# MEASUREMENT AND MODELING OF EROSION FROM FOUR RURAL UNPAVED ROAD SEGMENTS IN THE STILLWATER CREEK WATERSHED

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# MEASUREMENT AND MODELING OF EROSION FROM FOUR RURAL UNPAVED ROAD SEGMENTS IN THE STILLWATER CREEK WATERSHED

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# CHAPTER I

# INTRODUCTION

## 1.1 Background

Non-point source pollution, including sediment, has been recognized as a significant source of surface water quality impairment since the early 1980's. Consequently, soil erosion and water quality are increasingly becoming concerns of land managers and environmental planners across the United States and around the world. Sediment in surface water can be attributed to natural and anthropogenic sources. The most common anthropogenic sources of sediment in surface waters are related to agricultural, construction, mining, and timber harvesting activities; all of which may potentially contribute significant amounts of sediment to surface water (Nelson and Booth 2002). Increased sediment in streams potentially has a wide range of adverse environmental impacts on aquatic ecosystems. Some potential impacts of increased sediment loads include harming or killing aquatic organisms through increased turbidity and high suspended sediment concentrations, loss or alteration of aquatic habitat through siltation (Trombulak and Frissell 2000), and alterations to hydrologic and geomorphic characteristics of stream networks (Jones *et al*. 2000).

In addition to these commonly recognized sediment sources, an often overlooked sediment source is unpaved rural roads. Often referred to as unpaved low-volume roads, unpaved rural roads are used extensively around the world to provide low-cost transportation access to rural areas. Unpaved rural roads are of particular concern because most discharge runoff and sediment directly into surface waters. In fact, the World Bank identified the greatest direct environmental impact associated with rural roads as erosion (Riverson *et al*. 1991). Despite the extensive worldwide use of unpaved rural roads, few extensive or direct measurements of quantities of sediment delivered to water bodies from road erosion and the overall contributions to watershed sediment budgets have been performed.

Rural roads in Oklahoma are a necessary part of the transportation system that supports agricultural producers and other rural landowners. Many rural roads are unpaved and are maintained by counties with limited budgets. If designed and maintained improperly, unpaved roads may be a significant source of sediment to lakes and streams. Sediment has been identified as 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 the Stillwater Creek watershed and all are listed on the state of Oklahoma's 303d water quality impairment list as being impaired by sediment, with roads identified as a major probable source.

## 1.2 Definition of the Problem

Despite the acknowledgement of roads as a significant source of sediment, few studies have been conducted to measure erosion from unpaved rural roads. Most studies have relied upon rainfall simulation on a plot or small road segment scale, which determines an erosion rate over a limited area, but not the amount of sediment actually entering a water body. Simple approaches to estimate sediment loss from roads such as the Universal Soil Loss Equation (USLE) (Wischmeier and Smith. 1978) are of limited usefulness in estimating loading because they can only predict erosion from the road surface only, and have no mechanism for determining erosion from channelized areas such as ditches.

Models available to predict road erosion have generally been developed on the plot or segment scale, been calibrated to specific locations, and have most often been applied to forest road scenarios. These models tend to be complicated and require detailed input data, potentially limiting their usefulness to land managers and environmental planners with limited budgets and data collection options. The USDA, National Soil Erosion Research Laboratory (NSERL), and Purdue University have recently released a Windows based interface for the Water Erosion Prediction Project (WEPP) model, which provides a user friendly interface to the full version of WEPP. This version provides the user with templates with default input parameters for various road conditions, road types, soil types, and management scenarios; which are very useful for relative comparisons between sites and management options, but may or may not actually approach values observed in the field (Tysdal *et al.* 1997). This version of WEPP has been shown to provide reasonable results on forest roads when detailed parameter inputs are obtained (i.e. Elliot 1995b.), but limited data have been obtained for rural unpaved roads and it is uncertain how well this model predicts erosion from these roads using the parameters provided with the model and with parameters available in the literature.

## 1.3 Objectives

The specific objectives of this study are to:

1. Install a system for measuring the amount of total erosion from four rural unpaved road segments in Payne County, Oklahoma.
2. Determine the rainfall variables that are most influential on the amount of total erosion from the four rural unpaved road segments.
3. Use the WEPP model with limited parameter modifications to predict erosion on a storm by storm basis for each road segment monitored and compare these results to observed data to determine if WEPP reasonably predicts erosion from rural unpaved roads.

## 1.4 Scope and Limitations

Since most users of the WEPP model (e.g.: agencies, planners) may not have access to the detailed inputs required by the model, use of the model in this study was limited to using input parameters available in the WEPP literature and documentation. Aside from easily measurable parameters such as rainfall and basic soil characteristics, detailed WEPP erodibility parameters were not measured in the field. The intent of using WEPP in this study was to determine how well the model worked over different segments with limited parameter modifications, using the best possible parameter estimates based on the literature and the parameters supplied in the model. Attempts were made to account for management conditions such as grading in some WEPP Runs, but WEPP was not calibrated for each segment. Use of the model in this manner is important since most users of the model would likely rely upon similar methods for estimating WEPP inputs. Knowing how well WEPP performs under these circumstances is critical in determining the utility of the model for different applications in Oklahoma.

# CHAPTER II

# LITERATURE REVIEW

## 2.1 Unpaved Rural Roads

Few studies have been performed to directly quantify the amount of sediment delivered to water bodies from rural road erosion. Several studies have qualitatively noted the importance of unpaved roads as sediment sources in watershed sediment budgets. In an attempt to determine the contribution of agricultural erosion to reservoir sedimentation in the Dominican Republic, Nagle (2001) performed a sediment budget for the Niazo watershed. Since agriculture was the dominant land use in the watershed, it was assumed erosion from agricultural lands would be the major sediment source in the watershed. However, it was concluded that agricultural erosion only accounted for 17 % of the total basin sediment budget, and the roads and trails accounted for over 30 % of the sediment budget despite only covering a very small portion of the total basin. As presented in Nagle (2001), Murdiono and Beerens (1992) estimated that roads, paths, and villages within the Konto watershed in Java accounted for 73.1 % of the total measured erosion contribution while only encompassing 8 % of the total area within the watershed. A study by Dunne (1979) in the Kenya highlands found that rural roads and footpaths were estimated to be responsible for 25-50 % of the total basin sediment yields. Similar studies by Dunne and Dietrich (1982) in an agricultural area of Kenya estimated that rural roads, although encompassing only 2 % of a basin area, contributed disproportionately to basin sediment yield. These studies illustrate the importance of unpaved rural roads as sources of sediment to surface water bodies despite their relative lack of surface cover in most watersheds.

Working in northern Thailand, Ziegler *et al.* (1997) showed that unpaved road surfaces contributed more Horton Overland Flow (HOF) than other land surfaces. This study showed that both permeability and saturated hydraulic conductivity were greatly reduced on road surfaces, resulting in higher HOF, with runoff coefficients often exceeding 80%. It was found that most rainfall did not infiltrate road surfaces and that unpaved roads generated runoff sooner than other surfaces, with runoff occurring over nearly the entire road surface. Again working in northern Thailand, Ziegler *et al.* (2000) used rainfall simulation and field collection to measure the sediment contribution from unpaved road surfaces relative to other land surfaces. Rainfall simulation events yielded instantaneous sediment concentrations in road runoff as high as 100,000 mg/l early in storm events, but eventually decreased as available sediment supply decreased. Typical ranges of sediment concentration in runoff ranged from nearly 100,000 mg/l early in storm events, to approximately 1000 mg/l one hour into storm events. Simulation sediment concentrations were compared to concentrations generated by natural rainfall from a 165 m road segment. Sediment concentrations from the road segment had generally 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 the rainfall simulator were slightly higher than the sediment concentrations generated by natural rainfall (Ziegler *et al.* 2000).

Working in the Guanella Pass area of central Colorado, Stevens (2001) measured road erosion from 37.8 km of an unpaved county road stretching through two counties. Discharge and sediment concentrations were measured directly at four sites using continuous stage recorders and automatic pumping samplers. Manual samples were taken at 17 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. Suspended sediment concentrations for snowmelt events ranged from 66-7,360 mg/l, with a median of 7,190 mg/l. This study found that flow-weighted mean sediment concentrations (both fine and coarse sediments), ranged from 11,770-17,540 mg/l for rainfall events, and from 639-1,635 mg/l for snowmelt events. Approximately 52% of the road area drained directly into streams, delivering large quantities of sediment into the local stream network. In western Washington, Bilby (1985) determined that approximately 21% of the total suspended sediment input to a local stream was contributed from unpaved roads. The study measured the suspended sediment contribution from two unpaved rural roads using automatic samplers and grab samples during flow events. The study found that road runoff contributed 20.4 T of sediment from 1980-81, or approximately 21% of the total sediment budget for the entire stream.

On the island of St. John in the U.S. Virgin Islands, MacDonald *et al.* (1997) estimated erosion rates from unpaved roads at 26 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 amount into a volume of material lost using a relationship between area and slope. In one watershed, erosion was estimated at 600 T/yr for 16 km of unpaved road, or 37.5 T/km/yr. In the other watershed, erosion was estimated as 100 T/yr for 1.4 km of unpaved roads, or 71.4 T/km/yr. It is important to note that this study assumed there was no additional compaction of the road surface from traffic or rutting, meaning all observed material loss under the transect boards was attributed to erosion. Therefore, the reported erosion rates are likely somewhat higher than actual erosion rates. Nonetheless, this study illustrates the potentially significant contribution of sediment from roads.

In the Stillwater Creek watershed in central Oklahoma, initial estimates of road erosion from the 152 km of unpaved roads in the Lake Carl Blackwell sub-watershed alone was estimated to be 2,140 T/yr (14 T/km/yr of road surface). Rural roads in this region are typically incised below the surrounding land. As a result, there is little opportunity for sediment to be routed away from the roads before it reaches streams. Rural road drainage typically flows directly into streams. About 80% of the unpaved roads in the Lake Carl Blackwell drain directly into streams. The remaining 20% drain into riparian areas or vegetated ephemeral stream channels, where some filtering of sediment may occur (Turton, Storm and Neal, 2000, unpub.)

Other studies have attempted to quantify the amount of sediment delivered from unpaved rural roads. However, many of these studies simply use estimates from previous studies or other methods as a basis for estimating the sediment contribution from roads inside a watershed. For example, Nelson and Booth (2002) completed a sediment budget for the

144 km$^2$ Issaquah Creek watershed in western Washington. The 420 km of roads (both paved and unpaved) in the watershed were found to occupy 2.6 % of the total watershed area. 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 sediment produced annually in the basin.

Another example is a study in the Rio Puerco watershed in New Mexico (Phippen and Wohl 2003). The Rio Puerco watershed is experiencing rapid channel erosion that has been attributed to land use, climate changes, and internal channel adjustments. Average annual sediment loads were estimated for 17 sub-basins by measuring sediment accumulation behind sediment retention structures. Using original survey data for the completed structures, and re-surveying each structure again in 1999, estimates of mean annual sediment loads were estimated by converting the elevation changes behind the sediment retention structures into volumes of sediment and dividing by the period of record. The study hypothesized that sub-basins with higher grazing intensity and unpaved road density would be correlated to higher sediment loads. It was found that except for small, low-relief watersheds, grazing was not a significant factor in higher sediment loads. However, there was a strong correlation indicated between higher sediment loads and the density of unpaved roads. Although no direct measurements of erosion rates were collected in these studies, they highlight the potential contribution of a road network to an overall watershed sediment budget.

## 2.2 Forest Roads

Forest roads are similar to unpaved rural roads in that they carry a low traffic volume and are unpaved. In many instances, forest roads are indistinguishable from unpaved rural roads, with the exception of forest roads often carrying less traffic. Conversely, many forest road systems can be very different from rural road systems and direct comparisons may not be appropriate. Regardless, forest roads have historically received more attention in terms of erosion studies, and a more extensive literature base is available on erosion from forest road systems. Although sometimes different from unpaved rural roads, erosion studies on forest roads are useful since intensive measurements of unpaved rural road erosion are generally unavailable, especially for unpaved rural roads in Oklahoma.

Erosion from forest roads has long been recognized as an important source of sediment. The earliest estimates of erosion from road surfaces were first reported by Gilbert in 1917; however measured rates of forest road erosion did not occur until the 1950's. During the 1960's, long-term monitoring of watersheds began to be reported, but the majority of these studies did not isolate different sources within the watersheds studied (Reid and Dunne 1984). Work by researchers such as Megahan and Kidd (1972), Dunne and Dietrich (1982), and Reid and Dunne (1984), amongst others, began to quantify the sediment contribution of forest roads and established that erosion from road surfaces is many times higher than for undisturbed slopes.

In a review of past forest road studies in New Zealand, Fransen *et al.* (2001) found that annual sediment yields from forest roads as high as 15 kg/m$^2$. The studies represented in the review consisted of a variety of geologies, treatments, slope, precipitation, and other characteristics. It was shown that the highest sediment yields typically occurred on granite geologies with steep slopes or bare/ungraded road surfaces. Erosion rates varied widely on individual road segments, ranging from 38-380 T/km/yr for 10-year old roads; and 266-7600 T/km/yr for newly constructed roads. The studies reviewed indicated that the erosion rates were generally within natural background erosion rates, but sediment from the forest roads has the potential to cause adverse effects on local stream networks, although it was noted there are no studies to confirm this.

In the Clearwater Basin in western Washington, ten forest road segments with variety of characteristics were monitored in an attempt to quantify rates of erosion from the road surface (Reid and Dunne 1984). Rainfall, discharge, and sediment concentrations were measured at culverts that defined each segment. From 1977-1978, erosion rates as high as 440 T/km/yr were measured for heavy use forest roads, and as low as 0.43 T/km/yr for abandoned roads. Temporary nonuse roads and moderate use roads had sediment yields of 58 and 36 T/km/yr, respectively; while light use roads and paved roads had sediment yields of 3.4 and 1.9 T/km/yr, respectively. This study also found that cut bank and ditch erosion did not contribute significant amounts of sediment. Luce and Black (1999) studied sediment production from 68 forest road segments over a four month period in western Oregon. Of the 68 segments monitored in this study, 60 segments produced 0-200 kg of sediment over the study period, while the remaining segments produced as much as 1,800 kg. This indicates that most segments produce little sediment, while only a few produce large quantities, suggesting that managing sediment production on the few high risk segments would be the most efficient method of protecting water quality (Luce and Black 1999).

Several forest road erosion studies have been conducted in the Ouachita Mountains of Oklahoma. Turton and Vowell (2000) found that average erosion from a two-year old forest road measured 83 T/ha/yr over a three year period. Vowell (1985) found erosion rates from four forest road segments on a recently established forest road ranged from 42-470 T/ha, with an average yield of 224 T/ha. Over an 18-month period in 2003-2004, Busteed (2004) measured erosion on two established road segments in southeast Oklahoma. Erosion rates of 7.6 T/ha/yr and 6.5 T/ha/yr were observed from the segments. It is important to note that Busteed (2004) encountered below-normal precipitation for the study period, and that no large or infrequent sized storms occurred, so these measurements are likely lower than a typical year. In the Ouachita Mountains of Arkansas, Miller *et al.* (1984) found that over a one year period sediment was produced from four road segments on a typical road forest road at an average rate of 57 T/ha/yr. It was also reported that over 50 percent of the total sediment in this study was produced was from a single 100-year rain event. These studies demonstrate the high degree of variability in erosion between road segments in the same geographic region, and the importance of precipitation patterns and storm size on sediment production.

## 2.3 Water Erosion Prediction Project (WEPP) Model

The Water Erosion Prediction Project (WEPP) soil erosion model is a process based computer model used to predict runoff, soil erosion, and sediment delivery. The WEPP model is based on the fundamentals of stochastic weather generation, infiltration theory, hydrology, soil physics, plant science, hydraulics, and erosion mechanics. The WEPP model is physically-based and continuously models climate, soil water content, and plant growth on a daily time step. The most notable advantage of the WEPP model is that it provides spatial and temporal distributions of soil loss, which can be applied to many conditions without field testing since the model is process-based (Flanagan and Nearing 1995). Another advantage of the WEPP model is that it can be easily used in areas where soils, climate, and vegetation may vary widely (Elliot *et al.* 1995). WEPP has been commonly used for estimation of erosion from forest roads, where the model was calibrated to specific locations (i.e.: Tysdal *et al.* 1997, Elliot *et al.* 1995b, Elliot *et al.* 1994). No studies to date have been reported specifically for rural unpaved roads.

The WEPP model technology includes three versions: a hillslope profile version, a watershed version, and a grid version (Elliot *et al.* 1995b).The hillslope profile version allows users to model a hillslope of non-uniform condition. This version predicts when and where soil loss and deposition will occur on a hillslope, taking into account management practices and climate. The modeling is continuous, simulating the processes that affect erosion with a daily time step (Elliot *et al.* 1995b). The watershed version links hillslope elements, channel elements, and impoundment elements to describe small watersheds (Elliot *et al.* 1995, Elliot *et al.* 1995b). The grid version combines a grid of hillslopes into a catchment that can exceed several square miles.

The hillslope version of the WEPP model is the most widely used version and is the version most suitable for modeling simple road designs. The watershed version allows several hillslope features to be combined into a small watershed, and is useful because it allows more detailed modeling of the cut slope as well as the road surface. For this research, the hillslope version of WEPP was employed since the segments included in this study were simple road designs and the cut slopes were well vegetated. Several studies have noted that well vegetated cutslopes generally do not contribute significant amounts of sediment and are not necessary for reasonable modeling (e.g.: Reid and Dunne 1984, Elliot *et al.* 1994, Tysdal *et al.* 1997). Future references to WEPP in this paper are to the WEPP hillslope version.

There are four main input files in the WEPP hillslope version: slope, soil, climate, and management.

<u>Slope</u>: The slope input file contains the user specified length and width of the hillslope. This file contains at least two pairs of points specifying the percent difference from the top of the slope, and the percent slope at each point. Also identified is the slope aspect, which is the direction the profile faces, in degrees from 1 to 360. Up to ten points can be specified for each hillslope.

<u>Soil</u>: The soil input file describes the surface soil layer. Parameters required to describe the soil are albedo, initial saturation, interrill and rill erodibility, critical shear, and

conductivity. Up to ten other soil layers, each up to two meters deep, may be specified. The layer thickness, initial bulk density, initial hydraulic conductivity, field capacity, wilting point, textural composition, and cation exchange capacity (CEC) are specified by the user.

Climate: The climate input file requires input of daily maximum, minimum, and dew point temperatures; rainfall amount, duration, intensity and time to peak; solar radiation; and wind speed and direction. Generally, the stochastic weather generator CLIGEN is used to generate climate input files from a 100-km grid of weather stations. A single storm mode is available, where measured data from individual storms may be substituted.

Management: The management input files include the description of vegetation and the timing and effects of tillage operations on soil erodibility properties. The management input file also allows the user to set the number of overland flow elements (OFEs) for the hillslope profile. An OFE is an area on the hillslope where the soil type, vegetation type, and management practices are homogeneous. A single hillslope may contain up ten OFEs (Morfin *et al*. 1996).

The WEPP model divides soil erosion into two processes: rill and interrill erosion. Interrill erosion is driven by detachment and transport of sediment due to raindrop impact and shallow overland flow. Interrill erosion is determined from the equation:

$$D_i = K_i I^2 S_f \ f(\mathrm{c})$$

where $D_i$ is the interrill erosion rate (Kg/m$^2$/sec), $K_i$ is the interrill erodibility (Kg-s/m$^4$), $I$ is the rainfall intensity (m/s), $S_f$ is the slope factor, and $f$(c) is a function of vegetation canopy and residue (Elliot *et al*. 1994, Elliot *et al.* 1995b).

Rill erosion is the detachment and transport of sediment by concentrated channel flow. The erosion rate is a function of the hydraulic shear and the amount of sediment already in flow. Rill erosion is estimated from the equation:

$$D_t = K_r (t - t_c) (1\text{-}G/T_c)$$

where $D_t$ is the rill erosion rate (Kg/m$^2$/sec), $K_r$ is the rill erodibility (sec/m), $t$ is the hydraulic shear of the water flowing in the rill, $t_c$ is the critical shear below which no erosion occurs (Pa), $G$ is the sediment transport rate (Kg/m/sec), and $T_c$ is the rill sediment transport capacity (Kg/m/sec) (Elliot *et al.* 1995b). Discussion of inputs to the WEPP model and the assumptions used in this study will be discussed in Chapter 3.

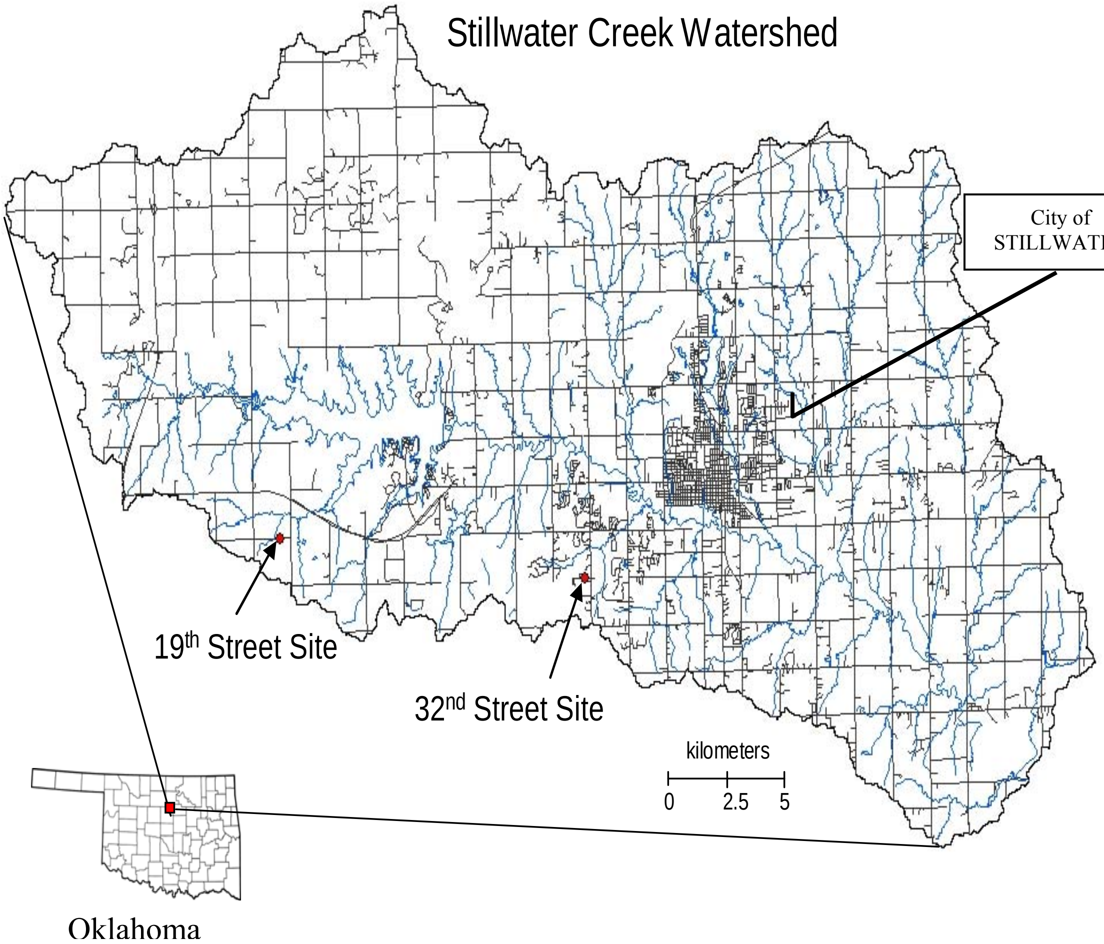
# CHAPTER III

# METHODS AND MATERIALS

## 3.1 Study Sites

Two monitoring sites in the Stillwater Creek Watershed were chosen based on various characteristics. Although two sites can never completely represent the variation of soils, topography, road conditions and traffic patterns of roads across a watershed, the roads on the two sites were "typical" of many rural unpaved roads in the watershed. The first site was locate on 32nd St. approximately two miles west of Stillwater, OK, and the second site was located about 15 miles west of the city of Stillwater on 19th St, between Vassar and Perry Roads (Figure 1). The sites will henceforth be called the 32nd St. and 19th St. sites.

Sediment collection stations collected water from only one half of each road segment, as defined by the crown in the road and bar ditches. Each station was named based on the street number and the compass quadrant in which it was located; ie: 32 NE, 32 NW, 19 NE and 19 NW. The 32nd Street site consists of two road drainage segments on either side of a valley that drain towards a stream. One segment drains east towards the stream, the other west. The road was constructed of sandy loam native material and covered with layers of gravel. These segments were chosen because of their insufficient crowning and shallow ditches that do not provide adequate drainage for the road bed. Direct observation suggested the ditches do not handle flows without eroding the ditch and road bed. These design deficiencies are common on rural unpaved roads in the watershed.



Streams ———
Roads ———

19th Street: 36º 6.080’ N, 97º 17.290’ W
32nd Street: 36º 4.895’ N, 97º 7.538’ W

Figure 1. Location Map of the Stillwater Creek, Oklahoma Watershed and study sites.

The 19th Street site consists of two road drainage segments on either side of a common ridge. One segment drains east, the other west. The westward draining segment drains into a stream. The eastward draining segment drains into an ephemeral swale on the south side and a farm pond on the north side. The road was constructed of sandy clay loam native material over bedrock and has no gravel cover. This site was selected because like many non-graveled roads in the watershed, it lacked bar ditches to provide 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. Individual road segments characteristics.

| Segment | Length (m) | Area (ha)* | Average Slope (%) | Soil Texture** |
|---|---|---|---|---|
| 19 NE | 154 | 0.05 | 8.6 | Clay Loam |
| 19NW | 199 | 0.06 | 9.1 | Sandy Clay Loam |
| 32 NE | 252 | 0.08 | 7.2 | Loamy Sand |
| 32NW | 178 | 0.05 | 6.6 | Sandy Loam |

* Area of road bed and ditch only.
** From USDA Handbook No. 18 August 1951.

### 3.2 Sediment Collection Methodology

A sediment collection station was installed on each segment. Each station consisted of a sediment collection trough, an approach box, and a 0.46 m H-Flume. The stations were also equipped with automatic pumping samplers that sampled water and sediment not trapped in the trough (Figure 2). The flumes allowed for the measurement of discharge through the station during storms. The sediment collection stations were connected to the bar ditches and located at the end of each road segment close to where the water would have entered streams or other natural outlets. Some modifications in location had to be made depending on the gradient of the road and surrounding land. Each sediment collection station trapped sediment from about one-half of the road prism (Figure 3); 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.

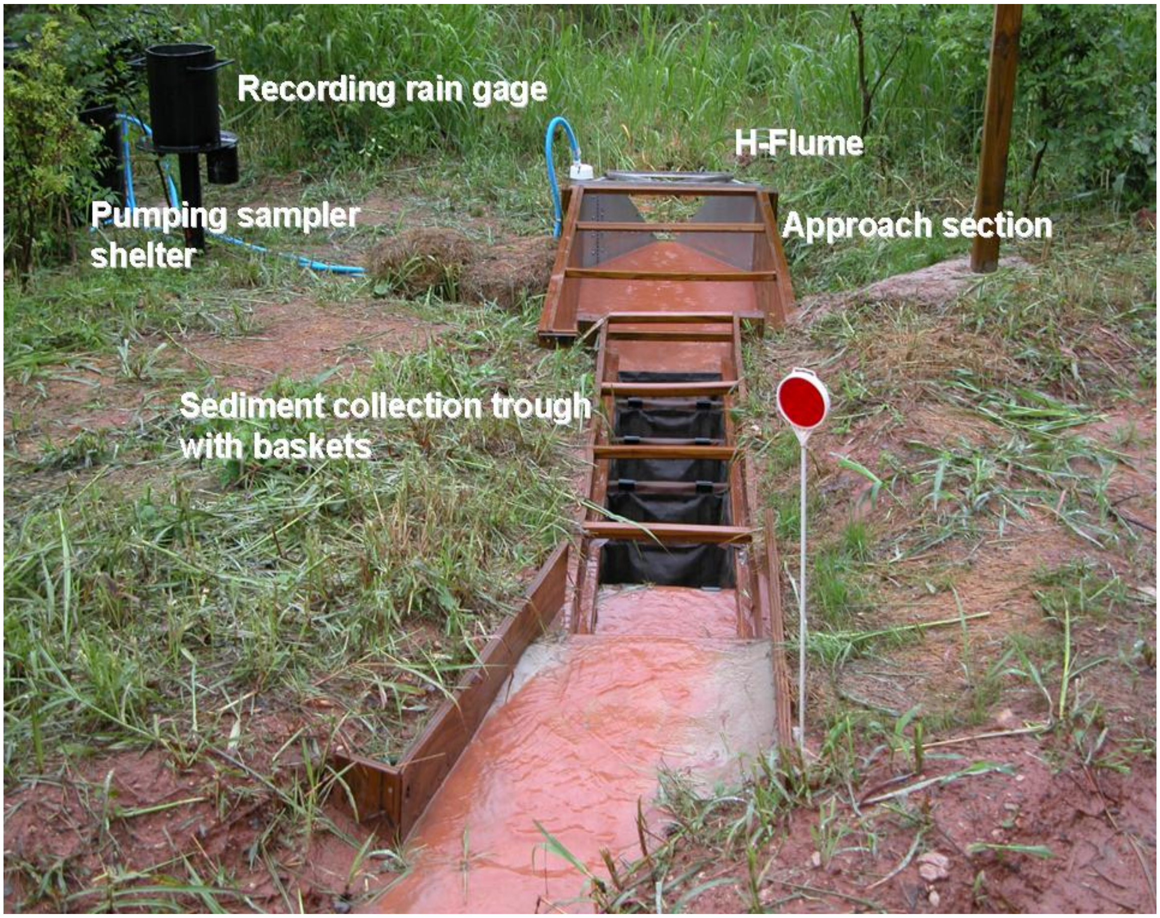


Figure 2. Components of the sediment collection stations used to measure erosion from each road segment.

Figure 3. View of the 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. Seven plastic baskets were placed in the troughs. The baskets were lined with landscape fabric that helped trap coarse 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 in the flumes was measured by pressure transducers (KWK Technologies, Inc. SPXD-600/610, 5 psi) 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 the velocity and hence mixing are greatest. The samplers had a capacity of twenty-four 500-ml bottles. Therefore, 24 discrete water samples could be collected during each storm.

One siphoning tipping bucket rain gage was installed at each site. Data from the gages were collected by the data loggers and shared by each pair of segments. A non-recording plastic rain gage was also installed at each site as a secondary measurement. The data loggers were programmed to measure stage and precipitation every five minutes. The program also 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 was above the minimum, samples were collected if the stage changed by a certain amount or if a certain amount of time elapsed (if stage remained constant). This allowed samples to be taken throughout a storm while preserving available bottles. However, bottles often had to be changed during long duration storm events.

### 3.3 Sediment Load Calculation Methodology

After each storm, the sediment in each collection basket was weighed in the field using hanging balances and emptied. Sub-samples were pulled from each basket , weighed, and oven dried at 105° C for 72 hours, then re-weighed upon drying. The moisture content of each sub-sample was then calculated using the equation:

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

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

Water samples from the automatic pump samplers were collected and returned to the laboratory. The weight of sediment-water mixture in the sample was estimated using a top-loading balance and the weight of the sediment in each sample was obtained by evaporation (Guy 1969). The PPM (parts per million) of sediment were calculated by dividing the dry weight of the sediment of the by the sample mass. At concentrations <16,000 PPM, PPM is equal to mg/l. Above 16,000 PPM, it becomes necessary to apply a correction factor to account for the mass of sediment in the sample in order to convert PPM to mgl/. The following equation was used to correct for the volume of sediment in the sample (Guy 1969):

$$\text{mg/l} = C\ (\text{ppm}) = C\ [(\text{weight of sediment} \times 1{,}000{,}000)/\text{weight of water-sediment mixture}]$$

where weights are in grams and C is a correction factor based upon the initial sediment concentration. C values were obtained from tables provide in Guy (1969).

For each storm, stage height measurements were recorded in five minute intervals. Stage height was then converted to discharge for each five minute interval using standard rating tables for 0.46m H-flumes. The sediment concentration for the interval was then multiplied by the discharge 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 sediment load represented the total load for the storm event.

## 3.4 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 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 the total flow for a storm. The rainfall erosion index (R) is a factor in the RUSLE, and is defined as the product of the total storm energy (E) times the $I^{30}$ divided by 100. The total storm energy (E) is defined by the equation: $E = e\ P$, where $e = 1099\ [1 - 0.72 \exp(-1.27i)]$ and P is the total precipitation and $i$ is the average rainfall intensity for the storm (as presented in Haan *et al*. 1994)

## 3.5 WEPP Methodology

The Hillslope option in WEPP Interface Version July 10, 2002 was used for this study. A total of 16 model runs (parameter sets) were performed, four for each segment: 1) using default input parameters provided in the model templates, 2) using values recommended in the literature and model documentation, 3) using default values and accounting for grading and 4) using recommended values and accounting for grading. The WEPP model was not calibrated for any parameter. The hillslope version required four main input files for each segment: climate, soil, management, and slope. A detailed summary of WEPP inputs is provided in Appendix A.

### 3.5.1 Climate Files

Climate files were derived from rain gage data collected at each site. Since only one gage was employed at 32nd St. and one at 19th St., identical rainfall data were used for both stations on each site. For each discrete storm, total precipitation, maximum five-minute precipitation intensity, storm duration, and the percent of time to maximum intensity were calculated. These parameters were then used to create WEPP storm files (.CLI files) for individual storms. The same climate files were used for each of the four WEPP runs on a given segment. The climate files for each site by storm date are summarized in Tables A-1 and A-2 in Appendix A.

### 3.5.2 Soil Files

Soil texture was obtained through soil particle size analysis of composite samples following methods outlined in Gavlak *et al*. (1994). Each composite sample consisted of a mixture of at least ten sub-samples (10 cm deep) collected at regular intervals from each segment. The percent of sand, silt, clay, and rock are shown in Table 2. The percent silt was not a required input in the WEPP model.

Table 2. Basic soil characteristics for each road segment.

| Segment | % Sand | % Silt | % Clay | % Rock | Soil Texture* |
|---|---|---|---|---|---|
| 19 NE | 43 | 28 | 29 | 35 | Clay Loam |
| 19 NW | 50 | 26 | 24 | 40 | Sandy Clay Loam |
| 32 NE | 74 | 10 | 16 | 20 | Loamy Sand |
| 32 NW | 64 | 20 | 16 | 44 | Sandy Loam |

* From USDA Handbook No. 18 August 1951.

After determining soil texture, the appropriate soil template (.SOL file) was selected in WEPP. Each WEPP soil template contained default soil parameters that were used for the initial WEPP run: $K_i$ – interrill erodibility, $K_R$ –rill erodibility, $T_c$ – critical shear stress, and $K_c$ – hydraulic conductivity. Initial percent saturation at the start of each storm was also required. Since percent saturation changes over time, a simple approach for estimation was devised based upon methods for determining antecedent moisture conditions in the SCS Curve Number Method. The dormant season 5-day antecedent rainfall totals described in Ward and Trimble (2004) were modified to include a category for very dry periods. The initial percent saturation was divided into four conditions: A (very dry), B (dry), C (average), and D (wet). The criteria for each condition are summarized in Table 3.

Table 3. Criteria for estimating the initial percents saturation of the soil.

| Condition | Initial % Saturation | Antecedent 5-Day Precipitation Total (mm) |
|---|---|---|
| A (Very Dry) | 35 | 0 |
| B (Dry) | 50 | < 13 mm |
| C (Average) | 60 | 13 to 27 mm |
| D (Wet) | 70 | > 28 mm |

An initial percent saturation of 70 percent represented a soil that was at approximately field capacity. Field capacity (70% saturation, 0.33 bars, or approximately 15 % water by weight) was the recommended value in the WEPP online manual. The wilting point is the point at which no water is available for use by plants (approximately 20-25 % saturation, 15 bars, approximately 3-4 % water by weight). Since vegetation near the segments and in the ditches on each segment never appeared stressed or wilted, it was assumed that wilting point was never reached, therefore a value of 35 percent initial saturation appeared a reasonable estimate for very dry periods. The percent saturation is the only variable that was altered in the soil file for each WEPP run. The percent saturation condition for each storm is provided in Tables A-1 and A-2 in Appendix A.

The WEPP template "Clay Loam Insloped Road, Bare Ditch, Native Surface" was used for the 19 NE and 19 NW segments, and the WEPP template "Sandy Loam Insloped Road, Bare Ditch" was used for the 32 NE and 32 NW segments. The default soil parameters for each template are shown in Table 3-4, and were the parameters used in the default WEPP run. Using the same soil templates for each segment, the soil parameters were then modified using values recommended in Elliot and Hall (1997). The recommended values were generic values recommended for situations where no soil parameter values were known, regardless of soil type. The same recommended values were used for all four segments, since they were generic values for roads subject to periodic maintenance. The recommended soil values are shown in Table 4, and were the soil parameter values used in the recommended WEPP run. For both the default and recommended WEPP runs, the only variable altered by storm was initial percent soil saturation.

Although not measured directly, field observations over the study period suggested grading likely had a substantial impact on the amount of total erosion. The first storm after grading generally was observed to experience more erosion than similar storms that occurred when there was no recent grading. The effects of grading were generally visible by observation for at least 2-3 storms after the grading, depending upon the characteristics of the storms. These observations were consistent with other studies (Ried and Dunne 1984, Grayson *et al*. 1993). The approximate observed dates of grading were June 1, June 15, and July 1, 2004.

To account for grading in the model, parameter values obtained from Elliot *et al*. (1994) and Tysdal *et al*. (1997) that described the effects of disturbance were used. For the first storm after grading, erodibility values near the high end of the published range were used to simulate the increase in material available for transport on the road surface (Grading Condition I). For the second and sometimes third storm after a grading event, erodibility parameters were reduced to values between the disturbed and baseline condition (Grading Condition II). The revised parameters were only applied to storms where grading was directly observed in the field. Two WEPP runs for each segment were performed to account for grading: default values accounting for grading, and recommended values accounting for grading. Only the storms affected by grading were altered for each of these runs, all other storms were left as default or recommended values for their respective runs. A summary of the values used to describe grading is provided in Table 4, as well as the affected storms

Table 4. WEPP soil file input parameters used for the WEPP parameter sets.

“Clay Loam Insloped Road, Bare Ditch, Native Surface” -19 NE and 19 NW

| | $K_i$ (kg-s/m$^{4)}$ | $K_R$ (s/m) | $T_c$ (Pa) | $K_c$ (mm/hr) | Storm Dates |
|---|---|---|---|---|---|
| Default | $1.5e^{006}$ | 0.0002 | 0.04 | 0.1 | All |
| Recommended | $3.0e^{006}$ | 0.0003 | 1 | 0.4 | All |
| Grading I | $3.0e^{006}$ | 0.01 | 0.7 | 0.4 | 6-2, 6-19, and 7-06 |
| Grading II | $2.5e^{006}$ | 0.0004 | 0.9 | 0.4 | 6-9, 6-20, and 6-21 |

“Sandy Loam Insloped Road, Bare Ditch” – 32 NE and 32 NW

| | $K_i$ (kg-s/m$^4$) | $K_R$ (s/m) | $T_c$ (Pa) | $K_c$ (mm/hr) | Storm Dates |
|---|---|---|---|---|---|
| Default | $2.0e^{006}$ | 0.0004 | 0.04 | 3.8 | All |
| Recommended | $3.0e^{006}$ | 0.0003 | 1 | 0.4 | All |
| Grading I | $3.0e^{006}$ | 0.01 | 0.04 | 3.8 | 6-2, 6-5, and 6-21 |
| Grading II | $2.5e^{006}$ | 0.001 | 0.5 | 3.8 | 6-9, 6-22 |

### 3.5.3 Management Files

The management input files (.ROT files) include the description of vegetation and the timing and effects of tillage operations on soil erodibility properties. The same management file was selected for all twelve runs: Insloped road-bare surface. This file contained default management values for typical insloped roads. This file was altered so the percentage of rill and interrill covers match the percentage of rock (Table 2) for each segment. All other parameters in this file were left as default values for each WEPP run.

### 3.5.4 Slope Files

When roads have both grade and crown gradient (inslope), water travels neither parallel nor perpendicular to the road surface and it becomes necessary to determine the effective slope, length, and width of the flow path over the road surface. These values were calculated using the equations (Elliot *et al*. 1994, Elliot 1999):

$$\text{Effective Slope} = \sqrt{\text{Crown Gradient}^2\ (\%) + \text{Road Gradient}^2}$$

Effective Length = Road Width x (Effective Slope/Outslope Slope)

Effective Width = (Road Length x Road Width)/Effective Length.

The only segments that were properly crowned with an inslope were 32 NE and 32 NW, and these equations were applied only to these segments. The slope of each segment was determined using differentially corrected Global Positioning System (GPS) data with sub-meter resolution. The slope of the crown was determined using cross sectional surveys taken at various locations on each segment. On the 19 NE and 19 NW segments, no crown was detected on either segment when cross sectional surveys were taken. Water on these segments essentially flows from the top of the hill to the bottom in a relatively straight path, making the use of the actual road width, length, and slope more appropriate for use in WEPP to describe the flow path. Direct observations of the flow of water from these segments during precipitation events support this. A summary of slope files (.SLP files) is provided in Table 5, and detailed slope information for each segment is included in Table A-3 in Appendix A.

Table 5. The characteristics of the flow path for each segment.

| Site | Effective Length (m) | Effective Width (m) | Effective Slope (%) |
|---|---|---|---|
| 19 NE | 154 | 3.6 | 8.6* |
| 19 NW | 194 | 3.6 | 9.1* |
| 32 NE | 6.3 | 136.6 | 9.3 |
| 32 NW | 5.9 | 119.3 | 8.8 |

* Overall average slope. Detailed slope inputs supplied in Appendix A.

### 3.5.5 WEPP Assumptions

Several assumptions were made in order to model erosion from each segment:

1) Since only one rain gage was used on each site, rainfall was identical on both segments for a given site.

2) Since the sediment collection stations were located at stream crossings or swales, the amount of sediment collected represented that amount of sediment actually reaching a stream.

3) For a given segment soil characteristics were uniform over the entire segment.

4) Since the cutslopes on each segment were well vegetated and stable, they did not contribute significant amounts sediment and were not included in the model.

5) Grading operations were identical and uniform on both segments on each site.

6) Road width was constant on each segment.

7) Slope of the inslope on 32 NW was the same as 32 NE.

8) Field capacity (70 % saturation) was the maximum initial saturation level since road surfaces drain excess water quickly.

9) Wilting point (35 % saturation) was the lowest estimated initial saturation level since the wilting point is approximately 20 % and no vegetation near the road or in the ditch ever appeared stressed or wilting during the study period.

## 3.6 Comparison of Results

Observed and predicted values were compared using linear regression. The coefficient of determination for the regression, $R^2$, indicates the variance about the best-fit line and proportion of the total variance in the observed data that can be explained by the model (Legates and McCabe 1999). Values range from 0-1.0, with higher values indicating better agreement. Additionally, the Nash-Sutcliffe Coefficient of model efficiency, NS, was also used to evaluate the goodness-of-fit between observed and predicted data. The NS coefficient describes the overall fit to a 1:1 line. The coefficient is calculated as follows (Nash and Sutcliffe 1970, as presented in Legates and McCabe 1999):

$$NS = 1 - [\sum (Q_i - Q_{*i})^2 / \sum (Q_i - \overline{Q})^2]$$

Where $Q_i$ are the observed values on an event-by event basis, $Q_{*i}$ are predicted values on an event-by-event basis, $\overline{Q}$ is the average of measured values (average of all events), and $n$ is the number of values. An NS value of 1indicates a perfect fit between measured and predicted values for all events. A value of zero indicates that the fit is as good as using the average value of all the measured data for each event (Legates and McCabe 1999).

# CHAPTER IV

# RESULTS

## 4.1 Precipitation

The collection stations were installed in May 2004. In the period from June 1, 2004 through November 11, 2004, data from 26 storms were collected and analyzed. Rainfall during the study period totaled 585 mm at the 32nd Street rain gauge and 463 mm at the 19th Street rain gauge. The normal rainfall total during this period in Payne County is 507 mm. Total precipitation over the study period was 8 percent below normal at 19th Street rain gauge, and 15 percent above normal at the 32nd Street rain gauge (Table 6). June was much wetter than normal, while August and September were much drier than normal. During August and September, only three storms were observed at 32nd Street and four storms were observed at 19th Street. The total precipitation from individual storms ranged from 3 mm to 56 mm. Maximum five-minute storm intensities ranged from 3 mm/hr to 100 mm/hr. A summary of rainfall characteristics by storm for each segment is provided in Tables 9 through 12.

Table 6. Summary of monthly and total precipitation (mm) for each site.

| | | June | July | Aug. | Sep. | Oct. | Nov.* | Total |
|---|---|---|---|---|---|---|---|---|
| Normal Precipitation (mm) | | 110 | 68 | 78 | 105 | 82 | 65 | 510 |
| 19th Street | Observed (mm) | 170 | 73 | 40 | 44 | 92 | 46 | 460 |
| | % of Normal[+] | + 53 | + 7 | - 48 | - 58 | + 12 | - 29 | - 8 |
| 32nd Street | Observed (mm) | 210 | 90 | 50 | 40 | 110 | 90 | 585 |
| | % of Normal | + 92 | + 31 | - 40 | - 62 | + 35 | + 34 | + 15 |

* Based on period from Nov. 1 through Nov. 11.

[+] US Department of Commerce long-term average 1971-2000 (2002).

## 4.2 Erosion

The total erosion for individual storms from the four segments ranged from 1 kg to 3,230 kg, with an average of 370 kg across all four segments. Erosion per unit area for individual storms ranged from 16 kg/ha to 53,100 kg/ha, with an average of 6,200 kg/ha across all four segments. The cumulative total erosion from the segments through the study period was 5,340 kg for 19 NE, 5,900 kg for 32 NW, 6,880 kg for 32 NE, and 14,300 kg for 19 NW. The cumulative erosion per unit area for each site was 89,500 kg/ha for 32 NE, 109,000 kg/ha for 32 NW, 113,000kg/ha for 19 NE, and 234,000 kg/ha for 19 NW, with an overall erosion per unit area across all four segments of 135,000 kg/ha (Table 7). Total erosion and erosion per unit area for individual storms for each segment is summarized in Tables 8 through 11.

Table 7. Summary of cumulative total erosion and erosion per unit area for each segment for the period June 1 through November 11, 2004.

| Site | Cumulative Erosion (kg) | Segment Area (ha)* | Erosion Per Unit Area (kg/ha) |
|---|---|---|---|
| 19 NE | 5,340 | 0.05 | 113,000 |
| 19 NW | 14,300 | 0.06 | 234,000 |
| 32 NE | 6,880 | 0.08 | 89,500 |
| 32 NW | 5,900 | 0.05 | 108,000 |
| ALL SITES | 32,400 | 0.24 | 135,000 |

* Area of road bed and ditches.

Table 8. Summary of precipitation variables and erosion by storm for 19 NE.

|  | Precipitation Variables |  |  |  |  |  | Erosion Variables |  |  |
|---|---|---|---|---|---|---|---|---|---|
| Date | Total (mm) | Maximum Intensity (mm/hr) | Maximum 30-Minute Intensity (mm/hr) | Mean Intensity (mm/hr) | R-Factor | Total Flow (L) | Total Erosion (kg) | Total Per Unit Area (kg/ha) | % of Total |
| 6-02 | 11 | 49 | 22 | 5 | 60 | 6,000 | 470 | 9,900 | 8.8 |
| 6-09 | 36 | 31 | 23 | 4 | 174 | 11,600 | 480 | 10,100 | 8.9 |
| 6-19 | 20 | 73 | 24 | 6 | 111 | 6,900 | 330 | 7,000 | 6.2 |
| 6-20 | 26 | 58 | 19 | 6 | 112 | 8,000 | 590 | 12,600 | 11.1 |
| 6-21 | 45 | 67 | 28 | 4 | 285 | 30,000 | 1,460 | 31,000 | 27.4 |
| 6-22 | 15 | 9 | 8 | 2 | 23 | 10,200 | 150 | 3,100 | 2.7 |
| 7-02 | 9 | 31 | 11 | 2 | 21 | 1,400 | 100 | 2,000 | 1.8 |
| 7-06 | 5 | 18 | 8 | 3 | 8 | 3,900 | 230 | 4,900 | 4.4 |
| 7-28 | 27 | 34 | 14 | 4 | 76 | 7,700 | 100 | 2,100 | 1.9 |
| 7-29 | 9 | 9 | 5 | 1 | 8 | 2,000 | 10 | 150 | 0.1 |
| 8-11 | 20 | 12 | 7 | 2 | 26 | 4,300 | 140 | 2,900 | 2.6 |
| 8-13 | 6 | 15 | 6 | 1 | 7 | 1,500 | 70 | 1,400 | 1.3 |
| 9-05 | 6 | 24 | 10 | 2 | 12 | 750 | 10 | 240 | 0.2 |
| 9-16 | 35 | 88 | 55 | 12 | 504 | 13,700 | 610 | 12,900 | 11.3 |
| 10-07 | 10 | 58 | 17 | 5 | 41 | 3,400 | 130 | 2,800 | 2.5 |
| 10-10 | 52 | 12 | 9 | 4 | 86 | 22,800 | 220 | 4,700 | 4.2 |
| 10-26 | 16 | 76 | 26 | 9 | 104 | 5,200 | 190 | 4,000 | 3.5 |
| 10-27 | 6 | 9 | 4 | 2 | 4 | 1,200 | 2 | 50 | 0.1 |
| 11-01 | 12 | 9 | 7 | 2 | 15 | 4,800 | 0 | 440 | 0.4 |
| 11-03 | 13 | 6 | 4 | 2 | 8 | 4,300 | 10 | 130 | 0.1 |
| 11-10 | 7 | 15 | 8 | 4 | 10 | 750 | 30 | 540 | 0.5 |
| 11-11 | 3 | 9 | 4 | 2 | 2 | 780 | 10 | 180 | 0.2 |

Table 9. Summary of precipitation variables and erosion by storm for 19 NW.

| | Precipitation Variables | | | | | | Erosion Variables | | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Total (mm) | Maximum Intensity (mm/hr) | Maximum 30-Minute Intensity (mm/hr) | Mean Intensity (mm/hr) | R-Factor | Total Flow (L) | Total Erosion (kg) | Total Per Unit Area (kg/ha) | % of Total |
| 6-02 | 11 | 49 | 22 | 6 | 60 | 9,800 | 1,300 | 20,700 | 9 |
| 6-09 | 36 | 31 | 23 | 4 | 174 | 15,900 | 1,300 | 21,200 | 9 |
| 6-19 | 20 | 73 | 24 | 4 | 24 | 13,600 | 800 | 13,500 | 6 |
| 6-20 | 26 | 58 | 19 | 8 | 112 | 12,800 | 2,000 | 31,900 | 14 |
| 6-22 | 15 | 9 | 8 | 3 | 23 | 13,200 | 280 | 4,600 | 2 |
| 7-02 | 8 | 31 | 11 | 2 | 21 | 2,300 | 290 | 4,800 | 2 |
| 7-06 | 9 | 18 | 8 | 2 | 8 | 3,900 | 730 | 12,000 | 5 |
| 7-24 | 11 | 18 | 7 | 1 | 15 | 960 | 30 | 560 | 0 |
| 7-28 | 27 | 34 | 14 | 3 | 76 | 16,000 | 790 | 12,900 | 6 |
| 7-29 | 9 | 9 | 5 | 1 | 8 | 5,400 | 100 | 1,700 | 1 |
| 8-11 | 20 | 12 | 7 | 2 | 26 | 8,700 | 740 | 12,100 | 5 |
| 8-13 | 6 | 15 | 6 | 1 | 7 | 4,300 | 370 | 6,100 | 3 |
| 9-05 | 6 | 24 | 10 | 2 | 12 | 790 | 50 | 760 | 0 |
| 9-16 | 35 | 88 | 55 | 12 | 504 | 26,900 | 3,200 | 53,100 | 23 |
| 10-07 | 10 | 58 | 17 | 5 | 41 | 3,500 | 260 | 4,300 | 2 |
| 10-10 | 52 | 12 | 9 | 4 | 86 | 32,200 | 1,200 | 19,600 | 8 |
| 10-26 | 16 | 76 | 26 | 9 | 104 | 6,600 | 650 | 10,600 | 5 |
| 10-27 | 6 | 9 | 4 | 2 | 4 | 1,900 | 70 | 1,100 | 0 |
| 11-01 | 12 | 9 | 7 | 2 | 15 | 3,500 | 60 | 1,100 | 0 |
| 11-02 | 3 | 3 | 2 | 1 | 1 | 1,700 | 30 | 500 | 0 |
| 11-03 | 13 | 6 | 4 | 2 | 8 | 3,600 | 50 | 890 | 0 |
| 11-11 | 3 | 9 | 4 | 2 | 2 | 740 | 20 | 250 | 0 |

Table 10. Summary of precipitation variables and erosion by storm for 32 NE.

| | Precipitation Variables | | | | | | Erosion Variables | | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Total (mm) | Maximum Intensity (mm/hr) | Maximum 30-Minute Intensity (mm/hr) | Mean Intensity (mm/hr) | R-Factor | Total Flow (L) | Total Erosion (kg) | Total Per Unit Area (kg/ha) | % of Total |
| 6-02 | 23 | 79 | 45 | 9 | 276 | 19,100 | 890 | 11,600 | 13.0 |
| 6-05 | 35 | 101 | 46 | 9 | 415 | 44,500 | 2500 | 32,500 | 36.3 |
| 6-09 | 38 | 18 | 10 | 2 | 73 | 17,200 | 190 | 2,500 | 2.8 |
| 6-19 | 18 | 24 | 19 | 5 | 72 | 7,400 | 90 | 1,100 | 1.3 |
| 6-21 | 50 | 79 | 34 | 5 | 385 | 53,500 | 1700 | 21,900 | 24.5 |
| 6-22 | 18 | 12 | 10 | 3 | 33 | 19,100 | 170 | 2,200 | 2.5 |
| 7-06 | 24 | 61 | 31 | 5 | 171 | 16,200 | 460 | 5,900 | 6.6 |
| 7-24 | 24 | 43 | 24 | 3 | 125 | 9,200 | 180 | 2,300 | 2.6 |
| 7-28 | 17 | 15 | 10 | 2 | 32 | 11,200 | 70 | 960 | 1.1 |
| 7-29 | 8 | 9 | 5 | 1 | 7 | 2,900 | 20 | 200 | 0.2 |
| 8-11 | 34 | 43 | 15 | 2 | 105 | 15,100 | 100 | 1,200 | 1.4 |
| 8-13 | 8 | 27 | 15 | 7 | 28 | 2,200 | 20 | 310 | 0.3 |
| 9-16 | 32 | 67 | 47 | 14 | 377 | 9,200 | 70 | 940 | 1.0 |
| 10-06 | 12 | 34 | 14 | 6 | 38 | 2,200 | 60 | 800 | 0.9 |
| 10-7 | 12 | 67 | 22 | 7 | 71 | 5,100 | 40 | 450 | 0.5 |
| 10-10 | 56 | 24 | 16 | 4 | 167 | 33,400 | 70 | 900 | 1.0 |
| 10-26 | 8 | 27 | 13 | 5 | 22 | 2,200 | 20 | 270 | 0.3 |
| 11-01 | 13 | 6 | 4 | 2 | 9 | 1,700 | 1 | 20 | 0.0 |
| 11-02 | 28 | 55 | 29 | 11 | 185 | 28,200 | 160 | 2,100 | 2.4 |
| 11-03 | 19 | 6 | 5 | 3 | 16 | 6,900 | 10 | 120 | 0.1 |
| 11-10 | 10 | 21 | 14 | 6 | 10 | 6,900 | 40 | 520 | 0.6 |
| 11-11 | 7 | 30 | 11 | 6 | 16 | 5,400 | 40 | 560 | 0.6 |

Table 11. Summary of precipitation variables and erosion by storm for 32 NW.

| | Precipitation Variables | | | | | | Erosion Variables | | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Total (mm) | Maximum Intensity (mm/hr) | Maximum 30-Minute Intensity (mm/hr) | Mean Intensity (mm/hr) | R-Factor | Total Flow (L) | Total Erosion (kg) | Total Per Unit Area (kg/ha) | % of Total |
| 6-02 | 23 | 79 | 45 | 7 | 276 | 17,500 | 1,070 | 19,700 | 18.2 |
| 6-09 | 35 | 101 | 46 | 6 | 415 | 40,900 | 2,050 | 37,700 | 34.8 |
| 6-19 | 38 | 18 | 10 | 2 | 73 | 25,300 | 150 | 2,800 | 2.6 |
| 6-20 | 18 | 24 | 19 | 5 | 72 | 8,900 | 100 | 1,800 | 1.7 |
| 6-22 | 15 | 34 | 11 | 4 | 35 | 12,100 | 120 | 2,200 | 2.1 |
| 7-02 | 50 | 79 | 34 | 5 | 385 | 53,100 | 1,250 | 21,100 | 19.5 |
| 7-06 | 18 | 12 | 10 | 3 | 33 | 38,900 | 110 | 2,100 | 1.9 |
| 7-24 | 24 | 61 | 32 | 6 | 171 | 9,500 | 180 | 3,200 | 3.0 |
| 7-28 | 25 | 43 | 24 | 2 | 125 | 7,100 | 60 | 1,200 | 1.1 |
| 7-29 | 17 | 15 | 10 | 3 | 32 | 6,400 | 50 | 1,000 | 0.9 |
| 8-11 | 8 | 9 | 5 | 1 | 7 | 2,400 | 10 | 130 | 0.1 |
| 8-13 | 34 | 43 | 15 | 2 | 105 | 13,700 | 100 | 1,800 | 1.7 |
| 9-05 | 8 | 27 | 15 | 5 | 28 | 3,800 | 60 | 1,100 | 1.0 |
| 9-16 | 32 | 67 | 47 | 14 | 377 | 7,800 | 60 | 1,100 | 1.0 |
| 10-07 | 12 | 34 | 14 | 6 | 38 | 1,600 | 10 | 120 | 0.1 |
| 10-10 | 56 | 24 | 16 | 4 | 167 | 19,500 | 40 | 900 | 0.8 |
| 10-26 | 8 | 27 | 13 | 5 | 22 | 3,700 | 50 | 1,100 | 1.0 |
| 10-27 | 13 | 6 | 4 | 2 | 9 | 3,700 | 60 | 170 | 0.2 |
| 11-01 | 28 | 55 | 29 | 11 | 185 | 23,900 | 10 | 6,800 | 6.3 |
| 11-02 | 19 | 6 | 5 | 3 | 16 | 10,900 | 370 | 500 | 0.5 |
| 11-03 | 10 | 21 | 14 | 6 | 1394 | 4,100 | 30 | 800 | 0.7 |
| 11-11 | 7 | 31 | 11 | 6 | 16 | 4,100 | 40 | 1,100 | 1.0 |

## 4.3 Precipitation Variable Analysis

Total precipitation, maximum intensity, maximum 30-minute intensity, mean intensity, rainfall erosion index value, and total flow were calculated for each storm. Each variable was compared to the total erosion from each storm using linear regression. The Coefficient of Determination ($R^2$) values of the regressions for all segments combined were: 0.21 for total precipitation, 0.39 for maximum intensity, 0.38 for maximum 30-minute intensity, 0.14 for mean intensity, 0.45 for rainfall erosion index value (R-Factor), and 0.39 for total flow; although there was considerable variation in precipitation variables between segments. The $R^2$ values and observed significance levels of the regressions for individual segments are presented in Table 12. A summary of precipitation variables by storm for each segment is provided in Tables 8 through 11. Scatter plots for the regression of rainfall variables against total erosion for all segments is provided in Figure 4, and scatter plots by segment for each variable against total erosion are provided in Figures B-1 through B-4 in Appendix B.

Table 12. Summary of $R^2$ values and observed significance levels for the regression of precipitation variables against total erosion.

| Site | | Total Precipitation (mm) | Maximum Intensity (mm/hr) | Maximum 30 Minute Intensity (mm/hr) | Average Intensity (mm/hr) | R Factor (MJ-mm/ ha-hr-storm) | Total Flow (L) |
|---|---|---|---|---|---|---|---|
| ALL | $R^2$ | 0.21 | 0.39 | 0.38 | 0.14 | 0.45 | 0.39 |
| | Significance[1] | < 0.05 | < 0.05 | < 0.05 | < 0.05 | < 0.05 | < 0.05 |
| 19 | $R^2$ | 0.45 | 0.38 | 0.41 | 0.19 | 0.41 | 0.64 |
| NE | Significance | < 0.05 | < 0.05 | < 0.05 | < 0.05 | < 0.05 | < 0.05 |
| 19 | $R^2$ | 0.49 | 0.45 | 0.73 | 0.69 | 0.79 | 0.57 |
| NW | Significance | < 0.05 | < 0.05 | < 0.05 | < 0.05 | < 0.05 | < 0.05 |
| 32 | $R^2$ | 0.21 | 0.55 | 0.43 | 0.06 | 0.48 | 0.63 |
| NE | Significance | < 0.05 | < 0.05 | < 0.05 | 0.262 | < 0.05 | < 0.05 |
| 32 | $R^2$ | 0.17 | 0.57 | 0.48 | 0.03 | 0.42 | 0.49 |
| NW | Significance | < 0.05 | < 0.05 | < 0.05 | 0.454 | < 0.05 | < 0.05 |

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

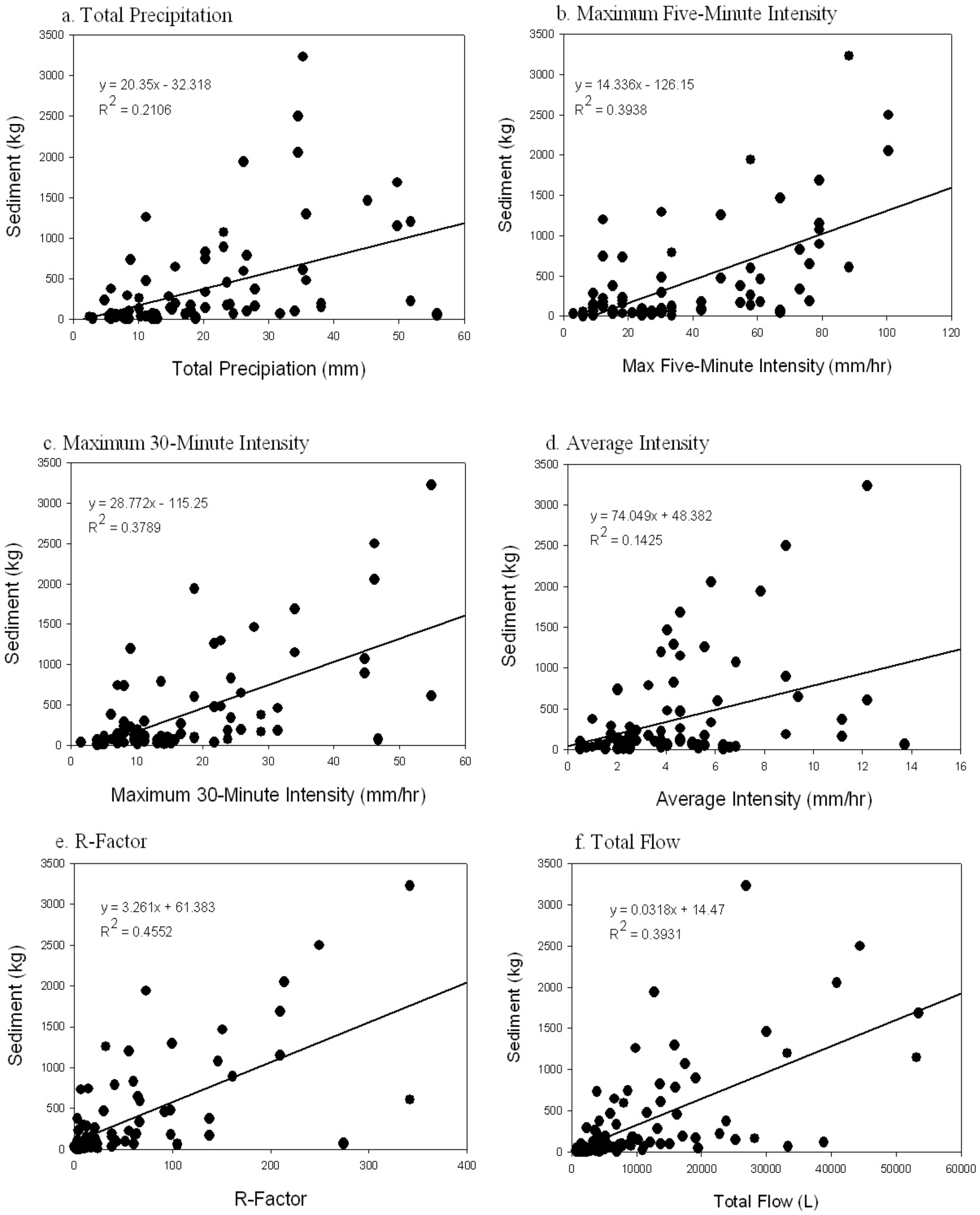


Figure 4. Scatter plots for the regression of rainfall variables against total erosion (kg) for all segments (n= 88).

## 4.4 WEPP Results (Overall)

A total of 16 WEPP model runs were performed, four for each road segment:

1) using default input parameters provided in the model templates,
2) using values recommended in the literature and model documentation,
3) using default values and accounting for grading and
4) using recommended values and accounting for grading.

The summary of the linear regression observed erosion and flow, predicted erosion and flow, $R^2$ values, and NS values for each WEPP run is provided in Table 13. Scatter plots with regression lines for observed versus predicted erosion and total flow for all segments by WEPP run are provided in Figures 5 and 6. Scatter plots for erosion and total flow for each segment by WEPP run are provided in Figures C-1 through C-8 in Appendix C. The residual values of predicted minus observed erosion and flow and the relative errors between predicted and observed erosion and flow were plotted against sediment load (kg) to determine if any trends were apparent based on storm size (sediment load). The residual plots for erosion and flow versus sediment load for all segments are provided in Figures 7 and 8, respectively; and the plots of relative error for erosion and flow versus sediment load are provided in Figures 9 and 10, respectively. The residual values of predicted minus observed erosion and flow were also plotted against storm date to determine if any temporal trends were apparent (See Figures 11 and 12). A tabular summary of observed and predicted total erosion and total flow for each WEPP run by segment is provided in Tables C-1 through C-4 in Appendix C.

Table 13. Summary of comparisons for observed vs. predicted values for erosion and flow for each set of WEPP parameters (p=0.05).

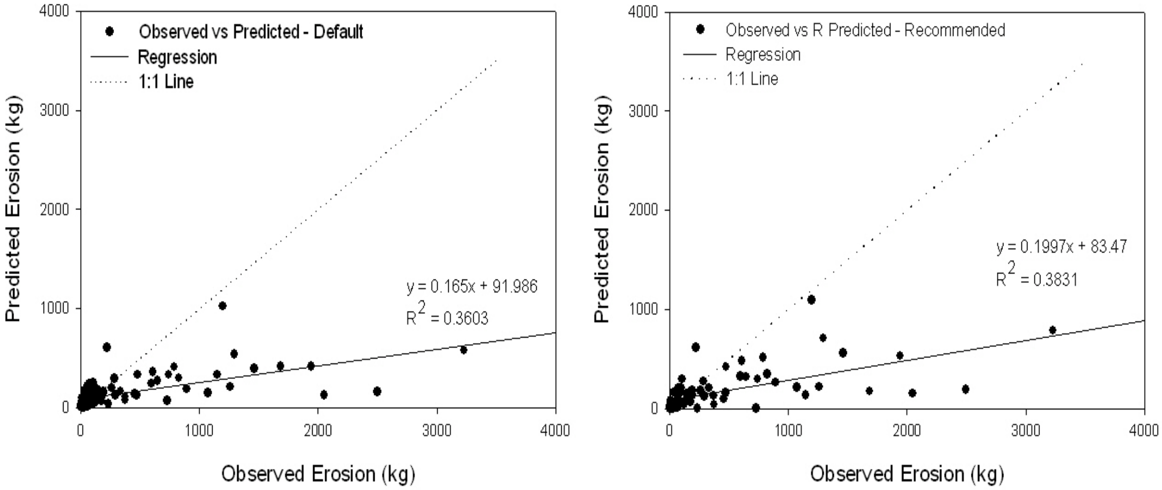
| EROSION | | Observed Erosion (kg) | Predicted Erosion (kg) | $R^2$ Value | NS[3] | Relative Error[1] |
|---|---|---|---|---|---|---|
| Default | Overall | 32,400 | 13,400 | 0.36 | 0.12 | -58 |
| | 19 NE | 5,300 | 3,600 | 0.34 | 0.26 | -32 |
| | 19 NW | 14,300 | 5,700 | 0.41 | 0.04 | -60 |
| | 32 NE | 6,900 | 2,300 | 0.37 | 0.05 | -66 |
| | 32 NW | 5,900 | 1,800 | 0.32 | 0.01 | -69 |
| Recommended | Overall | 32,400 | 13,800 | 0.38 | 0.17 | -57 |
| | 19 NE | 5,300 | 3,800 | 0.51 | 0.45 | -28 |
| | 19 NW | 14,300 | 6,000 | 0.54 | 0.16 | -58 |
| | 32 NE | 6,900 | 2,200 | 0.25 | -0.02 | -67 |
| | 32 NW | 5,900 | 1,800 | 0.32 | -0.03 | -70 |
| Default and Grading | Overall | 32,400 | 22,200 | 0.61 | 0.53 | -31 |
| | 19 NE | 5,300 | 4,800 | 0.64 | 0.59 | -11 |
| | 19 NW | 14,300 | 7,200 | 0.46 | 0.19 | -49 |
| | 32 NE | 6,900 | 5,400 | 0.81 | 0.75 | -22 |
| | 32 NW | 5,900 | 4,800 | 0.76 | 0.75 | -19 |
| Recommended and Grading | Overall | 32,400 | 22,200 | 0.65 | 0.56 | -31 |
| | 19 NE | 5,300 | 4,600 | 0.64 | 0.61 | -13 |
| | 19 NW | 14,300 | 7,200 | 0.58 | 0.28 | -49 |
| | 32 NE | 6,900 | 5,500 | 0.81 | 0.74 | -20 |
| | 32 NW | 5,900 | 4,900 | 0.76 | 0.75 | -17 |

| TOTAL FLOW | | Observed Flow (L) | Predicted Flow (L) | $R^2$ Value | NS | Relative Error |
|---|---|---|---|---|---|---|
| Default | Overall | 984,000 | 813,000 | 0.64 | 0.61 | -17 |
| | 19 NE | 152,000 | 157,000 | 0.83 | 0.80 | 3 |
| | 19 NW | 195,000 | 186,000 | 0.88 | 0.87 | -5 |
| | 32 NE | 319,000 | 262,000 | 0.70 | 0.64 | -18 |
| | 32 NW | 319,000 | 209,000 | 0.47 | 0.32 | -35 |
| Recommended | Overall | 984,000 | 904,000 | 0.66 | 0.66 | -8 |
| | 19 NE | 152,000 | 115,000 | 0.84 | 0.69 | -24 |
| | 19 NW | 195,000 | 137,000 | 0.86 | 0.75 | -30 |
| | 32 NE | 319,000 | 359,000 | 0.72 | 0.69 | 13 |
| | 32 NW | 319,000 | 294,000 | 0.49 | 0.48 | 8 |
| Default and Grading | Overall | 984,000 | 793,000 | 0.65 | 0.60 | -19 |
| | 19 NE | 152,000 | 147,000 | 0.81 | 0.76 | -3 |
| | 19 NW | 195,000 | 175,000 | 0.88 | 0.87 | -10 |
| | 32 NE | 319,000 | 264,000 | 0.70 | 0.64 | -17 |
| | 32 NW | 319,000 | 207,000 | 0.45 | 0.30 | -35 |
| Recommended and Grading | Overall | 984,000 | 858,000 | 0.56 | 0.54 | -13 |
| | 19 NE | 152,000 | 117,000 | 0.84 | 0.70 | -23 |
| | 19 NW | 195,000 | 139,000 | 0.88 | 0.77 | -29 |
| | 32 NE | 319,000 | 333,000 | 0.58 | 0.57 | 4 |
| | 32 NW | 319,000 | 270,000 | 0.28 | 0.26 | -15 |

[1] RE = ((Predicted – Observed)/Observed))*100

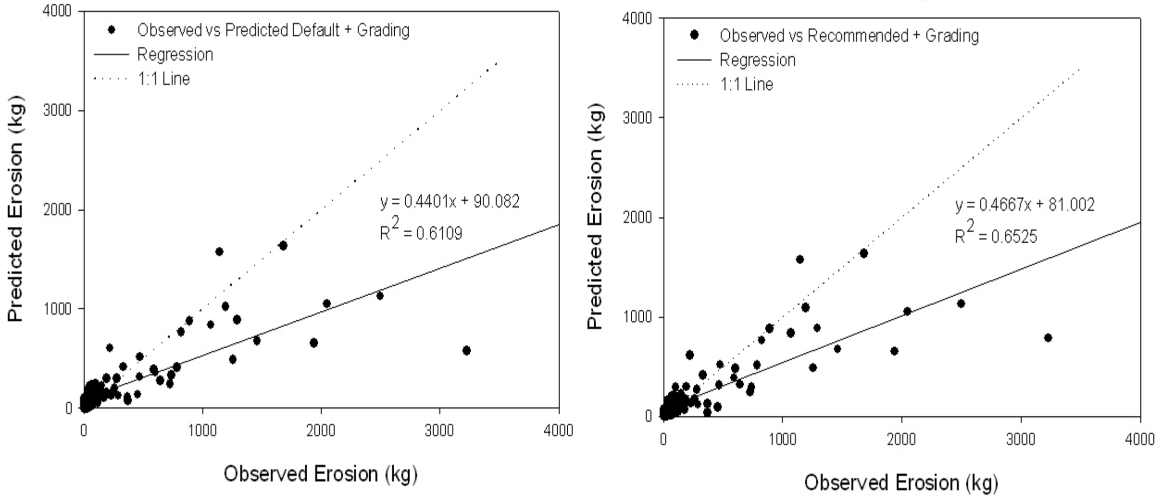
[2] Significance based on F-Test of ANOVA for each regression

[3] $NS= 1 - [\sum (Q_i - Q_{*i})^2 / \sum (Q_i - Q)^2]$



a. Default WEPP Runs

b. Recommended WEPP Runs



c. Default + Grading WEPP Runs

d. Recommended + Grading WEPP Runs

Figure 5. Scatter plots with regression lines for observed versus predicted erosion for all segments (n=88).

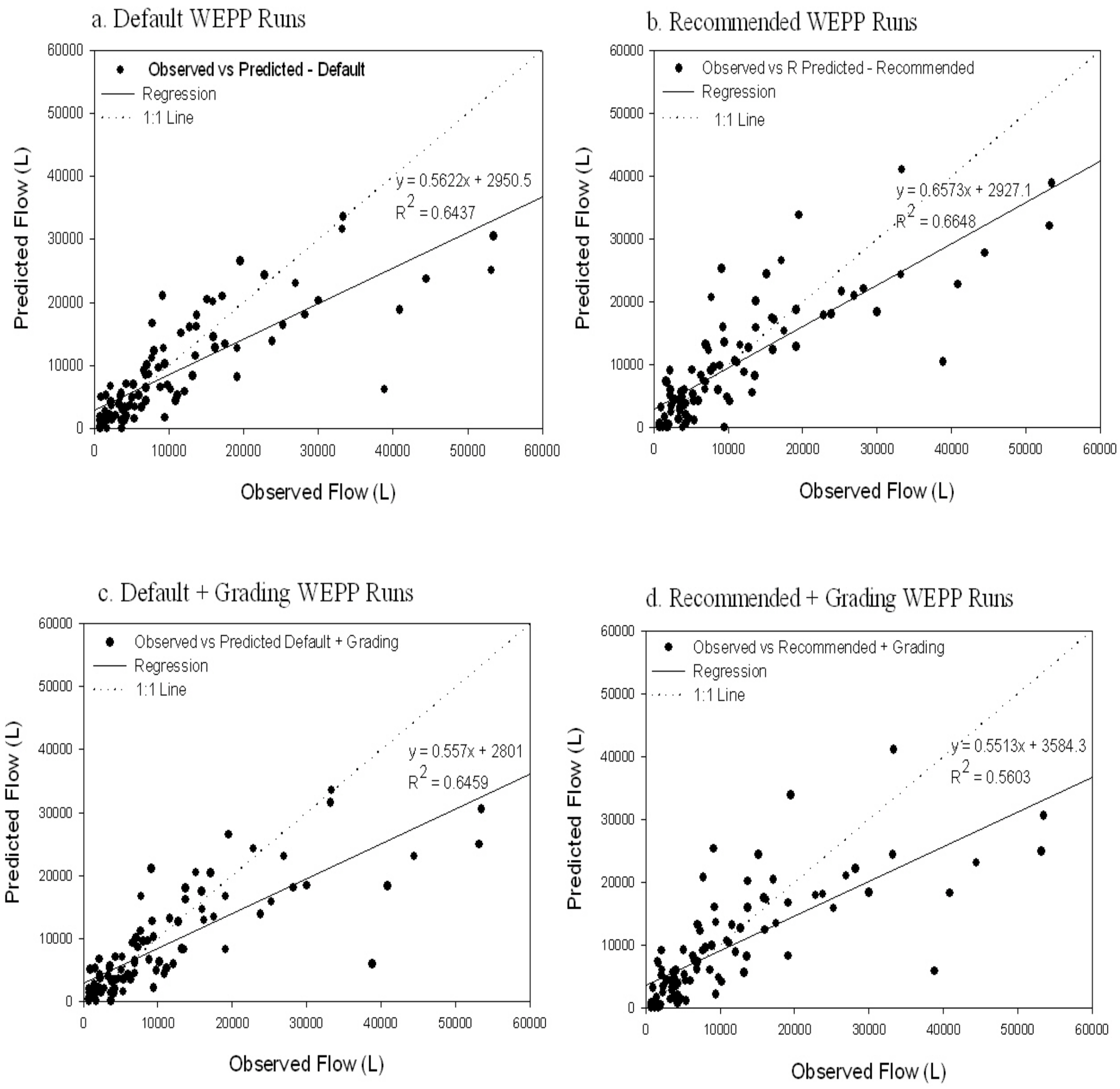
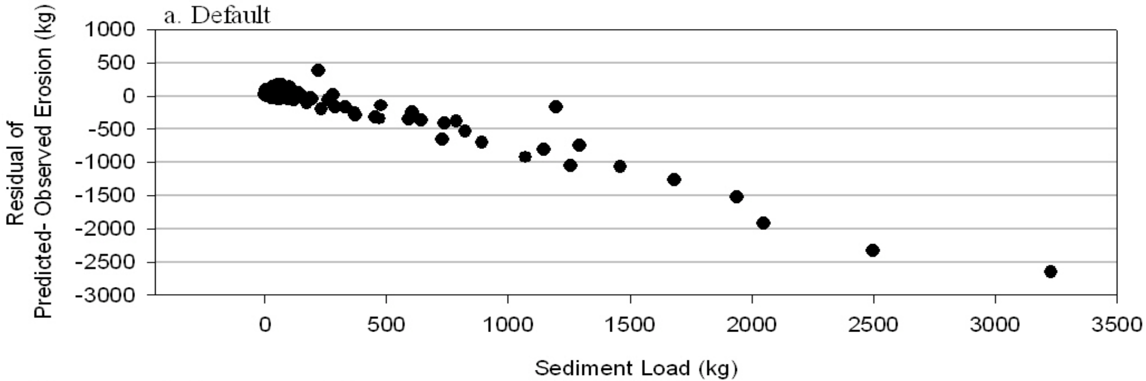
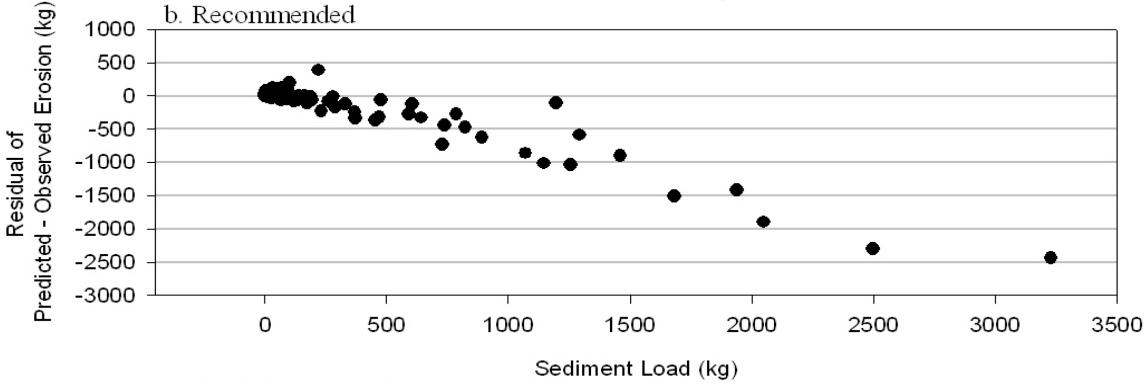


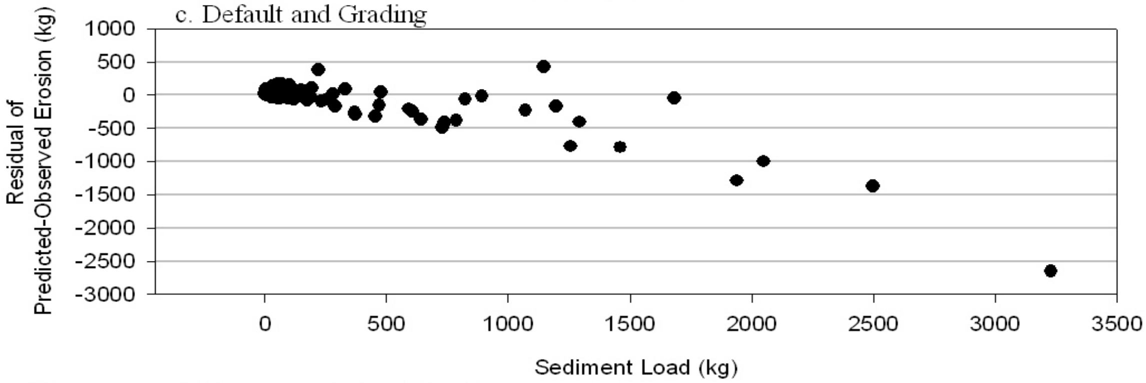
Figure 6. Scatter plots with regression lines for observed versus predicted total flow for all segments (n=88).



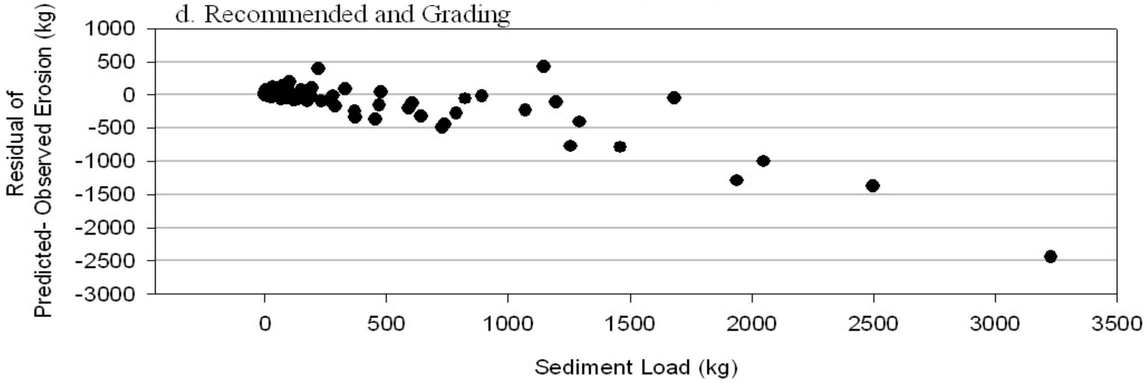
a. Default



b. Recommended



c. Default and Grading



d. Recommended and Grading

Figure 7. Residual plots of predicted minus observed erosion against storm size (sediment load) for all sites by WEPP parameter set.

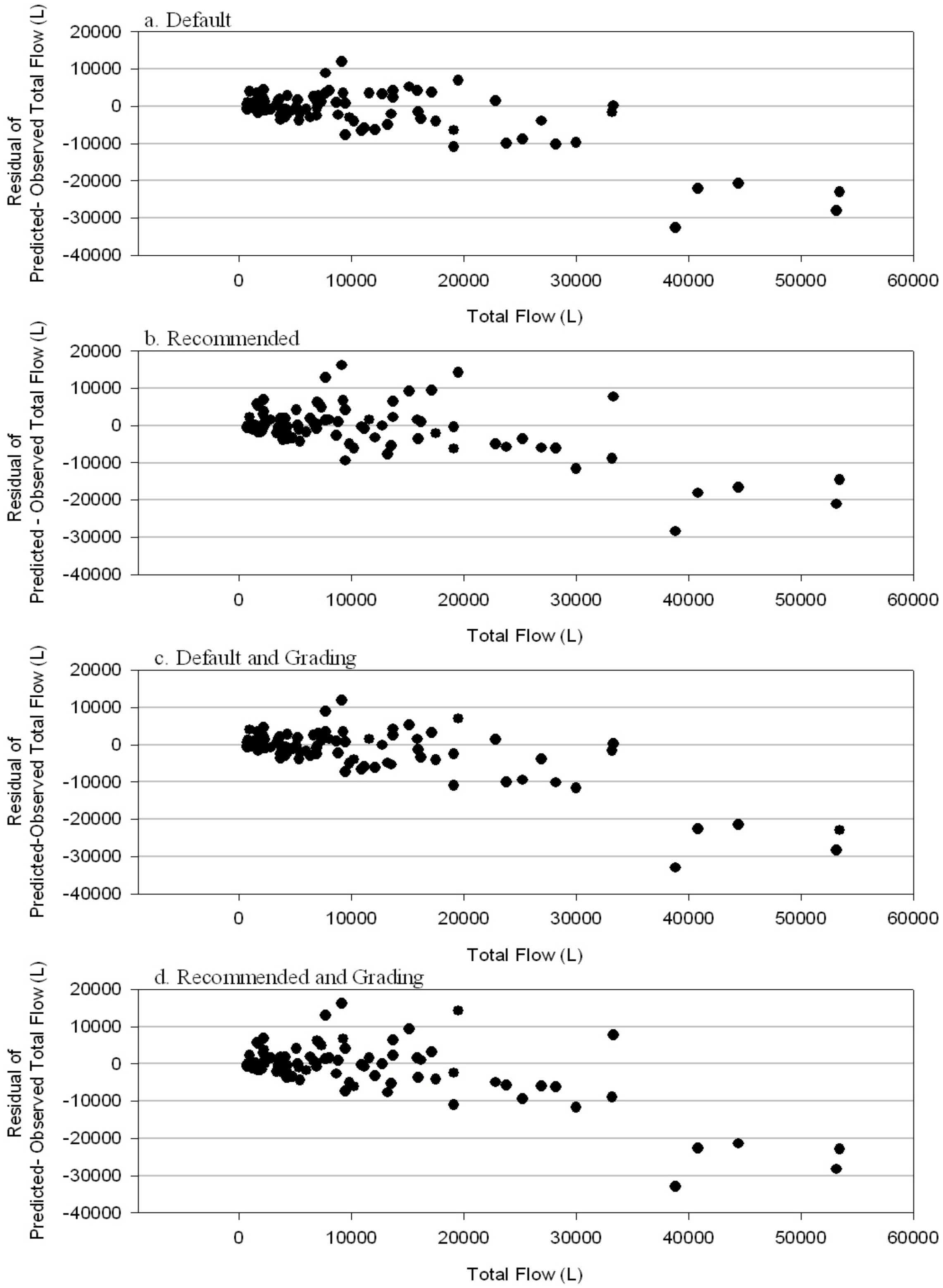


Figure 8. Residual plots of predicted minus observed flow against storm size (sediment load) for all sites by WEPP parameter set.

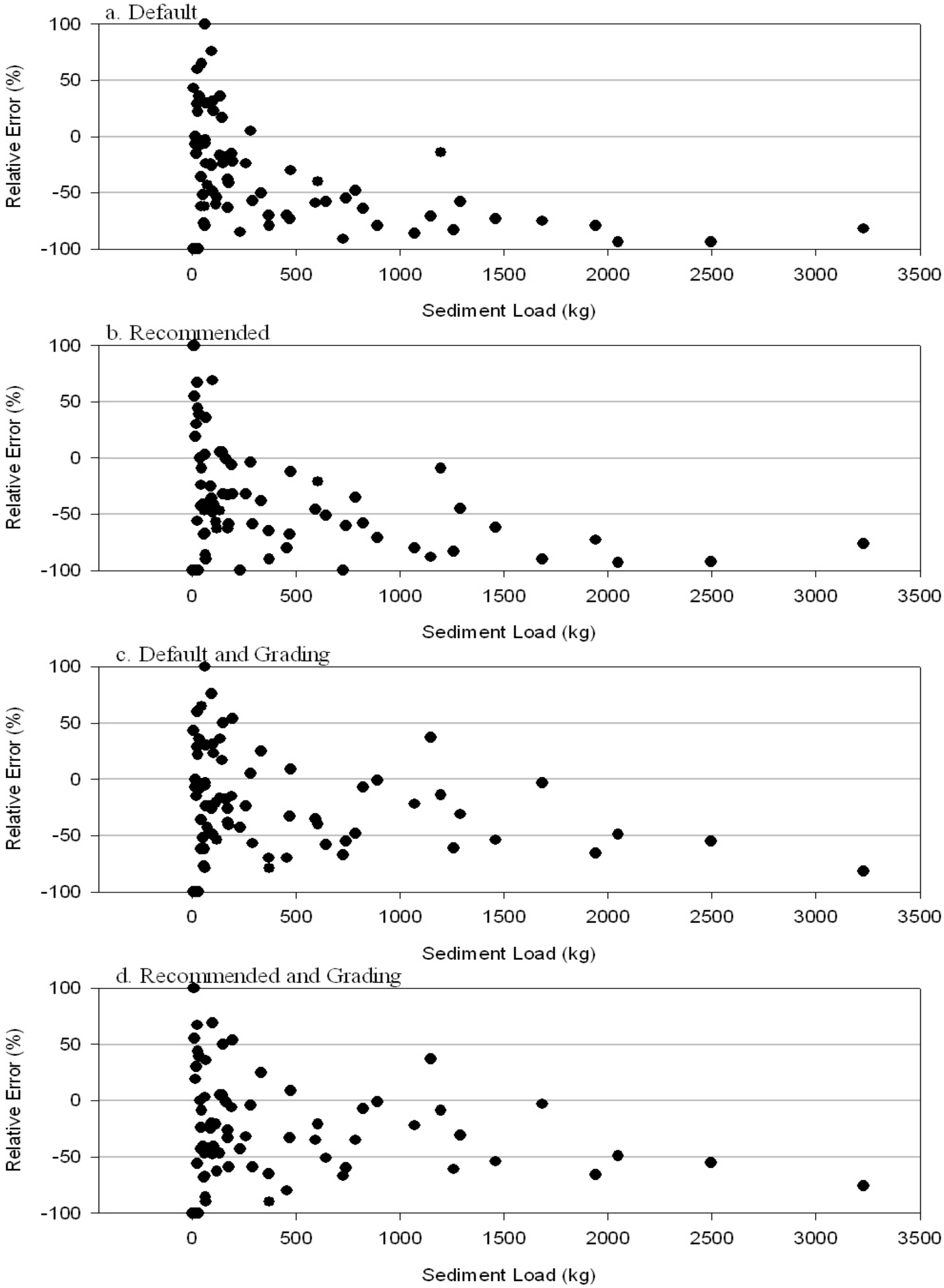


Figure 9. Relative Error (%) of observed versus predicted erosion by storm size (sediment load) for each set of WEPP parameters.

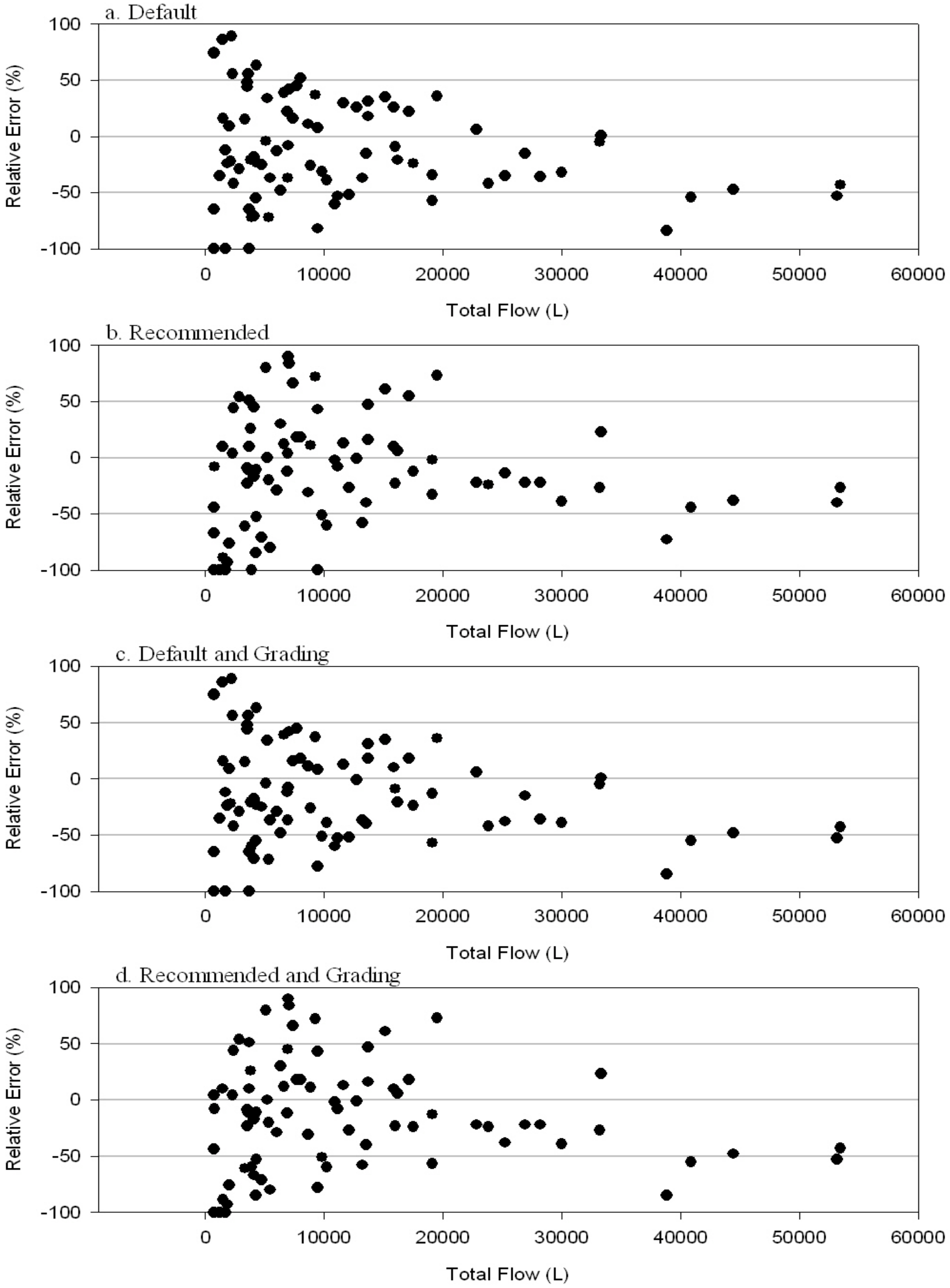
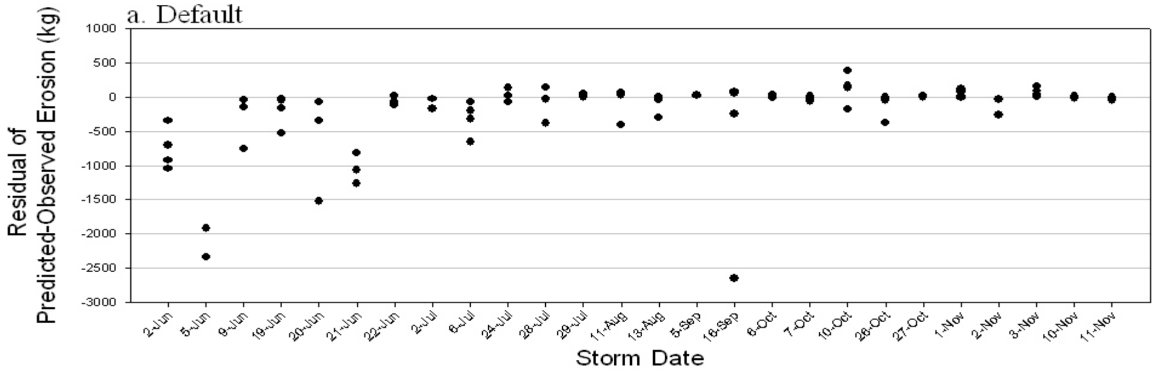
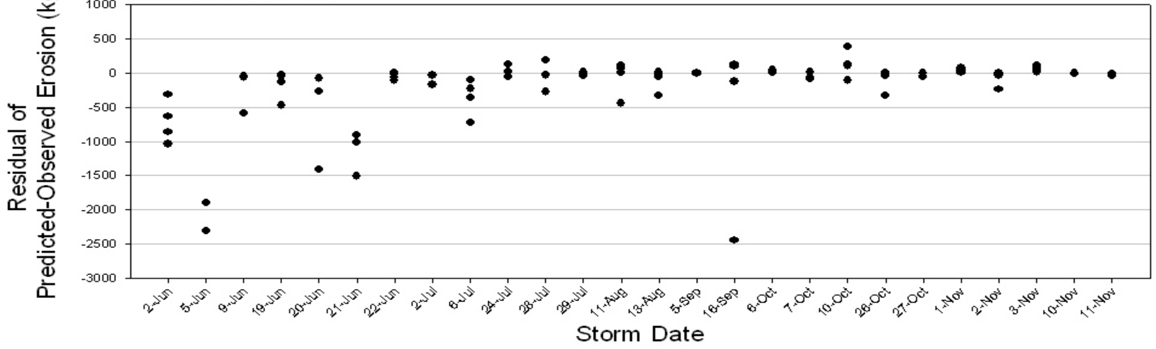


Figure 10. Relative Error (%) of observed versus predicted total flow by storm size (total flow) for each set of WEPP parameters.

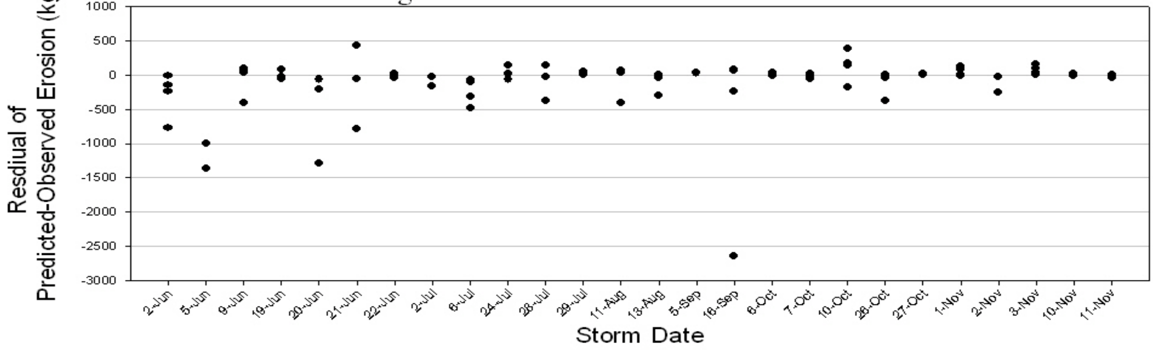
a. Default



b. Recommended



c. Default and Grading



d. Recommended and Grading

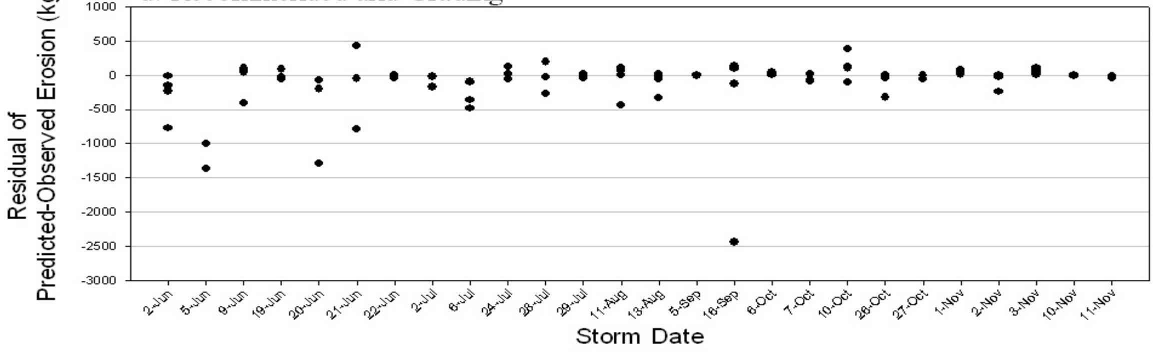
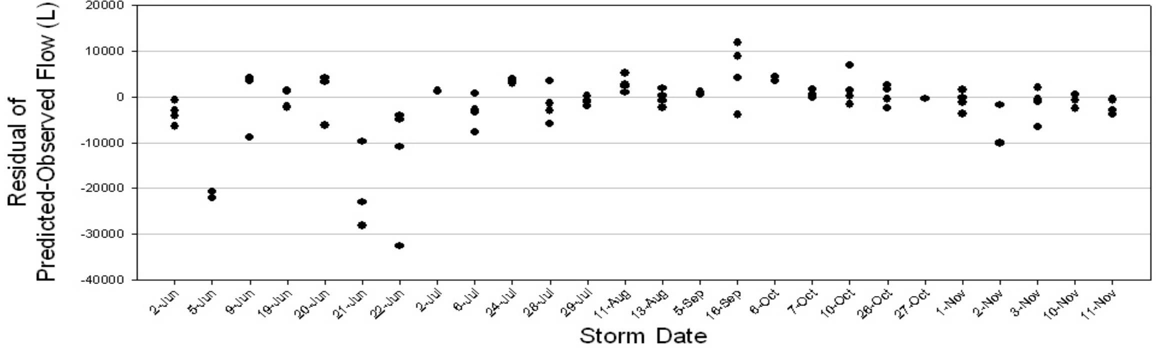
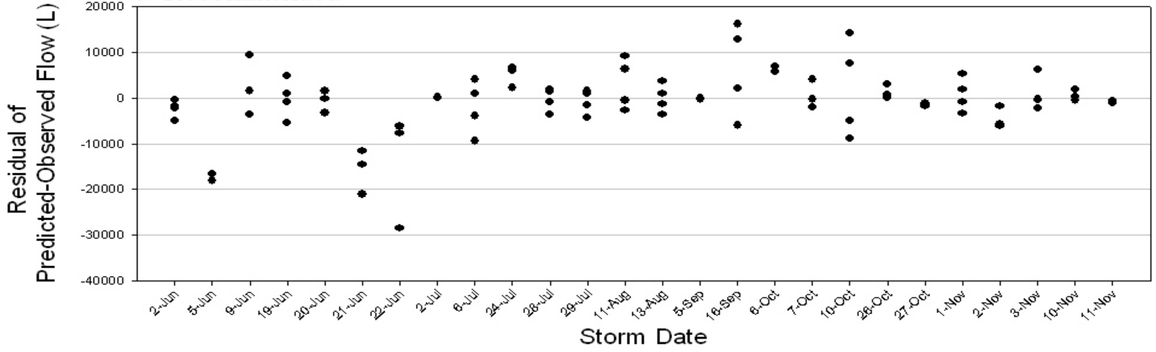


Figure 11. Residual plots of predicted minus observed erosion against storm date for all sites by WEPP parameters.

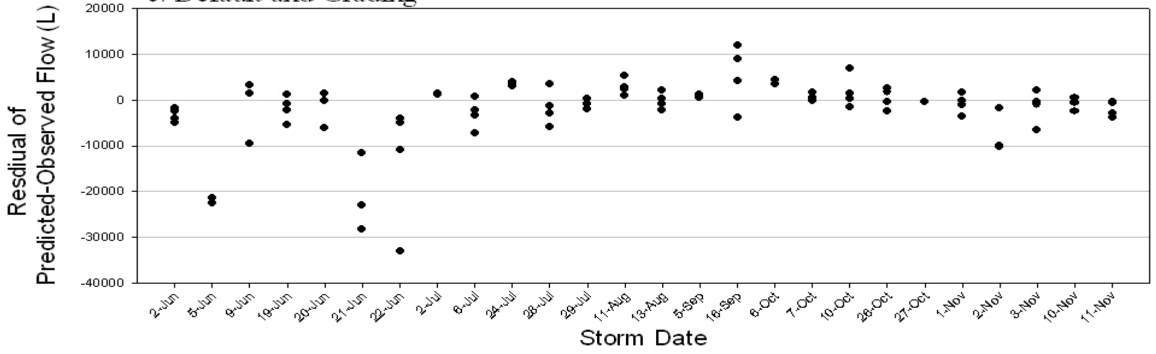
a. Default



b. Recommended



c. Default and Grading



d. Recommended and Grading

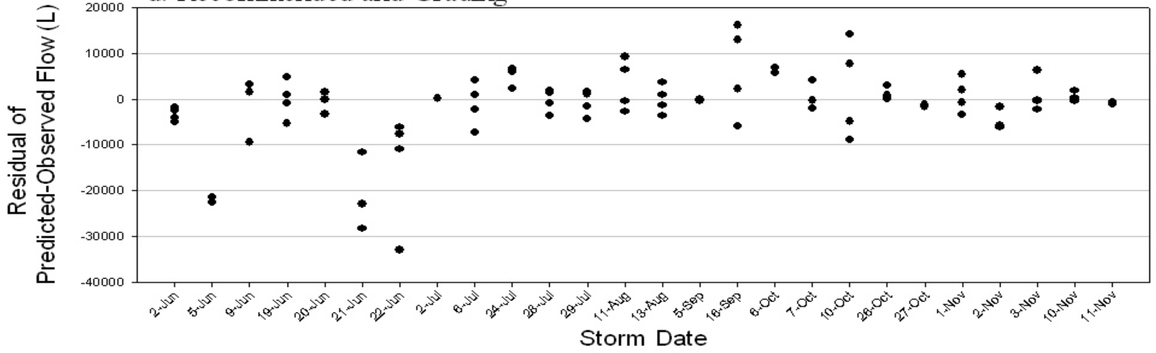


Figure 12. Residual plots of predicted minus observed total flow against storm date for all sites by WEPP parameters.

### 4.4.1 Default WEPP Parameters

The default input parameters resulted in $R^2$ values for observed versus predicted erosion ranging from 0.32 to 0.41, with an overall $R^2$ for total erosion over all segments of 0.36. For total flow, $R^2$ values for observed versus predicted ranged from 0.47 to 0.88, with an overall $R^2$ for total flow of 0.64. NS values were generally low, ranging from 0.01 to 0.26, with an overall NS value of 0.12 for erosion. For total flow, NS values were higher, ranging from 0.32 to 0.87, with an overall NS value 0.61. The overall observed erosion for all segments was 32,400 kg. WEPP predicted total erosion to be 13,400 kg using the default parameter set.

The overall observed total flow for all segments was 984,000 L. WEPP predicted total flow to be 813,000 L using the default parameter set. Relative errors ranging from -69 to -32% (– 58% overall) were observed for total erosion, and relative errors ranging from -35 to 3% (-17% overall) were observed for total flow (Table 13). Residual plots indicated that using the default parameters WEPP generally under-predicted for both erosion and total flow, with the magnitude of under-prediction increasing as storm size increased (Figures 7.a. through 10.a.). The magnitude of under-prediction was greater for erosion than for total flow. Additionally, WEPP under- predicted both erosion and flow considerably early in the study period using default input parameters (Figures 11.a. and 12.a.).

### 4.4.2 Recommended WEPP Parameters

Results of the recommended WEPP runs were similar to the results of the default WEPP runs. Recommended input parameters resulted in $R^2$ values for observed versus predicted erosion ranging from 0.25 to 0.54, with an overall $R^2$ for total erosion over all segments of 0.38. For total flow, $R^2$ values for observed versus predicted ranged from 0.49 to 0.86, with an overall $R^2$ for total flow of 0.66. NS values for erosion were also generally low, ranging from -0.03 to 0.45, with an overall NS value of 0.17. For total flow, NS values were again higher, ranging from 0.48 to 0.75, with an overall NS value 0.66. The overall observed erosion for all segments was 32,400 kg. WEPP predicted total erosion to be 13,800 kg using the recommended parameter set.

The overall observed total flow for all segments was 984,000 L. WEPP predicted total flow to be 904,000 L using the recommended parameter set. Relative errors ranging from -70 to -28 % (– 57 % overall) were observed for total erosion, and relative errors ranging from -30 to 13 % (-8 % overall) were observed for total flow (Table 13). Residual plots indicated that using the default parameters WEPP generally under-predicted for both erosion and total flow, with the magnitude of under-prediction increasing as storm size increased (Figures 7.b. through 10.b.). The magnitude of under-prediction was greater for erosion than for total flow. Additionally, WEPP under- predicted both erosion and flow considerably early in the study period using default input parameters (Figures 11.b. and 12.b.), a pattern similar to the default WEPP parameters.

### 4.4.3 Default and Grading WEPP Parameters

Results of the default and grading WEPP runs showed considerable improvement over the default runs. The only input parameters altered were for storms directly affected by grading as outlined in Table 4. All unaffected storms remained as default input parameters. Accounting for grading resulted in $R^2$ values for observed versus predicted erosion ranging from 0.46 to 0.81, with an overall $R^2$ for total erosion over all segments of 0.61. For total flow, $R^2$ values for observed versus predicted ranged from 0.45 to 0.88, with an overall $R^2$ for total flow of 0.65. For erosion, NS values were substantially higher than the default run, ranging from 0.19 to 0.75, with an overall NS value of 0.53 for erosion. For total flow, NS values were similar to the default, ranging from 0.30 to 0.87, with an overall NS value 0.60. The overall observed erosion for all segments was 32,400 kg. WEPP predicted total erosion to be 22,200 kg using the default and grading parameter set.

The overall observed total flow for all segments was 984,000 L. WEPP predicted total flow to be 793,300 L using the default and grading parameter set. Relative errors ranging from -49 to -11 % (– 31 % overall) were observed for total erosion, and relative errors ranging from -30 to 13 % (-8 % overall) were observed for total flow (Table 13). Residual plots exhibited a similar pattern to the default plots. Residual plots indicated that using the default parameters WEPP generally under-predicted for both erosion and total flow, with the magnitude of under-prediction increasing as storm size increased (Figures 7.c. through 10.c.). The magnitude of under-prediction was greater for erosion than for total flow. WEPP under-predicted erosion and total flow early in the study period

(Figures 11.c. and 12.c.), a pattern similar to the default WEPP runs. However, the magnitude of under-prediction was reduced by accounting for grading.

### 4.4.4 Recommended and Grading WEPP Parameters

Results of the recommended and grading WEPP runs showed considerable improvement over the recommended runs, and yielded the best overall agreement between observed and predicted values for erosion. The only input parameters altered were for storms directly affected by grading as outlined in Table 4. All unaffected storms remained as recommended input parameters. Accounting for grading resulted in $R^2$ values for observed versus predicted erosion ranging from 0.58 to 0.81, with an overall $R^2$ for total erosion over all segments of 0.65. For total flow, $R^2$ values for observed versus predicted ranged from 0.28 to 0.88, with an overall $R^2$ for total flow of 0.56. For erosion, NS values were substantially higher than the recommended run, ranging from 0.28 to 0.75, with an overall NS value of 0.56 for erosion. For total flow, NS values were lower than the recommended runs, ranging from 0.26 to 0.88, with an overall NS value 0.54. The overall observed erosion for all segments was 32,400 kg. WEPP predicted total erosion to be 22,200 kg using the recommended and grading parameter set.

The overall observed total flow for all segments was 984,000 L. WEPP predicted total flow to be 858,000 L using the recommended and grading parameter set. Relative errors ranging from -49 to -13 % (– 31 % overall) were observed for total erosion, and relative errors ranging from -30 to 4 % (-13 % overall) were observed for total flow (Table 13). Residual plots exhibited a similar pattern to the recommended plots. Residual plots indicated that using the default parameters WEPP generally under-predicted for both erosion and total flow, with the magnitude of under-prediction increasing as storm size increased (Figures 7.d. through 10.d.). The magnitude of under-prediction was greater for erosion than for total flow. WEPP under-predicted both erosion and flow considerably early in the study period (Figures 11.d. and 12.d.), a pattern similar to the recommended WEPP parameters. However, the magnitude of under-prediction in both plots was reduced by accounting for grading.

# CHAPTER V

# DISCUSSION

## 5.1 Precipitation and Erosion

The precipitation over the study period was close to the long-term annual average of 507 mm for the same period in the Stillwater, Oklahoma area (Table 6). The majority of storms were short-duration, high intensity storms that are typical of the spring and summer season in central Oklahoma. No exceptionally large or infrequent storms occurred during the study. All storms were below the depths for storms with the one-year return period for durations ranging from 6 to 24 hr. The largest storm was the October 10th storm, which lasted 14 hours and produced 56 mm of precipitation. The 1-year, 12-hour storm for the Stillwater, OK area is 58 mm (Hershfield, 1961). The storm of September 16 had the 2nd highest maximum intensity, 88 mm/hr and produced 35 mm of rainfall over a 2.25 hr period.. The 1-year 2-hour rainfall for the Stillwater, OK area is 43 mm (Hershfield, 1961). The overall precipitation and pattern of storms over the study period was normal.

It is not surprising that the R-Factor ($R^2$ = 0.45) maximum five-minute precipitation intensity ($R^2$ = 0.39) and maximum 30-minute precipitation intensity ($R^2$ = 0.38) were the rainfall variables that best explained the variability in storm erosion (Table 12, Figure 4). The intense, short duration storms typical of Oklahoma in spring and summer, deliver high kinetic energy to road surfaces loosening soil particles, readily exceeding the low infiltration capacities of road surfaces and producing large amounts of runoff quickly. Consequently these storms generated large amounts of sediment in a short time. Long-duration low intensity storms generated runoff at lower rates. Sediment concentrations in road runoff were generally lower in low intensity storms. The storms of September 16th and October 10th illustrate this well, and are depicted for the 19 NE station below (Figures 13 and 14). At 19 NE, the September 16th storm produced less rainfall than the October 10th storm (35 vs 52 mm), but generated nearly three times the amount of sediment as the October 10th storm because the maximum rainfall intensity was much higher (88 vs. 12 mm/hr) on September 16.

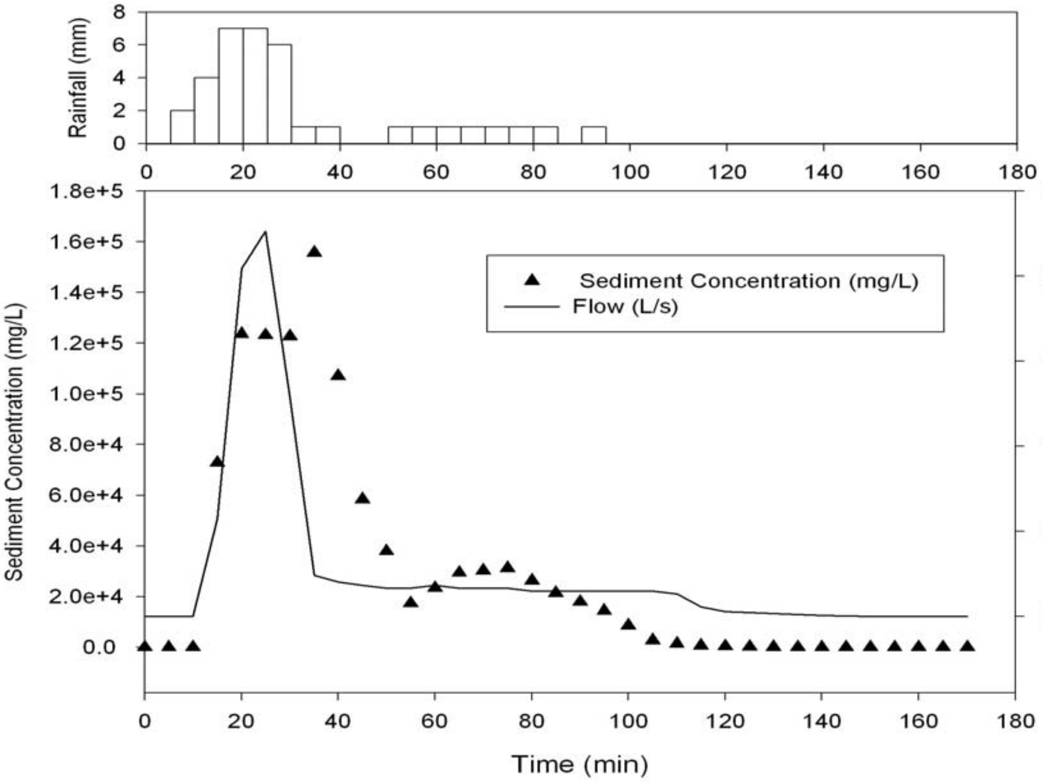


Figure 13. The runoff hydrograph and sediment concentrations of water samples collected at the 19NE station during the storm of September 16, 2004. This event is representative of storms of short duration and high intensity.

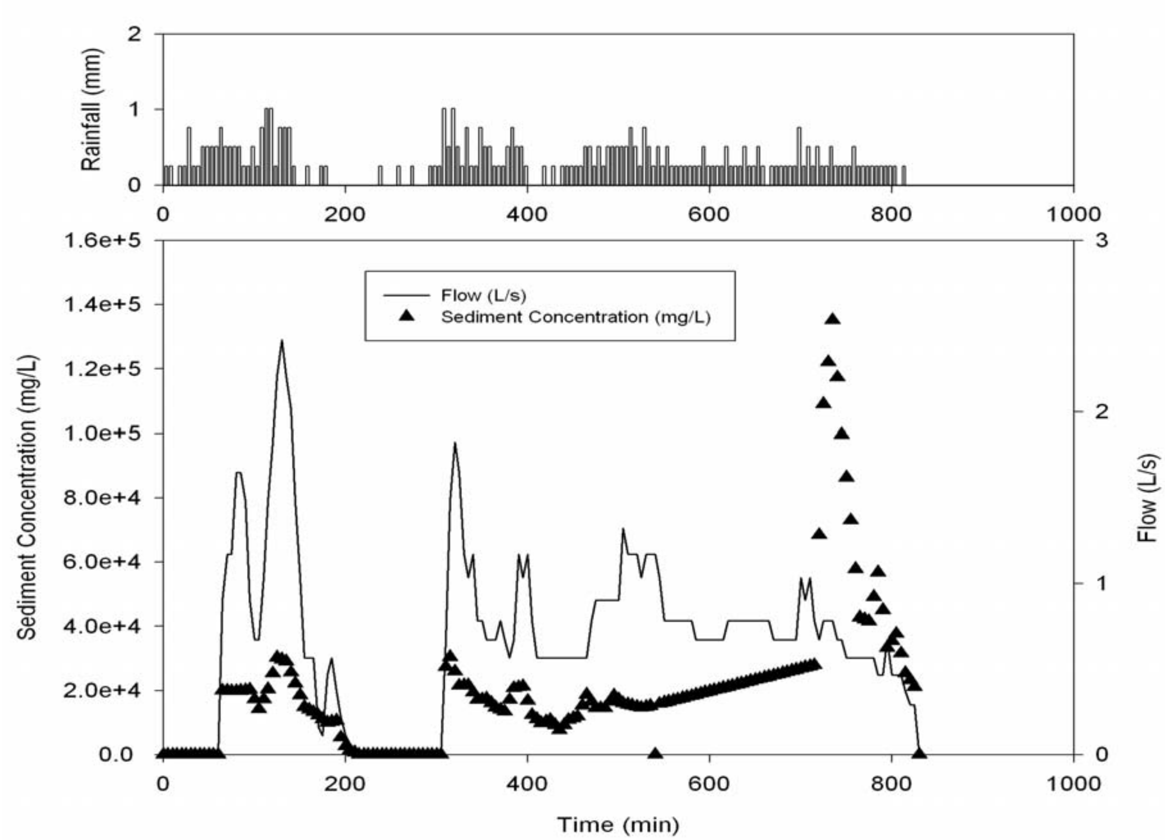


Figure 14. The runoff hydrograph and sediment concentrations of water samples collected at the 19NE station during the storm of October 10, 2004. This event is representative of storms of long duration and low intensity.

The wide range of variability in total erosion 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. Road maintenance, specifically grading operations, appeared to have an impact on the amount of erosion observed. Early in the study period, the roads were graded frequently and erosion was generally higher for storms of similar durations and intensities than later in the study period when the amount of grading decreased. Although not directly measured, changes were observed in the road surfaces after grading and following rainfall events that occurred between grading operations. In general, immediately after grading more loose material was available in the ditches and road edges for transport. Depending on the characteristics of the following storms, this loose material was generally carried away within two or three storms following grading, and the road surface appeared to return to a more stable condition.

Concentrations of sediment in runoff and erosion quantities measured in this study fell within the bounds measured in other road erosion studies. Suspended sediment concentrations as low as 34 mg/l (Stevens, 2001) and as high as 100,000 + mg/l (Ziegler *et al*., 2000) have been measured in runoff from unpaved roads in Colorado and Thailand, respectively. Observed suspended sediment concentrations were generally between 5,000-50,000 mg/l, although several samples routinely exceeded concentrations of 100,000 mg/l. Assuming the study period was "typical" in terms of rainfall, the average erosion per unit area from roads of 135,000 kg/ha extrapolates based on rainfall to 250,000 kg/ha/yr, or 152 Mg/km/yr. 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 ranging from 3-114 Mg/km/yr have been reported for forest roads (Busteed 2004, Turton and Vowell 2000, Vowell 1985, Miller *et al.,* 1984). The estimated annual erosion rate of 152 Mg/km/yr appeared to be reasonable when compared to other published rates.

Assuming that all of the 479 km of rural unpaved roads in the Stillwater Creek watershed eroded at the same rate as the study segments, the total estimated quantity of sediment eroded from rural unpaved roads is 72,800 Mg/yr. Using a modeling approach, Storm *et al.* (2003), predicted annual erosion 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. Those predictions of road and overall watershed erosion were based upon modeling using a simplified internet-based version of WEPP (WEPP: Roads) and Geographic Information Systems (GIS) to characterize roads in the watershed. Upland erosion was estimated using the Soil and Water Assessment Tool (SWAT2000) model, and the results of the predicted SWAT2000 erosion were summed with the predicted road erosion from WEPP: ROADS to estimate the total sediment load.

The estimated annual load from road erosion from my study of 72,800 Mg/yr alone would account for 62 % of the annual watershed sediment budget predicted by Storm *et al.* (2000). However, the estimated annual sediment load from roads may be high because my study segments may or may not represent road characteristics and conditions in other parts of the watershed, and assumes all sediment reaches water bodies. Histograms showing the distribution of segment lengths and slope used in Storm *et al.* (2000) are provided in Figures 15 and 16, respectively.

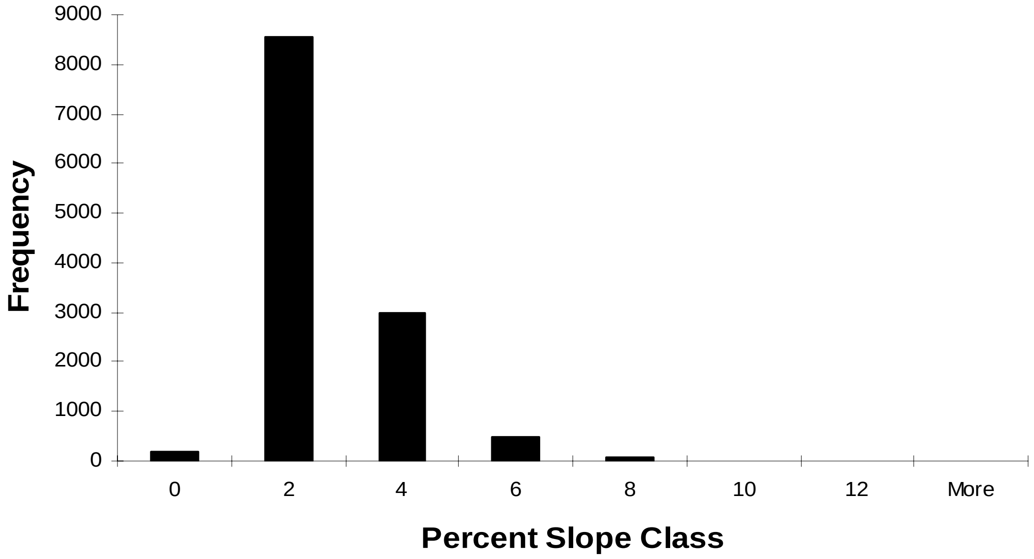


Figure 15. Histogram of the distribution of segment slopes from Storm *et al*.2003.

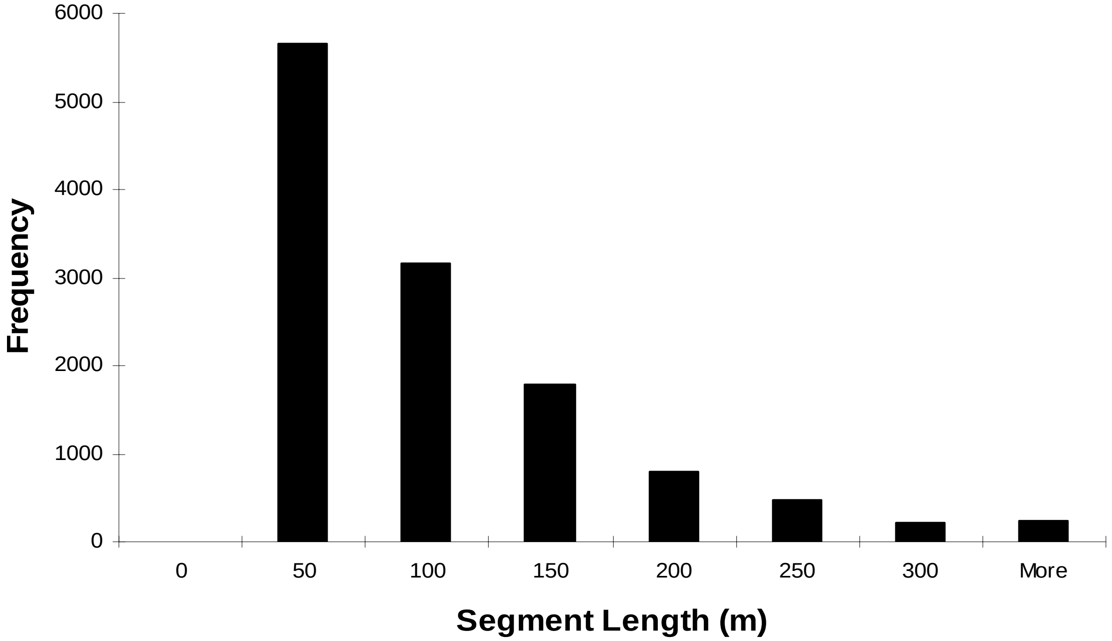


Figure 16. Histogram of the distribution of segment lengths from Storm *et al.* 2003.

The calculated average slopes of the segments in my study ranged from 6.6 to 9.1 percent (Table 3-1). The most frequently occurring slopes in the watershed were between 0 and 6 percent (Figure 15). The measured segment lengths for my study ranged from 154 to 252 m (Table 1). The most frequently occurring segment lengths were between 50 and 150 m (Figure 16). However, these frequency distributions may be deceiving because of the slope and segment length calculation methodology employed by Storm *et al.* 2000. Slopes and segment were calculated from 30 m resolution DEMs (Digital Elevation Model), which lack the level of detail of the GPS-based slope calculations, so direct comparison to measured slopes in my study may be of limited utility. In Storm *et al.* (2000), a segment was defined as a detectable break in topography on the DEM. I generally used 2-4 segments used in the Storm *et al.* (2000) study to define a segment in my study. WEPP: ROAD runs were performed on each segment individually and summed to obtain an overall erosion estimate in Storm *et al.* (2000). The segment lengths in my study were defined by drainage area of the road surface (length of ditch), and naturally tended to be longer than the segments represented in Figure 16. Ditches flowing undisrupted for lengths of approximately 1 km were observed in the watershed. The approach used by Storm *et al* 2000 likely underestimated actual segment length (ditch length) considerably. In general, the segments used my study had steeper slopes and longer lengths than most segments in the watershed as defined in Storm *et al*. 2000, but most of the differences can be attributed to methodology differences between the two studies.

An inventory that used a GPS to locate roads, ditches and stream crossings, in the Lake Carl Blackwell sub-watershed revealed that 80 % 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 58,200 Mg/yr, or 50 percent of the annual predicted watershed sediment budget from Storm *et al.* (2000). This is despite the fact that roads cover only 1.3 percent of the Stillwater Creek watershed. This observation agrees with studies that have shown that while roads only occupy small portions (2-8 %) of a watershed, they can account for 25-73 percent of a watershed's an annual sediment budget (Nagle 2001, Dunne and Dietrich, 1982 and Dunne 1979). These studies illustrate the importance of unpaved roads as sources of sediment to surface water bodies despite their small area compared to the area of the watershed in which they cover.

## 5.2 Comparisons of Overall WEPP Predictions to Observed Measurements

Overall, WEPP tended to under-predict erosion from each segment using the selected erodibility input parameters (Table 13). For total erosion, there were essentially no overall differences between the $R^2$ and NS values for the default and recommended parameter sets ($R^2$=0.36 and 0.38, NS=0.12 and 0.17). Using the default and recommended parameter sets accounting for grading, the $R^2$ and NS values improved. Again there were essentially no overall differences between the parameter sets that accounted for grading ($R^2$=0.61 and 0.65, NS=0.53 and 0.57). The $R^2$ and NS values for total flow were consistent ($R^2$=0.56-0.66, NS=0.54-0.66) for all parameter sets. It is important to note the observed data sets are relatively small and have limitations; namely they do not cover a whole year period and do not include any storms larger than 1-yr 24 hour and 1 year 6 hour return interval storms.

### 5.2.1 Comparison of Observed and Predicted WEPP Erosion

The overall pattern in terms of predicted erosion was under-prediction, especially for larger storms. The overall relative errors of the observed versus predicted erosion were –58 % for both the default and recommended parameter sets, and -31% percent for both the default and recommended parameter sets accounting for grading. The documented standard for WEPP performance is an overall relative error of +/-50%, since considerable variation in erosion can be observed on the same plot under similar conditions (Elliot *et al.* 1999, Tysdal *et al.* 1997). The standard of 50 % is meant to be applied to an overall period estimate, not the estimates for individual storms, which varied considerably (Tables C-1 through C-4, Appendix C). In this sense, the model appeared to reasonably predict the overall erosion for the study period when grading was accounted for (Table 13). Without accounting for grading, the $R^2$ values for the default runs were nearly identical to the $R^2$ values for predicting erosion based on use of the R-Factor, maximum intensity or maximum 30-minute intensity (Table 7, Figure 4), suggesting total erosion similar to the WEPP predictions would be predicted using these rainfall variables alone on the study segments. However, the regression equations were developed for these segments specifically and may not appropriate for use across the watershed.

Although the overall $R^2$ values were good for the default and recommended parameter sets accounting for grading (0.61 and 0.65), there was substantial variation in the scatter plots (Figure 5) of observed versus predicted erosion for individual storms. Figure 7 clearly shows the tendency of the model to under-predict erosion for large storms in terms of absolute error. This was expected because as storm size (sediment load) increases the same relative error results in larger absolute errors, even if relative errors remain constant. However, relative error plotted against storm size (sediment load) suggested that the relative error also appears to increase with storm size (Figure 9), although the data set did not include any storms larger than a one year return interval. The tendency of WEPP to under-predict for large storms using the selected parameters is especially important since for each segment, the five largest observed storms accounted for 63 to 83 % of the observed sediment load for the study period (Tables 7 through 10), despite that the largest storm had a return interval of approximately one year. Larger storms would likely have moved these percentages even higher. Miller *et al.* (1984) also reported similar observations. A single 100-year return interval storm in that accounted for over 50 percent of the annual sediment load in Miller's study. Under-prediction of these storms would limit the utility of WEPP for long-term erosion predictions. The temporal pattern of larger under-prediction in erosion evident in Figure 11 is likely a function of grading. When grading was accounted for, the extent of under-prediction was reduced.

If the patterns observed in the overall data remained consistent as storm size increased beyond one-year return interval storms, the extent of the under-prediction would be even more severe. To demonstrate this, the observed annual and predicted annual total erosion totals were extrapolated to annual estimates based on rainfall. The estimated annual erosion and predicted annual erosion are provided in Table 14. A 50 year WEPP simulation was performed on each segment using a 50-year CLIGEN generated climate for Perry, OK and using the recommended input values including four grading operations scheduled annually (5/1, 6/1, 7/1, and 10/1). The 50-year average annual predicted erosion total for each segment is included in Table 14.

Table 14. Estimated annual observed and predicted erosion (using recommended with grading parameter sets), including the 50-year annual WEPP predicted average.

| Site | Observed | Predicted | Relative Error % | Annual Observed | Annual Predicted | Relative Error | 50-year Average | Relative Error % |
|---|---|---|---|---|---|---|---|---|
| 19 NE | 5,340 | 4,630 | -13 | 9,860 | 8,540 | -13 | 7,940 | - 20 |
| 19 NW | 14,250 | 7,210 | -49 | 26,300 | 13,300 | -49 | 13,800 | - 63 |
| 32 NE | 6,880 | 5,490 | -20 | 12,940 | 10,130 | -20 | 2,500 | - 83 |
| 32 NW | 5,890 | 4,890 | -17 | 10,880 | 9,020 | -17 | 2,100 | - 82 |
| Overall | 32,350 | 22,220 | -31 | 60,000 | 41,000 | -31 | 26,340 | - 56 |

Applying WEPP over a 50-year period with the recommended parameters and accounting for grading resulted in substantial under-prediction, especially for the 32nd Street segments. This is despite the fact these input parameters had the best overall erosion results over the study period when measured rainfall records were used and exact grading dates were known. This reflects the systematic tendency of WEPP to under-predict erosion for larger storms using the selected parameters on the study segments. The under-prediction is most likely the result of grading operations. The grading operations on the road segments often resulted in piles of loose material in the ditches and road edges, which may have been difficult to account for in WEPP. This suggests that better sets of parameters need to be developed to better describe the effects of grading.

For each segment, the exceedance probability for annual predicted erosion over the 50-year simulation was plotted against total predicted erosion to determine how “typical” the estimated annual values in Table 14 were (Figure 17). For 19 NE and 19 NW, the estimated annual erosion had exceedance probabilities of approximately 0.1, meaning the observed annual erosion was larger than 90 percent of the predicted annual erosion for each year over the 50 year simulation period. For both 32 NE and 32 NW, the estimated annual erosion had exceedance probabilities of less than 0.01; meaning the observed annual erosion was larger than 99 percent of the predicted annual erosion quantities for each year through the 50 year simulation period. However, over the study period no storms exceeding a one year return interval were observed, suggesting the estimated annual load was a "typical" year in terms of overall annual erosion. This clearly shows the dramatic systematic under-prediction with increasing storm size, and the influence of larger storms on the amount of total erosion using WEPP for long-term simulations.

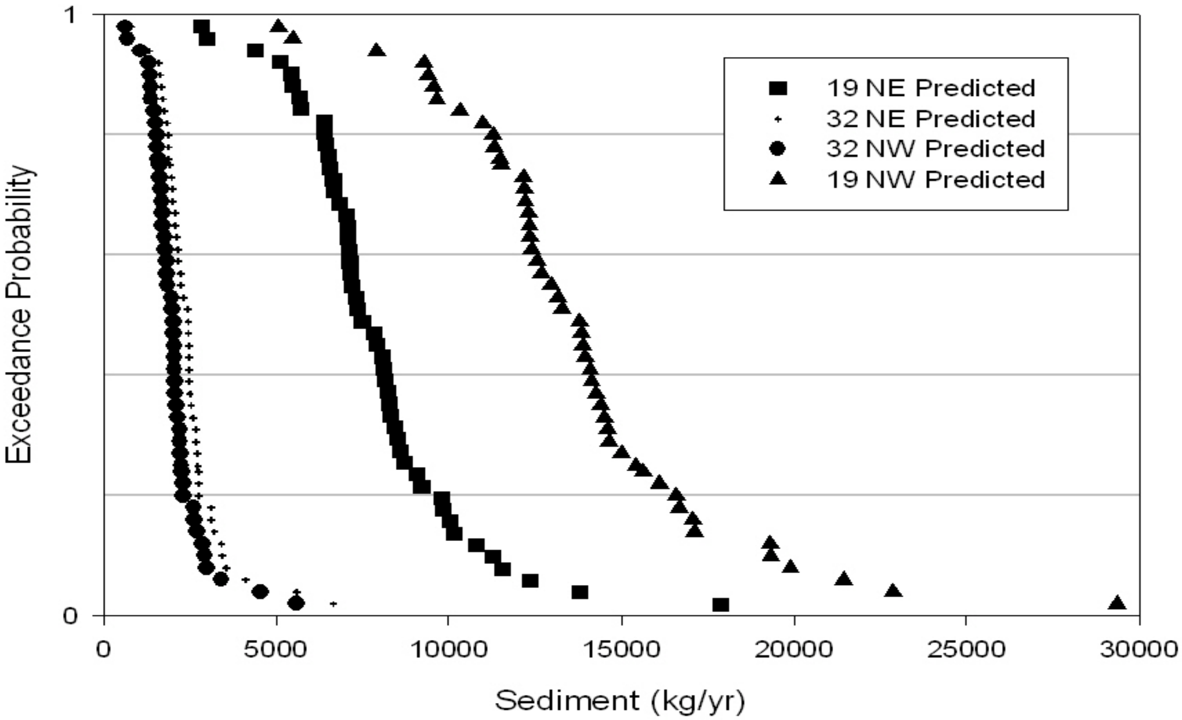


Figure 17. Total load exceedance probability for each segment (Predicted using 50-year WEPP Run with recommended values accounting for grading).

Cumulatively, these observations suggest use of WEPP to predict absolute erosion from single storms in this study is not appropriate using the selected erodibility parameters. When management conditions (grading) were known for each storm, reasonable overall erosion predictions (+/- 50 %) using the selected parameters were obtained, and the use of WEPP was appropriate. However, use of WEPP in this manner requires users obtain detailed rainfall records and dates of grading, which may not be practical in many instances. It is also important to again note that no large storms occurred over the study period, so the overall relative error was likely lower than it would have been had larger storms been observed, and the +/- 50 % standard may or may not have been met had larger storms been observed. The systematic under-prediction using the selected erodibility parameters made the use of WEPP for long-term modeling inappropriate for the segments in this study. Accounting for grading in the 50 year run appeared to have little effect on the predictions, and the model still under-predicted erosion in the long-term simulation mode. This suggests further research is necessary to determine appropriate erodibility input parameters and the effects of grading on these erodibility parameters.

### 5.2.2 Comparison of Observed and Predicted WEPP Total Flow

WEPP consistently predicted reasonable values for overall total flow across all parameter sets. $R^2$ values for each run ranged from 0.56 to 0.66, and NS values ranged from 0.54 to 0.66. Overall relative errors ranged from -17 to -8 percent. Although there was variation between observed versus predicted values on the scatter plots (Figure 6), the pattern towards increasing under-prediction with increasing storm size was not as strong as the pattern observed for erosion. As expected, the absolute error increased as storm size increased (Figure 8), and when relative error was plotted against storm size, the relative error increasingly under-predicted as storm size increased (Figure 12). This suggests that WEPP was generally consistent in predicting total flow for smaller storms, and had a tendency for under-prediction for larger storms using the selected input parameters. Again, the use of WEPP to predict total flow from individual storms would not be appropriate. It is important to note there were a limited numbers of large storms observed to establish a definitive pattern.

The observed total flow extrapolated to an annual estimate by rainfall for each segment is provided in Table 15, as well as the 50 year annual average total flow from the 50 year WEPP run described in Section 5.2.1. The estimated annual flow compared very well to the 50 year average, with relative errors ranging from -2 to 18 percent across all segments. This is further conformation that WEPP was reasonably predicting overall total flow for the study period. The observed storms were all under a one year return interval, meaning the year was relatively "typical", and should have compared well to the long-term average annual flow. For each segment, the exceedance probability of annual predicted total flow for each year of the 50 year simulation was plotted against annual predicted total flow (Figure 18) to determine how "typical" the estimated annual observed total flow values in Table 15 were.

Table 15. Estimated annual observed and predicted total flow (recommended with grading run), including the 50-year annual WEPP predicted average.

| Site | Observed | Predicted | Relative Error % | Annual Observed | Annual Predicted | Relative Error % | 50-year Average | Relative Error % |
|---|---|---|---|---|---|---|---|---|
| 19 NE | 151,500 | 116,600 | -23 | 277,600 | 215,090 | -23 | 279,500 | 1 |
| 19 NW | 195,039 | 139,076 | -29 | 359,800 | 256,564 | -29 | 365,400 | 2 |
| 32 NE | 318,720 | 332,803 | 4 | 587,900 | 613,946 | 4 | 577,600 | -2 |
| 32 NW | 318,782 | 269,475 | -15 | 588,000 | 497,119 | -15 | 478,300 | 18 |
| Overall | 984,000 | 858,000 | -13 | 1,813,300 | 1,582,720 | -13 | 1,700,800 | 6 |

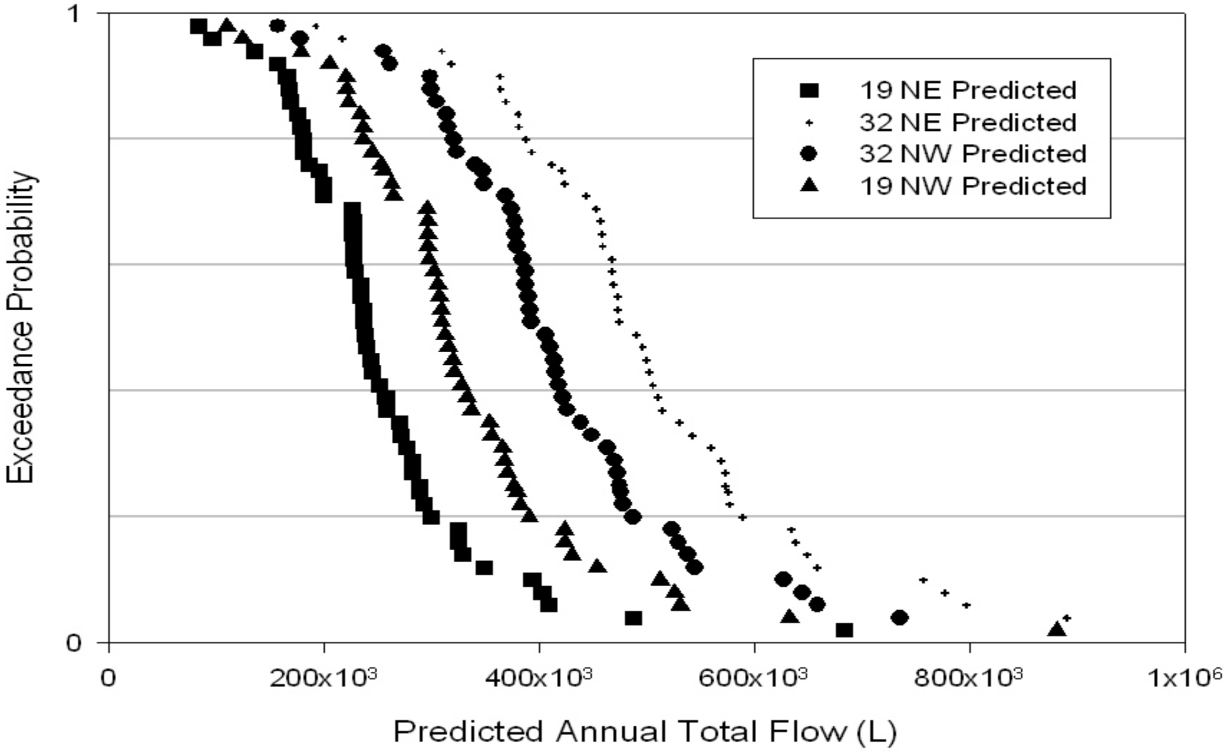


Figure 18. Total flow exceedance probability for each segment (Predicted using 50-year WEPP Run with recommended values accounting for grading).

For all segments, the estimated annual total flow (Table 15) had exceedance probabilities of approximately 0.3 to 0.5, meaning the observed annual total flow for each segment was exceeded 30- 50% of the time over the 50-year period. This suggests that observed annual total flow was typical, as would be expected with the observed storm data. Overall

WEPP reasonably predicted total flow in for all parameter sets, but did not predict well for individual storms.

### 5.2.3 Overall WEPP Analysis and Summary

Total flow in the WEPP model is directly related to the erosion prediction process. WEPP appeared to predict reasonably for overall total flow regardless of input parameters, suggesting WEPP performed reasonably in general and that the erodibility parameters used for this study may not have been appropriate for the study segments. Although the overall total flow predictions were reasonable, WEPP still under-predicted total flow for large storm events, and the largest relative errors in the erosion predictions were for the large events. Although the relative errors for erosion during large storms were larger than the relative errors for flow, the under-predictions in total flow may have accounted for at least some of the under-prediction in total erosion for large storms. There are several possible explanations WEPP under-predicting total erosion and total flow for large storm events.

For large storms and smaller storms during very wet periods, the ratio of runoff to total precipitation often exceeded 1.0, ranging from 1.03 to 3.96. This suggests that part of the measured flow was being contributed from an area other than the road surface, such as cutslopes or other upslope contributing areas. Similar observations have been reported for road studies in the Ouachita Mountains of southeast Oklahoma (Miller *et al.* 1985, Busteed 2004). The upslope contributing areas were not included as part of the WEPP model. Only runoff from the road surface and ditch was predicted by WEPP. During large events where additional flow contributions from upslope areas may have been significant, the observed total flow would have been higher than the predicted flow because WEPP does not model flow from these areas. This potentially accounts for some of the under-prediction of total flow for large storms. Although the upslope contributing areas may not contribute significant amounts of sediment because they were well vegetated, the increased flow may have increased ditch erosion during the large storms. This potential increase in erosion may explain some of the under-prediction of erosion from the larger storms.

The hillslope version of WEPP does account for upslope contributing areas. These areas may be best modeled as small watersheds in the WEPP watershed version. However, the watershed version is limited in that it is still under development and suitable road templates are generally not available. The current watershed version (July 2002) requires templates be programmed into the model. Additionally, the watershed version may be difficult to apply to road systems over a large area. The upslope contributing area of each modeled segment in the watershed would have to be accounted for. Field measurement of these areas would be difficult and expensive. Estimating the areas from maps or DEMs may not describe the areas with reasonable accuracy. Future research directed towards developing a more user-friendly watershed version of WEPP is necessary to allow for improved modeling of these areas.

Grading operations may also provide a partial explanation of some of the under-prediction of total erosion for large storms. Reasonable overall erosion estimates were obtained using the default and recommended parameters when grading was accounted for, but WEPP still under-predicted erosion for large storms in these runs as well. The observed grading operations all occurred in the in the month of June. When the predicted minus observed erosion was plotted against storm date, the largest under-predictions in erosion occurred during June (Figure 11). However, grading alone may not explain the under-predictions evident in Figure 11. Most of the largest storms over the study period also occurred during June (Figure 12). The largest under-predictions of total flow were also observed over the same time period, which was much wetter than normal (Table 12). The combination of large storms, additional flow from upslope areas, and the large amounts of loose sediment often present in the ditch and road margins following grading likely accounted for the under-predictions in erosion. This is evident in Figure 11 for the runs accounting for grading. When grading is accounted for, the under-prediction in erosion is reduced, but significant under-prediction for these storms is still evident. This suggests that grading accounts for some, but not all of the under-prediction. Future research is necessary to determine improved erodibility parameters to describe the effects of erosion on these segments.

A wide range of other variables may potentially account for some of the under-prediction of total erosion and flow by WEPP. An underlying assumption in this study is the observed values were reasonable. However, erosion can vary widely, even on the same segment for nearly identical storms. Sources of error in the observed data may include errors in field measurement, laboratory analysis, load calculation, and natural variability in erosion. Additionally, WEPP was originally developed for agricultural lands, and later adapted to be applied to roads. It is possible that some of the equations used by WEPP (e.g., Green-Ampt Equation for infiltration) may not be entirely appropriate for roads under certain conditions, and may partially account for some discrepancies between observed and predicted data.

WEPP has been shown to provide reasonable results for both erosion and flow when calibrated. (i.e.: Tysdal *et al.* 1997, Elliot *et al.* 1995b, Elliot *et al*. 1994). The use of WEPP without calibration (default or recommended parameters) remains a useful option for applications where absolute erosion estimates are not as important as relative comparisons, such as determining the relative differences between management operations or different surface treatments. However, for applications where absolute erosion estimates are required, such as TMDL calculations, the use of these erodibility parameters may not be appropriate depending on the acceptable level of uncertainty for the application.

# CHAPTER VI

# SUMMARY AND CONCLUSIONS

Four rural unpaved road segments at two sites (19th Street and 32nd Street) in the Stillwater Creek, Oklahoma watershed were selected for erosion measurements. The four road segments ranged from 160–250 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. 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 26 storms was collected during June-November, 2004. The conclusions from this study can generally be placed into two categories: 1) rainfall and erosion conclusions, and 2) WEPP conclusions.

## 6.1 Rainfall and Erosion Conclusions

Total precipitation over the study period was 8 percent below normal at 19th Street rain gauge, and 15 percent above normal at the 32nd Street rain gauge. The total precipitation from individual storms ranged from 3 mm to 56 mm. Maximum storm intensities ranged from 3 mm/hr to 100 mm/hr. The total erosion for individual storms from the four segments ranged from 1 kg to 3,230 kg, with an average of 370 kg across all four segments. Erosion per unit area for individual storms ranged from 16 kg/ha to 53,100 kg/ha, with an average of 6,200 kg/ha across all four segments. The cumulative total erosion from the segments through the study period was 5,340 kg for 19 NE, 5,900 kg for

32 NW, 6,880 kg for 32 NE, and 14,250 kg for 19 NW. The cumulative erosion per unit area for each site was 89,500 kg/ha for 32 NE, 108,500 kg/ha for 32 NW, 113,400kg/ha for 19 NE, and 234,300 kg/ha for 19 NW, with an overall erosion per unit area across all four segments of 545,600 kg/ha. This extrapolates to an annual estimate sediment yield of 152 Mg/km/yr. The observed overall sediment yields (Mg/km/yr) and instantaneous sample concentrations (mg/L) were well within the ranges established in the literature. The overall observed erosion estimates were considered reasonable.

The rainfall variables with the most substantial effect on observed erosion were the RUSLE R-Factor, Maximum Five-minute Intensity, and Maximum 30-minute Intensity, all factors related to rainfall intensity. The intense, short duration storms typical of Oklahoma springs and summers, deliver high amounts of kinetic energy to road surfaces loosening soil particles, readily exceeding the low infiltration capacities of road surfaces and producing large amounts of runoff quickly. Consequently these storms generate large amounts of sediment in a short time. Long-duration low intensity storms generated runoff more slowly and at lower rates. The five largest storms on each segment produced 63 to 83 % of the observed sediment load for the study period for each segment. The majority of erosion is the result of a limited number of storms. Similar findings have been reported by Busteed (2004) and Miller *et al.* (1984). Despite the relatively small surface area occupied by roads in the Stillwater Creek watershed, the contribution of roads to the overall sediment budget may be significant. As in many other watersheds, rural unpaved roads in the Stillwater Creek watershed contribute significantly to the overall sediment budget of the watershed despite their disproportionately small area. This finding is well supported in the literature.

## 6.2 WEPP Conclusions

Overall, WEPP tended to systematically under-predict erosion from each segment using the selected input parameters. The amount (absolute and relative) of under-prediction for both erosion and total flow appeared to increase with storm size, although no storms larger than a one year return interval were observed. Assuming this observed pattern continued as storm size increased, the predicted erosion would be substantially less than the observed erosion as larger return interval storms occurred. This was evident in a 50-year WEPP simulation, even when grading was accounted for. This suggests the erodibility parameters selected may not have been appropriate for the segments. Applying these parameters to other road segments in the watershed may not be appropriate. WEPP reasonably predicted overall erosion using the selected parameters when rainfall records were used and corrections for grading were made. Reasonable predictions were defined as overall predicted values within 50 percent of the observed values. WEPP parameter sets that did not account for grading estimated erosion as well as using the USLE R-factor, maximum intensity, or maximum 30-minute intensity alone for a given segment.

WEPP reasonably predicted overall total flow for all parameter sets, suggesting the model was performing well overall for total flow. Because erosion is in part a function of flow, this is further conformation that the erodibility parameters selected may not have been appropriate. However, WEPP consistently under-predicted both total erosion and total flow for large storms. These under-predictions may potentially be explained by several factors, including: contributions of flow from upslope areas that were measured but not included in the model, erosion due to grading operations not accounted for in the model, errors in the measured erosion, and WEPP limitations.

The use of the default and recommended values may remain useful for relative comparisons, such as comparisons between management options or BMPs. But for applications where absolute erosion estimates are required, such as TMDL calculations, the use of these erodibility parameters is generally not appropriate unless the acceptable level of uncertainty for the application is relatively high. Calibration to specific sites may be required for these applications.

### 6.3 Recommendations

This study revealed several interesting questions that were beyond the scope of the study:

1. The maintenance and operations on the unpaved rural road network in the watershed needs to be evaluated and BMPs should be implemented to reduce the amount of erosion from roads in the watershed in order to improve water quality.
2. Combinations of rainfall variables should be analyzed to determine if several variables considered together will improve the relationship to erosion, increasing their utility as erosion predictors.

3. Improved WEPP erodibility input parameters need to be developed for the rural unpaved road segments used in this study, especially parameters to more accurately describe grading operations.

4. Future research is necessary to provide more user-friendly interface to the watershed version of WEPP.

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# APPENDIX A

## WEPP INPUT PARAMETERS

Table A-1. WEPP storm input data for 19th Street segments.

| Date | Total Precipitation (mm) | Maximum Precipitation Intensity (mm/hr) | Storm Duration (h) | Percent of Time to Maximum Intensity (%) | Initial Soil Percent Saturation Condition |
|---|---|---|---|---|---|
| 06-02-04 | 11 | 49 | 0.5 | 33 | C |
| 06-05-04 | 36 | 30 | 7.8 | 42 | B |
| 06-19-04 | 20 | 73 | 2.8 | 6 | B |
| 06-20-04 | 26 | 58 | 2.8 | 6 | C |
| 06-21-04 | 45 | 67 | 9.5 | 16 | D |
| 06-22-04 | 15 | 9 | 2.8 | 50 | D |
| 07-02-04 | 9 | 30 | 2.0 | 96 | B |
| 07-06-04 | 5 | 18 | 0.6 | 0 | B |
| 07-24-04 | 11 | 18 | 9.4 | 2 | A |
| 07-28-04 | 27 | 34 | 7.6 | 10 | B |
| 07-29-04 | 9 | 9 | 15.1 | 96 | C |
| 08-11-04 | 20 | 12 | 9.7 | 6 | A |
| 08-13-04 | 6 | 15 | 3.8 | 96 | C |
| 09-05-04 | 6 | 24 | 0.6 | 86 | A |
| 09-16-04 | 35 | 88 | 1.5 | 17 | A |
| 10-06-04 | 12 | 34 | 1.1 | 85 | A |
| 10-07-04 | 12 | 67 | 1.6 | 16 | C |
| 10-10-04 | 56 | 24 | 13.9 | 13 | D |
| 10-26-04 | 8 | 27 | 1.2 | 36 | B |
| 10-27-04 | 6 | 9 | 2.4 | 86 | B |
| 11-01-04 | 13 | 6 | 7.8 | 20 | B |
| 11-02-04 | 28 | 55 | 2.2 | 8 | C |
| 11-03-04 | 19 | 6 | 7.0 | 43 | D |
| 11-10-04 | 10 | 21 | 1.5 | 39 | B |
| 11-11-04 | 7 | 30 | 1.0 | 50 | C |

Table A-2. WEPP storm input data for 32nd Street segments

| Date | Total Precipitation (mm) | Maximum Precipitation Intensity (mm/hr) | Storm Duration (h) | Percent of Time to Maximum Intensity (%) | Initial Soil Percent Saturation Condition |
|---|---|---|---|---|---|
| 06-02-04 | 23 | 79 | 0.8 | 56 | C |
| 06-05-04 | 35 | 101 | 2.9 | 63 | D |
| 06-09-04 | 38 | 18 | 19.0 | 16 | D |
| 06-19-04 | 18 | 24 | 3.3 | 18 | B |
| 06-20-04 | 15 | 34 | 2.6 | 45 | C |
| 06-21-04 | 50 | 79 | 9.5 | 32 | D |
| 06-22-04 | 18 | 12 | 4.1 | 58 | D |
| 07-06-04 | 24 | 61 | 3.6 | 4 | B |
| 07-24-04 | 24 | 43 | 9.6 | 8 | A |
| 07-28-04 | 17 | 15 | 6.6 | 68 | C |
| 07-29-04 | 8 | 9 | 12.1 | 84 | C |
| 08-11-04 | 34 | 43 | 15.0 | 1 | A |
| 08-13-04 | 8 | 27 | 0.8 | 33 | D |
| 09-16-04 | 32 | 67 | 2.1 | 16 | A |
| 10-06-04 | 12 | 34 | 1.1 | 85 | A |
| 10-07-04 | 12 | 67 | 1.6 | 16 | C |
| 10-10-04 | 56 | 24 | 13.9 | 13 | D |
| 10-26-04 | 8 | 27 | 1.2 | 36 | B |
| 11-01-04 | 13 | 6 | 7.8 | 20 | B |
| 11-02-04 | 28 | 55 | 2.2 | 0 | C |
| 11-03-04 | 19 | 6 | 7.0 | 43 | D |
| 11-10-04 | 10 | 21 | 1.5 | 39 | C |
| 11-11-04 | 7 | 30 | 1.0 | 50 | C |

Table A-3. WEPP Slope inputs for all segments.

| Site | Distance (m) | Slope (%) |
|---|---|---|
| 19NE | 0 | 0 |
| | 17.1 | 12.4 |
| | 49.4 | 15.4 |
| | 80.8 | 8.3 |
| | 127.7 | 3.8 |
| | 154.5 | 2.0 |
| 19 NW | 0 | 0 |
| | 21.3 | 8.5 |
| | 46.9 | 7.1 |
| | 73.2 | 8.9 |
| | 102.2 | 6.9 |
| | 139.9 | 8.8 |
| | 171.9 | 10.7 |
| | 179.2 | 6.1 |
| | 194.2 | 3.9 |
| 32 NE | 0 | 9.3 |
| | 20.5 | 9.3 |
| 32 NW | 0 | 8.8 |
| | 19.4 | 8.8 |

Table A-4. 32nd Street Slope of Inslope Calculations.

| Cross Section | Crown Elevation (m) | Edge of Road Elevation (m) | Distance (m) | Slope (%) |
|---|---|---|---|---|
| 1 | 309.665 | 309.100 | 5.48 | 4.3 |
| 2 | 300.447 | 301.05 | 3.66 | 5.3 |
| 3 | 298.233 | 298.983 | 3.05 | 10.1 |
| 4 | 297.844 | 297.797 | 3.05 | 4.2 |
| | | | Average | 5.9 |

$$\text{Effective Slope} = \sqrt{\text{Outslope Gradient}^2\ (\%) + \text{Road Gradient}^2}$$

$$\text{Effective Slope} = \sqrt{(5.9)^2 + (7.2)^2}$$

Effective Slope = 9.3 %

Effective Length = Road Width x (Effective Slope/Outslope Slope)

Effective Length = 3.96 m x (9.3/5.9)

Effective Length = 6.3 m

Effective Width = (Road Length x Road Width)/Effective Length

Effective Width = (215.2 m x 3.96 m)/ 6.3 m

Effective Width = 136.6 m

A-5. 32 NW WEPP SLOPE CALCULATIONS

Assumed grade of inslope to be the same as 32 NE.

$$\text{Effective Slope} = \sqrt{\text{Outslope Gradient}^2\ (\%) + \text{Road Gradient}^2}$$

$$\text{Effective Slope} = \sqrt{(5.9)^2 + (6.6)^2}$$

Effective Slope = 8.8 %

Effective Length = Road Width x (Effective Slope/Outslope Slope)

Effective Length = 3.96 m x (8.8/5.9)

Effective Length = 5.9 m

Effective Width = (Road Length x Road Width)/Effective Length

Effective Width = (178.01 m x 3.96 m)/ 5.9 m

Effective Width = 119.3 m

# Appendix B

## Precipitation and Erosion Data

Table B-1. Summary of Precipitation Variables and Erosion for the 19 NE Station.

| | Precipitation Variables | | | | | Erosion Variables | | | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Total (mm) | Maximum Intensity (mm/hr) | Maximum 30-Minute Intensity (mm/hr) | Mean Intensity (mm/hr) | Rainfall Erosion Index Value (R Factor) | Total Flow (L) | Total Erosion (kg) | Total Per Unit Area (kg/ha) | Percent of Period Total |
| 6-02 | 11.2 | 48.8 | 21.8 | 4.6 | 60.4 | 6011 | 469 | 9965 | 8.78 |
| 6-09 | 35.8 | 30.5 | 22.9 | 4.1 | 173.9 | 11610 | 477 | 10124 | 8.92 |
| 6-19 | 20.3 | 73.2 | 24.4 | 5.8 | 110.6 | 6905 | 332 | 7059 | 6.22 |
| 6-20 | 26.2 | 57.9 | 18.8 | 6.1 | 112.1 | 8053 | 593 | 12595 | 11.10 |
| 6-21 | 45.2 | 67.1 | 27.9 | 4.1 | 284.9 | 30013 | 1462 | 31035 | 27.36 |
| 6-22 | 15.0 | 9.1 | 8.1 | 2.0 | 22.8 | 10236 | 145 | 3071 | 2.71 |
| 7-02 | 8.6 | 30.5 | 11.2 | 2.0 | 20.9 | 1471 | 95 | 2007 | 1.77 |
| 7-06 | 4.8 | 18.3 | 8.1 | 2.8 | 8.1 | 3908 | 232 | 4930 | 4.35 |
| 7-28 | 26.7 | 33.5 | 13.7 | 3.6 | 75.5 | 7696 | 101 | 2145 | 1.89 |
| 7-29 | 8.6 | 9.1 | 5.1 | 0.5 | 7.5 | 2029 | 7 | 151 | 0.13 |
| 8-11 | 20.3 | 12.2 | 7.1 | 1.8 | 25.9 | 4310 | 138 | 2922 | 2.58 |
| 8-13 | 5.8 | 15.2 | 6.1 | 1.3 | 7.3 | 1506 | 68 | 1437 | 1.27 |
| 9-05 | 5.6 | 24.4 | 10.2 | 2.3 | 12.4 | 743 | 11 | 238 | 0.21 |
| 9-16 | 35.3 | 88.4 | 54.9 | 12.2 | 503.5 | 13721 | 605 | 12854 | 11.33 |
| 10-07 | 10.2 | 57.9 | 16.8 | 4.6 | 41.0 | 3360 | 134 | 2844 | 2.51 |
| 10-10 | 51.8 | 12.2 | 9.1 | 3.8 | 86.2 | 22842 | 222 | 4713 | 4.16 |
| 10-26 | 15.7 | 76.2 | 25.9 | 8.9 | 103.9 | 5236 | 189 | 4014 | 3.54 |
| 10-27 | 5.8 | 9.1 | 4.1 | 2.3 | 3.5 | 1239 | 2 | 52 | 0.05 |
| 11-01 | 12.2 | 9.1 | 7.1 | 2.3 | 15.1 | 4767 | 21 | 439 | 0.39 |
| 11-03 | 12.7 | 6.1 | 4.1 | 1.5 | 8.4 | 4300 | 6 | 127 | 0.11 |
| 11-10 | 6.6 | 15.2 | 8.1 | 3.8 | 10.1 | 760 | 25 | 535 | 0.47 |

Table B-2. Summary of Precipitation Variables and Erosion for the 19 NW Station.

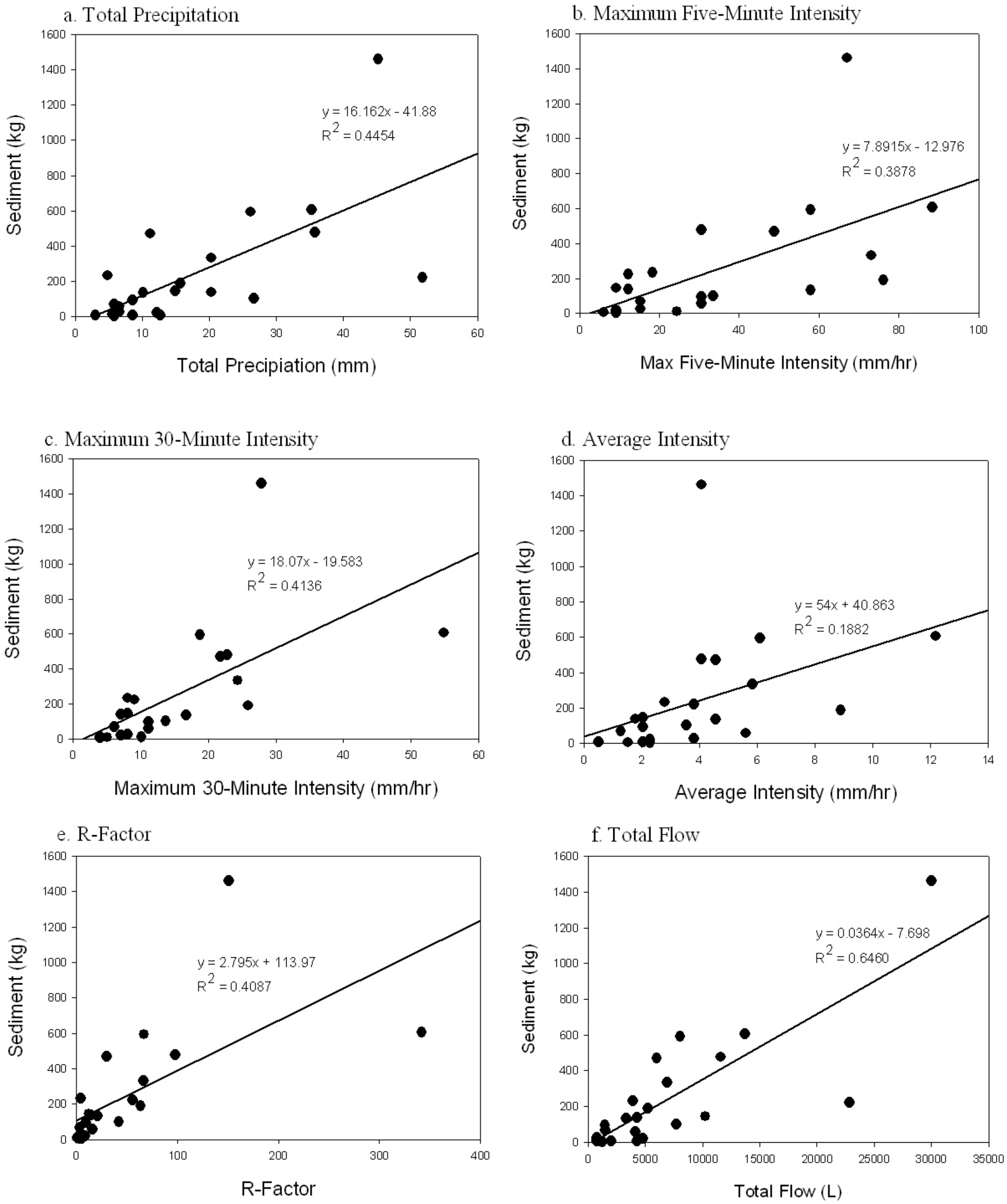
| | Precipitation Variables | | | | | Erosion Variables | | | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Total (mm) | Maximum Intensity (mm/hr) | Maximum 30-Minute Intensity (mm/hr) | Mean Intensity (mm/hr) | Rainfall Erosion Index Value (R Factor) | Total Flow (L) | Total Erosion (kg) | Total Per Unit Area (kg/ha) | Percent of Period Total |
| 6-02 | 11.2 | 48.8 | 21.8 | 5.6 | 60.4 | 9829 | 1257 | 20658 | 8.82 |
| 6-09 | 35.8 | 30.5 | 22.9 | 4.3 | 173.9 | 15909 | 1292 | 21239 | 9.07 |
| 6-19 | 20.3 | 73.2 | 24.4 | 4.3 | 24.4 | 13569 | 824 | 13534 | 5.78 |
| 6-20 | 26.2 | 57.9 | 18.8 | 7.9 | 112.1 | 12760 | 1940 | 31883 | 13.61 |
| 6-22 | 14.7 | 9.1 | 8.1 | 2.5 | 22.8 | 13223 | 281 | 4619 | 1.97 |
| 7-02 | 8.4 | 30.5 | 11.2 | 1.8 | 20.9 | 2309 | 290 | 4773 | 2.04 |
| 7-06 | 8.9 | 18.3 | 8.1 | 2.0 | 8.1 | 3908 | 729 | 11980 | 5.11 |
| 7-24 | 11.2 | 18.3 | 7.1 | 1.0 | 15.0 | 959 | 34 | 557 | 0.24 |
| 7-28 | 26.7 | 33.5 | 13.7 | 3.3 | 75.5 | 15989 | 787 | 12934 | 5.52 |
| 7-29 | 8.6 | 9.1 | 5.1 | 0.5 | 7.5 | 5439 | 104 | 1706 | 0.73 |
| 8-11 | 20.3 | 12.2 | 7.1 | 2.0 | 25.9 | 8661 | 739 | 12148 | 5.19 |
| 8-13 | 5.8 | 15.2 | 6.1 | 1.0 | 7.3 | 4295 | 373 | 6126 | 2.61 |
| 9-05 | 5.6 | 24.4 | 10.2 | 2.3 | 12.4 | 786 | 46 | 760 | 0.32 |
| 9-16 | 35.3 | 88.4 | 54.9 | 12.2 | 503.5 | 26943 | 3229 | 53069 | 22.65 |
| 10-07 | 10.2 | 57.9 | 16.8 | 4.6 | 41.0 | 3561 | 260 | 4276 | 1.83 |
| 10-10 | 51.8 | 12.2 | 9.1 | 3.8 | 86.2 | 33226 | 1197 | 19664 | 8.39 |
| 10-26 | 15.7 | 76.2 | 25.9 | 9.4 | 103.9 | 6633 | 645 | 10593 | 4.52 |
| 10-27 | 5.8 | 9.1 | 4.1 | 2.3 | 3.5 | 1871 | 65 | 1065 | 0.45 |
| 11-01 | 12.2 | 9.1 | 7.1 | 2.3 | 15.1 | 3539 | 64 | 1053 | 0.45 |
| 11-02 | 2.5 | 3.0 | 1.5 | 0.8 | 0.6 | 1734 | 30 | 495 | 0.21 |
| 11-03 | 12.7 | 6.1 | 4.1 | 1.5 | 8.4 | 3612 | 54 | 894 | 0.38 |
| 11-11 | 3.0 | 9.1 | 4.1 | 2.0 | 2.2 | 740 | 15 | 247 | 0.11 |

Table B-3. Summary of Precipitation Variables and Erosion for the 32 NE Station.

| | Precipitation Variables | | | | | Erosion Variables | | | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Total (mm) | Maximum Intensity (mm/hr) | Maximum 30-Minute Intensity (mm/hr) | Mean Intensity (mm/hr) | Rainfall Erosion Index Value (R Factor) | Total Flow (L) | Total Erosion (kg) | Total Per Unit Area (kg/ha) | Percent of Period Total |
| 6-02 | 23.1 | 79.2 | 44.7 | 8.9 | 276.4 | 23.1 | 892 | 11601 | 12.97 |
| 6-05 | 34.5 | 100.6 | 46.2 | 8.9 | 415.1 | 34.5 | 2497 | 32465 | 36.29 |
| 6-09 | 38.1 | 18.3 | 10.2 | 1.8 | 72.6 | 38.1 | 193 | 2509 | 2.80 |
| 6-19 | 18.0 | 24.4 | 18.8 | 5.1 | 71.5 | 18.0 | 88 | 1143 | 1.28 |
| 6-21 | 49.8 | 79.2 | 34.0 | 4.6 | 385.3 | 49.8 | 1683 | 21883 | 24.46 |
| 6-22 | 18.0 | 12.2 | 9.7 | 3.3 | 32.6 | 18.0 | 172 | 2233 | 2.50 |
| 7-06 | 23.6 | 61.0 | 31.5 | 4.6 | 170.8 | 23.6 | 456 | 5927 | 6.62 |
| 7-24 | 24.1 | 42.7 | 23.9 | 2.5 | 124.8 | 24.1 | 179 | 2322 | 2.60 |
| 7-28 | 17.3 | 15.2 | 9.7 | 2.3 | 32.0 | 17.3 | 74 | 957 | 1.07 |
| 7-29 | 7.9 | 9.1 | 4.6 | 0.5 | 6.6 | 7.9 | 16 | 206 | 0.23 |
| 8-11 | 34.0 | 42.7 | 14.7 | 2.3 | 105.0 | 34.0 | 95 | 1230 | 1.37 |
| 8-13 | 8.1 | 27.4 | 15.2 | 6.6 | 28.0 | 8.1 | 24 | 307 | 0.34 |
| 9-16 | 31.8 | 67.1 | 46.7 | 13.7 | 377.0 | 31.8 | 72 | 939 | 1.05 |
| 10-06 | 12.2 | 33.5 | 14.2 | 6.4 | 37.7 | 12.2 | 62 | 804 | 0.90 |
| 10-7 | 12.4 | 67.1 | 21.8 | 6.9 | 70.6 | 12.4 | 35 | 449 | 0.50 |
| 10-10 | 55.9 | 24.4 | 15.7 | 4.1 | 166.9 | 55.9 | 69 | 894 | 1.00 |
| 10-26 | 7.6 | 27.4 | 13.2 | 5.3 | 22.1 | 7.6 | 20 | 266 | 0.30 |
| 11-01 | 13.0 | 6.1 | 4.1 | 1.5 | 8.6 | 13.0 | 1 | 16 | 0.02 |
| 11-02 | 27.9 | 54.9 | 29.0 | 11.2 | 184.7 | 27.9 | 163 | 2119 | 2.37 |
| 11-03 | 18.8 | 6.1 | 5.1 | 2.5 | 16.1 | 18.8 | 9 | 116 | 0.13 |
| 11-11 | 10.4 | 21.3 | 14.2 | 6.4 | 10.1 | 10.4 | 40 | 521 | 0.58 |

Table B-4. Summary of Precipitation Variables and Erosion for the 32 NW Station.

| | Precipitation Variables | | | | | Erosion Variables | | | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Total Precipit ation (mm) | Maximum Intensity (mm/hr) | Maximum 30-Minute Intensity (mm/hr) | Mean Intensity (mm/hr) | Rainfall Erosion Index Value (R Factor) | Total Flow (L) | Total Erosion (kg) | Total Per Unit Area (kg/ha) | Percent of Period Total |
| 6-02 | 23.1 | 79.2 | 44.7 | 6.9 | 276.4 | 17531 | 1071 | 19711 | 18.17 |
| 6-05 | 34.5 | 100.6 | 46.2 | 5.8 | 415.1 | 40889 | 2049 | 37706 | 34.76 |
| 6-09 | 38.1 | 18.3 | 10.2 | 1.8 | 72.6 | 25261 | 150 | 2768 | 2.55 |
| 6-19 | 18.0 | 24.4 | 18.8 | 4.6 | 71.5 | 8863 | 99 | 1819 | 1.68 |
| 6-20 | 15.2 | 33.5 | 11.2 | 3.8 | 34.7 | 12107 | 121 | 2224 | 2.05 |
| 6-21 | 49.8 | 79.2 | 34.0 | 4.6 | 385.3 | 53170 | 1148 | 21118 | 19.47 |
| 6-22 | 18.0 | 12.2 | 9.7 | 2.8 | 32.6 | 38860 | 114 | 2096 | 1.93 |
| 7-06 | 23.6 | 61.0 | 31.5 | 5.6 | 170.8 | 9472 | 176 | 3238 | 2.99 |
| 7-24 | 24.6 | 42.7 | 23.9 | 2.3 | 124.8 | 7072 | 66 | 1217 | 1.12 |
| 7-28 | 17.3 | 15.2 | 9.7 | 2.5 | 32.0 | 6366 | 54 | 999 | 0.92 |
| 7-29 | 8.1 | 9.1 | 4.6 | 0.5 | 6.6 | 2379 | 7 | 125 | 0.12 |
| 8-11 | 34.0 | 42.7 | 14.7 | 2.3 | 105.0 | 13709 | 97 | 1793 | 1.65 |
| 8-13 | 8.1 | 27.4 | 15.2 | 5.1 | 28.0 | 3825 | 60 | 1103 | 1.02 |
| 9-16 | 31.8 | 67.1 | 46.7 | 13.7 | 377.0 | 7751 | 61 | 1123 | 1.03 |
| 10-06 | 12.2 | 33.5 | 14.2 | 6.4 | 37.7 | 1622 | 6 | 114 | 0.10 |
| 10-10 | 55.9 | 24.4 | 15.7 | 4.1 | 166.9 | 19534 | 35 | 876 | 0.81 |
| 10-26 | 7.6 | 27.4 | 13.2 | 5.3 | 22.1 | 3710 | 48 | 1119 | 1.03 |
| 11-01 | 13.0 | 6.1 | 4.1 | 1.5 | 8.6 | 3723 | 61 | 171 | 0.16 |
| 11-02 | 27.9 | 54.9 | 29.0 | 11.2 | 184.7 | 238333 | 9 | 6824 | 6.29 |
| 11-03 | 18.8 | 6.1 | 5.1 | 2.5 | 16.1 | 10906 | 371 | 502 | 0.46 |
| 11-10 | 10.4 | 21.3 | 14.2 | 6.4 | 1394.3 | 4094 | 27 | 779 | 0.72 |
| 11-11 | 6.6 | 30.5 | 11.2 | 5.6 | 16.0 | 4115 | 42 | 1058 | 0.98 |


a. Total Precipitation

b. Maximum Five-Minute Intensity

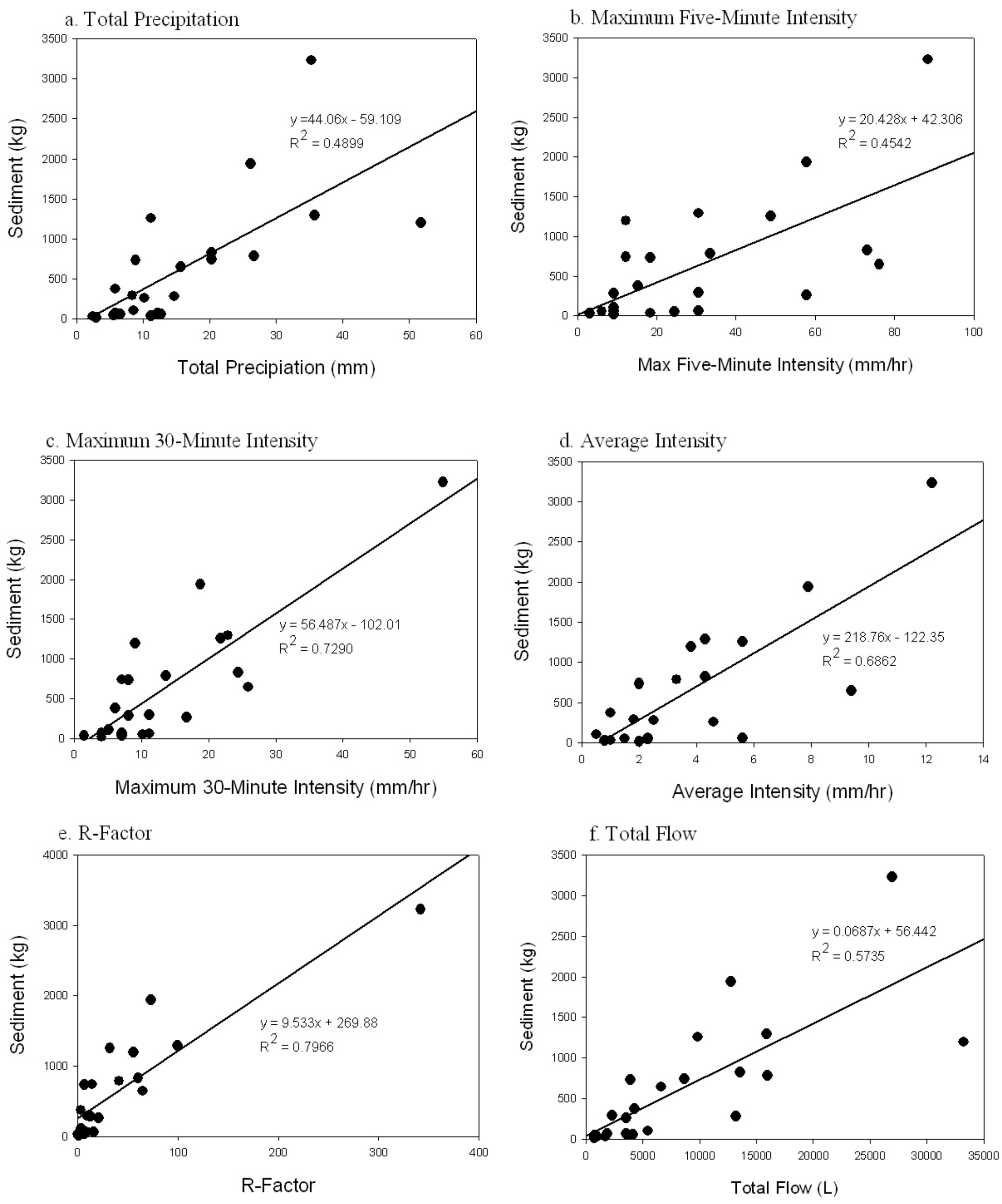
c. Maximum 30-Minute Intensity

d. Average Intensity

e. R-Factor

f. Total Flow

Figure B-1. Scatter plots for the regression of rainfall variables against total erosion for the 19 NE segment.


a. Total Precipitation

b. Maximum Five-Minute Intensity

c. Maximum 30-Minute Intensity

d. Average Intensity

e. R-Factor

f. Total Flow

Figure B-2. Scatter plots for the regression of rainfall variables against total erosion for the 19 NW segment.

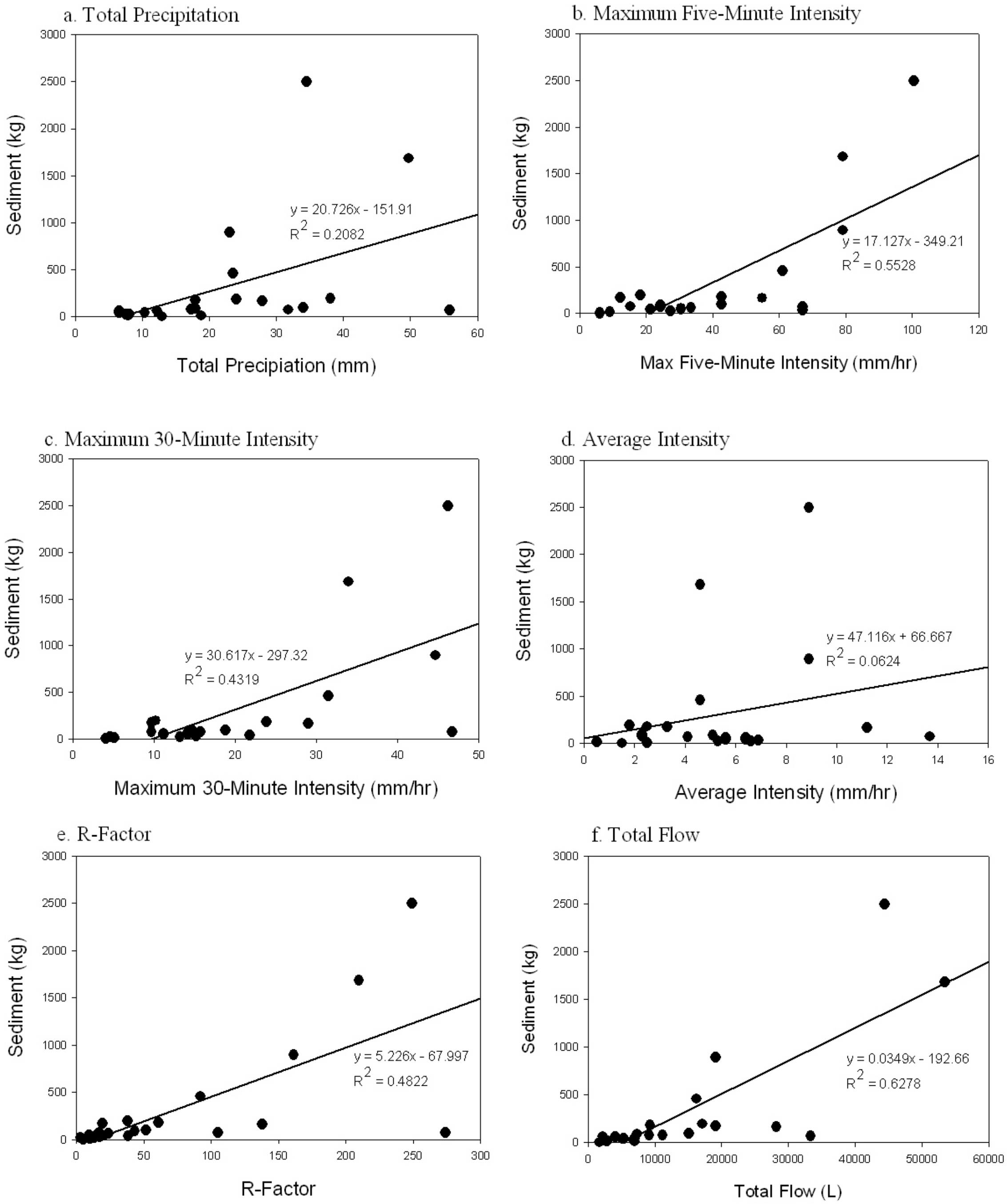


Figure B-3. Scatter plots for the regression of rainfall variables against total erosion for the 32 NE segment.

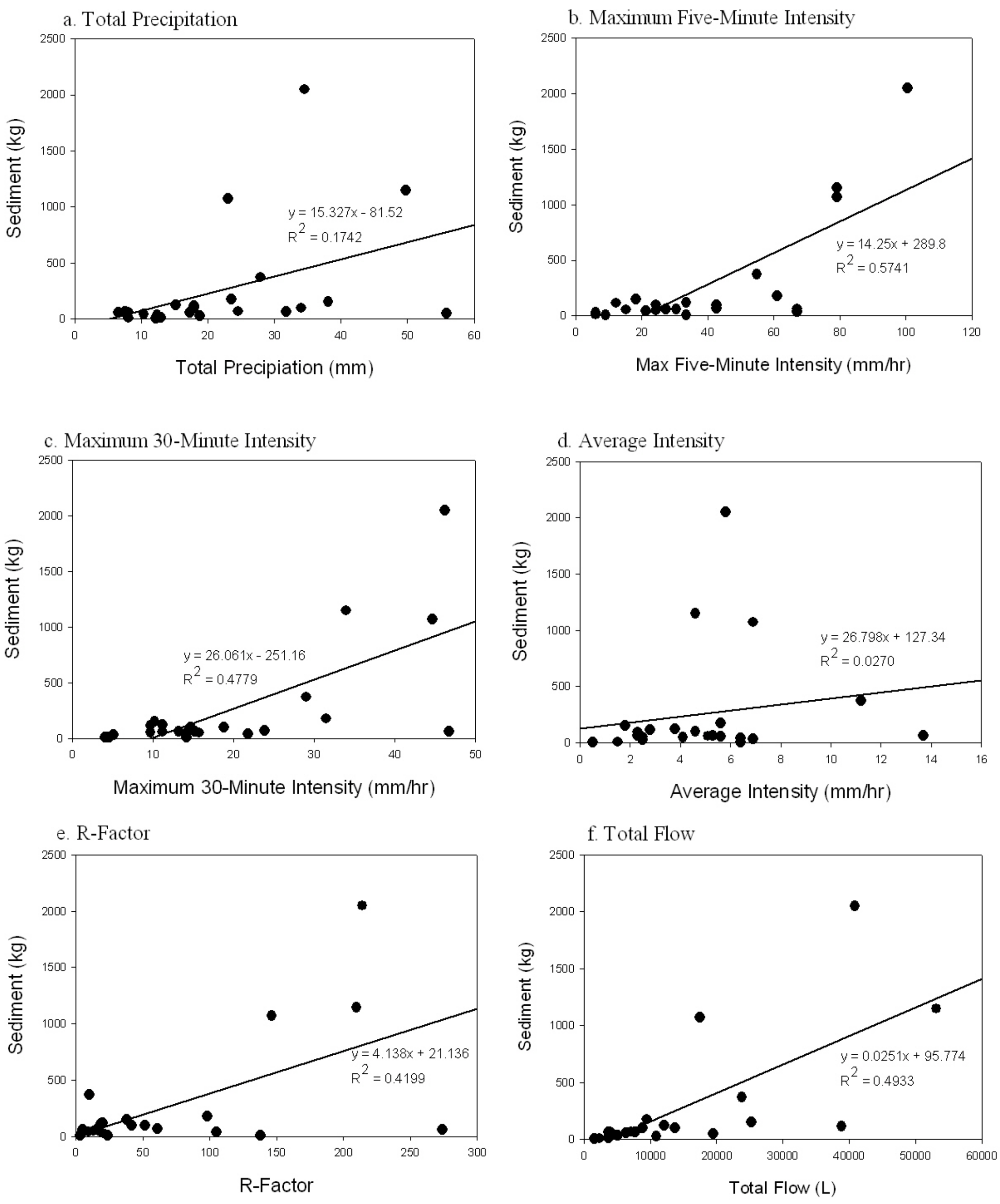


Figure B-4. Scatter plots for the regression of rainfall variables against total erosion for the 32 NW segment.

# APPENDIX C

## EXPANDED WEPP RESULTS

Table C-1. Summary of observed and predicted erosion and flow for 19 NE WEPP runs.

a. Erosion

| EROSION | | Default | | Recommended | | Default + Grading | | Recommended + Grading | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Observed | Predicted | % Diff. | Predicted | % Diff. | Predicted | % Diff. | Predicted | % Diff. |
| 6-02 | 470 | 127 | -73 | 152 | -68 | 470 | 317 | 317 | -33 |
| 6-09 | 476 | 332 | -30 | 418 | -12 | 476 | 517 | 517 | 9 |
| 6-19 | 332 | 167 | -50 | 205 | -38 | 332 | 416 | 416 | 25 |
| 6-20 | 593 | 245 | -59 | 320 | -46 | 593 | 387 | 387 | -35 |
| 6-21 | 1,461 | 392 | -73 | 557 | -62 | 1,461 | 675 | 675 | -54 |
| 6-22 | 144 | 169 | 17 | 151 | 5 | 144 | 169 | 151 | 5 |
| 7-02 | 95 | 70 | -26 | 61 | -36 | 95 | 70 | 76 | -20 |
| 7-06 | 232 | 34 | -85 | 0 | -100 | 232 | 133 | 133 | -43 |
| 7-28 | 102 | 248 | 143 | 294 | 188 | 102 | 248 | 294 | 188 |
| 7-29 | 7 | 63 | 800 | 20 | 186 | 7 | 63 | 20 | 186 |
| 8-11 | 137 | 187 | 36 | 144 | 5 | 137 | 187 | 144 | 5 |
| 8-13 | 67 | 51 | -24 | 7 | -90 | 67 | 51 | 7 | -90 |
| 9-05 | 11 | 39 | 255 | 17 | 55 | 11 | 39 | 17 | 55 |
| 9-16 | 605 | 360 | -40 | 480 | -21 | 605 | 360 | 480 | -21 |
| 10-07 | 133 | 111 | -17 | 70 | -47 | 133 | 111 | 70 | -47 |
| 10-10 | 222 | 605 | 173 | 610 | 175 | 222 | 605 | 610 | 175 |
| 10-26 | 189 | 160 | -15 | 177 | -6 | 189 | 160 | 177 | -6 |
| 10-27 | 2 | 27 | 1250 | 0 | -100 | 2 | 27 | 0 | -100 |
| 11-01 | 20 | 100 | 400 | 54 | 170 | 20 | 100 | 54 | 170 |
| 11-03 | 6 | 98 | 1533 | 77 | 1183 | 6 | 98 | 77 | 1183 |
| 11-10 | 25 | 40 | 60 | 11 | -56 | 25 | 40 | 11 | -56 |
| 11-11 | 8 | 0 | -100 | 0 | -100 | 8 | 0 | 0 | -100 |

b. Flow

| FLOW | | Default | | Recommended | | Default + Grading | | Recommended + Grading | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Observed | Predicted | % Diff. | Predicted | % Diff. | Predicted | % Diff. | Predicted | % Diff. |
| 6-02 | 6,011 | 5,245 | -13 | 4,245 | -29 | 4,245 | -29 | 4,245 | -29 |
| 6-09 | 11,610 | 15,097 | 30 | 13,113 | 13 | 13,113 | 13 | 13,113 | 13 |
| 6-19 | 6,904 | 8,422 | 22 | 6,054 | -12 | 6,054 | -12 | 6,054 | -12 |
| 6-20 | 8,052 | 12,220 | 52 | 9,541 | 18 | 9,541 | 18 | 9,541 | 18 |
| 6-21 | 30,013 | 20,280 | -32 | 18,341 | -39 | 18,341 | -39 | 18,341 | -39 |
| 6-22 | 10,235 | 6,212 | -39 | 4,120 | -60 | 6,212 | -39 | 4,120 | -60 |
| 7-02 | 1,470 | 2,736 | 86 | 1,617 | 10 | 2,736 | 86 | 1,617 | 10 |
| 7-06 | 3,907 | 1,085 | -72 | 0 | -100 | 1,566 | -60 | 0 | -60 |
| 7-28 | 7,695 | 11,146 | 45 | 9,106 | 18 | 11,146 | 45 | 9,106 | 18 |
| 7-29 | 2,028 | 2,210 | 9 | 486 | -76 | 2,210 | 9 | 486 | -76 |
| 8-11 | 4,310 | 7,037 | 63 | 3,821 | -11 | 7,037 | 63 | 3,821 | -11 |
| 8-13 | 1,506 | 1,747 | 16 | 170 | -89 | 1,747 | 16 | 170 | -89 |
| 9-05 | 743 | 1,300 | 75 | 413 | -44 | 1,300 | 75 | 413 | -44 |
| 9-16 | 13,721 | 17,923 | 31 | 15,900 | 16 | 17,923 | 31 | 15,900 | 16 |
| 10-07 | 3,359 | 3,855 | 15 | 1,317 | -61 | 3,855 | 15 | 1,317 | -61 |
| 10-10 | 22,842 | 24,231 | 6 | 17,889 | -22 | 24,231 | 6 | 17,889 | -22 |
| 10-26 | 5,236 | 6,992 | 34 | 5,257 | 0 | 6,992 | 34 | 5,257 | 0 |
| 10-27 | 1,239 | 803 | -35 | 0 | -100 | 803 | -35 | 0 | -100 |
| 11-01 | 4,767 | 3,567 | -25 | 1,362 | -71 | 3,567 | -25 | 1,362 | -71 |
| 11-03 | 4,300 | 3,290 | -23 | 2,029 | -53 | 3,290 | -23 | 2,029 | -53 |
| 11-10 | 760 | 1,323 | 74 | 249 | -67 | 1,323 | 74 | 249 | -67 |
| 11-11 | 775 | 0 | -100 | 0 | -100 | 0 | -100 | 0 | -100 |

Table C-2. Summary of observed and predicted erosion and flow for 19 NW WEPP runs.

a. Erosion

| EROSION | | Default | | Recommended | | Default + Grading | | Recommended + Grading | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Observed | Predicted | % Diff. | Predicted | % Diff. | Predicted | % Diff. | Predicted | % Diff. |
| 6-02 | 1,257 | 210 | -83 | 218 | -83 | 487 | -61 | 487 | -61 |
| 6-09 | 1,292 | 541 | -58 | 705 | -45 | 886 | -31 | 886 | -31 |
| 6-19 | 823 | 296 | -64 | 347 | -58 | 765 | -7 | 765 | -7 |
| 6-20 | 1,940 | 414 | -79 | 527 | -73 | 652 | -66 | 652 | -66 |
| 6-22 | 281 | 295 | 5 | 271 | -4 | 295 | 5 | 271 | -4 |
| 7-02 | 290 | 124 | -57 | 119 | -59 | 124 | -57 | 119 | -59 |
| 7-06 | 728 | 69 | -91 | 0 | -100 | 243 | -67 | 243 | -67 |
| 7-24 | 33 | 173 | 424 | 161 | 388 | 173 | 424 | 161 | 388 |
| 7-28 | 787 | 408 | -48 | 511 | -35 | 408 | -48 | 511 | -35 |
| 7-29 | 103 | 127 | 23 | 61 | -41 | 127 | 23 | 61 | -41 |
| 8-11 | 739 | 331 | -55 | 295 | -60 | 331 | -55 | 295 | -60 |
| 8-13 | 372 | 77 | -79 | 38 | -90 | 77 | -79 | 38 | -90 |
| 9-05 | 46 | 76 | 65 | 42 | -9 | 76 | 65 | 42 | -9 |
| 9-16 | 3,229 | 577 | -82 | 785 | -76 | 577 | -82 | 785 | -76 |
| 10-07 | 260 | 198 | -24 | 176 | -32 | 198 | -24 | 176 | -32 |
| 10-10 | 1,196 | 1,024 | -14 | 1,089 | -9 | 1,024 | -14 | 1089 | -9 |
| 10-26 | 644 | 273 | -58 | 318 | -51 | 273 | -58 | 318 | -51 |
| 10-27 | 64 | 62 | -3 | 9 | -86 | 62 | -3 | 9 | -86 |
| 11-01 | 64 | 186 | 191 | 140 | 119 | 186 | 191 | 140 | 119 |
| 11-03 | 30 | 0 | -100 | 0 | -100 | 0 | -100 | 0 | -100 |
| 11-10 | 54 | 217 | 302 | 165 | 206 | 217 | 302 | 165 | 206 |
| 11-11 | 15 | 14 | -7 | 0 | -100 | 14 | -7 | 0 | -100 |

b. Flow

| FLOW | | Default | | Recommended | | Default + Grading | | Recommended + Grading | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Observed | Predicted | % Diff. | Predicted | % Diff. | Predicted | % Diff. | Predicted | % Diff. |
| 6-02 | 9,828 | 6,817 | -31 | 4808 | -51 | 4,808 | -51 | 4,808 | -51 |
| 6-09 | 15,908 | 20,090 | 26 | 17427 | 10 | 17,427 | 10 | 17,427 | 10 |
| 6-19 | 13,569 | 11,476 | -15 | 8174 | -40 | 8,174 | -40 | 8,174 | -40 |
| 6-20 | 12,759 | 16,057 | 26 | 12641 | -1 | 12,641 | -1 | 12,641 | -1 |
| 6-22 | 13,222 | 8,323 | -37 | 5553 | -58 | 8,323 | -37 | 5,553 | -58 |
| 7-02 | 2,308 | 3,593 | 56 | 2400 | 4 | 3,593 | 56 | 2,400 | 4 |
| 7-06 | 9,461 | 1,697 | -82 | 0 | -100 | 2,088 | -78 | 2,088 | -78 |
| 7-24 | 959 | 4,964 | 418 | 3167 | 230 | 4,964 | 418 | 3,167 | 230 |
| 7-28 | 15,989 | 14,544 | -9 | 12342 | -23 | 14,544 | -9 | 12,342 | -23 |
| 7-29 | 5,438 | 3,409 | -37 | 1094 | -80 | 3,409 | -37 | 1,094 | -80 |
| 8-11 | 8,660 | 9,587 | 11 | 5979 | -31 | 9,587 | 11 | 5,979 | -31 |
| 8-13 | 4,295 | 1,953 | -55 | 646 | -85 | 1,953 | -55 | 646 | -85 |
| 9-05 | 786 | 1,925 | 145 | 724 | -8 | 1,925 | 145 | 724 | -8 |
| 9-16 | 26,943 | 22,995 | -15 | 20949 | -22 | 22,995 | -15 | 20,949 | -22 |
| 10-07 | 3,561 | 5,276 | 48 | 3245 | -9 | 5,276 | 48 | 3,245 | -9 |
| 10-10 | 33,226 | 31,573 | -5 | 24330 | -27 | 31,573 | -5 | 24,330 | -27 |
| 10-26 | 6,632 | 9,204 | 39 | 7421 | 12 | 9,204 | 39 | 7,421 | 12 |
| 10-27 | 1,871 | 1,427 | -24 | 135 | -93 | 1,427 | -24 | 135 | -93 |
| 11-01 | 3,539 | 5,092 | 44 | 2727 | -23 | 5,092 | 44 | 2,727 | -23 |
| 11-03 | 1,733 | 0 | -100 | 0 | -100 | 0 | -100 | 0 | -100 |
| 11-10 | 3,612 | 5,639 | 56 | 3224 | -11 | 5,639 | 56 | 3,224 | -11 |
| 11-11 | 740 | 256 | -65 | 0 | -100 | 256 | -65 | 0 | -100 |

Table C-3. Summary of observed and predicted erosion and flow for 32 NE WEPP runs.

a. Erosion

| EROSION | | Default | | Recommended | | Default + Grading | | Recommended + Grading | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Observed | Predicted | % Diff. | Predicted | % Diff. | Predicted | % Diff. | Predicted | % Diff. |
| 6-02 | 892 | 190 | -79 | 261 | -71 | 879 | -1 | 879 | -1 |
| 6-09 | 2,497 | 162 | -94 | 190 | -92 | 1,128 | -55 | 1,128 | -55 |
| 6-19 | 193 | 151 | -22 | 132 | -32 | 297 | 54 | 297 | 54 |
| 6-20 | 88 | 67 | -24 | 66 | -25 | 67 | -24 | 66 | -25 |
| 6-22 | 1,683 | 418 | -75 | 170 | -90 | 1,632 | -3 | 1,632 | -3 |
| 7-02 | 172 | 63 | -63 | 63 | -63 | 127 | -26 | 127 | -26 |
| 7-06 | 456 | 135 | -70 | 92 | -80 | 135 | -70 | 92 | -80 |
| 7-24 | 172 | 107 | -38 | 115 | -33 | 107 | -38 | 115 | -33 |
| 7-28 | 74 | 42 | -43 | 43 | -42 | 42 | -43 | 43 | -42 |
| 7-29 | 16 | 16 | 0 | 19 | 19 | 16 | 0 | 19 | 19 |
| 8-11 | 95 | 167 | 76 | 206 | 117 | 167 | 76 | 206 | 117 |
| 8-13 | 24 | 31 | 29 | 40 | 67 | 31 | 29 | 40 | 67 |
| 9-05 | 74 | 160 | 116 | 205 | 177 | 160 | 116 | 205 | 177 |
| 9-16 | 62 | 58 | -6 | 64 | 3 | 58 | -6 | 64 | 3 |
| 10-07 | 36 | 49 | 36 | 50 | 39 | 49 | 36 | 50 | 39 |
| 10-10 | 69 | 236 | 242 | 197 | 186 | 236 | 242 | 197 | 186 |
| 10-26 | 20 | 17 | -15 | 26 | 30 | 17 | -15 | 26 | 30 |
| 10-27 | 2 | 13 | 550 | 29 | 1,350 | 13 | 550 | 29 | 1,350 |
| 11-01 | 163 | 133 | -18 | 162 | -1 | 133 | -18 | 162 | -1 |
| 11-03 | 9 | 50 | 456 | 50 | 456 | 50 | 456 | 50 | 456 |
| 11-10 | 40 | 37 | -8 | 40 | 0 | 37 | -8 | 40 | 0 |
| 11-11 | 42 | 16 | -62 | 24 | -43 | 16 | -62 | 24 | -43 |

b. Flow

| FLOW | | Default | | Recommended | | Default + Grading | | Recommended + Grading | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Observed | Predicted | % Diff. | Predicted | % Diff. | Predicted | % Diff. | Predicted | % Diff. |
| 6-02 | 19,118 | 12,679 | -34 | 18,732 | -2 | 16,666 | -13 | 16,666 | -13 |
| 6-09 | 44,463 | 23,675 | -47 | 27,765 | -38 | 23,035 | -48 | 23,035 | -48 |
| 6-19 | 17,155 | 20,960 | 22 | 26,553 | 55 | 20,320 | 18 | 20,320 | 18 |
| 6-20 | 7,357 | 8,546 | 16 | 12,226 | 66 | 8,546 | 16 | 12,226 | 66 |
| 6-22 | 53,480 | 30,497 | -43 | 38,855 | -27 | 30,497 | -43 | 30,497 | -43 |
| 7-02 | 19,122 | 8,196 | -57 | 12,875 | -33 | 8,196 | -57 | 8,196 | -57 |
| 7-06 | 16,194 | 12,807 | -21 | 17,169 | 6 | 12,807 | -21 | 17,169 | 6 |
| 7-24 | 9,281 | 12,704 | 37 | 16,008 | 72 | 12,704 | 37 | 16,008 | 72 |
| 7-28 | 11,182 | 5,234 | -53 | 10,314 | -8 | 5,234 | -53 | 10,314 | -8 |
| 7-29 | 2,856 | 2,032 | -29 | 4,388 | 54 | 2,032 | -29 | 4,388 | 54 |
| 8-11 | 15,140 | 20,397 | 35 | 24,384 | 61 | 20,397 | 35 | 24,384 | 61 |
| 8-13 | 2,220 | 4,192 | 89 | 5,959 | 168 | 4,192 | 89 | 5,959 | 168 |
| 9-05 | 9,150 | 21,029 | 130 | 25,289 | 176 | 21,029 | 130 | 25,289 | 176 |
| 9-16 | 2,168 | 6,668 | 208 | 9,067 | 318 | 6,668 | 208 | 9,067 | 318 |
| 10-07 | 5,103 | 4,901 | -4 | 9,161 | 80 | 4,901 | -4 | 9,161 | 80 |
| 10-10 | 33,355 | 33,554 | 1 | 41,041 | 23 | 33,554 | 1 | 41,041 | 23 |
| 10-26 | 2,159 | 1,673 | -22 | 5,131 | 138 | 1,673 | -22 | 5,131 | 138 |
| 10-27 | 1,737 | 1,528 | -12 | 7,129 | 310 | 1,528 | -12 | 7,129 | 310 |
| 11-01 | 28,225 | 18,023 | -36 | 22,070 | -22 | 18,023 | -36 | 22,070 | -22 |
| 11-03 | 6,960 | 6,429 | -8 | 13,234 | 90 | 6,429 | -8 | 13,234 | 90 |
| 11-10 | 6,938 | 4,371 | -37 | 7,232 | 4 | 4,371 | -37 | 7,232 | 4 |
| 11-11 | 5,357 | 1,520 | -72 | 4,286 | -20 | 1,520 | -72 | 4,286 | -20 |

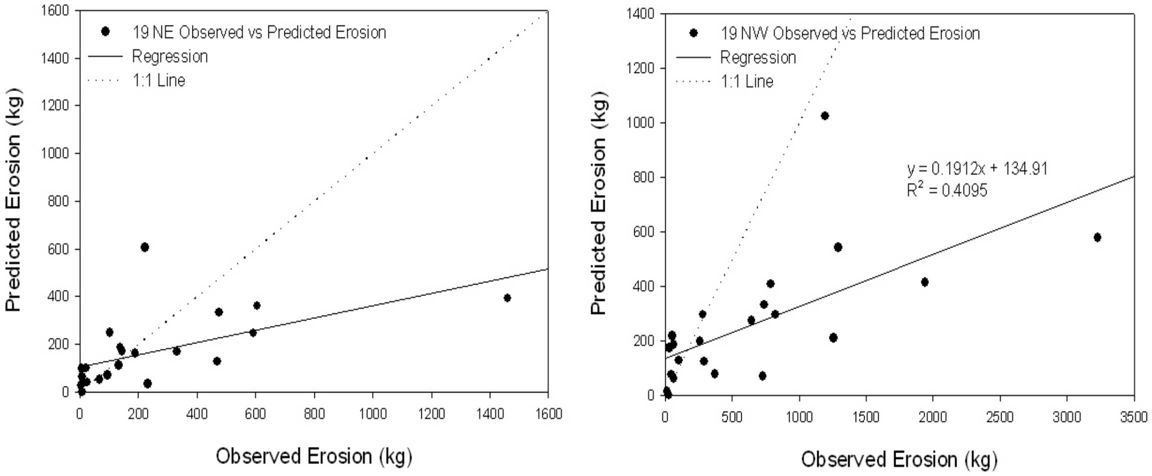
Table C-4. Summary of observed and predicted erosion and flow for 32 NW WEPP runs.

a. Erosion

| EROSION | | Default | | Recommended | | Default + Grading | | Recommended + Grading | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Observed | Predicted | % Diff. | Predicted | % Diff. | Predicted | % Diff. | Predicted | % Diff. |
| 6-02 | 1,071 | 150 | -86 | 209 | -80 | 835 | -22 | 835 | -22 |
| 6-09 | 2,049 | 128 | -94 | 150 | -93 | 1,049 | -49 | 1,049 | -49 |
| 6-19 | 150 | 114 | -24 | 102 | -32 | 225 | 50 | 225 | 50 |
| 6-20 | 98 | 50 | -49 | 51 | -48 | 50 | -49 | 51 | -48 |
| 6-22 | 120 | 55 | -54 | 44 | -63 | 55 | -54 | 44 | -63 |
| 7-02 | 1,147 | 335 | -71 | 133 | -88 | 1,574 | 37 | 1,574 | 37 |
| 7-06 | 114 | 46 | -60 | 49 | -57 | 90 | -21 | 90 | -21 |
| 7-24 | 176 | 104 | -41 | 73 | -59 | 104 | -41 | 73 | -59 |
| 7-28 | 66 | 86 | 30 | 90 | 36 | 86 | 30 | 90 | 36 |
| 7-29 | 54 | 26 | -52 | 32 | -41 | 26 | -52 | 32 | -41 |
| 8-11 | 7 | 10 | 43 | 14 | 100 | 10 | 43 | 14 | 100 |
| 8-13 | 97 | 127 | 31 | 164 | 69 | 127 | 31 | 164 | 69 |
| 9-05 | 60 | 23 | -62 | 32 | -47 | 23 | -62 | 32 | -47 |
| 9-16 | 61 | 122 | 100 | 160 | 162 | 122 | 100 | 160 | 162 |
| 10-07 | 6 | 43 | 617 | 50 | 733 | 43 | 617 | 50 | 733 |
| 10-10 | 46 | 183 | 298 | 150 | 226 | 183 | 298 | 150 | 226 |
| 10-26 | 61 | 13 | -79 | 20 | -67 | 13 | -79 | 20 | -67 |
| 10-27 | 10 | 0 | -100 | 20 | 100 | 0 | -100 | 20 | 100 |
| 11-01 | 370 | 111 | -70 | 128 | -65 | 111 | -70 | 128 | -65 |
| 11-02 | 27 | 33 | 22 | 39 | 44 | 33 | 22 | 39 | 44 |
| 11-03 | 42 | 27 | -36 | 32 | -24 | 27 | -36 | 32 | -24 |
| 11-11 | 57 | 13 | -77 | 18 | -68 | 13 | -77 | 18 | -68 |

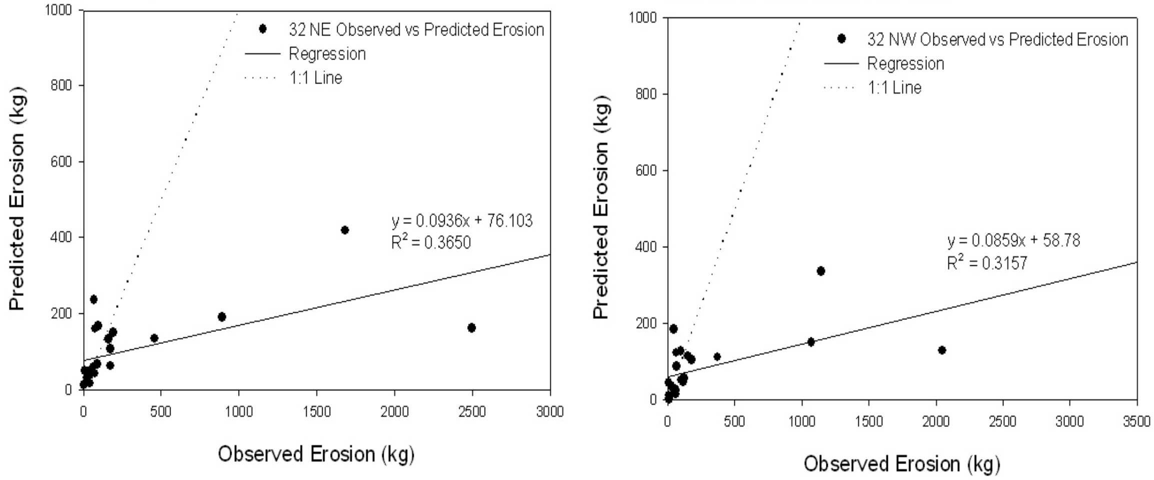
b. Flow

| FLOW | | Default | | Recommended | | Default + Grading | | Recommended + Grading | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Observed | Predicted | % Diff. | Predicted | % Diff. | Predicted | % Diff. | Predicted | % Diff. |
| 6-02 | 17,531 | 13,394 | -24 | 15,355 | -12 | 13,394 | -24 | 13,394 | -24 |
| 6-09 | 40,889 | 18,818 | -54 | 22,732 | -44 | 18,240 | -55 | 18,240 | -55 |
| 6-19 | 25,261 | 16,392 | -35 | 21,646 | -14 | 15,778 | -38 | 15,778 | -38 |
| 6-20 | 8,862 | 6,545 | -26 | 9,832 | 11 | 6,545 | -26 | 9,832 | 11 |
| 6-22 | 12,107 | 5,854 | -52 | 8,802 | -27 | 5,854 | -52 | 8,802 | -27 |
| 7-02 | 53,169 | 25,060 | -53 | 32,036 | -40 | 24,891 | -53 | 24,891 | -53 |
| 7-06 | 38,860 | 6,214 | -84 | 10,389 | -73 | 5,854 | -85 | 5,854 | -85 |
| 7-24 | 9,472 | 10,185 | 8 | 13,542 | 43 | 10,185 | 8 | 13,542 | 43 |
| 7-28 | 7,072 | 10,030 | 42 | 13,034 | 84 | 10,030 | 42 | 13,034 | 84 |
| 7-29 | 6,366 | 3,336 | -48 | 8,259 | 30 | 3,336 | -48 | 8,259 | 30 |
| 8-11 | 2,378 | 1,382 | -42 | 3,414 | 44 | 1,382 | -42 | 3,414 | 44 |
| 8-13 | 13,708 | 16,138 | 18 | 20,088 | 47 | 16,138 | 18 | 20,088 | 47 |
| 9-05 | 3,825 | 3,005 | -21 | 4,817 | 26 | 3,005 | -21 | 4,817 | 26 |
| 9-16 | 7,750 | 16,624 | 115 | 20,680 | 167 | 16,624 | 115 | 20,680 | 167 |
| 10-07 | 1,621 | 5,198 | 221 | 7,335 | 353 | 5,198 | 221 | 7,335 | 353 |
| 10-10 | 19,533 | 26,471 | 36 | 33,792 | 73 | 26,471 | 36 | 33,792 | 73 |
| 10-26 | 3,709 | 1,284 | -65 | 4,077 | 10 | 1,284 | -65 | 4,077 | 10 |
| 10-27 | 3,722 | 0 | -100 | 5,628 | 51 | 0 | -100 | 5,628 | 51 |
| 11-01 | 23,833 | 13,838 | -42 | 18,028 | -24 | 13,838 | -42 | 18,028 | -24 |
| 11-02 | 10,906 | 4,324 | -60 | 10,643 | -2 | 4,324 | -60 | 10,643 | -2 |
| 11-03 | 4,093 | 3,336 | -18 | 5,925 | 45 | 3,336 | -18 | 5,925 | 45 |
| 11-11 | 4,115 | 1,178 | -71 | 3,421 | -17 | 1,178 | -71 | 3,421 | -17 |



a. 19 NE Default WEPP Run.

b. 19 NW Default WEPP Run.



c. 32 NE Default WEPP Run.

d. 32 NW Default WEPP Run.

Figure C-1. Scatter plots with regression lines for observed versus predicted erosion for default WEPP parameter sets by segment.

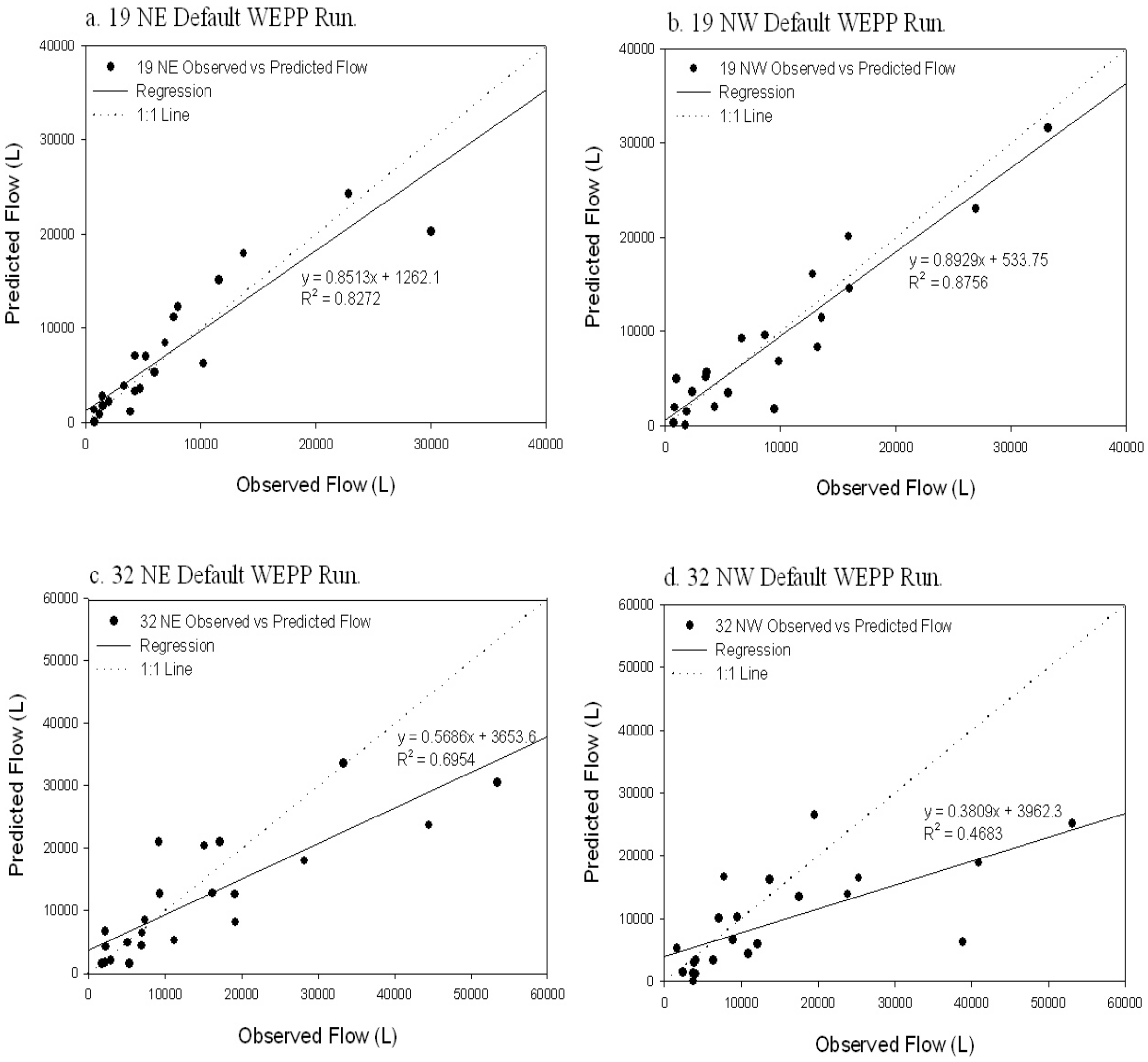


Figure C-2. Scatter plots with regression lines for observed versus predicted total flow for default WEPP parameter sets by segment.

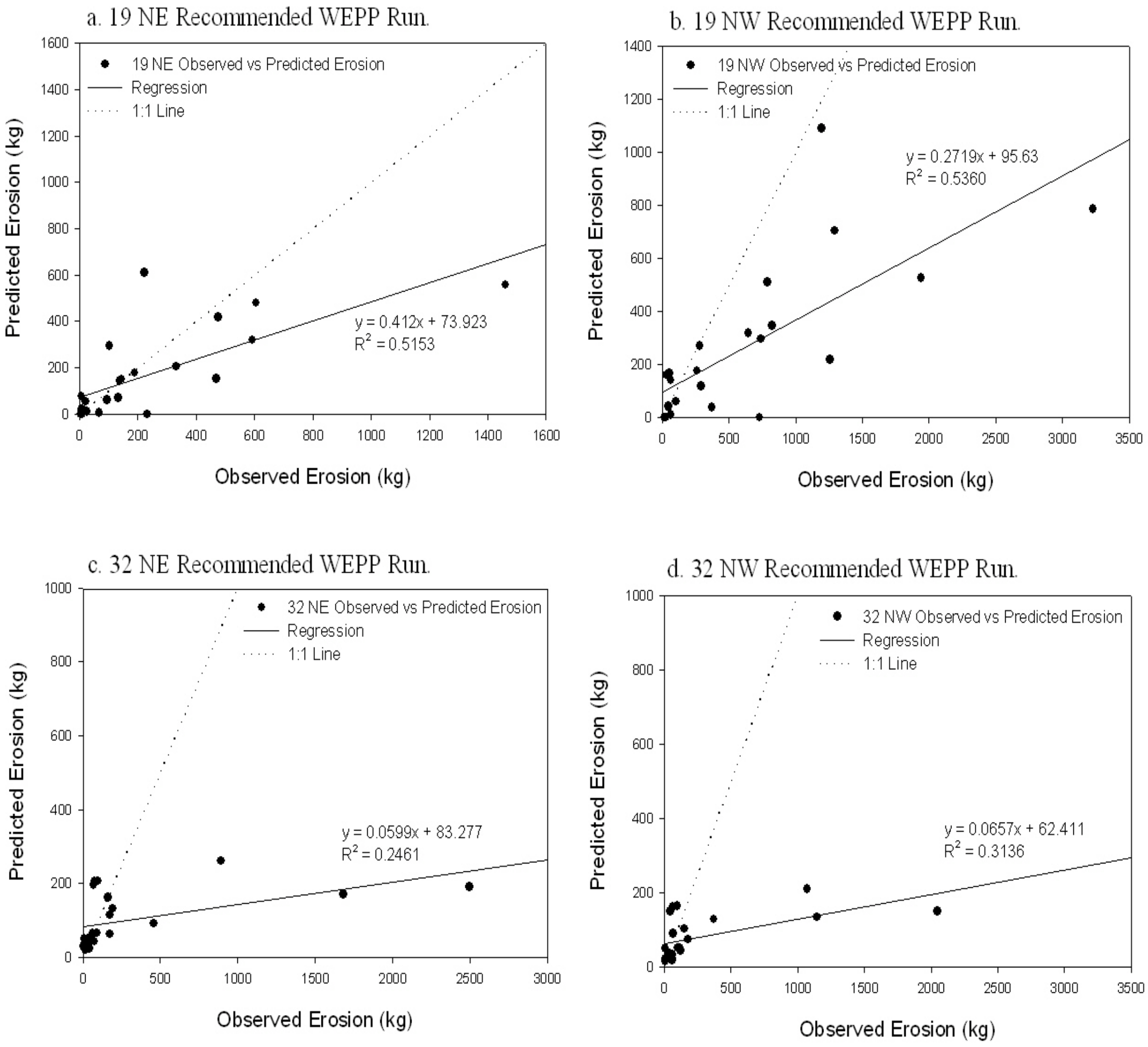


Figure C-3. Scatter plots with regression lines for observed versus predicted erosion for recommended WEPP parameter sets by segment.

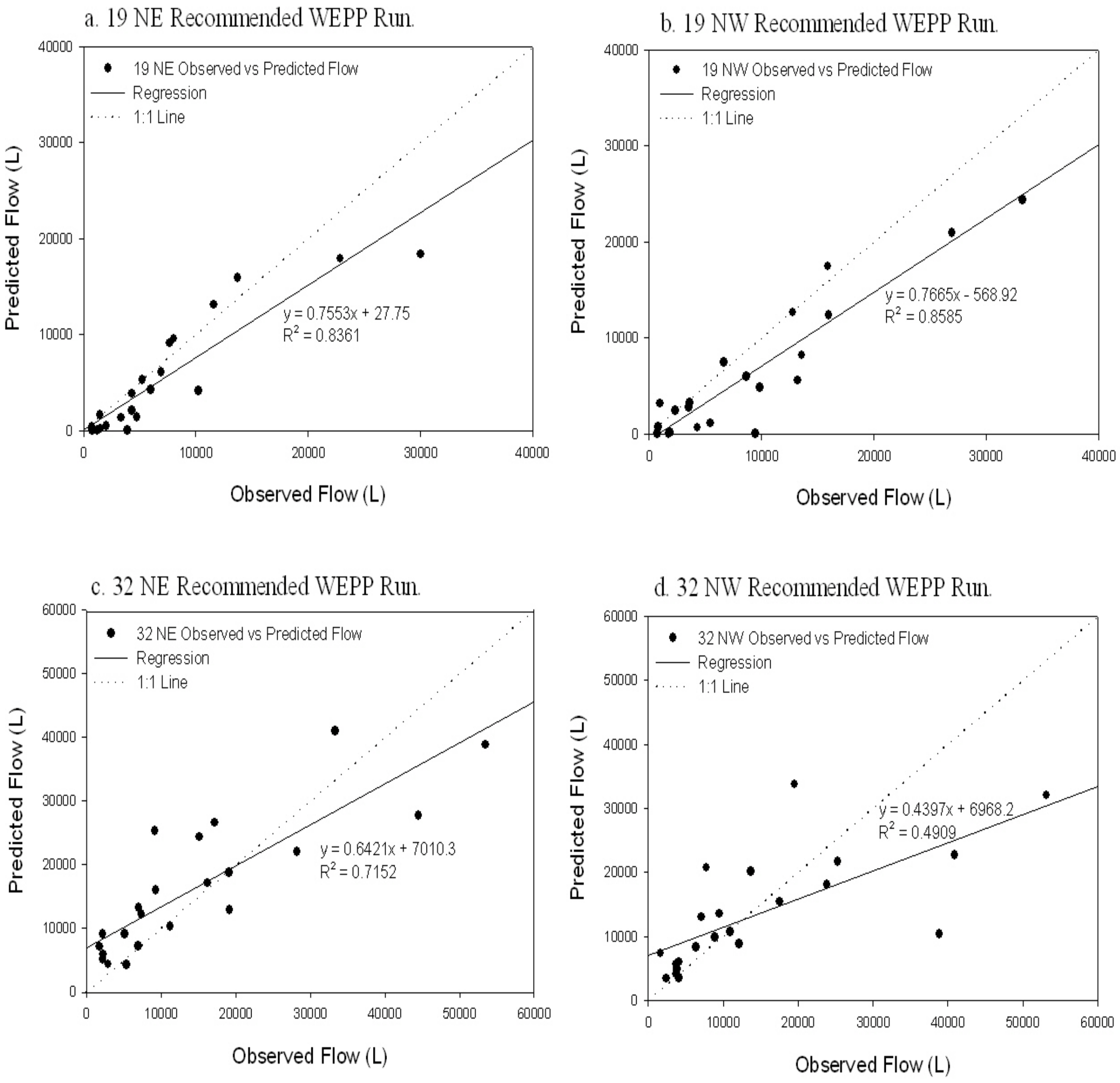


Figure C-4. Scatter plots with regression lines for observed versus predicted total flow for recommended WEPP parameter sets by segment.

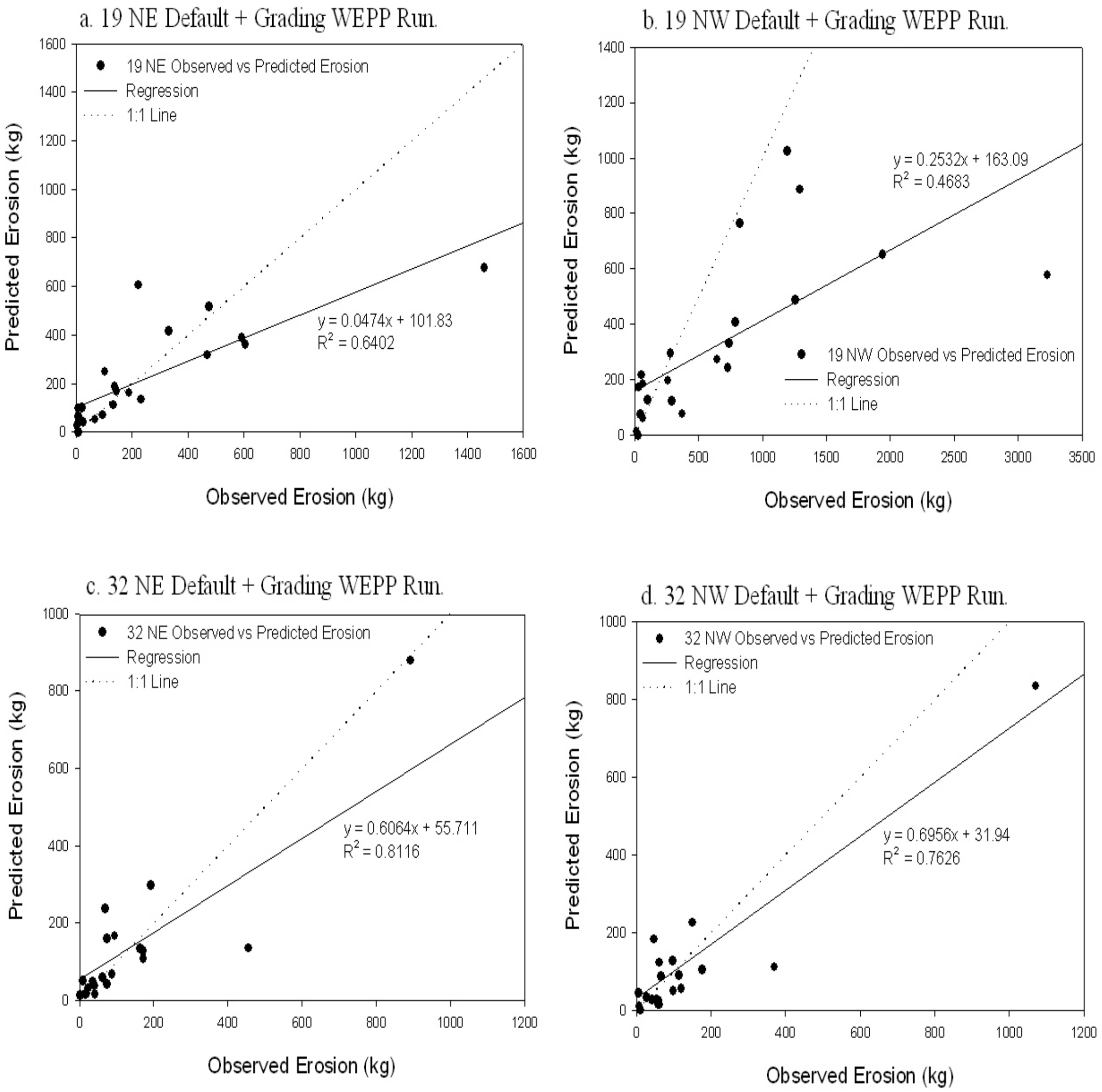


Figure C-5. Scatter plots with regression lines for observed versus predicted erosion for default and grading WEPP parameter sets by segment.

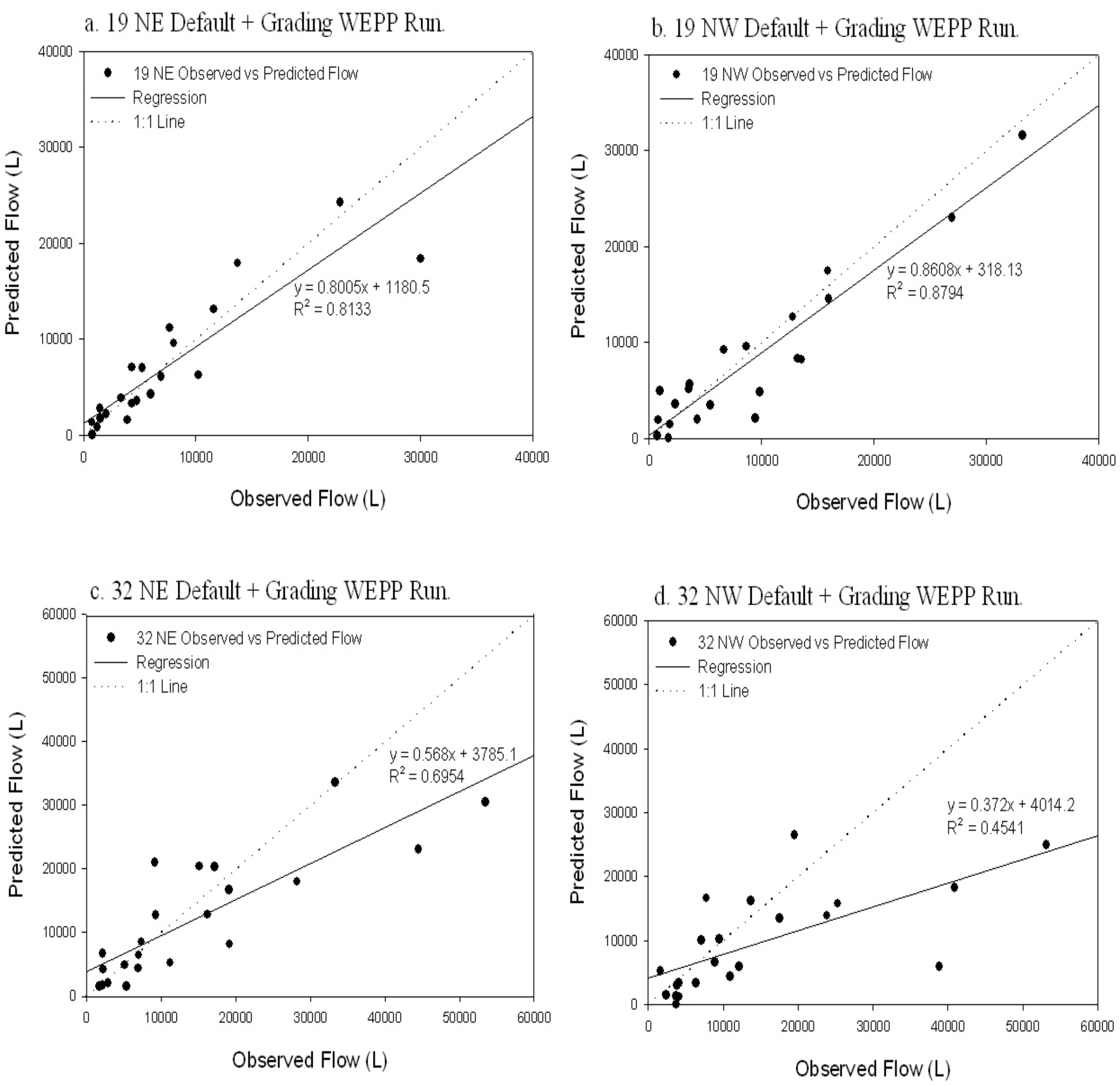
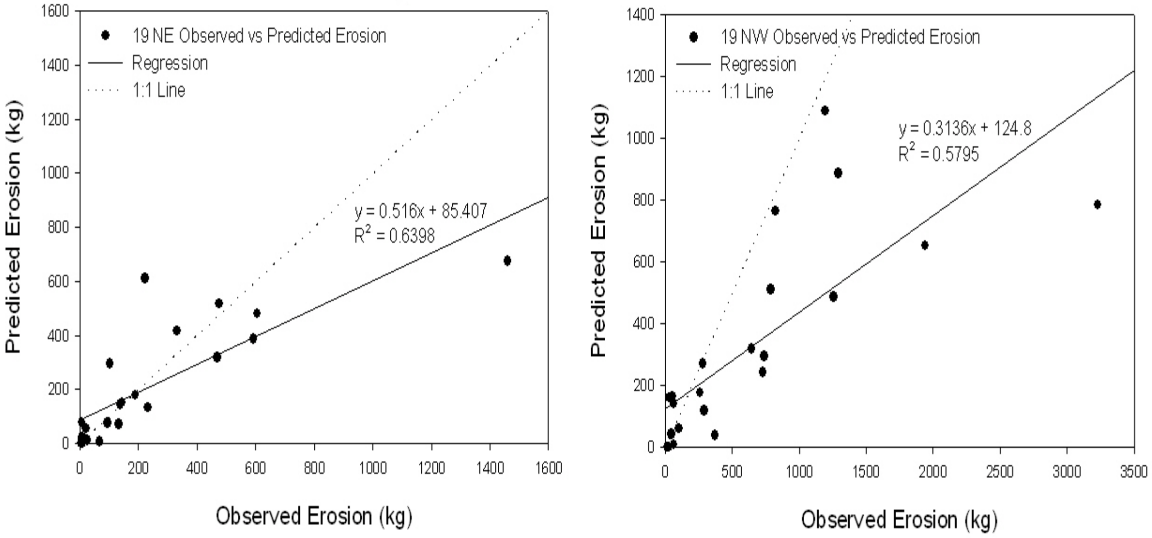


Figure C-6. Scatter plots with regression lines for observed versus predicted erosion for default with grading WEPP parameter sets by segment.

a. 19 NE Recommended + Grading WEPP Run.

b. 19 NW Recommended + Grading WEPP Run.



c. 32 NE Recommended + Grading WEPP Run.

d. 32 NW Recommended + Grading WEPP Run.

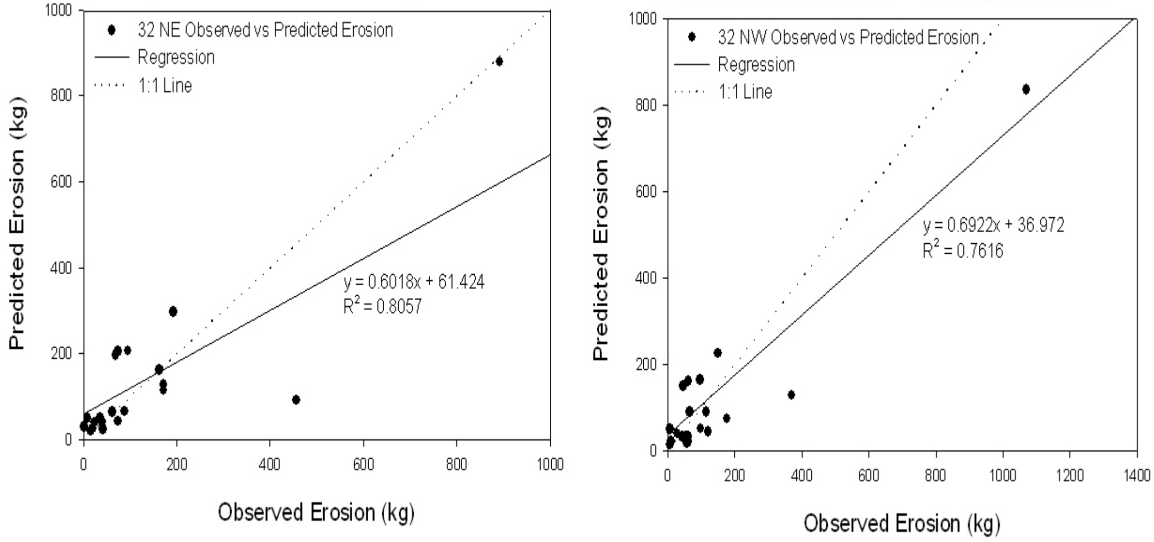


Figure C-7. Scatter plots with regression lines for observed versus predicted erosion for recommended with grading WEPP parameter sets by segment.

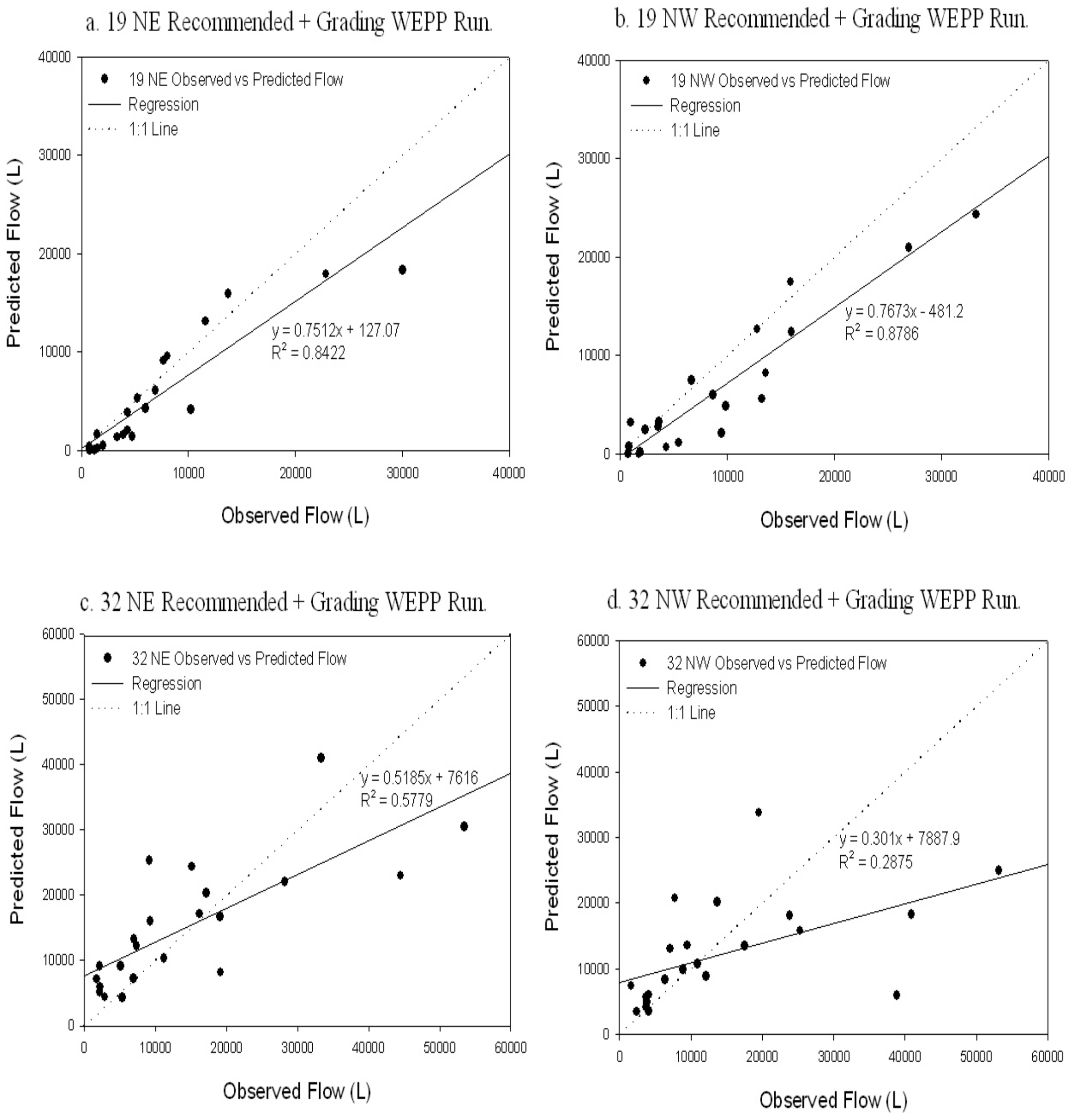


Figure C-8. Scatter plots with regression lines for observed versus predicted total flow for recommended with grading WEPP parameter sets by segment.

# VITA

Cory Michael Peranich

Candidate for the Degree of

Master of Science

Thesis: EROSION FROM FOUR RURAL UNPAVED ROAD SEGMENTS IN THE STILLWATER CREEK WATERSHED

Major Field: Environmental Science

Biographical:

Personal Data: Born in Montrose, Pennsylvania, On September 26, 1978, Son of Michael and Anna Peranich

Education: Graduated from Montrose Area High School, Montrose, Pennsylvania in June 1996; received Bachelor of Science degree in Biology from Delaware Valley College of Science and Agriculture, Doylestown, Pennsylvania, in May 2000. Completed the requirements for the Master of Science Degree with a major in Environmental Science at Oklahoma State University in May 2005.

Experience: Employed in the Biology and tutoring departments at the Delaware Valley College of Science and Agriculture; employed as an air quality technician; employed as an environmental planner; and as a graduate research assistant at the Oklahoma State University Department of Forestry.

Professional Memberships: Air and Waste Management Association, Phi Kappa Phi.

Name: Cory Michael Peranich Date of Degree: May, 2005

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: MEASUREMENT AND MODELING EROSION FROM FOUR RURAL UNPAVED ROAD SEGMENTS IN THE STILLWATER CREEK WATERSHED

Pages in Study: 107 Candidate for the Degree of Master of Science

Major Field: Environmental Science

Scope and Method of Study: The purpose of this study was to measure sediment yield from four rural unpaved road segments in the Stillwater Creek Watershed in central Oklahoma and compare those measurements to predictions generated by the Water Erosion Prediction Project (WEPP) erosion model using four different sets of erodibility parameters. The four road segments ranged from 160–250 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 and pressure transducer 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.

Findings and Conclusions: Data from 26 storms were collected during June-November, 2004. The total precipitation from individual storms ranged from 3 mm to 56 mm. Maximum five-minute storm intensities ranged from 3 mm/hr to 100 mm/hr. The total erosion for individual storms from the four segments ranged from 1 kg to 3,230 kg, with a mean of 370 kg across all four segments The cumulative total erosion from the segments through the study period was 5,340 kg for 19 NE, 5,900 kg for 32 NW, 6,880 kg for 32 NE, and 14,250 kg for 19 NW. Assuming that all of the 479 km of rural unpaved roads in the Stillwater Creek watershed eroded at the observed mean rate of 135,300 kg/ha, the total estimated quantity of sediment eroded for the 22 storms from rural unpaved roads in the watershed was 152 Mg/km/yr. Using the selected uncalibrated parameter sets, WEPP predicted overall total erosion ranging from -49 to -31 % of the observed total erosion; and overall total flow ranging from -19 to -8 % of the observed total flow.

ADVISOR'S APPROVAL: Dr. Donald J. Turton