Flow X Disturbed Area in Catchment	<0.0001
Use of PAM	0.0049
Stormwater Volume (L)	0.0007
Time Since Last Event (days)	0.0796
Peak Flow (cms)	0.463
Rainfall Depth (mm)	0.412
Intensity (mm/hr)	0.866
Length of Storm (hrs)	0.228
Disturbed Area in Catchment	0.361
Area (ha)	N/A
Peak Flow X Use of PAM	0.424
Average Slope in Catchment (%)	0.220

Table C3-1. Table (1) of Storms with Inlet Samples and Respective Properties

Site	Date	Avg Inlet Turb (NTU)	Avg Inlet TSS (mg/L)	Storm Volume (gal)
11.4 B	9/30/2010	198	498	23800
11.4 B	10/28/2010 Early	28900	68700	1830
11.4 B	10/28/2010 Late	27500	61100	1000
11.4 B	11/16/2010	21600	53000	15600
11.4 B	12/12/2010	1010	2600	8970
11.4 B	12/16/2010	491	1340	17000
11.4 B	1/26/2011	36.0	192	2920
11.4 B	2/4/2011	716	1620	22400
11.4 B	3/6/2011	103	283	16100
11.4 B	3/30/2011	13400	31200	64200
11.4 B	4/9/2011	4600	11000	54100
11.4 B	4/16/2011	29000	75600	87700
11.4 B	5/4/2011	749	1340	4880
9.2 C	3/26/2011	171	531	29800
9.2 C	3/30/2011	1070	1170	78800
9.2 C	4/8/2011	10600	10700	59600
9.2 C	4/16/2011	8980	10200	147000
9.2 C	5/4/2011	590	397	4010
9.2 C	6/27/2011	14900	4450	119000
9.2 C	7/6/2011	17600	19500	82200
9.2 C	8/6/2011	7500	7830	40500
9.2 C	8/12/2011	11700	12500	121000
9.2 C	8/21/2011	13500	13900	51300
9.2 C	8/26/2011	12000	14800	64700
10.3 B	6/28/2011	4540	10700	9230
10.3 B	8/12/2011	2380	5540	10500
10.3 B	9/6/2011	844	1540	3430
10.3 B	9/23/2011	224	270	1070
10.3 B	9/28/2011	1060	6600	540
10.3 B	10/18/2011	354	845	6000
10.3 B	11/4/2011	130	307	1960
5.10 B	Early 8/6/2011	3400	5780	29400
5.10 B	Late 8/6/2011	5060	7580	3840
5.10 B	8/12/2011	2020	3340	44000
5.10 B	8/21/2011	5500	6450	14600

Table C3-1. Continued

5.10 B	8/26/2011	3340	4800	17000
5.10 B	9/6/2011	688	1450	29900
5.10 B	9/21/2011	1740	4050	39000
5.10 B	9/23/2011	227	940	4850
5.10 B	10/29/2011	367	799	14800
5.10 B	11/4/2011	657	1310	46400
5.10 B	11/23/2011	21400	16100	22900
5.10 B	11/29/2011	7710	5740	47800
5.10 B	12/7/2011	1500	4310	3370

Table C3-2. Table (2) of Storms with Inlet Samples and Respective Properties

Site	Peak Flow (gpm)	Total Rainfall (in)	RUSLE2 Single Storm (kg)	Total Sediment (kg)
11.4 B	70.6	1.37	466	44.4
11.4 B	152	0.39	968	494
11.4 B	393	0.64	200	192
11.4 B	796	0.33	188	2730
11.4 B	59.9	0.24	79.0	86.6
11.4 B	26.8	0.58	65.8	85.6
11.4 B	10.4	0.18	65.9	2.12
11.4 B	225	0.44	106	136
11.4 B	163	0.22	83.0	17.1
11.4 B	2050	0.2	163	9150
11.4 B	2190	1.18	10300	2300
11.4 B	2980	0.39	1360	24800
11.4 B	41.8	0.08	5.58	22.85
9.2 C	20.2	0.18	69.0	61.4
9.2 C	232	0.2	58.3	320
9.2 C	703	0.49	6190	1320
9.2 C	2070	0.38	773	6270
9.2 C	12.9	0.08	28.8	6.02
9.2 C	1980	0.43	779	6910
9.2 C	1360	0.25	109	4150
9.2 C	299	0.23	21.1	1260

Table C3-2. Continued

9.2 C	1720	0.4	125	6020
9.2 C	153	0.41	13.7	4060
9.2 C	479	0.14	96.5	4680
10.3 B	659	1.11	111	543
10.3 B	726	0.4	93.3	277
10.3 B	151	1.69	760	18.0
10.3 B	14.2	0.21	22.6	1.09
10.3 B	21.0	0.54	86.3	13.5
10.3 B	10.5	2.12	884	12.8
10.3 B	75.6	1.09	3.49	2.28
5.10 B	1230	0.23	310	759
5.10 B	659	0.16	174	114
5.10 B	1850	0.4	2250	636
5.10 B	394	0.5	520	364
5.10 B	1280	0.14	310	375
5.10 B	1380	1.69	10200	199
5.10 B	1750	0.66	778	508
5.10 B	70.9	0.21	237	18.3
5.10 B	388	0.79	273	45.8
5.10 B	1010	1.09	513	225
5.10 B	1140	0.46	3100	1470
5.10 B	594	0.75	2600	1040
5.10 B	217	0.25	2130	57.6

Table C3-3. Table (3) of Storms with Inlet Samples with Respective Properties

Site	Total Sediment (kg/ac)	Sediment Loading (kg/ft^2)	Intensity (in/hr)	Days Since Last Event (days)
11.4 B	24.4	0.0117	0.11	2
11.4 B	271	0.0399	0.78	14
11.4 B	105	0.103	1.10	0.71
11.4 B	1010	0.719	0.18	10
11.4 B	32.2	0.0228	0.17	26
11.4 B	28.4	0.0225	0.08	4
11.4 B	0.704	0.000558	0.09	25
11.4 B	43.0	0.0357	0.055	9
11.4 B	12.1	0.00449	0.22	7

Table C3-3. Continued

11.4 B	6490	2.41	0.2	4
11.4 B	1630	0.606	0.84	1
11.4 B	13800	6.54	0.912	7
11.4 B	12.7	0.00601	0.12	18
9.2 C	11.8	0.00726	0.17	3
9.2 C	61.4	0.0379	0.2	4
9.2 C	252	0.156	0.98	3
9.2 C	1200	0.742	1.14	7
9.2 C	1.15	0.000712	0.12	18
9.2 C	1320	0.818	1.72	7
9.2 C	795	0.491	0.456	8
9.2 C	296	0.149	0.23	29
9.2 C	1420	0.712	0.936	6
9.2 C	955	0.480	0.55	8
9.2 C	1080	0.554	0.56	5
10.3 B	950	0.201	1.11	1
10.3 B	733	0.103	0.936	6
10.3 B	47.7	0.00668	0.691	7
10.3 B	2.88	0.000404	0.36	2
10.3 B	59.5	0.00499	1.30	5
10.3 B	33.8	0.00474	0.747	18
10.3 B	6.01	0.000843	0.211	6
5.10 B	360	0.112	0.23	31
5.10 B	54.2	0.0169	0.16	0.5
5.10 B	301	0.199	0.936	6
5.10 B	173	0.114	0.55	8
5.10 B	178	0.117	0.56	5
5.10 B	94.5	0.0623	0.689	7
5.10 B	241	0.159	0.463	5
5.10 B	8.66	0.00571	0.36	2
5.10 B	21.7	0.0143	0.287	10
5.10 B	107	0.0703	0.211	6
5.10 B	766	0.459	0.28	19
5.10 B	542	0.325	0.1482	6
5.10 B	30.0	0.0180	0.75	8

Table C3-4. Table (4) of Storms with Inlet with Respective Properties

Site	Length of Storm (hrs)	Inlet and Outlet Samples?	PAM?	Exposed Area/Grading?
11.4 B	12.3	Y	Y	N
11.4 B	0.5	N	Y	Y
11.4 B	0.583	N	Y	Y
11.4 B	1.83	Y	Y	Y
11.4 B	1.42	N	Y	N
11.4 B	3.6	N	Y	N
11.4 B	2	N	Y	N
11.4 B	8	Y	Y	N
11.4 B	1	N	Y	N
11.4 B	1	Y	Y	Y
11.4 B	1	Y	Y	Y
11.4 B	0.33	Y	Y	Y
11.4 B	0.667	N	Y	Y
9.2 C	0.75	N	N	N
9.2 C	1.00	N	N	N
9.2 C	0.75	N	N	N
9.2 C	0.33	N	N	N
9.2 C	0.67	N	N	N
9.2 C	0.25	Y	N	N
9.2 C	0.417	Y	N	N
9.2 C	1	N	N	N
9.2 C	0.417	Y	N	N
9.2 C	1	N	Y	Y
9.2 C	0.25	Y	Y	Y
10.3 B	1	Y	N	Y
10.3 B	0.417	Y	N	Y
10.3 B	2.33	Y	N	N
10.3 B	0.583	Y	N	N
10.3 B	0.417	Y	N	N
10.3 B	3	Y	N	N
10.3 B	5.17	Y	N	N
5.10 B	1	Y	N	N
5.10 B	1	Y	N	N
5.10 B	0.417	Y	N	N
5.10 B	1	Y	N	N

Table C3-4. Continued

5.10 B	0.25	Y	N	N
5.10 B	0.417	Y	Y	N
5.10 B	1.17	Y	Y	N
5.10 B	0.583	Y	Y	N
5.10 B	2.17	Y	Y	N
5.10 B	5.17	Y	Y	N
5.10 B	1.67	Y	Y	Y
5.10 B	4.67	Y	Y	Y
5.10 B	0.333	Y	Y	Y

Table C3-5. Table (1) of Storms with Inlet and Outlet Samples with Respective Properties

Site	Date	Avg Inlet Turb (NTU)	Avg Inlet TSS (mg/L)	Total Inlet Volume (gal)
11.4 B	9/30/2010	198.	498	23800
11.4 B	11/16/2010	21600	53000	15600
11.4 B	2/4/2011	716	1620	22400
11.4 B	3/30/2011	13400	31200	64200
11.4 B	4/9/2011	4600	11000	54100
11.4 B	4/16/2011	29000	75600	87700
9.2 C	6/27/2011	14900	4450	119000
9.2 C	7/6/2011	17600	19500	82200
9.2 C	8/12/2011	11700	12500	121000
9.2 C	8/26/2011	12000	14800	64700
10.3 B	6/28/2011	4540	10700	9230
10.3 B	8/12/2011	2380	5540	10500
10.3 B	9/6/2011	844	1540	3430
10.3 B	9/23/2011	224	270	1070
10.3 B	9/28/2011	1060	6600	540
10.3 B	10/18/2011	354	845	6000
10.3 B	11/4/2011	130	307	1960
5.10 B	Early 8/6/2011	3400	5780	29400
5.10 B	Late 8/6/2011	5060	7580	3840
5.10 B	8/12/2011	2020	3340	44000
5.10 B	8/21/2011	5100	6450	14600
5.10 B	8/26/2011	3340	4800	17000
5.10 B	9/6/2011	688	1450	29900
5.10 B	9/21/2011	1740	4050	39000
5.10 B	9/23/2011	227	939	48500
5.10 B	10/29/2011	367	799	14800
5.10 B	11/4/2011	657	1310	46400
5.10 B	11/23/2011	21400	16100	23000
5.10 B	11/29/2011	7710	5740	47800
5.10 B	12/7/2011	1091	368	3370

Table C3-6. Table (2) of Storms with Inlet and Outlet Samples with Respective Properties

Site	Peak Flow to Inlet from Storm (gpm)	Did Discharge Occur Over Spillway?	Sediment Over Spillway (kg)	Rain (in)	Sediment Load Into Basin (kg)
11.4 B	70.6	Y	5.69	1.37	44.4
11.4 B	796	Y	28.0	0.33	2730
11.4 B	225	Y	29.1	0.44	136
11.4 B	2050	Y	4.53	0.2	9150
11.4 B	2190	Y	2.89	1.18	2300
11.4 B	2980	Y	4140	0.39	24800
9.2 C	1980	Y	1320	0.43	6910
9.2 C	1360	N	0.00	0.25	4150
9.2 C	1720	N	0.00	0.4	6020
9.2 C	479	N	0.00	0.14	4680
10.3 B	659	Y	185	1.11	543
10.3 B	726	Y	105	0.4	277
10.3 B	151	Y	64.0	1.69	18.0
10.3 B	14.2	Y	4.95	0.21	1.09
10.3 B	21.0	Y	13.7	0.54	13.5
10.3 B	10.5	N	0.00	2.12	12.8
10.3 B	75.6	Y	23.4	1.09	2.28
5.10 B	1230	Y	168	0.23	758
5.10 B	659	Y	108	0.16	114
5.10 B	1850	Y	478	0.4	636
5.10 B	394	N	0.00	0.5	364
5.10 B	1280	N	0.00	0.14	375
5.10 B	1380	Y	236	1.69	199
5.10 B	1750	Y	230	0.66	508
5.10 B	71.0	Y	4.14	0.21	18.3
5.10 B	388	N	0.00	0.79	45.8
5.10 B	1010	Y	51.9	1.09	225
5.10 B	1140	N	0.00	0.46	1470
5.10 B	594	Y	153	0.75	1040
5.10 B	217	N	0.00	0.25	57.6

Table C3-7. Table (3) of Storms with Inlet and Outlet Storms with Respective Properties

Site	RUSLE2 Single Storm (kg)	Sediment Load (kg/Acre)	Mass Loading on Basin (kg/ft^2)	Basin Efficency (%) Reduction of Total Sediment	Basin Efficency (%) Reduction of Average NTU
11.4 B	466	24.4	0.0117	68.1	86.5
11.4 B	188	1010	0.719	98.6	99.4
11.4 B	106	43.0	0.0357	55.0	76.2
11.4 B	163	6490	2.41	99.9	99.3
11.4 B	10300	1630	0.606	99.8	90.1
11.4 B	1360	13800	6.54	83.4	1.04
9.2 C	779	1320	0.818	82.2	69.6
9.2 C	109	795	0.491	99.2	94.7
9.2 C	125	1420	0.712	91.6	77.2
9.2 C	96.5	1080	0.554	91.7	70.5
10.3 B	111	950	0.201	67.8	83.8
10.3 B	93.3	733	0.103	64.7	72.6
10.3 B	760	47.7	0.00668	-196	49.0
10.3 B	22.6	2.88	0.000404	-62.3	67.2
10.3 B	86.3	59.5	0.00499	21.5	83.3
10.3 B	884	33.8	0.00474	-94.9	35.2
10.3 B	3.49	6.01	0.000843	-521	-14.6
5.10 B	309	360	0.112	73.6	61.8
5.10 B	174	54.2	0.0169	-4.51	76.3
5.10 B	2250	301	0.199	14.3	-14.3
5.10 B	521	173	0.114	22.2	72.3
5.10 B	309	178	0.117	36.4	73.4
5.10 B	10200	94.5	0.0623	-70.0	39.4
5.10 B	778	241	0.159	41.8	85.8
5.10 B	237	8.66	0.00571	-18.0	68.8
5.10 B	273	21.7	0.0143	68.5	90.1
5.10 B	513	107	0.0703	49.3	69.1
5.10 B	3095	766	0.459	94.4	86.2
5.10 B	2600	542	0.325	77.4	73.3
5.10 B	2130	30.0	0.0180	92.3	27.4

Table C3-8. Table (4) of Storms with Inlet and Outlet Samples with Respective Properties

Site	Basin Efficency (%) Reduction of Average TSS	Intensity (in/hr)	Time Since Last Event (days)	Length of Storm (hrs)	PAM?	Grading/ Exposed Area?
11.4 B	73.8	0.11	2	12.3	Y	N
11.4 B	99.4	0.18	10	1.83	Y	Y
11.4 B	75.0	0.055	9	8	Y	N
11.4 B	99.2	0.2	4	1	Y	Y
11.4 B	92.1	0.84	1	1	Y	Y
11.4 B	6.55	0.912	7	0.33	Y	Y
9.2 C	-5.79	1.72	7	0.25	N	N
9.2 C	96.0	0.456	8	0.417	N	N
9.2 C	81.7	0.936	6	0.417	N	N
9.2 C	80.5	0.56	5	0.25	Y	Y
10.3 B	89.1	1.11	1	1	N	Y
10.3 B	79.8	0.936	6	0.417	N	Y
10.3 B	57.9	0.691	7	2.33	N	N
10.3 B	67.7	0.36	2	0.583	N	N
10.3 B	92.5	1.30	5	0.417	N	N
10.3 B	67.5	0.747	18	3	N	N
10.3 B	22.0	0.211	6	5.17	N	N
5.10 B	65.5	0.23	31	1	N	N
5.10 B	78.1	0.16	0.5	1	N	N
5.10 B	3.22	0.936	6	0.417	N	N
5.10 B	58.1	0.55	8	1	N	N
5.10 B	64.3	0.56	5	0.25	N	N
5.10 B	11.2	0.689	7	0.417	Y	N
5.10 B	64.1	0.463	5	1.1667	Y	N
5.10 B	46.1	0.36	2	0.583	Y	N
5.10 B	60.2	0.287	10	2.17	Y	N
5.10 B	51.6	0.211	6	5.17	Y	N
5.10 B	87.6	0.28	19	1.67	Y	Y
5.10 B	68.2	0.148	6	4.67	Y	Y
5.10 B	91.5	0.75	8	0.333	Y	Y

Table C3-9. Table (1) of p-values (top) and correlation coefficient (bottom) derived from the Pearson Correlation Coefficient between storm and basin characteristics.

	Site	Average Inlet Turbidity (NTU)	Average Inlet TSS (mg/L)	Total Inlet Volume (L)	Peak Flow to Inlet (m^3/s)	Rain (mm)
Site		0.0216 -0.476	0.0072 -0.545	0.0243 -0.468	0.178 -0.291	0.976 -0.00671
Average Inlet Turbidity (NTU)	0.0216 -0.476		<0.0001 0.845	0.0133 0.508	0.0162 0.495	0.0927 -0.359
Average Inlet TSS (mg/L)	0.0072 -0.545	<0.0001 0.845		0.172 0.295	0.0144 0.503	0.211 -0.271
Total Inlet Volume (L)	0.0243 -0.468	0.0133 0.508	0.172 0.295		0.0006 0.664	0.780 -0.056
Peak Flow to Inlet (m^3/s)	0.178 -0.291	0.0162 0.495	0.0144 0.503	0.0006 0.664		0.995 0.00149
Rain (mm)	0.976 -0.00671	0.0927 -0.359	0.211 -0.271	0.7980 -0.0560	0.995 0.00149	
Sediment Load (kg)	0.0096 0.0096	<0.0001 0.748	<0.0001 0.828	0.0019 0.611	0.0004 0.678	0.330 -0.213
Sediment Load by Area (kg/ha)	0.0197 -0.482	0.0006 0.660	<0.0001 0.833	0.0365 0.438	0.0007 0.657	0.468 -0.159
Sediment Loading on Basin Area (kg/m^2)	0.0225 -0.474	0.0002 0.696	<0.0001 0.855	0.0365 0.451	0.0007 0.652	0.459 -0.163
Basin Efficiency (%) Reduction of Total Sediment	0.0024 -0.602	0.003 0.591	0.0391 0.433	0.0135 0.507	0.196 0.196	0.259 -0.246
Basin Efficiency (%) Reduction of Turbidity	0.253 -0.249	0.829 0.0475	0.621 -0.109	0.978 -0.00601	0.317 -0.218	0.832 0.0468
Basin Efficiency (%) Reduction of TSS	0.281 -0.235	0.785 0.0602	0.881 0.0332	0.291 -0.230	0.115 -0.338	0.326 -0.214
Intensity (mm/hr)	0.659 -0.0973	0.300 0.226	0.764 0.0663	0.0014 0.627	0.0055 0.560	0.884 -0.0324
Time Since Last Storm Event (days)	0.289 0.231	0.481 0.155	0.863 0.0380	0.665 -0.0955	0.995 -0.00137	0.393 -0.187
Length of Storm (hr)	0.200 -0.277	0.154 -0.307	0.285 -0.233	0.315 -0.219	0.0297 -0.454	0.0282 0.457
Area (ha)	0.201 -0.277	0.130 0.325	0.896 -0.0288	0.0011 0.636	0.809 0.0535	0.199 -0.278

Table C3-10. Table (2) of p-values (top) and correlation coefficient (bottom) derived from the Pearson Correlation Coefficient between storm and basin characteristics.

	Sediment Load (kg)	Sediment Load by Area (kg/ha)	Sediment Loading on Basin Area (kg/m^2)	Basin Efficiency (%) Reduction of Total Sediment
Site	0.0096 -0.528	0.0197 -0.482	0.0225 -0.474	0.0024 -0.602
Average Inlet Turbidity (NTU)	<0.0001 0.748	0.0006 0.660	0.0002 0.696	0.003 0.591
Average Inlet TSS (mg/L)	<0.0001 0.828	<0.0001 0.833	<0.0001 0.855	0.0391 0.433
Total Inlet Volume (L)	0.0019 0.611	0.0365 0.438	0.0306 0.451	0.0135 0.507
Peak Flow to Inlet (m^3/s)	0.0004 0.678	0.0007 0.657	0.0008 0.652	0.196 0.280
Rain (mm)	0.330 -0.213	0.468 -0.159	0.459 -0.163	0.259 -0.246
Sediment Load (kg)		<0.0001 0.962	<0.0001 0.975	0.0651 0.391
Sediment Load by Area (kg/ha)	<0.0001 0.962		<0.0001 0.994	0.135 0.322
Sediment Loading on Basin Area (kg/m^2)	<0.0001 0.975	<0.0001 0.994		0.135 0.321
Basin Efficiency (%) Reduction of Total Sediment	0.0651 0.391	0.1347 0.322	0.1347 0.321	
Basin Efficiency (%) Reduction of Turbidity	0.210 -0.272	0.187 -0.285	0.149 -0.311	0.0421 0.427
Basin Efficiency (%) Reduction of TSS	0.205 -0.272	0.306 -0.223	0.225 -0.263	0.0302 0.452
Intensity (mm/hr)	0.0748 0.379	0.310 0.221	0.240 0.255	0.986 -0.00402
Time Since Last Storm Event (days)	0.785 -0.0601	0.762 -0.667	0.812 -0.0525	0.334 0.211
Length of Storm (hr)	0.250 -0.250	0.375 -0.194	0.365 -0.198	0.610 0.112
Area (ha)	0.617 0.110	0.510 -0.145	0.659 -0.0972	0.132 0.324

Table C3-11. Table (3) of p-values (top) and correlation coefficient (bottom) derived from the Pearson Correlation Coefficient between storm and basin characteristics

	Basin Efficiency (%) Reduction of Turbidity	Basin Efficiency (%) Reduction of TSS	Intensity (mm/hr)	Time Since Last Storm Event (days)	Length of Storm (hr)	Area (ha)
Site	0.253 -0.249	0.281 -0.235	0.659 -0.0973	0.289 0.231	0.200 -0.277	0.201 -0.277
Average Inlet Turbidity (NTU)	0.830 0.0475	0.785 0.0602	0.300 0.226	0.481 0.155	0.154 -0.307	0.130 0.325
Average Inlet TSS (mg/L)	0.621 -0.109	0.881 0.0332	0.764 0.0663	0.863 0.0380	0.285 -0.233	0.896 -0.0288
Total Inlet Volume (L)	0.978 -0.00601	0.291 -0.230	0.0014 0.627	0.665 -0.0955	0.315 -0.219	0.0011 0.636
Peak Flow to Inlet (m^3/s)	0.317 -0.218	0.115 -0.338	0.0055 0.560	0.995 -0.00137	0.0297 -0.454	0.809 0.0535
Rain (mm)	0.832 0.0468	0.326 -0.214	0.884 -0.0324	0.393 -0.187	0.0282 0.457	0.199 -0.278
Sediment Load (kg)	0.210 -0.272	0.205 -0.274	0.0748 0.379	0.785 -0.0601	0.250 -0.250	0.617 0.110
Sediment Load by Area (kg/ha)	0.187 -0.285	0.306 -0.223	0.310 0.221	0.762 -0.0667	0.375 -0.194	0.510 -0.145
Sediment Loading on Basin Area (kg/m^2)	0.149 -0.311	0.225 -0.263	0.240 0.255	0.812 -0.0525	0.365 -0.198	0.659 -0.0972
Basin Efficiency (%) Reduction of Total Sediment	0.0421 0.427	0.0302 0.452	0.986 -0.00402	0.334 -0.0327	0.609 0.112	0.132 0.324
Basin Efficiency (%) Reduction of Turbidity		0.0011 0.637	0.0394 -0.432	0.882 -0.0327	0.259 0.246	0.417 0.178
Basin Efficiency (%) Reduction of TSS	0.0011 0.637		0.0024 -0.602	0.844 0.0436	0.446 0.167	0.929 -0.0198
Intensity (mm/hr)	0.0394 -0.432	0.0024 -0.602		0.499 -0.148	0.0139 -0.505	0.031 0.450
Time Since Last Storm Event (days)	0.882 -0.0327	0.844 0.0436	0.499 -0.148		0.636 -0.104	0.996 0.00122
Length of Storm (hr)	0.259 0.246	0.446 0.167	0.0139 -0.505	0.636 -0.104		0.379 -0.193
Area (ha)	0.417 0.178	0.929 -0.0198	0.031 0.450	0.996 0.00122	0.379 -0.193	

Table C3-12. When basin efficiency by reduction of turbidity was used as the dependent variable, the P-values associated with the independent variables and interactions (not including interaction between area and intensity) when entered into regression model in the last step of the stepwise function using all storms with inlet and outlet samples collected. Parameter(s) and interaction(s) above the solid line were selected as significant when entered into the regression model. Model R-square = 0.361. P-value of model = 0.0114. N = 23. Model Intercept = 58.85.

Variable	P-Value
Intensity (mm/hr)	0.0044
Area (ha)	0.0302
Stormwater Volume (L)	0.419
Peak Flow (m^3/s)	0.428
Discharge occurring over emergency spillway	0.901
Rainfall Depth (mm)	0.374
Sediment Load Into Basin (kg)	0.640
Sediment Load per Unit Area (kg/ha)	0.663
Sediment Loading on Surface Area of Basin (kg/m^2)	0.557
Time Since Last Rain Event (days)	0.480
Length of Rain Event (hrs)	0.946
Use of PAM	0.832
Disturbed Area in Catchment	0.970
Intensity X Use of PAM	0.589
Intensity X Discharge over Emergency Spillway	0.620
Intensity X Disturbed Areas in Catchment	0.495

Table C3-13. When basin efficiency by reduction of turbidity was used as the dependent variable, the P-values associated with the independent variables and interactions when entered into regression model in the last step of the stepwise function using all storms with inlet and outlet samples collected. Parameter(s) and interaction(s) above the solid line were selected as significant when entered into the regression model. Model R-square = 0.497. P-value of model = 0.0010. N = 23. Model Intercept = 98.3.

Variable	P-Value
Intensity (mm/hr)	0.0003
Intensity X Area (ha)	0.0022
Stormwater Volume (L)	0.553
Peak Flow (m^3/s)	0.203
Discharge occurring over emergency spillway	0.636
Rainfall Depth (mm)	0.358
Sediment Load Into Basin (kg)	0.800
Sediment Load per Unit Area (kg/ha)	0.883
Sediment Loading on Surface Area of Basin (kg/m^2)	0.775
Time Since Last Rain Event (days)	0.344
Length of Rain Event (hrs)	0.533
Use of PAM	0.722
Disturbed Area in Catchment	0.693
Area (ha)	0.746
Intensity X Use of PAM	0.651
Intensity X Discharge over Emergency Spillway	0.894
Intensity X Disturbed Areas in Catchment	0.850

Table C3-14. When basin efficiency by reduction of turbidity was used as the dependent variable, the P-values associated with the independent variables and interactions when entered into regression model in the last step of the stepwise function using all storms with intensities less than 12.7 mm/hr with inlet and outlet samples collected. Parameter(s) and interaction(s) above the solid line were selected as significant when entered into the regression model. Model R-square = 0.390. P-value of model = 0.023. N = 13. Model Intercept = 77.5.

Variable	P-Value
Sediment Load Into Basin (kg)	0.023
Stormwater Volume (L)	0.627
Peak Flow (m^3/s)	0.645
Discharge occurring over emergency spillway	0.155
Rainfall Depth (mm)	0.385
Sediment Load per Unit Area (kg/ha)	0.320
Sediment Loading on Surface Area of Basin (kg/m^2)	0.820
Intensity (mm/hr)	0.650
Time Since Last Rain Event (days)	0.363
Length of Rain Event (hrs)	0.656
Use of PAM	0.360
Disturbed Area in Catchment	0.686
Area (ha)	0.493
Intensity X Use of PAM	0.315
Intensity X Discharge over Emergency Spillway	0.429
Intensity X Disturbed Areas in Catchment	0.603
Intensity X Area	0.521

Table C3-15. When basin efficiency by reduction of turbidity was used as the dependent variable, the P-values associated with the independent variables and interactions when entered into regression model in the last step of the stepwise function using all storms with intensities greater than 12.7 mm/hr with inlet and outlet samples collected. Parameter(s) and interaction(s) above the solid line were selected as significant when entered into the regression model. Model R-square = N/A. P-value of model = N/A. N = 9. Model Intercept = N/A.

Variable	P-Value
Stormwater Volume (L)	0.789
Peak Flow (m^3/s)	0.677
Discharge occurring over emergency spillway	0.558
Rainfall Depth (mm)	0.696
Sediment Load Into Basin (kg)	0.464
Sediment Load per Unit Area (kg/ha)	0.352
Sediment Loading on Surface Area of Basin (kg/m^2)	0.464
Intensity (mm/hr)	0.906
Time Since Last Rain Event (days)	0.175
Length of Rain Event (hrs)	0.309
Use of PAM	0.729
Disturbed Area in Catchment	0.792
Area (ha)	0.363
Intensity X Use of PAM	0.815
Intensity X Discharge over Emergency Spillway	0.623
Intensity X Disturbed Areas in Catchment	0.683
Intensity X Area	0.608

Table C3-16. When basin efficiency by reduction of turbidity was used as the dependent variable, the P-values associated with the independent variables and interactions when entered into regression model in the last step of the stepwise function using all storms collected on Basin 11.4 B with inlet and outlet samples collected. Parameter(s) and interaction(s) above the solid line were selected as significant when entered into the regression model. Model R-square = 0.729. P-value of model = 0.0305. N = 6. Model Intercept = 97.3. Note: Differentiating sediment yield and sediment yield per unit surface area of the basin is not applicable since the surface area of the basin was constant throughout the monitoring period.

Variable	P-Value
Sediment Yield (kg)	0.0305
Stormwater Volume (L)	0.614
Peak Flow (m^3/s)	0.424
Discharge occurring over emergency spillway	N/A
Rainfall Depth (mm)	0.488
Sediment Load per Unit Area (kg/ha)	0.232
Sediment Loading of Surface Area of Basin (kg/m^2)	N/A
Intensity (mm/hr)	0.765
Time Since Last Rain Event (days)	0.806
Length of Rain Event (hrs)	0.263
Use of PAM	N/A
Disturbed Area in Catchment	0.164
Area (ha)	0.382
Intensity X Use of PAM	0.765
Intensity X Discharge over Emergency Spillway	0.765
Intensity X Disturbed Areas in Catchment	0.872
Intensity X Area	0.713

Table C3-17. When basin efficiency by reduction of turbidity was used as the dependent variable, the P-values associated with the independent variables and interactions when entered into regression model in the last step of the stepwise function using all storms collected on Basin 9.2 C with inlet and outlet samples collected. Parameter(s) and interaction(s) above the solid line were selected as significant when entered into the regression model. Model R-square = N/A. P-value of model = N/A. N = 4. Model Intercept = N/A. Note: Differentiating sediment yield and sediment yield per unit surface area of the basin is not applicable since the surface area of the basin was constant throughout the monitoring period.

Variable	P-Value
Stormwater Volume (L)	0.789
Peak Flow (m^3/s)	0.949
Discharge occurring over emergency spillway	0.521
Rainfall Depth (mm)	0.831
Sediment Load Into Basin (kg)	0.348
Sediment Load per Unit Area (kg/ha)	0.273
Sediment Loading on Surface Area of Basin (kg/m^2)	0.348
Intensity (mm/hr)	0.413
Time Since Last Rain Event (days)	0.278
Length of Rain Event (hrs)	0.212
Use of PAM	0.569
Disturbed Area in Catchment	0.569
Area (ha)	0.604
Intensity X Use of PAM	0.569
Intensity X Discharge over Emergency Spillway	0.521
Intensity X Disturbed Areas in Catchment	0.569
Intensity X Area	0.477

Table C3-18. When basin efficiency by reduction of turbidity was used as the dependent variable, the P-values associated with the independent variables and interactions when entered into regression model in the last step of the stepwise function using all storms collected on Basin 5.10 B with inlet and outlet samples collected. Parameter(s) and interaction(s) above the solid line were selected as significant when entered into the regression model. Model R-square = 0.631. P-value of model = 0.0012. N = 13. Model Intercept = 105. Note: Differentiating sediment yield and sediment yield per unit surface area of the basin is not applicable since the surface area of the basin was constant throughout the monitoring period.

Variable	P-Value
Intensity (mm/hr)	0.0012
Stormwater Volume (L)	0.648
Peak Flow (m^3/s)	0.695
Discharge occurring over emergency spillway	0.186
Rainfall Depth (mm)	0.735
Sediment Load Into Basin (kg)	0.958
Sediment Load per Unit Area (kg/ha)	0.953
Sediment Loading on Surface Area of Basin (kg/m^2)	0.837
Time Since Last Rain Event (days)	0.634
Length of Rain Event (hrs)	0.388
Use of PAM	0.938
Disturbed Area in Catchment	0.308
Area (ha)	N/A
Intensity X Use of PAM	0.959
Intensity X Discharge over Emergency Spillway	0.440
Intensity X Disturbed Areas in Catchment	0.195
Intensity X Area	N/A

Table C3-19. When sediment yield per unit area was used as the dependent variable, the P-values associated with the independent variables when entered into regression model in the last step of the stepwise function using all storms collected with inlet samples. Parameter(s) and interaction(s) above the solid line were selected as significant when entered into the regression model. Model R-square = 0.473. P-value of model = <0.0001. N = 44. Model Intercept = -2110.

Variable	P-Value
Peak Flow (m^3/s)	<0.0001
Disturbed Area in Catchment	0.0182
Stormwater Volume (L)	0.977
Rainfall Depth (mm)	0.572
Intensity (mm/hr)	0.296
Time Since Last Event (days)	0.801
Length of Storm (hrs)	0.590
Use of PAM	0.562
Area (ha)	0.546

Table C3-20. When sediment yield per unit area was used as the dependent variable, the P-values associated with the independent variables and interactions when entered into regression model in the last step of the stepwise function using all storms collected with inlet samples. Parameter(s) and interaction(s) above the solid line were selected as significant when entered into the regression model. Model R-square = 0.761. P-value of model = <0.0001. N = 44. Model Intercept = -410.

Variable	P-Value
Stormwater Volume (L)	0.0267
Disturbed Area in Catchment	0.0341
Peak Flow X Disturbed Area in Catchment	<0.0001
Peak Flow (m^3/s)	0.832
Rainfall Depth (mm)	0.192
Intensity (mm/hr)	0.757
Time Since Last Event (days)	0.512
Length of Storm (hrs)	0.574
Use of PAM	0.931
Area (ha)	0.742
Peak Flow X Use of PAM	0.966

Table C3-21. When sediment yield was used as the dependent variable, the P-values associated with the independent variables and interactions when entered into regression model in the last step of the stepwise function using all storms collected with inlet samples. Parameter(s) and interaction(s) above the solid line were selected as significant when entered into the regression model. Model R-square = 0.718. P-value of model = <0.0001. N = 44. Model Intercept = -1110.

Variable	P-Value
Stormwater Volume (L)	<0.0001
Peak Flow X Disturbed Area in Catchment	<0.0001
Peak Flow (m^3/s)	0.958
Rainfall Depth (mm)	0.280
Intensity (mm/hr)	0.632
Time Since Last Event (days)	0.368
Length of Storm (hrs)	0.582
Use of PAM	0.804
Disturbed Area in Catchment	0.226
Area (ha)	0.901
Peak Flow X Use of PAM	0.993

Table C3-22. When sediment yield was used as the dependent variable, the P-values associated with the independent variables and interactions when entered into regression model in the last step of the stepwise function using all storms collected with inlet samples on Basin 11.4 B. Parameter(s) and interaction(s) above the solid line were selected as significant when entered into the regression model. Model R-square = 0.891. P-value of model = 0.0006. N = 13. Model Intercept = -2380.

Variable	P-Value
Stormwater Volume (L)	0.0001
Rainfall Depth (mm)	0.0200
Intensity (mm/hr)	0.036
Length of Storm (hrs)	0.131
Peak Flow (m^3/s)	0.933
Time Since Last Event (days)	0.406
Use of PAM	N/A
Disturbed Area in Catchment	0.972
Area (ha)	0.572
Peak Flow X Use of PAM	0.933
Peak Flow X Disturbed Area in Catchment	0.739

Table C3-23. When sediment yield was used as the dependent variable, the P-values associated with the independent variables and interactions when entered into regression model in the last step of the stepwise function using all storms collected with inlet samples on Basin 9.2 C. Parameter(s) and interaction(s) above the solid line were selected as significant when entered into the regression model. Model R-square = 0.981. P-value of model = <0.0001. N = 11. Model Intercept = 2820.

Variable	P-Value
Peak Flow (m^3/s)	<0.0001
Use of PAM	0.0002
Area	0.139
Stormwater Volume (L)	0.475
Rainfall Depth (mm)	0.596
Intensity (mm/hr)	0.778
Time Since Last Event (days)	0.554
Length of Event (hrs)	0.802
Disturbed Area in Catchment	N/A
Peak Flow X Use of PAM	0.492
Peak Flow X Disturbed Area in Catchment	0.492

Table C3-24. When sediment yield was used as the dependent variable, the P-values associated with the independent variables and interactions when entered into regression model in the last step of the stepwise function using all storms collected with inlet samples on Basin 10.3 B. Parameter(s) and interaction(s) above the solid line were selected as significant when entered into the regression model. Model R-square = 1.0000. P-value of model = <0.0001. N = 7. Model Intercept = -323.

Variable	P-Value
Stormwater Volume (L)	0.0311
Peak Flow (m^3/s)	0.0048
Intensity (mm/hr)	0.0085
Area (ha)	<0.0001
Rainfall Depth (mm)	0.906
Time Since Last Event (days)	0.491
Length of Event (hrs)	0.592
Use of PAM	N/A
Disturbed Area in Catchment	0.733
Peak Flow X Use of PAM	N/A
Peak Flow X Disturbed Area in Catchment	0.733

Table C3-25. When sediment yield was used as the dependent variable, the P-values associated with the independent variables and interactions when entered into regression model in the last step of the stepwise function using all storms collected with inlet samples on Basin 5.10 B. Parameter(s) and interaction(s) above the solid line were selected as significant when entered into the regression model. Model R-square = 0.955. P-value of model = <0.0001. N = 13. Model Intercept = 113.

Variable	P-Value
Stormwater Volume (L)	0.0007
Time Since Last Event (days)	0.0649
Use of PAM	0.0045
Peak Flow X Disturbed Area in Catchment	<0.0001
Peak Flow (m^3/s)	0.384
Rainfall Depth (mm)	0.389
Intensity (mm/hr)	0.973
Length of Event (hrs)	0.178
Disturbed Area in Catchment	0.373
Area (ha)	N/A
Peak Flow X Disturbed Area in Catchment	0.378

Table C4-1. Soil texture based on particle size analysis of soil sample from upper portion of catchment of basin 11.4 B

Upper Catchment of Basin 11.4 B	
% Sand	78.8
%Silt	14.4
%Clay	6.8

Table C4-2. Soil texture based on particle size analysis of soil sample from middle portion of catchment of basin 11.4 B

Middle Catchment of Basin 11.4 B	
% Sand	77.6
%Silt	14.2
%Clay	8.24

Table C4-3. Soil texture based on particle size analysis of soil sample from lower portion of catchment of basin 11.4 B

Lower Catchment of Basin 11.4 B	
% Sand	85.2
%Silt	11.9
%Clay	2.86

Table C4-4. Soil texture based on particle size analysis of soil sample from upper portion of catchment of basin 9.2 C

Upper Catchment of Basin 9.2 C	
% Sand	70
%Silt	18.2
%Clay	11.8

Table C4-5. Soil texture based on particle size analysis of soil sample from lower portion of catchment of basin 9.2 C

Lower Catchment of Basin 9.2 C	
% Sand	77.6
%Silt	10.8
%Clay	11.6

Table C4-6. Soil texture based on particle size analysis of soil sample from upper portion of catchment of basin 10.3 B

Upper Catchment of Basin 10.3 B	
% Sand	73.8
%Silt	14.2
%Clay	12.0

Table C4-7. Soil texture based on particle size analysis of soil sample from lower portion of catchment of basin 10.3 B

Lower Catchment of Basin 10.3 B	
% Sand	75.0
%Silt	11.4
%Clay	13.6

Table C4-8. Soil texture based on particle size analysis of soil sample from upper portion of catchment of basin 5.10 B

Upper Catchment of Basin 5.10 B	
% Sand	61.2
%Silt	33.9
%Clay	4.96

Table C4-9. Soil texture based on particle size analysis of soil sample from lower portion of catchment of basin 5.10 B

Lower Catchment of Basin 5.10 B	
% Sand	62.4
%Silt	32.6
%Clay	5.03

Appendix D

Alternative Approaches and Models

Using GIS Based Tools for Estimating Soil Erosion and Runoff with RUSLE2

Introduction of 2-D RUSLE2 Approach

Expansions of the current capabilities of RUSLE2 are being researched (Dabney et al., 2010; Agren, 2010.). These advancements attempt to eliminate two major problems for conservation planning on construction sites including the development of the profile length to be used in the RUSLE2 calculations and that gully erosion is not estimated by the current RUSLE2 model.

Model Fundamentals

A DEM of the catchment being analyzed in RUSLE2 is developed from LiDAR survey data. In order to create the DEM, cells are created using interpolative relationships between survey points and contain information such as slope, length, etc. Layers are then brought into GIS which describe the soils and management schemes, and the user defines the simulation area and channelized flow paths.

The program is run and internally flow paths are developed based on the topography, land use, and soils, starting from the areas of concentrated flow eventually developing a network of cells which drain into particular channel cells. The effective length slope draining into the cell determined using the aforementioned cell network and the resulting profile is used in the RUSLE2 calculation. The resulting sediment yield into each channel cell can then be optionally linked to a CREAMS based model for channel erosion estimates.

Subsequently, the sediment yield results results are displayed in graphs, tables, and maps to be analyzed.

Model Limitations

Currently the program is still under development. There is no interface for the program and not available in a package where it can be distributed to other users for use. However, there is a working model and an ability to do some analysis with the model remotely by providing management sequences, soil maps, and survey data (Seth Dabney, USDA-ARS, personal communication, 19 October 2011).

<u>SEDPRO (SEDIMOT IV)</u>

Introduction and Uses of SEDPRO

SEDPRO is a model developed to assess the trapping efficiency of BMPs within a catchment individually as well as evaluating entire treatment regimes. Its intended use is to predict the sediment loading from a catchment or watershed in transition from undisturbed to developed conditions. The model has a graphical interface where the user can drag in and connect together different catchments and BMPs into the workspace and edit them to customize their parameters for each scenario to be assessed. Each piece (catchment, BMP, etc.) can be copied and models can be run simultaneously for side-by-side comparisons of erosion control plans, or to model different phases of a project and design the basin for the entirety of the project even as it changes. Once the erosion and sediment control plan put into the model, a region and storm size is chosen to run in the model which will depend on the desired goals of the erosion control plan.

The BMPs available in the current version are sediment basins (wet or dry), sediment traps with rock check outlet, and silt fence. In development are bioswales, vegetated filter strips, bioretention cells, sand filter, and engineered devices.

Model Fundamentals

SEDPRO uses user defined inputs for the catchment such as curve number, the slope and length of a flow path, the peak rate factor, area, and time of concentration, as well as soil information such as the series and erodibility factors. From these parameters, peak flow rates, sediment yields, and total runoff volume can be calculated for the catchment.

Runoff volume is calculated using the NRCS curve number method or the Green-Ampt equation. They are used to develop the peak flow for the catchment as well as a hydrograph. It is subsequently used in calculations to come up with sediment loading and transport capacities to ultimately evaluate the effectiveness of each BMP as well as the erosion control plan as a whole.

Sediment loading on impervious areas is largely based on the event mean concentration of sediment and the total runoff from the catchment. This total mass of sediment calculated is then time distributed based on the flow rate of water given by the hydrograph.

For pervious areas, erosion from rainfall and runoff as categorized by rill, interrill, and ephemeral gulley is calculated. Rill and interrill erosion are determined using the CREAMS method with corrections made to it to account for deposition. Essentially, the amount of erosion is calculated initially then the amount of deposition is taken into account. The flow path in the catchment can be split into multiple parts and the erosion and deposition from the upper portion is calculated and added to the next session. Similarly if the flow path hits a BMP, the deposition is calculated at the BMP and the remainder added to the next segment or piece in the flow path. By calculating sediment yield in using this method, the user can obtain a more accurate estimate of the sediment yield as well as evaluate the efficiencies of each BMP and tell where sediment is being deposited.

Model Limitations

This is an ideal model for evaluating erosion control plans, designing sediment basins, and estimating sediment discharging loads for a design storm. The model can be used in the planning process of developing an erosion control plan since multiple phases of construction or different methods of control can be assessed simultaneously. With outputs of turbidity, discharge concentration, and total sediment discharge this model could be used as a tool for government entities to have a consistent basis on which to mandate a certain trapping efficiency for those who intend on developing an area. For instance, a contractor would have to develop and implement a plan to capture 80% of sediment through the entirety of the project for a 10 year 24 hour storm.

However, the model is still in development. There is no user manual, limited scientific documentation, or validity, and a lack of support for technical issues. Furthermore, there are only a few BMPs that can be inputted to the model and could not encompass all of the different BMPs commonly used on construction sites. As many scenarios will be run with it as possible to compare to rates of erosion, efficiencies of basins, average NTU and TSS, but without being reliable program further development, refinement, and research of the model is needed. Although, in the future, it could be a very valuable tool in designing sediment basins as well as overall erosion control plans in the future.