Variability in Rainfall Energy across Pennsylvania and Impacts on Construction Site Erosion Control Practices

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INTRODUCTION

Sediment loss is the greatest concern when addressing the water pollution problems from urban development/construction. Knowledge of the amount of sediment generated from a construction site determines the size of the sediment retention pond, and may affect the ability of vegetation (especially erosion mats) to establish prior to soil washout. In addition, excess erosion has economic impacts in terms of washing away of valuable topsoil and potentially adds the cost of regrading and cleaning out of stormwater pipes to the construction project. Controlling erosion at the source through the proper selection of control practices is both legally required and good economic practice.

The amount of soil lost on construction sites is often estimated using the Revised Universal Soil Loss Equation (RUSLE), which states that:

A = RK(LS)CP

Where R = rainfall energy, K = soil erodibility factor, LS = length-slope factor, C = (land) cover coefficient, and P = conversation practice coefficient. The rainfall and runoff factor (R) of the Universal Soil Loss Equation (USLE) was derived (Wischmeier 1959, Wischmeier and Smith 1958) from primarily agricultural research data. For a single site, assuming all factors that are site-related are held constant, soil losses are directly proportional to a rainstorm parameter: the total storm energy (E) times the maximum 30-min intensity (I_{30}). The sum of this project over all storms in a given period is designated R in RUSLE. The equation for calculating an annual R for a particular site is given as:

$$R = \frac{1}{n}\sum_{j=1}^{n}\left[\sum_{k=1}^{m} E(I_{30})_k\right]$$

Where: E = total storm kinetic energy, I_{30} is the maximum 30-minute rainfall intensity, n is the number of years used to perform the average, m is the number of storms per year. The calculated R then is the average annual rainfall erosivity.

Based on this past research, isoerodent maps were determined first for the Eastern United States (Figure 1, focusing on Pennsylvania). As can be seen on the map, R ranges from 80 near Erie (Lawrence, Greene and Erie counties) to approximately 175 in the southeast corner (near Philadelphia). Isoerodent maps were created from calculations at stations that had at least 22 years of record. The researchers believed that the effects of moderate and severe storms needed to be included in the R calculation. However, rains less than 0.5 inches were excluded unless at least 0.25 inches of rain fell in 15 minutes.

According to the isoerodent maps, the average annual R value for Pennsylvania varies from approximately 80 to 175, a two-fold difference across the state from the southeast (Philadelphia) to the west (Lawrence and Greene Counties). Prior calculations for the other stations showed that the range over the period of record indicated a large variability in the annual R value.

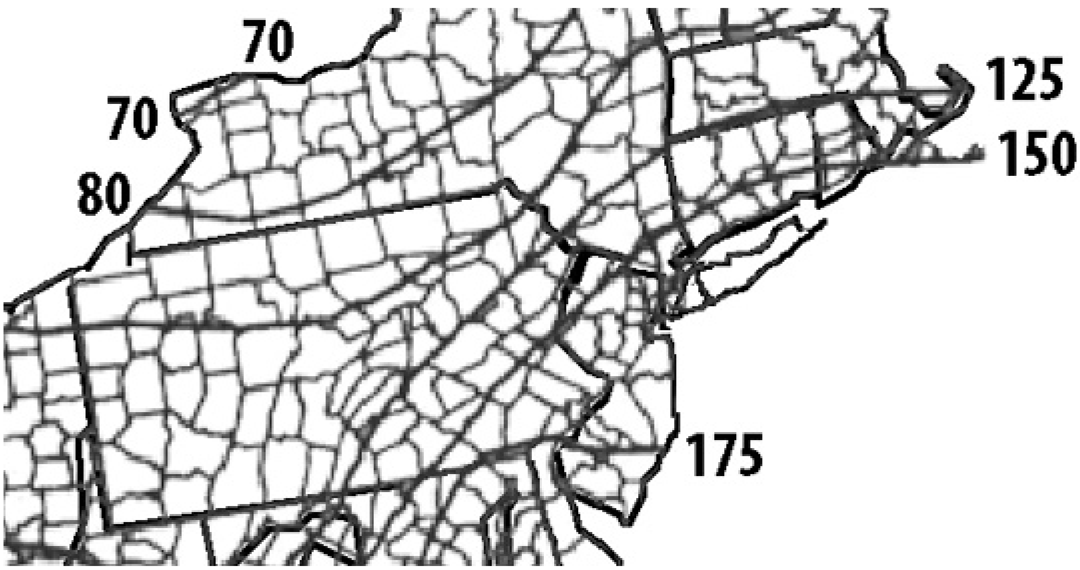

Figure 1. Eastern US isoerodent map, focusing on Pennsylvania.

Since that time, USDA has updated the R values using modern rainfall data (the original R values were calculated based on rain information from the late 1930s through mid- to late-1950s) and with the release of RUSLE 1.06c, they have recommended that users reference Figure 2 for updated R values. The authors do note that, according to their calculations, the newer values are sufficiently close to the older values that the older values are acceptable. This is important because the construction waiver R calculations used by EPA to determine if erosion control is not required on a site still use Figure 1.

The differences between the values in Figures 1 and 2 appear small but may be important in the calculation of erosion losses for sediment pond design and vegetation establishment. Using Figure 1, the annual R value ranges between 80 (around Erie) to approximately 175 (around Philadelphia). The newer R values for the state of Pennsylvania range between 100 (in the Northern Tier counties) to just over 100 in Erie to approximately 175 around Philadelphia. Instead of Dauphin County having an R value of 125, its current estimate is 150. This is an increase of approximately 20% in the estimated sediment loss at a single site, which could be a substantial increase in the cleaning frequency of the pond.

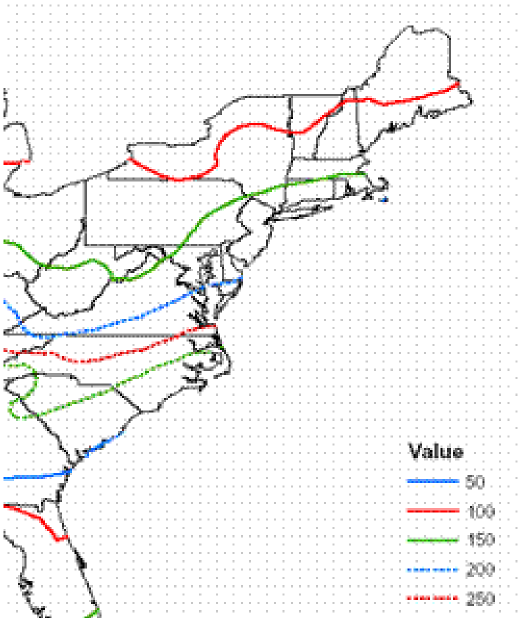

Figure 2. Updated R values for the Eastern US. (http://www.ars.usda.gov/Research/docs.htm?docid=5990)

The purpose of this study was to investigate the spatial distribution of annual rainfall erosivity in Pennsylvania based on actual rainfall records from nine stations evenly distributed around the state. Trends in R based on rainfall depth and year were examined. In addition, trends across the state will be noted. These results were compared with the historic R values to determine if the maps require updating.

METHODS

The rainfall records were extracted from NCDC Hourly Rainfall Precipitation Database. While the measurement requires a thirty-minute intensity, the hourly data was used since there is limited actual 30 minute or 15 minute data available. Depending on the station, the length of rainfall records available ranged between 23 and 55 years. Years with only partial rainfall records were excluded. The hourly precipitation database was purchased from Earth Info.

The rain storm extraction program, MPARA66.exe available in WinSLAMM was used to separate the entire rainfall record into individual storm events. For the purposes of this study, a 6 hour interevent period was chosen as the delineation time between separate storm events. Incorporated in this module of WinSLAMM is the calculation of the Thronson R on a per-storm basis.

For each location, the individual storm R values were summed calculate the annual R values. Unlike the original R calculations in AH-703 (USDA XXXX), all storms were included in the evaluation. For the years of record for each site, the median, 80th and 95th percentiles were calculated. Percentile calculations were used in this analysis in order to limit the effects of extreme climate on the data analysis. For example, the median R value for Harrisburg was 240, while the mean was 280. A review of the data showed that the mean was greatly affected by the year of Tropical Storm Agnes when the calculated R was greater than 1000 and twice the next largest R value.

RESULTS

Table 1 and Figures 3 and 4 show the median annual rainfall depths and Thronson R value as they relate to the station location and to each other.

Table 1. Median Thronson R values.

Location	Median Annual Rainfall Depth (in.)	Median Annual Thronson R (XX)
Erie	26.7	179
Pittsburgh	31.4	177
State College	24.2	160
Wellsboro	25.6	132
Scranton	40.0	318
Harrisburg	31.7	241
York	30.2	266
Allentown	37.3	295
Philadelphia	31.7	314

Figure 3 ranks the rainfall depth from smallest to largest (with location) and the corresponding erosivity. As can be seen in the graph, the higher median rainfall erosivities are not necessarily at the locations with the higher median annual rainfall depths. When the data is plotted as median erosivity versus median rainfall depth (Figure 4), however, a trend emerges. In general, high rainfall depths lead to elevated erosivities. A linear regression fitted through the data yields an equation of Median Annual R = 11.3(Median Annual Rainfall Depth) – 118, with $R^2 = 0.97$ and normality tests passed. The 95% confidence interval on the intercept is (-335, 98) and on the slope is (4.4, 18). These results show that the slope is statistically significantly different than zero while the intercept is not. This result “makes sense” because when there is no rainfall, there is no kinetic energy to cause erosion.

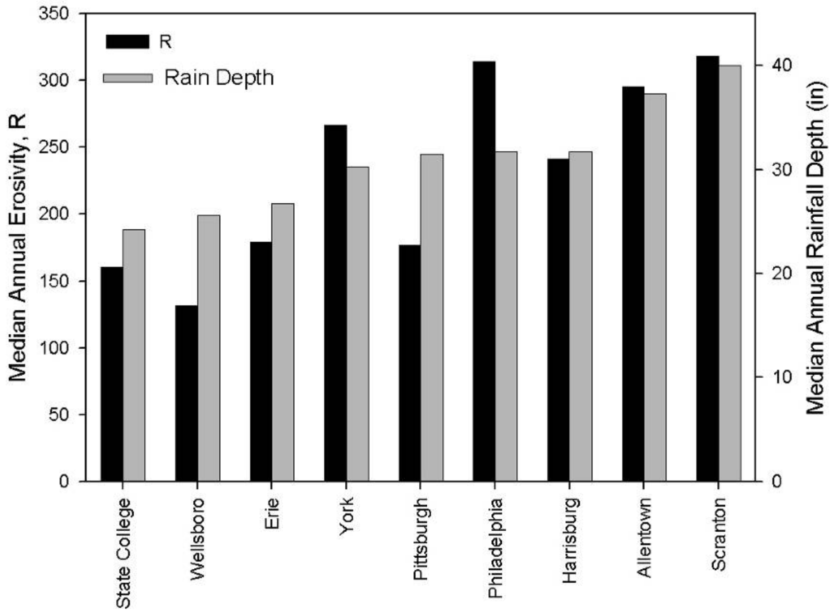

Figure 3. Median erosivities and rainfall depths by location.

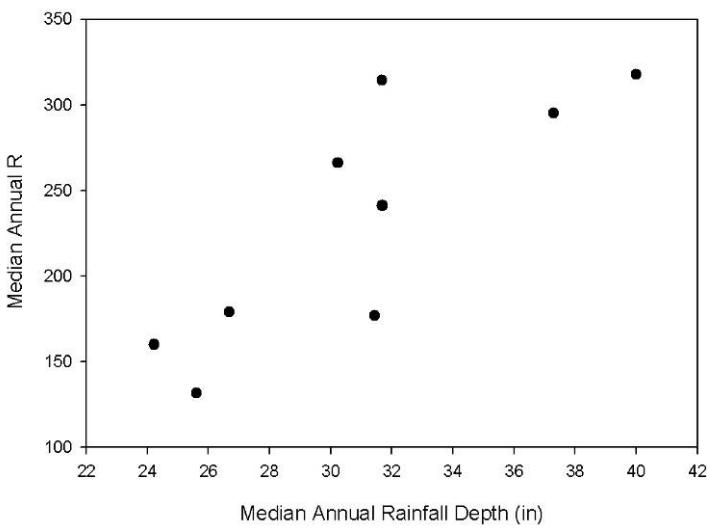

Figure 4. Erosivity vs. rainfall depth.

Figure 5 highlights the regional trends in the data set for the median annual R. Comparing it to the trends seen in the USDA maps, it appears relatively consistent, although the values are approximately 50% greater than those reported by USDA. The lowest erosivities occur in the Northern Tier county area, followed by the western part of the state. Higher erosivities occur in the east and southeastern part of the state, likely due to the influence of periodic tropical storms and their remnants on the weather patterns and rainfall intensities.

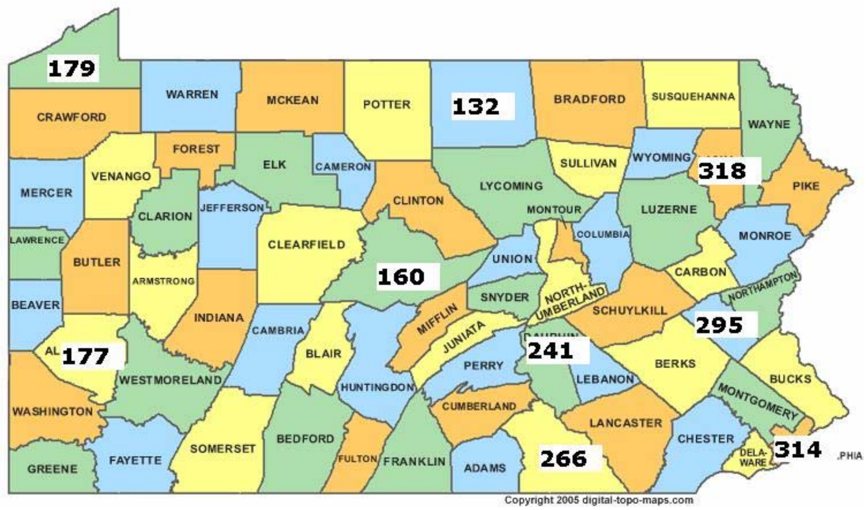

Figure 5. Median annual erosivity map.

CONCLUSIONS

When performing site development, often the first structure constructed is the sediment pond, followed shortly by a connected storm sewer system. The early installation of the storm sewer system allows for the direct transport of generated sediment to the piping and eventually to the stormwater pond. Correct design of sediment ponds require knowledge of the amount of sediment that is generated and transported. In addition, establishment of vegetation is difficult to impossible if the soil is washed away to the extent that roots from sod or vegetation mats are unable to reach the soil.

Calculations of soil erosion have often relied on RUSLE, which relates rainfall energy to soil and land characteristics to protective practices to calculate the amount of soil lost for a construction period. What this research has shown to date is that the trends in the rainfall erosivity follow the trends seen by USDA in their calculations, but the data used to estimate rainfall energy may be underestimated by as much as 50% in Pennsylvania, which results in a 50% underestimation of the soil loss.

Additional work includes statistical analysis of the data and the inclusion of five more sites to the analysis. The results of this research will be published in December 2007 as a master's paper by Aigul Allison and available at the Penn State Harrisburg library.