Sediment Production from Unpaved Oil Well Access Roads in the Allegheny National Forest

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STUDY NOTE

This study was funded and completed in two phases:

Phase one was completed in 2010 and consisted of 14 test conducted on “as is” roads in the Allegheny National Forest to provide a baseline and range of sediment productions. This was funded through the US Department of Energy’s National Energy Technology Laboratory. (Agreement 2010-SC-RES-30033026, 400.4.650.920.003)

Phase two was completed in 2011 and consisted on 4 tests conducted on newly placed aggregate on roads in the Allegheny National Forest to provide a comparison of sediment production compared to the findings in phase one. This was funded through the USDA Northern Research Station. (Agreement 11-CS-11242302-066)

Description and results of both phases are included in this paper.

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Abstract

The Center for Dirt and Gravel Road Studies at Penn State University has been working to reduce sediment pollution generated by unpaved roads in Pennsylvania for over a decade. Runoff from unpaved roads is a large source of sediment pollution in many forested watersheds. The Allegheny Nation Forest, located in Northwestern Pennsylvania, has over 1,695 miles of unpaved access roads that serve the shallow oil wells in the Forest (USDA-FS unpublished, 2010a). The purpose of this study was to quantify sediment generation rates from these oil access roads in the Allegheny National Forest. In addition, the objective of phase II of the study was to determine differences in sediment production after new aggregate had been placed on 4 of the sites.

The experimental approach taken in this study was to use a rainfall simulation device to create a repeatable rainfall event and collect sediment load data. The rainfall simulator was used to collect sediment in road runoff on 14 sites, each of which was 100’ in length. The simulated rainfall event was 0.61” in 30 minutes which has a return interval of slightly less than 2 months.

The 14 sites tested showed sediment productions ranging from 3.2 to 60 pounds of sediment for each 30 minute simulated rain event. The average sediment runoff from the sites was 24.7 pounds, which equates to a sediment production rate of 1,300 pounds per mile for each 30 minute simulated rain event. Extrapolation of these results indicates that a single storm of similar intensity and duration to the design storm could be expected to produce over 1,100 tons of sediment from the oil access roads in the Allegheny National Forest. An estimated 385 tons of that sediment can be expected to enter directly into nearby streams during each storm.

The study also identified a significant ‘first flush’ effect on the road segments studied. Additionally, road segments that received more traffic have been more compacted and exhibit higher structural strengths. Without traffic stress, the best indicators of sediment production from the roads tested were road slope combined with road width. If the road is stressed by traffic, then sediment production becomes less dependent on road width and slope, and more dependent on road strength as measured by the California Bearing Ratio. Finally it was observed that sediment generation would be greatly reduced from roads with very low usage by establishing vegetative cover on the road surface.

After initial testing, 4 of the 14 sites were surface with new aggregate material. Two sites were surface with local “pit run” material as is standard procedure. Two of the sites were surfaced with Driving Surface Aggregate. The 4 sites were then tested a year later to determine sediment production. All four sites showd reductions in sediment production (39% and 65% for pit-run, 67% and 65% for DSA). The two pit-run sits averaged ten times as much sediment production as the DSA sites (26.1 lbs versus 2.5 pounds).

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CHAPTER 1: INTROUDCTION

1.1 Background

The Commonwealth of Pennsylvania has recognized that a significant contributor of sediment pollution to Pennsylvania streams is runoff from publicly maintained dirt and gravel roads (*Figure 1.1*). In response to a statewide assessment of pollution sites on public unpaved roads, the Commonwealth established the Dirt and Gravel Road Maintenance Program [Program] in 1997 within the State Conservation Commission [SCC]. The Program provides a non-lapsing funding source with an objective of identifying the polluting sources and implementing solutions. The Center for Dirt and Gravel Road Studies [Center] was established within the Larson Transportation Institute on the University Park Campus of The Pennsylvania State University in 2000 to support the Conservation Commission's Program. The Center identifies and refines Environmentally Sensitive road Maintenance Practices [ESMPs] to reduce sediment pollution, teaches these practices to municipal road crews, and coordinates a technical outreach and assistance program for townships in the Commonwealth.

The Center has conducted more than 140 two-day training sessions which have been attended by over 5,000 state and township personnel. In the thirteen years that the DGRP has been in operation, over 2,000 individual road projects have been completed which mitigate sediment pollution to streams of the Commonwealth. A more detailed description of the Program and its accomplishments to date can be found at www.dirtandgravelroads.org.

In 2008, the Center completed a study funded by the Chesapeake Bay Commission [CBC] with the objective of quantifying sediment production values from unpaved roads. The CBC study implemented several ESMPs in order to quantify sediment after sediment reduction practices had been implemented on the roads. The CBC study employed an artificial rainfall simulator to provide a consistent and repeatable rain event on different sections of roadway. The procedures and methodologies developed in the 2008 CBC study were the basis for the current NETL study described in this report. A summary and full report on the Center's previous CBC study is available on the Center's website

Figure 1.1: Example of the effect of road runoff on aquatic ecosystems. This image, taken in the Allegheny National Forest adjacent to site "C" in this study, shows road runoff entering Grunder Run at a crossing. *(photo courtesy ANF)*

at www.dirtandgravelroads.org under "research".

The objective of Phase I of this study was to quantify sediment production rates for various unpaved roads created and maintained by the oil industry within the Allegheny National Forest. Another component of the study was to quantify sediment reductions after the placement of road aggregates, however, this component of the study has yet to be completed. The objective of Phase II of the study was to compare sediment productions after new aggregates had been placed on 4 of the sites.

1.2 Site Selection

The Center worked in cooperation with representatives from the Allegheny National Forest [ANF] to determine site selection criteria. ANF representatives also assisted in finding and evaluating many of the field sites that were used in this study. The Center worked cooperatively with ANF personnel throughout the study to make joint decisions on which sites to include.

Because of other sediment-related studies that were underway with Clarion University and the US Geological Survey (USGS), it was determined that the watersheds of Grunder Run and Hedgehog Run, located just south of Warren, PA, would be the ideal location for this study. The two adjacent watersheds are very similar in size, slope, and cover. The major difference in the two watersheds was the amount of oil well development, with Grunder being heavily developed, and Hedgehog being relatively undisturbed (Figure 1.2). The comparative study between these two watersheds that is being conducted by Clarion University may provide further insights to sediment effects to aquatic habitat on a watershed scale, but are not part of this study or report. In 2010, the USGS began sampling suspended sediment and streamflow to analyze sediment concentrations for the two basins during storm events.

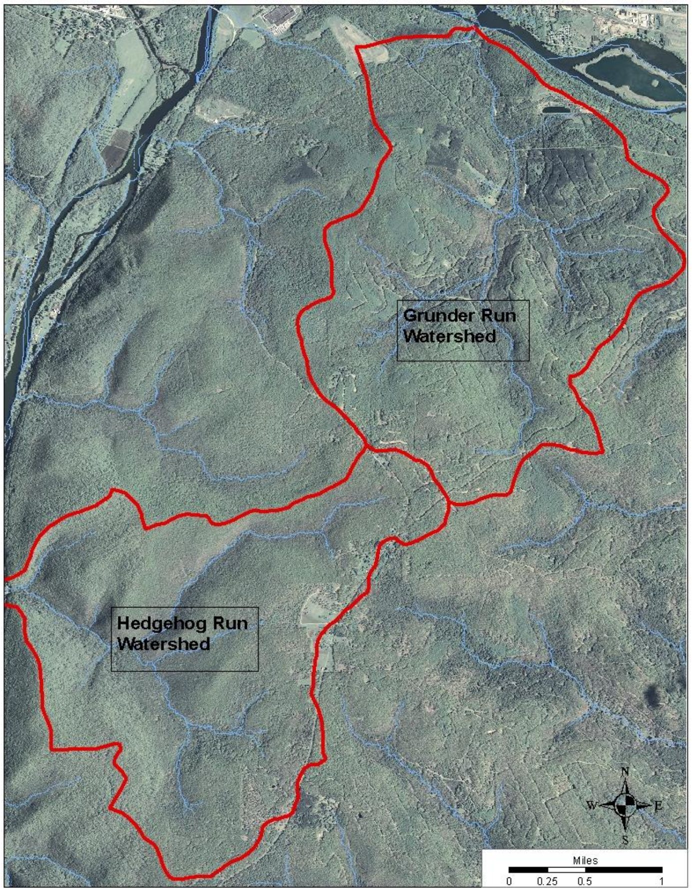


Figure 1.2: Aerial view of Grunder (right) and Hedgehog (left) watersheds. Notice amount of oil wells and access roads in Grunder watershed. *(map courtesy ANF)*

The major phase of oil and gas development began in Grunder Run watershed in the early 1980's. By 1990, most of the 455 wells in this watershed were completed (USDA-FS unpublished, 2010). In the last few years, some new wells and roads have been developed. In Hedgehog watershed, there are 27 recorded oil and gas wells, but only 7 are known to be active (USDA-FS unpublished, 2010). All of the 14 sites in Grunder and Hedgehog watersheds are on roads that have existed for at least 20 years. The roads in Grunder Run development receive use mainly from light trucks and all-terrain vehicles to operate and maintain the oil and gas wells. Some roads serve as main access routes to the majority of the oil and gas wells and tank batteries.

The 14 sites tested in this study were chosen to cover a wide variety of road slopes, widths, surface materials, and use levels. Two of this Study's 14 road sites were located in the Hedgehog Watershed and 11 sites were in the Grunder watershed. One site is located in the adjoining Sill Run watershed, on Forest Road 362. It was the intent of this study not only to give an overall sediment production average for the 14 roads, but to begin to determine which physical factors of the roads may be responsible for the highest sediment loads. Physical description and details of each site are included in the results section.

The second part of this study looked at sediment production after the placement of pit-run aggregate and Driving Surface Aggregate. Pit-run is a term used to describe a locally derived material that is mined from "unofficial borrow pits". Historically, tt has been widely used on most of the access roads in this study in the past. Compared with commercially supplied aggregate, locally excavated pit-run is less expensive. Since pit-run is taken directly from the ground at various locations without processing, it is also highly variable in its composition and quality. Driving Surface Aggregate is a specially designed aggregate specification designed to achieve maximum compacted density to resist traffic and erosion. The DSA used in this study was limestone based, although limestone is not required.

The experimental approach taken in this study was to collect sediment loads on a section of road long enough to be representative of the roadway during a simulated rain even. To ensure an accurate comparison of each road segment, a device was constructed that would deliver water to the test site in a uniform manner. The details of the "RainMaker", its performance characteristics, and testing protocol follow.

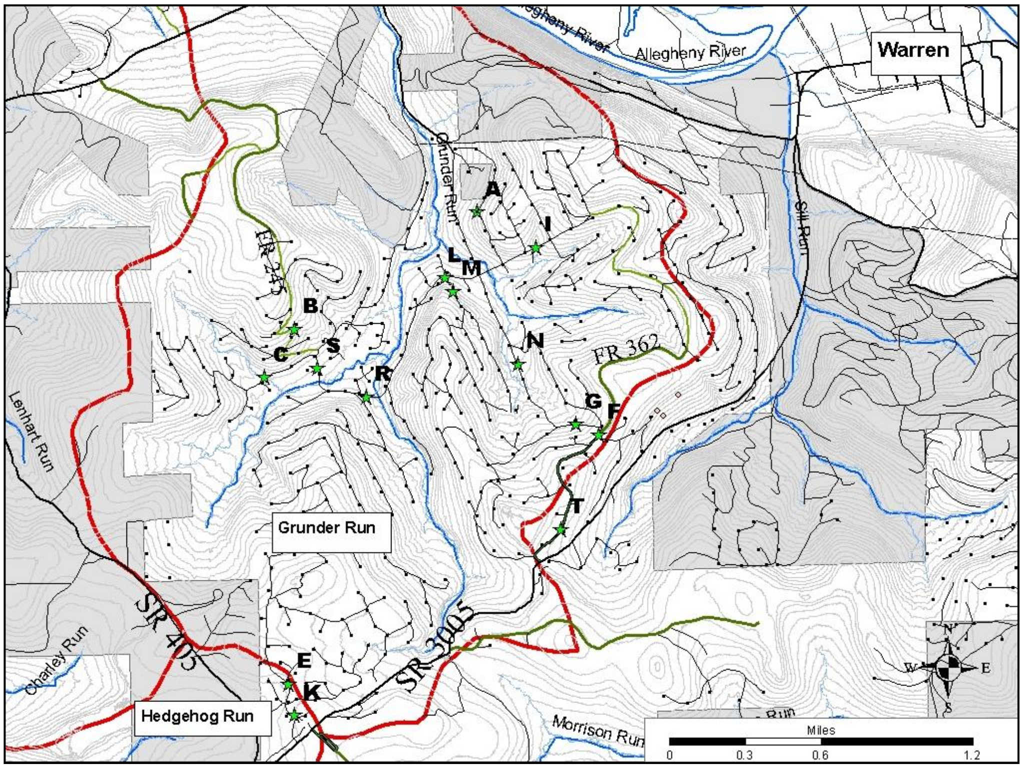


Figure 1.3: Locations of the 14 road sites used in this study (green stars, labeled with letters). The town of Warren and the Allegheny River can be seen in the upper right. *(map courtesy ANF)*

CHAPTER 2: Rainfall Simulator

The Center originally designed the first-generation rainfall simulator, or “RainMaker”, for use under a previous study funded by the Chesapeake Bay Commission, and described earlier in this report. The RainMaker is ideally suited to sediment monitoring because of the convenience and repeatability that cannot be achieved by sampling natural events. As part of this NETL study, the Center redesigned the RainMaker in order to improve road coverage, repeatability, drop size, and drop velocity to produce a more repeatable rainfall event that is more representative of natural rainfall. The “second-generation” RainMaker used in this study is described below. The RainMaker is designed to simulate a rain event on a 100’ length of road. It delivers approximately 1.2 inches of rainfall per hour in a highly controlled and repeatable event (Figure 2.1).

2.1 RainMaker Design Specifications

-water source: delivered to site and stored for use in collapsable bladders (figure 2.2).

-**pump**: 3”, 5hp Honda water pump.

-body: 100’ x 1½” PVC pipe (in 10’ sections).

-risers: 11 PVC risers at 10’ intervals, each ½” in diameter and 10’ tall. A “T” extends 2.5 feet in both directions laterally towards the adjacent risers in order to position a nozzle every 5 feet along the sample road section.

-nozzles: One 180^{o} nozzle every 5 feet along road (Rainbird® MPR Rotary Nozzles).

Figure 2.1: RainMaker being run on road Segment “R” as part of this study.

Figure 2.2: A water truck fills two 1,250 gallon collapsible bladders with water on site “T”.

-pressure: 30 psi measured on gauge at the terminal end of RainMaker.

-**rainfall rate**: measured average of 0.62 inches in 30 minutes (1.23 inches per hour).

2.2 RainMaker Calibration

The primary purpose of the RainMaker is to create a highly repeatable rainfall event. The repeatability of the setup was verified by collecting and measuring rainfall for three separate events on a flat paved surface (Figure 2.3). Rainfall intensities from the repeatability testing can be found in *Table 2.1*. The average rainfall intensity over the entire road was 1.23 inches per hour. The variability between rainfall collection jars within a single run of the RainMaker approximates the "evenness" of precipitation over the road. The standard deviation between collection jars was 0.37, or 30% of the mean intensity. This indicates that although the average intensity of rainfall is 1.23 in/hr, most rainfall rates can be expected to vary between 0.86 and 1.60 in/hr for any point on the road.

Sample Container	**Rainfall Intensities (inches per hour)**				**Std Dev Between Runs**
	Run 1	**Run 2**	**Run 3**	**Average**	
1	0.79	0.81	0.44	0.68	0.21
2	0.80	0.76	0.51	0.69	0.16
3	0.77	0.77	0.74	0.76	0.02
4	1.29	0.24	0.89	0.81	0.53
5	1.50	1.51	1.48	1.50	0.01
6	1.84	1.69	1.83	1.78	0.08
7	1.24	1.27	1.37	1.29	0.07
8	1.50	1.56	1.19	1.42	0.20
9	1.21	1.14	1.26	1.20	0.06
10	1.95	1.80	1.73	1.83	0.12
11	1.26	1.23	1.27	1.25	0.02
12	0.69	0.63	0.84	0.72	0.11
13	1.14	1.13	1.14	1.14	0.01
14	1.43	1.48	1.33	1.42	0.08
15	1.93	1.86	1.78	1.86	0.08
16	1.67	1.59	1.48	1.58	0.10
17	1.05	1.08	1.22	1.12	0.09
18	1.46	1.48	1.48	1.48	0.01
19	1.29	1.29	1.28	1.29	0.01
20	1.37	1.37	1.23	1.32	0.08
21	0.72	0.82	0.90	0.82	0.09
22	1.12	0.99	1.50	1.20	0.26
Average	**1.27**	**1.21**	**1.22**	**1.23**	**0.11**
St Dev within run	**0.38**	**0.41**	**0.38**	**0.37**	
Average rainfall rate is 1.23 inches per hour (0.62 inches per 30 minute test event)					
Std Dev between colleciton points in one run (evenness) = 0.37 or 30% of mean					
Stand Dev between three sample runs (consistency) = 0.11 or 8.9% of mean					

Table 2.1: Results of repeatability testing for the RainMaker. 22 rainfall collection jars were randomly placed on the roadway and subjected to three runs of the RainMaker.

Figure 2.3: Rainfall collection jars were used to measure and calibrate the rainfall simulator.

Consistency between separate RainMaker runs is of a greater importance to this study than evenness of coverage over the road. The primary advantage of the rainfall simulator is that it provides the same storm event every time it is run. Analysis of the data presented in *Table 2.1* indicates that the standard deviation between runs of the RainMaker is 0.11 or 9% of the mean intensity. This means that most points on the road can be expected to vary by less than 9% between separate runs of the RainMaker. A paired-t test was also run on the data presented in *Table 2.1* to test the statistical significance of the repeatability of the separate runs. The results of the paired-t test indicated with a 95% confidence that there were no significant differences in rainfall intensity between the three runs. In summary, the RainMaker does a satisfactory job of providing an evenly distributed rain event (SD of 30% of mean within run), and an excellent job of providing repeatability by providing the same rainfall intensity at the same points on successive runs (SD of 9% of mean between runs).

In order to better characterize the simulated storm event, testing was done to determine the size of the raindrops produced by the RainMaker. Fifteen covered petri dishes with a mixture of STP motor oil treatment and mineral oil [REF 2001] were placed randomly through the rainfall area (Figure 2.4). Each dish was individually uncovered for approximately one

Figure 2.4: One of the petri dishes used to capture and suspend raindrops in order to measure their size.

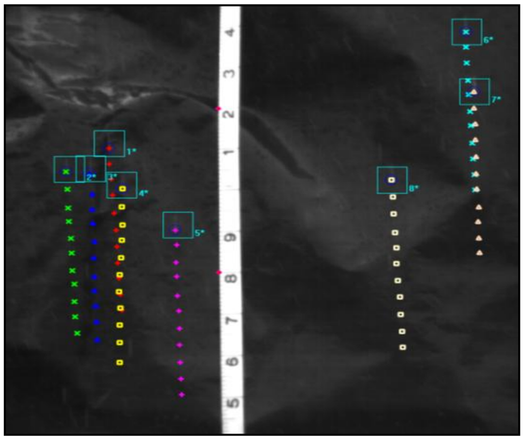


Figure 2.5: Eight individual raindrops are being tracked in this still frame from the high speed video used to determine raindrop velocity.

second; enough to allow rain drops to impact the oil mixture. The hydrophobic characteristics of the fluid mixture suspended the individual rain drops in the mixture from which they could be photographed. The numbers and size of the individual rain drops in each of the fifteen petri dishes was measured with a custom written program in MatLab. The average size of the rain drops measured was 0.84mm. Although it is on the smaller end, 0.84mm is within the normal size distribution of what most sources consider a moderate rainfall (Rogers, 1979).

In further efforts to better characterize the simulated rainfall, the velocity of individual raindrops was measured as well. Individual rain drops were videotaped with a Fastcam Ultima 1024 high speed video camera at 5000 frames per second to provide slow-motion images from which the speed of the rain drops could be measured. “Photron Motion Tools Analysis Software” was then used to determine the velocities of the individual drops. The drops averaged 11.5 miles per hour. Figure 2.5 is one of the photographic images of the drop movement that was used in the calculations. This velocity matches expected raindrop velocities for a moderate rainstorm of 9 to 16 miles per hour (Rogers, 1979).

2.3 RainMaker ‘Return Period’ Equivalence

The “RainMaker” simulates a 1.23 inches per hour rainfall on a 100’ length of road. The magnitude of the simulated rainfall was chosen to represent a ‘modest’ but not an extraordinary event for the region. The applied rate of 0.62 inches per one half-hour for this region of Northwestern Pennsylvania is equivalent to approximately a 1.9 month rain event (return period = 0.16 years). The return period for 0.62 inches of rainfall in 30 minutes was extracted from Aron et al. [1986] and extrapolated from the data presented in *Figure 2.6*.

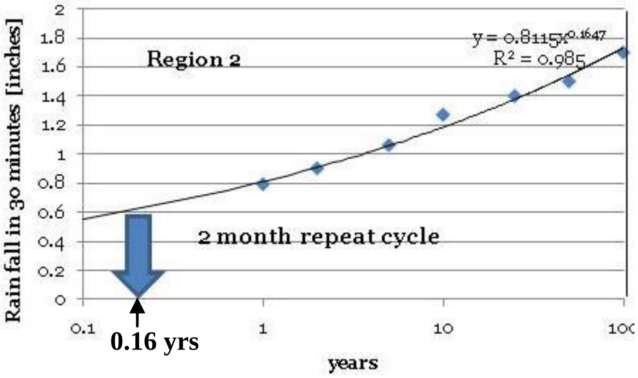


Figure 2.6: ‘Return Period’ estimate for a 0.62 inch 30-minute rainfall is slightly under two months (0.16 years). (Aron et al. 1986)

CHAPTER 3: Methodology

3.1 Study Setup and Timeline

Working with the Allegheny National Forest (ANF) in the Spring of 2010, the Center identified approximately 25 potential test sections of roadway 100 feet in length where the rainfall simulator could be applied. The initial study planned to incorporate 18 sections of roadway. In cooperation with the ANF, the Center narrowed down the site list to 14 sites that would be tested "as is" to quantify sediment production from "typical" oil well access roads. Four of these sites had been previously identified by the ANF as locations where new surface aggregates would be placed. For the remaining four rainfall simulator tests, it was decided that "after" tests should be run on the four sections of roadway that would receive new aggregate (two with pit-run and two with Driving Surface Aggregate).

Figure 3.1: An example of a RainMaker sampling point with the RainMaker in the background.

The Center completed construction and calibration of two RainMaker devices in the Spring and early Summer of 2010. The first road site to be tested, site K, was completed on June 18th, 2010. Working around summer rainstorms, the Center completed the remaining 13 "as is" test sections with the help of ANF personnel throughout the summer. All testing was done in accordance with the RainMaker testing procedure described below. The last road segment, site T, was completed on August 19th, 2010. The Center took all sediment samples back to the Water Lab at Penn State Institute for Energy and the Environment for analysis of total suspended solids. Photographs, detailed measurements, and road surface samples were also taken from each site to help in later analysis of sediment production.

In the Spring of 2011, four of the sites received placement of a new aggregate surface (sites B & F with "pit-run aggregate," and sites G & C with Driving Surface Aggregate). The RainMaker was run on these sites in the fall of 2011 in order to obtain sediment production figures for the new aggregates.

3.2 RainMaker Testing Procedure

- **General Considerations**
  - RainMaker was run after at least 2 days of dry weather to avoid saturated conditions.
  - A 100-ft stretch of road was evaluated for each test site.

  - Each test section of road was subjected to three 30-minute runs of the RainMaker.
  - Nozzles were checked before each run, and any clogged or malfunctioning nozzles were replaced.
- **Step-by-step procedure**
  - Set up RainMaker on test section. Insure the collapsible water bladders have a flat place to lay uphill of the test section.
  - Insure sample points are ready for collection. This procedure was site-specific, but included activates such as digging sampling points (see *Figure 3.1*), installing sheeting to make sampling easier, and insuring no runoff bypasses sampling point.
  - Flush any trenches or channels that were dug for the collection system, and test the sampling setup using a garden hose from the terminal end of the RainMaker.
- **RainMaker Run 1**
  - Pump was turned on and adjusted to 30psi at the gauge on the terminal end of the RainMaker. The pump ran for a total of 30 minutes in each run.
  - <u>Sampling</u>:
    - During each run of the RainMaker runoff flow rate and sediment samples were captured at regular intervals to determine the amount of sediment leaving each site (Figure 3.2).
    - <u>Sediment</u>: Runoff samples were taken at regular intervals and returned to the Water Lab at Penn State for Total Suspended Solids analysis. A total of six samples were collected at each sample point for each run of the RainMaker. With Time=0 (T=0) set when the wetting front reached the sample point, sediment samples were collected at one (T=1), five (5), ten (10), fifteen (15), twenty (20), and thirty (30) minutes after runoff reached the sample point.
    - <u>Flow</u>: Flow rate was determined by timing the amount of time it took to fill a container of known volume. The runoff flow was measured at T=1, T=5 and at five minute intervals until T= 60 or until runoff stopped.
  - After running for 30 minutes, the pump was turned off. Because of the delay in water reaching the sample point, the pump was typically shut off around T=25 in the sample timeline.

Figure 3.2: A sediment sample is taken at a sample point on site “N”.

- **Drying Time 1**
    - After the pump was turned off, the road was allowed to dry for a period of one hour.
    - Approximately 30 minutes into the 60 minute drying cycle, a light truck was driven a total of 20 passes over the entire test section. This was done to simulate traffic and further stress the road surface before the next RainMaker run.
- **RainMaker Run 2**
    - After the 60 minute drying time, the pump was turned back on for 30 minutes at 30psi. The sampling procedure outlined in “RainMaker Run 1” above was repeated.
- **Drying Time 2**
    - Another 60 minute drying cycle with 20 light truck passes was completed.
- **RainMaker Run 3**
    - After the 60 minute drying time, the pump was turned back on for 30 minutes at 30psi. The sampling procedure outlined in “RainMaker Run 1” above was repeated.

3.3 RainMaker Summary

By collecting sediment samples and measuring flow volumes at each sample point at regular time intervals, total sediment loading can be calculated for each site. Each time the RainMaker is run, it is run for three 30-minute sample periods as described in the “RainMaker procedure” above. The flow rates and sediment concentrations for these three runs are then combined to obtain the average sediment production for each section of road.

Figure 3.3: An oil well sits idle as the RainMaker runs on site “R” in the background.

CHAPTER 4: Results

4.1 Results of "existing condition" Road Testing on 14 sites

Sediment loads from each site were determined by combining the Total Suspended Solids (TSS) concentration found in the water samples with the know flow volumes for each simulated rainfall event. The RainMaker was run three times on each site, with 20 light truck passes before runs 2 and 3. All sediment figures are in pounds per 30 minute event unless otherwise noted. Sediment production rates (3 run average) ranged from 3.2 pounds to 60.1 pounds for the segments in this study. Site A, with the least amount of sediment, was a grass covered road where only the wheel tracks contained exposed soil. Site B, with the most amount of sediment, was a high traffic USFS road that was steep with runoff flowing in channels on the road surface.

The sediment results for individual sites, along with pertinent site information and photos are listed below. A summary of the site data and results can be found in Table 3.1. Sites are described in order of increasing sediment production (3 run average):

Site A: **3.2 pounds of sediment**
(1.0 lbs, 2.1 lbs, 6.4 lbs in successive runs)
Tested: 8/18/2010
Slope: 14.7% **Width**: 13'
Traffic: Very Low **CBR**(strength)**:** 31
Material: Loam: 43% sand, 31% silt, 26% clay
Site Notes: Grass covered road. AASHTO #1 stone exposed in wheeltracks. Minimal use gated road. Ditches also heavily grassed. Running vehicle over road between tests made a lot of difference, both visually and in sediment data. Most runoff came down wheel tracks.

Site T: **7.4 pounds of sediment**
(7.1 lbs, 7.0 lbs, 8.0 lbs in successive runs)
Tested: 8/19/2010
Slope: 3.3% **Width**: 12' (16' with berm)
Traffic: High **CBR**(strength)**:** 141
Material: Sandy Loam: 75% sand, 14% silt, 11% clay
Site Notes: Flattest road tested. Surface largely sand. A few large stones on top. This is a USFS Road with a relatively higher traffic count. Road surface was hard-packed. Traffic passes between tests had little effect, visually or in sediment data. Runoff was on road and in ditches.

Site S: 7.9 pounds of sediment

(4.2 lbs, 10.1 lbs, 9.4 lbs in successive runs)
Tested: 7/27/2010
Slope: 7.6% **Width**: 11' (11' with berm)
Material: Sandy Clayey Loam: 52% sand, 24% silt, 24% clay
Traffic: Med **CBR**(strength)**:** 91
Site Notes: Surface was a mixture of large stone with dirt and some exposed bedrock. Fabric was under surface and exposed in some locations. Ditches were non-existent and all runoff came down channels cut into road surface.

Site R: 11.1 pounds of sediment

(9.3 lbs, 9.8 lbs, 14.3 lbs in successive runs)
Tested: 7/27/2010
Slope: 9.0% **Width**: 11.5' (11.5' with berm)
Traffic: Low **CBR**(strength)**:** 99
Material: Loam: 47% sand, 29% silt, 24% clay
Site Notes: Ditches were cutoff from surface, and all runoff came down wheel tracks. Surface was hard packed with large rocks on surface. Fabric was under surface and exposed in some locations. Traffic had little visual effect.

Site K: 12.7 pounds of sediment

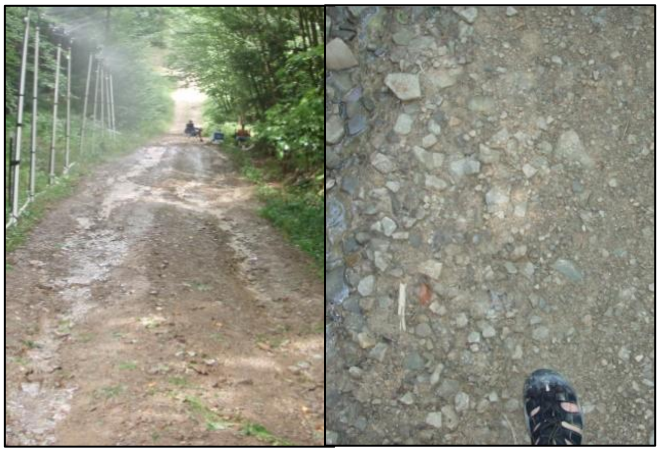
(7.9 lbs, 15.4 lbs, 14.9 lbs in successive runs)
Tested: 6/18/2010
Slope: 4.4% **Width**: 12' (13' with berm)
Traffic: Med **CBR**(strength)**:** 67
Material: Sandy Loam: 57% sand, 27% silt, 16% clay
Site Notes: Road had 10-20% ballast rock on surface. Ditches were cutoff from surface, and all runoff came down wheel tracks. Traffic passes made a difference, both visually and in sediment data. Runoff ran on road surface and in ditch.

Site G: 13.0 pounds of sediment

(15.1 lbs, 14.0 lbs, 10.9 lbs in successive runs)
Tested: 7/2/2010
Slope: 16.2% **Width**: 12.5' (12.5' with berm)
Traffic: High **CBR**(strength)**:** 126
Material: Loam: 41% sand, 38% silt, 21% clay
Site Notes: Very hard packed surface with some rock. High traffic road. Ditches were non-existent and all runoff came down channels cut into road surface. Traffic passes made little difference visually. One of few sites to have less sediment in successive runs.

Site I: 14.7 pounds of sediment

(14 lbs, 16.5 lbs, 13.7 lbs in successive runs)
Tested: 8/17/2010
Slope: 20.5% **Width**: 13’ (17’ with berm)
Traffic: Low **CBR**(strength)**:** 81
Material: Loam: 43% sand, 33% silt, 24% clay
Site Notes: Steepest road tested. A lot of rocks present on road surface. Most runoff ran down wheel tracks, with some running in ditch. Traffic passes made little difference visually or in sediment data.



Site C: 14.9 pounds of sediment

(11.9 lbs, 14.6 lbs, 18.0 lbs in successive runs)
Tested: 7/8/2010
Slope: 7.2% **Width**: 10’ (14’ with berm)
Traffic: Low **CBR**(strength)**:** unknown
Material: Loam: 45% sand, 30% silt, 25% clay
Site Notes: Runoff ran in wheel track and ditch. Lower use road with little rock on surface. Traffic passes made a difference visually and in sediment data.

Site L: 28.4 pounds of sediment

(12 lbs, 35.7 lbs, 37.5 lbs in successive runs)
Tested: 6/31/2010
Slope: 13.8% **Width**: 12’ (15’ with berm)
Traffic: Low **CBR**(strength)**:** 71
Material: Loam: 51% sand, 31% silt, 18% clay
Site Notes: In-sloped road with runoff flowing in ditch. Relatively low use road with soft surface. Water and traffic has large effect on surface, both visually and in sediment data. Surface became muddy and slippery, making walking or driving difficult.

Site N: 29.7 pounds of sediment

(14.3 lbs, 40.5 lbs, 34.4 lbs in successive runs)
Tested: 8/18/2010
Slope: 5.6% **Width**: 13’ (15’ with berm)
Traffic: High **CBR**(strength)**:** 103
Material: Loam: 49% sand, 31% silt, 20% clay
Site Notes: High use “trunk” road. Very few stones on surface. Water and traffic has large effect on surface, both visually and in sediment data. Ditches were cut off and water ran down wheel tracks.

Site E: 35.9 pounds of sediment
(7.8 lbs, 36.9 lbs, 62.8 lbs in successive runs)
Tested: 6/30/2010
Slope: 9.2% **Width**: 13’ (13’ with berm)
Traffic: Low **CBR**(strength)**:** 65
Material: Loam: 73% sand, 14% silt, 13% clay
Site Notes: Road was mostly sand with some small stones. Very deep ruts (6”) in road surface carried all runoff. Traffic had large effect on road, visually and in sediment data.

Site F: 42.7 pounds of sediment
(47.1 lbs, 42.2 lbs, 38.8 lbs in successive runs)
Tested: 7/2/2010
Slope: 13.3% **Width**: 15’ (15’ with berm)
Traffic: High **CBR**(strength)**:** 133
Material: Loam: 46% sand, 33% silt, 21% clay
Site Notes: Higher traffic road with hard packed surface with few rocks. No ditches, water runs in wheel tracks. Traffic had very little visual effect. One of few sites to have less sediment in successive runs. This site had the highest “run 1” sediment before traffic.

Site M: 43.1 pounds of sediment
(23.6 lbs, 50.5 lbs, *55.2* lbs* in successive runs)
Tested: 6/31/2010
Slope: 19.2% **Width**: 10’ (15’ with berm)
Traffic: Low **CBR**(strength)**:** 76
Material: Loam: 47% sand, 33% silt, 20% clay
Site Notes: Very steep road. Low traffic volume and soft surface. All runoff ran down wheeltracks. Traffic had large effect, visually and in sediment data.
** Run 3 was not completed due to water truck problems. Data extrapolated based on other sites average increase from run 2.*

Site B: 60.1 pounds of sediment
(31.7 lbs, 67.0 lbs, 81.7 lbs in successive runs)
Tested: 7/8/2010
Slope: 12.7% **Width**: 11’ (16’ with berm)
Traffic: Med **CBR**(strength)**:** unknown
Material: Loam: 48% sand, 32% silt, 20% clay
Site Notes: Surface was a mixture of soil and rock. Ditches were cut off. Water ran down channels in road surface. Traffic passes made noticeable difference, visually an in sediment data. This site had the highest total average sediment (60.1 lbs), and the highest single run sediment (81.7 lbs for run 3).

Site ID	Slope %	Road width (ft)	rd + berm width (ft)	Strength (CBR)	traffic level	Lbs Sediment per 30 min. event				Site ID
						Run 1	Run 2	Run 3	Avg	
A*	14.7	na	13	31	v. low	1.0	2.1	6.4	**3.2**	**A***
T	3.3	12	16	141	high	7.1	7	8	**7.4**	**T**
S	7.6	11	11	91	med	4.2	10.1	9.4	**7.9**	**S**
R	9	11.5	11.5	99	med	9.3	9.8	14.3	**11.1**	**R**
K	4.4	12	13	67	med	7.9	15.4	14.9	**12.7**	**K**
G	16.2	12.5	12.5	126	high	15.1	14.0	10.0	**13.0**	**G**
I	20.5	13	17	81	low	14.0	16.5	13.7	**14.7**	**I**
C	7.2	10	14	na	low	11.9	14.6	18.0	**14.9**	**C**
L	13.8	12	15	71	low	12.0	35.7	37.5	**28.4**	**L**
N	5.6	13	15	103	high	14.3	40.5	34.4	**29.7**	**N**
E	9.2	13	13	65	low	7.8	36.9	62.8	**35.9**	**E**
F	13.3	15	15	76	high	47.1	42.2	38.8	**42.7**	**F**
M	19.2	10	15	133	low	23.6	50.5	55.2**	**43.1**	**M**
B	12.7	11	16	na	med	31.7	67.0	81.7	**60.1**	**B**
* Site A on grass road: not used in averages.					**Avg**	**15.8**	**27.7**	**28.6**	**24.7**	**pounds**
* Site M, run 3 extrapolated					**Avg**	**836**	**1,463**	**1,511**	**1,306**	**lbs/mile**
						Run 1	**Run 2**	**Run 3**	**Average**	

Table 4.1: Summary of sediment results, in increasing order, along with site characteristics.

The sediment results for the 14 sites that were tested in this study are shown in Table 4.1, along with most of the physical information about each site. All sediment figures are in pounds per 30 minute event, and are based on the average of three RainMaker runs unless otherwise noted. When results from the 14 100' test sections are averaged, it shows that typical 100' section of oil access roads in the Allegheny National Forest can be expected to lose almost 25 pounds of sediment in a single 30 minute storm event with a ~2 month return cycle.

It should be noted, and will be discussed in detail later, that the rainfall simulator results represent a conservative estimate of sediment loss. Sediment loss from a similar sized actual rain event would be higher because of compounding effects form upslope road drainage and off site drainage, instead of a limited 100' rainfall on the road only.

4.2 Results of "after aggregate" Road Testing on 4 sites (Phase II)

New aggregate was placed on 4 of the sites in early 2011 (sites B & F with "pit-run aggregate," and sites G & C with Driving Surface Aggregate). RainMaker testing, using the same procedures as previously described, was completed on these four sites in the Fall of 2011.

Site B: New Pit-Run

Existing Road: **60.1 lbs** (31.7, 67.0, 81.7)

New Pit-Run Surface: **15.4 lbs**

Sediment Reduction: **39%**

Slope: 12.7%   **Width**: 11' (16' with berm)

Site Notes: This site had the highest overall sediment production in "existing road" testing. Although sediment production was less on the new pit-run surface, the 36.8 lbs of sediment found was still higher than 11 of the 14 original "existing condition" tests. Traffic created a significant increase in sediment production for both the existing road and new surface.

Site F: New Pit-Run

Existing Road: **42.7 lbs** (47.1, 42.2, 38.8)

New Pit-Run Surface: **15.4 lbs** (23.3, 13, 9.8)

Sediment Reduction: **64%**

Slope: 13.3%   **Width**: 15' (15' with berm)

Site Notes: This is one of the higher traffic roads in the study. It is also one of the few sites that showed a decrease in sediment production after traffic in successive runs, indicating that traffic did not have an effect on sediment production.

Site G: New Driving Surface Aggregate

Existing Road: **13.0** (15.1 lbs, 14.0 lbs, 10.9)

New DSA: **4.2 lbs** (6.3, 2.9, 3.5)

Sediment Reduction: **67%**

Slope: 16.2%   **Width**: 12.5' (12.5' with berm)

Site Notes: This site is located only ~300 feet from site F and also sees significant traffic. Also like site F, traffic did not increase sediment production. The 4.2 lbs found here was significantly lower than all of the "existing road" tests (other than grassed road).

Site C: New Driving Surface Aggregate

Existing Road: **14.9** (11.9 lbs, 14.6 lbs, 18.0)

New DSA: **0.8 lbs** (1.5, 0.5, 0.4)

Sediment Reduction: **95%**

Slope: 7.2%   **Width**: 10' (14' with berm)

Site Notes: This site showed the lowest sediment production by far of any site in the study, including the grassed road. This site also had a decrease in sediment production after traffic between the runs.

Table 4.2 summarizes the sediment production from the existing roads and newly place aggregate for site B, F, G, and C. While all sites showed a reduction in sediment compared to their “existing road” tests, the two pit-run sites produced ten times as much sediment as the two DSA sites (26.1 lbs and 2.5 lbs respectively)

Site ID	timeframe	Lbs Sediment per 30 min. event				% sediment reduction
		Run 1	Run 2	Run 3	Avg	
site B	**existing**	31.7	67.0	81.7	**60.1**	**39%**
	new pit-run	20.2	41.4	48.9	**36.8**	
site F	**existing**	47.1	42.2	38.8	**42.7**	**64%**
	new pit-run	23.3	13.0	9.8	**15.4**	
site G	**existing**	15.1	14.0	10.0	**13.0**	**67%**
	new DSA	6.3	2.9	3.5	**4.2**	
site C	**existing**	11.9	14.6	18.0	**14.9**	**95%**
	new DSA	1.5	0.5	0.4	**0.8**	

Table 4.2: Summary of sediment results from existing roads and after placement of new aggregate.

CHAPTER 5: Discussion

The average sediment production found in the 42 individual rainfall simulation tests on these 14 sites was 24.7 pounds per 30 minute event. This equates to a sediment production rate of 1,304 pounds per mile of road for a single 30 minute 0.62” rain event. Given that the Grunder Run watershed alone has approximately 52 miles of unpaved roads, it can be extrapolated that a single watershed-wide storm event similar to our design storm will cause a loss of nearly 34 tons of road sediment in the watershed (USDA-FS unpublished, 2010).

It is important to note when extrapolating, that these figures represent sediment loss from the road, not necessarily into a stream. Some roads higher in the watershed may not be hydrologically connected directly to the stream system. Unfortunately, many of the roads and ditches in the watershed serve as direct extensions of the stream channel. Based upon an inventory and assessment of 16,500 miles of unpaved roads throughout Pennsylvania, 35% of unpaved roads statewide are typically directly connected to streams. Applying this ratio to the Grunder watershed would yield an estimate of 12 tons of road sediment entering directly into Grunder Run in a single storm of similar intensity and duration to the RainMaker.

In addition to the total sediment load described above, the rainfall simulator testing also showed a significant “first flush” of sediment on the tested roads. The “First Flush” concept states that the majority of sediment pollution is generated at the beginning of the precipitation event. As the event continues, the easily detached sediment has been washed away, and the remaining material will be more resistant to erosion. Figure 5.1 shows the decrease in sediment production over time when the data for all 14 sites are combined. Figure 5.2 visually illustrates the decrease in sediment over time for site A (grassed site with least total sediment). These results clearly show the effect of the “first flush” of sediment during the first 5 minutes of the rainfall event.

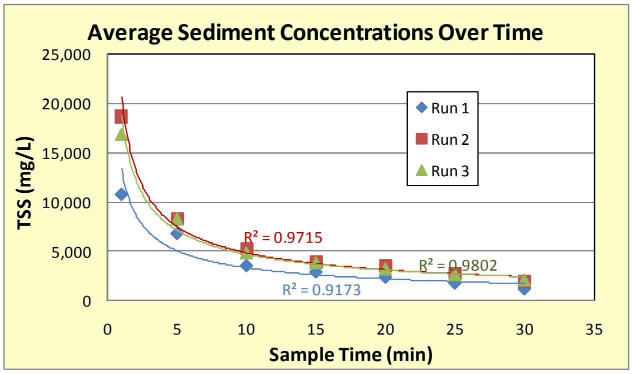


Figure 5.1: Average sediment concentration in samples over time for all 14 sites. T=0 when runoff reaches the sample point.

Figure 5.2: Runoff samples from site A are arranged by time, with T=1 on the right, through T=30 on the left.

5.1 Effect of Traffic During Testing

Each site test consisted of three individual rainfall simulator runs. The initial run (Run 1) on each site was completed on the road “as is” with no pre-traffic stresses other than normal use. Between Run 1 and Run 2, twenty light truck passes were run over the road segment. Again between Run 2 and Run 3, an additional twenty light truck passes were done. These passes were done in an effort to accelerate the pressures and stresses that roads would see under normal use. Figure 5.3 illustrates the sediment results for each individual run of the rainfall simulator. Most sites, as expected, showed an increase in sediment production after traffic had been applied. Ten of the 14 sites experience sediment increases of 50% or greater between runs 1 and 3. Two of the 14 sites (sites T and I) showed very little difference in sediment production between runs 1, 2, and 3. Contrary to expected, two of the sites (sites G and F) showed significantly less sediment when tested after traffic. Sites G and F were located in succession, about 500 feet apart, on a main “trunk” line road. Their resistance to traffic may have been a function of their material and frequent use.

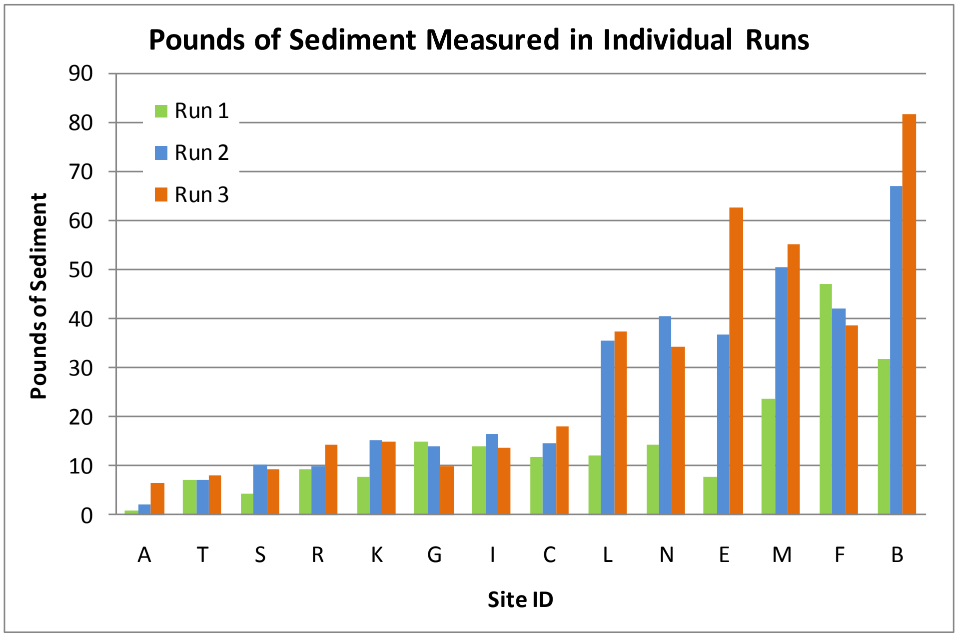


Figure 5.3 Sediment results from individual runs of the rainfall simulator. All roads were subject to 20 vehicle passes before run 2 and again before run 3.

5.2 Influencing Factors

As part of this study, measurements and notes were taken on as many site parameters as possible. It was hoped that the amount of sediment production from the road segments could be linked to one or more site variables such as road slope, road width, or road composition. Unfortunately, there was no strong correlation of sediment production to any one factor or combination of factors. The factors are discussed separately below.

5.2.1 Road Slope and Sediment

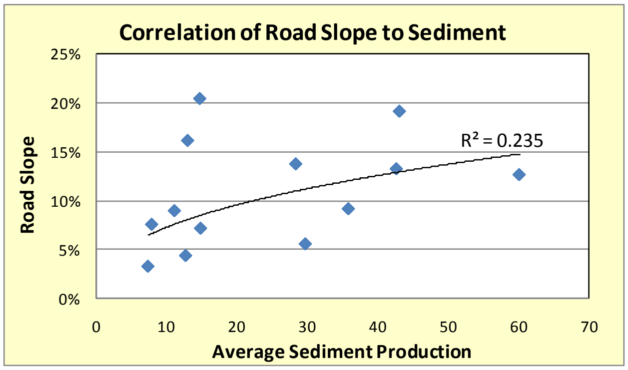


Figure 5.4: Road slope in relation to average sediment production. *(Site A omitted because of grass cover)*

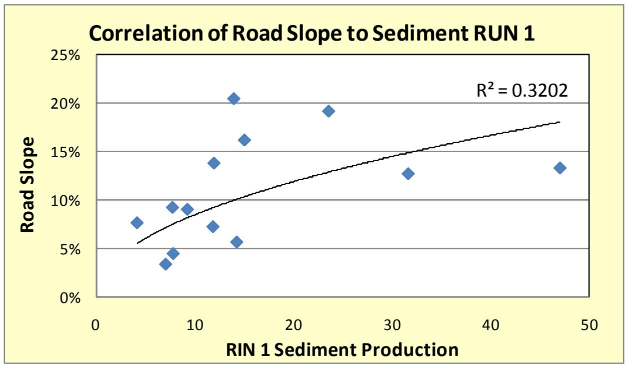


Figure 5.5: Road slope in relation to sediment production from RUN 1 only. *(Site A omitted because of grass cover)*

Road slope refers to the linear grade of the roadway. Road slope was one of the criteria used in choosing road segments to test. The 14 road segments tested were chosen in part because they represented a fairly wide distribution of slopes from 3.3% to over 20%. The relationship between road slope and average sediment production is illustrated in *Figure 5.4*. The correlation between road slope and sediment generation is very weak (R^2=0.24), meaning that in this study, road slope had little determination on the average amount of sediment generated. Part of the reason slope was not a large factor may be the spatially limited rainfall event. The RainMaker only produced rainfall on 100 linear feet of roadway. In a natural rain event, portions of roadway outside the test section would be receiving rainfall and generating runoff that would flow onto the test section. In this situation, an increase in road slope would cause increase velocities of runoff and increased erosion. While the rainfall simulator does a good job at simulating the impact erosion of rainfall, it lacks the ability to generate rainfall on a large enough area to simulate the extent of rill and gully erosion that occurs in a real storm. The slope for each road segment is included in Table 4.1. It is worth noting that road slope showed a slightly better correlation (R^2 increase from 0.24 to 0.32) to sediment production in the first run of the RainMaker that was completed before traffic passes (Figure 5.5). Sediment production from runs 2 and 3, done after traffic passes, had less correlation with road slope.

5.2.2 Road Width and Sediment

The width of the road was measured in two ways. First, the width of the actual traveled roadway was measured. This measurement was typically based on the presence or absence of vegetation. Vegetated areas beside the road that do not typically see traffic were considered berms. The width of the road including berms was also measured since the berms, although typically not driven on, can still contribute sediment to the test sections. Road widths ranged

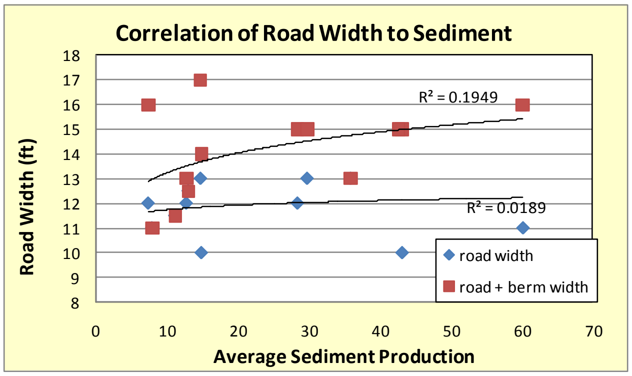


Figure 5.6: Road width, with and without berm, in relation to average sediment production. *(Site A omitted because of grass cover and indeterminate width)*

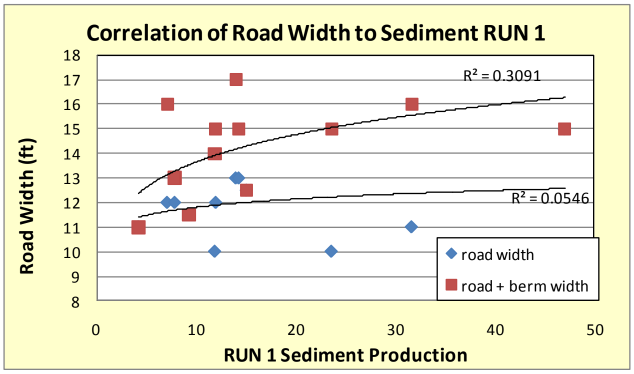


Figure 5.7: Road width, with and without berm, in relation to RUN 1 sediment production. *(Site A omitted because of grass cover and indeterminate width)*

from 10 feet to 15 feet in width, with an average of 12.0 feet. The road and berm combined width ranged from 11 feet to 17 feet with an average of 14.1 feet. The correlation of road width and "road+berm" width in relation to total sediment production is illustrated in Figure 5.6. Although neither factor showed a strong correlation with sediment production, the "road+berm" width did have a better correlation (R^2=0.19) than road width alone (R^2=0.02). The widths for each road segment are included in Table 4.1. Just as with road slope, it is worth noting that road width showed a better correlation (R^2 increase from 0.19 to 0.31) to sediment production in the first run of the RainMaker that was completed before traffic passes (Figure 5.7). Sediment production from runs 2 and 3, done after traffic passes, had less correlation with road width.

5.2.3 Road Use and Sediment

Road use, or traffic volume, was approximated using field observations and maps. The 14 sites tested encompassed a wide array of traffic volumes. Some roads served as main access routes to the majority of the oil and gas wells and tank batteries. These roads routinely see traffic such as loaded tanker trucks, pickup trucks, and all-terrain vehicles. Some roads were secondary, only serving a handful of wells. Site A was on a gated road where the traffic level was low enough to allow grass to cover most of the roadway.

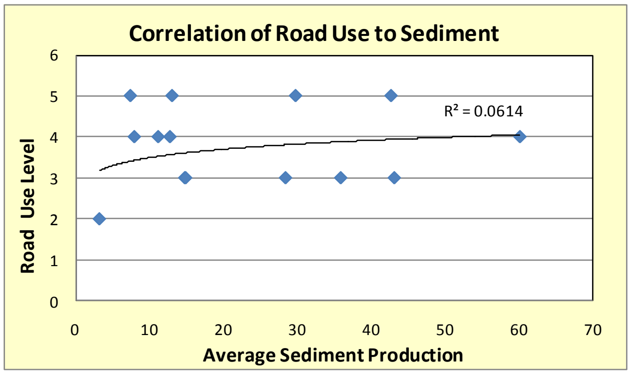


Figure 5.8: Road use, or traffic volume, in relation to average sediment production.

Each road segment was assigned a rating from 1 (lowest) through 5 (highest) to approximate its traffic level. Use levels were based on field observations of traffic and wear, and on the amount of wells the road accessed. The use level for each road segment is included in Table 4.1. The correlation between road use level and sediment production was very weak (R^2=0.06). Visual differences in road use can be seen in pictures in individual site results.

5.2.4 Road Strength and Sediment

The in-place strength of each road segment was measured using a dynamic cone penetrometer [DCP]. The DCP, pictured in Figure 5.9, consists of a pointed steel shaft with a standard weight that is free to slide up and down. Following ASTM standards (D6951/D6951M-09), the weight is lifted and dropped repeatedly from a know height in order to slowly drive the pointed end of the shaft into the road surface. In simplest terms, the ease of which the shaft can be driving into the road can be correlated to the strength of the road. This strength is often expressed as the road's "California Bearing Ratio" [CBR]. The DCP was used to provide an inexpensive and quick approximation of the CBR for each site. The CBR rating was developed for measuring the load-bearing capacity of soils used for building roads. The stronger the surface is, the more resistant it is to penetration, the higher its CBR rating. A CBR of 3 equates to tilled farmland, a CBR of 4.75 equates to turf or moist clay, while moist sand may have a CBR of 10. High quality crushed rock has a CBR over 80. The standard material for this test is crushed California limestone which has a value of 100 (Salgado, 2003).

Figure 5.9: The dynamic cone penetrometer pictured here is used to measure road surface strength.

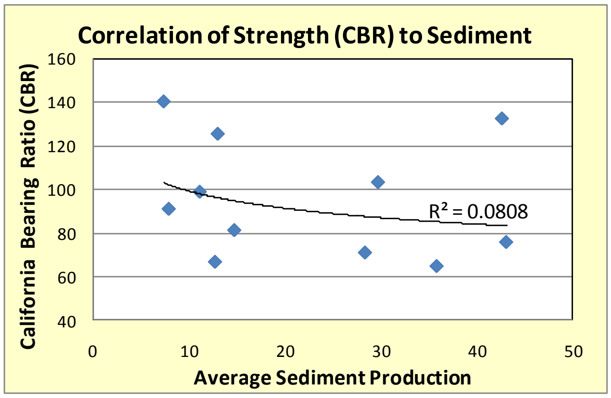


Figure 5.10: Road strength, expressed as California Bearing Ratio, in relation to average sediment production. *(Site A omitted because of grass cover. No data for Site B & C)*

All CBR testing was done on the same day to eliminate soil moisture and weather as variables. The Cone Penetrometer was run at five random locations on each road segment to a depth of 100mm. The five data points were then averaged and used to determine the CBR for each site. CBRs ranged from a low of 31 for the grassed site (Site "A"), to a high of 141 (Site "T"). As illustrated in Figure 5.10, the CBR had almost no correlation with the actual amount of sediment produced from each site (R^2=0.08).

However, when the amount of sediment increase between Run 1 and Run 3 for each site is compared to road hardness, a relationship is found. Figure 5.11 illustrates that roads with

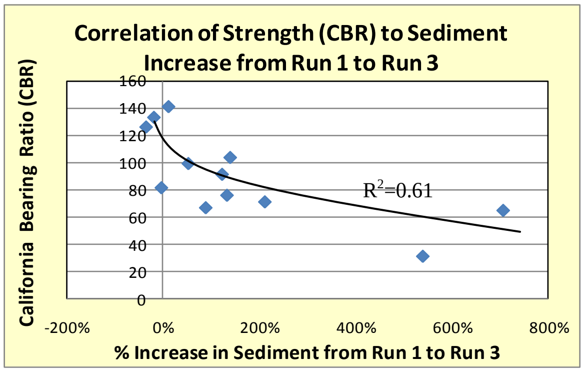


Figure 5.11: The relationship of strength, expressed as California Bearing Ratio, to the percent of sediment increase from Run 1 to Run 3. (*No data for Site B & C)*

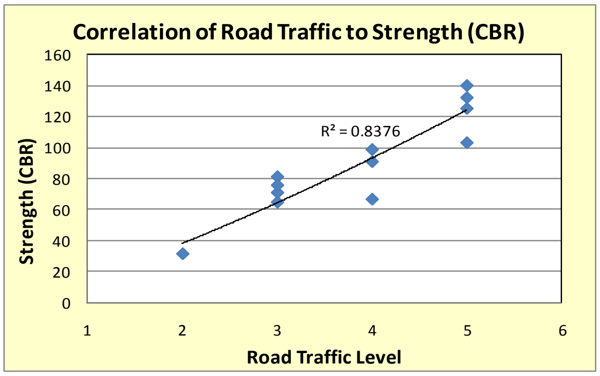


Figure 5.12: The relationship of strength, expressed as California Bearing Ratio, to the traffic volume level. (*No data for Site B & C)*

a lower strength or CBR tend to be more effected (larger sediment increase) by the traffic that the sites were subjected to between runs (R^2=0.61). Roads with a higher strength or CBR were less affected by traffic. The CBRs for each road segment are included in Table 4.1.

A correlation also exists between the use or traffic level assigned to each road, and the road strength expressed as the California Bearing Ratio. *Figure 5.12* illustrates that as road use increases, the strength or CBR of the road surface increases as well (R^2=0.84).

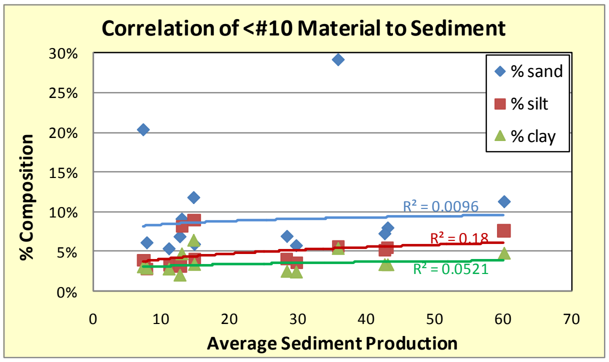


Figure 5.13: The relationship of the percent sand, silt, and clay in road surface samples to average sediment production. (*Site A omitted because of grass cover)*

5.2.5 Road Composition and Sediment

As part of the effort to quantify the characteristics of each site, road surface samples

Site	Percent of Sample Retained on Seives						Breakdown of <#10 Material			Average	Site
	#2	3/4"	3/8"	#4	#10	<#10	sand %	silt %	clay %	Sediment (lbs)	
A	18%	36%	19%	10%	7%	11%	*5%*	*3%*	*3%*	3.2	A
T	0%	32%	15%	14%	9%	27%	*20%*	*4%*	*3%*	7.4	T
S	13%	16%	24%	22%	15%	12%	*6%*	*3%*	*3%*	7.9	S
R	16%	28%	18%	15%	11%	11%	*5%*	*3%*	*3%*	11.1	R
K	50%	11%	12%	9%	6%	12%	*7%*	*3%*	*2%*	12.7	K
G	0%	18%	26%	19%	15%	22%	*9%*	*8%*	*5%*	13.0	G
I	0%	13%	16%	19%	25%	27%	*12%*	*9%*	*6%*	14.7	I
C	6%	28%	18%	20%	16%	13%	*6%*	*4%*	*3%*	14.9	C
L	38%	18%	12%	10%	8%	13%	*7%*	*4%*	*2%*	28.4	L
N	4%	32%	25%	17%	10%	12%	*6%*	*4%*	*2%*	29.7	N
E	8%	21%	8%	11%	12%	40%	*29%*	*6%*	*5%*	35.9	E
F	18%	23%	22%	12%	10%	16%	*7%*	*5%*	*3%*	42.7	F
M	16%	22%	16%	17%	13%	17%	*8%*	*5%*	*3%*	43.1	M
B	0%	25%	21%	17%	13%	24%	*11%*	*8%*	*5%*	60.1	B

Table 5.1: Composition of road surface samples. Samples are in order of increasing sediment production.

were taken and analyzed for composition. The samples were obtained by excavating an area approximately two square feet by four inches deep in the surface of each site. Material sample locations were randomly located on each test section. These samples were taken to the soils lab at Penn State University for analysis. The samples were first screened to obtain the size distribution of the larger particles. Any particles passing through a #10 screen (1/10th of an inch nominal max size) were further analyzed to determine the percent sand, silt, and clay in the sample. Table 5.1 lists the composition of each sample.

There were no significant effects on sediment production that could be predicted by any one particle size or combination of particle sizes in the samples taken from the road surface. Figure 5.13 shows that there is not a significant correlation between the amount of sand silt and clay in the road surface samples and average sediment production.

5.3 Multi-Variable Analysis

No one variable showed a strong correlation with the amount of sediment produced from the road segments. This is most likely due to the high number of variables involved in determining sediment loss. There is, however, an interesting point of discussion when looking at the combined effect of road slope and width on sediment production both before and after traffic stresses. If road slope and road width are combined into a "slope/width" factor, it presents a stronger correlation to sediment production than either factor alone (Figure 5.14). The R^2 for "slope/width" correlation to sediment on run 1 was 0.51, compared to an R^2 of 0.32 and 0.30 for road slope and width individually.

One interesting result of this analysis is that the "slope/width" factor shows a much better correlation with sediment production from run 1 before traffic stresses. Runs 2 and 3, after traffic, show a much lower correlation. These observations can be combined with trends found in road strength (Section 5.2.4) to generate some general theories on sediment production.

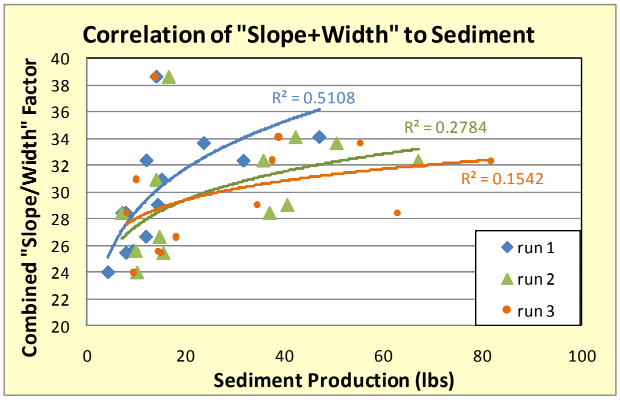


Figure 5.14: Road "slope+width" factor, in relation to average sediment production for each run. *(Site A omitted because of grass cover)*

Initially, without traffic stress, the amount of sediment production from each road segment is best correlated with the slope and width of the road (as the slope and width of the road increases, sediment production increases (Figure 5.14)). For runs 2 and 3 of the RainMaker, each done after 20 vehicle passes, road slope and width played less of a role in determining sediment production. Instead, sediment production from runs 2 and 3 can best be explained by the road strength. Road strength was shown to be a good indicator of how much sediment would increase on the sites after being stressed by traffic (Figure 5.11). Roads with the lowest strength, measured by CBR, had the highest percentage of sediment increase after traffic stresses. Roads with the highest strength showed little sediment increase, and some even showed a decrease, in runs 2 and 3 after traffic stresses.

5.4 Sediment Production After Aggregate Placement

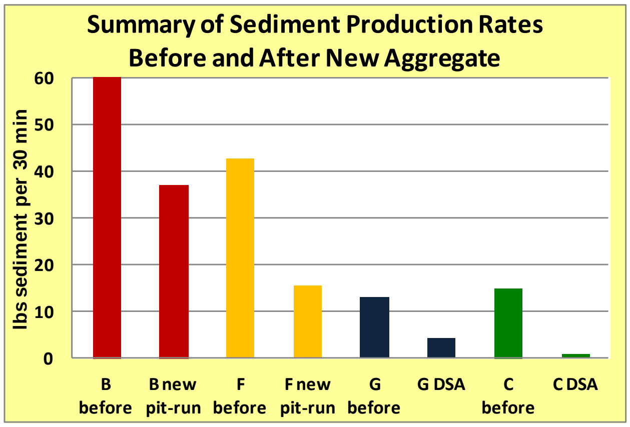


Figure 5.15: Summary of sediment reductions found between existing road surfaces and new aggregate

The second part of this study looked at sediment production after the placement of pit-run aggregate and Driving Surface Aggregate. As stated earlier, pit-run is a term used to describe a relatively cheap locally derived material of varying quality and DSA is a specially designed aggregate specification designed to achieve maximum compacted density to resist traffic and erosion. The DSA used in this study was limestone based, although limestone is not required. DSA is a processed commercial product that is typically more expensive than pit-run. Depending on the site location and aggregate source, DSA may also have to be hauled a substantial distance which also increases the cost. The Allegheny National Forest has been using DSA on roads adjacent to streams in an effort to reduce sediment pollution. More information about DSA is available from PennDOT specification MS-0450-0004 or from the Center's website at www.dirtandgravelroads.org. Previous research conducted by the Center has showed that DSA reduced sediment production by over 90% for at least two years after placement when compared to native surfaced roads in Potter County. This research is also available on the Center's website.

Figure 5.16 visually depicts each of the four sites for both the existing road surface and the new road aggregate. All four sites showed sediment reductions after new aggregate placement ranging from 39% to 95% compared to the existing road surface. It is worth noting, however, that the two sites where new pit-run was placed had significantly higher "existing road" sediment production than the two sites where DSA was placed. This was not planned and is simply a result random road location when Allegheny National Forest personnel performed work on the road system in early 2011. This higher "existing road" sediment production may have helped show a more significant sediment reduction for the new pit-run sites.

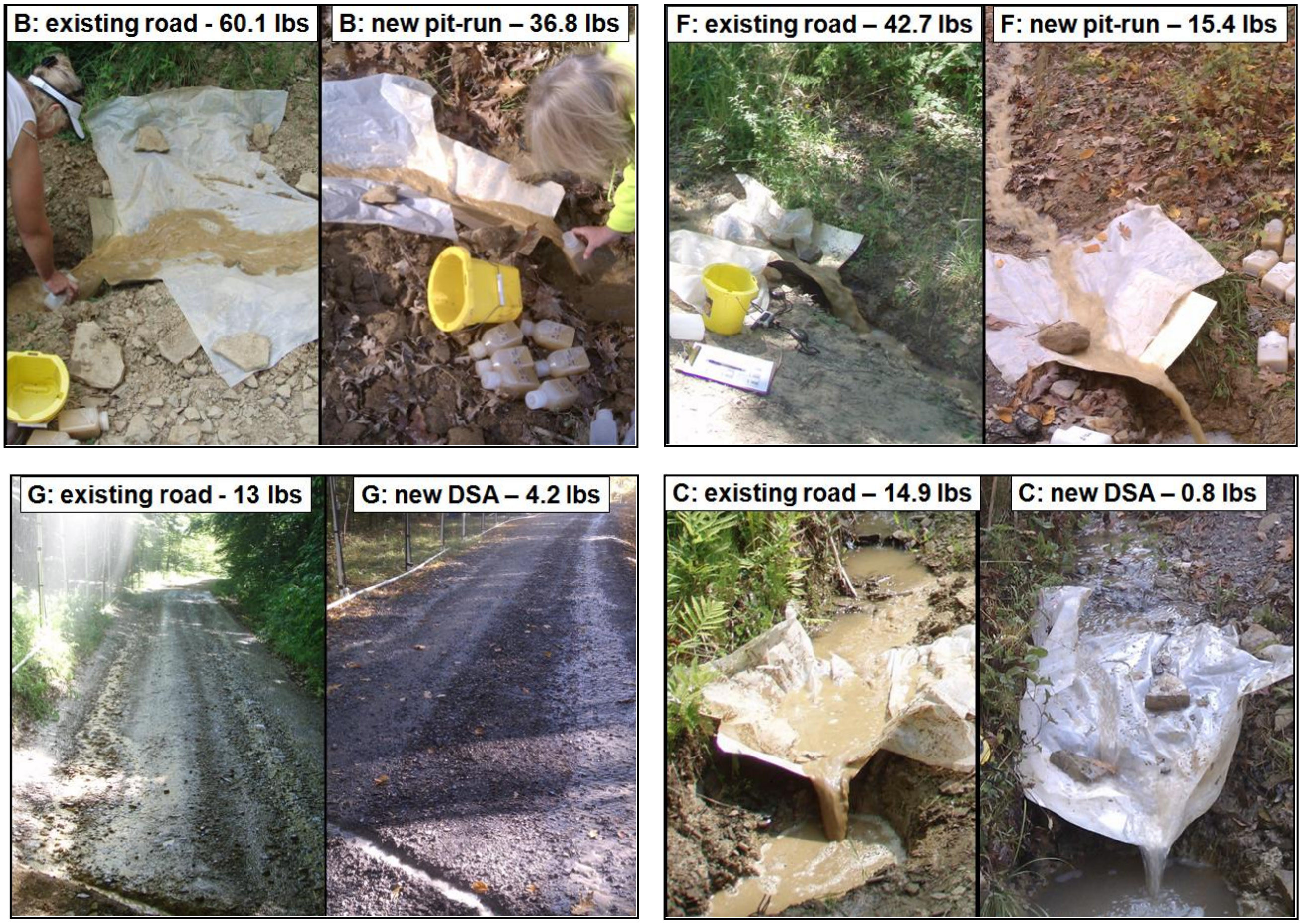


Figure 5.16: Visual comparison of the four sites in exiting condition during testing in 2010 and with new aggregate during testing in 2011. Average sediment production for three runs is included on each photo.

The two new pit-run sites examined in this part of the study averaged 26.1 pounds of sediment per 30 minute event. This is slightly higher than the sediment production of 24.7 pounds per event that was found when all 13 "existing condition" tests (excluding grass road on site A) were averaged. This means that while the pit-run sites did produce reductions in sediment compared to the "existing road" test for their individual sites, the sediment productions found were typical of other existing pit-run surfaces tested.

The two new DSA sites examined in this part of the study averaged 2.5 pounds of sediment per 30 minute event. This is significantly lower than all of the "existing road" testing done where sediment production averaged 24.7 pounds. Both DSA sites were significantly below the sediment production rates of even the lowest "existing road" test of 7.4 lbs found on site T. In fact, the sediment production from the two DSA sites was most similar to the grassed road tested on site A. The DSA on site C showed an extremely high sediment reduction of 95%, which is similar to previous studies conducted by the Center. The DSA on site C also had the lowest sediment production figure found in the study by far, even including the grassed road on Site A (0.8 lbs avg; 1.5 lbs, 0.5 lbs, 0.4 lbs in individual runs). It should also be noted that both DSA sites showed significant reduction in sediment production in sequential runs, an indication that traffic stresses between runs did not generate additional sediment from the aggregate. This discussion is illustrated in figure 5.17.

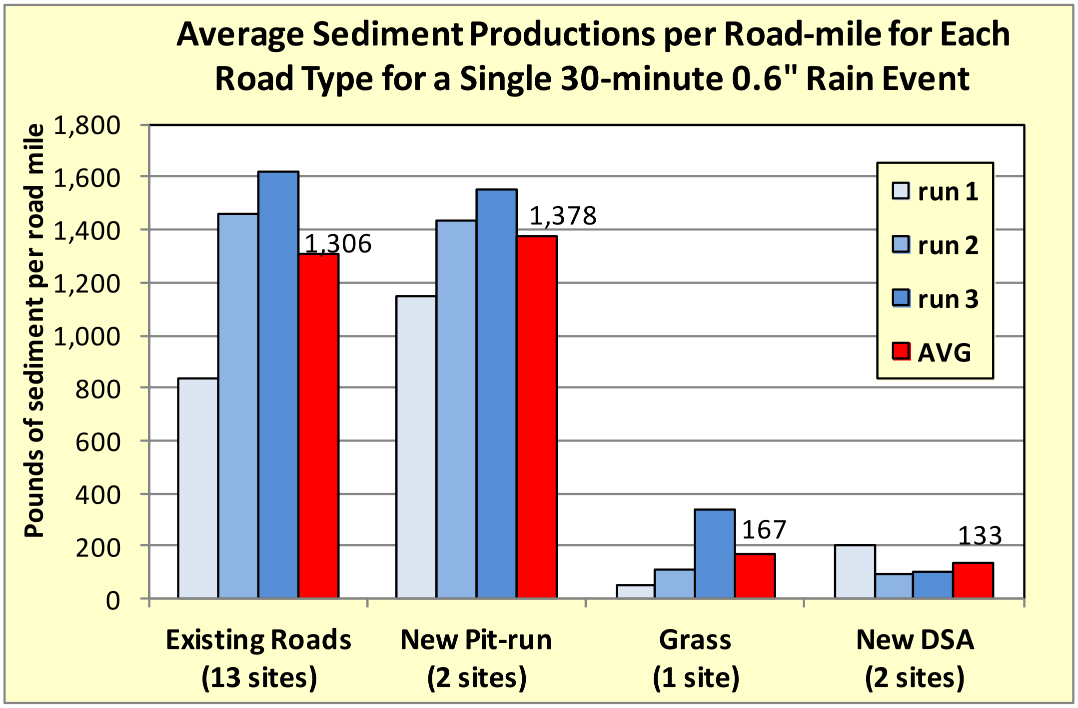


Figure 5.17: Summary of average sediment production by road type. All figures are in pounds of sediment produced per mile of road. Note the differing number of each type of sites that was available for use in obtaining average.

CHAPTER 6: Conclusions

The construction and maintenance of access roads is an often overlooked environmental impact of oil and gas development. Access roads can represent a significant change in land use patterns, especially in forested watersheds. These roads, almost all of which are unpaved, not only generate significant sediment, but also add to the hydrologic connectivity of the watershed. The purpose of this study was to quantify sediment runoff rates from existing shallow oil well access road in the Allegheny National Forest.

It is important to note that the sediment figures obtained in this study should be considered conservative. Sediment production rates from an actual rain event of similar magnitude can be expected to be higher because:

- The rainfall simulator produces rainfall on 100' of roadway. In actual rain events, runoff from upslope sections of roadway would have entered all of the test section. In addition to rainfall falling directly on other sections of the road, many sites would also experience water running onto the road from adjacent banks, well pads, and other areas in a natural event. This additional volume of water would have caused more erosion on each of the test sections.
- The size and velocity of raindrops from the RainMaker were within the range of natural rain events. Both drop size and velocity, however, were towards the low end of the expected range. Larger drop size and higher velocity would also contribute to increased sediment detachment.
- The rainfall simulator was only run during the summer and after two days of dry weather. Running the simulator in other times of year, such as during spring thaw, may yield more sediment.

The Center's rainfall simulator showed that even a modest rainstorm (*0.6" in 30 minutes, 2 month-recurrence*) causes these roads to produce significant amounts of sediment. The average sediment production from these roads before traffic stresses was 840 pounds per mile for a single 30 minute event. If traffic stresses are introduced onto the road, the average sediment production increases 83% to 1,540 pounds per mile for a single 30 minute event.

Figure 6.1: Testing on site "E".

Looking beyond the immediate study watersheds, there were 9,764 existing wells within the Allegheny National Forest in 2009. These wells are accessed by a network of 1,695 miles of road, not including ANF owned roads (USDA-FS Unpublished, 2010a). Combining this information with the results of the study indicate that a single 30 minute rainfall event of 0.6” can be estimated to generate over 1,106 tons of sediment from existing oil and gas roads in the Allegheny National Forest. Projections are that the network of 1,695 miles of existing oil and gas roads will increase to 2,258 miles by 2020 (USFS Unpublished, 2010a). This increases the estimated sediment production from 1,106 tons to over 1,470 tons per storm event from oil and gas roads in the forest in 2020.

Figure 6.2: This image, taken in the Grunder watershed in late March after a natural rain event, illustrates the effect of poor road material, excessive moisture, and vehicle traffic on sediment generation. (photo courtesy ANF)

In order to minimize sediment delivery to streams, roads should be built away from streams and avoid stream crossings. Also, roads should be maintained to avoid directing road runoff to streams. Results reported by Bloser and Scheetz [2008] show significant sediment reductions ranging from 31% to 94 % by applying individual road drainage control practices that reduce and control the volume of road runoff. These practices include raising the roads profile, installing grade breaks, adding additional drainage outlets, and berm removal. The combined sediment reduction effects of these practices have not been studied, but can be expected to be greater than that of the individual practices.

Results reported by Bloser and Scheetz [2008] can be used to compare the sediment production results found on the oil access roads in this study with the Center’s previous RainMaker findings on State Forest and Municipal roads. Please note that the earlier study was completed with the Center’s “first-generation” RainMaker. The storm intensities of the first and second generation RainMakers are very similar (0.55” per 30 minutes for old and 0.62” per 30 minutes for new), and the procedures used were virtually identical, allowing some generalizations to be made by comparing results of the two studies. The Center’s previous research was completed on five “as-is” roads, two municipal owned, and three State Forest owned. The averaged sediment productions in the previous study ranged from 0.7 pounds to 12.2 pounds, with an average of 5.6 pounds per 30 minute event. The 14 oil access roads in this study ranged from 3.2 pounds to 60 pounds, with an average of 25 pounds per 30 minute event. The oil access roads in this study produced an average of 450% more sediment than the public roads in the Center's previous study, despite only a 13% increase in rainfall intensity in the new study. This greater sediment production is likely due to the lack of consideration of drainage structures, road shape, and quality surface materials. Municipal and Forestry roads are open to the public and must meet user standards, including the passage of passenger cars. These access roads have no user standards except to be passable by truck or All Terrain Vehicle.

One of the secondary goals of this study was to begin to determine which road factors played a role in determining the amount of sediment generated by the various road segments. While none of the individual factors tested (slope, CBR, etc) showed a strong relationship to the amount of sediment produced, there were a number of noteworthy observations:

- There was a significant "First Flush" effect, in which sediment concentrations in runoff were significantly higher at the beginning of each test, and slowly decreased over each 30 minute event (Details in Figure 5.1).
- Roads that served as "trunk lines" or accessed more well pads had a higher CBR indicating they have much more compacted surfaces. These roads also showed the lowest percentage of sediment increases after being stressed by traffic. Roads with lower traffic showed large increases in sediment production after traffic stresses.
- Site "A" was similar to all other sites, except that the low amount of traffic on the road allowed the establishment of grass over most of the road surface. Site "A" had the lowest CBR and was the most impacted by traffic stresses. Traffic removed some grass cover and created rutting, causing sediment production to increase over 600% between run 1 and run 3. Despite its relatively steep slope (14.7%), Site A produced significantly less sediment than the other sites (*3.2 pounds on Site A versus 24.7 pound average for other sites*). Furthermore, during Run 1 of the RainMaker before traffic, sediment production from this site was only 1.0 pound in 30 minutes. This would suggest that significant sediment reductions could be achieved by establishing grass on access roads with low traffic volumes.
- Without traffic stress, the best indicators of sediment production from the roads tested were road slope combined with road width. If the road is stressed by traffic, then sediment production becomes less dependent on road width and slope, and more dependent on road strength as measured by the California Bearing Ratio.

The second component of this study looked at changes in sediment production after the placement of new pit-run and Driving Surface Aggregate surfaces. While both new pit-run surfaces reduced sediment compared to the "existing road" tests, the amount of sediment produced was consistent with the average sediment production for all 13 "existing condition" road tests as illustrated in figure 5.17. Because pit-run material is simply excavated instead of mined and processed, there is little quality control and the product is highly variable. The use of pit-run material represents the traditional approach to road maintenance for this part of Pennsylvania.

The sediment production rates found for the two DSA sites was approximately one-tenth that of the pit-run surfaces. This is consistent with previous research done by the Center that showed sediment production rates well below 1 pound per run for at least two years after DSA placement on two separate sites in Potter County, PA, in 2008. DSA has been in use since 2000 in Pennsylvania and was designed to resist erosion and to provide a longer lasting road surface and reduce runoff pollution to nearby streams. From this study and previous testing, it is clear that Driving Surface Aggregate significantly reduces sediment production compared to traditional “locally derived materials”.

It is also important to note that the two DSA sites tested both showed a significant decrease in sediment in sequential individaul runs despite being subjected to traffic between runs. This shows that DSA provides greater surface durability and structural support for traffic loads. This is evidence that a hard and well graded aggregate is less likely to break down into finer particles under traffic and subsequently leave the road composite in storm run-off or as dust. The likely result is significantly longer maintenance cycles related to required grading and/or re-graveling (i.e. – a longer elapsed time between needed reshaping of the road surface or replenishment of surface material). Along with the potential for significant long term environmental benefits, the long-range economic benefits should be considered when selecting road surface materials. In prioritizing the selection of different road surface materials, factors such as anticipated volume and type of traffic (mining and timber hauling), and proximity to surface waters might be emphasized.

While the environmental and traffic resistance road benefits of DSA may be apparent, its use does represent a significant cost increase over locally derived materials such as pit-run. This is especially true in locations such as the Allegheny National Forest where DSA must be imported significant distances. In 2011, DSA was approximately 2.5 times more expensive than pit-run for locations in the Allegheny National Forest. It is up to individual road managers and departments to weight the benefits of DSA against the increase in cost. Over the past decade as aggregate costs have risen, Allegheny National Forest personnel have been focusing their DSA usage to environmentally sensitive locations. These include stream crossings and streamside locations where road runoff to the stream is unavoidable. DSA is typically used in approximately 300 foot stretches around such streamside locations. DSA has also been used on roads experiencing higher traffic loads and volumes since it tends to hold up better to those stresses. Sections of road that are not near streams and do not have excessive traffic have continued to be surfaced with cheaper materials such as pit-run. Additonally, consideration should be given to avoiding direct road discharge into streams throug the use of imporved drainage practices, regardless of the road surface selected. These drainage improvements may prove to be a more cost-effective way to reduce sediment pollution than the use of DSA alone. However, it is clear that the Allegheny National Forest's use of DSA in locations where direct runoff to the stream is unavoidable is an effective practice to reduce sediment pollution.

Future Research

This study was an effort to begin quantifying the sediment pollution generated by oil access roads on the Allegheny National Forest. The results of the study, with average sediment production of 1,300 pounds per mile for a single 30 minute 0.61" storm, illustrate the magnitude of the problem. There are many other potential topics that should be considered for future study:

- Analysis of the connectivity of the road drainage network and the stream network to determine how much of the sediment that is produced can be expected to reach a stream.
- Obtain additional data from other test sites within the ANF. The 14 sites tested in this study represent only 1,400 linear feet of roadway, or about 0.02% of the known existing of oil access road in the Allegheny National Forest. More test sites will yield more accurate sediment production figures, and may help to determine which road characteristics are closely tied to sediment production. Even nearby roads, if owned by a different company, may have different sediment production rates because a different set of standards and practices are used to maintain the road.
- Obtain additional data from other test sites outside the ANF. Local geology and climate play a large role in determining sediment generation from unpaved roads. In addition, other activities, such as wind farms and Marcellus gas drilling, require access roads of varying densities and sizes where sediment production has not been quantified.
- In addition to testing "existing" roads, another beneficial study would be to determine sediment reductions achieved by implementing Best Management Practices (BMP) to reduce sediment generation on roads. By running the RainMaker on an existing road, then running it again at various timeframes after BMP installation, the long term performance of the BMP in reducing sediment pollution could be quantified. For instance, grade brakes, broad-based dips and maintaining road crown direct runoff to ditches and the forest floor and are effective at reducing runoff on the road surface. They also reduce the length of roads that are hydrologically connected to streams.
- Run the rainfall simulator on different aggregate such as 2A or 2RC that are widely used for road surfacing throughout Pennsylvania. This can begin to address the question of

was it actually “DSA” that caused the sediment reductions, or simply the use of a graded limestone aggregate. It is probable that both 2A and 2RC would also have significantly lower sediment productions than pit-run. It would be useful to compare their sediment productions to those of DSA found here and in previous studies.

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APPENDIX A – RainMaker Data

The runoff rates and sediment concentration for all sites in this study are on the following tables. Sites are in order of increasing average sediment production, as listed throughout this report.

Appendix A: RainMaker Data: SITE A

3.2 lbs average sediment production

		FLOW RATE				CONCENTRATION		
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 1	6.20	0	-	-	0	-	-	-
		1	11.03	1	5.4	**Kd1.01**		1,210
		5	7.12	1	8.4	**Kd1.05**		720
		10	4.31	1	13.9	**Kd1.10**		420
		15	3.38	1	17.8	**Kd1.15**		210
		20	2.69	1	22.3	**Kd1.20**		125
		25	2.97	1	20.2	-	-	72
		30	9.63	1	6.2	**Kd1.30**		19
		35	21.41	1	2.8	-	-	19
		40	39.28	1	1.5	-	-	19
		45	103.47	1	0.6	-	-	19
		50	139.44	1	0.4	-	-	19
		60	-	-	0	-	-	-

	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 2	3.60	0	-	-	0	-	-	-
		1	12.47	1	4.8	**Kd2.01**		5,000
		5	4.88	1	12.3	**Kd2.05**		1,280
		10	3.16	1	19.0	**Kd2.10**		410
		15	2.60	1	23.1	**Kd2.15**		250
		20	2.88	1	20.8	**Kd2.20**		182
		25	2.71	1	22.1	-	-	134
		30	4.81	1	12.5	**Kd2.30**		85
		35	11.31	1	5.3	-	-	85
		40	22.50	1	2.7	-	-	85
		45	36.13	1	1.7	-	-	85
		50	54.50	1	1.1	-	-	85
		60	0	-	0	-	-	-

	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 3	3.55	0	-	-	0	-	-	-
		1	13.87	1	4.3	**Kd3.01**		11,400
		5	4.72	1	12.7	**Kd3.05**		3,900
		10	2.97	1	20.2	**Kd3.10**		1,350
		15	2.41	1	24.9	**Kd3.15**		870
		20	2.34	1	25.6	**Kd3.20**		680
		25	2.48	1	24.2	-	-	410
		30	4.84	1	12.4	**Kd3.30**		140
		35	12.44	1	4.8	-	-	140
		40	24.07	1	2.5	-	-	140
		45	39.34	1	1.5	-	-	140
		50	101.05	1	0.6	-	-	140
		60	-	-	0	-	-	-

Appendix A: RainMaker Data: SITE T

7.4 lbs average sediment production

		FLOW RATE				CONCENTRATION		
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 1	5.40	0	-	-	0	-	-	-
		1	10.31	1	5.8	**Kd1.01**		7,400
		5	4.84	1	12.4	**Kd1.05**		2,910
		10	4.04	1	14.9	**Kd1.10**		2,110
		15	3.85	1	15.6	**Kd1.15**		1,890
		20	3.67	1	16.3	**Kd1.20**		1,640
		25	3.55	1	16.9	-	-	1,105
		30	66.87	1	0.9	**Kd1.30**		570
		35	1.00	0	0.0	-	-	570
		40	1.00	0	0.0	-	-	570
		45	1.00	0	0.0	-	-	570
		50	1.00	0	0.0	-	-	570
		60	-	-	0	-	-	-
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 2	2.25	0	-	-	0	-	-	-
		1	6.47	1	9.3	**Kd2.01**		4,200
		5	3.57	1	16.8	**Kd2.05**		2,160
		10	3.35	1	17.9	**Kd2.10**		1,390
		15	3.18	1	18.9	**Kd2.15**		1,210
		20	3.40	1	17.6	**Kd2.20**		1,450
		25	3.22	1	18.6	-	-	1,235
		30	6.96	1	8.6	**Kd2.30**		1,020
		35	16.66	0.132	0.5	-	-	1,020
		40	1.00	0	0.0	-	-	1,020
		45	1.00	0	0.0	-	-	1,020
		50	1.00	0	0.0	-	-	1,020
		60	0	-	0	-	-	-
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 3	2.11	0	-	-	0	-	-	-
		1	5.95	1	10.1	**Kd3.01**		10,300
		5	3.96	1	15.2	**Kd3.05**		2,200
		10	3.68	1	16.3	**Kd3.10**		1,780
		15	3.61	1	16.6	**Kd3.15**		1,390
		20	3.61	1	16.6	**Kd3.20**		1,420
		25	3.59	1	16.7	-	-	1,200
		30	7.30	1	8.2	**Kd3.30**		980
		35	12.09	0.132	0.7	-	-	980
		40	78.68	0.132	0.1	-	-	980
		45	1.00	0	0.0	-	-	980
		50	1.00	0	0.0	-	-	980
		60	-	-	0	-	-	-

Appendix A: RainMaker Data: SITE S 7.9 lbs average sediment production

		FLOW RATE				CONCENTRATION		
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 1	5.00	0	-	-	0	-	-	-
		1	4.67	0.132	1.7	**Kd1.01**		3,900
		5	3.38	1	17.8	**Kd1.05**		1,500
		10	3.13	1	19.2	**Kd1.10**		780
		15	3.08	1	19.5	**Kd1.15**		940
		20	2.89	1	20.8	**Kd1.20**		690
		25	2.86	1	21.0	-	-	750
		30	12.78	1	4.7	**Kd1.30**		810
		35	6.08	0.132	1.3	-	-	810
		40	11.41	0.132	0.7	-	-	810
		45	18.53	0.132	0.4	-	-	810
		50	27.69	0.132	0.3	-	-	810
		60	-	-	0	-	-	-

	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 2	3.09	0	-	-	0	-	-	-
		1	3.97	1	15.1	**Kd2.01**		8,500
		5	3.09	1	19.4	**Kd2.05**		2,530
		10	3.02	1	19.9	**Kd2.10**		1,620
		15	2.72	1	22.1	**Kd2.15**		1,140
		20	2.68	1	22.4	**Kd2.20**		1,240
		25	2.76	1	21.7	-	-	1,120
		30	7.53	1	8.0	**Kd2.30**		1,000
		35	3.38	0.132	2.3	-	-	1,000
		40	6.25	0.132	1.3	-	-	1,000
		45	11.87	0.132	0.7	-	-	1,000
		50	26.66	0.132	0.3	-	-	1,000
		60	0	-	0	-	-	-

	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 3	2.66	0	-	-	0	-	-	-
		1	4.36	1	13.8	**Kd3.01**		8,600
		5	3.42	1	17.5	**Kd3.05**		3,200
		10	3.06	1	19.6	**Kd3.10**		1,450
		15	3.06	1	19.6	**Kd3.15**		1,190
		20	3.09	1	19.4	**Kd3.20**		1,140
		25	2.98	1	20.1	-	-	1,070
		30	6.35	1	9.4	**Kd3.30**		1,000
		35	3.40	0.132	2.3	-	-	1,000
		40	7.87	0.132	1.0	-	-	1,000
		45	14.32	0.132	0.6	-	-	1,000
		50	15.75	0.132	0.5	-	-	1,000
		60	-	-	0	-	-	-

Appendix A: RainMaker Data: **SITE R** 11.1 lbs average sediment production

		FLOW RATE				CONCENTRATION		
	Time To Runoff	**Minutes**	**Time (sec)**	**Volume (gal)**	**Flow (gpm)**	**Sample ID**	**Lab Code**	**TSS (mg/l)**
Run 1	3.00	0	-	-	0	-	-	-
		1	9.10	0.132	0.9	**Kd1.01**		3,300
		5	3.47	1	17.3	**Kd1.05**		5,500
		10	3.50	1	17.1	**Kd1.10**		1,970
		15	3.34	1	18.0	**Kd1.15**		1,700
		20	3.08	1	19.5	**Kd1.20**		1,670
		25	3.29	1	18.2	-	-	1,235
		30	10.82	1	5.5	**Kd1.30**		800
		35	9.04	0.132	0.9	-	-	800
		40	21.45	0.132	0.4	-	-	800
		45	42.22	0.132	0.2	-	-	800
		50	93.30	0.132	0.1	-	-	800
		60	-	-	0	-	-	-

	Time To Runoff	**Minutes**	**Time (sec)**	**Volume (gal)**	**Flow (gpm)**	**Sample ID**	**Lab Code**	**TSS (mg/l)**
Run 2	2.50	0	-	-	0	-	-	-
		1	4.52	1	13.3	**Kd2.01**		5,300
		5	3.43	1	17.5	**Kd2.05**		2,410
		10	3.27	1	18.3	**Kd2.10**		2,040
		15	3.58	1	16.8	**Kd2.15**		1,970
		20	3.22	1	18.6	**Kd2.20**		2,010
		25	3.19	1	18.8	-	-	1,690
		30	10.10	1	5.9	**Kd2.30**		1,370
		35	7.10	0.132	1.1	-	-	1,370
		40	16.45	0.132	0.5	-	-	1,370
		45	30.28	0.132	0.3	-	-	1,370
		50	53.09	0.132	0.1	-	-	1,370
		60	0	-	0	-	-	-

	Time To Runoff	**Minutes**	**Time (sec)**	**Volume (gal)**	**Flow (gpm)**	**Sample ID**	**Lab Code**	**TSS (mg/l)**
Run 3	2.00	0	-	-	0	-	-	-
		1	3.75	1	16.0	**Kd3.01**		6,000
		5	3.44	1	17.4	**Kd3.05**		4,800
		10	2.92	1	20.5	**Kd3.10**		3,100
		15	3.12	1	19.2	**Kd3.15**		2,440
		20	3.09	1	19.4	**Kd3.20**		1,990
		25	3.03	1	19.8	-	-	1,965
		30	7.31	1	8.2	**Kd3.30**		1,940
		35	6.00	0.132	1.3	-	-	1,940
		40	15.16	0.132	0.5	-	-	1,940
		45	27.88	0.132	0.3	-	-	1,940
		50	46.53	0.132	0.2	-	-	1,940
		60	-	-	0	-	-	-

Appendix A: RainMaker Data: SITE K

12.7 lbs average sediment production

		FLOW RATE				CONCENTRATION		
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 1	2.50	0	-	-	0	-	-	-
		1	6.33	0.132	1.3	**Kd1.01**		3,700
		5	4.17	1	14.4	**Kd1.05**		4,000
		10	2.83	1	21.2	**Kd1.10**		2,120
		15	3.17	1	18.9	**Kd1.15**		1,410
		20	2.96	1	20.3	**Kd1.20**		1,330
		25	2.98	1	20.1	-	-	1,070
		30	6.10	1	9.8	**Kd1.30**		810
		35	4.13	0.132	1.9	-	-	810
		40	6.97	0.132	1.1	-	-	810
		45	8.50	0.132	0.9	-	-	810
		50	10.71	0.132	0.7	-	-	810
		60	-	-	0	-	-	-
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 2	2.00	0	-	-	0	-	-	-
		1	6.50	1	9.2	**Kd2.01**		7,600
		5	2.80	1	21.4	**Kd2.05**		6,800
		10	2.90	1	20.7	**Kd2.10**		3,200
		15	2.88	1	20.8	**Kd2.15**		2,320
		20	2.57	1	23.3	**Kd2.20**		1,580
		25	2.55	1	23.5	-	-	1,375
		30	4.10	1	14.6	**Kd2.30**		1,170
		35	9.50	1	6.3	-	-	1,170
		40	3.15	0.132	2.5	-	-	1,170
		45	4.41	0.132	1.8	-	-	1,170
		50	5.25	0.132	1.5	-	-	1,170
		60	-	-	0	-	-	-
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 3	1.83	0	-	-	0	-	-	-
		1	11.90	1	5.0	**Kd3.01**		7,900
		5	2.59	1	23.2	**Kd3.05**		5,900
		10	2.55	1	23.5	**Kd3.10**		2,680
		15	2.68	1	22.4	**Kd3.15**		2,000
		20	2.70	1	22.2	**Kd3.20**		1,730
		25	2.30	1	26.1	-	-	1,310
		30	3.40	1	17.6	**Kd3.30**		890
		35	6.50	1	9.2	-	-	890
		40	2.75	0.132	2.9	-	-	890
		45	3.88	0.132	2.0	-	-	890
		50	5.32	0.132	1.5	-	-	890
		60	-	-	0	-	-	-

Appendix A: RainMaker Data: SITE G 13.0 lbs average sediment production

		FLOW RATE				CONCENTRATION		
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 1	2.90	0	-	-	0	-	-	-
		1	12.00	1	5.0	**Kd1.01**		9,300
		5	5.94	1	10.1	**Kd1.05**		6,600
		10	2.65	1	22.6	**Kd1.10**		3,700
		15	2.85	1	21.1	**Kd1.15**		2,540
		20	2.65	1	22.6	**Kd1.20**		2,610
		25	2.85	1	21.1	-	-	2,435
		30	6.62	1	9.1	**Kd1.30**		2,260
		35	23.15	1	2.6	-	-	2,260
		40	9.95	0.132	0.8	-	-	2,260
		45	23.01	0.132	0.3	-	-	2,260
		50	50.35	0.132	0.2	-	-	2,260
		60	-	-	0	-	-	-
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 2	2.53	0	-	-	0	-	-	-
		1	7.66	1	7.8	**Kd2.01**		8,700
		5	3.03	1	19.8	**Kd2.05**		3,500
		10	2.75	1	21.8	**Kd2.10**		2,840
		15	2.58	1	23.3	**Kd2.15**		1,990
		20	2.58	1	23.3	**Kd2.20**		2,150
		25	2.50	1	24.0	-	-	2,030
		30	6.08	1	9.9	**Kd2.30**		1,910
		35	28.23	1	2.1	-	-	1,910
		40	7.80	0.132	1.0	-	-	1,910
		45	15.23	0.132	0.5	-	-	1,910
		50	27.00	0.132	0.3	-	-	1,910
		60	-	-	0	-	-	-
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 3	2.51	0	-	-	0	-	-	-
		1	8.31	1	7.2	**Kd3.01**		4,100
		5	3.12	1	19.2	**Kd3.05**		2,490
		10	2.91	1	20.6	**Kd3.10**		1,840
		15	2.64	1	22.7	**Kd3.15**		1,670
		20	2.54	1	23.6	**Kd3.20**		1,370
		25	2.71	1	22.1	-	-	1,515
		30	5.50	1	10.9	**Kd3.30**		1,660
		35	22.96	1	2.6	-	-	1,660
		40	7.43	0.132	1.1	-	-	1,660
		45	13.00	0.132	0.6	-	-	1,660
		50	15.47	0.132	0.5	-	-	1,660
		60	-	-	0	-	-	-

Appendix A: RainMaker Data: SITE I

14.7 lbs average sediment production

		FLOW RATE				CONCENTRATION		
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 1	2.03	0	-	-	0	-	-	-
		1	14.34	1	4.2	**Kd1.01**		16,100
		5	3.79	1	15.8	**Kd1.05**		8,900
		10	3.02	1	19.9	**Kd1.10**		2,150
		15	3.08	1	19.5	**Kd1.15**		2,150
		20	2.94	1	20.4	**Kd1.20**		1,320
		25	2.86	1	21.0	-	-	1,355
		30	3.91	1	15.3	**Kd1.30**		1,390
		35	4.66	0.132	1.7	-	-	1,390
		40	12.25	0.132	0.6	-	-	1,390
		45	27.90	0.132	0.3	-	-	1,390
		50	55.55	0.132	0.1	-	-	1,390
		60	-	-	0	-	-	-
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 2	1.90	0	-	-	0	-	-	-
		1	5.81	1	10.3	**Kd2.01**		11,500
		5	3.15	1	19.0	**Kd2.05**		5,100
		10	2.87	1	20.9	**Kd2.10**		3,700
		15	2.85	1	21.1	**Kd2.15**		2,740
		20	2.95	1	20.3	**Kd2.20**		1,850
		25	2.72	1	22.1	-	-	1,795
		30	4.53	1	13.2	**Kd2.30**		1,740
		35	3.97	0.132	2.0	-	-	1,740
		40	10.13	0.132	0.8	-	-	1,740
		45	20.22	0.132	0.4	-	-	1,740
		50	37.25	0.132	0.2	-	-	1,740
		60	0	-	0	-	-	-
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 3	1.75	0	-	-	0	-	-	-
		1	5.13	1	11.7	**Kd3.01**		8,400
		5	3.03	1	19.8	**Kd3.05**		4,100
		10	2.67	1	22.5	**Kd3.10**		2,330
		15	2.77	1	21.7	**Kd3.15**		1,850
		20	2.68	1	22.4	**Kd3.20**		1,600
		25	2.60	1	23.1	-	-	1,590
		30	3.75	1	16.0	**Kd3.30**		1,580
		35	3.78	0.132	2.1	-	-	1,580
		40	8.91	0.132	0.9	-	-	1,580
		45	21.15	0.132	0.4	-	-	1,580
		50	32.50	0.132	0.2	-	-	1,580
		60	-	-	0	-	-	-

Appendix A: RainMaker Data: SITE C

14.9 lbs average sediment production

		FLOW RATE				CONCENTRATION		
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 1	4.67	0	-	-	0	-	-	-
		1	20.78	1	2.9	**Kd1.01**		5,300
		5	4.09	1	14.7	**Kd1.05**		7,000
		10	3.25	1	18.5	**Kd1.10**		3,500
		15	2.90	1	20.7	**Kd1.15**		2,410
		20	2.60	1	23.1	**Kd1.20**		1,450
		25	2.50	1	24.0	-	-	925
		30	11.12	1	5.4	**Kd1.30**		400
		35	5.40	0.132	1.5	-	-	400
		40	8.71	0.132	0.9	-	-	400
		45	9.62	0.132	0.8	-	-	400
		50	11.72	0.132	0.7	-	-	400
		60	-	-	0	-	-	-

	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 2	2.33	0	-	-	0	-	-	-
		1	12.10	1	5.0	**Kd2.01**		9,000
		5	3.22	1	18.6	**Kd2.05**		5,000
		10	2.88	1	20.8	**Kd2.10**		3,200
		15	2.55	1	23.5	**Kd2.15**		2,640
		20	2.69	1	22.3	**Kd2.20**		1,820
		25	2.50	1	24.0	-	-	1,560
		30	4.37	1	13.7	**Kd2.30**		1,300
		35	17.31	1	3.5	-	-	1,300
		40	4.69	0.132	1.7	-	-	1,300
		45	6.70	0.132	1.2	-	-	1,300
		50	7.93	0.132	1.0	-	-	1,300
		60	0	-	0	-	-	-

	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 3	3.33	0	-	-	0	-	-	-
		1	4.72	1	12.7	**Kd3.01**		8,900
		5	3.25	1	18.5	**Kd3.05**		5,700
		10	2.64	1	22.7	**Kd3.10**		3,900
		15	2.85	1	21.1	**Kd3.15**		2,910
		20	3.09	1	19.4	**Kd3.20**		2,150
		25	3.10	1	19.4	-	-	2,165
		30	4.00	1	15.0	**Kd3.30**		2,180
		35	5.00	0.132	1.6	-	-	2,180
		40	6.50	0.132	1.2	-	-	2,180
		45	7.98	0.132	1.0	-	-	2,180
		50	8.28	0.132	1.0	-	-	2,180
		60	-	-	0	-	-	-

Appendix A: RainMaker Data: SITE L 28.4 lbs average sediment production

		FLOW RATE				CONCENTRATION		
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 1	1.00	0	-	-	0	-	-	-
		1	19.59	1	3.1	**Kd1.01**		18,800
		5	6.00	1	10.0	**Kd1.05**		7,200
		10	2.50	1	24.0	**Kd1.10**		2,560
		15	2.19	1	27.4	**Kd1.15**		2,160
		20	2.60	1	23.1	**Kd1.20**		1,350
		25	2.94	1	20.4	-	-	1,050
		30	6.50	1	9.2	**Kd1.30**		750
		35	15.54	1	3.9	-	-	750
		40	31.59	1	1.9	-	-	750
		45	63.87	1	0.9	-	-	750
		50	145.00	1	0.4	-	-	750
		60	-	-	0	-	-	-
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 2	3.50	0	-	-	0	-	-	-
		1	7.81	1	7.7	**Kd2.01**		35,000
		5	5.12	1	11.7	**Kd2.05**		14,600
		10	3.31	1	18.1	**Kd2.10**		10,200
		15	2.90	1	20.7	**Kd2.15**		7,600
		20	2.92	1	20.5	**Kd2.20**		5,800
		25	3.71	1	16.2	-	-	4,065
		30	7.97	1	7.5	**Kd2.30**		2,330
		35	19.06	1	3.1	-	-	2,330
		40	5.50	0.132	1.4	-	-	2,330
		45	9.22	0.132	0.9	-	-	2,330
		50	14.81	0.132	0.5	-	-	2,330
		60	-	-	0	-	-	-
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 3	3.67	0	-	-	0	-	-	-
		1	14.97	1	4.0	**Kd3.01**		22,200
		5	4.04	1	14.9	**Kd3.05**		14,100
		10	3.09	1	19.4	**Kd3.10**		9,400
		15	2.68	1	22.4	**Kd3.15**		7,300
		20	2.70	1	22.2	**Kd3.20**		6,200
		25	2.75	1	21.8	-	-	5,000
		30	6.84	1	8.8	**Kd3.30**		3,800
		35	20.78	1	2.9	-	-	3,800
		40	43.97	1	1.4	-	-	3,800
		45	71.02	1	0.8	-	-	3,800
		50	107.50	1	0.6	-	-	3,800
		60	-	-	0	-	-	-

Appendix A: RainMaker Data: SITE N 29.7 lbs average sediment production

		FLOW RATE				CONCENTRATION		
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 1	3.00	0	-	-	0	-	-	-
		1	4.32	1	13.9	**Kd1.01**		4,900
		5	3.81	1	15.7	**Kd1.05**		3,700
		10	3.13	1	19.2	**Kd1.10**		2,630
		15	2.42	1	24.8	**Kd1.15**		2,470
		20	2.26	1	26.5	**Kd1.20**		2,320
		25	2.01	1	29.9	-	-	1,780
		30	8.09	1	7.4	**Kd1.30**		1,240
		35	31.64	1	1.9	-	-	1,240
		40	9.67	0.132	0.8	-	-	1,240
		45	15.88	0.132	0.5	-	-	1,240
		50	23.07	0.132	0.3	-	-	1,240
		60	-	-	0	-	-	-
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 2	1.20	0	-	-	0	-	-	-
		1	4.14	1	14.5	**Kd2.01**		33,000
		5	2.30	1	26.1	**Kd2.05**		9,500
		10	2.26	1	26.5	**Kd2.10**		4,600
		15	2.26	1	26.5	**Kd2.15**		3,900
		20	2.25	1	26.7	**Kd2.20**		3,100
		25	1.98	1	30.3	-	-	3,100
		30	3.01	1	19.9	**Kd2.30**		3,100
		35	2.73	0.132	2.9	-	-	3,100
		40	5.04	0.132	1.6	-	-	3,100
		45	8.37	0.132	0.9	-	-	3,100
		50	12.13	0.132	0.7	-	-	3,100
		60	0	-	0	-	-	-
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 3	0.40	0	-	-	0	-	-	-
		1	4.75	1	12.6	**Kd3.01**		6,200
		5	2.40	1	25.0	**Kd3.05**		10,000
		10	1.93	1	31.1	**Kd3.10**		4,700
		15	1.99	1	30.2	**Kd3.15**		3,600
		20	1.91	1	31.4	**Kd3.20**		2,840
		25	1.76	1	34.1	-	-	2,755
		30	1.92	1	31.3	**Kd3.30**		2,670
		35	2.20	0.132	3.6	-	-	2,670
		40	5.04	0.132	1.6	-	-	2,670
		45	5.30	0.132	1.5	-	-	2,670
		50	9.55	0.132	0.8	-	-	2,670
		60	-	-	0	-	-	-

Appendix A: RainMaker Data: SITE E 35.9 lbs average sediment production

		FLOW RATE				CONCENTRATION		
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 1	2.50	0	-	-	0	-	-	-
		1	10.00	1	6.0	**Kd1.01**		3,300
		5	4.05	1	14.8	**Kd1.05**		2,770
		10	3.54	1	16.9	**Kd1.10**		1,700
		15	3.13	1	19.2	**Kd1.15**		1,470
		20	3.03	1	19.8	**Kd1.20**		1,340
		25	2.70	1	22.2	-	-	1,210
		30	8.87	1	6.8	**Kd1.30**		1,080
		35	35.40	1	1.7	-	-	1,080
		40	13.37	0.132	0.6	-	-	1,080
		45	27.52	0.132	0.3	-	-	1,080
		50	60.06	0.132	0.1	-	-	1,080
		60	-	-	0	-	-	-
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 2	3.17	0	-	-	0	-	-	-
		1	6.62	1	9.1	**Kd2.01**		38,000
		5	3.25	1	18.5	**Kd2.05**		13,600
		10	2.97	1	20.2	**Kd2.10**		8,800
		15	2.78	1	21.6	**Kd2.15**		5,000
		20	2.95	1	20.3	**Kd2.20**		4,500
		25	2.80	1	21.4	-	-	3,250
		30	11.25	1	5.3	**Kd2.30**		2,000
		35	36.19	1	1.7	-	-	2,000
		40	11.84	0.132	0.7	-	-	2,000
		45	21.22	0.132	0.4	-	-	2,000
		50	33.53	0.132	0.2	-	-	2,000
		60	-	-	0	-	-	-
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 3	3.00	0	-	-	0	-	-	-
		1	3.62	1	16.6	**Kd3.01**		63,000
		5	3.04	1	19.7	**Kd3.05**		18,800
		10	2.80	1	21.4	**Kd3.10**		9,000
		15	2.95	1	20.3	**Kd3.15**		6,400
		20	2.80	1	21.4	**Kd3.20**		6,000
		25	2.75	1	21.8	-	-	4,600
		30	12.80	1	4.7	**Kd3.30**		3,200
		35	40.06	1	1.5	-	-	3,200
		40	11.68	0.132	0.7	-	-	3,200
		45	22.10	0.132	0.4	-	-	3,200
		50	36.28	0.132	0.2	-	-	3,200
		60	-	-	0	-	-	-

Appendix A: RainMaker Data: SITE M

42.7 lbs average sediment production

		FLOW RATE				**CONCENTRATION**		
	Time To Runoff	**Minutes**	**Time (sec)**	**Volume (gal)**	**Flow (gpm)**	**Sample ID**	**Lab Code**	**TSS (mg/l)**
Run 1	2.21	0	-	-	0	-	-	-
		1	12.39	1	4.8	**Kd1.01**		26,000
		5	4.81	1	12.5	**Kd1.05**		14,300
		10	3.52	1	17.0	**Kd1.10**		6,300
		15	3.35	1	17.9	**Kd1.15**		4,700
		20	3.38	1	17.8	**Kd1.20**		3,600
		25	3.28	1	18.3	-	-	2,710
		30	5.62	1	10.7	**Kd1.30**		1,820
		35	26.53	1	2.3	-	-	1,820
		40	13.93	0.132	0.6	-	-	1,820
		45	39.50	0.132	0.2	-	-	1,820
		50	99.59	0.132	0.1	-	-	1,820
		60	-	-	0	-	-	-
	Time To Runoff	**Minutes**	**Time (sec)**	**Volume (gal)**	**Flow (gpm)**	**Sample ID**	**Lab Code**	**TSS (mg/l)**
Run 2	3.57	0	-	-	0	-	-	-
		1	5.55	1	10.8	**Kd2.01**		40,000
		5	4.15	1	14.5	**Kd2.05**		19,500
		10	3.25	1	18.5	**Kd2.10**		11,800
		15	3.11	1	19.3	**Kd2.15**		8,300
		20	3.13	1	19.2	**Kd2.20**		8,100
		25	3.09	1	19.4	-	-	5,700
		30	6.37	1	9.4	**Kd2.30**		3,300
		35	4.71	0.132	1.7	-	-	3,300
		40	13.65	0.132	0.6	-	-	3,300
		45	29.90	0.132	0.3	-	-	3,300
		50	52.75	0.132	0.2	-	-	3,300
		60	-	-	0	-	-	-

Run 3 could not be complete due to water truck problems. Data in this report for run 3 was extrapolated based on the average sediment increase between runs 2 and 3 for the other 13 sites.

Appendix A: RainMaker Data: SITE F

43.1 lbs average sediment production

		FLOW RATE				CONCENTRATION		
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 1	2.90	0	-	-	0	-	-	-
		1	9.38	1	6.4	**Kd1.01**		26,100
		5	3.91	1	15.3	**Kd1.05**		20,800
		10	3.18	1	18.9	**Kd1.10**		12,100
		15	3.05	1	19.7	**Kd1.15**		9,700
		20	2.96	1	20.3	**Kd1.20**		7,800
		25	2.72	1	22.1	-	-	5,900
		30	11.09	1	5.4	**Kd1.30**		4,000
		35	5.00	0.132	1.6	-	-	4,000
		40	14.28	0.132	0.6	-	-	4,000
		45	26.81	0.132	0.3	-	-	4,000
		50	74.72	0.132	0.1	-	-	4,000
		60	-	-	0	-	-	-
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 2	2.50	0	-	-	0	-	-	-
		1	5.65	1	10.6	**Kd2.01**		13,800
		5	2.87	1	20.9	**Kd2.05**		9,000
		10	2.59	1	23.2	**Kd2.10**		6,600
		15	2.50	1	24.0	**Kd2.15**		7,300
		20	2.35	1	25.5	**Kd2.20**		8,200
		25	2.50	1	24.0	-	-	6,450
		30	6.72	1	8.9	**Kd2.30**		4,700
		35	26.03	1	2.3	-	-	4,700
		40	13.03	0.132	0.6	-	-	4,700
		45	27.91	0.132	0.3	-	-	4,700
		50	47.97	0.132	0.2	-	-	4,700
		60	-	-	0	-	-	-
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 3	2.67	0	-	-	0	-	-	-
		1	3.78	1	15.9	**Kd3.01**		16,900
		5	3.02	1	19.9	**Kd3.05**		8,600
		10	2.90	1	20.7	**Kd3.10**		6,700
		15	2.75	1	21.8	**Kd3.15**		7,200
		20	2.72	1	22.1	**Kd3.20**		7,200
		25	2.51	1	23.9	-	-	5,700
		30	8.13	1	7.4	**Kd3.30**		4,200
		35	41.47	1	1.4	-	-	4,200
		40	14.25	0.132	0.6	-	-	4,200
		45	26.25	0.132	0.3	-	-	4,200
		50	44.35	0.132	0.2	-	-	4,200
		60	-	-	0	-	-	-

Appendix A: RainMaker Data: SITE B

60.1 lbs average sediment production

		FLOW RATE				CONCENTRATION		
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 1	6.33	0	-	-	0	-	-	-
		1	5.70	1	10.5	**Kd1.01**		21,300
		5	3.90	1	15.4	**Kd1.05**		9,400
		10	3.23	1	18.6	**Kd1.10**		7,900
		15	3.00	1	20.0	**Kd1.15**		7,300
		20	2.91	1	20.6	**Kd1.20**		6,400
		25	3.70	1	16.2	-	-	3,780
		30	18.00	1	3.3	**Kd1.30**		1,160
		35	6.75	0.132	1.2	-	-	1,160
		40	16.00	0.132	0.5	-	-	1,160
		45	32.50	0.132	0.2	-	-	1,160
		50	57.00	0.132	0.1	-	-	1,160
		60	-	-	0	-	-	-
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 2	3.55	0	-	-	0	-	-	-
		1	3.70	1	16.2	**Kd2.01**		42,000
		5	2.85	1	21.1	**Kd2.05**		21,000
		10	2.50	1	24.0	**Kd2.10**		13,000
		15	2.52	1	23.8	**Kd2.15**		8,800
		20	2.28	1	26.3	**Kd2.20**		6,700
		25	2.35	1	25.5	-	-	4,125
		30	6.04	1	9.9	**Kd2.30**		1,550
		35	3.00	0.132	2.6	-	-	1,550
		40	5.77	0.132	1.4	-	-	1,550
		45	10.25	0.132	0.8	-	-	1,550
		50	17.43	0.132	0.5	-	-	1,550
		60	0	-	0	-	-	-
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 3	3.40	0	-	-	0	-	-	-
		1	3.85	1	15.6	**Kd3.01**		46,000
		5	2.70	1	22.2	**Kd3.05**		24,100
		10	2.25	1	26.7	**Kd3.10**		14,700
		15	2.00	1	30.0	**Kd3.15**		10,900
		20	2.20	1	27.3	**Kd3.20**		7,200
		25	2.11	1	28.4	-	-	4,945
		30	6.41	1	9.4	**Kd3.30**		2,690
		35	2.65	0.132	3.0	-	-	2,690
		40	5.55	0.132	1.4	-	-	2,690
		45	9.69	0.132	0.8	-	-	2,690
		50	15.26	0.132	0.5	-	-	2,690
		60	-	-	0	-	-	-

Appendix A: RainMaker Data: SITE F AFTER NEW PIT RUN

15.4 lbs average sediment production

		FLOW RATE				CONCENTRATION		
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 1	2.50	0	-	-	0	-	-	-
		1	9.38	1	6.4	**Kd1.01**		6,200
		5	3.91	1	15.3	**Kd1.05**		13,800
		10	3.18	1	18.9	**Kd1.10**		7,800
		15	3.05	1	19.7	**Kd1.15**		4,200
		20	2.96	1	20.3	**Kd1.20**		2,560
		25	2.72	1	22.1	-	-	2,025
		30	11.09	1	5.4	**Kd1.30**		1,490
		35	5.00	0.132	1.6	-	-	1,490
		40	14.28	0.132	0.6	-	-	1,490
		45	26.81	0.132	0.3	-	-	1,490
		50	74.72	0.132	0.1	-	-	1,490
		60	-	-	0	-	-	-
			Time	Volum				
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 2	2.00	0	-	-	0	-	-	-
		1	5.65	1	10.6	**Kd2.01**		7,200
		5	2.87	1	20.9	**Kd2.05**		4,200
		10	2.59	1	23.2	**Kd2.10**		2,870
		15	2.50	1	24.0	**Kd2.15**		1,630
		20	2.35	1	25.5	**Kd2.20**		1,450
		25	2.50	1	24.0	-	-	1,315
		30	6.72	1	8.9	**Kd2.30**		1,180
		35	26.03	1	2.3	-	-	1,180
		40	13.03	0.132	0.6	-	-	1,180
		45	27.91	0.132	0.3	-	-	1,180
		50	47.97	0.132	0.2	-	-	1,180
		60	-	-	0	-	-	-
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 3	2.00	0	-	-	0	-	-	-
		1	3.78	1	15.9	**Kd3.01**		4,000
		5	3.02	1	19.9	**Kd3.05**		2,680
		10	2.90	1	20.7	**Kd3.10**		2,150
		15	2.75	1	21.8	**Kd3.15**		1,550
		20	2.72	1	22.1	**Kd3.20**		1,550
		25	2.51	1	23.9	-	-	1,265
		30	8.13	1	7.4	**Kd3.30**		980
		35	41.47	1	1.4	-	-	980
		40	14.25	0.132	0.6	-	-	980
		45	26.25	0.132	0.3	-	-	980
		50	44.35	0.132	0.2	-	-	980
		60	-	-	0	-	-	-

Note that because the road project affected the drainage pattern of the road, less water was running at the sample point for each of the 4 “after aggregate” tests. For this reason, flow volumes from the “existing road” tests (in red) were used in combination with the “after aggregate” sediment concentrations in order to determine the total volume of sediment that was attributable to the aggregate and not lost water volume.

Appendix A: RainMaker Data: SITE G AFTER NEW DSA

4.2 lbs average sediment production

		FLOW RATE				CONCENTRATION		
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 1	5.00	0	-	-	0	-	-	-
		1	12.00	1	5.0	**Kd1.01**		4,500
		5	5.94	1	10.1	**Kd1.05**		2,790
		10	2.65	1	22.6	**Kd1.10**		2,020
		15	2.85	1	21.1	**Kd1.15**		1,400
		20	2.65	1	22.6	**Kd1.20**		1,070
		25	2.85	1	21.1	-	-	580
		30	6.62	1	9.1	**Kd1.30**		89
		35	23.15	1	2.6	-	-	89
		40	9.95	0.132	0.8	-	-	89
		45	23.01	0.132	0.3	-	-	89
		50	50.35	0.132	0.2	-	-	89
		60	-	-	0	-	-	-
			Time	Volum				
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 2	2.50	0	-	-	0	-	-	-
		1	7.66	1	7.8	**Kd2.01**		2,010
		5	3.03	1	19.8	**Kd2.05**		1,410
		10	2.75	1	21.8	**Kd2.10**		1,020
		15	2.58	1	23.3	**Kd2.15**		78
		20	2.58	1	23.3	**Kd2.20**		85
		25	2.50	1	24.0	-	-	228
		30	6.08	1	9.9	**Kd2.30**		370
		35	28.23	1	2.1	-	-	370
		40	7.80	0.132	1.0	-	-	370
		45	15.23	0.132	0.5	-	-	370
		50	27.00	0.132	0.3	-	-	370
		60	-	-	0	-	-	-
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 3	2.50	0	-	-	0	-	-	-
		1	8.31	1	7.2	**Kd3.01**		1,370
		5	3.12	1	19.2	**Kd3.05**		850
		10	2.91	1	20.6	**Kd3.10**		760
		15	2.64	1	22.7	**Kd3.15**		940
		20	2.54	1	23.6	**Kd3.20**		610
		25	2.71	1	22.1	-	-	430
		30	5.50	1	10.9	**Kd3.30**		250
		35	22.96	1	2.6	-	-	250
		40	7.43	0.132	1.1	-	-	250
		45	13.00	0.132	0.6	-	-	250
		50	15.47	0.132	0.5	-	-	250
		60	-	-	0	-	-	-

Note that because the road project affected the drainage pattern of the road, less water was running at the sample point for each of the 4 “after aggregate” tests. For this reason, flow volumes from the “existing road” tests (in red) were used in combination with the “after aggregate” sediment concentrations in order to determine the total volume of sediment that was attributable to the aggregate and not lost water volume.

Appendix A: RainMaker Data: SITE B AFTER NEW PIT-RUN

36.8 lbs average sediment production

		FLOW RATE				CONCENTRATION		
	Time To Runoff	**Minutes**	**Time (sec)**	**Volume (gal)**	**Flow (gpm)**	**Sample ID**	**Lab Code**	**TSS (mg/l)**
Run 1	4.00	0	-	-	0	-	-	-
		1	5.70	1	10.5	**Kd1.01**		14,800
		5	3.90	1	15.4	**Kd1.05**		8,400
		10	3.23	1	18.6	**Kd1.10**		4,160
		15	3.00	1	20.0	**Kd1.15**		3,410
		20	2.91	1	20.6	**Kd1.20**		3,120
		25	3.70	1	16.2	-	-	1,990
		30	18.00	1	3.3	**Kd1.30**		860
		35	6.75	0.132	1.2	-	-	860
		40	16.00	0.132	0.5	-	-	860
		45	32.50	0.132	0.2	-	-	860
		50	57.00	0.132	0.1	-	-	860
		60	-	-	0	-	-	-
	Time To Runoff	**Minutes**	**Time (sec)**	**Volume (gal)**	**Flow (gpm)**	**Sample ID**	**Lab Code**	**TSS (mg/l)**
Run 2	2.50	0	-	-	0	-	-	-
		1	3.70	1	16.2	**Kd2.01**		39,000
		5	2.85	1	21.1	**Kd2.05**		9,800
		10	2.50	1	24.0	**Kd2.10**		5,300
		15	2.52	1	23.8	**Kd2.15**		3,670
		20	2.28	1	26.3	**Kd2.20**		3,650
		25	2.35	1	25.5	-	-	3,440
		30	6.04	1	9.9	**Kd2.30**		3,230
		35	3.00	0.132	2.6	-	-	3,230
		40	5.77	0.132	1.4	-	-	3,230
		45	10.25	0.132	0.8	-	-	3,230
		50	17.43	0.132	0.5	-	-	3,230
		60	0	-	0	-	-	-
	Time To Runoff	**Minutes**	**Time (sec)**	**Volume (gal)**	**Flow (gpm)**	**Sample ID**	**Lab Code**	**TSS (mg/l)**
Run 3	2.20	0	-	-	0	-	-	-
		1	3.85	1	15.6	**Kd3.01**		43,200
		5	2.70	1	22.2	**Kd3.05**		12,400
		10	2.25	1	26.7	**Kd3.10**		6,200
		15	2.00	1	30.0	**Kd3.15**		4,900
		20	2.20	1	27.3	**Kd3.20**		4,680
		25	2.11	1	28.4	-	-	3,050
		30	6.41	1	9.4	**Kd3.30**		1,420
		35	2.65	0.132	3.0	-	-	1,420
		40	5.55	0.132	1.4	-	-	1,420
		45	9.69	0.132	0.8	-	-	1,420
		50	15.26	0.132	0.5	-	-	1,420
		60	-	-	0	-	-	-

Note that because the road project affected the drainage pattern of the road, less water was running at the sample point for each of the 4 “after aggregate” tests. For this reason, flow volumes from the “existing road” tests (in red) were used in combination with the “after aggregate” sediment concentrations in order to determine the total volume of sediment that was attributable to the aggregate and not lost water volume.

Appendix A: RainMaker Data: SITE C AFTER NEW DSA

0.8 lbs average sediment production

		FLOW RATE				CONCENTRATION		
	Time To Runoff	Minutes	-	-	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 1	8.00	0	-	-	0	-	-	-
		1	20.78	1	2.9	**Kd1.01**		1,160
		5	4.09	1	14.7	**Kd1.05**		1,410
		10	3.25	1	18.5	**Kd1.10**		260
		15	2.90	1	20.7	**Kd1.15**		170
		20	2.60	1	23.1	**Kd1.20**		120
		25	2.50	1	24.0	-	-	86
		30	11.12	1	5.4	**Kd1.30**		51
		35	5.40	0.132	1.5	-	-	51
		40	8.71	0.132	0.9	-	-	51
		45	9.62	0.132	0.8	-	-	51
		50	11.72	0.132	0.7	-	-	51
		60	-	-	0	-	-	-
			Time	Volum				
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 2	6.25	0	-	-	0	-	-	-
		1	12.10	1	5.0	**Kd2.01**		280
		5	3.22	1	18.6	**Kd2.05**		150
		10	2.88	1	20.8	**Kd2.10**		110
		15	2.55	1	23.5	**Kd2.15**		92
		20	2.69	1	22.3	**Kd2.20**		73
		25	2.50	1	24.0	-	-	56
		30	4.37	1	13.7	**Kd2.30**		39
		35	17.31	1	3.5	-	-	39
		40	4.69	0.132	1.7	-	-	39
		45	6.70	0.132	1.2	-	-	39
		50	7.93	0.132	1.0	-	-	39
		60	0	-	0	-	-	-
	Time To Runoff	Minutes	Time (sec)	Volume (gal)	Flow (gpm)	Sample ID	Lab Code	TSS (mg/l)
Run 3	6.50	0	-	-	0	-	-	-
		1	4.72	1	12.7	**Kd3.01**		190
		5	3.25	1	18.5	**Kd3.05**		105
		10	2.64	1	22.7	**Kd3.10**		81
		15	2.85	1	21.1	**Kd3.15**		64
		20	3.09	1	19.4	**Kd3.20**		57
		25	3.10	1	19.4	-	-	45
		30	4.00	1	15.0	**Kd3.30**		32
		35	5.00	0.132	1.6	-	-	32
		40	6.50	0.132	1.2	-	-	32
		45	7.98	0.132	1.0	-	-	32
		50	8.28	0.132	1.0	-	-	32
		60	-	-	0	-	-	-

Note that because the road project affected the drainage pattern of the road, less water was running at the sample point for each of the 4 “after aggregate” tests. For this reason, flow volumes from the “existing road” tests (in red) were used in combination with the “after aggregate” sediment concentrations in order to determine the total volume of sediment that was attributable to the aggregate and not lost water volume.