Abstract

The Clark Fork of the Columbia River through Deer Lodge Valley, Montana, is a meandering stream that has experienced high cutbank erosion rates over the past several decades due to extreme thinning of woody riparian vegetation. Bank erosion rate data available for the period 1989 to 1997 were examined along with large-scale aerial photographs in order to assess the relation between vegetation along cutbanks in meander bends and cutbank erosion rates. These data clearly show a downward trend in erosion rate with increasing density of woody riparian vegetation. Where vegetation density is high and erosion rates are low, however, the amount of bank retreat cannot be determined from the aerial photographs. Consequently, a lower limit on erosion rate as a function of density of woody riparian vegetation cannot be calculated from the available data.

INTRODUCTION

The Clark Fork of the Columbia River through the Deer Lodge Valley, Montana (fig. 1), is vulnerable to high rates of bank erosion as a result of extreme thinning of woody riparian vegetation (Smith and others, 1998). In this valley, the Clark Fork is a highly sinuous river with well-developed cutbanks. A large flood in 1908 left silty deposits of mine tailings (called "slickens") along the flood plain, primarily within the meander belt of the river (fig. 2; Nimick and Moore, 1991). The recurrence interval for this flood was approximately 300 years, based on calculations of flood magnitude and an extrapolation of the flood-frequency curve for the Clark Fork at Deer Lodge, provided by Smith and others (1998). Where slickens or grassy fields extend all the way to the river’s edge, the banks are particularly susceptible to erosion.

The presence of dense, woody vegetation on streambanks can decrease erosion substantially both by reducing the shear stress along the bases of the banks and by increasing the cohesion of the soil that forms the banks. Over the past several decades, rapid bank retreat (as much as 6 feet per year) has been occurring along the Clark Fork through the Deer Lodge Valley (R2 Resource Consultants, Inc., unpub. data, 1998).
Figure 2. Example of slickens along a half-mile-long reach near Warm Springs in September 1988. (RM denotes river mile.) The arrow indicates flow direction. Vegetation is sparse on the silt clay overbank deposits contaminated with mine tailings (light-colored areas), which occur in many areas within the river meander belt. The slickens in this area were amended during the study period, and by 1997, the interior flood-plain tab surfaces were generally grass covered. However, vegetation along the riverbanks, which is the focus of this study, was not affected by the amendment work.

Available Data

Large-scale aerial photographs were taken in September 1988 at a very low flow (35 ft³/s) and again in July 1997, when flow was about one-half bankfull (841 ft³/s). Because the 1988 photographs were taken near the beginning of water year 1989 (October 1, 1988), the study period is considered to be 1989 to 1997, about 9 years. The 1988 photographs were taken at a scale of about 1:7,000 and the 1997 photographs at a scale of about 1:11,800. The photographs were scanned at high resolution, with a resulting pixel size of about 1 ft², then rectified to geographic coordinates. Bank erosion rates were determined by R2 Resource Consultants, Inc. (unpub. data, 1998) from the rectified images for short (average of about 21 ft long) bank segments along 43 river miles of the Clark Fork from Warm Springs to just upstream from the mouth of the Little Blackfoot River, near Garrison (figs. 1 and 3).

A geographic-information-system coverage containing the river centerline for the study period (fig. 3) was provided, together with the erosion rate data specified for either the left or right bank along the entire reach (R2 Resource Consultants, Inc., unpub. data, 1998). Owing to the intended use of the data for an equilibrium mass balance model, erosion was assumed to have occurred on only one side of the stream at any given location within the relatively short study period (9 years). Daily mean discharge data from the streamflow-gaging stations Clark Fork near Galen (station number 12323800) and at Deer Lodge (station number 12324200) are also available for the study period (fig. 4).

Figure 3. The river centerline through Deer Lodge Valley (blue lines), identified from large-scale aerial photographs (R2 Resource Consultants, Inc., unpub. data, 1998). In this study, radius of curvature was estimated, and average erosion rates were calculated for 276 bends (dashed circles) between RM 0.0 and 34.3. The edges of the channel (brown lines) are shown for one bend, and arrows generally indicate magnitude and direction of cutbank erosion along individual segments of the centerline arc (R2 Resource Consultants, Inc., unpub. data, 1998) through this bend.
Calculation of Average Erosion Rates through Bends

At the outset of the investigation, it was noted that more than one-half of the bank erosion occurred at the cutbanks on the outside of meander bends, so efforts were focused on these easy-to-characterize sites. Using the river centerline coverage, 276 bends were identified by drawing circular arcs generally fitting the curvature of the bends (fig. 3). The bend radius of curvature was expected to have a strong influence on erosion rate. Therefore, radius of curvature was estimated from the circular arcs, and bend length was computed from the distance along the centerline where it follows the circular arc. An average erosion rate for each bend was computed by multiplying the erosion rate associated with each centerline arc segment (R2 Resource Consultants, Inc., unpub. data, 1998) by the arc length (fig. 3), summing the result for all arcs through the bend, then dividing by the total bend length.

Average 1989–97 erosion rates for the 276 bends plotted as a function of distance downstream (fig. 5) show that the lowest rates occur primarily in the first 8 river miles. Erosion rates become more variable and much higher on average farther downstream. Exceptions to this general pattern occur locally, such as at the bend at RM 1.67, which had the highest measured erosion rate (4.25 feet per year). This bend is located in the middle of a recent change in the channel visible in figure 2. The much shorter path of the new channel results in a much steeper river slope, increasing the boundary shear stress at the base of the bank. Because of these anomalous conditions, this bend was excluded from the calculation of average erosion rate as a function of vegetation class.

The cumulative eroded planimetric area as a function of distance downstream (fig. 6) shows the effect of the consistently high erosion rates, particularly between RM 23.0 and RM 27.7. From RM 0.0 to 34.3, the cumulative river centerline length through the bends is only 12.5 miles, or 36 percent of the total length. The eroded area through these bends makes up 52 percent of the total eroded area up to RM 34.3.

Local river slope and bank sedimentology and stratigraphy are important factors contributing to erosion rate, and neither of these parameters is known for the individual bends. It is assumed, however, that effects of differences in local slope and bank sedimentology will tend to average out in the large number of bends examined. Between RM 34.3 and RM 43.0, the river is confined to a narrow region between railroad and highway berms, resulting in shorter meander wavelengths and steeper average centerline slopes than for the river upstream. Therefore, bends in this reach were not included in the analysis. In addition, several streambank stabilization projects were conducted at four locations in the study reach between 1989 and 1997. Nine bends were affected by these projects. Because of bank and channel alterations made at these locations, these nine bends were also excluded from the analysis.

Classification of Density and Type of Vegetation

Vegetation density and type along the cutbanks on the outside of the bends were identified for 211 of the 276 bends for which the 1988 aerial photographic coverage was sufficient. The 1988 photographs were used in order to assess cutbank vegetation at the beginning of the study period, which was the condition generally
acted upon during the study period. Shrubs common along the banks of the Clark Fork include water birch (*Betula occidentalis*) and a variety of shrub willows (*Salix* spp.).

A semiquantitative classification scheme was applied to evaluate differences in erosion rates as a function of the vegetation density and type immediately adjacent to the eroding cut-banks of the Clark Fork in the meander bends. The seven classes were based on types of vegetation present and, where there were shrubs, the relative distance between adjacent shrub canopies, as shown in figure 7. In vegetation classes 5 and 6, the shrubs were close enough that their canopies were in contact. Shrub canopies

Vegetation class 0—bare slickens

Vegetation class 1—all grass

Vegetation class 2—grass and a few shrubs

Vegetation class 3—grass and moderately spaced shrubs lining most of the outside of the bend

Figure 7. Examples of the seven classes of vegetation density and type. The arrows indicate flow direction. The area of the bank between the two red lines in each image is the portion of the bank examined to classify vegetation. The bend shown with bare slickens along the outside bank (class 0) is located at River Mile 23.0, where the average erosion rate from 1989 to 1997 was 1.67 feet per year. The edge of the cut-bank in vegetation class 6 was completely hidden by shrub canopy, and the amount of bank retreat (if any) could not be determined from the aerial photographs.
Vegetation class 5—moderate to dense woody vegetation

Figure 7. Examples of the seven classes of vegetation density and type. The arrows indicate flow direction. The area of the bank between the two red lines in each image is the portion of the bank examined to classify vegetation. The bend shown with bare slickens along the outside bank (class 0) is located at River Mile 23.0, where the average erosion rate from 1989 to 1997 was 1.67 feet per year. The edge of the cutbank in vegetation class 6 was completely hidden by shrub canopy, and the amount of bank retreat (if any) could not be determined from the aerial photographs—Continued.

RESULTS OF ANALYSIS

After determining vegetation density and type for a large number of bends (211) and assigning each to a vegetation class, the average erosion rate for each class was computed. An early hypothesis was that radius of curvature exerts a strong enough control on erosion rate to have a measurable effect. However, no direct correlation between radius of curvature and erosion rate was found, even for bends with similar vegetation density and type along the outside bank (fig. 8), probably because of the strong influence that local bank sedimentology has on erosion of moderately to sparsely vegetated cutbanks. Field observations indicated that the most rapidly eroding bends typically had a thick (about 1 ft) layer of well-sorted pebbles at or near the base of the cutbank.

A high degree of variability in erosion rate was found in each vegetation class, and the standard deviation of erosion rate was about the same as the mean. For bends in vegetation classes 2, 3, and 4, the location of woody vegetation in relation to the points of greatest radius of bend curvature and the sites of pebble layers in the banks probably produce variability in erosion rate within a given vegetation class. Regardless of the within-class variations, the average erosion rate decreases monotonically with increasing density of woody vegetation, as represented by vegetation class (fig. 9).

covered the entire cutbank in class 6, but there were short (less than 25 percent of the cutbank length) gaps in canopy cover in class 5.

Using this classification scheme, there was some subjectivity in assigning bends to particular vegetation classes. However, the high resolution of the aerial photographs and the consistent application of the classification criteria provided a systematic means of evaluating the bank-protecting effects of an increasing density of riparian shrubs.
Figure 8. Average bank erosion rate as a function of bend radius of curvature for the 35 bends in vegetation class 4.

The class-average erosion rates calculated from the 1989 to 1997 erosion rate data decrease from 1.27 feet per year for the bends with bare slickens (class 0) to 0.27 foot per year for the bends with dense woody vegetation (class 6). The lowest cutbank erosion rates were expected in the densely vegetated bends, and the erosion rate data provided by R2 Resource Consultants, Inc., (unpub. data, 1998) do support that conclusion. However, at bends with moderate to dense woody vegetation (classes 5 and 6), visibility of the cutbanks in the aerial photographs was limited to the point that the extent of bank erosion could not be determined. For the class 6 bends, essentially all of the cutbanks were obscured by shrub canopies. The class 5 bends typically had 90 percent of the cutbank hidden by shrub canopies. In order to make accurate measurements of erosion on cutbanks, most of the bank must be visible in both aerial photographs (fig. 10). Therefore, the amount of bank retreat at the 35 bends in these two vegetation classes could not be measured from the aerial photographs, and a lower limit on cutbank erosion rate could not be determined. The hypothesis that the lowest possible erosion rate is zero cannot be disproved with the available data.

The vegetation classes were defined to represent an approximately linear increase in density of woody vegetation. Therefore, cutbank erosion rate as a function of density and type of vegetation in bends where most of the cutbank was visible (classes 0 through 4) can be transformed to an approximately linear decrease in erosion rate with increasing woody vegetation (fig. 11). The correlation coefficient for a linear regression on the class 0 through 4 data is -0.977. Extrapolating this linear decrease to vegetation classes 5 and 6 results in predicted average erosion rates of 0.23 ft/yr for vegetation class 5 and 0.04 ft/yr for vegetation class 6. Both of these values are consistent with the original data when considered in light of an error analysis, which is discussed in the next section.

Figure 9. Average bank erosion rate as a function of vegetation class. The limit of pixel resolution (0.11 foot per year) is shown. The numbers above the points indicate the number of bends identified in each class. Error bars show the standard deviations for classes 0 - 4. Because of the limited bank visibility for the class 5 and 6 bends, erosion rates determined for these bends from the erosion rate data (R2 Resource Consultants, Inc., unpub. data, 1998) are not meaningful, even though they do follow the trend.

Figure 10. A 0.6-mile (0.9-kilometer) reach in July 1997 where dense woody vegetation and shrub canopies obscured both banks through much of the reach.
Over one-half (107) of the 211 bends were identified as being in vegetation classes 0 to 2, having little to no woody vegetation. The average erosion rate for these bends between 1989 and 1997 was 0.87 ft/yr (fig. 9), resulting in an average total bank retreat of 7.83 feet in the 9-year period. Bends with moderately spaced woody vegetation along the cutbank (classes 3 and 4) make up 33 percent of the 211 bends. At these bends, the average erosion rate was reduced by about 40 percent, to 0.53 ft/yr and resulted in an average total bank retreat of 4.77 feet in the 9-year period.

CONCLUSIONS

Two sets of large-scale aerial photographs scanned at a high resolution (to produce a pixel size on the order of 1 ft by 1 ft) and rectified to geographic coordinates can be used to determine erosion rates over long reaches by determining changes in bank position. The ability to quantify bank retreat, however, is limited where the banks are hidden by vegetation canopies. Most of the bank must be visible in both sets of aerial photographs in order to measure small amounts of bank retreat. In addition, the accuracy of the calculated erosion rate at a location is dependent on both the image pixel size and the accuracy of the geographic registrations of the two images. These factors limit the ability to measure accurately the amount of bank retreat where erosion rates are low. In the data set used for this investigation (R2 Resource Consultants, Inc., unpub. data, 1998), the likely degree of accuracy in measured erosion rate is no better than 3.3 feet per decade. Therefore, for the Clark Fork through Deer Lodge Valley, the hypothesis that erosion rates for the most densely vegetated bends are zero cannot be disproved with the available data.

The results of this analysis of vegetation controls on bank erosion rates clearly indicate a monotonically downward trend in erosion rate with increasing density of woody vegetation along cutbanks in meander bends. The trend suggests that dense, woody vegetation along the cutbank could reduce the average erosion rate in bends with no woody vegetation by a factor of 6 or more (from 1.27 ft/yr to less than 0.23 ft/yr). Even moderately spaced shrubs along the cutbank, where their canopies are not in contact (vegetation class 3), reduced the average erosion rate by about one-half, from 1.27 ft/yr at the bends with bare slickens to 0.58 ft/yr.
REFERENCES


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