Simulating Reach-scale Sediment Reduction from Stream Stabilization using CONCEPTS in the Fort Cobb Reservoir Watershed

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INTRODUCTION

Excess sediment from upland sources, channel and gully erosion, and the resuspension of bed material is a major polluter of surface waters across the US, with streambank erosion from unstable channels contributing as much as 50-80%. Several techniques can be used to stabilize streambanks and reduce erosion, including toe protection, bank armoring, vegetation, grade control, etc. While these techniques are effective erosion and sediment loss at the site scale, reach-scale sediment loss may not be reduced. Site scale stabilizations can potentially impact an entire stream reach by cutting off sediment supplies leading to increased scouring and erosion upstream or downstream of the site. Therefore, an understanding of the entire stream reach is important when evaluating stream stabilization strategies at a site.



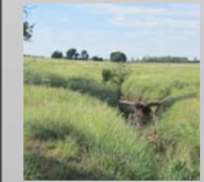
Unstable channels in the Fort Cobb Reservoir Watershed contribute a significant amount of sediment to the reservoir.

FORT COBB RESERVIOR WATERSHED DESCRIPTION

The Fort Cobb Reservoir, located in southwest Oklahoma, provides public water supply, recreation, and wildlife habitat. The land use in the watershed primarily agricultural, with roads and urban areas accounting for 5% of land use. Several conservation practices have been implemented in the watershed in recent years including adoption of no-tillage management, conversion of cropland to grassland, cattle exclusion from streams, and various structural and water management practices, but the reservoir still fails to meet water quality standards based on sediment. Streambank erosion from unstable streambanks in the watershed is one of the primary contributors of sediment loading to the reservoir.

Selected research sites in the Fort Cobb Watershed

Nine sites have been selected along two of the major tributaries to Fort Cobb Reservoir: Fivemile (F) and Willow (W) Creeks. At each site a water level logger was installed and cross-sectional surveys performed. Soils samples from the streambeds and each layer of the banks were collected and a particle size distribution analysis performed determine soil texture. At least one cross-section was selected at each site. A portion of Fivemile Creek (Site F2) is heavily impacted by several headcuts and is very unstable.



Site F1: Upstream of the headcuts

Headcut at site F2

Site F2: Downstream of the headcuts

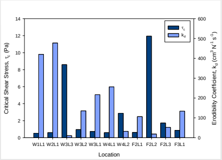
RESEARCH OBJECTIVES

- Evaluate the effectiveness of stream bank and bed stabilization techniques at reducing sediment loss from a site
- Determine the impact of site stabilization on sediment reduction and dynamics from an entire reach

QUANTIFYING STREAMBANK RESISTANCE TO EROSION

JET apparatus used to measure erodibility parameters

Composite streambanks in the Fort Cobb Watershed



Erodibility parameters, τ_c and k_d for each research site on each exposed layer

Jet erosion tests (JETs) were used to quantify the erodibility parameters for input into the excess shear stress equation:

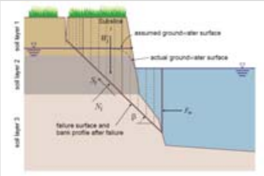
$$e_r = k_d(\tau - \tau_c)$$

where e_r = erosion rate of soil (cm/s); k_d = erodibility coefficient (cm^3/Ns); τ = applied shear stress (Pa); and τ_c = critical shear stress (Pa).

Streambanks in the watershed are comprised of a single sand or sandy loam while other exhibit layers of sand or sandy loam above or below layers with a higher clay content. Where the layering effect can be seen, JETs were conducted on each layer of the streambank. Multiple JETs were conducted at each site and each layer. The scour depth solution was used to analyze the JET data. Averages for the critical shear stress, τ_c, and erodibility coefficent, k_d, for each location are shown above. A higher critical shear stress and lower erodibility coefficient were seen on layers with higher clay content (F2L2, W3L3, and W4L2).

STREAMBANK EROSION\SEDIMENT TRANSPORT MODELING

The CONservational Channel Evolution and Pollutant Transport System (CONCEPTS) is a process-based model that simulates open-channel hydraulics, graded sediment transport, and streambank erosion processes on a reach-scale. CONCEPTS simulates streambank erosion as both fluvial erosion (using the excess stress equation) and geotechnical failures (using a factor of safety approach). Outputs include changes in thalweg profile and channel geometry, as well as sediment yield.



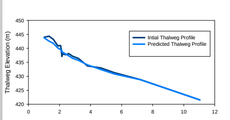
Geotechnical failure of a streambank. (Langendoen, 2000)

CONCEPTS simulations were developed for Fivemile and Willow Creeks. A 10 km reach of Fivemile and a 9 km reach of Willow were modeled. CONCEPTS inputs included soil strength parameters (c' and ϕ'), t_c, and k_d from JETs, channel geometry, soil layering and soil and bed sediment particle size distributions. A SWAT generated hydrograph for a 2003-2013 study period and long term erosion rates determined from NAIP images were used to calibrate CONCEPTS.

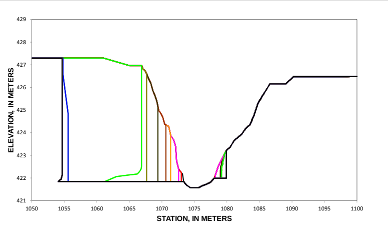
CONCEPTS Calibration results:

	FM1	FM2*	FM3	FM4	FM5	WC1	WC2	WC3	WC4
Aerial Imaginery Retreat (m)	0	0-5	12	0	11.3	0	0	7	8.6
CONCEPTS Predicted Retreat (m)	0	0-6	6	0	12	0	0	1	4

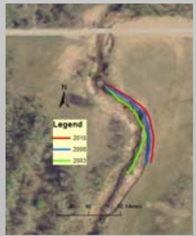
*Multiple cross-sections at this site



Changes in thalweg profile simulated by CONCEPTS



Changes in cross-sectional geometry at site FM as simulated by CONCEPTS



Example of aerial bank retreat rates

SEDIMENT REDUCTION FROM STABILIZATION

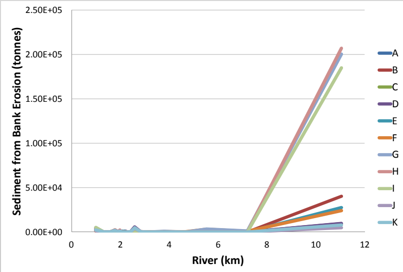
Various scenarios using bed grading and stabilization, and bank grading and protection were simulated for Fivemile Creek using the calibrated CONCEPTS model. Site F2 is severely impacted by a series of headcuts, which will eventually migrate upstream leading to incision of the stream. Stabilization of this critical site could reduce further erosion upstream, but may increase erosion downstream. Example scenarios for site F2 are shown in the table below. A percentage change in sediment generated from streambank erosion was determined by comparing the amount of sediment generated from streambank erosion outputted by CONCEPTS for each scenario to that of the calibrated simulation for both the site-scale (F2) and the reach-scale (Fivemile).

Sediment reduction from stabilization of Site F2 on the site- and reach-scale:

				% Change in sediment from Bank Erosion***	
Scenario ID	Bed stabilization	Bank Grading	Bank stabilization	Site: F2	Reach: Fivemile Creek
A*	None	none	none	--	--
B	Fixed Bed	none	none	**-47.4**	123.8
C	graded, fixed	none	none	6.4	**-16.7**
D	graded, fixed**	none	none	48.7	6.2
E	Graded	none	none	**108.9**	75.5
F	graded	2:1	riprap toe	**-97.3**	70.5
G	graded, fixed	2:1	riprap toe	**-98.6**	824.4
H	graded	4:1	riprap toe	**-90.9**	839.4
I	graded, fixed	4:1	riprap toe	**-86.3**	739.7
J	graded	2:1	vegetation	**-100.0**	707.6
K	graded, fixed	2:1	vegetation	**-100.0**	**-13.9**

*Base Case **First two headcuts ***Negative values indicate a percent reduction

All scenarios with bank protection (Scenarios F-K) showed high reduction in sediment from streambank erosion on the site-scale. Scenario J and K (bank protection with vegetation) gave the highest reduction in sediment from streambank erosion at the site scale. Scenarios F and G (2:1 side slopes with a riprap toe) also showed high reductions at the site scale. While these scenarios decreased bank erosion on the site scale, reach-scale bank erosion was increased for most of the scenarios.



Bank stabilization at F2 lead to a significant amount of increased erosion further downstream at site F5, leading to a higher amount of streambank erosion overall. Bank stabilization at the site-scale did not reduce reach scale sediment loss from Fivemile Creek. Additional stabilization is needed to see significant reduction in bank erosion.

Sediment from streambank erosion along Fivemile Creek.

CONCLUSIONS

Models such as CONCEPTS are valuable tools to evaluate the effects of streambank stabilization. When considering streambank stabilization at a site it is important to consider the effect downstream and understand the sediment dynamics of the entire reach. Streambank stabilization was effective at reducing bank erosion at a site scale, but lead to increased erosiojn along the entire reach. Additional scenarios will be simulated in CONCEPTS to determine the effect of stabilizing multiple sites along Fivemile and Willow Creeks. The length of stream that needs to be stabilized to significantly reduce sediment loss will also be determine.

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