Modeling the Evolution of Incised Streams. III: Model Application

Eddy J. Langendoen, M.ASCE¹; Robert R. Wells²; Robert E. Thomas³; Andrew Simon⁴; and Ronald L. Bingner⁵

Abstract: Incision and the ensuing widening of alluvial stream channels represent important forms of channel adjustment. Two accompanying papers have presented a robust computational model for simulating the long-term evolution of incised and restored or rehabilitated stream corridors. This work reports on applications of the model to two incised streams in northern Mississippi, James Creek, and the Yalobusha River, to assess: (1) its capability to simulate the temporal progression of incised streams through the different stages of channel evolution; and (2) model performance when available input data regarding channel geometry and physical properties of channel boundary materials are limited (in the case of James Creek). Model results show that temporal changes in channel geometry are satisfactorily simulated. The mean absolute deviation (MAD) between observed and simulated changes in thalweg elevations is 0.16 m for the Yalobusha River and 0.57 m for James Creek, which is approximately 8.1% and 23% of the average degradation of the respective streams. The MAD between observed and simulated changes in channel top width is 5.7% of the channel top width along the Yalobusha River and 31% of the channel top width along James Creek. The larger discrepancies for James Creek are mainly due to unknown initial channel geometry along its upper part. The model applications also emphasize the importance of accurate characterization of channel boundary materials and geometry.

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CE Database subject headings: Computer models; Morphology; Open channel flow; Sediment transport; River bank erosion; Geometry.

Introduction

Channelization-induced stream incision is widespread in the Mid-Continental United States. The highly erodible soil is unable to halt the incision and subsequent widening of these channelized streams, leading to increased sediment yields as material is eroded from both the bed and banks. The evolution of incised stream systems has been widely studied and the progression of the stream through various evolutionary stages has been documented in conceptual models of channel evolution (Schumm et al. 1984; Simon and Hupp 1986). Conceptual channel evolution models have aided in identifying and studying the processes playing a role in incised channel dynamics, but they are only able to qualitatively predict several important phases in the evolution of incised streams, and cannot predict the time it takes for streams to progress through the stages. Assessment and mitigation of downstream impacts require accurate quantification of the channel-erosion contribution to sediment yield. Quantitative numerical models simulating all important aspects of incised stream dynamics are therefore required.

Two accompanying papers (Langendoen and Alonso 2008; Langendoen and Simon 2008) describe the numerical model conservation channel evolution and pollutant transport system (CONCEPTS) aimed at simulating the processes that shape degraded stream corridors over long periods of time: i.e., incision, followed by width adjustment, and ensuing recovery of the stream bed. The model has been shown to accurately predict sediment transport and streambank erosion mechanics for laboratory and field studies in which the factors controlling bed and streambank adjustment are well known. This paper presents an application of the model to two incised stream systems in northern Mississippi: the Yalobusha River and James Creek, and assesses model performance in two ways. First, it tests the ability of the model to simulate the temporal adjustment of the fluvial systems through the different evolutionary stages. Second, the application to James Creek illustrates the performance of the model when data on channel geometry and the factors controlling streambed and streambank adjustment are poor or limited.
Watershed and Channel Descriptions

Yalobusha River

Background
The potential for catastrophic flooding along reaches of the Yalobusha River upstream of Grenada Lake, North-Central Mississippi (Fig. 1) dramatically increased during the 1990s and early 2000s. Between the 1910s and the 1940s, the Yalobusha River and Topashaw Creek were channelized and the downstream end of Topashaw Creek was relocated to improve drainage and reduce the frequency of flooding (Mississippi Board of Development 1940a,b). However, by 1940, the new outlet was obstructed in some places with sediment and debris, and the conveyance capacity of the Yalobusha River in the vicinity of Calhoun City, Miss. was greatly reduced (Mississippi Board of Development 1940a). As a response to this, a comprehensive river basin work plan was devised and implemented in the late 1960s to deepen and widen the downstream ends of both streams. The Yalobusha River and Topashaw Creek were cleared and dredged from a point 4.5 km downstream of their confluence up to the Calhoun-Chickasaw County line (Fig. 1). The Yalobusha River was dredged to a gradient of 0.0005, with top widths ranging from 58 m at the downstream end of the channel work to 22 m at the upstream end. In addition most tributary streams were cleared, dredged, and realigned (Simon 1998).

As a consequence of channelization, upstream-migrating knickpoints caused deepening of upstream reaches and tributary channels, leading to significant channel widening by mass failure of channel banks. Woody vegetation growing on these channel banks was delivered to the flow when the banks failed and was transported downstream. A large sediment plug and debris jam formed at the downstream terminus of the channelization works, where channelized reaches terminate into an unmodified, sinuous reach with much smaller cross sections and conveyances. Sediment eroded from the boundary of the Yalobusha River, its tributaries, and from upland areas has been deposited at the debris jam, further reducing sediment-transport capacity. The debris jam has caused increased stages and flood frequencies in the vicinity of Calhoun City, 10 km upstream. The U.S. Army Corps of Engineers (USACE) has identified a number of remediation strategies including debris jam removal, numerous grade-control structures to arrest headward migration of knickpoints, and flood-retarding structures. To this end USACE conducted an extensive survey of

Fig. 1. Map of Yalobusha River watershed showing location of study area, towns, roads, watercourses, and location of plug. Modeled reach extends from Highway 8 bridge crossing upstream of Fair Creek to sinuous reach downstream of plug.
the river system in 1997. Thalweg profiles and approximately 600 cross sections were surveyed along the Yalobusha River and its major tributaries.

From a geomorphic evaluation of the Yalobusha River system, Simon (1998) reported that the channel banks contribute at least 85% and as much as 92% of the sediment eroded from the channels of the stream system. Sediment yields range from about 320 t/km²/year for the Yalobusha River to almost 1,800 t/km²/year for Cane Creek.

**Basin Characteristics**

The drainage area of the Yalobusha River Watershed at the downstream terminus of channelization works is approximately 880 km² (Langendoen et al. 2002). Terrain elevations range from 63 to 186 m above mean sea level. From Landsat satellite imagery taken July 31, 1991, the land use of the watershed comprises 7% cultivated, 30% pasture or grassed areas, 59% forested areas, and 4% containing water or urban areas. The soils range from a silty clay to loamy sand. Based on mean-daily rainfall data from 1968 to 1997, the local National Weather Service climate station near Calhoun City, Miss., receives an annual rainfall of 1,362 mm. Precipitation occurs mainly in winter and early spring.

The U.S. Geological Survey (USGS) operates gauging stations at the Highway 9 bridge crossings of the Yalobusha River and Topashaw Creek (Fig. 1). Flow data from these stations are combined and reported as “Yalobusha River and Topashaw Creek Canal at Calhoun City” (USGS Station # 07282000). The contributing drainage area is 765 km². Mean-daily discharge and peak flow data have been available since 1950 and 15-min records have been available since 1987. Discharges of 1.01-, 2-, 5-, and 10-year recurrence intervals are 155.7, 719.2, 1,161, and 1,472 m³/s, respectively.

The dominant type of bed material changes gradually from fine or medium sand at the downstream end to clay, a change accompanied by knickpoints or knickzones. The sand D₅₀ varies from 0.27 to 0.39 mm. The clay formations are Naheola and Porters Creek Clay. Porters Creek Clay, predominantly found between river kilometers (RKM) 31 and 36, is very firm and highly resistant to erosion. Upstream and downstream of this reach, the bed is composed of the Naheola formation. The erosion rate of cohesive sediments in CONCEPTS is expressed by an excess shear-stress approach (Ariathurai and Arulanandan 1978)

\[ E = M(\tau / \tau_c - 1) \]  

where \( E \) = erosion rate; \( M \) = erosion-rate coefficient; \( \tau \) = average bed shear stress; and \( \tau_c \) = critical shear stress to initiate erosion. Critical shear stresses needed to erode these formations were measured utilizing a submerged jet-test device (Hanson 1990) by Simon et al. (2002b). The \( \tau_c \) for the Naheola formation is quite variable, and the mean and median values of 105 tests are 23.1 and 1.5 Pa, respectively; the mean \( M \) = 4.4 × 10⁻⁶ m/s. The \( \tau_c \) for the Porters Creek Clay formation is fairly constant, and the mean value of 67 tests is 185 Pa; the mean \( M \) = 2.0 × 10⁻⁶ m/s.

Bank material shear-strength properties were obtained from in situ testing with a borehole shear tester (BST) (Lutenegger and Hallberg 1981) and miniature tensiometer. The banks are composed of two principal units. The upper unit comprises about 90% of the bank height and is composed of sandy clays. Effective cohesion ranges from 0.1 to 24.2 kPa, with a mean value of 8.9 kPa and a median value of 7.2 kPa. The lower unit is composed of low-plasticity clays with an average effective cohesion of 17.2 kPa.

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**James Creek**

**Background**

James Creek drains Monroe County, North-East Mississippi (Fig. 2). Much of the channel network is incised and has been channelized, with only the lower 6.6 km retaining a natural, sinuous alignment. Evidence of bank erosion by mass failures is prevalent throughout its course. Like the trunk stream, most of the tributaries are incised and experience bank failures (Simon et al. 2002a).

James Creek and many of its tributaries were dredged and straightened in about 1905 (R. Goodgame, land owner, personal communication, 2002). Little is known of the details of this channelization project. The 62-year period between channelization and the next engineering works in 1967 was probably of sufficient duration for the erosion process to affect upstream reaches and for downstream reaches to fill and restabilize. A clearing and snagging project was undertaken by the USACE in 1967 from the mouth of James Creek to a point 16.7 km upstream in order to restore channel capacity that had been compromised by sediment deposition, accumulation of large woody debris emanating from upstream bank failures, and the growth of riparian vegetation.

Seven low-water crossings (LWCs) have been constructed across James Creek between the 1960s and 1990s to replace small bridges that were endangered by channel incision and widening (Table 1). These concrete structures produce an upstream backwater effect and trap sediment with many protruding about 1.0 m above the streambed.

The construction of the Tennessee-Tombigbee Waterway during the early 1980s impacted James Creek in several ways. In the vicinity of the mouth of James Creek, the Tombigbee River was deepened and the lower 215 m of James Creek was cut off to align the creek with the new waterway. Further, a dam was constructed on the waterway at Aberdeen, Miss., altering the flow regime of the Tombigbee River.

Simon et al. (2002a) conducted a comprehensive study of the James Creek Watershed to determine: (1) sediment loads emanating from the watershed; (2) the contributions to sediment loads from various channel and upland sources to identify potential areas for future remediation work; and (3) an applicable reference condition and sediment load obtained from unimpaired streams in the same ecoregion. To this end, 49 cross sections were surveyed along James Creek and bed and bank materials were characterized.

**Basin Characteristics**

The drainage area of the James Creek Watershed is approximately 112 km². Terrain elevations range from 47 to 101 m above mean sea level. The James Creek Watershed is in a highly agricultural area, with most of the watershed in cultivated croplands, pasture, or fallow conditions. From Landsat satellite imagery taken August 3, 2001, the land use of the watershed comprises 32% cultivated, 42% pasture or fallow areas, 23% forested areas, and 3% containing water or urban areas. The prevailing soils are silty clays. Other major soil types are silt loams and clays.

Average annual precipitation for Aberdeen is 1,431 mm. Air temperatures are mild in the winter and hot in the summer resulting in an average annual temperature of 18.3 °C. The USGS operates a gauging station (#02437600) at the State Highway 25 bridge southwest of Aberdeen. Daily streamflow was monitored between 1963 and 1968. Peak flows were monitored between 1963 and 2005. Peak instantaneous discharge for the period of record is 197 m³/s and occurred on October 22, 1984. Four of the nine highest peak flows occurred between January 1982 and Oc-
October 1984. Discharges of 1.01-, 2-, 5-, and 10-year recurrence intervals are 33.4, 104, 145, and 170 m³/s, respectively.

For most of its length, the channel boundary of James Creek is composed predominantly of cohesive silts and clays. Critical shear stresses were determined with a submerged jet-test device (Hanson 1990), and range from 0.6 to 190 Pa. The mean and median values of 28 tests are 21.1 and 3.7 Pa, respectively; the mean $M$ is $6.1 \times 10^{-6}$ m/s. However, downstream of RKM 8.6 the streambed is composed of sands and gravels with an average $D_{50}$ of 17.1 mm.

The banks are composed of two principal units both of silty clays. The thickness of the upper unit varies from 0.5 to 2.5 m with an average composition of 6% sand, 40% silt, and 54% clay. As in the Yalobusha River example, bank material shear-strength properties were obtained from in situ testing with a BST and miniature tensiometer. Effective cohesion ranges from 0.0 to 11.9 kPa, with a mean value of 3.6 kPa. The lower unit is more sandy and has a slightly higher bulk density. Its average composition is 19% sand, 34% silt, and 47% clay. Effective cohesion varies from 0.0 to 17.6 kPa, with a mean value of 6.6 kPa. Critical shear stresses of bank-toe materials range from 0.6 to 37 Pa. The mean and median values of 38 tests along the channel are 4.7 and 1.0 Pa, respectively; the mean $M$ is $7.1 \times 10^{-6}$ m/s.

**Table 1. Time and Location of Low-Water Crossing Installation**

<table>
<thead>
<tr>
<th>Year of construction</th>
<th>River kilometer (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1967</td>
<td>12.3</td>
</tr>
<tr>
<td>1982</td>
<td>20.0</td>
</tr>
<tr>
<td>1982</td>
<td>14.8</td>
</tr>
<tr>
<td>1990</td>
<td>23.3</td>
</tr>
<tr>
<td>1999</td>
<td>17.5</td>
</tr>
<tr>
<td>1999</td>
<td>15.8</td>
</tr>
<tr>
<td>1999</td>
<td>9.1</td>
</tr>
</tbody>
</table>

**CONCEPTS Model Description**

CONCEPTS simulates unsteady flow, transport of cohesive and cohesionless sediments selectively by size class, and bank erosion processes in stream corridors (Langendoen and Alonso 2008; Langendoen and Simon 2008). Hence, it can predict the dynamic response of flow, sediment transport, and channel cross-sectional
geometry to disturbances including channelization, altered hydrologic regime (e.g., by dam construction or urbanization), or in-stream hydraulic structures. This section summarizes: (1) the characterization of these processes in CONCEPTS; and (2) input data required by the model.

Hydraulics

CONCEPTS assumes stream flow to be one dimensional along the centerline of the channel. It computes the flow as a function of time simultaneously at a series of cross sections along the stream using the Saint Venant equations (Cunge et al. 1980). The governing equations are discretized using the generalized Preissmann scheme, and the resulting set of algebraic equations is solved using Gaussian elimination with partial pivoting for banded matrices (Langendoen and Alonso 2008). Required input data are: channel form, channel boundary roughness, and water inflows.

Sediment Transport and Bed Adjustment

CONCEPTS calculates total-load sediment transport rates by size fraction from a mass conservation law and taking into account the differing processes governing entrainment and deposition of cohesive and cohesionless bed material (Langendoen and Alonso 2008). Following Hirano (1971), CONCEPTS divides the bed into a surface or active layer and a subsurface layer. Sediment particles are continuously exchanged between the flow and surficial layer, whereas particles are only exchanged between the surface layer and substrate when the bed scours and fills. For cohesive materials, the erosion rate is calculated by an excess shear stress approach [Eq. (1)]. For cohesionless materials, CONCEPTS assumes that the erosion or deposition rate is proportional to the difference between the sediment transport rate and sediment transport capacity (Bennett 1974). Sediment transport capacity is calculated by a modified version of the sediment transport capacity predictor SEDTRA developed by Garbrecht et al. (1995). Total sediment transport is calculated by size fraction for 14 predefined size classes, with a suitable transport equation for each class: as wash load without deposition for sizes smaller than 10 μm; Laursen (1958) for silts; Yang (1973) for sands; and Meyer-Peter and Müller (1948) for gravels. Required input data are: grain size distribution and stratigraphy of the bed material, critical shear stress and erodibility of cohesionless bed material, and sediment inflows.

Streambank Erosion

CONCEPTS simulates channel width adjustment by incorporating the fundamental physical processes responsible for bank retreat: (1) fluvial erosion or entrainment of bank toe material by flow; and (2) bank mass failure due to gravity (Langendoen and Simon 2008). Streambank material may be cohesive or noncohesive, and may comprise numerous soil layers reflecting the depositional history of the bank materials; each layer can have physical properties quite different from those of other layers. Eq. (1) is used to calculate the rate of fluvial erosion for each soil layer.

Bank stability is analyzed via the limit equilibrium method based on static equilibrium of forces and/or moments. Streambank failure occurs when gravitational forces that tend to move soil downslope exceed the forces that resist movement. The bank’s geometry, soil properties, pore-water pressure, confining pressure, and riparian vegetation determine the stability of the bank. CONCEPTS performs stability analyses of planar slip failures and cantilever (shear type) failures of overhanging banks by dividing the bank into slices and evaluating the balance of forces on each slice in vertical and horizontal directions (Langendoen and Simon 2008).

Required input data are: stratigraphy and grain size distribution of the bank material, the resistance to erosion (critical shear stress and erodibility), and the shear strength (effective cohesion and effective angle of internal friction) of each bank soil.

Model Setup

Yalobusha River

The 1966 channelization plan and the 1997 survey of the Yalobusha River provide a means to test the performance of CONCEPTS to simulate the evolution of an incised stream. A reach of the Yalobusha River between the Highway 8 bridge at RKM 40.7 to the downstream-most cross section surveyed in 1997 (RKM ~1.7) was selected (Fig. 1), and its evolution simulated between January 1, 1968 and December 31, 1997. The following sections describe the input data used in the simulation. Thomas and Langendoen (2002) provide a more detailed description of model setup.

Hydrology

To simulate the hydraulics and morphology of the model reach, hydrographs of all runoff events between January 1, 1968 and December 31, 1997 had to be imposed at the upstream boundary (RKM 40.7) and at the mouths of major tributaries [Fair, Johnson, Mud, Naron, Canes, Meridian, Duncan, Miles, Hurricane, Splughe, Big, Topashaw, Unnamed, and Shutispaw Creeks (Fig. 1)]. Observed hydrographs were not available, and the hydrologic model annualized agricultural nonpoint source pollutant loading model (AnnAGNPS) was therefore used to generate these hydrographs (Langendoen et al. 2002).

AnnAGNPS is a continuous simulation, daily time step, watershed scale, pollutant loading model (Bingner and Theurer 2001), that analyzes a watershed subdivided into suitably small cells of homogeneous land-use management, climate, and soils, which can adequately approximate site conditions. Runoff, sediment, and other contaminants are routed from each cell through a channel network to the outlet of the watershed. AnnAGNPS uses the Natural Resources Conservation Service (NRCS) curve number model to calculate runoff. Curve numbers are selected based on Section 4 of the National Engineering Handbook (NRCS 1985). AnnAGNPS uses an extended version of NRCS Technical Release 55 (TR-55) to compute peak discharge (Bingner and Theurer 2001). Hydrologic simulation yields the peak discharge ($Q_p$) and runoff volume ($V$) for each rainfall event, cell, and tributary. NRCS triangular hydrographs are constructed at the downstream end of each stream segment using peak discharge, time-to-peak, and storm event duration (NRCS 1985). The storm event duration is calculated as $D=2V/Q_p$, and time-to-peak equals 0.375D. AnnAGNPS uses standard NRCS data bases, available for the entire United States, that describe soils and their distributions, land use, and land management. These data are complimented by daily climate data and topography.

Fig. 3 compares the observed and simulated annual peak discharges from 1968 to 1997 and the observed and simulated storm event peak discharges from 1987 to 1997 at the HWY 9 bridge crossing on the Yalobusha River (cf. Fig. 1). Peak discharges less
than 500 m$^3$/s are underpredicted but flows above this value that transport the most sediment are well simulated. The differences for peak discharges smaller than 80 m$^3$/s may possibly be caused by backwater effects at the gauging stations due to the debris jam, producing erroneously large measured discharges. Differences can be further attributed to: (1) the use of a single rain gauge in an area where rainfall events tend to be convective and so can be highly localized; (2) coarse watershed delineation with varying land uses within cells may cause inaccurate curve number selection, which may lead to poor runoff prediction; (3) rainfall events that cross midnight are seen by AnnAGNPS as two different rainfall events; and (4) the use of a daily time-step model that cannot simulate rainfall events with large temporal variations in rainfall intensity. In spite of the above assumptions in the hydrologic model and the fact that no calibration has taken place, the predicted hydrology of the Yalobusha River is generally consistent with that observed (Fig. 3). The relationship of predicted to observed discharges has an $r^2$ of 0.722 and a $P$ value of 0.083.

Channel Dimensions and Properties
The model reach was subdivided into 107 intercross-sectional subreaches. Cross sections for the upstream-most 34 km were provided by Colorado State University (C.C. Watson, personal communication, 2001), who also provided sediment rating curves for sands and fine gravels for each tributary. Rating curves for silts were derived from those for sands by scaling them based on the fractional content of silt within the bed material. The geometry of the remaining 6.5 km downstream of the terminus of the channelized reach was obtained by simplifying the 1997 USACE surveys. In sinuous upstream and plugged downstream reaches, Manning’s $n$ values for the channel bed and banks were 0.033 and 0.035, respectively, while in middle reaches (between RKMs 10 and 36), Manning’s $n$ for the channel bed was set to 0.022.

The bed material in depositional reaches in and upstream of the plug (RKMs 5–10) is sand. Different compositions were used for the slack water reaches downstream of the plug (RKMs 1.7–5) and for depositional middle reaches (RKMs 10–30), representing deposited silty sands from upstream reaches, and also for degrading reaches (upstream of RKM 30), representing a shift in the bed material to silty clays composed of the Naheola and Porters Creek Clay geologic formations. Median values of critical shear stresses for bed and bank materials were used, whereas average measured values were used for bank material shear-strength properties.

James Creek
CONCEPTS was used to simulate the morphology of James Creek between Darracott Road (RKM 7.3) and the confluence upstream of Old Magnolia Highway (RKM 24.0). The period of simulation is from 1967 to 2001, coinciding with conducted channel surveys. The simulation was separated into three time periods, each delineated by the construction of low-water crossings. Table 1 lists the year of construction and river kilometer of the structure. The following sections describe the input data used in the simulation. Simon et al. (2002a) provide a detailed description of model setup.

Hydrology
Flow and sediment data had to be imposed at the upstream boundary, at the mouths of tributaries, and at the downstream end of fields adjacent to the channel from January 1, 1967 to December 31, 2001. As in the Yalobusha River simulation, AnnAGNPS was used to provide these data. Fig. 4 shows that annual peak discharges at the USGS gauging station on State Highway 25 are overestimated. The best-fit line intercepting the origin has a slope of 1.15. It is hypothesized that this discrepancy is caused by the issues highlighted in the “Model Setup” section of the Yalobusha River example. Therefore, no attempt was made to improve the simulated runoff.

Channel Dimensions and Properties
The model reach was subdivided into 40 subreaches. Channel-geometry data surveyed in 1967 were available for six cross sections along the modeled reach at the following RKMs: 7.3, 9.3, 9.8, 12.0, 13.5, and 17.3. These data were used as inputs for the initial channel geometry used by CONCEPTS. Additional cross sections between those surveyed in 1967 were synthesized based on the average top width and channel depth of the adjacent measured cross sections.

Cross sections upstream of RKM 17.3 had to be synthesized from available data. To accomplish this, relations between channel geometry and distance upstream were developed. Fig. 5(a)
plots channel depth (CD) for 1967 and 2002 against river kilometer. Between RKM 12 and 17.3 the 1967 and 2002 channel depths are similar. Above RKM 17.3 channels were probably 1–2 m deeper in 2002 than they were in 1967. The reason for this is likely related to the clearing and snagging work conducted downstream of RKM 17.3 in 1967, which may have created a knickpoint at RKM 17.3 that has migrated upstream. The above reasoning is supported by an observed deepening of the lower reaches of the main tributary entering James Creek around RKM 19 (Simon et al. 2002a). Fig. 5(b) shows channel cross-sectional areas (A) for 1967 and 2002 plotted against river kilometer. Note the change in slope of the 2002 regression line above RKM 17.3. The 1967 regression line would cross the 2002 regression slightly upstream of RKM 20.0, indicating that upstream of this point 1967 channels were larger than 2002 channels, which is highly unlikely. By using the 1967 depth relation in Fig. 5(a) and the 2002 cross-sectional relation in Fig. 5(b) a range of synthesized cross-section geometries was obtained. Geometries with 45° bank angles were selected so as to be within the range of 1967 width-to-depth ratios (2.6).

Manning’s n values for bed and banks were 0.032 and 0.05, respectively. The model reach was subdivided into segments of fairly uniform bed sediments and bank soils. The collected parameters representing resistance to erosion and shearing, and material composition were composited within these segments. The composited parameters were assumed representative for bed- and bank-material properties within the segments, and were assigned to the cross sections within these segments. Median values of critical shear stresses for bed and bank materials were used, whereas mean values were used for bank material shear-strength properties.

### Model Results

#### Yalobusha River

**Thalweg Elevation Adjustment**

Fig. 6(a) shows the change in thalweg elevation between 1968 and 1997. A positive elevation change denotes deposition, whereas a negative elevation change denotes erosion. Overall, comparison between the modeled and observed elevation change shows good agreement; middle reaches were found to have incised approximately 2 m, an amount closely comparable to that predicted by CONCEPTS. There is a slight overprediction of the bed elevation between RKMs 13 and 18, a discrepancy likely to be caused by two factors. First, the developing debris jam creates backwater conditions, which causes sand- to silt-sized material to be deposited, perhaps at rates not adequately predicted by a one-dimensional model. Second, because of local berm development, flow is concentrated in a narrower channel than simulated within CONCEPTS, which has promoted deepening of the thalweg. In contrast, the rate of deposition in areas between RKMs 5 and 10 of the model reach is underpredicted. This may also be due to two factors. First, because of the premature deposition noted above, the model channel carries less sediment into this reach than the Yalobusha River does in reality. More importantly, the model cannot simulate the transport and deposition of woody vegetation, which is likely to be responsible for the additional accumulated debris. The mean absolute deviation (MAD) and root mean squared deviation (RMSD) between modeled and observed change in elevation are 0.69 and 1.00 m respectively. The MAD and RMSD are defined as

\[
\text{MAD} = \sum_{i=1}^{k} |o_i - m_i|
\]

\[
\text{RMSD} = \sqrt{\sum_{i=1}^{k} (o_i - m_i)^2}
\]

where \(i=\) cross section index; \(k=\) number of cross sections; \(m_i=\) modeled and observed value, respectively; weighting coefficient \(o_i=(\text{RKM}_{i+1}-\text{RKM}_{i-1})/2L;\) and \(L=\) channel length. Excluding the cross sections within the debris jam reduces the MAD and RMSD to 0.16 and 0.33 m, respectively.

**Active Channel Top Width**

Fig. 6(b) compares the modeled and observed change in the channel top width between 1968 and 1997. Generally, there is good agreement; discrepancies in upstream reaches are due to uncertainties in assigning bank top locations, while those in middle reaches are due to narrowing caused by berm development upstream of the plug associated with the later stages of channel evolution, an aspect that cannot presently be simulated. Utilizing dendrochronologic methods, Simon (1998) found that 1979, 1983, and 1991 were periods of accelerated widening. CONCEPTS predicts 1978 and 1991 to be periods of particularly rapid widening, which compares favorably with these findings. The mean absolute deviation and root mean squared deviation between modeled and observed change in top width are 5.60 and 7.27 m, respectively. Excluding the cross sections within the debris jam reduces the MAD and RMSD to 1.79 and 3.10 m, respectively. The discrepancies between modeled and observed channel top width at RKMs 37, 38, and 41 largely contribute to these values of MAD and RMSD. Using the observed top width
in 1997 to normalize the modeled and observed values of change in top width, yields a MAD and RMSD upstream of the debris jam of 5.7 and 10.8%, respectively.

**Stage of Channel Evolution**
Combining the results for both the channel top width and thalweg evolution, a picture of the predicted stage of channel evolution (Simon and Hupp 1986, also see Appendix) can be developed. Fig. 6(c) compares the predicted and observed (Simon and Thomas 2002) stage of channel evolution. Model results compare favorably to the observed results. The model predicts that Stage VI conditions occur from RKMs −1.7–21.3, Stage V conditions between RKMs 21.3 and 34.4, Stage IV conditions between RKMs 34.4 and 36.2, and Stage III conditions from RKMs 36.2 to 40.7. The only significant difference between the model results and the observed conditions occurs at the downstream onset of Stage V conditions, although the model result (RKM 21.3) does lie within the oscillatory, transitional reach (RKM 14.8–22.6) noted by Simon (1998, Table 21).

**James Creek**

**Thalweg Elevation Adjustment**
In the first 10 years, large amounts of sediment were eroded above and including the transition zone, between the measured
and synthesized 1967 cross sections, at the upper end of the 1967 clearing and snagging work [Fig. 7(a)]. The simulated changes in thalweg elevation are in good agreement with those observed. Up to 3 m of incision in the upstream reach initiated mass-bank instabilities [Fig. 7(b)]. Fig. 7(a) shows the effects of the LWCs on the evolution of the thalweg by controlling the grade of the channel bed. CONCEPTS overpredicts the amount of sediment deposited upstream of the LWC at RKM 20.0, and the amount of sediment eroded downstream of the LWC at RKM 12.3. The downstream end of the modeled reach (RKM 7.3) is affected by processes occurring between this location and the Tennessee-Tombigbee Waterway; specifically, the continuous dredging of the Tennessee-Tombigbee. These processes are not included in the simulation, hence precluding an accurate simulation of thalweg elevation adjustment downstream of the LWC at RKM 9.1. The mean absolute deviation and root mean squared deviation between modeled and observed change in elevation are 0.57 and 0.69 m, respectively.

**Active Channel Top Width**

Fig. 7(b) shows the simulated temporal adjustment of the channel top bank width. At the upper end of the reach (between RKM 22 and 24), CONCEPTS underestimates the top bank width of the channel. This may be in large part due to the technique used to synthesize the upper cross sections (RKM 17-24). The 2002 channel survey showed that the cross sections between RKM 17.6 and 24 are relatively narrow across the bottom half of the channel depth and widen rapidly across the top half of the channel depth.
This possibly indicates failures induced by saturation of the top part of the streambank due to infiltrating rainfall. Predicted cross-sectional area, however, agrees well with that measured between RKM 22 and 24 (Simon et al. 2002a). The top width between RKM 17 and 22 is overpredicted. This is due to too much erosion at the toe of the bank. The employed critical shear stresses and erodibility coefficients were not calibrated against the observed widening, and were probably too small. Between RKM 12 and 17, CONCEPTS underestimates the top bank widths near the LWCs. Continued maintenance of the vehicle-access lane across the channel at the LWCs greatly increases local channel widths at those locations. Between RKM 9 and 12, CONCEPTS overestimates the top bank width. This can be mainly attributed to an overestimation of erosion of the channel bed by about 0.5 m [Fig. 7(a)]. Both this and the excessive erosion at the bank toe may in part be explained by the overprediction of peak discharge (Fig. 4). The mean absolute deviation and root mean squared deviation between modeled and observed change in top width are 9.81 and 12.24 m, respectively. Using the observed top width in 2002 to normalize the modeled and observed values of change in top width, yields a MAD and RMSD of 31.2 and 42.8%, respectively.

**Stage of Channel Evolution**

Fig. 7(c) compares the predicted and observed stage of channel evolution. The observed stage of channel evolution shows an alternating pattern of Stage IV and Stage V conditions, largely coinciding with LWC locations. Model results compare favorably to the observed results. The main difference is that modeled Stage V conditions upstream of LWCs cover a greater length of channel, indicating that the modeled adjustment is slightly faster than that observed.

**Conclusions**

A computer model, CONCEPTS, that simulates the evolution of incised stream systems, was tested against observed adjustment of two incised streams in northern Mississippi. This application summarized both the type and amount of data needed to adequately evaluate the evolution of highly disturbed streams.

Application of the model showed that it can satisfactorily predict and quantify: (1) the temporal progression of an incised stream through the different stages of channel evolution; (2) changes in thalweg elevation; and (3) changes in channel top width. However, bed- and bank-material properties representing resistance to erosion and failure must be adequately characterized. It is highly recommended to perform a geomorphic analysis of the stream system to determine channel conditions and variations in sediments and soils along the stream. Such an analysis could be performed using the rapid geomorphic assessment technique (Simon et al. 2002a). Differences between observed and simulated evolution were commonly largest along reaches where either: model assumptions regarding flow and sediment transport (e.g., one-dimensional assumption) are inappropriate, as is the case in the late stages of channel adjustment [Stage VI of the model of Simon and Hupp (1986)]; or assumptions regarding input data (e.g., channel geometry, water inflows, or bed- and bank-material properties) were required.

The use of median and average values of critical shear stresses and effective cohesion generally provided good results. This is supported by application of the model to other streams in which calibration of critical shear stress was performed. Measured critical shear stresses typically vary greatly both between different soils and within a soil. Hence, users of the model should therefore measure an adequate number of critical shear stress values for each soil in the bed and banks.

The application of the model to James Creek showed the importance of: (1) simulated channel hydraulics; and (2) the availability of channel geometry data. Bed and width adjustment may not be predicted satisfactorily if simulated channel hydraulics do not agree well with those observed or if data on channel grade and width are deficient. If sufficient data are available to adequately predict applied forces and represent resisting forces, e.g., the Yalobusha River application, the model can accurately simulate channel evolution. If model inputs are not as good, e.g., the James Creek application, the model still produced the correct process representation and reasonable quantitative channel morphology. The root mean squared deviation between observed and modeled changes in thalweg elevation was approximately twice as large for James Creek as that for the Yalobusha River. The root mean squared deviation between observed and modeled changes in channel top width normalized by channel top width was approximately four times as large for James Creek as that for the Yalobusha River.

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**Appendix. Conceptual Channel Evolution Model of Simon and Hupp (1986)**

Alluvial channels, destabilized by a variety of natural and human-induced disturbances, pass through a temporal sequence of channel forms and active processes. Simon and Hupp (1986) developed a six-stage model of these forms and adjustment processes. They consider the equilibrium channel as the initial, pre-disturbed Stage I of channel evolution and the disrupted channel as an instantaneous condition (Stage II). As the channel begins to adjust, rapid degradation of the channel bed ensues due to an imbalance between sediment supply and available stream power (Stage III). Concurrently, bank heights are increased and bank angles are steepened. Once bank heights and angles exceed critical thresholds, channel banks are destabilized and exhibit mass failures, while bed degradation continues (Stage IV). Channel widening combined with aggradation (Stage V) becomes the dominant trend in previously degraded downstream sites because degradation flattens channel gradients, preventing them from transporting the increased sediment loads emanating from degrad-
ing reaches upstream. This aggradation occurs at rates roughly 60% less than the associated degradation rate (Simon 1992), causing bed-level recovery to be incomplete. The new dynamic equilibrium (Stage VI) will hence be reached after bank stability has been regained and the channel gradient reduced by meander extension and elongation. Concurrently, riparian vegetation will begin to establish itself, adding roughness elements, enhancing bank accretion, and reducing the stream power for given discharges.

**Notation**

The following symbols are used in this paper:

- \( A \) = channel cross-sectional area (m\(^2\))
- \( CD \) = channel depth (m)
- \( D_s \) = storm event duration (s)
- \( D_{50} \) = median particle diameter (mm)
- \( E \) = erosion rate (m/s)
- \( i \) = cross-sectional index
- \( k \) = number of cross sections
- \( L \) = channel length (km)
- \( M \) = erosion-rate coefficient (m/s)
- \( m \) = modeled data value
- \( n \) = Manning roughness coefficient (s/m\(^{1/3}\))
- \( o \) = observed data value
- \( Q_p \) = peak discharge (m\(^3\)/s)
- \( V \) = runoff volume (m\(^3\))
- \( \tau_c \) = critical shear stress (N/m\(^2\))
- \( \omega \) = weighting coefficient

**References**


