

USING A BANK EROSION HAZARD INDEX (BEHI) TO ESTIMATE ANNUAL SEDIMENT LOADS FROM STREAMBANK EROSION IN THE WEST FORK WHITE RIVER WATERSHED

M.A. Van Eps¹, S.J. Formica, T.L. Morris, J.M. Beck, A.S. Cotter

ABSTRACT

The Arkansas Department of Environmental Quality (ADEQ), through an EPA Section 319 NPS grant, utilized a bank erosion hazard index (BEHI) and data collected from surveys of streambank profile measurements to develop a graphical model to estimate streambank erosion rates and to estimate the annual sediment load due to accelerated streambank erosion in the West Fork White River (WFWR) watershed. The WFWR watershed, located in Northwest Arkansas, has a watershed area of 31,700 Ha (79,400 ac) and is a tributary to the White River which eventually drains to the primary drinking water source for the region, Beaver Lake. Sediment is a contaminant of concern because the WFWR has been designated as impaired due to “excessive turbidity and siltation” (ADPC&E, 1998). As part of a comprehensive project to assess the various sources of sediment in the WFWR watershed, ADEQ utilized methods, developed by Rosgen (2001), to estimate sediment (bedload and suspended) contributions from accelerated streambank erosion. A streambank erosion inventory was conducted in 2002 to determine the bank erosion potential of streambanks along 64 river kilometers (40 river miles) of the main stem and tributaries of the WFWR watershed. Using ranking criteria consisting of bank angle, root depth, bank material, and other variables, streambanks were evaluated and scores were assigned based on erosion potential. Toe pins were installed at permanent survey sites and lateral erosion was measured over a one-year period. A graphical model to predict streambank erosion rates based on relationships between BEHI, near-bank shear stress, and observed annual erosion was developed. For the WFWR watershed, it was estimated that on an annual basis, a total of 21,455 metric tons of sediment enter the river network from streambanks where accelerated streambank erosion was observed. The mass of bedload and suspended load was 7,493 metric ton/yr and 13,962 metric ton/yr, respectively.

KEYWORDS. Sediment, watershed assessment, streambank erosion, sedimentation, erosion, river stability

INTRODUCTION

Sediment is the second leading cause of impairment of monitored rivers and streams in the United States according to the U.S. Environmental Protection Agency (U.S. EPA, 2000). Sources of sediment often cited include agriculture, urban runoff, construction, and silviculture. Streambank erosion contributions of sediment have been found to constitute a majority of total sediment supplies in some watersheds (Rosgen, 1976). Lateral streambank erosion may be accelerated in systems that have been hydraulically affected by changes in land-use, removal of riparian vegetation, and/or changes in channel dimension from activities, such as, in-stream gravel removal. Accelerated lateral erosion contributes additional sediment to the stream network that can impact water quality and increase the potential for river instability. The focus of this investigation was on the West Fork White River (WFWR) in Northwest Arkansas, having a total watershed area of 31,700 Ha (79,400 ac). The State Water Quality Inventory Report of 1998, prepared by ADEQ pursuant to section 305(b) of the Federal Water Pollution Control Act, had assessed the aquatic life use as “not supported” in 53.8 km (33.4 miles) of the WFWR. The cause cited was ‘high turbidity levels and excessive silt loads.’ The probable sources listed were: (1) agricultural land clearing; (2) road construction and maintenance; and (3) gravel removal from stream beds. Based on the results of the inventory report, the WFWR was added to the State’s list of impaired waters known as 303(d) list by the ADEQ in 1998 (ADPC&E, 1998). The work presented in this paper was a component of an overall effort to determine the relative annual loads from various sediment sources in the WFWR watershed (ADEQ, 2004).

¹Arkansas Department of Environmental Quality, Environmental Preservation Division, 8001 National Drive, Little Rock, AR 72219

During the overall WFWR watershed assessment, accelerated lateral streambank erosion was identified as a potential sediment source contributing to water quality problems in the WFWR watershed. For the purposes of this paper, sediment from streambank erosion is defined as consisting of bedload, particles with mean diameters greater than 2 mm, and suspended load, particles with mean diameters equal to or less than 2 mm. Using methods proposed by Rosgen (2001), both the annual bedload and suspended load of sediment resulting from accelerated streambank erosion in the WFWR watershed was estimated. The general method used to estimate sediment loads from excessive stream bank erosion in the WFWR involved: 1) Conducting an inventory of streambanks for erosion potential based on a bank erosion hazard index (BEHI) and the near-bank shear stress (NBSS), 2) Developing a graphical model to predict streambank erosion rates in the watershed by measuring erosion rates at permanent survey sites representing the various BEHI and NBSS values observed during the streambank erosion inventory, and 3) Applying the graphical model to the streambank erosion inventory.

STREAMBANK EROSION INVENTORY

An inventory of eroding streambanks in the WFWR watershed was developed by traveling the entire length of the main stem and several kilometers of tributary streams of major subwatersheds. The banks inventoried or evaluated were streambanks where there were indications of accelerated erosion including hanging roots, exposed bank material, or sod mats at the toe of the bank. The erosion potential was estimated for each inventoried bank by estimating ratings for erosion risk (BEHI) and NBSS. BEHI variables included bank angle, bank height ratio, root density, rooting depth, percent of bank protected by boulders or logs, and bank materials. The height of the streambank was measured with a survey rod and the length of the streambank was determined using a range finder. A rating for NBSS was estimated for each inventoried streambank based on the general cross-section shape of the channel and local stream slope conditions. All of the BEHI variables and NBSS information were electronically cataloged using ArcPad GIS software on a water-resistant, Cassiopeia EG-800 handheld PC. Forms were developed for the ArcPad software which allowed for the input of the streambank BEHI and other data. The general locations of streambanks were created in the GIS environment by adding a feature to a streambank line shapefile previously loaded into ArcPad. In the office, the data was downloaded from the handheld PC and then managed in ArcGIS. This approach reduced the amount of time required to transfer raw field data into a digital format. It also allowed for rapid manipulation and presentation of the results of the field work. Photographs of each of the eroding banks that were inventoried were taken using a Kodak DC5000 water resistant 2.1 MP digital camera.

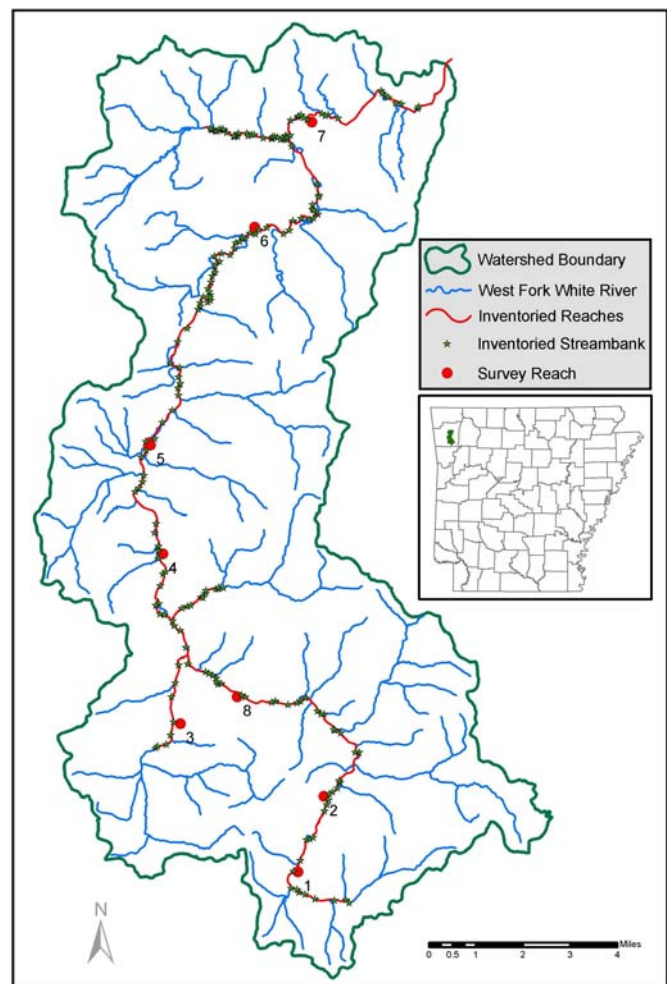


Figure 1. Locations of inventoried streambanks and reaches where erosion rates were measured in the WFWR watershed.

During the spring of 2002, the main stem of the WFWR, 48.8 km (30.3 miles), and the lower 3.9 km (2.4 miles) of Winn Creek, a major tributary, were inventoried for eroding streambanks. The lower 2.3 km (1.4 miles) of Mill Creek was inventoried in February of 2003 and the lower 3.7 km (2.3 miles) of Town Branch were inventoried in January of 2004. A map highlighting the areas of the WFWR stream network where the streambank inventory was performed is shown in Figure 1. Once the field data had been collected, a spreadsheet was used to convert the recorded BEHI variable values of each streambank into points using the scoring system proposed by Rosgen (2001). Based on the total number of points a streambank received, a general rating of the erosion risk was assigned. As the number of points increased, the erosion risk increased. BEHI risk rating categories included low, moderate, high, very high, and extreme. Some

streambanks that did not display obvious signs of active erosion were included in the inventory to allow comparison of erosion rates between streambanks of lower and higher erosion risk ratings. Evaluation of NBSS was based on rating categories that ranged from low to extreme.

Inventory Results: During the inventory process, 192 individual streambanks were evaluated. Based on the field evaluated BEHI variables, the erosion risk of the streambanks along the main stem of the WFWR and selected tributaries was estimated. Table 1 indicates the number of streambanks within each erosion risk rating category that were cataloged.

The estimated ratings for NBSS of inventoried streambanks are also shown in Table 1. The combination of a streambank erosion risk rating (BEHI) and local NBSS affects the degree of lateral migration observed for an eroding streambank. For streambanks with similar erosion risk ratings, higher NBSS will result in greater amounts of lateral erosion.

Table 1. Counts of inventoried streambanks, erosion risk rating, NBSS rating

Number of Inventoried Streambanks	Erosion Risk Rating	Number of Inventoried Streambanks	NBSS Rating
4	Low	34	Low
44	Moderate	64	Moderate
113	High	56	High
28	Very High	33	Very High
3	Extreme	5	Extreme

GRAPHICAL MODEL TO PREDICT STREAMBANK EROSION RATES

To estimate the lateral erosion rates of inventoried streambanks using the BEHI and NBSS ratings, a graphical prediction model based on physical measurements of streambank erosion was developed for the WFWR watershed. The graphical model was developed based on the methods described by Rosgen (2001).

Methods: Eight reaches were selected on the main stem of the WFWR where annual lateral erosion rates could be measured. Within these reaches, 24 permanent survey sites were established. The permanent survey sites were selected based on various combinations of BEHI and NBSS ratings representing different streambank conditions along the main stem of the WFWR observed during the streambank inventory process. The general locations of the eight reaches with permanent survey sites are shown in Figure 1.

Annual lateral erosion rates at the permanent survey sites were determined by installing vertical pins at the toe of the streambanks. The toe pins were installed by driving sections of 1.2 m (4 ft.) long 1.9 cm (¾ inch) thick rebar vertically into the channel bed immediately adjacent to the streambank of interest. The BEHI variables and NBSS condition for each bank where toe pins had been installed were evaluated and recorded. Using a pair of flat-edged survey rods and a framing level, the profile of the eroding streambank was surveyed by measuring the horizontal distance from the landward side of the toe pin to the streambank for various heights above the toe pin cap, depending on the shape of the bank profile (Figure 2). The toe pins were resurveyed after one year to determine annual erosion rates. The range of stream discharge during the one-year period was monitored by using data from a USGS gage station (07048550) at the downstream end of the watershed. This allowed for a determination of the discharge conditions represented by the graphical model.



Figure 2. Measurement of lateral streambank erosion in the WFWR watershed.

Bank profile survey data from 2002 and 2003 were placed into a spreadsheet and graphed. Using the graphed data, the average lateral erosion for the entire height of the streambank was calculated by taking the average of the lateral erosion data measured every two tenths of a foot of vertical elevation above each surveyed toe pin. By relating the BEHI rating, the local NBSS, and the measured erosion rate at each permanent survey site, a graphical model to predict streambank erosion rates was developed. Using the graphical model, erosion rates were predicted for all the streambanks included in the streambank erosion inventory. The volume of sediment generated due to erosion of individual streambanks was calculated by multiplying the predicted annual lateral erosion rate by the length and height of the bank from the original streambank erosion inventory.

Results: A total of 24 streambanks were surveyed in 2002 and 2003 within the eight reaches evaluated for this study. Graphical representations of the results of 2002 and 2003 streambank profiles for selected toe pins at permanent survey sites are shown in Figure 3. The graphical model for predicting streambank erosion rates in the WFWR watershed is shown in Figure 4.

Using the recorded BEHI and NBSS values determined during the streambank inventory, and the graphical model developed based on the toe pin surveys at the permanent survey station sites, the lateral erosion rates of inventoried streambanks were estimated. The maximum erosion rate predicted was 3.9 m/yr (12.9 feet/yr). The average erosion rate for inventoried banks where the rated erosion risk was moderate or greater was 0.2 m/yr (0.6 feet/yr).

The maximum measured flow during the period between surveys was 117 m³/s (4120 cfs) as measured on the WFWR at the USGS gage station. This discharge exceeds the bankfull discharge based on regional curves (ADEQ, 2002) by approximately 27%. In addition, project team members observed bankfull discharge and slightly greater than bankfull discharge at several of the reaches during the time that the 117 m³/s discharge was recorded. Since the discharge during the period between the surveys was at or slightly above bankfull, the survey data should represent erosion rates for years where bankfull flow is approached, equaled, or slightly exceeded. In years where the discharge is either well below or greatly exceeds the bankfull discharge, the graphical model will lose accuracy.

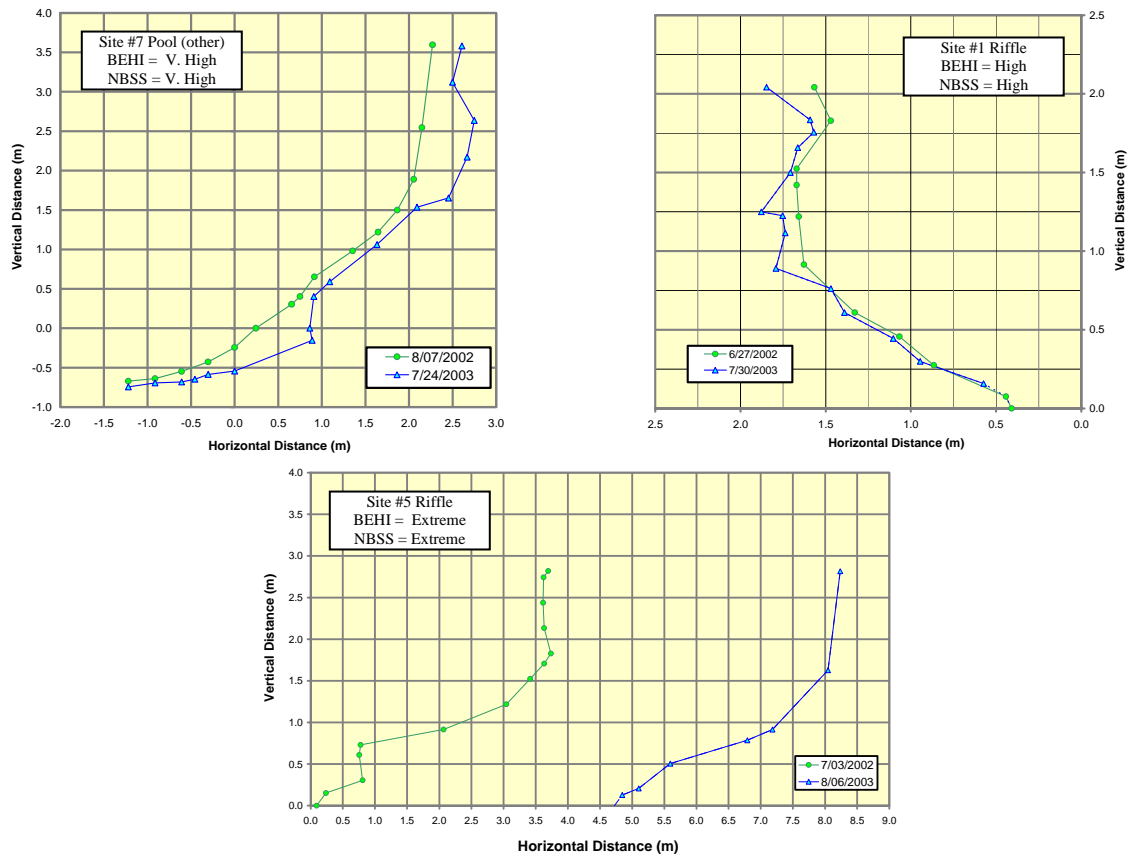


Figure 3. Examples of lateral erosion measurements taken at selected locations in the WFWR watershed.

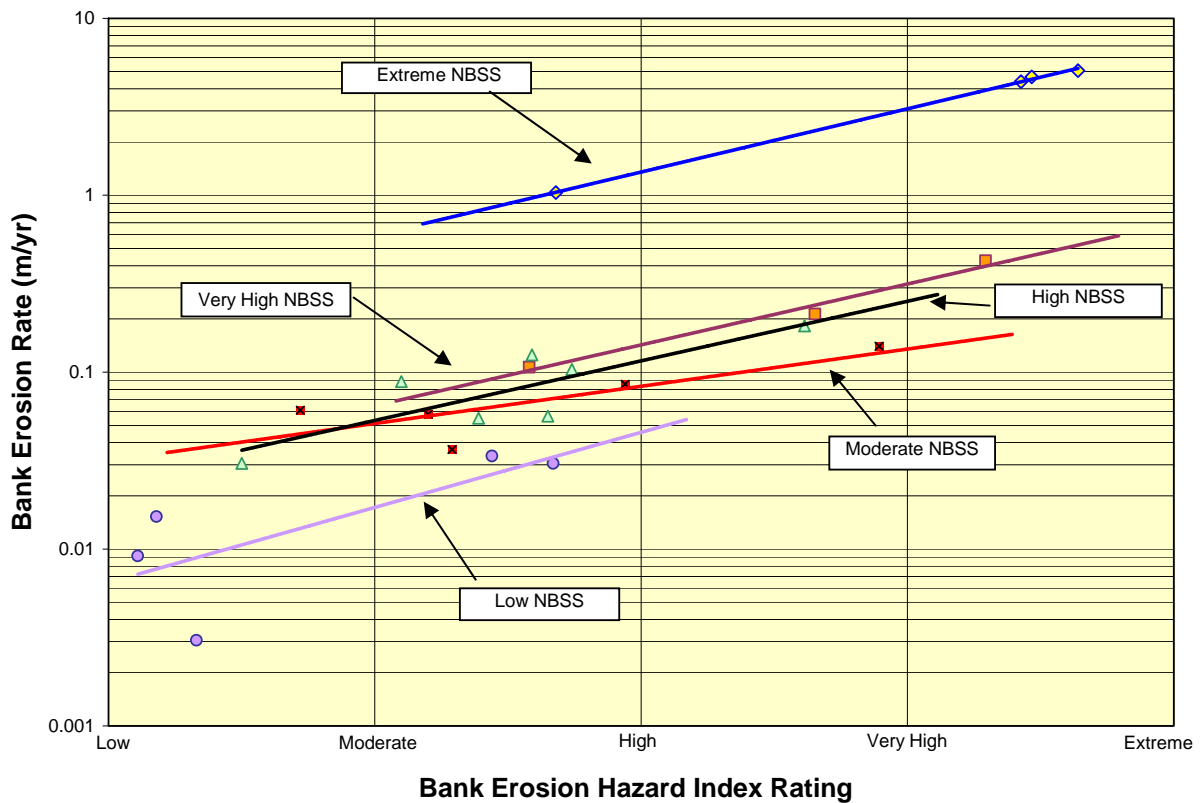


Figure 4. Graphical model for predicting streambank erosion rates in the WFWR watershed

A comparison of the predicted erosion rates developed through this work to erosion rates based on models developed by Rosgen (2001) as well as Jessup and Harmon (2004) is shown in Table 2. Lateral erosion rates predicted by the model were less than half the rates predicted by the Colorado model for a BEHI and NBSS combination rating of moderate and high. However, for other combinations of BEHI and NBSS, erosion rates predicted by the WFWR model were higher than those predicted by the other models by a factor ranging from 1.3 to 2.8 times.

Table 2. Lateral erosion rates predicted by the WFWR watershed graphical model compared to erosion rates predicted by models developed in Colorado (Rosgen, 2001) and North Carolina (Jessup and Harmon, 2004)

Bank Erosion Hazard Index	Near-Bank Shear Stress	Predicted by WFWR Model (m/yr)	Predicted by Colorado Model (m/yr)	Predicted by North Carolina Model (m/yr)
Moderate	High	0.05	0.12	0.05
Moderate	Extreme	0.60	0.45	0.8
High	Extreme	1.4	0.76	1.1
Extreme	Extreme	7.0	4.27	3.0

The WFWR model appears to compare relatively well with the North Carolina model, but begins to diverge at the upper end of the BEHI and NBS categories. Differences between models may be due to variation in watershed size or characteristics of the various physiographic regions, such as, soils and precipitation.

ESTIMATE OF ANNUAL SEDIMENT LOADS FROM STREAMBANK EROSION

In order to relate streambank erosion rates predicted by the graphical model to water quality impacts and to be able to compare the overall impact of sediment from streambank erosion to other sources of sediment in the watershed, the mass and particle size distribution of sediment in the streambanks was determined. Coarse and fine grain layers of streambanks in the watershed were sampled to determine the in-situ bulk density and particle size distribution. Fine grain sediment streambank layers where particle sizes were generally less than 2 mm in size, were sampled using a hammer-driven Shelby tube. To characterize streambank layers generally composed of coarse materials, methods developed by Brye et. al.(2004) were utilized to collect samples. The in-situ bulk density and particle size distributions were then related to inventoried streambanks by comparing sampled bank strata to photos of banks inventoried during the streambank erosion inventory process. The average in-situ bulk density for fine grain material samples was 1.4 g/cm³ (1.2 ton/yd³). By weight, 8% of the particles in the fine material samples were greater than 2 mm in particle size. The average in-situ bulk density for coarse samples was 2.6 g/cm³ (2.2 ton/yd³). By weight, 80% of the particles in coarse samples were greater than 2 mm in particle size.

Based on the streambank inventory, the development of the graphical model, and the measurement of in-situ bulk density, an estimate of the annual load of sediment resulting from streambank erosion was made. Sediment loads generated by streambank erosion for major tributaries of the WFWR that were not included in the streambank inventory process were estimated by developing streambank erosion export coefficients from inventoried tributaries having similar characteristics. Export coefficients were applied to the length of the tributaries that were 3rd order or greater streams. For the WFWR watershed, it was estimated that on an annual basis, a total of 21,455 metric tons of sediment enter the river network from streambanks where accelerated streambank erosion was observed. Natural erosion rates for the WFWR watershed were assumed to be equivalent to the rate predicted by the graphical model for a BEHI-NBSS rating of low-low. Using this assumption, the sediment load for natural erosion from streambank included in the streambank erosion inventory would be 739 metric tons/yr, which is 3% of the total load estimate.

Using the particle size distribution of streambank materials, bedload and suspended loads were determined and are shown in Table 3. The mass of bedload and suspended load from streambanks included in the watershed inventory was 7,493 metric ton/yr and 13,962 metric ton/yr, respectively. Suspended sediment represented 65 percent of the estimated total sediment load. The sediment load that consisted of particles less than 0.02 mm in size was 6,563 metric ton/yr.

The estimated sediment load resulting from erosion of streambanks along the main stem of the WFWR that were included in the inventory was 16,812 metric ton/yr. Of that amount, 11,227 metric tons or 67% of the load consisted of sediment 2 mm or less in size. 80 percent of the estimated suspended sediment load for the watershed resulted from erosion of streambanks along the main stem of the WFWR that were included in the inventory. One reach along the main stem approximately 1.6 km long contributed 25% of the total load of particles less than 2 mm in size.

Table 3. Estimated sediment loads from eroding streambanks in the WFWR watershed

Main Stem and Tributaries	Length		Watershed Area		Sediment Load (metric ton/yr)		
	km	mi	km ²	mi ²	Particles > 2 mm	Particles ≤ 2 mm	Total
Main Stem	48.7	30.3	321.16	124	5,585	11,227	16,812
Wilson Branch	2.1	1.3	8.5	3.3	18	241	259
Dye Creek	3.5	2.2	9.4	3.6	166	190	356
Riley Creek	4.0	2.5	10.2	4.0	196	94	290
Cato Springs	3.1	1.9	11.9	4.6	26	347	374
West Mtn Creek	4.1	2.6	12.1	4.7	196	224	420
Sinclair Creek	3.6	2.3	13.1	5.1	227	127	355
London Creek	3.7	2.3	13.3	5.1	174	199	372
Rock Creek	4.2	2.6	15.3	5.9	199	228	426
Hutchins Creek	5.1	3.2	15.3	5.9	244	279	523
Mill Creek	4.1	2.5	19.0	7.3	195	223	418
Town Branch	4.2	2.6	30.2	11.7	35	474	509
Winn Creek	4.8	3.0	37.4	14.4	231	110	342
					7,493	13,962	21,455

CONCLUSION

A bank erosion hazard index (BEHI) and estimated near-bank shear stress (NBSS) was used to inventory eroding streambanks in the WFWR watershed. Twenty-four permanent survey sites were established on 8 reaches to develop a relationship between BEHI and NBSS ratings and lateral streambank erosion rates. From these relationships, a graphical model to predict streambank erosion rates was developed for the WFWR watershed. The graphical model should be appropriate for use during years where the bankfull discharge is approached, equaled, or slightly exceeded. The graphical model was used to estimate erosion rates for inventoried streambanks in the WFWR watershed. Streambank materials were characterized to determine the in-situ bulk densities of various layers of the streambanks. Based on the data collected, a total of 21,455 metric tons/yr of sediment enter the WFWR from streambanks where accelerated streambank erosion was observed. The sediment load was estimated to be 739 metric tons/yr if the same banks were in a stable condition. The model developed through this work yielded lateral streambank erosion rates as much as 2.8 times greater than those predicted by existing models that were developed for other physiographic regions. The differences between the models indicate the importance of collecting data specific to the physiographic region of interest. The work performed as part of this study was conducted in one 124 mi² watershed that was in portions of the Boston Mountain and Springfield-Salem Plateau physiographic regions. The model may be effective for predicting streambank erosion rates outside of the WFWR watershed if applied to the same physiographic regions. However, more streambank erosion data should be collected to validate and improve the model for other watersheds within those physiographic regions.

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