# QUANTIFYING AND MODELING SEDIMENT LOADS FROM STREAMBANK EROSION ALONG THE HEADWATERS OF TOWN CREEK IN MISSISSIPPI

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**ABSTRACT**

The prediction of erosion is an important component in the development of land management strategies, particularly where sediment is identified as the cause of water quality impairment. Computational models that predict streambank erosion allow the user not only to quantify the streambank erosion rates and processes along a stream, but also to take subsequent decisions regarding sediment loads reduction, especially when those decisions need to pay special attention to stream channel processes and stabilization of eroding reaches. Streambank erosion processes were hypothesized to be an important mechanism driving sediment supply from the Town Creek Watershed in Mississippi. Field monitoring observations along the main channel of the Town Creek and several of its tributaries have indicated that the incised headwaters can contribute up to 70% of the suspended sediment loads exported by the watershed. Observations also evidenced that annual streambank retreat rates and loads in the Town Creek headwaters could be as high as 2.67 m and 28.5 Mg per meter of stream length, respectively. Thus, streambanks were a significant source of sediments loads to the Tombigbee River and the Aberdeen Pool on the Tennessee-Tombigbee Waterway. The ability of the Conservational Channel Evolution and Pollutant Transport System (CONCEPTS) computer model to predict streambank erosion along the Town Creek Watershed in MS was tested through its application to a 270-m long headwater incised reach. Model predictions over a 13 month period were compared with cross section surveys at 8 transects along the modeling reach. Results showed that CONCEPTS accurately predicted top width retreat and streambank failures in time and magnitude. Results from field monitoring and computational modeling offer important insights into the relative effects of land and streambank erosion on the stream water quality and sediment budget for Town Creek Watershed. Reduction of suspended sediment loads should focus on the attenuation of geomorphic processes and stabilization of reaches and agricultural lands near streambanks at the headwaters within the watershed.

## INTRODUCTION

Research along the Town Creek Watershed, MS (TCW) provided evidence that gravitational failure of the incised streambanks located along the northern and western headwaters channels of this watershed was the primary source of sediment loads to the system (Ramirez-Avila, 2011). Monitoring of streambank erosion processes and rates along these unstable channels has documented the occurrence of channel changes, loss of valuable agricultural land, and degradation of stream habitat for fish and other aquatic organisms (Ramirez-Avila, 2010; Ortega-Achury et al., 2009).

Prediction of erosion processes (upland, gully and streambank) is an important component of the development of land management strategies in areas where sediment is identified as the cause of impairment (Staley et al., 2006). Computational models to predict streambank erosion allow the user not only to quantify the streambank erosion rates and processes along a stream, but also to guide subsequent decisions regarding sediment loadings reductions, especially when those decisions need to pay special attention to stream channel processes and stabilization of eroding reaches.

The CONservational Channel Evolution and Pollutant Transport System (CONCEPTS) computer model is a product of continuing research at the US Department of Agriculture, Agricultural Research Service (ARS) National Sedimentation laboratory (NSL) to predict channel adjustment and evolution of incised stream systems. Various studies have been carried out to compare CONCEPTS model predictions of streambed and streambank degradation to field measurements in different areas under diverse scenarios, including studies in the Yalobusha River, MS, Goodwin Creek, MS, Kalamazoo River, MI, Shades Creek, AL, Stroubles Creek, VA and James Creek, MS (Simon et al., 2002; Thomas and Langendoen, 2002; Wells et al., 2007; Simon et al., 2004; Staley et al., 2006; Langendoen and Simon, 2008; Langendoen and Alonso, 2008). Only one of these studies has been carried out within the Ecoregion 65. The study in TCW was the first developed within that Ecoregion that involves comparison of assessed and predicted sediment streambank erosion processes and yields in a short term scenario. The field monitoring dataset includes information on stormflow events, changes in streambank morphology, and characterization of streambank soils and streambed.

Results are presented from the application of the CONCEPTS model to simulate and predict streambank erosion rates along an incised section of a 270 m long reach on the Yonaba Creek, MS, a representative stream segment located at the northern headwaters area of the TCW. The general objective of the study was to assess the performance and capability of the CONCEPTS model to simulate temporal and spatial streambanks changes along the modeled reach. The model evaluation includes: 1) calibration of the CONCEPTS model against existing data detailing streambank changes over the entire reach from February 2009 to July 2009; 2) validation of the model application over the entire reach from August 2009 to March 2010; and 3) development of a sensitivity analysis for CONCEPTS parameters directly related with the prediction of streambank top width retreat, planar failures and fluvial erosion. This paper includes final results from the first two components of evaluation, only.

### CONCEPTS Model

The CONservational Channel Evolution and Pollutant Transport System (CONCEPTS) is a computer model developed by the US Department of Agriculture (USDA), Agricultural Research Service (ARS) at the National Sedimentation Laboratory (NSL) in Oxford, MS. The model simulates unsteady one-dimensional flow, graded-sediment transport, streambank erosion and failure processes to predict the dynamic response of flow, and sediment transport to in-stream hydraulic structures (Langendoen, 2000). The CONCEPTS model is a tool designed for the assessment of stream corridor restoration projects. CONCEPTS is composed of three physical processes simulation components: 1) hydrodynamics for unsteady flow hydraulics, 2) mobile streambed dynamics for sediment transport and streambed adjustment, and 3) streambank erosion and channel widening from both hydraulic and geotechnical mechanisms. CONCEPTS is capable of assessing the long term effectiveness of restoration efforts when combined with watershed scale modeling programs as AGNPS or SWAT (Staley et al., 2006).

CONCEPTS simulates open channel hydraulics by numerically integrating the St. Venant equations representing open channel flow. The model uses the generalized Preissman method of discretization, a forward time finite difference numerical method to approximate the Saint Venant equations. CONCEPTS predicts sediment transport capacity and streambed adjustment through sediment scour and aggradation dynamics by solving the sediment mass conservation equation. A modification of the SEDTRA (Sediment Transport Capacity Predictor) model (Garbrecht et al., 1996) is included into the CONCEPTS model to calculate the total sediment transport by size fraction for a total of 17 pre-defined size classes with a specific sediment transport equation for each one. Channel width adjustments are modeled by CONCEPTS by incorporating the physical process for streambank retreat through hydraulic erosion and gravitational failure. Hydraulic erosion of bank material is calculated by CONCEPTS using an excess shear stress approach for cohesive soils. CONCEPTS also simulates the two most frequent types of streambank failure observed for incised streams with steep banks: 1) planar failure and 2) cantilever failure for heterogeneous cohesive streambank materials (Langendoen, 2000). Based on the shear strength of the streambank soils, a Factor of Safety (FS) is determined for the geometry and the soil properties of the streambank. For the cantilever failure, CONCEPTS determines a FS based on the weight of the overhanging streambank and the shear strength of the streambank soil. Detailed information about the model can be found in Langendoen (2000),

A Java-based Graphical User Iinterface facilitates the model input for CONCEPTS (Figure 1). Three main elements are observed when the interface is opened: the physical data, the channel models, and the run data elements. Detailed information about the model components and the use of the interface to enter information to develop a simulation is found in Ramirez-Avila (2011).

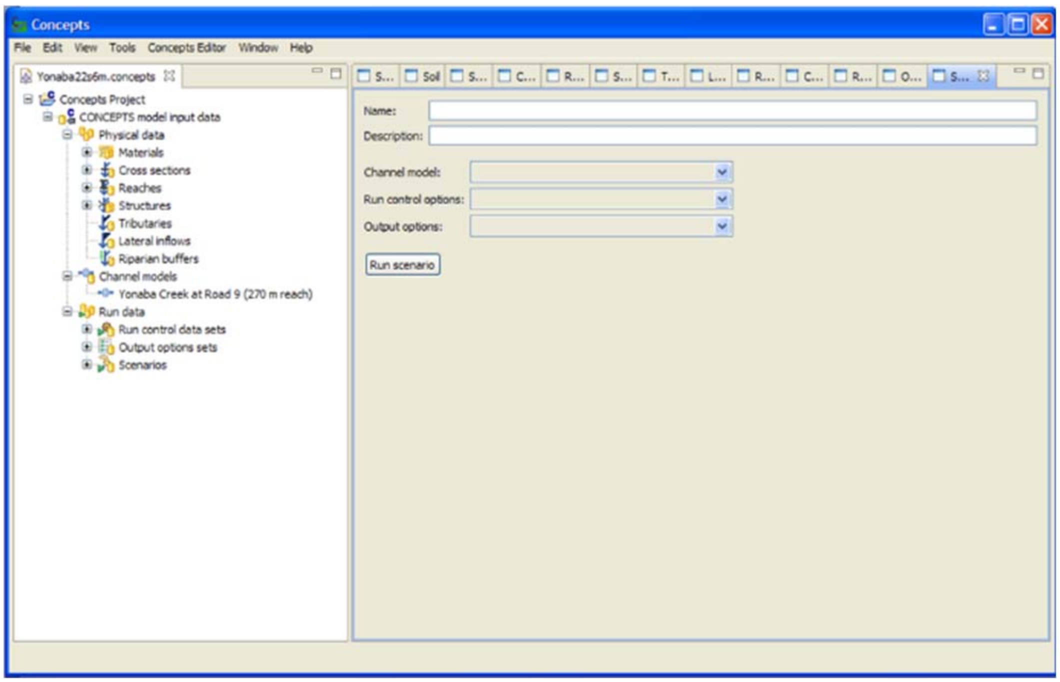


Figure 1. View of the Java Graphical User Interface for the CONCEPTS model

## METHODS

### Model Setup

The Yonaba Creek reach is a principal tributary of Town Creek located in the northern area of the TCW. The geometry of the 270-m long modeling reach is represented by 8 cross sections (Figure 2). Although the modeling reach is intersected by a bridge along the State Road 9 approximately 50 m below the first cross section, under visual observations its substructure did not contract streamflow or induce deposition or scour so was not included in simualtions. Along the modeling reach, three regions with differing characteristics were identified. First, two cross sections along the upstream sub-reach, which is a straight segment including an 85 m long section with rip rap protection along its entire streambank height.

This segment intersects the State Road 9 bridge. Second, four cross sections along the bendway sub-reach, which evidenced the most significant amounts of streambank erosion and streambank instability. Third, two sections along the downstream sub-reach, which is a straight segment evidencing some streambank gully erosion events, although its geomorphical characteristics did not favor streambank instability processes because of the presence of a berm along its entire length.

***Channel Geometry***

The eight transects (at river stations 0, 20, 135, 140, 165, 210, and 270 m) along the 270 m modeling reach were periodically surveyed from February 2009 to March 2010. Initial cross sections were surveyed between left to right streambank looking upstream by using a Total Station Positioning System (Leica TSP 1100 Professional Series) in February 13 and 20, 2009. A Real Time Kinematic (RTK) GPS system (TOPCON Hiperlite Plus) was used for the next surveys from May 19, 2009 to March 19 2010. A more detailed description about the cross section surveying performed at this reach was provided in Ramirez-Avila (2011).

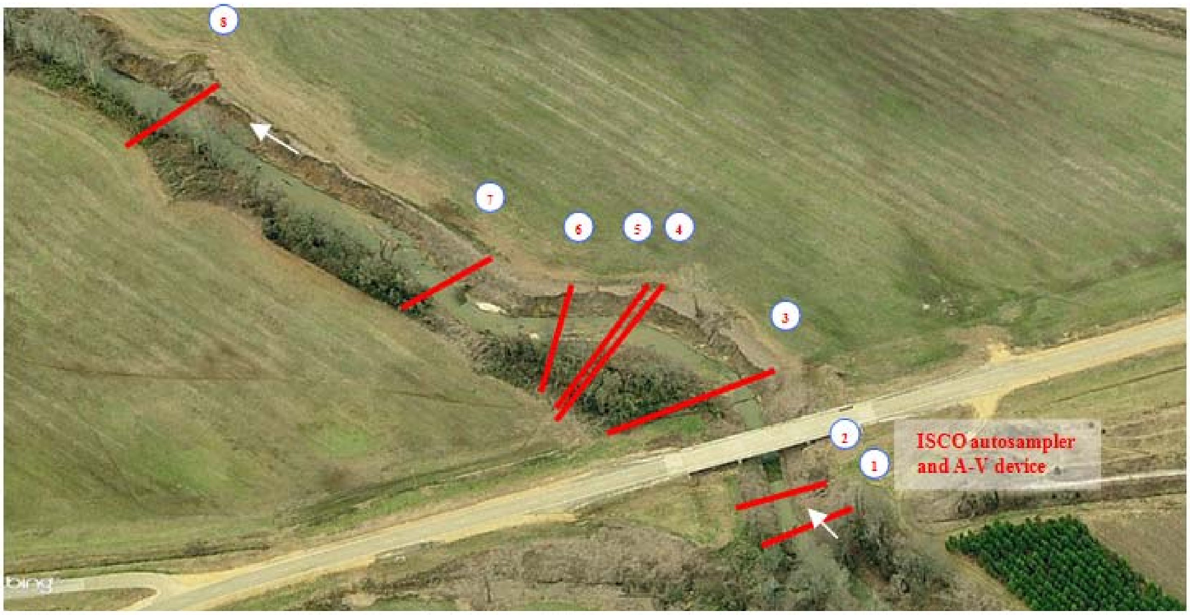


Figure 2. Yonaba Creek study site. Plan view showing the location of surveyed cross sections

***Streambank Material Physical Properties***

Sampling and testing of streambed and streambank materials for textural composition and geotechnical properties was conducted at the Environmental Laboratory of the Civil and Environmental Engineering Department of Mississippi State University and at the National Sedimentation Laboratory in Oxford, MS. Streambank and streambed materials were analyzed to determine particle size distribution by sieve-hydrometer and by the sieve-pipet method, respectively. Streambed sampling did not show a significant difference in textural composition along the length of the modeling reach. The field observation and particle size analysis results for the streambanks material allows defining representative streambank profiles, including the 85 m segment with rip rap protection.

The modeling reach formed into the spatial distribution of the Jena soil series. The streambank profile along the entire modeling reach is very homogenous. Particle size analysis characterized the entire layers of soils as very fine sandy loam. The soil series description for a typical pedon presents one main layer below the top soil (0.1 m) to a depth of 1.2 m and a second main layer from this depth going deeper than 2 m. Field observations showed an apparently less permeable third soil layer (approximately 5.5 to 6 m depth) and a subsequent gray bottom layer, usually covered by loose material located at the toe of the streambank produced by streambank failures (Figure 3). Particle size analysis for the deposited material showed a significant reduction in the contents of silt and clay of about 58%.

Streambanks along the modeling reach are very steep. The streambanks at the outer margin (left) of the bendway segment are eroded to near vertical profiles until a failure event produces deposition of loose material at the streambank toe (Figure 3). The angle of the first planar failure of the streambanks ($\beta$) was directly related to the friction angle of the streambank material ($\phi'$) and the initial streambank slope ($\alpha$) (Equation 1), which was considered homogeneous along the streambank height. Considering the homogeneity of the textural composition along the streambanks height in the modeling reach, the friction angle ($\phi'$) was determined by evaluating the change in the streambank slope observed after consecutive failure events in the streambanks where it occurred. Initial values for the suction angle ($\phi_b$) for each soil were assumed based on their corresponding textural characterization from values suggested by Selby (1993) and Nieber et al. (2008). The cohesion (c') of the streambank soil was considered negligible due to the textural composition of the streambank material, based on the typical values for different materials suggested by Selby (1993) and Nieber et al. (2008).

$$\beta = \left( \frac{\alpha}{\mathbf{2}} + \frac{\phi'}{\mathbf{2}} \right) \qquad \text{Eq. 1}$$


Figure 3. Representative streambank soil profiles observed along the modeling reach at Yonaba Creek in Blue Springs, MS

The submerged jet test device was used to determine the streambank material soil resistance to hydraulic erosion (Figure 4). The average value of three jet tests conducted at each streambank layer was used for input of $\tau_c$ and $k_d$ into the CONCEPTS model. Critical shear stress and erodibility of the streambank material ranged from 0.14 to 11.84 Pa and from 0.76 to 35.8 $cm^3\ N^{-1}\ s^{-1}$, respectively. Coarse grain loose material deposited on the streambank toes presented an average value of 1.12 Pa and 99.41 $cm^3\ N^{-1}\ s^{-1}$ for $\tau_c$ and $k_d$, respectively.

Roughness values (Manning n) were assigned to streambed and streambank sections of each cross section based on in-situ characteristics of the channel (e.g. rip rap protection of streambank, woody vegetation, etc), using the guidelines proposed by Langendoen (2000) and Chow (1959). In general, roughness values for the channel streambed ranged from 0.02 to 0.1 and streambanks from 0.03 to 0.17.

Figure 4. View of the a) jet test device setup, b) jet of water applied on the streambank material, and c) scour generated on the streambank material after a test

***Discharge***

Hydraulic conditions at the upstream and downstream boundaries of the simulated reach were obtained from observed discharge and stage. A monitoring station consisting of an automatic sampler (ISCO Model 6712) and area velocity flow module (ISCO-750) was setup at the upstream location of the modeling reach from early February 2009 to April 1, 2010. The continuous 15-min hydrographs of all runoff events between February 27, 2009 and April 1, 2010 were used to simulate the hydraulics and morphology of the model reach.

A rating curve (Equation 2) was developed as the downstream boundary condition based on stream velocity and depth profiles measured using a Son Tek flow tracker at cross section #8 (X=270 m) on different dates between August 2008 and June 2009.

$$\mathbf{Q} = \mathbf{3.25 * h^{1.95}} \qquad \text{Eq. 2}$$

where Q=Discharge in $m^3s^{-1}$ and h=flow depth in m.

***Modeling Assumptions, Calibration and Validation***

Although the major amount of the boundary physical properties to evaluate the prediction of streambank erosion processes and rates by using the CONCEPTS model were determined or measured *in situ*, some assumptions had to be made about the data assigned to materials and cross sections within the modeling reach. These assumptions concern sediment loadings, the streambed material resistance parameters, the effective cohesion and the suction angle of the streambanks. CONCEPTS is unable to predict the increased hydraulic forces acting on the left streambank side caused by the helical streamflow pattern in the bendway. Following Langendoen and Simon (2008), the increased shear stresses along the bendway were represented by a reduction in the resistance to erosion of the streambank material in the left streambanks of the sections #3 and #6. Similarly, the presence of a pipe on the lower part of left streambank at the section #5 was represented by a modification in the magnitude of its critical shear stress. Sediment inflows into the study reach were assumed equal to the transport capacity of the streamflow at the section #1 (wash load size class <0.025 mm). No downstream control was established. Processes related with the streambank stability analysis for this simulation included positive pore water pressures, matric suction, confining pressures, and groundwater table dynamics. A number of 5 shear emergences and a block retention time (time needed by flow to remove failed material deposited on the streambank toe) of 15 days were selected. From field observations, the maximum tension crack depth in the streambank stability analyses was determined as 1.7 m.

The calibration scenario included the analysis of hydraulics and streambank stability processes for the entire modeling reach from February 22, 2009 to June 30, 2009. The validation scenario was setup from July 1, 2009 and ended in March 19, 2010. A sensitivity analysis was performed to evaluate the effect of the critical shear stress, erodibility, friction angle and cohesion of the streambank material, streambank roughness and block retention time on the sediment loads and streambank failure events. Results from the sensitivity analysis are reported in Ramirez-Avila (2011).

## RESULTS

The 15-min time series of modeled and observed streamflow values at the downstream end of a 270 m long reach along the Yonaba Creek in Blue Spring, MS, are shown in Figure 5. The calibrated modeled time series agreed very well with the observed streamflow time series. A minimum rational change in the initial input value of the determined friction angle ($\phi$') for the streambank material was necessary to improve the model accuracy during the calibration phase.

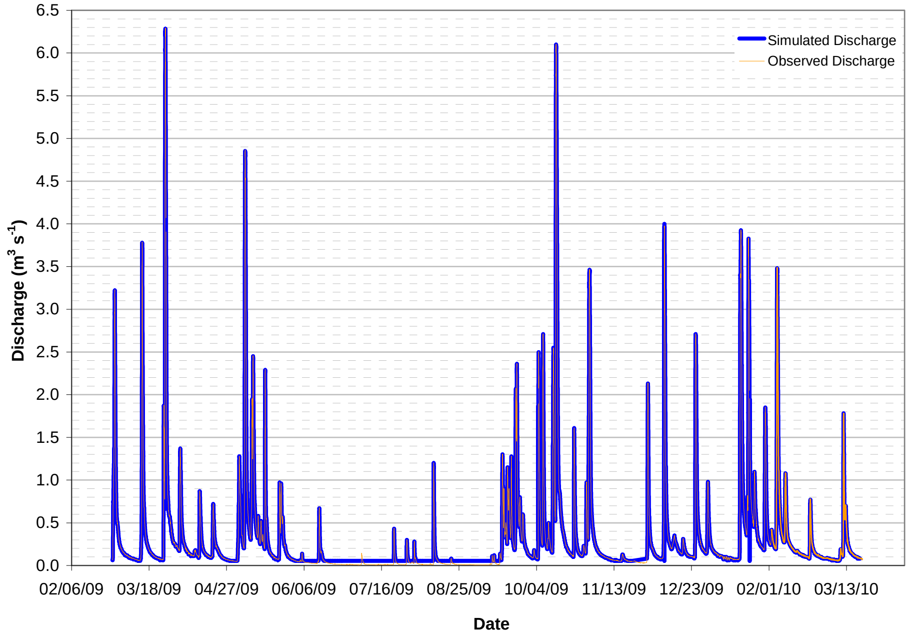


Figure 5. Observed and simulated streamflow discharge for a 270 m long modeling reach along the Yonaba Creek in Blue Springs, MS

### Factor of Safety and Streambank Instability

The time series of the computed Factor of Safety (Figure 6) allows visualizing the time of occurrence of a planar or a cantilever failure event during continuous changes in streamflow depths. Along the FS time series, a FS=0.987 during the stormflow event that started in February 26, 2009, and a FS=0.975 during the successive stormflow events that started in March 25, 2009, were observed for sections #3 and #6, respectively. In both cases, the streambank presented a planar failure. The stormflow event that induced the planar failure of section #6 did not induce a planar failure on section #3, probably due to the presence of remaining streambank material deposited on the streambank toe after the previous streambank failure. It also could be because only a cantilever failure of streambank material at the streambank toe height occurred.

Figure 6 shows how the factor of safety (FS) for sections #3, #4, #5 and #6 was reduced after the occurrence of the stormflow peak observed in March 26, 2009. The reduction in the FS indicated two processes: 1) the steepening of the streambank caused by the scour of the streambank material from the streambank itself or from deposited loose material near the streambank by fluvial erosion (Langendoen, 2000); and 2) the loss of matric suction relative to the increase in confining pressure along the streambank height caused by the rising stormflow level. When the FS was smaller than 1, a planar failure on the streambank occurred.

Although the FS for Section #6 was reduced below the critical value of 1 just after the occurrence of the stormflow peak, the planar failure occurred only until the stormflow depth felt to a depth where the forces reducing the strength on the saturated streambank were not higher than the confining pressure exerted by the stormflow (for this specific condition h=2.14 m). Once the failure occurred, the FS was increased due to reduction in streambank angle.

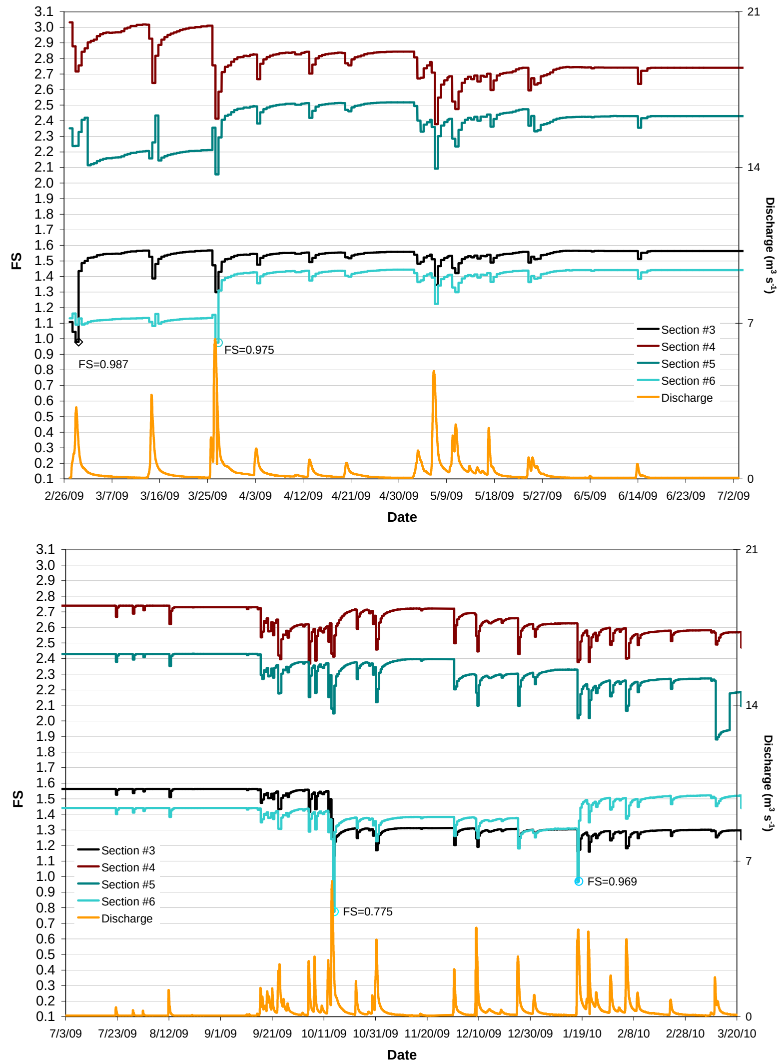


Figure 6. Predicted Factor of Safety (FS) for the left streambanks on a bendway along a 270 m long reach on the Yonaba Creek, MS, between February 22, 2009, and March 18, 2010

**Streambank Top Width Retreat**

Figures 7 and 8 compare simulated and surveyed cross section changes along the modeling reach obtained during the phases of calibration and validation. The changes in sections #3 and #6 were observed from the surveys performed in May 12, 2009, November 3, 2009, and March 18, 2010, and notes and pictures from field observations confirmed dates when the failures occurred. During the entire simulation, CONCEPTS accurately predicted the stability of the sections upstream and downstream of the bendway segment (Sections #1 #2, #7 and #8). The model adequately predicted in time and magnitude the 1.53 m of streambank top width retreat caused by the planar failure event that occurred on February 28, 2009, on the left streambank of section #3. In general, the simulation of individual planar failures in section #6 was well predicted in time, but the magnitude of the retreat was over-predicted. The 0.89 m of change in the streambank top width observed in March 27, 2009, was slightly over-predicted by 4.5%, but the 0.76 m retreat occurred in January 17, 2010, was over-predicted by 88.2% (Table 1). CONCEPTS predicted a change in FS that reflected a planar failure along the left streambank of section #6 in October 15, 2009, but the model under-predicted by 40.6% the 1.97 m of the top width retreat observed in the survey dated in November 3, 2009. Overall, the total top width retreats induced by planar failures on section #3 and section #6 were well predicted by CONCEPTS with a difference of 0.02 m and 0.09 m, respectively.

Sections #1, #2 and #7 did not reflect any erosive process from these streambanks, whereas CONCEPTS overestimated the observed streambank erosion in section #8. Both conditions differed from the actual observations due to the inability of CONCEPTS to simulate sediment deposition on the streambank surface. The deposition of sediment on the streambanks surfaces represented at least a 3.5% of difference in the total amount of the actual sediment amount contributed by the streambanks.

Table 1. Observed and simulated changes in top width at the left streambank of two sections along the Yonaba Creek between February and July 2009

| Failure Date | Simulated | Observed | Absolute error | Relative Error |
|---|---|---|---|---|
| | | **Section #3** | | |
| Feb 28, 2009[c] | 1.54 m | 1.53 m | 0.01m | 0.7% |
| Total | 1.54 m | 1.53 m | 0.01m | 0.7% |
| | | **Section #6** | | |
| March 27, 2009[c] | 0.93 m | 0.89 | 0.04 m | 4.5 % |
| October 15, 2009[v] | 1.17 m | 1.97 m | -0.80 m | -40.6 % |
| January 17, 2010[v] | 1.43 m | 0.76 m | 0.67 m | 88.2 % |
| Total | 3.53 m | 3.62 m | -0.09 m | -2.5 % |
| | | **Segment (Section #3 + Section #6)** | | |
| Total | 5.07 m | 5.15 m | -0.08 m | -1.6 % |

[c] Results obtained during model calibration [v] Results obtained during model validation

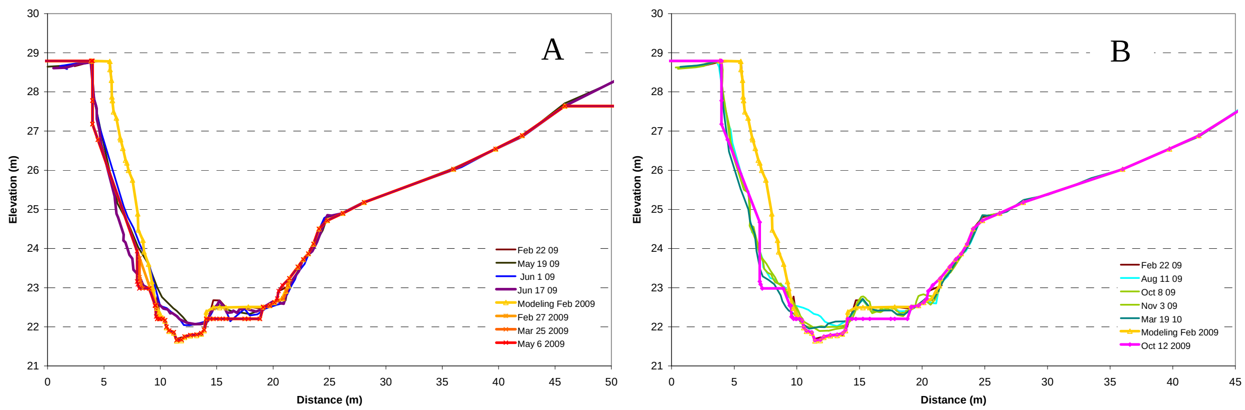


Figure 7. Comparison between simulated and observed cross-sectional changes of section #3 between February 2009 and June 2009 (A), and between July 2009 and March 2010 (B).

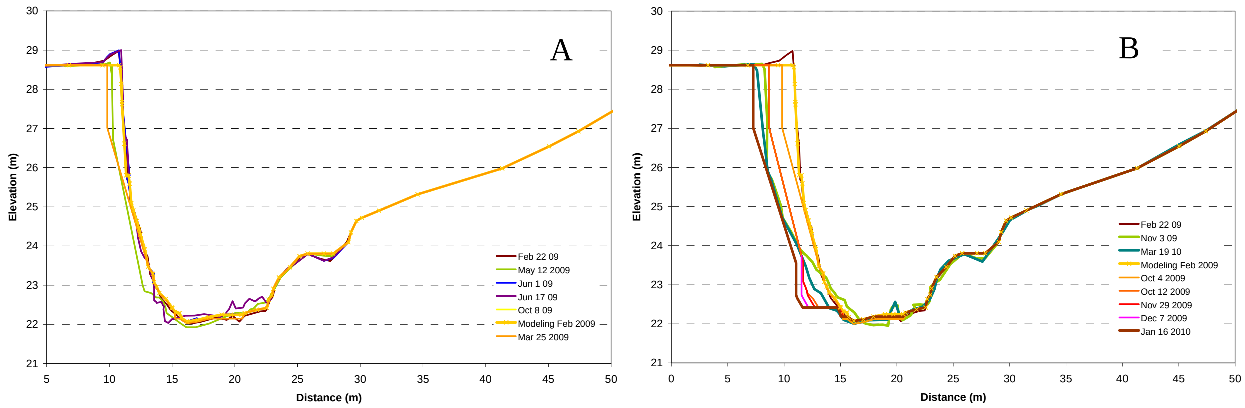


Figure 8. Comparison between simulated and observed cross-sectional changes of section #6 between February 2009 and June 2009 (A), and between July 2009 and March 2010 (B)

Table 2. Observed and simulated streambank erosion yield along a 270 m long reach on the Yonaba Creek in Blue Springs, MS between February 22, 2009 and March 18, 2010

| Section | Distance (m) | Simulated | | Observed | |
|---|---|---|---|---|---|
| | | Streambank Erosion- (Mg) | Contribution~ (%) | Net Streambank Erosion+ (Mg) | Contribution (%) |
| #1 | 0 | 0.0 | 0.0% | 3.7 | -0.2 |
| #2 | 20 | 0.0 | 0.0% | -54.8* | 3.2 |
| #3 | 90 | -892.2 | 44.5% | -506.4 | 29.3 |
| #4 | 135 | -49.4 | 2.5% | -49.3 | 2.8 |
| #5 | 140 | -56.8 | 2.8% | -289.3 | 16.7 |
| #6 | 165 | -996.3 | 49.7% | -827.6 | 47.8 |
| #7 | 210 | 0.0 | 0.0% | -7.8 | 0.5 |
| #8 | 270 | -5.2 | 0.3% | 0.8’ | -0.1 |
| **Total** | | **-1999.9** | | **-1,730.7** | |

Positive values = Deposition Negative values (-) = Erosion
-Simulated streambank erosion yield did not include sediment deposited on streambanks surfaces
~Overall cumulated sediment yield ratio across the total amount of gross streambank erosion
+Observed streambank erosion yield included sediment deposited on streambanks surfaces
*Erosion and deposition on section #2 was merely related to exchange of loose material carried by the stormflow events. A net contribution of streambank material was not expected because the streambank was revetted with rip rap
’ Estimated only for the cross section

CONCEPTS was able to simulate fluvial erosion and cantilever failures acting at the height of the left toe streambank at section #5, but was not able to replicate the different events of mass wasting which occurred above this height. Total contributions from this section represented around 16.7% of the total streambank erosion observed along the modeling reach. Mass wasting events at section #5 were induced by the scouring effect caused by the streamflow around a 0.75 m diameter corrugated pipe, which collected the concentrated runoff flow from upland. One of these observed events also included pop-out failures that occurred above the pipe height.

It was previously documented that CONCEPTS was very accurate when simulating the total magnitude of planar failures occurring sections #3 and #6. However, simulated total streambank erosion yield and contributions from both sections was overestimated by 1.8 and 1.2 times the observed results, respectively (Table 2). This condition could be caused by the difference in the actual block retention time and the 15-days value used by the model (a higher value for block retention time could not be assigned to the model due to an interruption during the running process attributed to a bug in the block retention routine, which has since been corrected). The block retention time represents the time that the failed loose material stayed on the streambank toe, protecting the streambank from fluvial erosion and streambank failures, and reducing the amount of sediment yield directly contributed to the streambed and the streamflow after a planar failure. Figure 9 shows how after the first planar failure at section #3, the failed material could stay on the streambank toe during at least 4 more months before being removed by fluvial erosion. It also shows how the streambed received direct contribution from the failed streambank material, changing, among other conditions, the geometry of the cross section and the streambed elevation. The actual change in the streambed was not simulated by CONCEPTS after the first streambank planar failure, and in general during the entire simulation. This condition could also be an important factor affecting the net contribution of the streambank at section #3, as well as the sediment transport analysis along the entire reach. Another factor that could be affecting the total amount of sediment yield by the streambanks could be the magnitude of the soil erodibility parameter determined *in-situ* by jet testing.

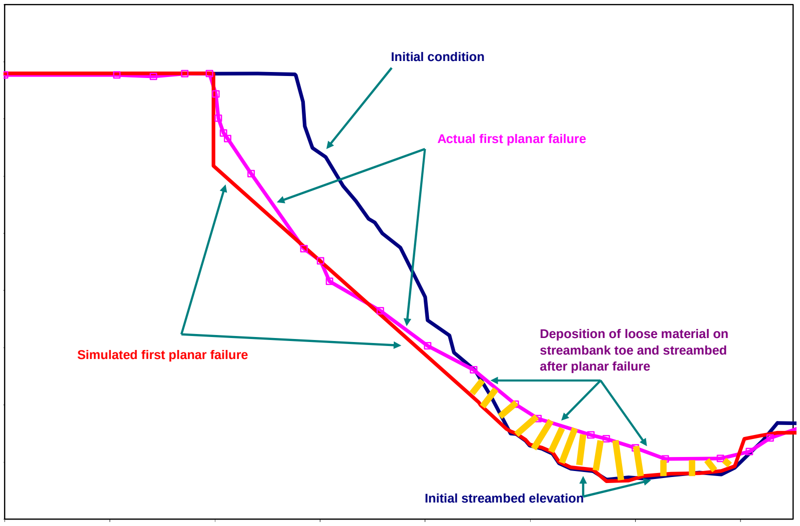


Figure 9. Comparison between actual and simulated planar failure, streambed deposition and erosion of deposited material on the streambank toe at section #3 on Yonaba Creek, MS.

## CONCLUSIONS

The ability of CONCEPTS to predict streambank erosion was tested through its application to a 270 m long reach along the Yonaba Creek in Blue Springs, MS. Model predictions between February 2009 and March 2010 were compared with cross section surveys on 8 transects along the modeling reach. Results showed that CONCEPTS very accurately predicted top width retreat and streambank failures in time and magnitude. CONCEPTS simulation yielded streambank degradation predictions comparable to those observed during the studied period. An annual rate of about 2,000 Mg of streambank retreat was assessed by both methods; field measurements and CONCEPTS modeling. However, CONCEPTS did not account for sediment deposition that occurred on the streambank, a condition that slightly reduced the observed net amount of sediment yield contributed by streambank processes. Streambank gravitational failure was the dominant mechanism inducing streambank erosion for the studied reach. CONCEPTS is unable to simulate tangential flows through the bendway section. Moderate changes in the critical shear stress of streambanks for the cross sections along the bendway represent the increased shear stress generated by stormflows along this section. The presence of a pipe on the lower part of left streambank at the section #5 was represented by a modification in the magnitude of its critical shear stress. However, the model was unable to simulate local streambank retreat caused above the pipe. Although it was not observed or studied in detail, the influence of subaerial erosion processes could be significant in accounting for the total retreat amount during winter.

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