EROSION CONTROL ON RURAL UNIMPROVED ROADS IN THE STILLWATER CREEK WATERSHED

By

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CHAPTER 1

INTRODUCTION

1.1 Background

Non-point source pollution, like sediment, has been recognized as a significant source of water quality impairment. Unlike point source pollution, non-point source pollution is derived from diffuse sources like runoff, percolation, and atmospheric deposition. Since identification of non-point source pollution can be difficult, regulatory and management practices are not easily implemented. Common sources include agriculture, construction, mining, and timber harvesting. Increased sediment input can have detrimental consequences for aquatic ecosystems. Sediment is abrasive and can clog fish gills. It also eliminates spawning habitat and reduces visibility of sight-feeding fish. Sediment can affect the chemistry of water bodies by decreasing light penetration and releasing absorbed nutrients like nitrogen and phosphorus. The release of nutrients can cause algal blooms which can result in fish kills. Sediment can also alter hydrologic and geomorphic variables within stream networks (Jones *et al* 2000). The impact of sediment on fish is just one example of how increased sediment can adversely impact aquatic systems; sediment may also damage phytoplankton communities and decrease aquatic invertebrate diversity.

Rural unpaved roads are a source of sediment input that is generally overlooked. Rural unpaved roads are used extensively around the world. In Oklahoma, rural unpaved roads are a major means of transportation for agricultural producers and rural residents. These roads are economically important as they provide low-cost transportation routes. Many rural unpaved roads drain into nearby ponds, streams, and lakes. Water runoff and sediment yield has been recognized as the key physical processes whereby roads have an adverse impact on streams and other aquatic systems (Forman and Alexander, 1998).

1.2 Definition of the Problem

Few studies have been conducted to quantify erosion and sediment yield entering water bodies from rural unpaved roads. Most road studies have relied upon rainfall simulation on a small scale, which estimates erosion over a limited area and not actual sediment yield into water bodies. Simple soil loss prediction approaches, like the Universal Soil Loss Equation (USLE), are limited in usefulness in estimating yields because they can only predict erosion from road surfaces and not channelized areas such as ditches (Troeh *et al.* 1999).

Sediment is a source of water quality impairment in the Stillwater Creek watershed in central Oklahoma. Little Stillwater Creek, Brush Creek, and Lake Carl Blackwell are all sub-watersheds within Stillwater Creek watershed and are listed on Oklahoma’s 303(d) water quality impairment list as being impaired by sediment, with roads identified as a probable contributor (Oklahoma Department of Environmental Quality, 2004). Best management practices (BMPs) need to be identified and utilized to reduce sediment impairment of water quality from rural unpaved roads in the Stillwater Creek watershed.

1.3 Objectives

The specific objectives of this study were to:

1) Measure the amount of total erosion from four rural unpaved road segments in Payne County, Oklahoma.
2) Compare total erosion from treated and untreated road segments before and after the installation of erosion control practices, and evaluate the effectiveness of these practices at reducing erosion.

CHAPTER II

LITERATURE REVIEW

2.1 Unpaved Rural Roads

Few studies have been conducted to quantify sediment yield from rural unpaved roads. As a result, researchers have not been able to successfully incorporate roads into watershed runoff and erosion models (Ziegler *et al.* 2000). Despite evidence that road-related impacts often outweigh those of other activities, conservation efforts have historically focused on agricultural and timber removal activities (Ziegler *et al.* 2001).

Three studies have been conducted within the Stillwater Creek watershed to measure and estimate sediment yield from rural unpaved roads into water bodies. Peranich *et al.* (2005) measured erosion from four rural unpaved road segments in the Stillwater Creek watershed. They found that from June-November 2004, cumulative erosion from each segment was 89,800; 112,000; 122,000; and 246,000 kg/ha. Mean erosion across all segments was 180 Mg/km/yr. Neal *et al.* (2000, unpublished) initially estimated the erosion in the Stillwater Creek watershed from 152 km of unpaved roads in Lake Carl Blackwell sub-watershed to be 14 T/km/yr. Rural unpaved roads in this region are typically incised below the surrounding land. As a result there is little opportunity to route sediment away from roads before it reaches water bodies. Rural roads typically drain directly into streams. About 80% of the unpaved roads in Lake Carl Blackwell watershed drain directly into streams. The remaining 20% drain into riparian zones or vegetated ephemeral stream channels, where some filtering may occur (Neal *et al.* 2000, unpublished). Storm *et al.* (2003) estimated the density of unpaved county roads by utilizing available Geographic Information Systems (GIS) data and ground truth data. Assuming a 10 m road width, roads cover 1.3% (2,377 acres) of the watershed and contribute 12,730 Mg of sediment annually as predicted by the WEPP Roads model.

Nagle (2001) found that contrary to the main assumption that cultivation of steep slopes in tropical watersheds is the primary cause of erosion and dam sedimentation, agricultural erosion in the Nizao watershed of the Dominican Republic was much lower than often reported. Only 17% of the total basin sediment budget could be attributed to agricultural erosion, and roads and trails accounted for over 30% of the budget despite only occupying a very small portion of the total basin area. As presented by Nagle (2001), Murdiono and Beerens (1992) estimated that roads, villages, and paths within the Konto watershed in Java accounted for 73.1% of the total measured erosion while comprising only 8% of the total watershed area. A study by Gruszowski *et al.* (2003) in the United Kingdom found that roads are an important secondary source of suspended sediment. Modeling suggested that roads were responsible for 30% of the suspended sediment collected in the River Leadon.

A study by Dunne (1979) in the Kenya Highlands found that rural roads were estimated to have contributed 15-35% of the total basin sediment yields. Footpaths cover at least as large of an area as roads and they cross steeper gradients. Therefore, the sediment contribution from footpaths is of the same order as that from rural roads. In similar studies by Dunne and Dietrich (1982) in an agricultural area of Kenya, they estimated that rural roads, although encompassing only 2% of the basin area, contributed disproportionately to basin sediment yields.

In the mountainous northern region of Thailand, Ziegler *et al.* (1997) demonstrated that rural unpaved roads could disrupt hydrological and erosional processes disproportionately to their area, as compared with agricultural lands. Ziegler *et al.* (1997) also showed that unpaved roads contributed more Horton overland flow than other land surfaces. It was found that rainfall generally did not infiltrate unpaved road surfaces and runoff was generated quicker from other surfaces. Working in Thailand and Hawaii, Ziegler *et al*. (2000) used rainfall simulation to measure sediment contributions from unpaved road surfaces relative to other surfaces. Rain splash processes contributed 38-45% of total sediment output. For low and medium magnitude rainstorms, splash erosion on roads is initially controlled by the removal of easily eroded material, followed by a drastic reduction in sediment output due to the limited detachment from the resistant, highly compacted road surface. Again working in northern Thailand, Ziegler *et al.* (2000b) used rainfall simulation to measure the sediment contribution from unpaved road surfaces relative to other surfaces. Rainfall simulations yielded instantaneous sediment concentrations as high as 100,000 mg/l early in storm events, but eventually decreased as available sediment supply decreased. Sediment concentrations typically ranged from 100,000 mg/l early in storm events to approximately 1,000 mg/l one hour into storm events. The sediment concentrations from the simulation plots were compared to concentrations generated by natural rainfall from a 165 m road segment. Generally, sediment concentrations from the road segments had similar values, ranging from 60,000 mg/l early in storms to approximately 5,000 mg/l one hour into storm events. In general, sediment concentrations from rainfall simulator tests were slightly higher than the sediment concentrations generated by natural rainfall (Ziegler *et al.* 2000b).

Working in the Guanella Pass, 40 miles west of Denver, Colorado, Stevens (2001) measured road erosion from 37.8 km of unpaved county roads that stretched through two counties. Discharge and sediment concentrations were measured at four sites using continuous stage recorders and automatic pumping samplers. Manual samples were also taken at seventeen other sites to establish relationships to the detailed study sites. Instantaneous suspended sediment concentrations for rainfall events ranged from 34-38,880 mg/l, with a median of 1510 mg/l. The suspended sediment concentrations for snowmelt ranged from 66-7,360 mg/l, with a median of 7,190 mg/l. Stevens (2001) found that flow-weighted mean sediment concentrations of both fine and coarse sediments ranged from 11,770 mg/l to 17,540 mg/l for rainfall events and ranged from 639 mg/l to 1,635 mg/l for snowmelt events. Approximately 52% of the road area directly drained into local stream networks, delivering large quantities of sediment into the stream network.

In Washington, Bilby (1985) found that approximately 21% of the total suspended sediment input to a local stream was delivered from unpaved roads. The study measured the suspended sediment contribution from two unpaved rural roads using automatic samplers and grab samples during flow events. Bilby (1985) found that road runoff contributed 20.4 T of sediment from 1980 to 1981, or approximately 21% of the total sediment budget for the entire stream.

On the island of St. John, U.S. Virgin Islands, MacDonald *et al.* (1997) estimated erosion rates from unpaved roads at twenty-six locations across two watersheds. The estimation method involved using a transect board to measure the amount of material eroded from under the board and converting this into a volume of material lost by using the relationship between area and slope. In one watershed, erosion was estimated at 600 T/yr for 16 km of unpaved roads or 37.5 T/km/yr. In the remaining watershed, erosion was estimated at 100 T/yr for 1.4 km of unpaved roads or 71.4 T/km/yr. This study assumed that there was no additional compaction of the road surface from traffic or rutting, thus assuming that all observed material loss under the transect boards was due to erosion. Therefore, the reported erosion rates are likely to be higher than actual erosion rates.

Working on the island of St. John again, MacDonald *et al.* (2001) measured sediment yields from July 1996 to March 1997 from four plots on unpaved road surfaces and two cutslope plots. Each installation consisted of an upper road plot, a lower road plot, and a cutslope plot. All plots were on insloped roads with a cutslope extending up from the inside ditch. The top of the upper road plot was a topographic divide or other existing runoff barrier. This upper road plot was separated from the lower road plot by a heavy, flexible, entrenched rubber strip that diverted surface runoff across the road toward the fillslope. This runoff was then directed into a 3 cm diameter PVC pipe that emptied into a series of 100 l collection reservoirs. After each storm the volume of settleable solids in the reservoirs was measured by thoroughly agitating the contents of each reservoir, taking three replicate 1 l water samples with an Imhoff cone, and allowing each sample to settle for 20 minutes.

They found that storm precipitation explained 26-76% of the observed variation in runoff. Storm precipitation was also found to be a better predictor of storm runoff than precipitation energy. The relationships between storm precipitation and runoff were significant ($p \leq 0.03$) for each of the plots. Sediment yields per unit area for the four unpaved road surface plots ranged from 0.08 to 2.7 kg m^{-2}. The observed relationships between storm energy and storm sediment yields suggest that the annual sediment yields for three of the four road plots were 8 to 15 kg m^{-2}. MacDonald *et al.* (2001) determined that under present conditions, unpaved roads are almost certainly the dominant source of sediment on St. John, even though they occupy a very small fraction of land area.

In another study performed on the island of St. John, Ramos-Scharrón and MacDonald (2005) monitored the sediment production from 21 road segments with sediment traps from July 1998 to November 2001. After normalizing by precipitation and slope, the mean sediment production rate for roads that had been graded within the last two years was 0.96 kg m^{-2} cm^{-1} m m^{-1} or approximately 11 kg m^{-2} a^{-1} for a typical road with a 10%

slope and an annual rainfall of 115 cm a^{-1}. The mean erosion rate for ungraded roads was 42% lower or 0.56 kg m^{-2} cm^{-1} m m^{-1}. The measured and predicted erosion rates indicate that roads are capable of increasing hillslope-scale sediment production rates by up to four orders of magnitude relative to undisturbed conditions. They recommended that other than paving, the most practical methods to reduce current erosion rates are to minimize the frequency of grading and improve road drainage.

Other studies have attempted to estimate erosion and sediment yield from unpaved roads. However, these studies use estimates from earlier studies or other methods as a basis for quantifying the sediment contribution from roads. For example, Phippen and Wohl (2003) conducted a study in the Rio Puerco watershed in New Mexico. This watershed is experiencing rapid channel erosion that has been attributed to land use, climate changes, and internal channel adjustments. Phippen and Wohl (2003) calculated the average annual sediment load for 17 sub-basins of 0.67-17.97 km^2 by comparing sediment accumulation at two points in time (mid-1960s and 1999) behind intact sediment retention structures. They assessed land use via grazing records. Road density was calculated by digitizing all unpaved roads on 1973 aerial photographs. Using survey data for the completed structures and re-surveying each structure again in 1999, estimates of mean sediment loads were derived by converting the elevation changes behind the retention structures into volumes of sediment and dividing by the period of record. They hypothesized that sub-basins with higher grazing intensity and unpaved road density would be correlated to higher sediment loads. Their results indicated that sediment load does not correlate with grazing intensity except in small, relatively low-relief basins with fewer bedrock exposures. However, there was a strong correlation between sediment loads and the density of unpaved roads; thus indicating that sediment load is highly sensitive to the presence of unpaved roads, which serve as high gradient, channelized conduits of water and sediment during storms. Phippen and Wohl (2003) found that historical erosion control techniques (small sediment retention and detention dams), as implemented in the Rio Puerco watershed, prove largely ineffective against accelerated sediment loads because they have not been appropriately implemented or maintained.

The Issaquah Creek watershed, in western Washington, is a rapidly urbanizing watershed of 144 km^2 where sediment aggradation of the main channel and delivery of fine sediment into a large downstream lake have raised increasingly frequent concerns over flooding, loss of fish habitat, and degraded water quality (Nelson and Booth, 2002). A watershed-scale sediment budget was developed to determine the relative effects of land-use practices, including urbanization, on sediment supply and delivery. The 420 km of roads (both paved and unpaved) within the watershed occupy 2.6% of the total watershed area. By using erosion rates of 3.4 T/km/yr for gravel roads and 36 T/km/yr for unpaved forest roads from Reid and Dunne (1984), Nelson and Booth estimated that the total road sediment contribution was 268 T/yr and the forest road contribution was 677 T/yr, or approximately 15% of the 6,372 T/yr of the sediment annually produced in the basin. The literature review of unpaved roads yielded erosion rates that ranged from 11-180 Mg/km/yr.

2.2 Forest Roads

Forest roads are similar to rural unpaved roads in that they are unpaved and receive low-volume traffic. Historically, many more studies have been conducted on forest roads than rural unpaved roads. A greater literature base is available for forest roads than rural unpaved roads. Although there are differences between forest roads and unpaved rural roads, the erosion studies on forest roads are still useful since rigorous measurements from rural unpaved roads, especially in Oklahoma, are not readily available.

Erosion from forest roads has long been recognized as an important source of sediment; the earliest estimates were first reported by Gilbert in 1917 (Peranich, 2005). However, measured rates of erosion weren't reported until the 1950's. During the 1960's, long-term monitoring of watershed erosion began to be reported, but most studies did not isolate the different contributors of erosion to the watershed (Peranich, 2005). Researchers began to quantify the sediment contribution of forest roads and established that erosion from roads was much greater than for undisturbed slopes (Hoover, 1952; Megahan and Kidd, 1972; Dunne and Dietrich, 1982; Reid and Dunne, 1984).

Forest roads are now recognized as a major source of erosion from forested lands across the United States, historically accounting for as much as 90% of all sediment produced from forest land (Grace III, 2000). Roads accelerate erosion by increasing slope gradients and interrupting normal drainage patterns by concentrating overland flow into ditches and channels (Grace III, 2000). Erosion produced from forest roads eventually reaches stream systems and degrades the water quality. Sediment from forest roads can shorten the life of reservoirs, degrade water quality, and detrimentally affect aquatic systems.

In a review of twelve studies on forest road erosion in New Zealand, Fransen *et. al.* (2001) found annual sediment yields up to 15 kg/m^2. The studies included in the review varied for range of treatment and source types including graded, ungraded and graveled road surface ditch, cutbank, and sidecast. Erosion rates from individual road segments varied greatly, ranging from 38-380 T/km/yr for a 10 year old road section. For newly constructed roads, erosion rates ranged from 266-7600 T/km/yr. Annual road surface erosion rates reviewed by Fransen *et. al.* (2001) were generally within natural levels. Sediment from forest road surface erosion has only indicated a potential to cause significant adverse effects to the stream environment, though no studies have confirmed this. However, mass erosion related to forest roads is of a greater concern (Fransen *et al.* 2001). They concluded that road mass erosion rates are up to three orders of magnitude greater than surface erosion rates.

Luce and Black (1999) studied sediment production from 68 road segments in western Oregon over a four month period. Of the 68 segments, 60 segments produced 0-200 kg of sediment over the study period, while remaining segments produced as much as 1,800 kg. In general, most road segments produced little sediment, but a few produced large amounts. This shows that substantial amounts of sediment can be produced from relatively standard roads with little use and that it may be possible to substantially reduce erosion by targeting those few segments with the greatest sediment production (Luce and Black, 1999).

Reid and Dunne (1984) attempted to quantify erosion rates from road surfaces through monitoring ten forest road segments in western Washington. They measured rainfall, discharge, and sediment concentrations at culverts, which defined each segment. From 1977-1978, measured erosion rates ranged from 440 T/km/yr for heavy use forest roads to 0.43 T/km/yr for abandoned forest roads. Temporary and moderate use roads had sediment yields of 3.4 T/km/yr and 1.9 T/km/yr. They found that a heavily used road segment produced 130 times more sediment than an abandoned segment and that cut bank and ditch erosion was not a significant contributor of sediment (Reid and Dunne, 1984).

Several forest road erosion studies have been conducted in the Ouachita Mountains of Oklahoma and Arkansas. In Arkansas, Miller *et al.* (1985) found that over a one year period sediment was produced from four typical forest road segments at an average rate of 57 T/ha/yr. In this study, they found that fifty percent of the total sediment yield was produced from a single 100-year rain event. In Oklahoma, Vowell (1985) found erosion rates from four road segments on a recently established forest road to range from 42-470 T/ha, with an average yield of 224 T/ha. Turton and Vowell (2000) found an average erosion rate from a two year old forest road was 83 T/ha/yr for a three year period. Over an 18 month period, Busteed (2004) measured erosion from two segments of a 25 year old industrial forest road for 76 storms. Erosion rates of 7.6 T/ha/yr and 6.5 T/ha/yr were observed from the two segments. Busteed (2004) encountered below normal precipitation for the study period and no large or infrequent sized storms occurred. Therefore, the measurements were lower than what was expected for a typical year (Busteed, 2004). These studies demonstrate the high degree of variation that can exist for erosion rates from road segments within the same geographic region. These studies also illustrate the importance of storm size and precipitation on sediment production.

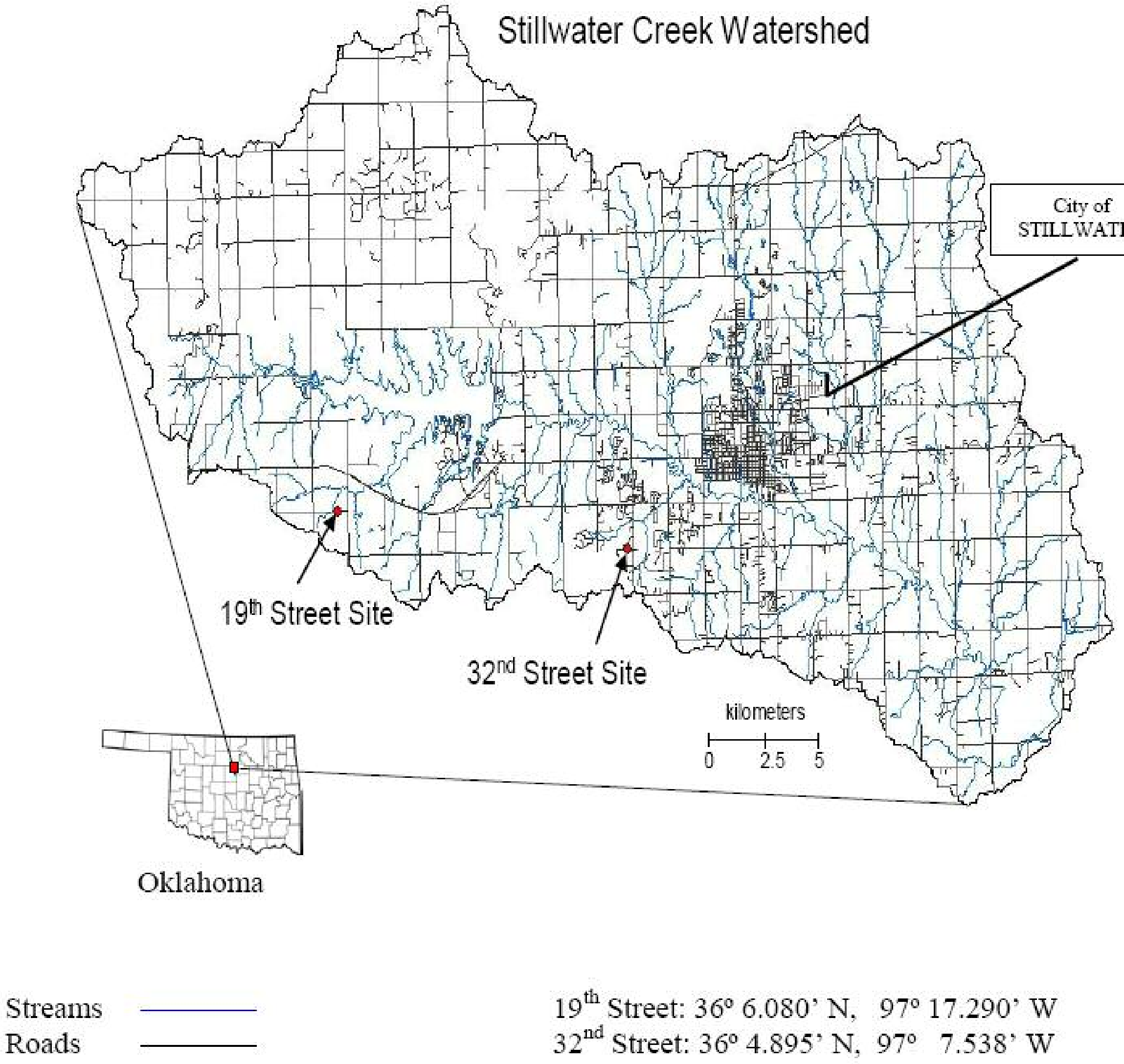
CHAPTER III

METHODS AND MATERIALS

3.1 Study Sites

Two road sites were chosen within the Stillwater Creek Watershed based on various road characteristics. Although two sites can never completely represent the variation among soils, topography, road conditions, and traffic patterns across an entire watershed, the two sites were characteristic of the condition of many rural unpaved roads within the watershed. The first site was located on 32nd St., approximately two miles west of Stillwater, Oklahoma (Figure 1). The second site was located on 19th St, approximately fifteen miles west of Stillwater, Oklahoma between Vassar and Perry Roads (Figure 1). The sites will be referred to as 32nd St. and 19th St.

Each site contained two road segments that drained from a common ridge or to a stream. Sediment collection stations collected water from one half of each road segment, which was defined by the crown in the road and bar ditches. Each segment was named based on the street number and compass quadrant in which it was located: 32 NE, 32 NW, 19 NE, and 19 NW. The two segments located on 32nd Street site drain towards a stream, one towards the east and the other towards the west. The road was constructed of native sandy loam material and overlaid with gravel. These two segments were chosen because of insufficient crowning and shallow ditches that were inadequate in providing proper drainage for the road bed, a common condition among unpaved rural roads. Direct observation suggested that the ditches do not sufficiently accommodate flows without eroding the ditch and road bed.



19th Street: 36° 6.080' N, 97° 17.290' W
32nd Street: 36° 4.895' N, 97° 7.538' W

Figure 1. Location of study sites within Stillwater Creek Watershed, Oklahoma (Peranich, 2005).

The 19th Street site consisted of two road segments that drained on either side of a common ridge; one segment drained east and the other west. The eastward segment drained into an ephemeral swale on the south side and a farm pond on the north side. The westward segment drained into a stream. The road was constructed of native sandy clay loam material over bedrock and had no gravel cover. This site was selected because like many non-graveled roads in the Stillwater Creek watershed, it lacked properly constructed bar ditches to accommodate road bed drainage, was poorly crowned and was susceptible to rutting when the surface was wet. The characteristics of each segment are summarized in Table 1.

Table 1. Road segment characteristics.

Segment	Length (m)	Area (ha)*	Average Slope (%)	Soil Texture**
19 NE	158	0.06	8.3	Clay Loam
19 NW	203	0.07	7.8	Sandy Clay Loam
32 NE Pre	215	0.19	6.5	Loamy Sand
32 NE Post	215	0.19	6.8	Loamy Sand
32 NW	264	0.11	6.7	Sandy Loam

* Area of road bed, ditch and cutbank only.

** Texture determined from samples of road bed (Peranich, 2005).

3.2 Erosion Control Treatments

One segment at each road site was improved with erosion control treatments, which will be referred to as Best Management Practices (BMP). The treatments were applied to 32nd NE and 19th NW. The two untreated segments (32nd NW and 19th NE) were used as controls to demonstrate the effectiveness of the treatments at reducing sediment yield. The Local Technical Assistance Program (LTAP) at Okalahoma State University recommended the treatments and aided in the installation. LTAP serves counties and municipalities in Okalahoma by providing training and technical assistance for road and bridge construction, repair, and maintenance as well as other transportation related issues.

The treatments installed at the 19th NW segment included proper crowning of the road bed and raising the road bed above the bar ditches to provide drainage, re-shaping steep cut banks, and installing geosynthetic fabric. Approximately 700 feet of non-woven geosynthetic fabric was laid on 19th NW segment. The geosynthetic fabric was designed to act as a separator between poor soil base materials and the aggregate surface. The fabric was overlaid with crusher-run limestone containing approximately 20% fines and then graded to a uniform depth of approximately four inches.

Bermuda grass was seeded and approximately 34,000 ft^2 of American Green S150® Double Net Straw Blanket was laid on 32nd NE segment. The S150® Double Net Straw Blanket was designed to provide erosion control and assist with vegetation establishment for up to twelve months on 2:1 to 3:1 slopes and in moderate flow drainage channels. In addition to this, treatments also included proper crowning of the road, raising the road bed above the bar ditches, and re-shaping cut banks. In order to widen and re-shape the cut bank, trees were removed on the south side of the segment. No geosynthetic fabric was installed at this location.

3.3 Sediment Collection Methodology

Sediment collection stations were installed on each segment. Each station consisted of a sediment collection trough, an approach box, and a 0.46 m H-Flume (Figure 2). Stations were also equipped with automatic pumping samplers that collected samples of water and sediment not trapped in the trough. The H-Flumes allowed for discharge measurements during storm events. The sediment collection stations were connected to bar ditches and located at the end of each road segment near natural outlets where the water would have entered a stream or other body of water. Some modifications in location had to be made depending on the gradient of the road and surrounding area. Each sediment collection station trapped sediment from approximately one-half of the road prism: an area that included the road surface from the crown to the bar ditch where the collector was connected, the bar ditch, and the associated cut slope (Figure 3).

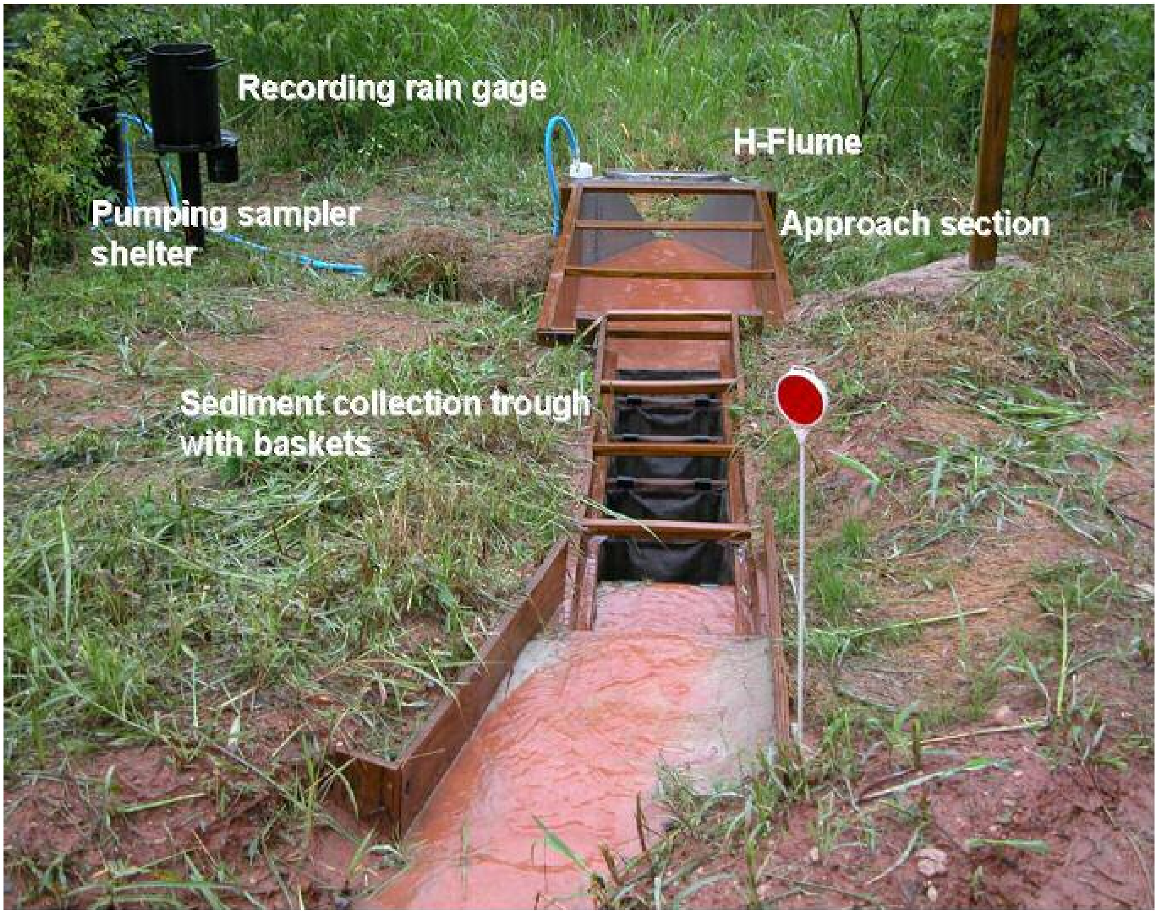


Figure 2. Components of the sediment collection stations used to measure erosion from each road segment.

Figure 3. View of westward draining road segment (32 NE) at the 32nd St. site with drainage boundaries drawn in.

The troughs were constructed of treated plywood and were approximately 2.4 m long, 0.6 m deep and 0.4 m wide. A series of seven plastic baskets were installed in the troughs. These baskets were lined with landscape fabric that helped to trap course sediment. When one basket filled, flow moved over its top to the next basket and passed through the approach box and H-Flume. Water stage within the flumes was measured by pressure transducers (KWK Technologies Inc. SPXD-600/610, 5 KPa) installed in the stilling wells on the H-Flumes. Excitation and measurements were distributed, controlled, and collected by data loggers (Campbell Scientific CR510). Samples of water and sediment not trapped in the troughs were collected by automatic pump samplers (ISCO 3700C). The sampler intakes were located in the wall of the flume near the flume outlet where velocity and hence mixing was the greatest. Sampling was controlled by data loggers that triggered the pumping samplers, based on certain criteria. No sample was taken if the stage was below the sample intake (about 21 mm). If the stage rose above the minimum, a sample was collected. If the stage remained above the minimum, samples were collected with further changes in the stage or at predetermined intervals of time (if stage remained constant). This allowed samples to be taken throughout a storm while preserving bottles. However, bottles often had to be changed during long duration storm events. The automatic pump samplers had a capacity of twenty-four 500 ml bottles. Thus, twenty-four discrete water samples could be collected during each storm event.

A siphoning tipping bucket rain gage was installed at each road site. Data from the gages were collected by a data logger. A non-recording plastic rain gage was also installed at each site as a secondary measurement of rainfall. Data loggers were programmed to measure stage and precipitation every five minutes.

3.4 Sediment Load Calculation Methodology

After each storm, the sediment in each collection basket was weighed in the field using a hanging balance. Sub-samples were taken from each basket; they were weighed in the laboratory, oven dried at 105° C for seventy hours, then re-weighed. The moisture content of each sub-sample was then calculated using the following equation:

$$\% \text{ Moisture} = [(\text{Wet Weight} - \text{Dry Weight})/\text{Dry Weight}] * 100$$

The total weight of the sediment in each basket weighed was corrected for moisture by multiplying by (1-% moisture) and reported as dry weight. The weights of the sediment in the baskets were then summed to obtain an estimate of the total weight of sediment collected in the baskets.

Water samples collected from the automatic pump samplers were returned to the laboratory. The weight of sediment-water mixture in the sample was measured using a top-loading balance and the weight of the sediment in each sample was obtained by evaporation (Guy, 1969). Sediment concentration in parts per million (ppm) was calculated by dividing the dry weight of the sediment by the weight of the water-sediment mixture and then multiplying by 1,000,000. At concentrations less than 16,000 ppm, ppm is equivalent to mg/l. When concentrations exceed 16,000 ppm, it becomes necessary to apply a correction factor to account for the volume that sediment occupies in the sample in order to convert ppm to mg/l. The value of C is based upon the initial sediment concentration (Guy, 1969). The C values ranged from 0 to 0.12.

During each storm, stage measurements were recorded in five minute intervals. Stage was then converted to discharge for each five minute interval using standard rating tables for 0.46m H-Flumes. The total flow was calculated by converting the stage reading for each five minute (300 s) interval to discharge and multiplying by 300 seconds. The flow for each five-minute interval was then summed to obtain total flow for a storm. The sediment concentration for the interval was then multiplied by discharge volume to obtain the total suspended sediment load for the interval. The suspended sediment loads for each interval were then summed to obtain the total suspended sediment load for the storm. The total weight of the sediment collected from the baskets plus the suspended load represented the total load for respective storm events.

3.5 Precipitation Analysis Methodology

Precipitation data from individual storms were regressed against sediment production for six storm variables: total precipitation, maximum five-minute precipitation intensity, maximum 30-minute precipitation intensity (I^{30}), average precipitation intensity, rainfall erosion index (R), and total flow. Total precipitation, maximum five-minute precipitation intensity, I^{30}, and average precipitation intensity were calculated directly from storm data obtained from the data loggers. The rainfall erosion index (R) is defined as the sum of the products of the total storm energy (E) times the I^{30} divided by 100. The total storm energy (E) is defined by the following equation: $E= eP$, where $e= 916+\log_{10}i$ when $i < 3$in/hr or $e= 1074$ when $i > 3$in/hr, and P is the amount of precipitation for each increment and i is the average rainfall intensity for the storm increment (as presented in Haan *et al.* 1994). E was calculated for each 5 minute increment of rainfall.

3.6 Comparison of Results

Observed values were compared between the pre and post BMP periods by using linear regression. The coefficient of determination for the regression, R^2, indicated the variance around the best-fit line and measured how well the regression model described these data. Values range from 0 to 1; values near 1 indicated that the equation was a good description of the relation between the independent and dependent variables. Accumulated sediment was also compared using linear regression. A *t* test was used to compare the slopes of the two regression lines and determine if there was a significant reduction in erosion between the treated and un-treated sites.

CHAPTER IV

RESULTS

4.1 Precipitation

The collection stations were installed in May 2004. For the period from June 2, 2004 through May 31, 2006, data from 63 storms were collected and analyzed for 19th Street site and 64 storms were analyzed for the 32nd Street site. At the 19th site, 41 of the 63 storms occurred before the installation of erosion control treatments. At the 32nd site, 40 of the 64 storms occurred before the installation of erosion control treatments. Rainfall during the study period totaled 1422 mm at the 19th Street rain gage and 1816 mm at the 32nd Street rain gage. The normal rainfall total during this period in Payne County was 1890 mm. Total precipitation over the study period was 468 mm below normal at the 19th Street rain gage, and 74 mm below normal at the 32nd Street rain gage (Table 2). June 2004 was much wetter than normal at the 32nd Street site. August 2005 was also much wetter than normal at both sites, while April 2005 was much drier than normal (Appendix A). The total precipitation from individual storms ranged from 3 mm to 116 mm. Maximum five-minute storm intensities ranged from 3 mm hr^{-1} to 162 mm hr^{-1}. A summary of rainfall characteristics by storm for each segment is provided in Appendix A.

Table 2. Summary of precipitation (mm) for 19th and 32nd St.

	1st year*	2nd year*	Total
Normal Precipitation (mm)	945	945	1890
19th St. Observed (mm)	722	700	1422
Departure from Normal+	-223	-245	-468
32nd St. Observed (mm)	908	908	1816
Departure from Normal+	-37	-37	-74

*Based on period June 2004-May 2005 and June 2005-May 2006

+The Oklahoma Climatological Survery, data for Payne County from 1971-2000

4.2 Runoff and Sediment Yield

The total runoff for individual storms from 19th NE and 32nd NW segments ranged from 0 m^3 to 133 m^3. The total pre-BMP runoff for 19th NW and 32nd NE ranged from 0 kg m^3 to 72 m^3. The post BMP runoff ranged from 0 m^3 to 138 m^3.

The total sediment yield for individual storms for the two segments that did not receive erosion control practices (19th NE and 32nd NW) ranged from 0 kg to 5,700 kg. The total pre-BMP sediment yield for 19th NW and 32nd NE ranged from 0 kg to 4,300 kg; the total post sediment yield ranged from 0 kg to 2,720 kg. Sediment production per unit area for 19th NE and 32nd NW ranged from 0 kg ha^{-1} to 52,200 kg ha^{-1}. Pre-BMP sediment production for 19th NW and 32nd NE ranged from 0 kg ha^{-1} to 57,700 kg ha^{-1}; post BMP production ranged from 0 kg ha^{-1} to 36,500 kg ha^{-1}. The cumulative total sediment yields from the segments through the study period are located in Table 3. Cumulative total sediment yield and yield per unit area for the pre and post BMP periods are located in Table 4. The overall sediment yield per unit area across all four segments was 269,000 kg ha^{-1} (Table 3). Total sediment yields and yields per unit area for individual storms for each segment are summarized in Appendix A.

Table 3. Summary of cumulative total sediment yield and cumulative yield per unit area for each segment for the period June 2, 2004 through May 31, 2006.

Segment	Cumulative Erosion (kg)	Erosion Per Unit Area (kg ha^{-1})
19 NE	12,100	219,000
19 NW	31,600	427,000
32 NE	18,600	96,900
32 NW	36,100	331,000
All Sites	98,400	269,000

Table 4. Summary of cumulative total sediment yield and cumulative yield per unit area pre- and post installation of erosion control practices.

Pre-BMP	Cumulative Erosion (kg)	Erosion Per Unit Area (kg ha^{-1})
19 NW	22,800	308,000
32 NE	12,900	67,200
Post BMP		
19 NW	8,800	119,000
32 NE	5,670	29,700

4.3 Analysis of Precipitation and Hydrologic Variables

Total precipitation, maximum 5-minute intensity, maximum 30-minute intensity (I_{30}), mean intensity and rainfall erosion index value (R-factor), and total flow were calculated for each storm. Maximum 30-minute intensity and R-factor were compared to the total sediment production from each segment using linear regression. At all sites, each variable was also compared to the pre- and post BMP sediment production using linear regression. The Coefficient of Determinations (R^2) of the regressions and observed significance levels for individual segments are presented in Table 5. Scatter plots for the regression of rainfall variables against sediment yield for both sites are provided in Figures 4 and 5. The variable that best explained erosion was the R-factor.

Table 5. Summary of linear regression equations (x=hydrologic variable, y=sediment yield), R^2 values, and observed significance levels for precipitation and hydrologic variables against sediment yield.

Site	Pre	I_{30} (mm h^{-1})	R-factor (MJ-mm/ha-hr-storm)
19 NE	equation	y=19.56x-58.12	y=2.29x+32.88
	R^2	0.44	0.52
	Significance[1]	<0.05	<0.05
19 NW	equation	y=70.31x-241.98	y=8.32x+80.31
	R^2	0.60	0.73
	Significance	<0.05	<0.05
32 NE	equation	y=29.66x-213.35	y=3.91x-99.49
	R^2	0.43	0.60
	Significance	<0.05	<0.05
32 NW	equation	y=21.21x-142.25	y=2.64x-48.42
	R^2	0.51	0.63
	Significance	<0.05	<0.05
Site	**Post**	**I_{30} (mm h^{-1})**	**R-factor (MJ-mm/ha-hr-storm)**
19 NE	equation	y=11.43x+8.88	y=0.61x+158.36
	R^2	0.43	0.65
	Significance	<0.05	<0.05
19 NW	equation	y=22.98x-19.51	y=0.87x+329.10
	R^2	0.28	0.20
	Significance	<0.05	<0.05
32 NE	equation	y=11.00x-124.73	y=0.49x+52.38
	R^2	0.48	0.47
	Significance	<0.05	<0.05
32 NW	equation	y=53.68x-725.06	y=2.41x+139.27
	R^2	0.75	0.74
	Significance	<0.05	<0.05

[1] Based on F-test of ANOVA for each regression

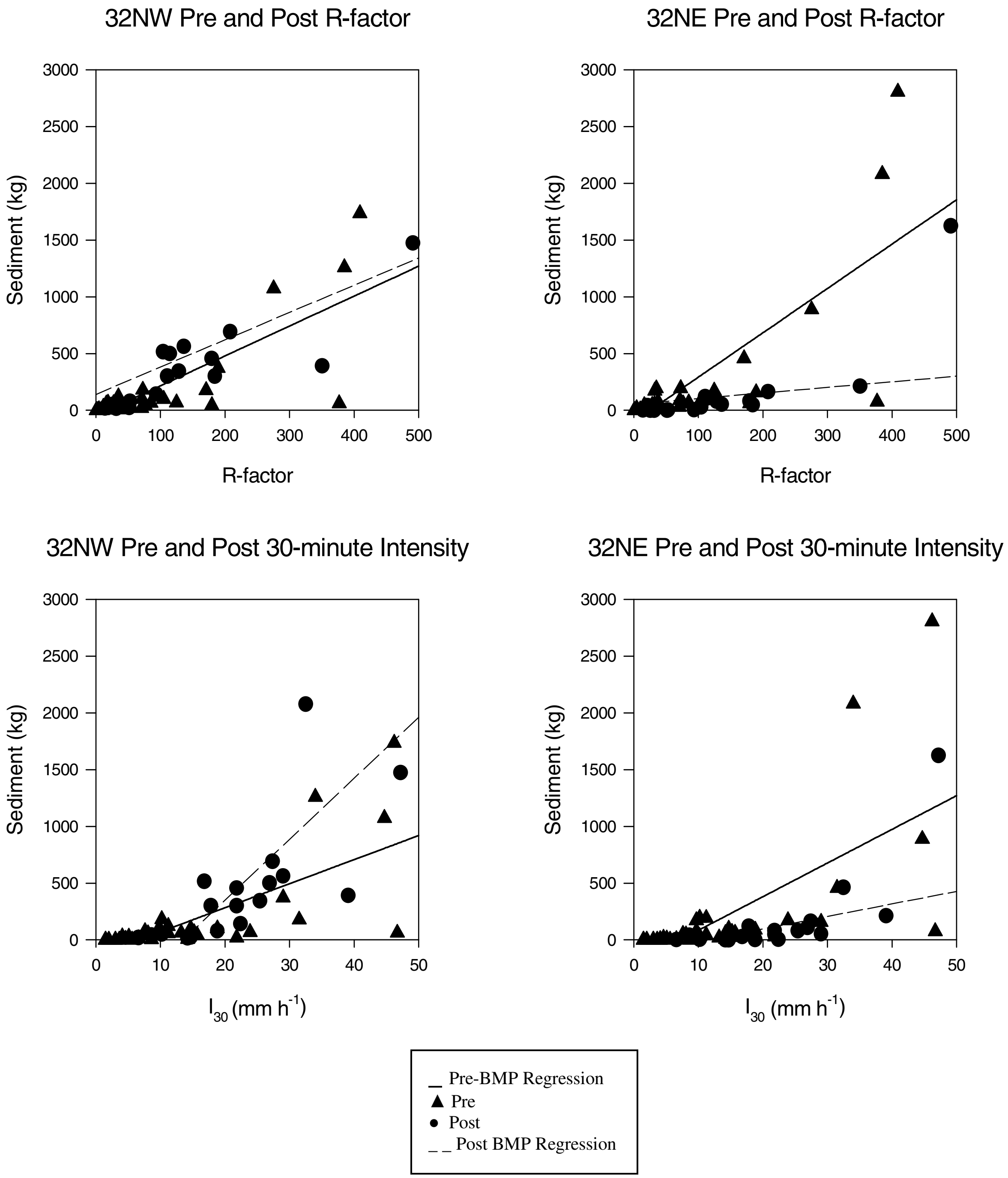


Figure 4. Scatter plots and the linear regression of precipitation and hydrologic variables against sediment yield for 32nd Street.

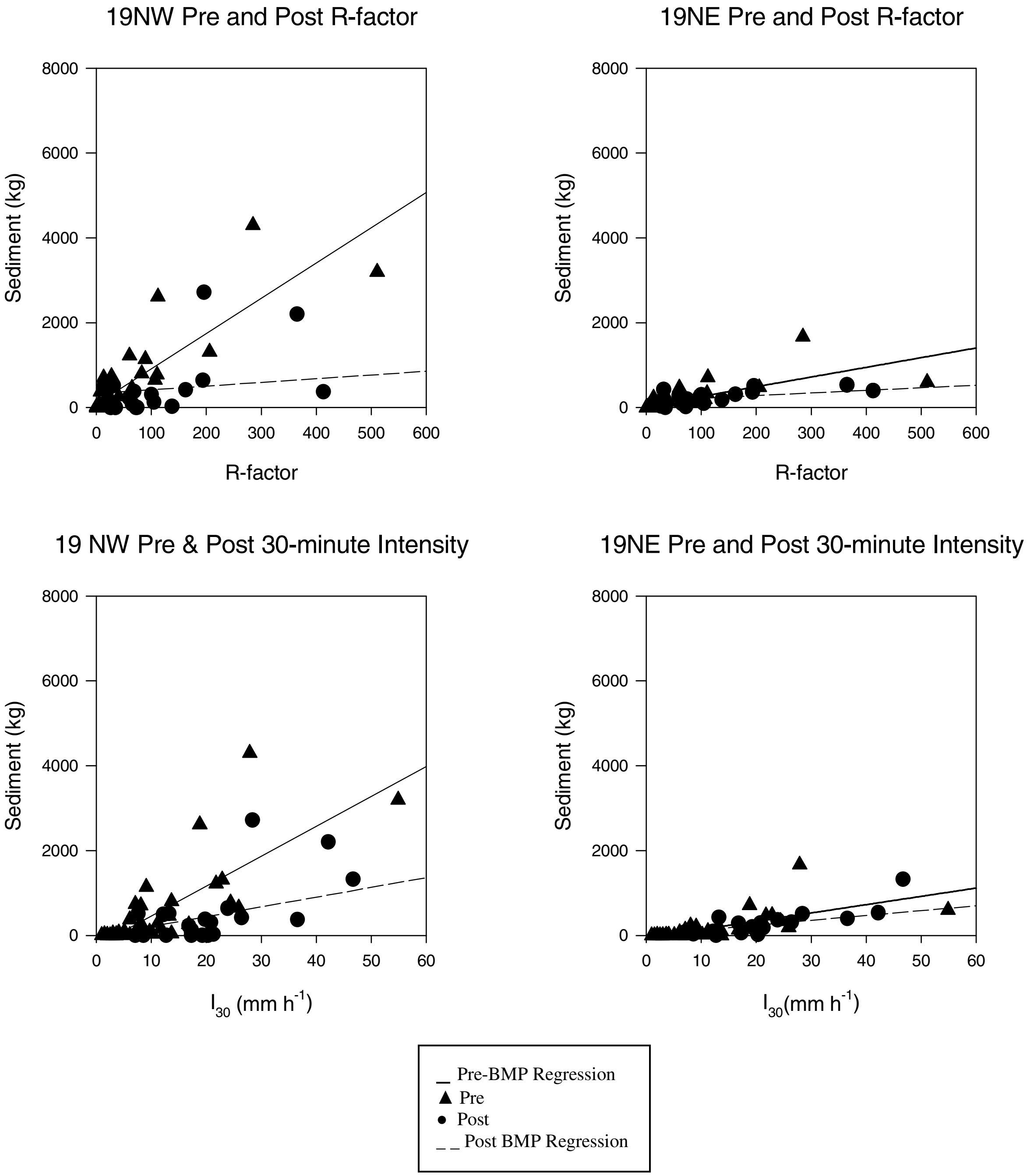


Figure 5. Scatter plots for the regression of precipitation and hydrologic variables against sediment yield for 19th Street.

4.4 Accumulated Sediment

Accumulated sediment was determined for each site within the pre and post BMP periods. The treated sites were compared to the control sites using linear regression (Figure 6). A *t* test employing pooled variance was used to compare the slopes of the two regression lines for pre and post accumulated sediment and R-factor. The R^2 values and equations for accumulated sediment are shown in Table 6. The significance levels for pre and post R-factor and accumulated sediment are shown in Tables 7 and 8.

Table 6. R^2 values and equations for the linear regressions of accumulated sediment.

Site	Pre-equation	Pre-R^2	Post-equation	Post R^2
19th	y=3.68x-2027	0.98	y=1.43x+3406.02	0.95
32nd	y=1.38x-74.06	0.96	y=0.25x+493.29	0.90

Table 7. Pre and post R-factor *t* test results for significant differences between slopes.

Site	Resulting *t* value	*df*	Critical *t* value	P	Significance
19NE (Control)	4.71	59	1.6706	0.05	Significant
19NW (BMP)	7.54	59	1.6706	0.05	Significant
32NE (BMP)	13.27	60	1.6706	0.05	Significant
32NW (Control)	0.51	60	1.6706	0.05	Not Significant

Table 8. Accumulated sediment *t* test results utilizing pooled variance to determine significant differences between the slopes of pre and post BMP.

Site	Resulting *t* value	*df*	Critical *t* value	P	Significance
19th	46.81	59	1.6706	0.05	Significant
32nd	82.65	60	1.6706	0.05	Significant

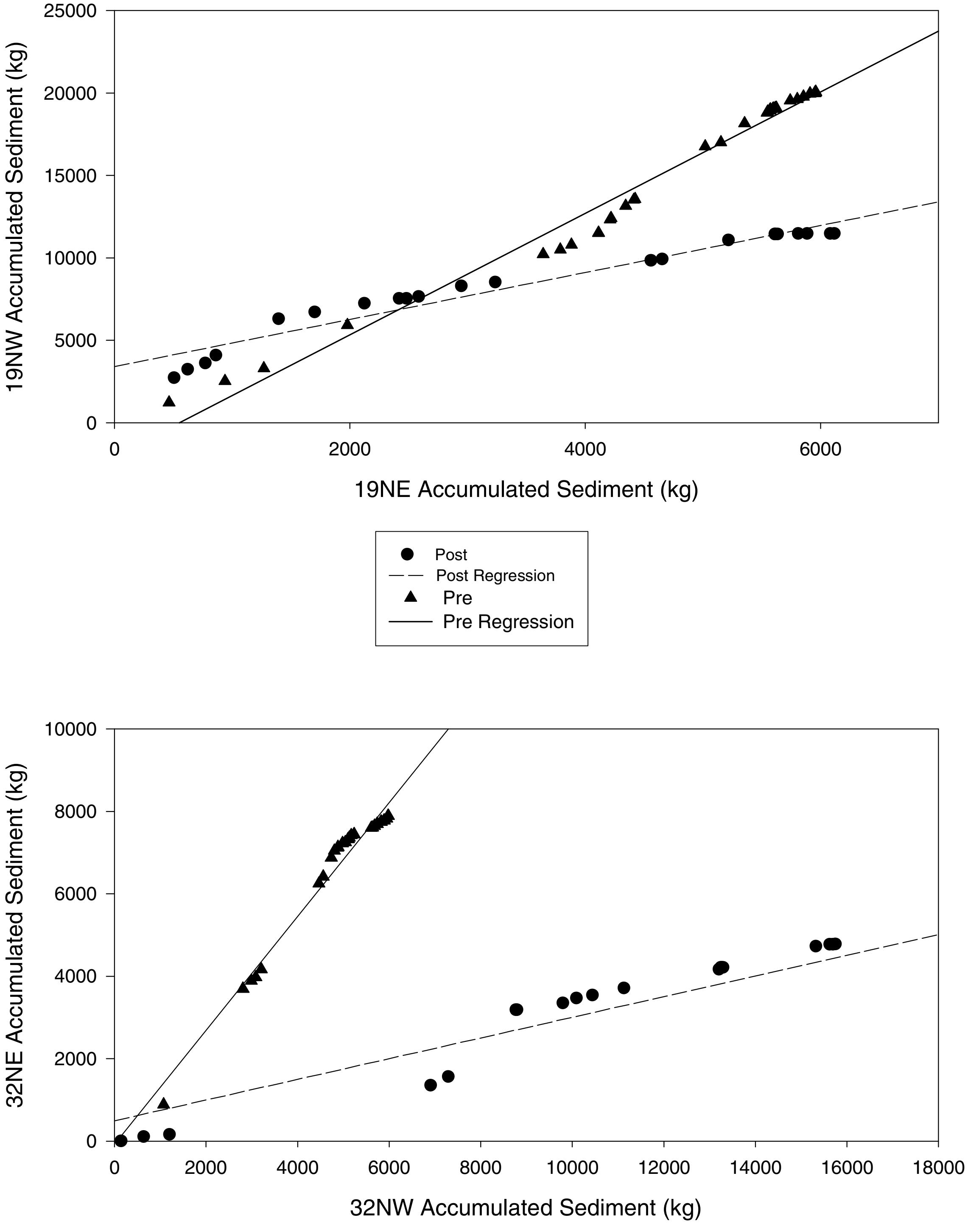


Figure 6. Scatter plots and linear regressions of 19th and 32nd St. pre and post BMP accumulated sediment.

CHAPTER V

DISCUSSION

5.1 Precipitation and Hydrologic Variables

The precipitation over the study period for 32nd Street was much closer to the long-term average of 1890mm for Payne County than 19th Street (Table 2). The majority of the storms were high intensity, short-duration storms that are typical of the spring and summer season in central Oklahoma. The largest storm occurred on August 22, 2005, which lasted for 14 hours on 19th Street and produced 116 mm of precipitation. It lasted for 13 hours on 32nd Street and produced 89 mm of precipitation. The overall precipitation over the study period was close to normal for 32nd Street (-4%) and dry for 19th Street (-25%).

It is not surprising that the R-factor was the rainfall variable that best explained erosion (Table 5, Figures 4 & 5). The relationship between R-factor and sediment indicated a difference between the pre and post periods. The *t* test results for pre and post R-factor showed a decrease ($P<0.05$) on all sites except 32NW (Table 7). After the implementation of erosion control practices, this decrease was expected on the treated sites.

Table 9. Annual R-factors and % deviations from the long-term average for Stillwater Creek watershed.

Year	19th St. R and % Departure (MJ mm $ha^{-1}hr^{-1}$)*	32nd St. R and % Departure (MJ mm $ha^{-1}hr^{-1}$)	Mean Annual Stillwater Creek (MJ mm $ha^{-1}hr^{-1}$)
1	2210 (-48%)	4250 (-1%)	4255
2	4660 (+9%)	8940 (+110 %)	4255

The annual R-factors for 19th Street were 48% below and 12% above the annual mean for the first and second years of the study (Table 9). The annual R-factors for 32nd Street were 1% below and 110% above the annual mean for the first and second years of the study (Appendix C). Although precipitation was below normal during both years of the study, rainfall energy (R-factor) was above normal after the installation of BMPs. Thus illustrating that despite the increased erosion potential generated by storms within the second year, the BMPs resulted in a decrease of sediment yield per unit of rainfall energy (Figures 4 & 5).

The short-duration, intense storms typical of Oklahoma, deliver high kinetic energy to road surfaces. This detaches soil particles and readily exceeds the low infiltration capacities of road surfaces and produces large amounts of runoff quickly. Thus, these storms generated large amounts of sediment in a short time. Long duration, low intensity storms generated runoff at lower rates. Sediment concentrations were generally lower in low intensity storms.

5.2 Runoff and Sediment Yield

The wide range of variability in runoff and sediment yield generated by individual storms may also be attributed to many non-hydrologic variables, such as traffic and maintenance operations, and how these activities affect the erodibility of the road surface. Through field observations, road maintenance, more specifically grading operations, appeared to have an impact on the amount of erosion produced. Early in the study period, the roads were graded frequently and erosion appeared to be generally higher for storms of similar durations and intensities than later in the study when the amount of grading decreased. Generally, more loose material was available in the ditches and road edges for transport immediately after grading. Depending on the storm characteristics, this loose material was usually transported within two or three storms following grading, and then the road surface appeared to return to a more stable condition (Peranich, 2005).

After the installation of BMPs, field observations between the treated and control sites suggested that there was a significant decrease in erosion on the treated sites. The erosion control practices on 19NW appeared to decrease the amount of rutting that occurred and reduce the need for road grading. The erosion control practices on 32NE provided substantial Bermuda grass cover adjacent to the road segment. Accumulated sediment was less during the post BMP period than the pre BMP period, despite higher rainfall energy.

The cumulative erosion per unit area from all segments was 269,000 kg ha^{-1}; the average erosion was 56 Mg/km/yr. Peranich (2005) estimated annual erosion rates of 152

Mg/km/yr on the same four unpaved road segments within the Stillwater Creek Watershed. Fransen *et al*. (2000) measured erosion rates of 30-380 Mg/km/yr from established roads and rates as high as 266-7,600 Mg/km/yr from newly constructed roads at various locations across New Zealand. Ried and Dunne (1984) reported erosion rates as high as 440 Mg/km/yr on heavily used forest roads in western Washington. In the Ouachita Mountains of southeastern Oklahoma and central Arkansas, erosion rates on forest roads have been reported to range from 3-114 Mg/km/yr (Busteed, 2004; Turton and Vowell, 2000; Vowell, 1985; Miller *et al*., 1985). The average annual erosion of 56 Mg/km/yr appeared to be reasonable when compared to other published rates.

5.3 BMP Effectiveness

The relationship between accumulated sediment during the pre and post BMP period was used to determine the effectiveness of BMPs by using a double mass analysis procedure. Accumulated sediment was determined for each site within the pre and post BMP periods. The treated sites were compared to the control sites using linear regression (Figure 6). The R^2 values and equations for accumulated sediment are shown in Table 6. The accumulated sediment equations were utilized to predict the amount of erosion that could have occurred if BMPs were not implemented. A *t*-test utilizing pooled variance was used to test for significant differences between the slopes of accumulated sediment during the pre and post periods (Haan, 1979). The predicted pre-BMP accumulated sediment for 19th Street was 42,400 kg. The predicted accumulated sediment after the installation of BMPs was 20,700 kg. The implementation of these practices resulted in a 51 percent reduction in erosion (Figure 7). The predicted pre BMP accumulated sediment for 32nd Street was 42,600 kg. The predicted post-BMP accumulated sediment was 8,230 kg. The installation of BMPs resulted in an 80 percent reduction in erosion at the 32nd Street site (Figure 7). This analysis determined that the BMPs were effective in reducing the amount of sediment produced on the treated sites.

5.4 Significance of Erosion at the Watershed Scale

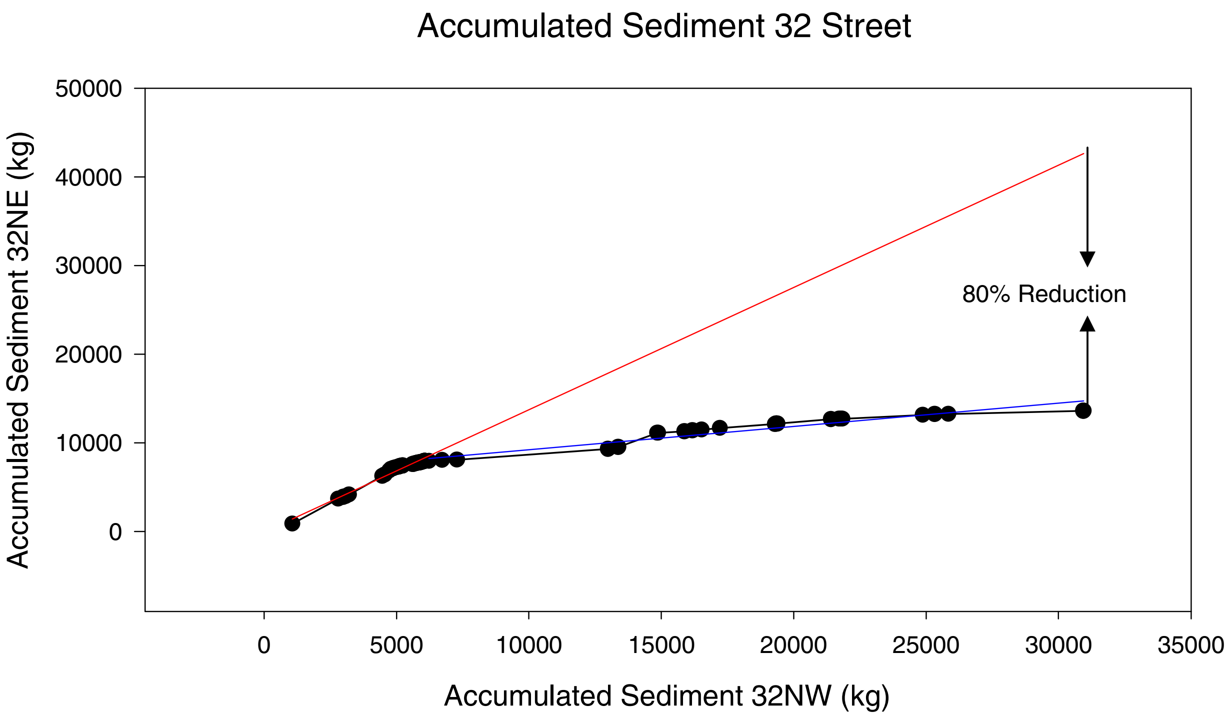
Assuming that all the 479 km of rural unpaved roads in the Stillwater Creek watershed eroded at the same rate as the study segments before the installation of BMPs, the total estimated quantity of sediment eroded from unpaved roads is 32,100 Mg/yr. Using a modeling approach, Storm *et al.* (2003) predicted annual erosion rates from roads in the Stillwater Creek watershed to be 12,700 Mg/yr, or approximately 10 percent of the predicted 118,000 Mg annual sediment load in the watershed. The estimated annual sediment load from my study of 32,100 Mg/yr would account for 23 percent of the annual watershed sediment budget predicted by Storm *et al.* (2003). Storm *et al.* (2003) noted that their prediction my underestimate the annual sediment load that roads contribute to the watershed.

Peranich (2005) estimated an annual load of 72,800 Mg/yr that would account for 62 percent of the annual watershed sediment budget predicted by Storm *et al.* (2003). However, the estimated loads from Peranich (2005) may be high because the sampling period was only five months and collected data from only 26 storms. The sampling period during my study lasted two years and collected data from 63 storms on 19th Street and 64 storms on 32nd Street.

If similar erosion control practices were implemented on all the 479 km of unpaved roads in the Stillwater Creek watershed, assuming they eroded at the same rate as the post BMP study segments, then the total estimated quantity eroded from rural unpaved roads would be 10,900 Mg/yr. This would account for 18 percent of the annual watershed budget predicted by Storm *et al.* (2003).

An inventory that used a GPS to locate roads, ditches, and stream crossings in the Lake Carl Blackwell sub-watershed revealed that 80 percent of the total unpaved road distance drains directly into streams (Neal *et al.* 2000, unpublished data). Assuming 80 percent of the roads drain directly into streams, the estimated annual sediment load from roads delivered to streams is 25,700 Mg/yr, or 22 percent of the annual predicted watershed sediment budget from Storm *et al.* (2003). Roads only cover 1.3 percent of the Stillwater Creek watershed. This observation agrees with studies that have shown while roads only occupy a small percent of a watershed (2-8%), they can account for 25-73 percent of a watershed's annual sediment budget (Peranich, 2005; Nagle, 2001; Dunne and Dietrich, 1982; and Dunne, 1979).

These studies illustrate the importance of unpaved roads as sources of sediment to water bodies despite the small percentage of area they occupy as compared to the area of the watershed in which they cover. The relative small percentage of area cover of rural unpaved roads within a watershed allows for a more viable solution of targeting and reducing non-point source pollution like sediment.



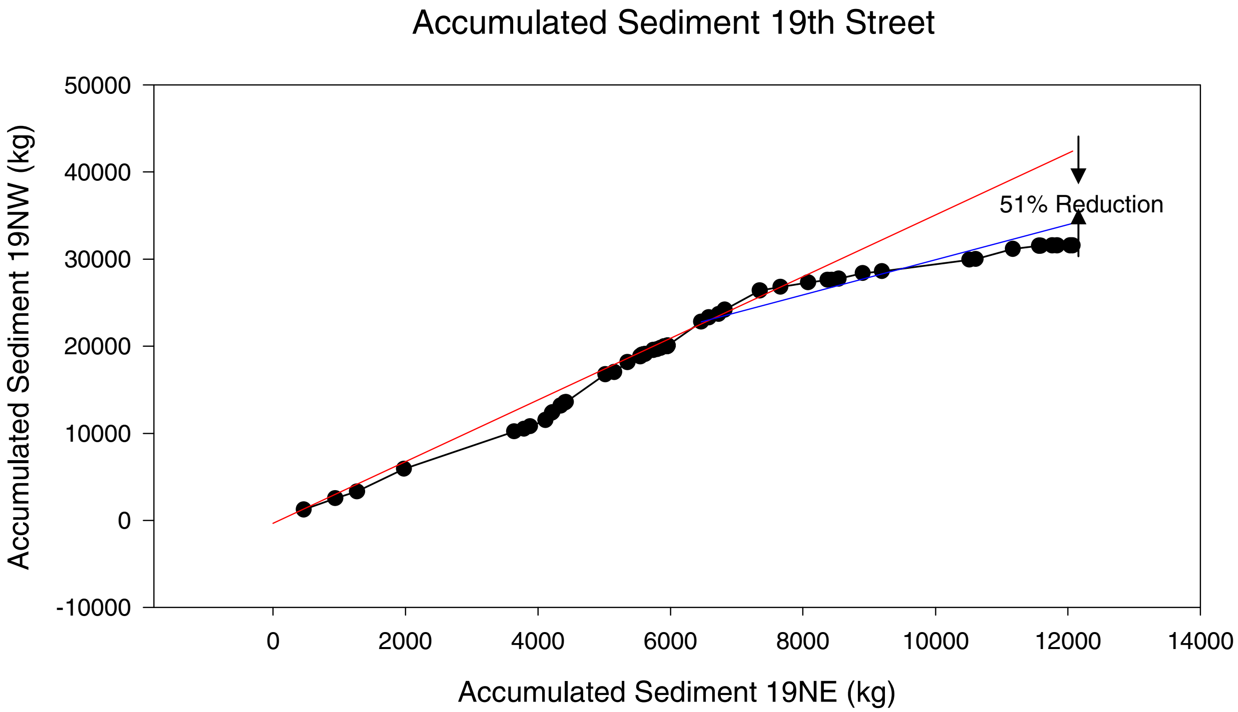


Figure 7. Erosion reduction between pre and post periods.

CHAPTER VI

SUMMARY AND CONCLUSIONS

6.1 Study Sites

Four rural unpaved road segments at two sites (19th and 32nd Street) in the Stillwater Creek, Oklahoma watershed were selected for erosion measurements. Erosion control practices were implemented on two of the four road segments. The practices on 19th NW included proper crowning of the road and raising the road bed above the bar ditches to provide proper drainage, re-shaping cut banks, and utilizing geosynthetic fabric. The practices utilized on 32NE included proper crowing of the road and raising the road bed above the bar ditches, re-shaping cut banks, and seeding Bermuda grass to establish cover along the road. The four road segments ranged from 158-264 m in length and drained directly into streams. Sediment traps were connected to each bar ditch and consisted of a settling trough, a H-flume to measure discharge and a pumping sampler. A data logger controlled data retrieval and storage. Each sediment trap collected erosion from one half of the road area and the associated bar ditch and cut slope. Data from 63 storms on 19th Street and 64 storms on 32nd Street were collected during June 2, 2004 to May 31, 2006.

6.2 Precipitation and Sediment Yield

Total precipitation during the first year of the study period was approximately 24 percent below normal at 19th Street and 4 percent below normal at 32nd Street. During the second year of the study period, total precipitation was approximately 26 percent below normal on 19th Street and 4 percent below normal on 32nd Street. Total precipitation from individual storms ranged from 3 mm to 116 mm. Maximum five-minute storm intensities ranged from 3 mm hr^{-1} to 162 mm hr^{-1}.

The sediment yield for individual storms ranged from 0 kg to 5,700 kg. The cumulative erosion from the segments through the study period was 12,100 kg for 19NE, 31,600 kg for 19NW, 18,600 kg for 32NE, and 36,100 kg for 32NW. The cumulative erosion per unit area over the entire study for each site was 219,000 kg/ha for 19NE, 427,000 kg/ha for 19NW, 96,900 kg/ha for 32NE, and 331,000 kg/ha for 32NW, with overall erosion per unit area across all four segments 269,200 kg/ha. The average erosion across all four segments was 56 Mg/km/yr. The observed sediment yields (Mg/km/yr) were within the ranges reported in the literature (11-180 Mg/km/yr). The observed erosion rates were considered reasonable.

R-factor was the rainfall variable that best explained erosion. Sediment yield per unit of rainfall energy (R-factor) decreased on the treated sites ($P<0.05$), even though R-factor was higher during the post BMP period. The short-duration, intense storms typical of Oklahoma, deliver high amounts of kinetic energy to road surfaces; thus, detaching soil particles and readily exceeding the low infiltration capacities of road surfaces and quickly producing large amounts of runoff. Consequently, generating large sediment yields in a short time. Long duration, low intensity storms generated runoff more slowly and at lower rates.

6.3 BMP Effectiveness

Accumulated sediment was determined for each site within the pre and post BMP periods. The treated sites were compared to the control sites using linear regression. A *t* test was utilized to determine if erosion was significantly reduced between the pre and post BMP periods. There was a significant difference (P=0.05) between the pre and post BMP periods at both 19th and 32nd Street. Thus illustrating that the installation of erosion control practices was effective in reducing erosion. The implementation of these practices resulted in a 51 percent reduction in erosion at 19th Street and an 80 percent reduction in erosion at 32nd Street. Despite the relatively small surface area that roads occupy in the Stillwater Creek watershed, the contribution of roads to the overall sediment budget may be significant.

6.4 Recommendations

The major goal of this study was to determine the effectiveness of BMPs at reducing erosion from rural unpaved roads. The study showed that the BMPs were effective and there was a significant decrease in sediment yield between the pre and post BMP periods. The BMPs reduced the need for grading which disturbs the road surface and can increase erosion. Researchers, managers, and others should understand that unpaved rural roads are significant contributors of sediment to water bodies. For example if a water body is listed on the 303(d) list as being impaired by sediment, managers may have to calculate the maximum amount of a pollutant that a water body can receive and still meet water quality standards; this process is known as calculating total maximum daily loads (TMDLs). The relatively small percentage of area cover of rural unpaved roads within a watershed allows managers to easily target and reduce sediment.

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APPENDIX A

PRECIPITATION VARIABLE ANALYSIS

Table A-1. 19NE Precipitation Variable Analysis.

	Precipitation Variables							
	Precipitation		Precip Intensity (mm/hr)			% Time		
Date	Total	Duration	Max	Max	Ave	to Peak	R-Factor	Flow
	(mm)	(h)	5-min	30-min		Intensity	(units)*	(L)
06/02/04	11.18	0.58	48.77	21.84	19.16	28.57	60.43	5565.14
06/09/04	43.94	18.75	30.48	22.86	2.34	2.22	205.85	13616.80
06/19/04	20.32	2.83	73.15	24.38	7.17	14.71	110.56	6056.16
06/20/04	26.16	2.83	57.91	18.80	9.23	5.88	112.06	11433.56
06/21/04	45.21	9.50	67.06	27.94	4.76	15.79	284.91	45293.32
06/22/04	14.99	4.92	9.14	8.13	3.05	54.24	22.75	10145.70
07/02/04	8.64	3.33	30.48	11.18	2.59	57.50	20.91	1373.66
07/06/04	8.89	3.17	18.29	8.13	2.81	2.63	13.49	3854.23
07/24/04	11.18	9.42	18.29	7.11	1.19	83.19	14.95	646.48
07/28/04	29.72	14.25	33.53	13.72	2.09	32.75	82.38	7188.55
07/29/04	5.33	5.00	9.14	5.08	1.07	48.33	4.73	1473.90
08/11/04	21.59	15.08	12.19	7.11	1.43	39.78	27.75	4257.74
08/12/04	5.84	3.75	15.24	6.10	1.56	95.56	7.34	1507.03
09/05/04	5.59	0.58	24.38	10.16	9.58	85.71	12.38	696.60
09/16/04	36.58	4.92	88.39	54.86	7.44	66.10	510.95	13683.91
10/07/04	10.16	1.67	57.91	16.76	6.10	35.00	40.97	3404.84
10/10/04	53.85	24.75	12.19	9.14	2.18	8.08	89.23	23232.40
10/26/04	16.51	3.33	76.20	25.91	4.95	87.50	107.09	5368.05
10/27/04	6.60	6.33	9.14	4.06	1.04	84.21	4.62	1608.12
11/01/04	16.76	12.25	9.14	7.11	1.37	56.46	20.38	6376.42
11/02/04	2.54	3.25	3.05	1.52	0.78	10.26	0.62	689.80
11/03/04	13.21	8.92	6.10	4.06	1.48	84.11	8.76	4616.24
11/10/04	6.60	1.58	15.24	8.13	4.17	68.42	10.09	965.89
11/11/04	4.57	2.75	9.14	4.06	1.66	21.21	3.36	1426.33
11/15/04	16.51	11.83	6.10	3.56	1.40	35.92	9.75	5815.75
11/16/04	4.32	6.42	15.24	4.06	0.67	84.42	3.20	2091.49
11/17/04	25.91	9.83	21.34	13.21	2.63	17.80	64.98	14586.09
11/21/04	12.95	4.83	15.24	9.65	2.68	18.97	22.84	3580.68
11/23/04	11.43	2.58	24.38	11.68	4.42	45.16	26.92	4466.72

12/05/04	5.08	5.75	9.14	3.05	0.88	82.61	2.67	161.41
12/06/04	17.78	9.83	12.19	8.13	1.81	1.69	26.80	5270.36
01/04/05	16.51	9.83	18.29	6.10	1.68	44.92	18.17	546.23
01/05/05	14.48	15.83	12.19	8.13	0.91	72.63	20.73	6705.18
01/28/05	8.38	7.75	3.05	3.05	1.08	29.03	4.12	0.00
01/29/05	2.79	1.33	6.10	2.54	2.10	62.50	1.18	0.00
01/31/05	3.05	4.25	3.05	1.02	0.72	13.73	0.50	0.00
02/06/05	15.49	10.17	6.10	3.05	1.52	91.80	7.66	914.92
02/08/05	3.05	2.75	6.10	2.03	1.11	3.03	1.08	0.00
02/12/05	3.05	3.67	6.10	2.03	0.83	95.45	1.03	0.00
02/23/05	6.35	5.58	6.10	3.56	1.14	11.94	3.74	0.00
03/21/05	8.89	1.83	24.38	13.72	4.85	40.91	25.62	48.42
05/14/05	29.97	4.42	64.01	28.45	6.79	15.09	195.77	12232.94
06/11/05	10.16	6.25	18.29	7.62	1.63	80.00	14.51	4095.49
06/13/05	16.00	3.50	33.53	19.81	4.57	38.10	68.44	4860.05
06/16/05	9.91	3.33	21.34	12.19	2.97	7.50	23.77	2820.37
06/17/05	35.56	3.92	88.39	42.16	9.08	4.26	365.10	7503.72
07/04/05	28.70	5.83	60.96	26.42	4.92	8.57	162.37	5437.71
07/05/05	11.68	1.67	21.34	13.21	7.01	20.00	31.74	6706.88
07/12/05	20.32	2.25	45.72	20.83	9.03	11.11	100.32	4177.04
07/18/05	8.64	0.50	39.62	17.27	17.27	50.00	34.98	794.29
08/06/05	28.70	4.83	24.38	17.27	5.94	29.31	104.78	4498.16
08/14/05	37.08	28.67	57.91	23.88	1.29	0.58	193.57	8205.42
08/17/05	15.24	1.17	33.53	16.76	13.06	78.57	59.49	6007.73
08/22/05	115.57	14.17	91.44	46.74	8.16	51.76	1301.52	26232.02
08/23/05	17.78	4.00	36.58	17.27	4.45	8.33	65.36	8383.81
09/15/05	64.01	8.58	146.30	82.30	7.46	5.83	1353.99	10307.10
10/01/05	48.01	8.08	64.01	36.58	5.94	79.38	412.90	14229.29
01/31/06	13.21	10.08	36.58	12.70	1.31	100.00	34.77	230.22
04/25/06	14.99	4.33	79.25	20.32	3.46	80.77	72.26	1948.78
04/28/06	29.97	10.67	79.25	21.34	2.81	92.19	138.12	9816.09
04/29/06	20.57	9.75	12.19	7.11	2.11	56.41	26.13	7957.36
05/04/06	17.02	4.08	51.82	19.30	4.17	8.16	74.01	5077.52
05/11/06	16.51	6.42	21.34	8.64	2.57	35.06	26.98	3895.00

Table A-2. 19NW Precipitation Variable Analysis.

	Precipitation Variables							
Date	Precipitation		Precip Intensity (mm/hr)			% Time to Peak Intensity	R-Factor (units)*	Flow (L)
	Total (mm)	Duration (h)	Max 5-min	Max 30-min	Ave			
06/02/04	11.18	0.58	48.77	21.84	19.16	28.57	60.43	8425.44
06/09/04	43.94	18.75	30.48	22.86	2.34	2.22	205.85	16695.42
06/19/04	20.32	2.83	73.15	24.38	7.17	14.71	110.56	11128.58
06/20/04	26.16	2.83	57.91	18.80	9.23	5.88	112.06	18730.85
06/21/04	45.21	9.50	67.06	27.94	4.76	15.79	284.91	63000.51
06/22/04	14.99	4.92	9.14	8.13	3.05	54.24	22.75	13227.72
07/02/04	8.64	3.33	30.48	11.18	2.59	57.50	20.91	2296.23
07/06/04	8.89	3.17	18.29	8.13	2.81	2.63	13.49	8440.73
07/24/04	11.18	9.42	18.29	7.11	1.19	83.19	14.95	948.05
07/28/04	29.72	14.25	33.53	13.72	2.09	32.75	82.38	17930.61
07/29/04	5.33	5.00	9.14	5.08	1.07	48.33	4.73	3701.32
08/11/04	21.59	15.08	12.19	7.11	1.43	39.78	27.75	8654.81
08/12/04	5.84	3.75	15.24	6.10	1.56	95.56	7.34	4139.66
09/05/04	5.59	0.58	24.38	10.16	9.58	85.71	12.38	526.70
09/16/04	36.58	4.92	88.39	54.86	7.44	66.10	510.95	24852.42
10/07/04	10.16	1.67	57.91	16.76	6.10	35.00	40.97	3372.55
10/10/04	53.85	24.75	12.19	9.14	2.18	8.08	89.23	34200.42
10/26/04	16.51	3.33	76.20	25.91	4.95	87.50	107.09	7251.42
10/27/04	6.60	6.33	9.14	4.06	1.04	84.21	4.62	3160.18
11/01/04	16.76	12.25	9.14	7.11	1.37	56.46	20.38	4753.01
11/02/04	2.54	3.25	3.05	1.52	0.78	10.26	0.62	1714.31
11/03/04	13.21	8.92	6.10	4.06	1.48	84.11	8.76	4299.37
11/10/04	6.60	1.58	15.24	8.13	4.17	68.42	10.09	1103.51
11/11/04	4.57	2.75	9.14	4.06	1.66	21.21	3.36	1025.36
11/15/04	16.51	11.83	6.10	3.56	1.40	35.92	9.75	4983.48
11/16/04	4.32	6.42	15.24	4.06	0.67	84.42	3.20	2014.19
11/17/04	25.91	9.83	21.34	13.21	2.63	17.80	64.98	20711.05
11/21/04	12.95	4.83	15.24	9.65	2.68	18.97	22.84	6283.83
11/23/04	11.43	2.58	24.38	11.68	4.42	45.16	26.92	8597.04
12/05/04	5.08	5.75	9.14	3.05	0.88	82.61	2.67	146.97
12/06/04	17.78	9.83	12.19	8.13	1.81	1.69	26.80	11760.62
01/04/05	16.51	9.83	18.29	6.10	1.68	44.92	18.17	1626.81
01/05/05	14.48	15.83	12.19	8.13	0.91	72.63	20.73	2169.65
01/28/05	8.38	7.75	3.05	3.05	1.08	29.03	4.12	0.00
01/29/05	2.79	1.33	6.10	2.54	2.10	62.50	1.18	361.89
01/31/05	3.05	4.25	3.05	1.02	0.72	13.73	0.50	823.18
02/06/05	15.49	10.17	6.10	3.05	1.52	91.80	7.66	5384.19
02/08/05	3.05	2.75	6.10	2.03	1.11	3.03	1.08	175.85
02/12/05	3.05	3.67	6.10	2.03	0.83	95.45	1.03	305.82
02/23/05	6.35	5.58	6.10	3.56	1.14	11.94	3.74	195.39
03/21/05	8.89	1.83	24.38	13.72	4.85	40.91	25.62	564.07

05/14/05*	29.97	4.42	64.01	28.45	6.79	15.09	195.77	20724.65
06/11/05	10.16	6.25	18.29	7.62	1.63	80.00	14.51	6658.46
06/13/05	16.00	3.50	33.53	19.81	4.57	38.10	68.44	9918.88
06/16/05	9.91	3.33	21.34	12.19	2.97	7.50	23.77	7919.13
06/17/05	35.56	3.92	88.39	42.16	9.08	4.26	365.10	43790.54
07/04/05	28.70	5.83	60.96	26.42	4.92	8.57	162.37	7042.44
07/05/05	11.68	1.67	21.34	13.21	7.01	20.00	31.74	12904.91
07/12/05	20.32	2.25	45.72	20.83	9.03	11.11	100.32	6330.55
07/18/05	8.64	0.50	39.62	17.27	17.27	50.00	34.98	0.00
08/06/05	28.70	4.83	24.38	17.27	5.94	29.31	104.78	7258.21
08/14/05	37.08	28.67	57.91	23.88	1.29	0.58	193.57	10939.14
08/17/05	15.24	1.17	33.53	16.76	13.06	78.57	59.49	3389.54
08/22/05	115.57	14.17	91.44	46.74	8.16	51.76	1301.52	39198.94
08/23/05	17.78	4.00	36.58	17.27	4.45	8.33	65.36	9815.24
09/15/05	64.01	8.58	146.30	82.30	7.46	5.83	1353.99	40736.55
10/01/05	48.01	8.08	64.01	36.58	5.94	79.38	412.90	10295.21
01/31/06	13.21	10.08	36.58	12.70	1.31	100.00	34.77	238.71
04/25/06	14.99	4.33	79.25	20.32	3.46	80.77	72.26	838.47
04/28/06	29.97	10.67	79.25	21.34	2.81	92.19	138.12	10396.30
04/29/06	20.57	9.75	12.19	7.11	2.11	56.41	26.13	7722.05
05/04/06	17.02	4.08	51.82	19.30	4.17	8.16	74.01	3674.98
05/11/06	16.51	6.42	21.34	8.64	2.57	35.06	26.98	3828.74

*Post BMP

Table A-3. 32NE Precipitation Variable Analysis.

	Precipitation Variables							
	Precipitation		Precip Intensity (mm/hr)			% Time		
Date	Total (mm)	Duration (h)	Max 5-min	Max 30-min	Ave	to Peak Intensity	R-Factor (units)*	Flow (L)
06/02/04	23.11	0.75	79.25	44.70	30.82	55.56	275.49	19099.53
06/05/04	34.54	2.25	100.58	46.23	15.35	81.48	409.13	50233.57
06/09/04	38.10	19.00	18.29	10.16	2.01	95.18	72.60	17632.43
06/19/04	18.03	3.33	24.38	18.80	5.41	17.50	71.53	7357.61
06/20/04	15.24	2.58	33.53	11.18	5.90	45.16	34.74	11630.64
06/21/04	49.78	9.50	79.25	34.04	5.24	31.58	384.96	71980.68
06/22/04	18.03	4.17	12.19	9.65	4.33	58.00	32.61	19094.44
07/06/04	23.62	3.67	60.96	31.50	6.44	6.82	170.78	15991.18
07/24/04	24.64	10.25	42.67	23.88	2.40	1.63	124.83	9312.33
07/28/04	20.83	13.33	15.24	9.65	1.56	33.75	37.69	11469.23
07/29/04	5.33	2.08	9.14	4.57	2.56	12.00	4.49	2542.58
08/11/04	34.04	15.00	42.67	14.73	2.27	0.56	105.00	15131.47
08/12/04	8.13	0.75	27.43	15.24	10.84	33.33	28.01	2211.27
09/16/04	31.75	2.08	67.06	46.74	15.24	16.00	377.01	9101.65
10/06/04	12.19	1.08	33.53	14.22	11.25	84.62	37.67	2201.93
10/07/04	12.45	1.58	67.06	21.84	7.86	15.79	70.61	3871.22
10/10/04	60.71	23.25	24.38	15.75	2.61	9.68	179.68	33959.16
10/26/04	9.91	6.33	27.43	13.21	1.56	88.16	27.39	2106.78
11/01/04	15.49	12.50	6.10	4.06	1.24	42.00	10.26	1796.71
11/02/04	28.96	8.42	54.86	28.96	3.44	1.98	189.44	26619.40
11/03/04	19.81	9.42	6.10	5.08	2.10	54.87	16.91	7183.46
11/10/04	10.92	2.08	21.34	14.22	5.24	56.00	31.90	7115.50
11/11/04	6.60	1.00	30.48	11.18	6.60	50.00	16.00	5790.26
11/15/04	14.22	11.33	12.19	4.06	1.26	42.65	9.78	4284.93
11/16/04	2.79	6.25	9.14	2.03	0.45	1.33	0.98	137.62
11/17/04	23.11	11.50	15.24	7.62	2.01	21.01	31.97	21010.08
11/21/04	8.89	3.58	12.19	6.60	2.48	9.30	10.38	3334.33
11/23/04	9.65	3.67	18.29	10.16	2.63	61.36	18.65	7592.92
12/05/04	5.84	6.33	6.10	3.56	0.92	10.53	3.49	0.00
12/06/04	19.05	10.00	12.19	8.13	1.91	4.17	28.62	12497.99
01/04/05	27.18	9.92	33.53	15.24	2.74	42.86	85.34	6944.74
01/05/05	28.70	17.75	36.58	14.22	1.62	69.48	76.46	12240.59
01/28/05	8.38	6.33	3.05	3.05	1.32	26.32	4.12	0.00
01/29/05	6.35	3.25	3.05	3.05	1.95	87.18	3.12	0.00
02/06/05	17.53	10.17	6.10	4.06	1.72	46.72	11.70	744.17
02/08/05	3.05	3.67	6.10	1.52	0.83	4.55	0.77	0.00
02/12/05	3.56	4.42	3.05	1.52	0.81	47.17	0.87	0.00
02/23/05	10.41	7.58	9.14	5.59	1.37	8.79	10.11	0.00
03/21/05	12.19	9.67	24.38	8.64	1.26	0.86	21.54	0.00
05/14/05*	68.33	23.08	161.54	73.66	2.96	78.34	1221.94	No data
06/11/05	18.80	6.33	30.48	22.35	2.97	77.63	93.52	1278.51

06/13/05	17.53	2.17	76.20	26.92	8.09	7.69	114.45	8655.66
06/16/05	19.81	2.08	67.06	28.96	9.51	12.00	136.42	9849.22
06/17/05	83.82	3.58	143.26	108.20	23.39	18.60	2424.17	138273.89
07/04/05	40.13	6.08	57.91	39.12	6.60	6.85	350.66	32059.66
07/05/05	40.39	1.92	109.73	47.24	21.07	13.04	491.29	79338.29
08/06/05	16.51	4.42	33.53	14.73	3.74	3.77	51.60	0.00
08/12/05	34.29	4.33	112.78	58.42	7.91	40.38	522.34	22038.84
08/14/05	30.23	37.50	39.62	17.78	0.81	99.33	110.46	20555.76
08/17/05	21.08	1.33	36.58	25.40	15.81	18.75	128.25	24637.49
08/20/05	31.50	2.92	60.96	27.43	10.80	5.71	208.17	27612.47
08/22/05	88.90	13.08	64.01	32.51	6.79	43.31	672.36	122145.95
08/23/05	12.45	4.83	24.38	8.64	2.58	46.55	21.67	8871.43
09/12/05	10.16	3.83	42.67	14.22	2.65	4.35	31.59	0.00
09/14/05	7.62	0.58	30.48	14.73	13.06	57.14	25.66	163.11
09/15/05	73.15	9.17	140.21	76.71	7.98	4.55	1418.34	91393.68
10/01/05	37.85	13.17	67.06	21.84	2.87	39.24	184.41	16898.45
10/31/05	12.19	1.50	48.77	18.80	8.13	11.11	52.98	732.28
01/31/06	13.46	10.58	33.53	10.16	1.27	98.43	26.97	1284.46
04/25/06	46.74	4.67	109.73	67.56	10.01	89.29	843.81	56039.63
04/28/06	38.35	21.50	51.82	21.84	1.78	62.79	179.37	38596.64
04/29/06	31.50	5.67	33.53	16.76	5.56	23.53	104.40	44905.10
05/04/06	47.75	5.33	143.26	60.45	8.95	10.94	733.72	74839.88
05/11/06	12.192	6.5	9.144	6.604	1.875692	38.46154	14.05257	1727.05

*Post BMP

Table A-4. 32NW Precipitation Variable Analysis.

				Precipitation Variables				
	Precipitation		Precip Intensity (mm/hr)			% Time		
Date	Total	Duration	Max	Max	Ave	to Peak	R-Factor	Flow
	(mm)	(h)	5-min	30-min		Intensity	(units)*	(L)
06/02/04	23.11	0.75	79.25	44.70	30.82	55.56	275.49	17512.65
06/05/04	34.54	2.25	100.58	46.23	15.35	81.48	409.13	31581.38
06/09/04	38.10	19.00	18.29	10.16	2.01	95.18	72.60	29286.01
06/19/04	18.03	3.33	24.38	18.80	5.41	17.50	71.53	8853.59
06/20/04	15.24	2.58	33.53	11.18	5.90	45.16	34.74	12097.87
06/21/04	49.78	9.50	79.25	34.04	5.24	31.58	384.96	64527.08
06/22/04	18.03	4.17	12.19	9.65	4.33	58.00	32.61	22104.25
07/06/04	23.62	3.67	60.96	31.50	6.44	6.82	170.78	9534.90
07/24/04	24.64	10.25	42.67	23.88	2.40	1.63	124.83	7105.30
07/28/04	20.83	13.33	15.24	9.65	1.56	33.75	37.69	9724.34
07/29/04	5.33	2.08	9.14	4.57	2.56	12.00	4.49	2133.97
08/11/04	34.04	15.00	42.67	14.73	2.27	0.56	105.00	13870.80
08/12/04	8.13	0.75	27.43	15.24	10.84	33.33	28.01	3888.21
09/16/04	31.75	2.08	67.06	46.74	15.24	16.00	377.01	7575.08
10/06/04	12.19	1.08	33.53	14.22	11.25	84.62	37.67	1660.79
10/07/04	12.45	1.58	67.06	21.84	7.86	15.79	70.61	3154.23
10/10/04	60.71	23.25	24.38	15.75	2.61	9.68	179.68	21542.72
10/26/04	9.91	6.33	27.43	13.21	1.56	88.16	27.39	3847.43
11/01/04	15.49	12.50	6.10	4.06	1.24	42.00	10.26	4685.05
11/02/04	28.96	8.42	54.86	28.96	3.44	1.98	189.44	24816.74
11/03/04	19.81	9.42	6.10	5.08	2.10	54.87	16.91	11298.48
11/10/04	10.92	2.08	21.34	14.22	5.24	56.00	31.90	4231.41
11/11/04	6.60	1.00	30.48	11.18	6.60	50.00	16.00	4474.37
11/15/04	14.22	11.33	12.19	4.06	1.26	42.65	9.78	3305.44
11/16/04	2.79	6.25	9.14	2.03	0.45	1.33	0.98	225.12
11/17/04	23.11	11.50	15.24	7.62	2.01	21.01	31.97	22421.12
11/21/04	8.89	3.58	12.19	6.60	2.48	9.30	10.38	5824.24
11/23/04	9.65	3.67	18.29	10.16	2.63	61.36	18.65	10023.37
12/05/04	5.84	6.33	6.10	3.56	0.92	10.53	3.49	355.94
12/06/04	19.05	10.00	12.19	8.13	1.91	4.17	28.62	16412.53
01/04/05	27.18	9.92	33.53	15.24	2.74	42.86	85.34	8689.64
01/05/05	28.70	17.75	36.58	14.22	1.62	69.48	76.46	5164.17
01/28/05	8.38	6.33	3.05	3.05	1.32	26.32	4.12	0.00
01/29/05	6.35	3.25	3.05	3.05	1.95	87.18	3.12	56.92
02/06/05	17.53	10.17	6.10	4.06	1.72	46.72	11.70	7892.80
02/08/05	3.05	3.67	6.10	1.52	0.83	4.55	0.77	18.69
02/12/05	3.56	4.42	3.05	1.52	0.81	47.17	0.87	348.30
02/23/05	10.41	7.58	9.14	5.59	1.37	8.79	10.11	486.77
03/21/05	12.19	9.67	24.38	8.64	1.26	0.86	21.54	1277.66
05/14/05	68.33	23.08	161.54	73.66	2.96	78.34	1221.94	78423.37
06/11/05	18.80	6.33	30.48	22.35	2.97	77.63	93.52	7684.67

06/13/05	17.53	2.17	76.20	26.92	8.09	7.69	114.45	10134.65
06/16/05	19.81	2.08	67.06	28.96	9.51	12.00	136.42	12472.51
06/17/05	83.82	3.58	143.26	108.20	23.39	18.60	2424.17	133398.56
07/04/05	40.13	6.08	57.91	39.12	6.60	6.85	350.66	32153.36
07/05/05	40.39	1.92	109.73	47.24	21.07	13.04	491.29	42301.35
08/06/05	16.51	4.42	33.53	14.73	3.74	3.77	51.60	8154.45
08/12/05	34.29	4.33	112.78	58.42	7.91	40.38	522.34	25100.47
08/14/05	30.23	37.50	39.62	17.78	0.81	99.33	110.46	19389.22
08/17/05	21.08	1.33	36.58	25.40	15.81	18.75	128.25	23879.73
08/20/05	31.50	2.92	60.96	27.43	10.80	5.71	208.17	32352.74
08/22/05	88.90	13.08	64.01	32.51	6.79	43.31	672.36	112284.83
08/23/05	12.45	4.83	24.38	8.64	2.58	46.55	21.67	13463.88
09/12/05	10.16	3.83	42.67	14.22	2.65	4.35	31.59	1521.47
09/14/05	7.62	0.58	30.48	14.73	13.06	57.14	25.66	2229.11
09/15/05	73.15	9.17	140.21	76.71	7.98	4.55	1418.34	73231.16
10/01/05	37.85	13.17	67.06	21.84	2.87	39.24	184.41	19726.47
10/31/05	12.19	1.50	48.77	18.80	8.13	11.11	52.98	3234.93
01/31/06	13.46	10.58	33.53	10.16	1.27	98.43	26.97	4021.58
04/25/06	46.74	4.67	109.73	67.56	10.01	89.29	843.81	50218.78
04/28/06	38.35	21.50	51.82	21.84	1.78	62.79	179.37	34479.91
04/29/06	31.50	5.67	33.53	16.76	5.56	23.53	104.40	44053.89
05/04/06	47.75	5.33	143.26	60.45	8.95	10.94	733.72	64470.16
05/11/06	12.192	6.5	9.144	6.604	1.875692	38.46154	14.05257	3949.63

APPENDIX B

SEDIMENT ANALYSIS

Table B-1. 19NE Sediment Analysis

	Sediment Analysis					
	Sediment (kg)			Sediment Production (Kg/Ha)	Cubic meters	
Date	Bulk	Susp	Total		Total Rainfall	Total Runoff
06/02/04	150.78	312.42	463.20	8400.52	6.16	5.57
06/09/04	222.08	253.67	475.76	8628.26	24.21	13.62
06/19/04	72.17	258.37	330.54	5994.60	11.20	6.06
06/20/04	230.92	477.12	708.04	12840.96	14.42	11.43
06/21/04	425.85	1238.92	1664.77	30191.99	24.91	45.30
06/22/04	72.12	73.12	145.25	2634.14	8.26	10.15
07/02/04	23.94	70.61	94.55	1842.35	4.43	1.37
07/06/04	68.23	161.66	229.89	4169.18	4.90	3.85
07/24/04	0.00	0.00	0.00	0.00	6.16	0.65
07/28/04	32.85	65.44	98.29	1782.53	16.38	7.19
07/29/04	2.67	4.59	7.26	131.66	2.94	1.47
08/11/04	56.42	69.16	125.59	2277.60	11.90	4.26
08/12/04	21.24	46.47	67.71	1227.93	3.22	1.51
09/05/04	3.84	7.37	11.21	203.25	3.08	0.70
09/16/04	82.90	512.32	595.22	10794.83	20.15	13.69
10/07/04	24.18	109.84	134.02	2430.48	5.60	3.41
10/10/04	18.90	183.13	202.02	3663.87	29.67	23.23
10/26/04	10.57	181.20	191.77	3477.83	9.10	5.37
10/27/04	0.00	2.49	2.49	45.16	3.64	1.61
11/01/04	0.35	19.58	19.92	361.34	9.24	6.38
11/02/04	0.17	0.00	0.17	2.99	1.40	0.69
11/03/04	0.27	3.53	3.80	68.84	7.28	4.62
11/10/04	0.67	22.13	22.80	413.55	3.64	0.97
11/11/04	0.12	6.07	6.20	112.39	2.52	1.43
11/15/04	0.00	11.30	11.30	205.00	9.10	5.82
11/16/04	0.00	9.72	9.72	176.28	2.38	2.09
11/17/04	3.86	115.68	119.54	2167.95	14.28	14.59
11/21/04	0.00	59.67	59.67	1082.25	7.14	3.58
11/23/04	6.86	45.95	52.81	957.81	6.30	4.47
12/05/04	0.00	0.00	0.00	0.00	2.80	0.16
12/06/04	4.76	49.39	54.15	982.11	9.80	5.27

01/04/05	0.00	0.00	0.00	0.00	9.10	0.55
01/05/05	0.00	42.40	42.40	768.88	7.98	6.71
01/28/05	0.00	0.00	0.00	0.00	4.62	0.00
01/29/05	0.00	0.00	0.00	0.00	1.54	0.00
01/31/05	0.00	0.00	0.00	0.00	1.68	0.00
02/06/05	0.00	0.00	0.00	0.00	8.54	0.92
02/08/05	8.40	0.00	8.40	152.28	1.68	0.00
02/12/05	0.00	0.00	0.00	0.00	1.68	0.00
02/23/05	0.00	0.00	0.00	0.00	3.50	0.00
03/21/05	0.00	0.00	0.00	0.00	4.90	0.05
05/14/05	58.48	447.35	505.83	9173.64	16.52	12.23
06/11/05	16.31	99.42	115.73	2098.88	5.60	4.10
06/13/05	12.48	135.10	147.58	2676.40	8.82	4.86
06/16/05	18.11	73.07	91.18	1653.70	5.46	2.82
06/17/05	264.91	266.75	531.66	9642.08	19.59	7.50
07/04/05	178.30	130.51	308.80	5600.37	15.82	5.44
07/05/05	170.85	249.80	420.65	7628.87	6.44	6.71
07/12/05	160.16	134.91	295.06	5351.21	11.20	4.18
07/18/05	36.20	26.63	62.83	1139.50	4.76	0.79
08/06/05	79.42	23.19	102.61	1860.92	15.82	4.50
08/14/05	196.00	167.57	363.57	6593.70	20.43	8.21
08/17/05	134.00	154.16	288.16	5226.01	8.40	6.01
08/22/05	347.42	974.65	1322.07	23976.85	63.68	26.23
08/23/05	16.89	77.89	94.78	1718.88	9.80	8.38
09/15/05	202.08	359.99	562.06	10193.51	35.27	10.31
10/01/05	40.80	355.67	396.47	7190.26	26.45	14.23
01/31/06	0.62	0.00	0.62	11.30	7.28	0.23
04/25/06	0.00	20.63	20.63	374.18	8.26	1.95
04/28/06	15.39	160.89	176.29	3197.12	16.52	9.82
04/29/06	7.17	67.72	74.89	1358.22	11.34	7.96
05/04/06	39.62	156.74	196.37	3561.30	9.38	5.08
05/11/06	8.25	26.54	34.79	630.89	9.10	3.90

Table B-2. 19NW Sediment Analysis

Sediment Analysis						
	Sediment (kg)			Sediment	Cubic meters	
	Bulk	Susp	Total	Production	Total	Total
Date				(Kg/Ha)	Rainfall	Runoff
06/02/04	467.59	755.06	1222.65	16424.16	8.31	8.43
06/09/04	435.95	873.88	1309.83	17595.21	32.69	16.70
06/19/04	243.30	528.79	772.09	10371.65	15.12	11.13
06/20/04	599.29	2016.60	2615.89	35139.78	19.46	18.73
06/21/04	821.10	3475.71	4296.81	57719.89	33.63	63.01
06/22/04	75.84	205.22	281.07	3775.63	11.15	13.23
07/02/04	94.91	195.70	290.61	3903.82	6.42	2.30
07/06/04	212.91	490.11	703.02	9443.75	6.61	8.44
07/24/04	11.31	19.13	30.44	408.88	8.31	0.95
07/28/04	227.09	576.13	803.21	10789.73	22.11	17.93
07/29/04	37.01	51.50	88.51	1188.97	3.97	3.70
08/11/04	348.67	387.80	736.47	9893.19	16.06	8.66
08/12/04	165.03	206.79	371.82	4994.75	4.35	4.14
09/05/04	21.43	17.20	38.63	518.92	4.16	0.53
09/16/04	699.40	2495.83	3195.23	42922.26	27.21	24.86
10/07/04	119.07	139.35	258.42	3471.38	7.56	3.37
10/10/04	359.88	779.50	1139.38	15305.55	40.06	34.20
10/26/04	200.50	451.24	651.75	8755.06	12.28	7.25
10/27/04	29.16	34.97	64.13	861.42	4.91	3.16
11/01/04	30.40	40.52	70.92	952.63	12.47	4.75
11/02/04	12.74	15.65	28.39	381.38	1.89	1.71
11/03/04	27.09	9.73	36.83	494.69	9.83	4.30
11/10/04	14.98	20.05	35.03	470.54	4.91	1.10
11/11/04	8.88	6.13	15.02	201.70	3.40	1.03
11/15/04	8.21	20.12	28.32	380.49	12.28	4.98
11/16/04	0.00	8.49	8.49	114.02	3.21	2.01
11/17/04	95.22	360.91	456.13	6127.33	19.27	20.71
11/21/04	17.63	63.33	80.96	1087.57	9.64	6.28
11/23/04	43.88	106.79	150.66	2023.90	8.50	8.60
12/05/04	0.00	0.00	0.00	0.00	3.78	0.15
12/06/04	42.09	140.18	182.27	2448.41	13.23	11.76
01/04/05	0.00	6.89	6.89	92.58	12.28	1.63
01/05/05	0.00	12.40	12.40	166.57	10.77	2.17
01/28/05	0.00	0.00	0.00	0.00	6.24	0.00
01/29/05	0.00	0.00	0.00	0.00	2.08	0.36
01/31/05	0.88	0.00	0.88	11.88	2.27	0.82
02/06/05	23.85	16.30	40.14	539.26	11.53	5.38
02/08/05	9.03	0.00	9.03	121.35	2.27	0.18
02/12/05	0.00	0.00	0.00	0.00	2.27	0.31
02/23/05	0.00	0.00	0.00	0.00	4.72	0.20
03/21/05	26.97	13.09	40.07	538.23	6.61	0.56

05/14/05*	565.31	2154.78	2720.09	36539.57	22.30	20.73
06/11/05	281.10	226.09	507.19	6813.15	7.56	6.66
06/13/05	220.69	153.48	374.17	5026.33	11.90	9.92
06/16/05	268.86	225.28	494.14	6637.89	7.37	7.92
06/17/05	500.05	1704.14	2204.18	29609.25	26.45	43.80
07/04/05	224.39	188.68	413.07	5548.88	21.35	7.04
07/05/05	252.43	266.77	519.21	6974.59	8.69	12.91
07/12/05	146.74	157.97	304.71	4093.25	15.12	6.33
07/18/05	0.00	0.00	0.00	0.00	6.42	0.00
08/06/05	94.46	26.87	121.32	1629.77	21.35	7.26
08/14/05	333.23	303.37	636.60	8551.62	27.59	10.94
08/17/05	153.03	74.23	227.26	3052.77	11.34	3.39
08/22/05	551.92	768.84	1320.76	17742.04	85.98	39.20
08/23/05	26.27	52.32	78.59	1055.70	13.23	9.82
09/15/05	298.59	855.31	1153.90	15500.61	47.62	40.74
10/01/05	166.15	201.25	367.40	4935.38	35.71	10.30
01/31/06	0.00	0.00	0.00	0.00	9.83	0.24
04/25/06	0.00	0.25	0.25	3.36	11.15	0.84
04/28/06	0.00	25.99	25.99	349.09	22.30	10.40
04/29/06	0.00	3.14	3.14	42.20	15.31	7.72
05/04/06	0.00	3.01	3.01	40.48	12.66	3.68
05/11/06	0.00	2.75	2.75	36.92	12.28	3.83

*Post BMP

Table B-3. 32NE Sediment Analysis

Sediment Analysis						
	Sediment (kg)			Sediment	Cubic meters	
	Bulk	Susp	Total	Production	Total	Total
Date				(Kg/Ha)	Rainfall	Runoff
06/02/04	188.05	698.59	886.64	4624.70	44.29	19.10
06/05/04	245.35	2559.17	2804.52	14628.26	66.18	50.24
06/09/04	101.78	91.23	193.01	1006.72	73.00	17.63
06/19/04	24.33	63.61	87.94	458.67	34.55	7.36
06/20/04	30.61	160.70	191.32	997.90	29.20	11.63
06/21/04	285.36	1794.83	2080.19	10850.18	95.38	71.99
06/22/04	117.62	53.64	171.26	893.29	34.55	19.10
07/06/04	117.63	337.63	455.26	2374.59	45.26	15.99
07/24/04	57.85	112.32	170.17	887.62	47.21	9.31
07/28/04	13.45	61.45	74.90	390.68	39.91	11.47
07/29/04	1.02	14.85	15.86	82.75	10.22	2.54
08/11/04	18.66	75.96	94.61	493.49	65.21	15.13
08/12/04	4.72	16.97	21.69	113.14	15.57	2.21
09/16/04	12.89	60.72	73.62	383.97	60.83	9.10
10/06/04	0.46	7.85	8.30	43.31	23.36	2.20
10/07/04	8.46	20.28	28.74	149.93	23.85	3.87
10/10/04	3.46	58.02	61.48	320.66	116.31	33.96
10/26/04	1.28	19.12	20.40	106.43	18.98	2.11
11/01/04	0.00	0.40	0.40	2.09	29.69	1.80
11/02/04	19.78	134.95	154.73	807.08	55.48	26.62
11/03/04	1.99	6.75	8.74	45.61	37.96	7.18
11/10/04	7.37	32.76	40.13	209.31	20.93	7.12
11/11/04	7.77	35.02	42.79	223.21	12.65	5.79
11/15/04	0.00	4.57	4.57	23.83	27.25	4.29
11/16/04	0.00	0.00	0.00	0.00	5.35	0.14
11/17/04	5.04	44.50	49.53	258.37	44.29	21.01
11/21/04	0.00	4.55	4.55	23.76	17.03	3.33
11/23/04	3.43	27.03	30.46	158.88	18.49	7.59
12/05/04	0.00	0.00	0.00	0.00	11.19	0.00
12/06/04	0.00	45.73	45.73	238.50	36.50	12.50
01/04/05	34.15	32.75	66.89	348.92	52.07	6.95
01/05/05	0.00	56.62	56.62	295.33	54.99	12.24
01/28/05	0.00	0.00	0.00	0.00	16.06	0.00
01/29/05	0.00	0.00	0.00	0.00	12.17	0.00
02/06/05	0.00	0.00	0.00	0.00	33.58	0.74
02/08/05	0.00	0.00	0.00	0.00	5.84	0.00
02/12/05	0.00	0.00	0.00	0.00	6.81	0.00
02/23/05	0.00	0.00	0.00	0.00	19.95	0.00
03/21/05	0.00	0.00	0.00	0.00	23.36	0.00
05/14/05*	No data	No data	No data	No data	No data	No data
06/11/05	1.30	1.33	2.63	13.72	36.01	1.28

06/13/05	4.95	101.79	106.75	556.78	33.58	8.66
06/16/05	0.00	50.97	50.97	265.83	37.96	9.85
06/17/05	9.87	1180.91	1190.79	6211.09	160.59	138.29
07/04/05	10.88	199.90	210.78	1099.42	76.89	32.06
07/05/05	168.10	1454.65	1622.76	8464.22	77.38	79.35
08/06/05	0.00	0.00	0.00	0.00	31.63	0.00
08/12/05	12.34	146.99	159.33	831.05	65.70	22.04
08/14/05	5.38	114.91	120.30	627.46	57.91	20.33
08/17/05	6.67	72.29	78.96	411.85	40.39	24.64
08/20/05	10.46	153.20	163.65	853.60	60.34	27.62
08/22/05	63.98	397.46	461.43	2406.82	170.33	122.16
08/23/05	24.60	14.78	39.38	205.40	23.85	8.87
09/12/05	0.00	0.00	0.00	0.00	19.47	0.00
09/14/05	0.00	0.00	0.00	0.00	14.60	0.16
09/15/05	36.32	482.67	518.99	2707.03	140.16	91.40
10/01/05	10.00	38.34	48.34	252.13	72.51	16.90
10/31/05	0.31	1.06	1.37	7.14	23.36	0.73
01/31/06	0.78	2.65	3.43	17.87	25.79	1.28
04/25/06	1.93	424.82	426.75	2225.93	89.54	56.05
04/28/06	2.36	76.65	79.01	412.12	73.48	38.60
04/29/06	0.00	27.53	27.53	143.59	60.34	44.91
05/04/06	1.67	352.71	354.38	1848.43	91.49	74.85
05/11/06	0.00	0.58	0.58	3.05	23.36	1.73

*Post BMP

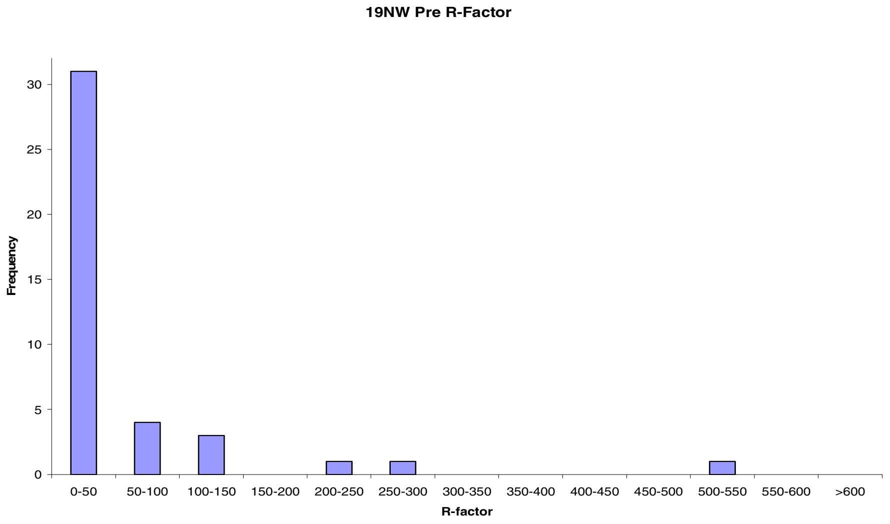
Table B-4. 32NW Sediment Analysis

	Sediment Analysis					
	Sediment (kg)			Sediment Production (Kg/Ha)	Cubic meters	
Date	Bulk	Susp	Total		Total Rainfall	Total Runoff
06/02/04	275.99	795.28	1071.28	9816.00	25.21	17.51
06/05/04	297.56	1436.43	1733.99	15888.37	37.68	31.58
06/09/04	38.37	141.94	180.31	1652.19	41.55	29.29
06/19/04	19.59	79.25	98.84	905.70	19.67	8.85
06/20/04	14.49	106.43	120.92	1107.97	16.62	12.10
06/21/04	230.61	1028.60	1259.21	11538.01	54.30	64.53
06/22/04	42.15	50.48	92.63	848.77	19.67	22.11
07/06/04	45.52	131.39	176.91	1621.04	25.76	9.54
07/24/04	13.44	52.62	66.05	605.22	26.87	7.11
07/28/04	3.31	71.35	74.66	684.12	22.72	9.73
07/29/04	0.00	6.80	6.80	62.33	5.82	2.13
08/11/04	13.28	84.42	97.69	895.16	37.12	13.87
08/12/04	10.72	50.35	61.07	559.54	8.86	3.89
09/16/04	7.31	53.68	60.99	558.83	34.63	7.58
10/06/04	0.00	6.39	6.39	58.54	13.30	1.66
10/07/04	5.00	15.15	20.15	184.59	13.57	3.15
10/10/04	1.46	40.35	41.81	383.12	66.21	21.55
10/26/04	6.47	54.42	60.89	557.92	10.80	3.85
11/01/04	0.00	6.62	6.62	60.64	16.90	4.69
11/02/04	110.23	260.80	371.03	3399.72	31.58	24.82
11/03/04	11.86	14.58	26.43	242.22	21.61	11.30
11/10/04	11.56	30.82	42.38	388.37	11.91	4.23
11/11/04	19.89	37.73	57.61	527.91	7.20	4.47
11/15/04	0.38	4.15	4.53	41.52	15.51	3.31
11/16/04	0.00	0.00	0.00	0.00	3.05	0.23
11/17/04	32.94	43.32	76.26	698.73	25.21	22.42
11/21/04	1.04	9.98	11.02	100.94	9.70	5.82
11/23/04	17.72	47.20	64.92	594.87	10.53	10.02
12/05/04	0.00	0.00	0.00	0.00	6.37	0.36
12/06/04	0.00	55.52	55.52	508.69	20.78	16.41
01/04/05	10.13	55.12	65.25	597.87	29.64	8.69
01/05/05	0.00	39.51	39.51	361.98	31.30	5.16
01/28/05	0.00	0.00	0.00	0.00	9.14	0.00
01/29/05	0.00	0.00	0.00	0.00	6.93	0.06
02/06/05	12.38	16.84	29.22	267.76	19.11	7.89
02/08/05	0.00	0.00	0.00	0.00	3.32	0.02
02/12/05	0.00	0.00	0.00	0.00	3.88	0.35
02/23/05	0.00	0.00	0.00	0.00	11.36	0.49
03/21/05	0.41	3.99	4.40	40.30	13.30	1.28
05/14/05	424.23	4721.99	5146.22	47154.29	74.52	78.43
06/11/05	38.89	102.41	141.30	1294.76	20.50	7.69

06/13/05	148.89	350.96	499.85	4580.12	19.11	10.14
06/16/05	159.71	402.01	561.72	5147.02	21.61	12.47
06/17/05	451.23	5250.90	5702.13	52248.12	91.42	133.41
07/04/05	127.30	262.85	390.15	3574.94	43.77	32.16
07/05/05	274.36	1198.99	1473.35	13500.13	44.05	42.31
08/06/05	0.00	23.60	23.60	216.29	18.01	8.16
08/12/05	192.79	808.53	1001.32	9174.98	37.40	25.10
08/14/05	113.13	186.81	299.94	2748.31	32.97	17.57
08/17/05	137.06	207.33	344.39	3155.61	22.99	23.88
08/20/05	188.97	502.15	691.12	6332.66	34.35	32.36
08/22/05	296.17	1778.88	2075.05	19013.44	96.96	112.30
08/23/05	19.12	23.18	42.30	387.58	13.57	13.47
09/12/05	1.23	13.37	14.60	133.80	11.08	1.52
09/14/05	10.19	24.86	35.04	321.10	8.31	2.23
09/15/05	459.52	1566.01	2025.53	18559.73	79.78	73.24
10/01/05	60.00	239.89	299.89	2747.89	41.28	19.73
10/31/05	24.17	53.46	77.63	711.29	13.30	3.24
01/31/06	3.69	46.59	50.28	460.67	14.68	4.02
04/25/06	408.96	2626.32	3035.29	27812.04	50.97	50.22
04/28/06	137.11	317.83	454.94	4168.56	41.83	34.48
04/29/06	122.68	391.56	514.25	4711.98	34.35	44.06
05/04/06	590.22	4495.97	5086.20	46604.33	52.08	64.48
05/11/06	13.49	6.74	20.23	185.39	13.30	3.95

APPENDIX C

RAINFALL ENERGY (R-FACTOR) DISTRIBUTIONS



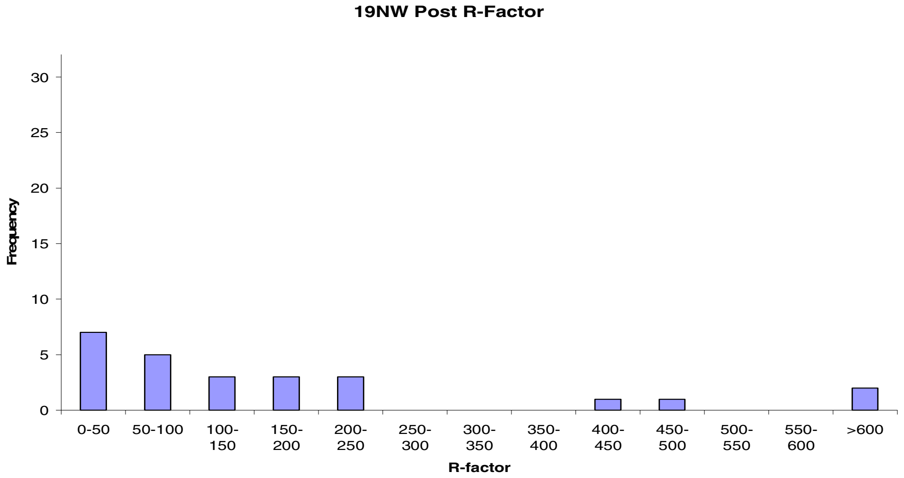
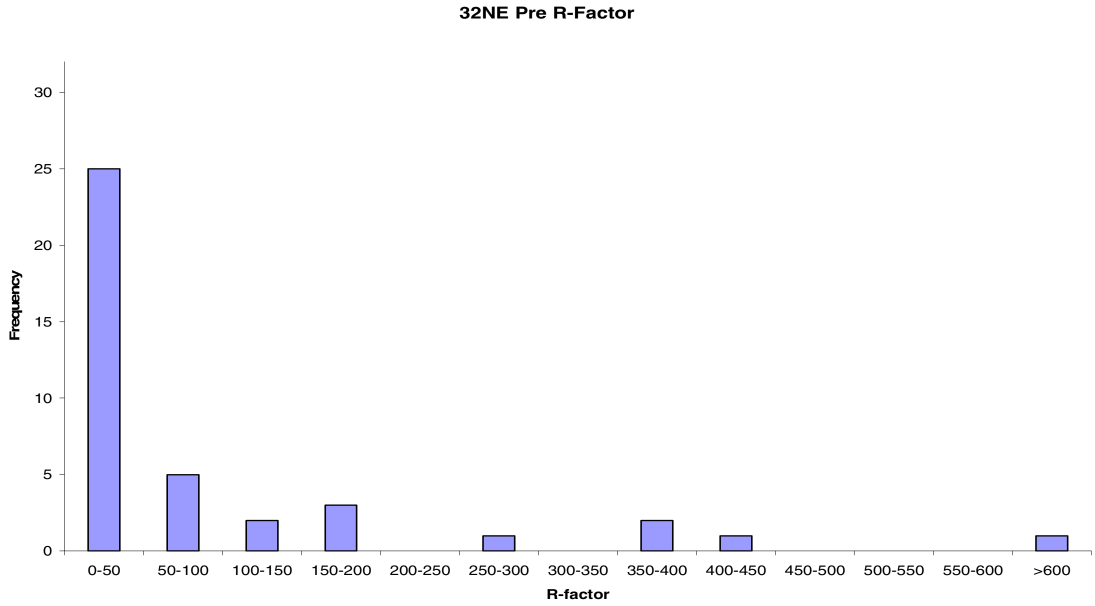


Figure C-1. Rainfall energy distributions and frequencies for 19NW pre and post periods.



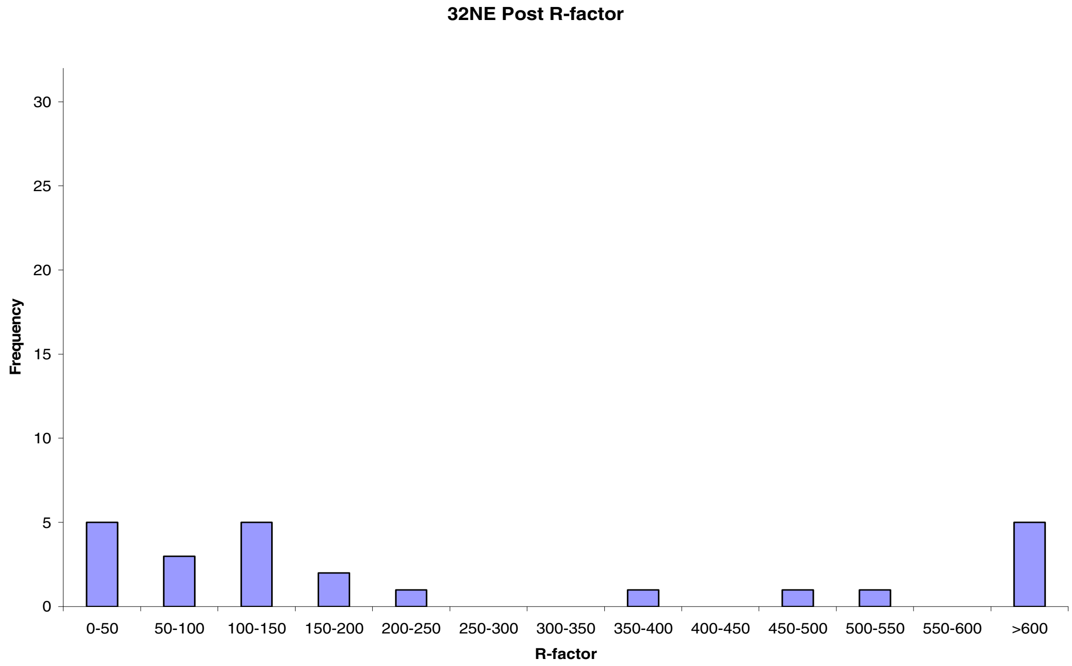


Figure C-2. Rainfall energy distributions and frequency for 32NE pre and post periods.

VITA

Leah Dale Thomas

Candidate for the Degree of

Master of Science

Thesis: EROSION CONTROL ON RURAL UNIMPROVED ROADS IN THE STILLWATER CREEK WATERSHED

Major Field: Environmental Science

Biographical:

Personal Data: Born in Duncan, Oklahoma, On June 4, 1982, Daughter of Roger and Dianne Oxley

Education: Graduated from Canadian High School, Canadian, Oklahoma; received Associates of Science degree in Environmental Science from Eastern Oklahoma State College, Wilburton, Oklahoma, in May 2002; received Bachelor of Science degree in Environmental Science from Oklahoma State University, Stillwater, Oklahoma in May 2004; completed the requirements for Master of Science degree with a major in Environmental Science at Oklahoma State University, Stillwater Oklahoma in December 2006.

Experience: Employed as a research assistant/water quality technician in the Forestry Watershed Research Laboratory at Oklahoma State University; employed as a physical scientist at the Defense Ammunition Center in McAlester, Oklahoma.

Professional Memberships: Air and Waste Management Association, Phi Kappa Phi, National Society of Collegiate Scholars, Golden Key Honor Society.

Name: Leah Dale Thomas Date of Degree: December, 2006

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: EROSION CONTROL ON RURAL UNIMPROVED ROADS IN THE STILLWATER CREEK WATERSHED

Pages in Study: 67 Candidate for the Degree of Master of Science

Major Field: Environmental Science

Scope and Method of Study: The purposes of this study was to measure sediment yields from two pairs of rural unpaved road segments in the Stillwater Creek Watershed in central Oklahoma and compare those measurements to the measurements obtained after the installation of erosion control practices. The four road segments ranged from 158-264 m in length, were crowned, and had bar ditches on both sides that drained directly into streams. Sediment traps were connected to each bar ditch and consisted of a settling trough, an H-flume to measure discharge, and a pumping sampler to obtain suspended sediment samples. A data logger controlled data retrieval and storage. Each sediment trap collected erosion from one half of the road area and the associated bar ditch and cut slope. One segment from each pair was subjected to erosion control practices, and the other segment was untreated. Erosion control practices on one site included installing geosynthetic fabric, overlaying it with crusher run limestone, and properly crowning the road. The practices on the other site included reshaping the cut slope, widening the bar ditch, seeding Bermuda grass, laying a straw net blanket, and properly crowning the road.

Findings and Conclusions: Data from over 60 storms were collected during June, 2004 to May, 2006. The total precipitation from individual storms ranged from 3-116 mm. Maximum five-minute storm intensities ranged from 3-162 mm hr^{-1}. Sediment yields ranged from 0-5,700 kg. The overall erosion per unit area across all four segments was 269,200 kg ha^{-1}. The average erosion across all four segments was 56 Mg/km/yr. There was a significant reduction in erosion between the pre and post installation periods on both sites. The implementation of erosion control practices resulted in a 51% reduction in erosion on one site and an 80% reduction in erosion on the other site.

ADVISOR'S APPROVAL: Dr. Don Turton