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Assessment of Spatial Patterns of Sediment Transport and Delivery for Soil and Water Conservation Programs

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Abstract

Soil erosion has tremendous impacts on most river systems throughout the United States. Such non-point pollution results from land-use and agricultural practices and leads to sedimentation downstream, a decrease in the transport capacity of streams, an increase in the risk of flooding, filling of reservoirs, and eutrophication. This paper uses a spatially-explicit model to identify the sediment sources and delivery paths to channels and link these sediment supply processes to in-channel sediment transport and storage. The paper analyzes hillslope erosion and deposition rates using the Unit Stream Power Erosion and Deposition model in a GIS to estimate patterns of sediment supply to rivers in order to predict which portions of the channel network are more likely to store large amounts of fine sediments and thus are most sensitive to the effects of on and off-site soil erosion. This study focuses on the Pitman Creek Basin, a predominantly agricultural sub-basin in the Upper Green River in Kentucky. Results indicate that while much of the eroded sediments are redistributed within the hillslope system, a large proportion is also delivered to the channel. Sediment delivery to the stream is estimated using buffers defined in accordance with currently implemented conservation practices. These predictions have been tested by sampling the fine sediment content of the streambed at key locations along the channel network and comparing the observed patterns to those predicted by the soil erosion model. Overall, high intensity erosion tends to occur at contact between different vegetation covers, on barren lands and croplands, and 15-25% slopes poorly protected by vegetation, thus highlighting several erosion hot spots.

Keywords: off-site soil erosion, soil erosion and deposition model, sediment delivery, GIS

I. Introduction

In order to understand and efficiently manage watersheds, major emphasis must be placed on studying surface erosion, which has been recently recognized as a priority because of the increase in the transport and storage of fine sediments in rivers across the United States (Novotny and Chesters, 1989). Soil erosion is a physical process that occurs naturally, but it is commonly accelerated by various human activities such as agriculture (Risser, 1981, Morgan, 2005). The negative effects of soil erosion are manifested both on-site and off-site, with huge costs for a country's economy. Soil erosion is therefore a major problem and a major control on suspended sediment yield that has been recognized as such since the early 1930s and considered "an extremely serious environmental problem, if not a crisis," with estimates of the average annual cropland soil erosion losses in the United States ranging from 2 to 6.8 billion tons/year (Trimble and Crosson, 2000).The on-site effects of soil erosion occur largely on agricultural lands where soil loss, destruction of soil aggregates, and reduction in organic matter content lead to a decline in soil fertility. Off-site effects of soil erosion include sedimentation downstream and downwind that can reduce the flow capacity of streams, cause siltation of in-

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stream habitat, increase the risk of flooding, and accelerate reservoir filling (Morgan, 2005). Siltation is currently recognized as one of the main sources of pollution of streams in the Eastern US (Morgan, 2005). In addition, fine sediment loading to rivers and lakes can pollute waters by increasing turbidity, thus reducing sunlight penetration and affecting water temperature. By contributing nutrients, heavy metals, or other toxins adsorbed to fine particles, erosion causes eutrophication or otherwise degrades water quality (Toy *et al*., 2002). Various agencies in the U.S. are currently implementing soil and water conservation practices based on more or less reliable existing assessments of on- and off-site soil erosion, especially in agricultural basins. However, there is an increasing need for relatively simple yet very efficient tools land managers can employ to determine, for example, the most appropriate width for soil and water conservation buffers in agricultural watersheds. The main research question is whether it is possible to estimate rates of sediment delivery to streams from a spatially-explicit soil erosion and deposition model with a set number of inputs that are widely available and relatively easy to parameterize and thus identify potential hot spots of soil erosion in a landscape. Further, can these estimated soil erosion and sediment delivery rates be translated into meaningful guidelines for soil and water conservation programs? This question has important implications for prioritizing areas of intervention in the case of suspended sediment- polluted river courses in agricultural regions, such as the study site in this paper.

Soil erosion models as diagnostic tools

Sediment yield at catchment mouths may be only a small proportion of both erosion from hillslopes and change in storage of sediments within the alluvial system (Slattery *et al*., 2002), because the materials eroded from hillslopes are in part redeposited within the slope system and in part delivered to channels, as indicated by the slope delivery ratio (Phillips, 1991). Thus the net loss of materials from the slope system will result in a particular spatial pattern of erosion *and* deposition. The sediment budget of a stream is likely to change significantly over short periods of time as a result of natural environmental variability or human activities, including soil conservation programs. By far the most effective means of determining sediment delivery ratios is field measurements from either discrete or chronic erosion processes (Reid and Dunne, 1996). Since distributed estimates of soil mobilization cannot be based directly on observations, there is uncertainty in any attempt to estimate delivery ratios. Uncertainty mainly occurs because mobilization of sediment on hillslopes is dependent on the magnitude/frequency distribution of events and on the fact that sediment fluxes may be either supply or transport limited (transport limited case refers to the fact that the sediment transport rate is determined by the erosional strength of flowing water and not limited by the supply of transportable materials). Beven *et al.* (2005) outline several standardization approaches necessary in order to make delivery estimation a more reliable practice, admitting though that more research needs to be done in order to attain a satisfactory level of standardization. Thus, uncertainty in rates of soil mobilization from slopes represents one of the sensitive aspects of the sediment delivery ratio concept that this paper addresses by implementing a spatially-distributed erosion and deposition model that incorporates mass conservation. Models are not merely important from a quantitative point of view, but rather as key instruments in deciding upon monitoring objectives and the elements that should go into a process of continuous adaptive management of soil and water conservation projects.

The goal of this project was to assess the impacts of agriculture on water quality in the Upper Green River Basin in south-central Kentucky in the context of the implementation of soil and

water conservation practices under the USDA Conservation Reserve Enhancement Program (CREP). The paper addresses the means to derive quantitative estimates of soil erosion to better understand the overall connectivity between the hillslope and channel systems. The focus is on the relationship between the supply of sediments delivered to the river, estimated using a soil erosion and transport model implemented in a GIS (Geographical Information System) environment, and measured patterns of sedimentation within the channel. By analyzing hillslope erosion rates using a soil erosion model, and thereby estimating patterns of sediment supply to rivers, the model can predict which portions of the landscape are more likely to contribute larger amounts of sediments to the channel network and where large amounts of fine sediment will tend to be stored in the stream bed. These predictions are tested by sampling the fine sediment content of the streambed at key locations along the channel network and comparing the observed patterns to those predicted by the soil erosion model. Thus, the model focuses on the complex interaction between topography, soils and land use in affecting the potential for soil erosion and on how the spatial distribution of these factors leads to variations in net erosion and deposition within a watershed and in the delivery of sediments to stream channels. Various empirical soil erosion models have been developed and implemented, mostly in a GIS environment, in various countries based on information compiled on these factors (Pistocchi *et al*., 2002; Raghunath, 2002; Shi *et al*., 2002; Bayramin *et al*., 2003; Kandrika and Dwivedi, 2003; Zaluski *et al*., 2003; Brough *et al*., 2004; Essa, 2004). However, most of these applications have not focused on the sediment delivery to streams segment or on making clear management suggestions for soil and water conservation programs, which is the main focus of this paper.
The basis for the development of the soil erosion model implemented for the study area is the Revised Universal Soil Loss Equation (RUSLE) which predicts annual average soil loss as a product of five factors: rainfall erosivity index, soil erodibility, slope length and steepness, land cover management, and support practice factor (Renard et al., 1996). In order to complement this model and obtain estimates of the spatial patterns of both erosion and deposition and assess sediment delivery within the Big Pitman Creek basin, the Unit Stream Power Erosion and Deposition Model (USPED), (Mitasova *et al*. 1996, Mitas and Mitasova 1999) was used.

The results should prove useful for planning soil conservation, stream restoration and monitoring programs, and also for evaluating present and future environmental impacts associated with overland soil erosion and stream sedimentation (Reid and Trustrum, 2002).

Study area

The research focused primarily on Big Pitman Creek, one of the northern tributaries of the Upper Green River (Figure 1). Big Pitman Creek basin has a total drainage area of 328.12 km^2, calculated using the Kentucky HUC (hydrologic unit codes) 14 data. The HUC system of classifying watersheds in the USA was created by the United States Geological Survey (USGS), ranking drainage areas of various sizes from the largest to the smallest. The KY HUC 14 corresponds to a subregion including the area drained by a river system, a reach of a river and its tributaries in that reach. The watershed is used primarily for agriculture (52% cropland and pastures) with only 0.09% developed land, mostly around the town of Campbellsville, whereas 36% of the watershed is covered with deciduous forests (NLCD01 – Anderson Level III). The slope values for the basin vary between 2 and 53%, with the highest values in the northern parts of the basin and lowest values for the large interfluves between the main left tributaries: Middle and Little Pitman Creek (USGS Seamless database). The predominant soil class in terms of areal coverage (113792.401 m^2) is Frederick silt loam, generally characterized by 6-12% slopes, followed by the Nolin silt loam class, Frederick silt loam with 20-30% slopes, and Riney loam soils (SSURGO soils database). These soil classes have in common the silt loam texture that makes them more susceptible to erosion, susceptibility that increases with increasing slope values.

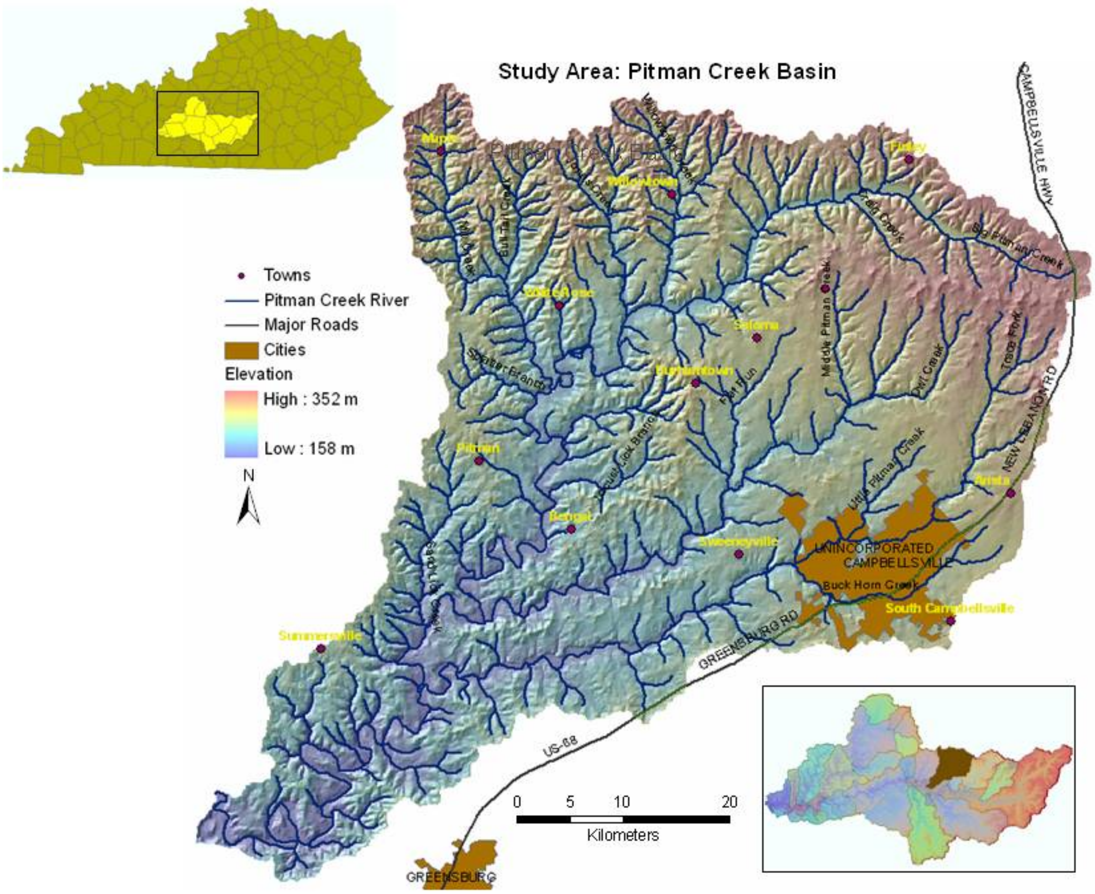

Figure 1 Study area: Big Pitman Creek Basin, right tributary of the Upper Green River Basin. Upper left inset shows the location of the Upper Green River Basin in the state of Kentucky; lower right inset sows the location of the Big Pitman Creek Basin in the Upper Green River Basin.

II. Methodology

II.1. Model formulation

This paper attempts to identify and predict the spatial patterns of soil erosion and sediment delivery within the Big Pitman Creek basin. The Unit Stream Power Erosion and Deposition Model (Mitasova *et al*. 1996, Mitas and Mitasova 1999) predicts the spatial distribution of erosion and deposition rates for a steady state overland flow associated with a given rainfall input. Maps of erosion and deposition were derived for Big Pitman Creek and its individual sub-basins by implementing the USPED model with the objective to use these maps as indicators of the areas of the landscape that are most likely to be the suppliers of fine sediments to the channel network, and to derive quantitative indices of sediment supply to the channel network.

The USPED model employs a stream power-based sediment transport model with an expression of mass conservation to simulate soil erosion and deposition. The model departs from the RUSLE annual average soil loss equation expressed by **E** (tons/acre/year) (Renard et al., 1996):

$$\mathbf{E = R\ K\ LS\ C\ P} \qquad (1)$$

Where **R** represents the rainfall erosivity index**, K** the soil erodibility factor, **LS -** the slope length and steepness, **C** the land cover management factor, and **P** represents the support practices factor. The R, K, C, and P factors have fixed values and can be determined empirically (Renard and Freimund, 1993, Wischmeier and Smith, 1978, Zaluski *et al*., 2003). The LS factor accounts for the strength/erosivity of the surface runoff and is expressed as the ratio of soil loss under a given slope steepness and length to the soil loss from the standard condition of a 5^{o} (9%) slope, and 22.13 m length (Wischmeier and Smith, 1978):

$$LS = (\lambda/22.13)^{t}\ (65.4 \sin^{2}\beta + 4.56 \sin\beta + 0.0654) \qquad (2)$$

where **λ** is the slope length in meters (horizontal projection of the slope length in meters), **β** is the slope angle (degrees), and **t** is the length exponent that depends on slope steepness, with values of 0.5 for slopes exceeding 5%, 0.4 for 3-5% slopes, and 0.3 for slopes less than 3% slopes. This expression assumes standard slope parameters failing to take into account the topographic complexity of the upslope contributing area and is thus inappropriate for sediment delivery estimations. For example, Kinnell (2004, pp. 3191) argues that "the use of sediment delivery ratios owes its origin to the observation that using erosion predicted by the USLE overestimates the amount of sediment delivered from hillslopes, because sediment deposition often occurs on hillslopes and the USLE does not account for deposition."

The USPED model assumes that sediment transport on slopes is capacity-limited, meaning that sediment transport rates are determined by the erosional strength of flowing water, and never limited by the supply of transportable soil particles. Thus it is assumed that the sediment transport rate (capacity) is given by:

$$qs = K_t\ q^{m} \sin^{n} b \qquad (3)$$

where *b* represents the local surface slope (degrees), *q* is the unit water flow rate (m^2/sec.), K_t is the soil transportability coefficient (dependent on soil properties and vegetation cover), and *m and n* are constants depending on the type of flow and soil properties. equation 3 provides the sediment flux (volume per unit width, m^2/s) in the direction of the maximum hillslope gradient.

The value of exponent *n* (slope steepness exponent) has been documented to vary with slope shape, plant cover, and also the process of erosion. Thus, various exponent values have been established for different climates and zones, but the standard for the USA (Morgan, 2005, p.58) is about 0.3 – 1.0 for rainsplash and approximately 0.7 and 1.7 – 2.0 respectively for detachment and transport of soil particles by overland flow (sheet erosion). Kirkby (1971) cited by Morgan (2005) suggests that the slope length exponent *m* ranges between 0.3 to 0.7 for overland flow and rises to between 1.0 and 2.0 in case rilling occurs . The value used in the USPED model for *n* (1.3) has been determined to be the most accurate exponent both in the RUSLE and by deriving

it from the unit stream power theory (Moore and Burch, 1986; Moore and Wilson, 1992). For sheet flow, the constants *m* and *n* are set to: m = 1.6 and n = 1.3.
Steady-state water flow can be expressed as a function of upslope contributing area per unit contour width *A* [m^2/m]:

$$\mathbf{q} = \boldsymbol{A\ i} \qquad \textbf{(4)}$$

where **i** [m/s] is uniform rainfall intensity. Thus equation 3 can be restated as:

$$\mathbf{qs} = \boldsymbol{K_t}\ \mathbf{(A\ i)}^{\boldsymbol{m}}\ \mathbf{sin}^{\boldsymbol{n}}\ \mathbf{b} \qquad \textbf{(5)}$$

This formulation is limited because no experimental work has yet been performed to assign values to the parameter $\mathbf{K_t}$ (Mitas and Mitasova, 1999). If it is further assumed that $\mathbf{K_t}$ ~ KCP and $\mathbf{i^m}$ ~ R**,** then the relative magnitude of the sediment flux may be estimated in terms of USLE parameters as:

$$\mathbf{q_s = R\ K\ C\ P\ A^m\ sin}^{\boldsymbol{n}}\ \mathbf{b} \qquad \textbf{(6)}$$

where the constants *m* and *n* have the values 1.6 and 1.3 respectively for prevailing rill erosion and 1 for prevailing sheet erosion (Mitas and Mitasova, 1999, Clarke *et al*., 2002). This formulation is thus a stream power erosion law incorporating the empirically derived values of the USLE parameters. By comparison to RUSLE (equation 1), is may be seen that LS ~ $\boldsymbol{A^m}\ \mathbf{sin}^{\boldsymbol{n}}\boldsymbol{b}$. Because the USPED formulation is a hybrid between the RUSLE and a stream power-based transport model, the results of the USPED model represent relative magnitudes of the soil erosion and deposition rates rather specific soil loss values traditionally expressed in tons/acre/year. This issue of dimensionless units were addressed by standardizing the model results in order to make comparisons meaningful at the sub-basin scale.

The net rate of soil erosion or deposition (**ED**) is given by the two-dimensional (horizontal plane) divergence of the sediment flux that expresses mass conservation:

$$\boldsymbol{ED} = \mathbf{div}\ (\boldsymbol{q_s}) = \mathbf{d}(\boldsymbol{q_s}\ \mathbf{cos}\ \boldsymbol{a})/\mathbf{dx} + \mathbf{d(q_s\ sin}\ \boldsymbol{a})/\mathbf{dy} \qquad \textbf{(7)}$$

in which ***a*** represents the aspect of the terrain (the direction of maximum hillslope gradient in the horizontal plane in degrees). The sediment transport model (equation 6) in combination with the mass conservation statement (equation 7) illustrate that spatial patterns of overland flow rate (and thus upstream contributing area, equation 4) and hillslope gradient and aspect are the basic topographic controls on the distribution of soil erosion and deposition.

The formulations for the sediment flux (equation 6) and the sediment flux divergence (equation 7) account for the effects of topography on the magnitude and direction of the transport and resulting patterns of erosion and deposition. Maps of erosion and deposition were derived for Big Pitman Creek and its individual sub-basins by implementing the USPED model (equation 6 and equation 7) with the objective to use these maps as visual indicators of the areas of the landscape that are most likely to be the suppliers of fine sediments to the channel network, and to derive quantitative indices of sediment supply to the channel network.

II. 2. Model implementation

Elevation, soil, landcover, and hydrographic data for the Big Pitman Creek basin were acquired from a number of sources. These spatial data were used to derive the parameters needed for the soil loss equation (equation 6), on which the entire modeling approach was based.

The soil loss equation parameters have been derived as follows:

1. Erosivity factor (R) - for the study area, the values of R range from 180-260 hundreds of foot-tons acre^{-1}in hour^{-1} (Wischmeier and Smith, 1978, Renard *et al*., 1996). A constant value of 255 (the average for the Green and Taylor counties based on values from the RUSLE database) was used to run the model in the absence of real-time precipitation data.

2. Erodibility factor (K) Soil information for Hart, Green, Barren, Taylor, Adair, and Edmonson counties was obtained from the NRCS (Natural Resources Conservation Service) SSURGO (Soil Survey Geographic) online database, in both tabular and spatial formats.

3. Topographic index ($A^m \sin^n b$) – The topographic index was calculated using the 10m Digital Elevation Model (DEM, NAD83, NAVD88) obtained from the USGS (United States Geological Survey) Seamless Data Distribution database. The use of 10m DEM has been documented by Mitasova *et al.* (1996) to be the most reliable elevation data when higher resolution data is unavailable because it allows for lower levels of systematic errors and artifacts of analysis compared to the lower resolution DEMs that are available (30m resolution DEM was also tested). Contributing area per contour width (A) was obtained through the D-Infinity flow algorithm available in TAS (Terrain Analysis System, Creed et al., 1996 and Creed et al., 2003).

4. Land cover and management factor (C) – The distribution of C factor values was based on the Anderson Level III (2001) land cover map for the entire state of Kentucky obtained from the Kentucky Landcover Dataset (KLCD). The data were reclassified based on values for the C factor determined by Wischmeier and Smith (1978) and Renard *et al*. (1996). Each type of Anderson III landcover present in the Pitman Creek basin was assigned a C value based on the degree of protection offered by various canopy covers. Since the lowest degree of soil protection is provided by mined and barren lands, and croplands, these land uses get assigned the highest C values, in accordance with literature. Pastures and areas covered by shrubby vegetation, depending on the degree of coverage, are assigned C values lower than 0.1, whereas forested areas, which provide the highest degree of protection, are assigned the lowest C values (lower than 0.01).

5. Support practice factor (P) – The P factor was held constant (equal to 1) in the analysis due to the lack of reliable data sources necessary to document the various conservation practices applied in the basin through CREP. Thus, the resulting analysis does not account for differences in erosion and soil loss due to differing cropping and land use practices.

The 11 and 14-digit hydrologic unit codes (HUC) dataset made available by the National Hydrography Dataset (NHD) was used to delineate individual sub-basins in the Big Pitman Creek basin for the various sub-basin level assessments.

II. 3. Analysis of results methodology

The approach was to compare the distribution of values for sediment transport and soil erosion and deposition with different forcing parameters: a) only topographic forcing, b) topographic and soil erodibility forcing, and c) topographic, soil erodibility, and land cover forcing.

Results scaling. In order to make the comparisons meaningful in the absence of specified units of measurement for the sediment transport rate and erosion and deposition rates, the results of the modeling process were standardized as 0-100 range = 100(value-min)/(max-min) for the sediment transport rate (because the original range of values is greater than 0) and z-scores (z = (value-mean)/standard deviation) for erosion and deposition rates (original outputs range between a negative and a positive value). Standardizing the values, however, was primarily useful for comparing the different model outputs in terms of spatial patterns and distribution of erosion and deposition rates across the landscape. The data was divided into defined intervals for each raster, the area (number of pixel contained in each interval) of each interval was determined and the percent area for each class was then calculated in order to assess the relative contribution to total erosion/deposition rates.

Source area assessment. Secondly, a general assessment of the stability of the watershed in terms of the interplay between erosion and deposition was performed through a comparison of the relative sediment contribution of individual sub-basins of the Pitman Creek watershed. The first step in this assessment was represented by calculating the zonal statistics for each sub-basin. Then, the mean values were plotted on maps and symbolized as bars to compare the contributions of various sub-basins and identify those areas (sub-basins) that might qualify as erosion “hot-spots”. This analysis was finally linked with the sediment samples taken from key locations along the channel.

Riparian corridor analysis. The third part of the paper focuses on analyzing patterns of sediment delivery from slopes to the channel network based on varying-distance buffers from the stream channel and statistical values calculated in the previous step. The varying-distance buffer analysis was employed to define the patterns of sediment erosion and deposition for stream-corridor areas based on distance thresholds. The term buffer in this context is not used to refer to a vector feature, but to raster subsets defined by distances from stream channels. I chose the following maximum distance values: 50 m, 100 m, 200 m, 300 m, and 350 m, choices guided by the current stream buffer distances used by the KY CREP program. Although the current stream buffer widths for the Upper Green River CREP area are 300 ft for small streams and 1000 ft for the main stem and major tributaries. (Jay Nelson, KY CREP coordinator, personal communication, 2006), I chose to start at 50 m from the main channel in order to get a continuous estimate of changes in the erosion/deposition balance. The distance rasters are then employed to extract erosion/deposition estimates within each distance zone. The buffering procedure was applied at the sub-basin scale, based on the 14 digit hydrologic unit delineation of the Big Pitman Creek basin, with the intention to derive relative estimates of sediments delivered to the stream channel by calculating zonal statistical measures for individual sub-basins. This approach to estimating sediment delivery to streams was considered the most feasible taking into account the data and software available

.

Field sampling methodology and relationship with modeled results. In the final part of the paper, the modeling results are correlated with sediment grain size data obtained through field sampling. This approach is based on the assumption that those sub-basin areas where intense erosion in close proximity to the stream is predicted will be likely to have relatively high proportions of fine (< 2 mm) sediment in the bed material. According to Lisle and Hilton (1992, 1999), the transport (and storage) of fine bed material can be considered supply-dependent as the annual transport of these materials seems to be more dependent on the supply from the catchment than on the duration and magnitude of the stream flow. This is important because it means that there may be a correlation between the pattern of fine sediment storage observed in the field and the modeled patterns of erosion/deposition, provided no secondary factors intervene to obscure this pattern (e.g. floodplain and bank erosion that are not explicitly accounted for by the soil erosion/deposition model). Stream bed sediment samples were collected from key locations within the basin and compared to model outputs.

The procedure included wet sieving in the field, followed by the laboratory analysis of the bed material samples. Seven ~100 kg samples were collected in October – November, 2005 and February 2006. Bed material samples were wet-sieved in the field. Whole- phi size fractions between 64 and 8 mm were weighted with a spring scale and the >8 mm material was weighed and sub-sampled for laboratory analyses. Lab analysis consisted of dry-sieving of the samples using an electric sieve shaker for the 8 mm to 0.063 mm size fractions in ½ phi increments. The sieve data were used to generate grain size distributions for each sample and to calculate grain size percentiles. These data were then correlated with the assessment of erosion and deposition rates at the sub-basin scale, performed on aggregated sub-basin regions.

III. Results and Discussion

1. USPED Model Results

The modeled patterns of sediment transport and erosion and deposition rates in the Pitman Creek basin were analyzed for three categories of driving factors: topographic forcing, topographic forcing modified by soil erodibility, and topographic forcing modified by soil erodibility and land cover. Also, the analysis included both sheet flow and rill flow erosion mechanisms calculated using all the driving factors.

Figure 2 presents the distribution of scaled values of erosion and deposition within the basin for four different combinations of factors derived using the USPED erosion and deposition model. Initially, the model was run only with the topographic factor included and the soil erodibility and land cover factors were subsequently added in the model. Thus, there are three cases derived suing the sheet flow mechanism exponents and one using the rill flow exponents for comparison purposes. Since there are no clearly definable units of measurement for the model outputs, it was necessary to standardize them (by creating a 0-100 range for the sediment transport rate and a z-score for the erosion and deposition) in order to be able to compare them in terms of spatial patterns and proportional distribution. Over all, the distribution of values is closely clustered around 0 indicating that the magnitude of the high intensity erosion and deposition processes is relatively low. The distribution also changes with the addition of factors into the model, with the highest mean erosion values in the topographic forcing case.

However, the areal percentages of predominant erosion (negative indexes) and deposition (positive indexes) presented in table 1 have been calculated based on the original output values because it was considered more appropriate to show the classification of the original values (i.e. non-standardized values). Table 1 presents the total percent of the area within the basin experiencing either erosion or deposition with various model factors combinations, from topographic forcing only to an inclusion of both soil erodibility and land cover. The results suggest that under rill erosion the landscape would experience the highest amount of erosion, while if vegetation were removed (case 2), the rates of erosion would also increase significantly.

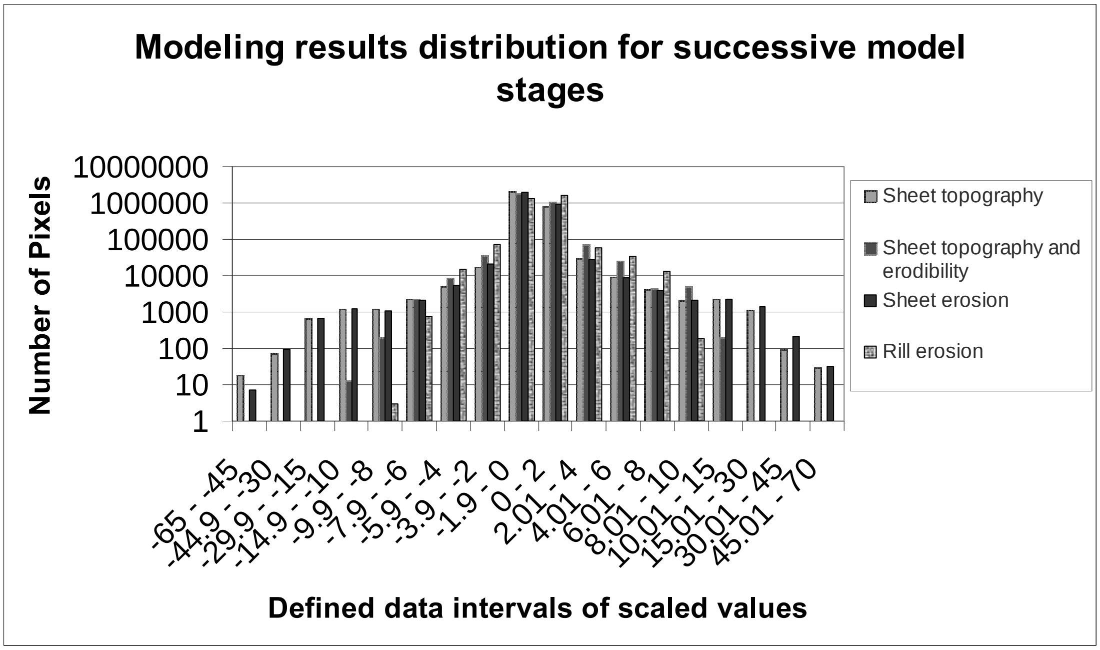

Figure 2 The distribution of the scaled (z-scores) values of erosion (negative index) and deposition (positive index) resulting from various combinations of factors in the USPED model.

1A. Sediment transport rate and the spatial distribution of erosion and deposition as a function of topography

In deriving the sediment transport capacity for the Pitman Creek watershed, the terrain geometry plays by far the most important role. Moreover, there is an underlying pattern of transport capacity controlled by the topography that remains even when modified by the vegetation cover and soil type distributions.

The geometric properties of topography (slope, terrain curvatures) are the determining factor in the spatial distribution of the sediment transport capacity of a particular watershed. Sheet flow is normally characteristic for areas with good vegetation cover, but it can also occur on severely compacted soils on which soil detachment and rill formation are prevented by compaction. Increasing upslope contributing area combined with a high value of the local slope is translated into a high sediment transport rate. The areas of high transport rate are also associated with concave slope profiles and valleys because these are areas of convergent accelerated flow.

Table 1 Areal assessment of erosion and deposition rates by various mechanisms and with different driving factors (values highlighted in red represent areas of predominant erosion). Values in grey indicate areal percentages of erosion.

Sheet erosion/deposition (topographic forcing only)				
Defined interval	**Z-score value**	**Cell count**	**Total area (m2)**	**Percent area**
-10,988 - -9,315	-63.3 - -53.7	4	42.9244	0.00000131
-9,314 - -6,986	-53.6 - -40.2	25	268.2775	0.00000821
-6,985 - -4,657	-40.1 - -26.8	108	1158.9588	0.00003549
-4,656 - -2,328	-26.7 - -13.4	854	9164.3594	0.00028060
-2,327 - 0	-13.3 - 0	2209744	23712983.84	0.72604807
0 - 2,328	0 - 13.3	831066	8918252.353	0.27306053
2,239 - 4,656	13.4 - 26.7	1528	16397.1208	0.00050205
4,657 - 6,985	26.8 - 40.1	139	1491.6229	0.00004567
6,986 - 9,314	40.2 - 53.6	47	504.3617	0.00001544
9,315 - 11,643	53.6 - 67.1	8	85.8488	0.00000263
Total			32660349.67	0.72637368
Sheet erosion/deposition (topography modified by soil erodibility)				
-57,337 - -47,443	-11.6 - -9.7	24	20088.6192	0.0006150
-47,442 - -35,582	-9.6 - -7.3	593	6363.5423	0.0001948
-35,581 - -23,721	-7.2 - -4.8	5835	62615.9685	0.0019169
-23,720 - -11,860	-4.7 - -2.4	29744	319185.8384	0.0097714
-11,859 - 0	-2.3 - 0	2177084	23362506.11	0.7152073
0 - 11,859	0 - 2.3	748479	8032002.997	0.2458875
11,860 - 23,720	2.4 - 4.7	60218	646205.3798	0.0197826
23,721 - 35,581	4.8 - 7.2	16883	181173.1613	0.0055463
35,582 - 47,442	7.3 - 9.6	3021	32418.6531	0.0009924
47,443 - 59,304	9.7 - 12.2	261	2800.8171	0.0000857
Total			32665361.09	0.7277054
Sheet erosion/deposition (topography + soil erodibility+ land cover)				
-30,274 - -27,177	-57.4 - -51.5	5	53.6555	0.0000016
-27,176 - -20,383	-51.4 - -38.6	22	236.0842	0.0000072
-20,382 - -13,588	-38.5 - -25.7	132	1416.5052	0.0000434
-13,587 - -6,794	-25.6 - -12.8	959	10291.1249	0.0003155
-6,793 - 0	-12.7 - 0	2099261	22527379.72	0.6907018
0 - 6,793	0 - 12.7	936367	10048247.91	0.3080848
6,794 - 13,587	12.8 - 25.6	1884	20217.3924	0.0006199
13,588 - 20,382	25.7 - 38.5	611	6556.7021	0.0002010
20,383 - 27,176	38.6 - 51.4	66	708.2526	0.0000217
27,177 - 33,972	51.5 - 64.4	9	96.5799	0.0000030
Total			32615203.93	0.6910696
Rill erosion/deposition (topography + soil erodibility + land cover)				
-6,331 - -5,311	-8.3 - -7.1	78	837.0258	0.0000257
-5,310 - -3,983	-7 - -5.3	3810	40885.491	0.0012537
-3,982 - -2,655	-5.2 - -3.5	22974	246536.2914	0.0075597
-2,654 - -1,327	-3.4 - -1.7	86853	932028.2283	0.0285793
-1,326 - 0	-1.6 - 0	2105878	22598387.41	0.6929473
0 - 1,326	0 - 1.6	703503	7549361.043	0.2314904
1,327 - 2,654	1.7 - 3.4	72766	780859.2226	0.0239439
2,655 - 3,982	3.5 - 5.2	32892	352967.3412	0.0108232
3,983 - 5,310	5.3 - 7	9130	97974.943	0.0030043
5,311 - 6,638	7.1 - 8.8	1132	12147.6052	0.0003725
Total			32611984.6	0.7303657

A comparison between the sediment transport rates by sheet vs. rill flow indicates that rill flow, which is inherently a turbulent flow, can carry sediment farther and will be more concentrated along valleys and in concave parts of hillslopes than if flow is dispersed by vegetation as is the case with sheet flow. This general statement is supported by modeled data presented in Table 1 which indicate that the sediment transport rates for the rill formulation are higher on average than the ones for the sheet formulation.

The divergence of the sediment transport rate **div(q_s)** as expressed in equation 7 identifies areas where the sediment transport rate increases in the flow direction (leading to erosion), decreases (leading to deposition), or stays constant (no net erosion/deposition). It is important to emphasize the difference between the quantities computed using equations 6 and 15, namely the sediment transport rate and rates of erosion and deposition: the first facilitates the detection of areas of high mass transport capacity, whereas the second allows detection of the patterns of erosion and deposition as determined by the distribution of incoming sediment supply relative to local transport capacity.

The resulting erosion/deposition map (based solely on topography) shows that estimated high risk erosion areas are located on upper convex parts of hillslopes, in hollows and centers of valleys with concentrated flow. Areas of deposition usually occur on lower concave parts of hillslopes and in concave valleys. This situation is consistent with previous results suggesting that the highest erosion rates correlate with divergent shoulder elements and deposition with convergent footslope elements (Busacca et al., 1993) or that the maximum soil loss occurs on slope convexities and maximum soil gain in both the slope concavities and the main thalwegs (Quine et al., 1994). It results that 72.6% of the basin area experiences erosion, but the highest proportion of it is in the category of extremely low erosion (Table 1).

1B. Sediment transport rate and the spatial distribution of erosion and deposition as a function of topography and soil erodibility.

Overall, introducing the K-factor in the analysis, the spatial pattern of the sediment transport capacity reflects the influence of areas of high erodibility, and thus sediment flow will have lower values on larger areas across the landscape rather than having very high values concentrated in concave areas of high slope. However, since the distribution of soil types is strongly correlated with topography, the pattern is also strongly dominated by topography.

The spatial distribution of erosion and deposition is also modified by the inclusion of the pattern of soil erodibility in the sense that it increases the areal extent of areas of high erosion risk. Although the percent area with erosion/deposition values smaller than 0 is approximately the same as for the case where topography was the only driver (72.7%), it is important to notice the distribution of z-score values for erosion and deposition for the two cases: for erosion/deposition modified by soil erodibility the range of z-scores is between -12 and -13, while for the topography only case the total z-score range is much greater (-63 to 67) and the corresponding range of z-scores (~ -13 to 13) includes 99.9% of the area (Table 1). Areas of high erosion risk are concentrated along steep slopes (15-54%) that also have high soil erodibility values, while deposition occurs in adjacent areas of lower slope and along valley floors.

1C. The influence of land cover on the sediment transport rate and spatial distribution of erosion and deposition

The general pattern of sediment transport rate dictated by topography and soil distribution is altered by the addition of the land cover management factor in the model. Forested lands have low C values indicating that they are naturally better protected from erosion by overland flow as opposed to croplands and barren lands that are less resistant to erosion and have the highest C values, thus less resistant to erosion. The effect of this factor on the sediment transport capacity is to decrease the flux in areas that are well-protected by the vegetation cover and to increase it in areas that are poorly protected by a deeper root system. The inclusion of the C factor significantly alters the distribution of the areas of high sediment transport rate, making the topographic influence less pronounced and highlighting those areas of low protective vegetation cover, such as the regions at the confluence of the main stem with Willowtown and Jones Creeks, Mill Creek, and Falling Timber and Locust Lick Creeks.

By adding the land cover factor in the computation, the patterns of both erosion and deposition shift to include areas of high erosion and deposition risk occurring at the contact line between cropland/pasture lands and forested lands, or on slopes of 15-25% that are less protected by the vegetation cover. This occurs as a result of the changes in the sediment transport rate associated with the transition from one land cover to another. For example, increasing transport rate in the direction of flow (as determined by local topography) would lead to net erosion.

At the same time, on lower slopes and locations with convergent slope geometry (concave slope profiles), net deposition occurs, with rates dependent on local slope values and vegetation cover. Based on this analysis, it might be concluded that land cover works both as an inhibitor and an accelerating factor in the distribution of erosion risk on slopes: areas that are well-protected by a layer of vegetation will reduce the risk of erosion that the terrain configuration suggests. Overall, the percent area experiencing erosion at the basin scale is lower than in the previous two cases (69.1%), with predominance of very low erosion rates (Table 1). Comparing results of erosion/deposition modeling with and without a land cover factor can also be interpreted as a prediction of what the distribution of erosion and deposition (basically as a result of changes in sediment transport rates) might be in the case of extensive clear-cutting and reconversion of forested lands into agriculture.

In this context, it is also valuable to mention that using different exponent values for the models (*m* and *n,* equation 6) to reflect different erosion mechanisms (sheet vs. rill) modifies the magnitude and spatial distribution of erosion and deposition (Figure 6). In terms of the areal extent of erosion by rill flow, 73.03% of the basin experiences erosion vs. only 69.1% under the same conditions for sheet erosion and also the range of z-scores is much smaller for the rill case.

2. Comparative spatial patterns of sediment transport and erosion and deposition for sub-basins of the Big Pitman Creek Basin

In order to compare the relative sediment contribution of individual sub-basins in the Pitman Creek basin based on modeled patterns of erosion and deposition, the basin has been divided into twenty-seven individual sub-basins based on the HUC 14 (Hydrologic Unit Code) classification. These twenty seven sub-basins aggregate to form the main stem and a series of right and left tributaries, namely the Big Pitman Creek (area that includes the main stem of the watershed plus Craig Creek), Little Pitman Creek, Middle Pitman Creek, Sand Lick, Locust Lick, Falling Timber, Mill Creek, Jones Creek, and Willowtown Creek basins.

Focusing the analysis on individual sub-basins within Pitman Creek basin was done in order to attain one of the aims of the project, namely that of identifying areas of relatively high contribution in terms of sediment delivery to the main stream channel and also areas that might represent “hot spots” in terms of high erosion risk areas. The starting point for the analysis is to compare the sediment transport rates and erosion/deposition rates across the basin on an individual HUC 14 unit basis.

For theoretical comparison purposes, the sediment transport rate for the basin was initially calculated without including the current land cover conditions in the computation (Figure 2 and 3). The mean sediment transport values are relatively high for the entire basin, the lowest values being associated with areas of the lowest relief in the headwater tributaries of the Little and Middle Pitman Creek basins (refer to Figure 7 to locate these sub-basins). The highest values for the transport capacity are associated with the areas of high slope values in the headwaters (Falling Timber Creek and Mill Creek) and areas of the main stem of Big Pitman Creek basins with higher slope values. This once again emphasizes the strong influence of terrain geometry on the rate and distribution of sediment transport and erosion and deposition rates.

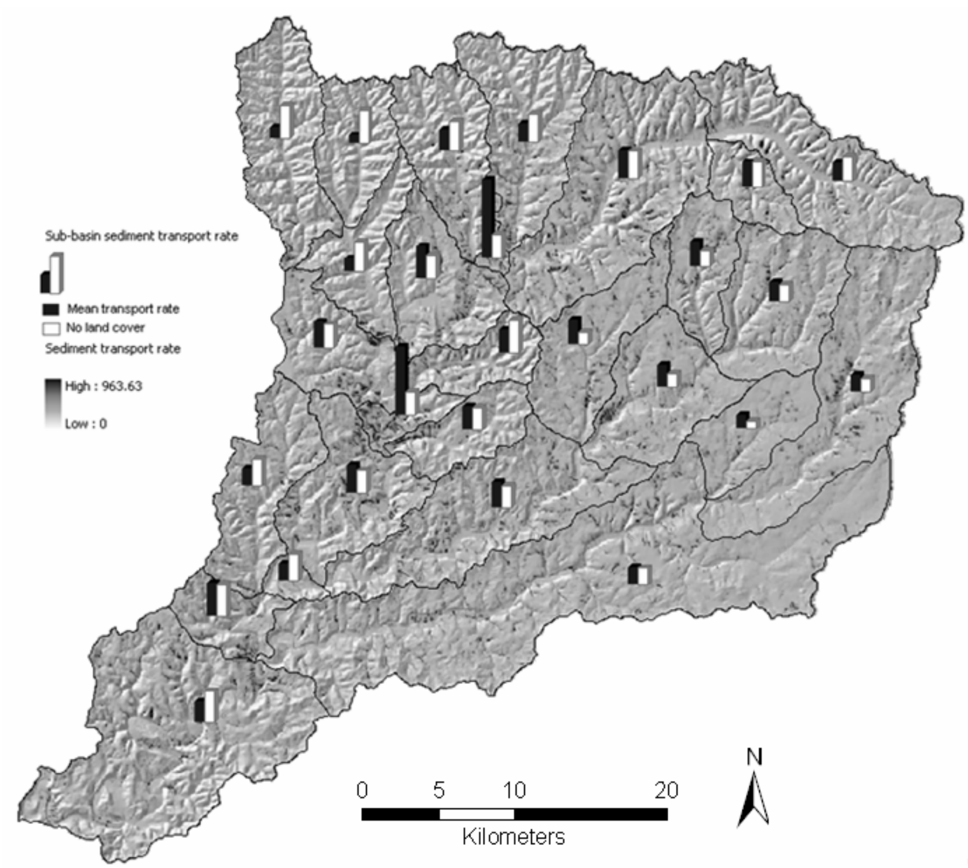

Figure 3: Big Pitman Creek mean sub-basin sediment transport rate with and without the land cover factor included overlaid on the basin sediment transport rate map. The sub-basin delineation is based on the Hydrologic Unit Code (HUC) 14 database.

When the sediment transport and erosion/deposition rates are computed including the land cover/land use factor, the direct correlation with the terrain geometry is less obvious and the highest values for transport capacity and erosion are generally recorded in the basins that are predominantly used for agricultural purposes (croplands and pastures). This is the case with two areas that are part of the main stem of the Big Pitman Creek intensely used for agriculture (Figure 4).

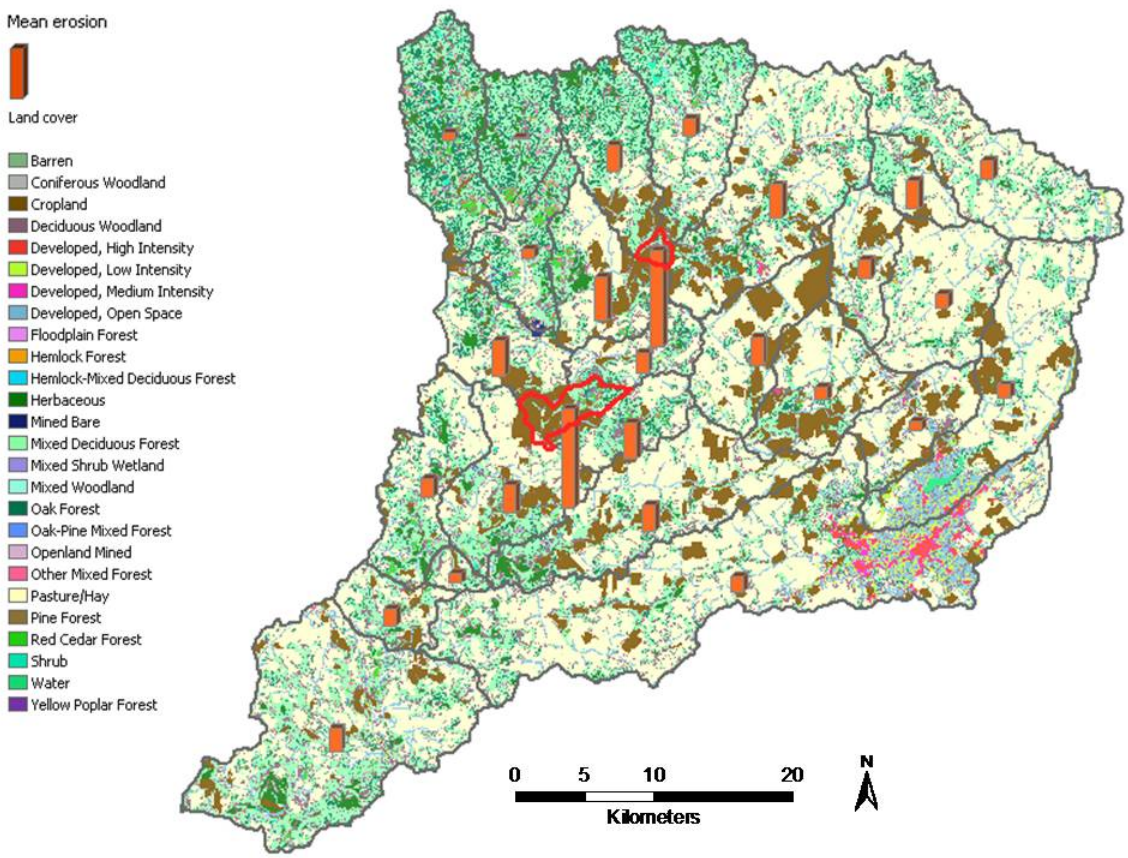

Figure 4: Mean erosion rates for individual sub-basins in the Big Pitman Creek Basin overlaid on the land cover/use map. The two sub-basins highlighted have the highest mean erosion value and correspond with sub-basin of intense agricultural use.

In terms of identifying erosion hot spots, in addition to the two Big Pitman Creek sub-basins, Falling Timber and Mill Creek basins are once again highlighted as target areas for soil erosion monitoring and possibly mitigation measures as part of the Kentucky CREP conservation program.

3. Streambed sediment samples and relationship with modeled patterns of erosion and deposition

Based on the information provided by the modeling results, the next step was to decide upon locations where streambed sediment sampling could be done to correlate the modeling results with the proportion of fine sediment in the bed material. The general fieldwork strategy has involved delineating a number of sub-catchments and establishing sampling points at key locations along the stream: in the upstream part of the basin, before the confluence with the major tributaries Little and Middle Pitman Creek, as well as along these tributaries and downstream from them, roughly at the divides between the middle and lower parts of the basin.

The sieve data obtained after the field and laboratory analyses of the bed material samples were used to generate grain size distributions for each sample and to calculate grain size percentiles in order to further correlate them with modeled values of erosion/deposition.

Figure 5 shows the segmentation of the Big Pitman Creek Basin in accordance with the location of streambed sediment samples. For example, for the sample called PC 6 (Pitman Creek 6), the drainage area included all the HUC 14 basins upstream of the location along the stream where the sample was taken. Similarly, the sample PC 5, located downstream from PC 6, includes the sub-basins already part of the PC 6 drainage area and an additional two. In order to establish a connection between the modeled mean erosion rates for each of the drainage areas corresponding with a sampling location and the grain size distribution of the samples, the finer than 2 mm grain size was chosen. The drainage area upstream of PC 6, characterized by high slope rates and agricultural use (croplands and pasture), has the highest mean erosion rate and the streambed sample PC 6 also has the highest percent of finer than 2 mm bed materials. This result supports the assumption that those sub-basin areas where intense erosion in close proximity to the stream is predicted are more likely to have relatively high proportions of fine (< 2 mm) sediment in the bed material. Also, the samples PC 2 and 3 (both located at PC 3 on the map) have high modeled erosion rates and high proportion of fine sediments stored on the stream bed. The area with the lowest amount of fine stored sediments of the stream bed corresponds with the drainage area of the sample location MPC 1, characterized by very low relief and relatively low use for cropping in close proximity to the stream.

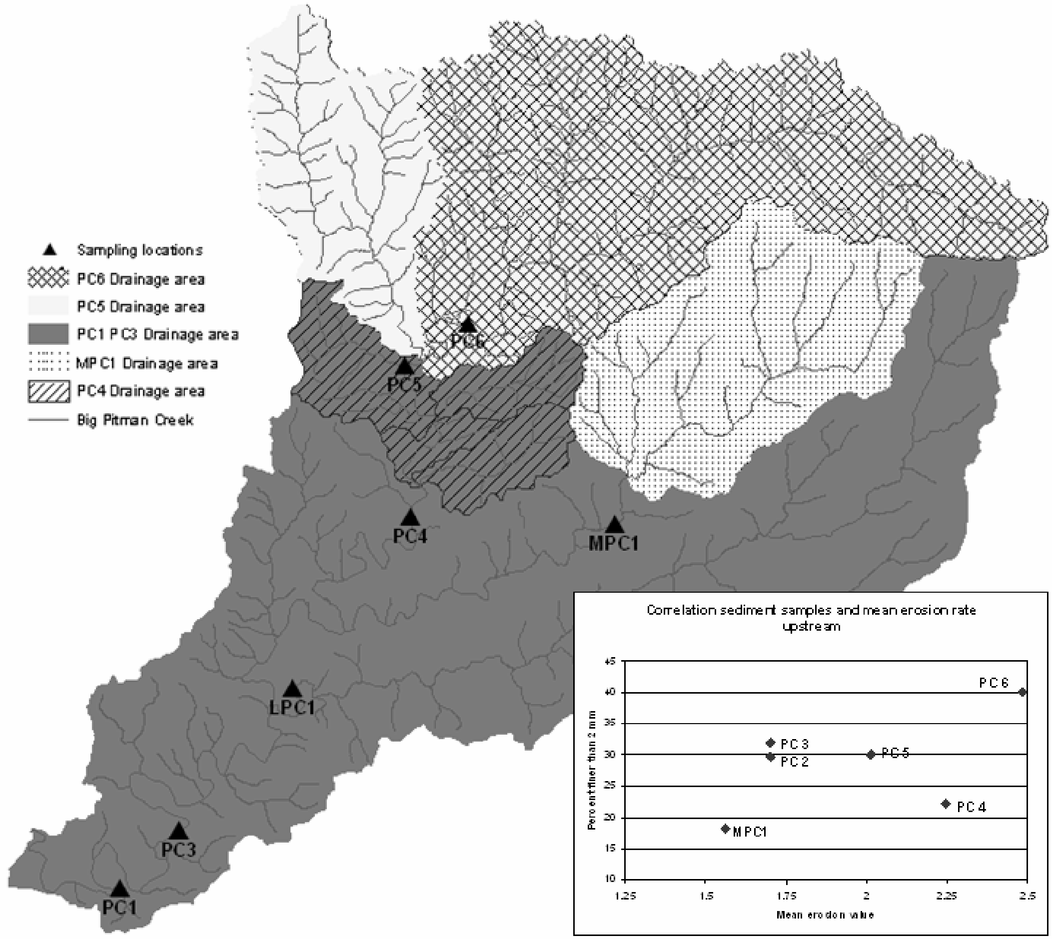

Figure 5: Segmentation of the Big Pitman Creek Basin in accordance with the location of streambed sediment samples with graph showing the correlation between finer than 2 mm grain sizes and mean erosion value upstream of the sample location.

The following section includes a discussion of sediment delivery to the stream network based on varying distances from the main stem. This riparian analysis is intended to inform land use management and conservation measures in the Big Pitman Creek Basin as part of the USDA CREP efforts in the Upper Green River Basin.

4. Assessment of sediment delivery from the slope to the alluvial system based on varying-distance stream buffers for the Pitman Creek basin

Stream buffers of varying distances were used to evaluate the interplay between erosion and deposition within individual sub-basins of the Pitman Creek basin, and to link these patterns to sediment delivery. The results indicate that the greatest amount of deposition occurs in closest proximity to the stream channels, decreasing gradually with increasing distance, whereas erosion dominates in other sub-basins at smaller distances from the channel mainly as a function of local topography and land use. Figure 6 and Table 3 present a summary of the mean erosion/deposition rates for various distances from the stream channel based on the erosion/deposition map that includes all the USPED parameters.

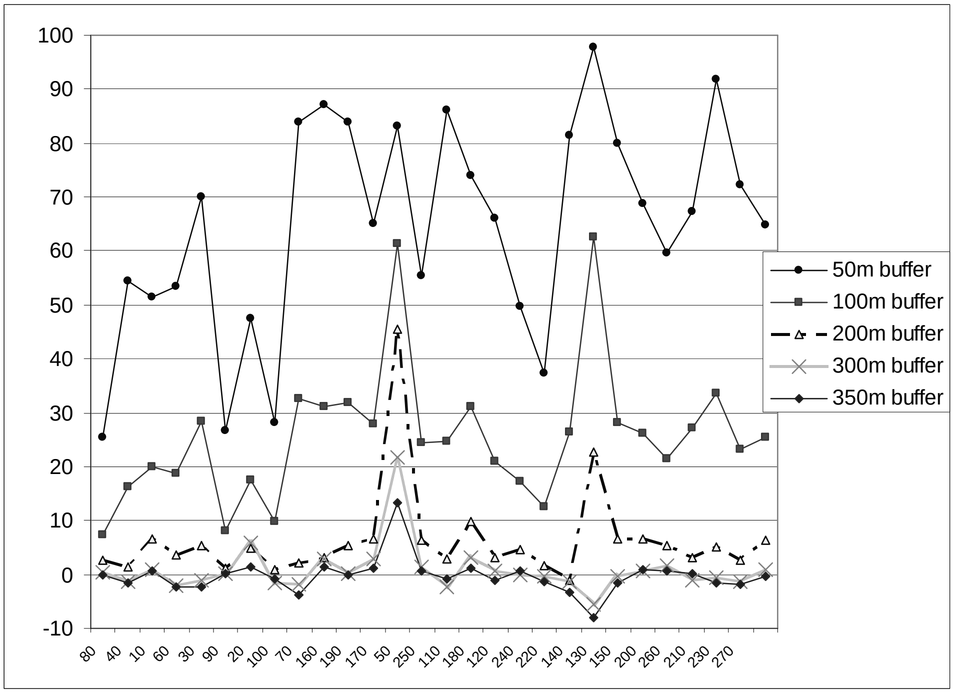

Figure 6: Mean net erosion and deposition rates at sub-basin level for 50 m to 350 m stream buffer areas within Big Pitman Creek Basin.

Table 3: Summary of average net erosion and deposition rates at sub-basin level for various stream buffer areas within Big Pitman Creek Basin.

HUC 14	Basin Name	50m buffer	100m buffer	200m buffer	300m buffer	350m buffer
90-080	Mill Creek	25.37	7.26	2.65	0.5	-0.09
90-040	Willowtown Creek	54.34	16.16	1.36	-1.22	-1.61
90-010	Big Pitman Creek	51.32	19.89	6.5	0.94	0.7
90-060	Jones Creek	53.54	18.78	3.59	-2.13	-2.43
90-030	Big Pitman Creek	70.03	28.51	5.38	-1.19	-2.42
90-090	Bull Tail Creek	26.72	7.99	1.2	0.28	0.13
90-020	Craig Creek	47.44	17.48	4.87	5.88	1.31
90-100	Mill Creek	28.06	9.74	0.95	-1.48	-0.94
90-070	Big Pitman Creek	84.02	32.52	2.23	-1.85	-3.92
90-160	Middle Pitman Creek	87.06	31.02	3.15	2.86	1.39
90-190	Flat Run	84.02	31.97	5.28	0.05	-0.05
90-170	Owl Creek	65.07	27.87	6.66	2.81	1.25
90-050	Big Pitman Creek	83.06	61.31	45.43	21.6	13.39
90-250	Trace Fork	55.39	24.34	6.35	1.49	0.6
90-110	Big Pitman Creek	86.07	24.76	2.8	-2.3	-0.91
90-180	Middle Pitman Creek	73.92	31.21	9.87	3.22	1.14
90-120	Falling Timber Branch	66.17	20.89	3.09	0.61	-1.06
90-240	Little Pitman Creek	49.67	17.21	4.67	-0.05	0.71
90-220	Sand Lick Creek	37.37	12.5	1.61	-0.42	-1.44
90-140	Locust Lick Branch	81.4	26.33	-1.07	-1.31	-3.38
90-130	Big Pitman Creek	97.69	62.55	22.63	-5.46	-7.99
90-150	Big Pitman Creek	79.85	28.11	6.48	-0.33	-1.5
90-200	Middle Pitman Creek	68.71	26.29	6.57	0.77	0.83
90-260	Little Pitman Creek	59.63	21.4	5.47	1.53	0.71
90-210	Big Pitman Creek	67.26	27.12	3.08	-0.97	0.07
90-230	Big Pitman Creek	91.85	33.54	5.22	-0.68	-1.48
90-270	Big Pitman Creek	72.29	23.08	2.52	-1.37	-1.87
Mean Rate		64.72	25.55	6.24	0.81	-0.33

Within a 50 m distance from the stream, the rates of deposition are relatively high with little variation among sub-basins, with the highest values being recorded for HUC 130 and HUC 230 that are part of the Big Pitman Creek basin (Figure 7). These variations in deposition rates are mainly correlated with topography, quantified in terms of slope values, with higher deposition rates corresponding to higher slope values, especially for smaller-area basins. However, this correlation is not straightforward because there are other factors that may intervene, such as type of soil or land cover type.

For the 100 m stream buffer, the relative rates of deposition experience a decrease throughout the basin with increasing distance from the main stem, as illustrated in Figure 6. The pattern of variation in deposition is similar to the 50 m distance from the stream in terms of relatively high overall deposition rates, with the highest values associated with high mean slope values (between 8 and 10 degrees) in the same two sub-basins highlighted for the 50 m buffer.

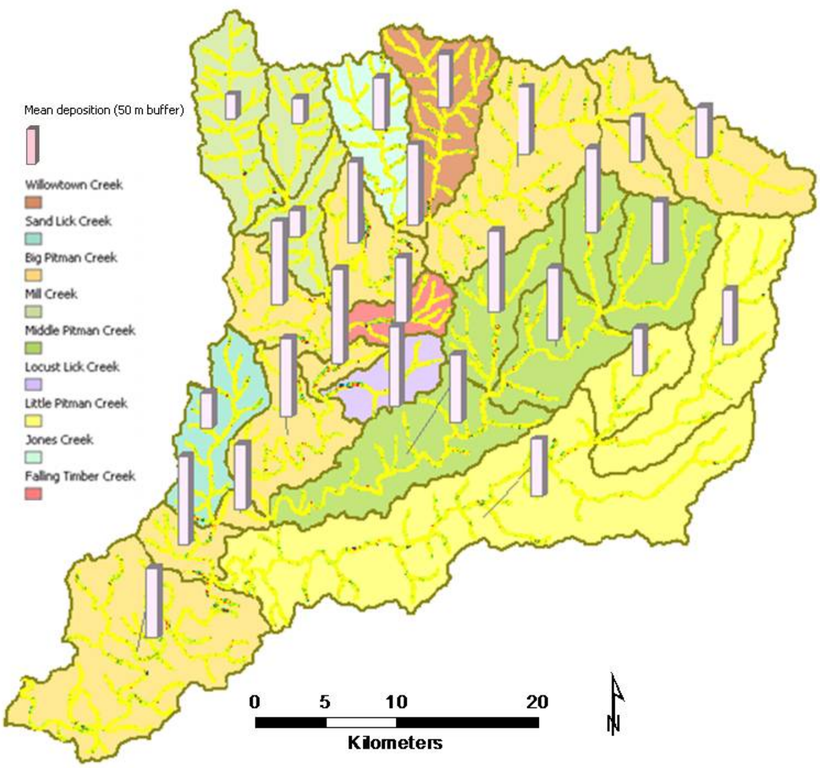

Figure 7: Mean deposition rates for the 50 m stream buffer for individual sub-basins in the Big Pitman Creek Basin.

Increasing the distance from the stream to 200 m led to a substantial decrease in the deposition rates with the first occurrence of a basin average negative rate, indicating predominant erosion. Locust Lick Branch sub-basin, with an area of 1569.1 acres and slope values ranging from 0 to 39.12 degrees, is the only one to experience net erosion for the specified buffer width. This might be explained by a net predominance (68%) of agricultural land use in the basin, which is translated into higher modeled erosion values. These areas should therefore be managed accordingly towards preventing erosion and deposition along and within the stream channel.

At 300 m distance from the stream, the interplay between erosion and deposition becomes more balanced, with 13 out of the 27 sub-basins experiencing net deposition and 14 of them net erosion. The sub-basins experiencing net deposition are either low slope areas, as is the case with Middle and Little Pitman Creek basins (3.5, 2.2 degrees mean slope value respectively), or are areas with high slope values and well-protected by deciduous forests: headwaters of Mill Creek and Big Pitman Creek. Falling Timber Creek (HUC120) has an average slope value of 8.68 degrees and is predominantly covered by deciduous forest and pasture and, although on average it experiences net deposition, it is very close to the net erosion threshold. This might be important information for land use planners and policy makers in charge of the area (within the Kentucky CREP program) because it provides data on what the optimum stream buffer distance for conservation and erosion control should be for this particular sub-basin. In fact, this is the very intent of this evaluation: to provide guidelines for erosion control and conservation practices for various basins and watersheds based on several parameters rather than just predominantly social considerations.

The last buffer distance applied in this analysis (350 m) roughly corresponds with the 1000 feet conservation buffer value proposed by the Green River CREP program for the tributaries of the Upper Green River. The patterns of erosion and deposition are relatively similar to those discussed in the previous section (Figure 8). Most sub-basins along the main stem experience net erosion. However, currently, the main stem of Big Pitman Creek is protected by a 1000 feet buffer but only up to the confluence with Willowtown Creek. Thus, there are other sub-basins which are experiencing net erosion between 300 and 350 m from the channel that are not currently protected against soil erosion and sediment deposition within the channel by any conservation program, such as: Mill Creek, Jones Creek, Sand Lick Creek, and sub-basins of Big Pitman Creek. According to this analysis, those sub-basins should also be included in the conservation efforts taking place in the Upper Green River Basin and its tributaries.

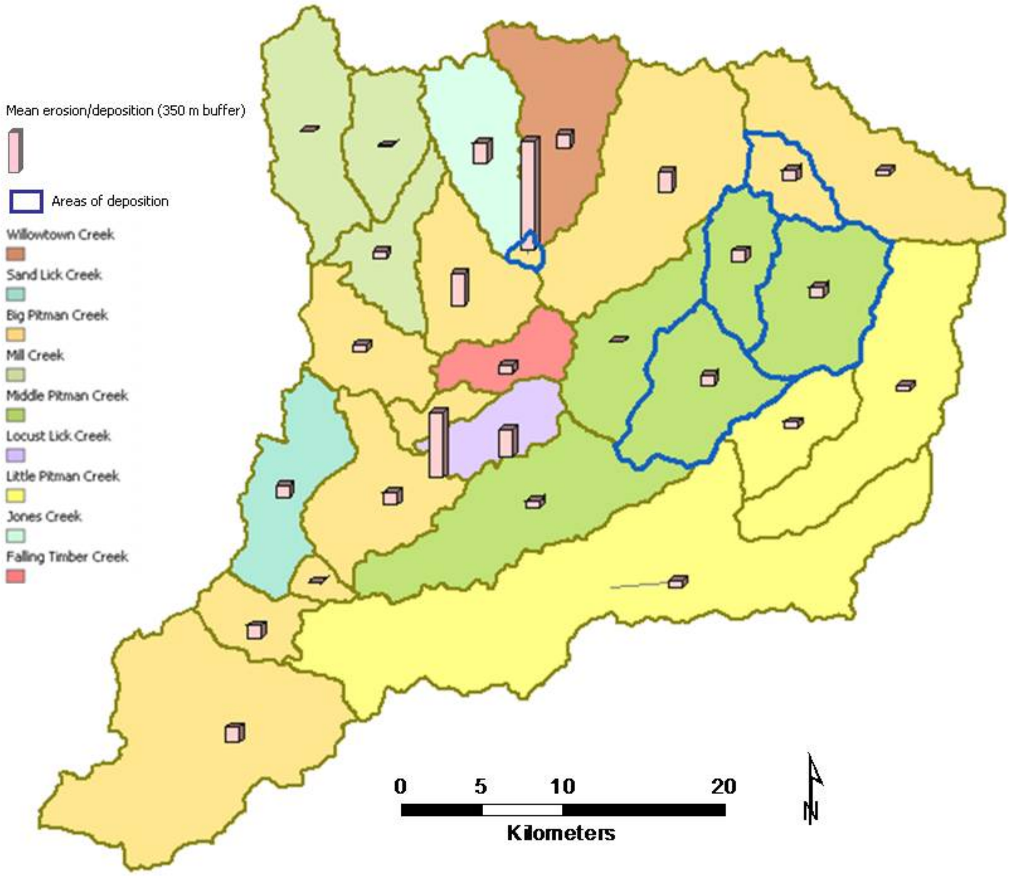

Figure 8: Mean erosion and deposition rates for the 350 m stream buffer for individual sub-basins in the Big Pitman Creek Basin. The sub-basins highlighted in dark color experience net deposition, while the remaining ones experience net erosion at 350 m from the channel, which is the current width of the stream conservation buffer applied by USDA.

IV. Summary and Conclusions

The assessment of soil erosion as part of evaluating sediment budgets at basin scales has become a matter of increasing interest in watershed management. This statement is particularly true for the Upper Green River basin and the KY CREP program, under which best management practices are adopted to reduce soil erosion, optimize profit from farming, and to protect habitat and water quality. Since soil erosion is a non-point source of suspended sediment pollution, one possible method of assessing the sediment loads from various areas is to model soil erosion at the basin scale.

The goal of this paper was to identify areas with high erosion risk due to terrain configuration (steep slopes, convex hillslopes or convergent topography), soil properties and variable land cover. The ultimate goal was to evaluate the potential effectiveness of various conservation strategies by providing information on current conditions and modeling possible land cover change scenarios. The model provides an assessment of the topographic potential for erosion and deposition in the Pitman Creek watershed, modified by the distribution of land cover and soil types. Interaction among the spatial distributions of the parameters describing terrain geometry, soil erodibility, and vegetation cover controls the modeled patterns of erosion. This model is a hybrid between an empirical and physically-based model that predicts sediment transport rates and uses mass conservation to estimate spatial patterns of soil erosion and deposition. For the particular geographical area it has been applied to in this study, the model has returned important parameters (sediment transport and soil erosion and deposition rates) that help understand the general spatial pattern of soil mobilization on slopes and how this pattern is related topography and distributions of soil type and land cover. The distribution of erosion and deposition is controlled by the change in overland flow due to a series of complex interactions between terrain geometry, soil, and land cover parameters. Thus, from a topographical point of view, it can be summarized that high-risk erosion areas tend to be associated with the upper convex parts of slopes, hollows, and centers of valleys with concentrated flow, whereas areas of predominant deposition occur mostly on lower concave parts of slopes and concave valleys.

The process of establishing general physical enhancers and inhibitors of erosion and deposition processes for the Pitman Creek Basin is an important step in further quantifying the degree of stability/instability of this landscape under current land use conditions. By linking topographic and soil characteristics with land cover data, it has been concluded that high intensity erosion tends to occur at contact between different vegetation covers, on barren lands and croplands, and 15-25% slopes poorly protected by vegetation. Erosion “hot spots” have been identified in the Pitman Creek HUC 05110001-90-130 and 05110001-90-050, both part of the Big Pitman Creek sub-basin, as well as in Mill and Falling Timber Creeks with lower intensity.

In order to make the connection between estimates of soil erosion and deposition patterns and the siltation of streams, as well as to provide relevant information for conservation planning, an assessment of sediment delivery to the channel network has been attempted. It has been demonstrated that sediment delivery to streams for individual sub-basins in the Pitman Creek basin varies with distance from the channel due to valley width, general topography and land cover distribution. After being initially highlighted as an erosion “hot spot”, the assessment of sediment delivery based on varying distances from the stream has helped determine with more accuracy which parts of the Big Pitman sub-basin (HUC 05110001-90-130) should be subject to immediate attention from the CREP program in terms of soil erosion buffering. This sub-basin is characterized by a maximum slope of 43%, mean slope = 6.5%, 78% agricultural use, and experiences the highest rates of deposition within the 100m buffer zone and the highest rates of erosion within buffer zones equal or greater than 250m. It can be thus concluded that sediment delivery assessment based on varying distance from the stream, when aided by field observations, can represent a reliable tool for conservation planning and decision making.

The results of this work can thus be translated into a map of “hot spots” or high erosion risk areas that can subsequently become the focus for a more detailed analysis or field erosion inventory and for which prevention measures might be considered when the results are confirmed in the field. The ultimate aim of soil conservation measures is to reduce erosion to a level at which “the maximum sustainable level of agricultural production, grazing or recreational activity can be obtained from an area of land without unacceptable environmental damage” (Morgan, 2005, pp. 152). Since the rates of soil formation are usually very small relative to acute erosion rates, a threshold value for soil erosion needs to be imposed, given the maximum permissible rate of erosion at which soil fertility can be maintained over long periods of time (soil loss tolerance). One of the most significant aspects of soil erosion modeling is that the prevention measures that might be applicable for various parts of a watershed are largely dictated by the predominant type of flow. Thus, one important measure is changing turbulent flow characteristic for rills and gullies to dispersed sheet flow by creating contour filter strips, spreaders, and grassed waterways, depending on the situation (Mitasova et al., 2001). Sheet erosion is most likely to occur on upper convex parts of hillslopes (accelerated flow), and the best conservation measure is increasing/preserving a thick vegetation cover. In areas that have been highlighted as high erosion risk based on locational analyses and estimates of sediment delivery to the stream channel, stream buffers can be implemented as an aid in reducing the amount of sediments delivered during intense storm events.

However, it is the weak indirect link with field measurements both in terms of availability of input data into a GIS and calibration/validation of the model outputs that might represent an impediment in using such a modeling approach as a reliable tool for conservation planning and decision making in the future. More experimental work needs to be performed on improving the parameters included in the analysis and especially on the field validation procedure of both the parameters and the results of the USPED model. These drawbacks have become conspicuous when attempting to correlate the modeling results with the bed material samples and have also been affected by the fact that the modeling does not account for the sediment dynamics of the alluvial system.

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