# A multifaceted approach to prioritize and design bank stabilization measures along the Big Sioux River, South Dakota, USA

## Une approche pluri-méthodologique pour la priorisation et la conception de travaux de stabilisation de berge le long de la rivière Big Sioux, Dakota du Sud, Etats-Unis

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## RÉSUMÉ

Une approche pluri-méthodologique a été utilisée pour gérer l'apport de sédiments fins provenant de l'érosion des berges de la rivière Big Sioux entre Dell Rapids et Sioux Falls, Dakota du Sud, Etats-Unis. Des simulations numériques à l'aide des deux modèles morphodynamiques RVR MEANDER et CONCEPTS ont été menées afin d'identifier les zones potentielles d'érosion de berge. Celles-ci ont été classées, en fonction de l'étendue de l'érosion, pour planifier des travaux de stabilisation futurs. La conception, la construction et l'installation d'embâcles à base de bois dans la rivière ont été réalisées grâce à un travail de modélisation physique en laboratoire. En outre, une large collecte de données in situ a eu lieu, portant sur la caractérisation de la forme de la rivière et la résistance à l'érosion du matériau alluvial. D'après les résultats de modélisation numérique, 1,8 km (5,5%) du site d'étude aurait un potentiel d'érosion sévère (> 15 m/an pour des débits supérieurs au débit de pleins bords). La modélisation physique a montré que la longueur et la largeur de la déformation du lit en aval des embâcles pourraient être de 22 et 15 fois la hauteur d'eau pour le débit à pleins bords, respectivement. Enfin, la mise en place d'embâcles permettrait de protéger une longueur de berge de l'ordre de 30 fois la hauteur d'eau pour le débit à pleins bords.

## ABSTRACT

A multifaceted approach was used to manage fine-grained sediment loadings from river bank erosion along the Big Sioux River between Dell Rapids and Sioux Falls, South Dakota, USA. Simulations with the RVR Meander and CONCEPTS river-morphodynamics computer models were conducted to identify stream-bank erosion locations, and prioritise these locations for future stabilisation. Guidelines for the design, construction, and installation of environment-friendly engineered log jams (ELJs) specific for the Big Sioux River were developed using physical scale modelling. The modelling efforts were supported by an extensive field data collection effort to characterise channel form and the erosion resistance properties of the boundary materials. Computer modelling identified 1.8 km (5.5%) of the study reach as having severe erosion potential (> 15 m/yr for flows greater than bank full). Physical modelling indicated that the length and width of the bed deformation downstream of the ELJ can be as large as 22 and 15 times the bank-full flow depth, respectively. The potential length of bank protection provided by an ELJ can be as large as 30 times the bank-full flow depth.

## KEYWORDS

Channel erosion, computer simulation, engineered log jam, physical scale model, bank protection

# 1 INTRODUCTION

The State of South Dakota identified large portions of the Big Sioux River and its tributaries in South Dakota, USA that are impaired because of increased levels of Total Suspended Solids. Bankhead and Simon (2009) determined that approximately 25% of stream loading was coming from the river's banks, which were retreating up to 10 m/yr in active meander bends. Current bank protection measures are rock spurs and conventional rip rap, but the top of the rock in either of these cases is only allowed to reach the 1.5-year flow. As this water surface elevation is 1 to 2 m below top-of-bank, the upper portion of the bank face is exposed to erosion. Further, these measures do not provide sufficient resources for instream habitat.

The primary objective of the presented research was to determine optimal application of environment-friendly engineered log jams (ELJs) to reduce bank erosion and minimize associated bed erosion along the Big Sioux River. This was carried out using multiple approaches: (1) field data collection to characterise channel form and the resistance-to-erosion properties of the boundary materials; (2) computer modelling using the RVR Meander (Motta et al., 2012) and CONCEPTS (Langendoen et al., 2009) models to identify and prioritise unprotected locations with the highest, probable bank erosion rates for future stabilisation; (3) physical scale models of ELJs to provide guidelines for their design, construction, and installation on the Big Sioux River.

The geographic scope of the project is a 34-km long reach on the Big Sioux River between Dell Rapids and Sioux Falls, South Dakota (Figure 1). The reach is fairly sinuous with an average sinuosity of 1.6. The average channel slope is 0.4 m/km. The bed material is sand dominated with the median bed material grain size along the study reach varying between 0.03 and 7.0 mm with a mean value of 1.4 mm. Bank material is cohesive except for the sediments/soils at depth, which consist of sands and gravels. The upper cohesive layer primarily comprises erodible loam and sandy loam soils, but percent clay is found as high as 55%. The critical shear stress required to erode these materials was fairly constant (about 10 Pa) for the lower 25 km of the study reach, and linearly reduced to about 2 Pa at the upstream end of the study reach. Snow-melt driven flows in late Spring can be quite large and remain close to bank-full conditions for extended periods of time.

# 2 RESULTS

## 2.1 Bank protection prioritisation

The one-dimensional channel evolution computer model CONCEPTS was used to identify locations vulnerable for erosion along the study reach under a range of different flow conditions. Evaluated flow discharges ranged from discharge with a 1.5- to 2-yr (bank-full) return period to discharges with a return period of 50 years. The computer model RVR Meander was used to determine the enhanced shear stresses exerted by the helical flow on the outer bank of meander bends, which were then used to modify the bank soil erodibility employed by the CONCEPTS model.

Changes in bed elevation did not vary much between the different flow scenarios or because of the presence of bank protection measures. Channel top width increased significantly at a few locations. Bank erosion potential was categorised as minor (< 5 m), moderate (> 5 m), and severe (> 15 m). 6.5 km (19.3%) of the study reach was classified as having minor erosion potential, 0.5 km (1.5%) of the study reach was classified as having moderate erosion potential, and 1.8 km (5.5%) of the study reach was classified as having severe erosion potential (Figure 1).

## 2.2 Engineered log jam design

Using the mean annual flow of the Big Sioux River as the design discharge, and employing channel dimensions and slopes along the corridor in question, two Froude-scaled physical models were constructed (1:20 vertical scale): (1) a fixed-bed model (1:21 horizontal scale), and (2) a movable-bed model (1:27 horizontal scale). This scaling procedure also extended to the availability of timber to be used. Two types of bank-attached deflector jams (ELJ-1 and ELJ-2) were tested, see Figure 2.

Results, listed in Table 1, show that (1) ELJs have modest effects of spatially-averaged flow, but cause localised changes to flow, turbulence, and bed shear stress near the structures, (2) ELJ-1 had a more pronounced effect on flow and alluvial channel adjustment as compared to ELJ-2, and (3) the zone of influence downstream of an ELJ was relatively large, and the presence of multiple structures immediately upstream could alter these effects.

## LIST OF REFERENCES

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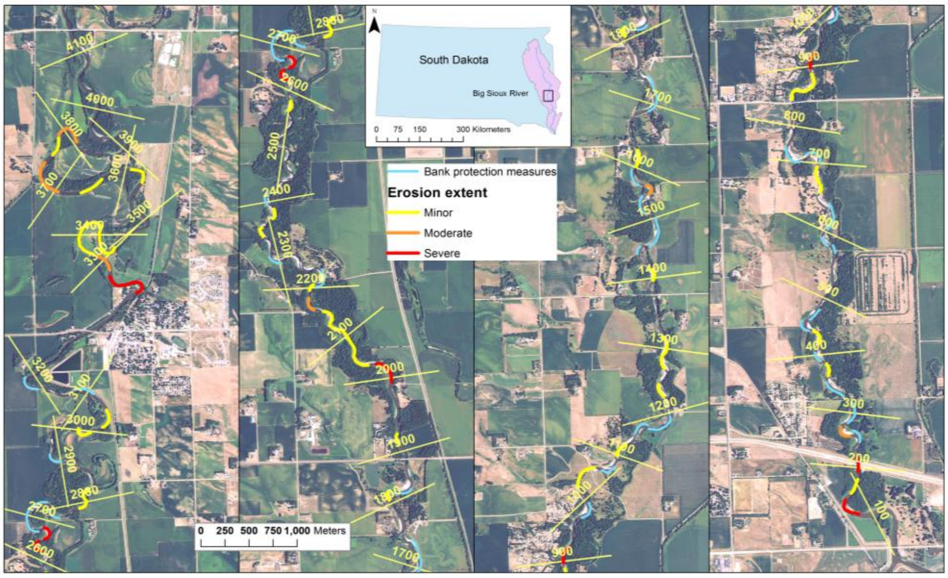


Figure 1. Map of erosion potential along the study reach of the Big Sioux River determined using the RVR Meander and CONCEPTS computer models.

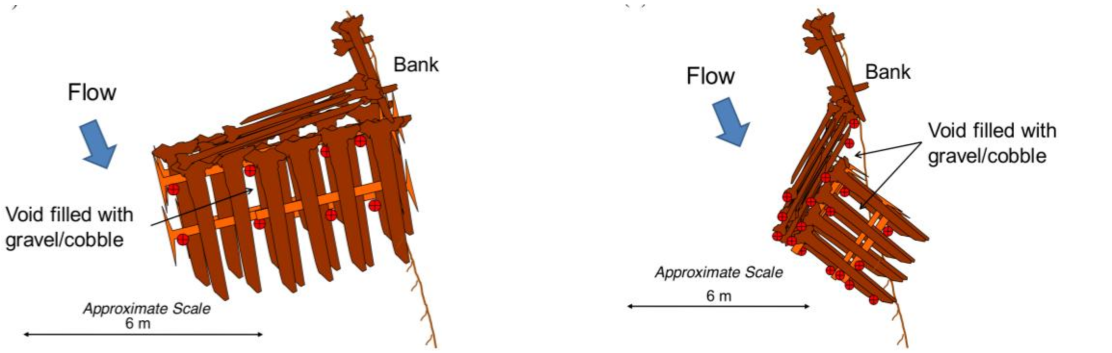


Figure 2. Proposed engineered log jams to be installed along the Big Sioux River: Left, a bank-attached deflector jam (ELJ-1); and Right, a bank-attached spur jam (ELJ-2).

Table 1. Findings of ELJ physical scale model study. Parameters are scaled to bankfull channel depth (H), bankfull channel width (W), and bankfull mean bed shear stress ($\tau$).

| Parameter | ELJ-1 | ELJ-2 |
|---|---|---|
| Maximum bed shear stress near outside edge of structure | 6 to 9 $\tau$ | 3 $\tau$ |
| Maximum near-bank bed shear stress downstream of structure | 0.5 $\tau$ | 0.5 $\tau$ |
| Length of bed deformation downstream of structure | 22 H or 17 W | 17 H or 1 W |
| Width of bed deformation downstream of structure | 15 H or 1 W | 7 H or 0.6 W |
| Potential length of bank protection | > 30 H or > 2 W | 15 to 30 H or 1 to 2 W |