# The Impact of Vegetation on the Bank Erosion (Case Study: The Haraz River)

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**Abstract**

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Vegetation establishment is a suitable biological method of erosion control. Bank erosion is one form of water erosion and its adverse effects include an increase in turbidity, degradation of riverbank lands, difficulties caused by sediments depositing in the downstream. The rate of riverbank erosion can be decreased by application of biological methods in sensitive reaches identified. In this study, a 3250 m section of the Haraz River was studied to evaluate the effects of vegetation establishment on shear stress, water velocity and finally on the bank erosion. In this research, Geographical Information System (HEC-GeoRAS extension), HEC-RAS software, and topographic maps of riverbed at the scale of 1:500 were used to simulate hydraulic behaviour of the Haraz River. In order to evaluate the effect of vegetation cover on the bank erosion, roughness coefficient of Manning was determined with the Cowan method for two seasons (winter and summer) separately, due to changes in vegetation in the considered sections during different seasons of the year. The results showed that vegetation establishment on riverbanks caused changes in water velocity, water depth, power of shear stress and this all should finally be reflected in the rate of bank erosion.

**Keywords**: GIS; hydraulic behaviour; HEC-RAS; roughness coefficient

Bank erosion causes degradation of fertile lands around rivers and transport of sediments downstream by water flow (Lawler *et al.* 1997). The transfer of sediments from slopes by overland flow towards river system highly depends on the presence/absence of vegetation in riverbeds and should therefore be accounted for in assessments of landscape degradation and/or recovery (Molina *et al.* 2009). Recently, there has been an increasing interest in the effect of vegetation establishment on the resistance of the soil to erosion. Removal of vegetation reduces the riverbank surface resistance to erosion (Zierholz 1997; Prosser & Williams 1998; Wilson 1999; Rosso *et al.* 2007). Hence, vegetation reduction causes decrease of soil resistance to erosion and increases runoff generation. Material yielded from bank erosion enters the water flow of rivers directly and, as a result, causes water turbidity and reduction of its quality (Sharpley & Kleinman 2003; Broadmeadow & Nisbet 2004; Hively *et al.* 2006). Bank erosion happens when shear stress of flowing water is higher than soil resistance. Application of biological methods to control erosion is due to compatibility with the environment and lowering of the expenses (making an interaction between vegetation and hydrologic processes) a priority for programs of erosion control (Wilcox *et al.* 2003; Ludwig *et al.* 2005; Saco *et al.* 2007). In addition, the banks of rivers are a suitable place to establish native plants and these plants increase soil resistance against scouring by water (Schmugge *et al.* 1998; Lee *et al.* 2002a, b). River morphology is a function of water flow, quantity and kind of transported sediments, vegetation and arrangement of constructive materials of beds and banks of the river. The rate of shear stress is calculated by the following equation:

Shear stress = $\gamma \times R \times S$

where:
$\gamma$ – water density
$R$ – hydraulic radius
$S$ – bed slope

The objective of the study was the calculation of maximum shear stress, which is presented in Figures 1–11. According to the Manning's relationship $v = 1/n \times R^{2/3} \times I^{1/2}$, water velocity or $v$ is a function of water surface and has an inverse relation to roughness coefficient $n$ (Acreman *et al.* 2003). Therefore, the roughness parameter turns out to be an effective parameter commonly obtained through a calibration procedure (Lane & Ferguson 2005; Hunter *et al.* 2007; Casas *et al.* 2010). The effect of shear stress of flow on banks and riverbeds depends on the rate of soil sensitivity and alluvial materials. In addition, the activity of scouring by water and water erosion that in the absence of methods of measurement of shear resistance of soil, plasticity index, porosity ratio and characteristics of curve of granulometry can be suitable criteria for measurement of vulnerability of different soils. Andam (2003) compared the status of power of shear stress and water velocity in rivers with respect to different states of vegetation cover changes. His results showed that vegetation could reduce water shear stress (Andam 2003). Johnson *et al.* (1999) used the HEC-RAS model to predict hydraulic behaviour in a 10 km section of the river Woming-Griool. Islam and Sado (2000) used Geographical Information System (GIS) to predict the hydraulic behaviour of floods in several rivers of Bangladesh. Their results showed that GIS increases accuracy of the results in simulation. Lyons *et al.* (2000) investigated the influence of intensive rotational grazing on bank erosion. They found out that vegetation removal increased the rate of bank erosion. Although bank erosion has been dealt with in many studies, just few of them have focused on investigation of the effect of vegetation establishment. Further research into other factors influencing soil resistance to bank erosion is needed. The method proved to be efficient for resolving a number of various problems. In this paper, we demonstrated its application to bank erosion. The present study evaluates the effect of vegetation establishment on bank erosion, water velocity, and shear stress on the banks of the Haraz River in northern Iran.

## MATERIAL AND METHODS

The Haraz River originates from the Alborz highlands located in the north of Iran and passing through Amol City, it enters into the Caspian Sea (Figure 1). This study focused on a 3250 m long reach of the Haraz River and its flood plain at its entrance into Amol City in Mazandaran Province (upstream of Amol). The section under study is delimited by 52°22'E longitude and 36°23'N to 36°25'N latitude. Annual average discharge is 36.2 m$^3$/s. Annual precipitation averages 888 mm. Most of the precipitation falls in the cloudy seasons. Annual average evaporation is about 670 mm. Floodplains of this section include paddy lands that are left as fallow in the cold seasons of the year. Mazandaran Province is the second province in terms of rice production and is one of the main agricultural regions in Iran. The studied area is located in the centre of Mazandaran Province with

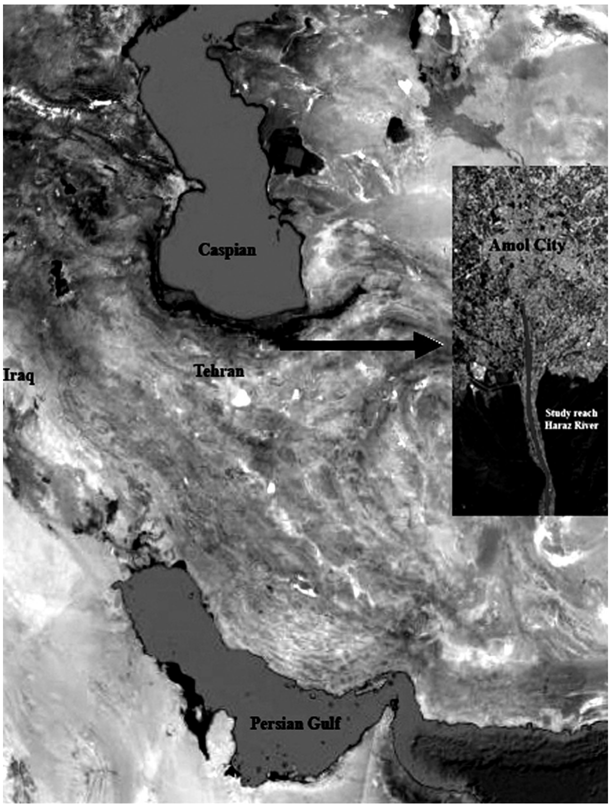


Figure 1. Location of the studied area

productive agricultural terrains. On the southern Caspian coast there are plains of Quaternary sediments (Gholami *et al.* 2010). To evaluate effects of vegetation establishment on shear stress, water velocity and bank erosion in this research, roughness (a key parameter in hydraulic modeling) Manning's coefficient with the method of Cowan (Cowman 1956) was determined in two different seasons – winter (lack of vegetation in the river bed and banks) and summer (vegetation establishment). In the season out of growth, paddy lands are left as fallow and the riverbed and banks are also free of vegetation, but in the growth season annual plants and grasses are sparse in the riverbed and banks and paddy lands on the margins of the river are planted. Different plant species occur on the banks and flood plain such as grasses, paddy, *Sorghum*, and *Paspalum.* Best part of the Haraz River bed in the studied reach lacks vegetation but for grasses on the banks. In this research, in order to simulate hydraulic conditions of the river, Geographic Information System (extension HEC-GeoRAS) and HEC-RAS model were used since their application is very powerful in the simulation of the river conditions and the flood plain (Hill 2001). At first, 50-year statistics of peak discharges of the Karesang station were analyzed from the viewpoint of homogeneity, relationship, and sufficiency and then confirmed by a succession test at confidence level of 0.05. Suitable statistical distribution was determined using the software SMADA (Stormwater Management and Design Aid), and maximum discharges with different return periods were determined using the suitable statistical distribution (Log Pearson type III). The Haraz River at the section under study was simulated (centre streamline, banks, flow paths, and cut lines) using HEC-GeoHMS extension and digital map at the scale of 1:500. At the length of the reach, 84 sections were considered so as to represent the river morphology. At the next stage, the section under study was divided into 7 reaches with equal conditions to determine roughness coefficient and in each of these 7 reaches the roughness coefficient was determined separately for river beds and left and right bank, separately for winter and summer, using the Cowan's method (Cowan 1956). Roughness coefficients were determined by field studies and walking along the reach under study for each of 84 sections considered. According to Cowan's method, the Manning's roughness coefficient was estimated as follows:

$$n = (n_0 + n_1 + n_2 + n_3 + n_4) \times m_5$$

where:

$n$ – Manning's roughness coefficient

$n_0$ – bed roughness coefficient depending on channel materials is selected for homogeneity, smooth, and direct channels

$n_1$, $n_2$, $n_3$, $n_4$, $m_5$ – roughness coefficients of the effects of cross-section irregularity, variation of cross-section, existence of barriers in channel path, vegetation and meandering degree in the path, respectively

Manning's roughness coefficient changes depending on vegetation changes. Due to growing vegetation and also cultivation of paddy lands in the flood plain in summer, roughness coefficients of left and right banks were changed in comparison with those in winter when floodplain and river banks are without vegetation, but in the roughness coefficient of main channel of the river no change was manifested (lack of vegetation). Then simulated geometry information from GIS was used by the HEC-RAS model for presenting a model and simulation of hydraulic status of the Haraz River. In this study, the flow regimen is simulated by using the mixed flow regimen. The Haraz River bed is covered with sand, gravel, and stone. Morphological conditions of the Haraz River bed and banks are unequal. Mean values of the channel width, water depth, and bed slope are about 50 m, 1 m, and 0.03 m/m, respectively. The width of the flood plain is 100–500 m. In this research, two simulated models were applied, differing just in roughness coefficients (due to growing vegetation on riverbanks) for comparison of statuses of shear stress and water velocity on the banks and riverbed.

## RESULTS

Hydrometric stations data of Karesang were applied for estimating maximum instantaneous discharges and analyzed using Smada software. According to the results, Log Pearson Type III distribution is best for estimating maximum instantaneous discharges in different return periods (results shown in Table1). Also, using GIS (HEC-GeoRAS extension) and digital maps simulated the physical model of bed and adjacent areas of the river as given in Figure 2. Applying GIS and the software HEC-RAS model in two states with changes of vegetation in bed banks of river, the results obtained from simulated model of hydraulic state of river show the considerable effect of vegeta-

Table1. Maximum instantaneous discharges ($Q$ max) in Karesang stations (based on distribution of Log Pearson III)

| Return period | $Q$ max ($m^3/s$) |
|---|---|
| 2 | 107.55 |
| 5 | 177.06 |
| 10 | 232.6 |
| 25 | 314.2 |
| 50 | 383.5 |
| 100 | 460.5 |
| 200 | 546.03 |

tion establishment in erosion control of riverbanks. Figure 3a shows simulated water velocity during flood occurrences with different return periods on the banks (with vegetation establishment) while Figure 3b shows the same but without vegetation. In Figure 3, changes of water velocity are observed during flood occurrences with different return periods on the river banks. As it is observed in Figure 3, by growing and vegetation establishment due to an increase in roughness coefficient, water velocity was reduced considerably on the river banks. Figure 4 shows changes of water velocity during flood occurrence in the main channel without and with vegetation establishment, respectively. As it can be seen from the data, by decreasing water velocity on the bank and floodplain of river and by growing vegetation and increasing Manning's roughness coefficient, considerable changes are not observed in the main river channel (Table 2). Figures 3–5 show changes in shear stress on the banks and main channel of the river by growing vegetation. Figure 5a shows changes of shear stress during flood occurrence with different return periods in left and right banks with vegetation establishment. Figure 5b shows the same but without vegetation establishment. Figure 6 shows changes of shear stress during flood occurrence in the main channel. These results are almost as accurate as the previously obtained data.

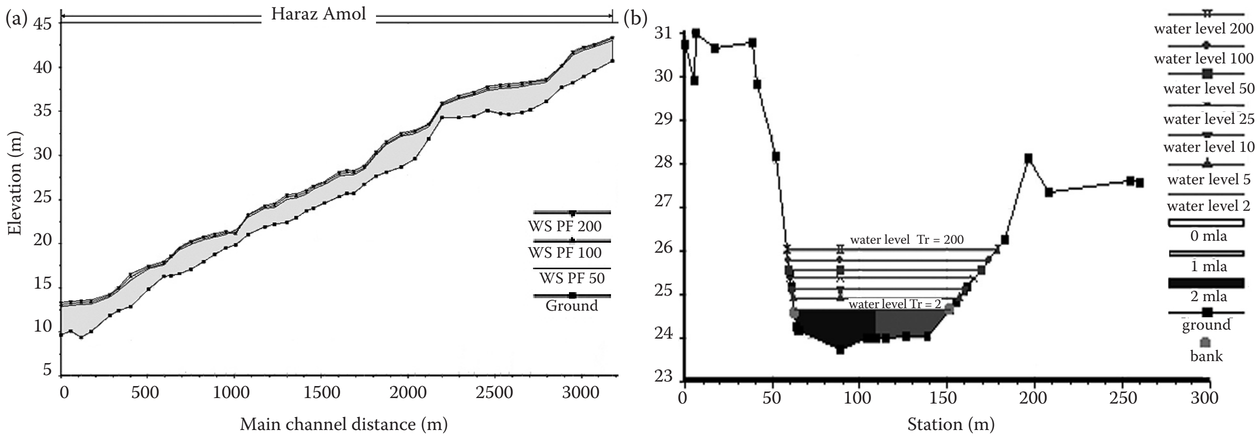


Figure 2. Longitudinal (a) and cross (b) section of the Haraz River and water level in different return periods

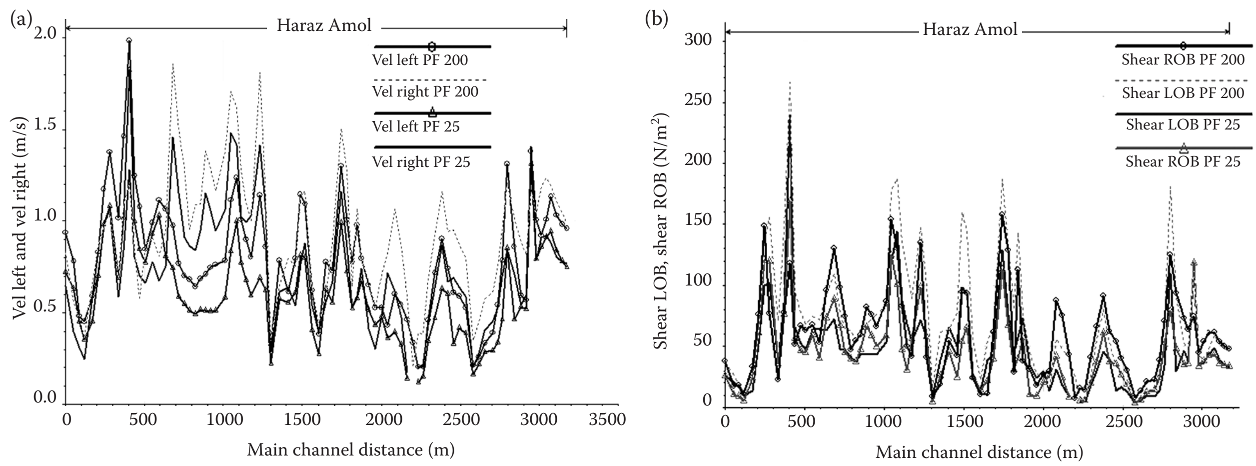


Figure 3. Simulated water velocity during flood occurrences with different return periods on the banks with vegetation establishment (a) and without vegetation (b)

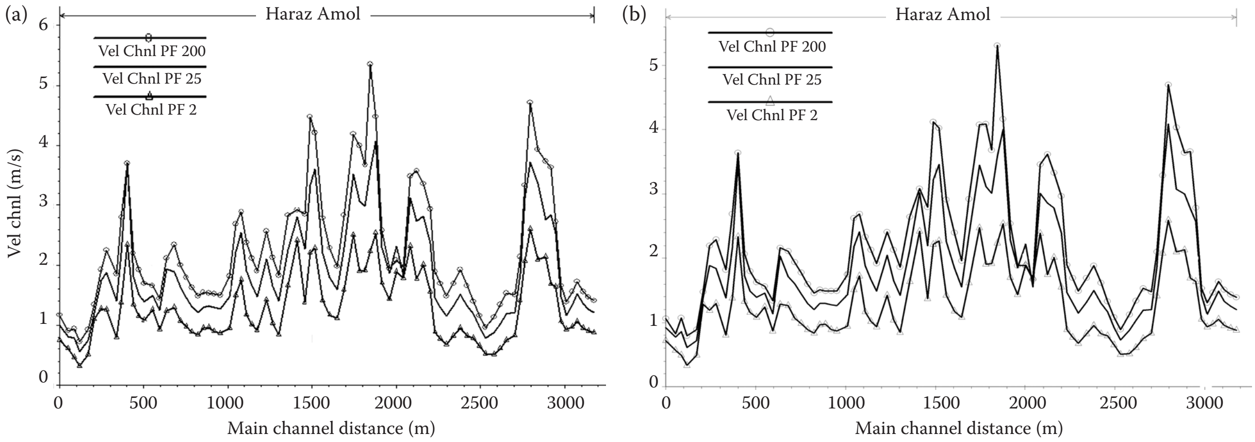


Figure 4. Simulated changes of water velocity during flood occurrence in the main channel with vegetation establishment (a) and without vegetation establishment (b)

## CONCLUSION

Simulating hydraulic behaviour of the Haraz River was carried out using GIS and HEC-RAS hydraulic model. Based on previous investigations we may state that GIS brings acceptable results in simulating river conditions and adjacent areas (Hirsch *et al.* 1990; Hill 2001; Burns *et al.* 2005). Also,

Table 2. Manning's roughness coefficients for considered cross-sections (in two conditions of current situation and riverbed improvement)

| Reach No. | Right bank | Main channel | | Left bank | Section numbers of each reach |
|---|---|---|---|---|---|
| | | current conditions | improvement and removal of point bars | | |
| 1 | 0.049 | 0.095 | 0.049 | 0.049 | 1–8 |
| 2 | 0.053 | 0.095 | 0.050 | 0.078 | 9–18 |
| 3 | 0.053 | 0.045 | 0.045 | 0.078 | 19–25 |
| 4 | 0.053 | 0.050 | 0.050 | 0.060 | 26–42 |
| 5 | 0.053 | 0.095 | 0.045 | 0.060 | 43–50 |
| 6 | 0.049 | 0.051 | 0.051 | 0.066 | 51–67 |
| 7 | 0.049 | 0.095 | 0.055 | 0.053 | 68–84 |

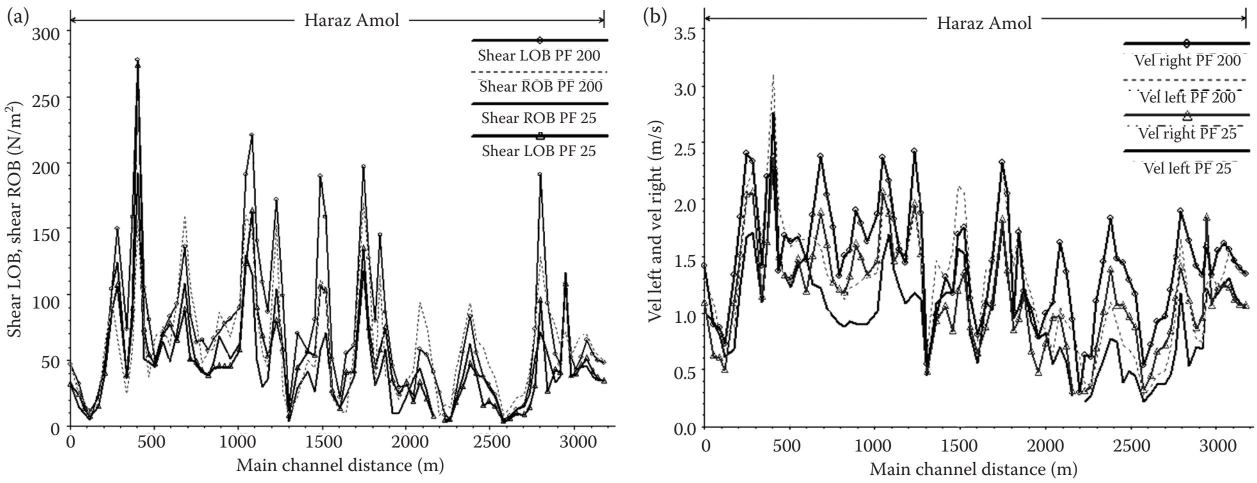


Figure 5. Simulated changes of shear stress during flood occurrence with different return periods in left and right banks with vegetation establishment (a) and without vegetation establishment (b)

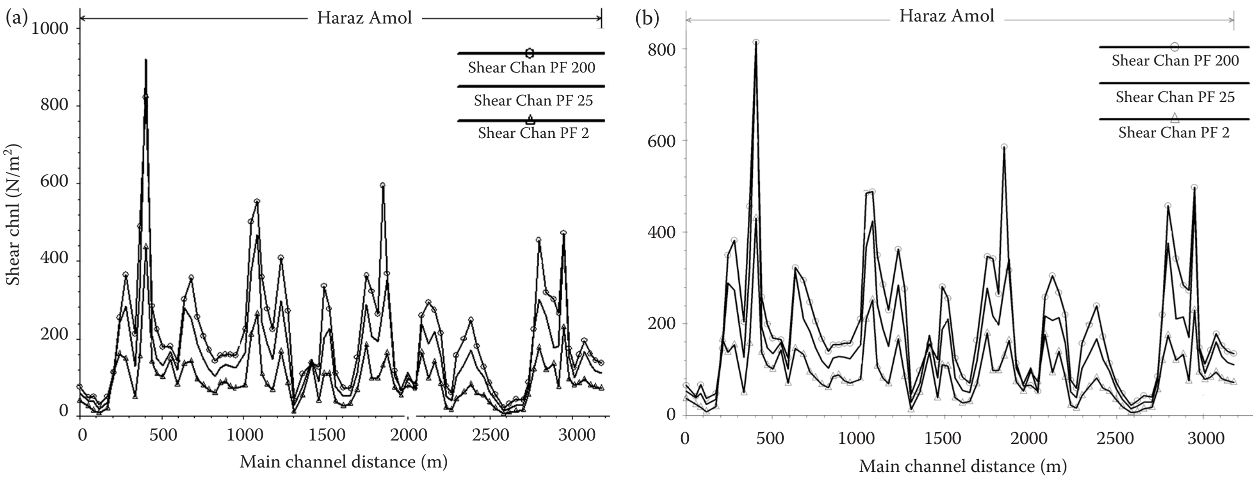


Figure 6. Simulated changes of shear stress during flood occurrence in different return periods in the main channel with vegetation establishment in banks (a) and without vegetation establishment on the banks (b)

this method leads to higher efficiency and lower expenses (Pappas *et al.* 2008). As it is observed in Figures 5–6, by growing vegetation and increasing roughness coefficient, the rate of shear stress also increased on the banks and main channel of the river, to which the increase in the case of the main channel of the river is more sensible. According to the results obtained, vegetation establishment causes an increase in the Manning's roughness coefficient and given that water velocity has an inverse relation to roughness coefficient, there will be a considerable reduction of water velocity on the banks. Also, increase in roughness coefficient and as a result, reduction in water velocity is along with increase of water height that leads to an increase of shear stress, but the maximum observed shear stress on the banks in different return points is 340 $kg/m^2$. In this case, plants can tolerate shear stress higher than 10 $kg/m^2$. Also, grass with good quality on a bank with slope 2:3 can tolerate shear stress of 5–8 $kg/m^2$. As the density of the established vegetation on the river banks is not optimum (present conditions), with respect to the considerable curvature of the section, water velocity, and hydraulic slope it is necessary to establish a dense vegetation from native plants adapted to local conditions and/or even apply other non-biological methods in order to decrease the erosion of river banks. Native grasses, such as *Paspalum*, and *Salix* are suitable for the management of bank erosion. Biological methods generally are the best methods of controlling bank erosion and accomplishing the goals of river engineering. However, other practices, such as riprap cover and floodwall, are necessary for bank erosion controlling in some sections. The data indicate that there is a connection between the effects of vegetation establishment in riverbank and the rate of erosion. The quantitative data support the initial hypothesis.

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