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Application of Regional Sediment Approach to Hickahala Creek Watershed, Northern Mississippi

by David S. Biedenharn, Chester C. Watson, John B. Smith, and Lisa C. Hubbard

PURPOSE. Biedenharn (2004) described the systematic approach to Regional Sediment Management (RSM) that has been developed as part of the Demonstration Erosion Control (DEC) project. The purpose of this Coastal and Hydraulics Engineering Technical Note (CHETN) is to describe how this RSM approach was successfully applied to the Hickahala Creek watershed in northern Mississippi.

BACKGROUND. Channel modification or channelization activities are listed among the top 10 sources for nonpoint pollution impacts to rivers (USEPA 1993). Activities such as straightening, widening, deepening, and clearing channels of debris generally fall into this category. These activities can severely impact major river projects such as navigation and flood control, as well as alter or reduce the diversity of in-stream and riparian habitats. Without a proper understanding of the fluvial system, even projects intended to rehabilitate streams can cause severe instability.

River systems maintain stability by providing just the necessary flow to transport the available water and sediment. When this balance of water and sediment transport discharge is upset, the system will adjust by increasing or decreasing erosion from the channel bed or river banks. This is a complex interaction that involves the entire watershed and river system. Therefore, a system-wide approach must be taken to analyze these impacts and develop remedial measures.

THE DEMONSTRATION EROSION CONTROL PROJECT. The DEC project seeks to develop and demonstrate a watershed systems approach to address problems associated with watershed instability: (1) erosion, (2) sedimentation, (3) flooding, and (4) environmental degradation. Initiated by the Federal government in 1984, DEC activities are targeted at 16 watersheds comprising 6,797 sq km within the Yazoo River Basin in the Lower Mississippi Valley. The measured suspended sediment yields in the DEC watersheds average about twice the national average. The DEC project is conducted through cooperative efforts of several agencies. The US Army Corps of Engineers Vicksburg District and the US Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) are responsible for planning, design, and construction of the DEC project. The USDA Agricultural Research Service National Sedimentation Laboratory, the US Army Engineer Research Development Center (ERDC), the University of Mississippi, the US Geological Survey (USGS), and Colorado State University (CSU) are responsible for research and monitoring of the DEC project.

The DEC project provides for the development of a system for control of sediment, erosion, and flooding in the hill areas of the Yazoo Basin, MS. Features that are being used to achieve the project goals include grade control structures, reservoirs, and bank-stabilization measures. In

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addition, pipe drop structures are being constructed to prevent gullying of the channel banks. Other features being employed in the DEC project are levees, pumping plants, land treatments, and developing technologies.

THE DEC APPROACH TO REGIONAL SEDIMENT MANAGEMENT. Through the DEC project, a systematic approach to channel rehabilitation and regional sediment management has been developed. The basic components of the approach include: (1) project initiation, (2) geomorphic assessment, (3) plan formulation, (4) plan evaluation and preliminary design, (5) plan selection, (6) implementation, and (7) monitoring and feedback. Biedenharn (2004) gives a more detailed discussion of the DEC design approach. The systems approach to channel rehabilitation and regional sediment management was applied to the Hickahala Creek watershed, one of 16 DEC watersheds.

DESCRIPTION OF THE WATERSHED. The Hickahala Creek watershed is located approximately 50 km south of Memphis, TN, in northwestern Mississippi (Figure 1). Hickahala Creek is a tributary of the Coldwater River upstream of Arkabutla Reservoir, and encompasses approximately 596 sq km.

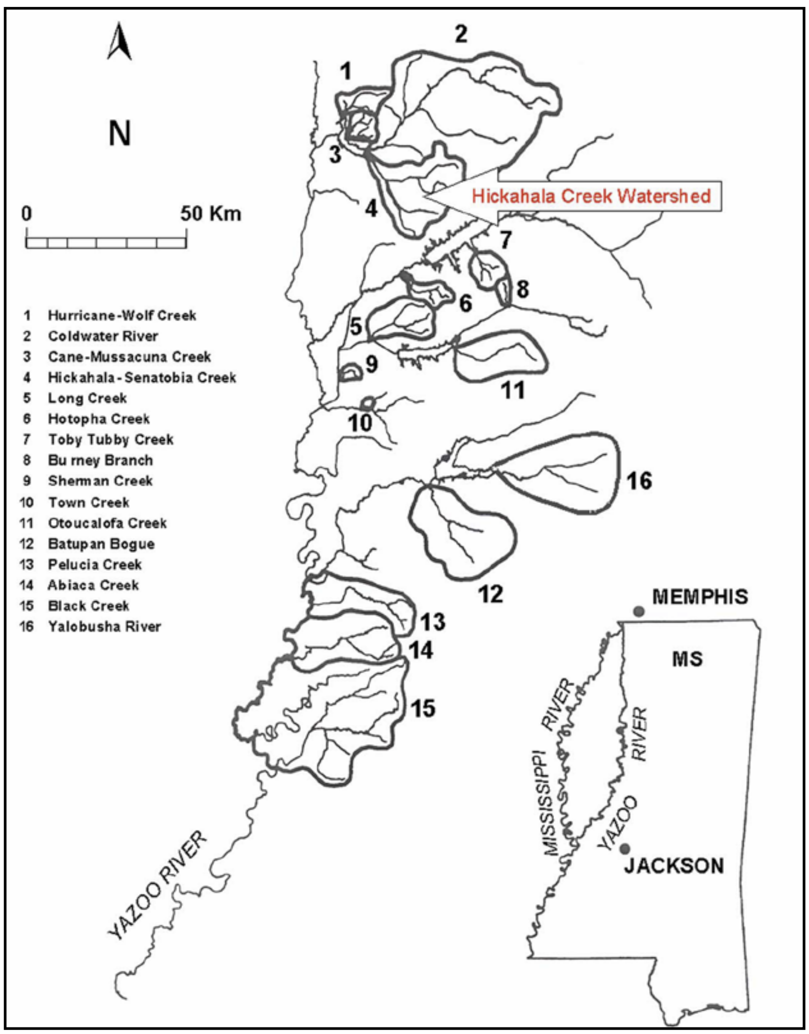

Figure 1. DEC project site location.

The early settlers to the Hickahala area chose the loess hills for home sites and farming. The hillsides were easily eroded when cleared of the natural vegetation and within a short period the sediment eroded from the watershed choked the hill streams and valleys. From shortly after the Civil War to the early 1900s, land clearing for agriculture continued, resulting in extreme sedimentation and flooding problems. Drainage districts began organizing for collective efforts at solving the problems, resulting in extensive channel clearing and straightening programs beginning in the 1920s and 1930s. From about 1930 to present, Federal agencies began instituting programs to help minimize erosion, reclaim lands, improve drainage, and provide flood control.

Hickahala Creek and several major tributaries such as Senatobia Creek were cleared and straightened for the first time in the 1930s under the direction of local drainage districts. A flood-control reservoir, Arkabutla Lake, was constructed by the Corps of Engineers on the Coldwater River in the early 1940s. The maximum flood-control pool for the reservoir inundates Hickahala Creek upstream from the confluence with Coldwater River for approximately 10 km, to a point above the confluence with Senatobia Creek (Figure 2).

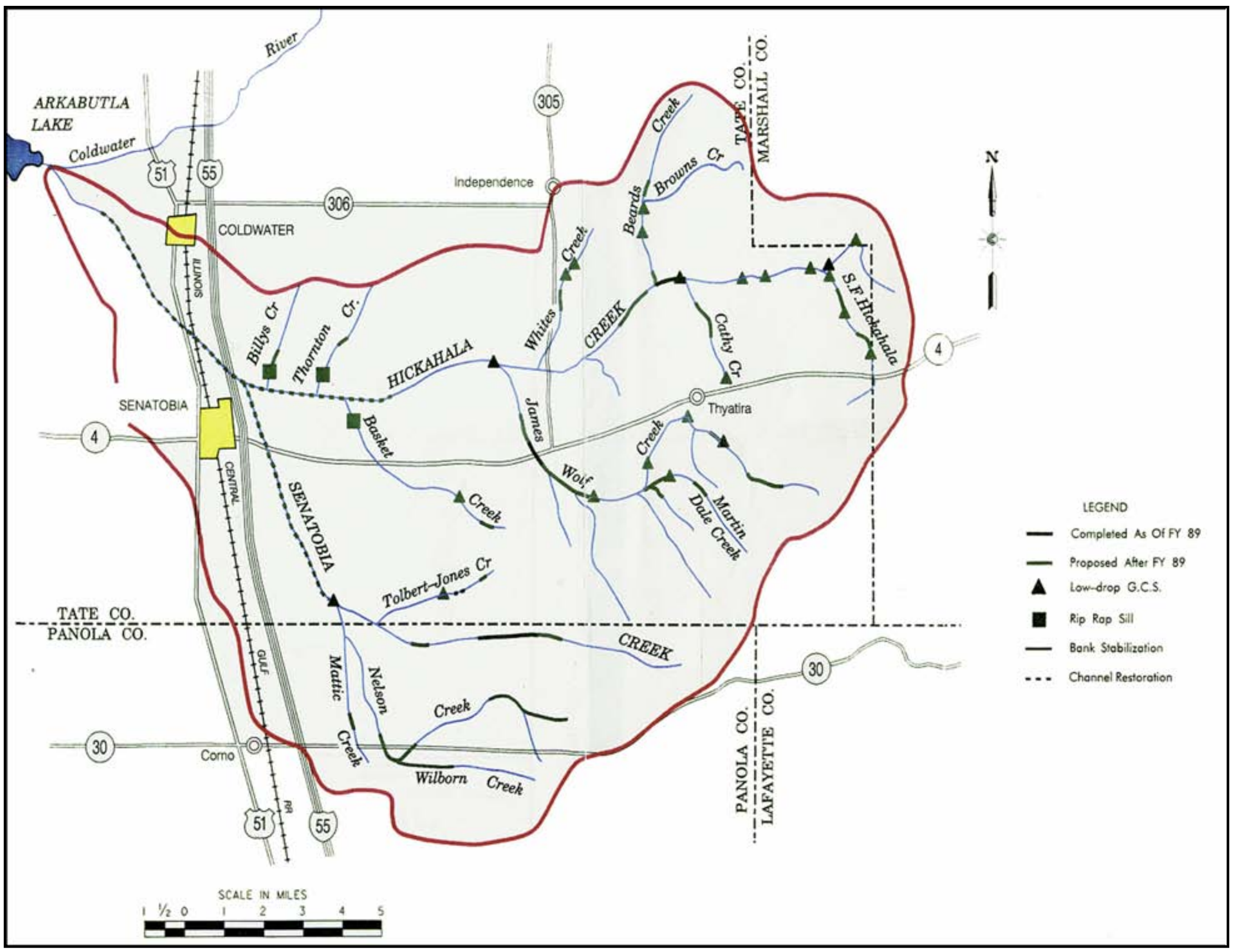

Figure 2. Hickahala Creek Watershed, Northern Mississippi.

Channels in the vicinity of the Arkabutla Reservoir boundary have demonstrated a historic tendency for aggradation. Deposition of sediment in these channels has resulted in a continued loss of flood-carrying capacity. A major cause of this accelerated deposition is the increased sediment supply from upstream degrading channels. This aggradational tendency has resulted in the need to restore channel capacity in the lower portions of the watershed. Early attempts to provide flood control in these channels were unsuccessful due to the large sediment supply from upstream. In 1967, portions of Hickahala Creek and Senatobia Creek were extensively cleared, enlarged, and straightened under direction of the USDA Soil Conservation Service (SCS). The increased hydraulic efficiency resulted in headcutting of the main channel and its tributaries. By the 1980s, the lower end of Hickahala Creek was blocked by sediment and large woody debris, with the main flow path being diverted to the southwest through an older channel. Surveys of the channels in 1985 showed that about 1.8 to 2.4 m of aggradation had occurred in the vicinity of the reservoir boundary. The aggradation and loss of flood capacity in the lower channels resulted in the need to develop a flood-control plan that addressed both the hydraulic efficiency of the channels and the sediment supply from upstream.

APPLICATION OF DEC APPROACH TO HICKAHALA CREEK WATERSHED.

The following sections briefly describe the plan development, and discuss the observed response to the implemented channel improvement project.

Project Initiation. The Hickahala Creek watershed has a number of interrelated problems involving bed and bank erosion, sedimentation, gullying, environmental degradation, and flood control. The goals of the project were to correct the system-wide bed and bank erosion, reduce the aggradational problems in the lower basin, protect riparian infrastructure, provide flood control to the lower channels, and enhance the environmental aspects of the channels. Consequently, an interdisciplinary team of engineers and scientists was assembled to develop alternatives to address these problems.

Geomorphic Assessment of Hickahala Creek Watershed. A detailed geomorphic assessment of the Hickahala Creek watershed was conducted. Data gathering was one of the first efforts in this process. The primary sources of information used in the study of the Hickahala Creek watershed came from the Corps of Engineers, the Agricultural Research Service, the NRCS, the USGS, and the Mississippi State Highway Department. The types of information gathered included channel surveys, flood history information, stream gage data, sediment transport data, watershed erosion data, land use data, existing erosion and flood-control features, bridge plans, and aerial photography. In addition to the historical data, a new channel survey of Hickahala Creek and all its major tributaries was conducted. These extensive surveys included a thalweg survey with cross sections spaced approximately 750 m apart.

Review of historical data is important in developing an understanding of the dynamics of the system, but is not sufficient to develop solutions and assess expected impacts. The available historical data must be supplemented with field investigations. Field investigations, including both aerial and ground reconnaissance, of the entire Hickahala Creek watershed were conducted. The information collected during the field investigations included documentation of erosion sites, areas of flooding, location and status of all infrastructure, bed and bank materials, bank height and angles, depth of sediment in the channel, sediment sources, and stream crossings.

Fifty-eight samples of bed and bank materials were collected at representative locations along the channels.

The results of the field investigations were combined with comparisons of historical and current surveys and mapping, and evaluation of gage data to document the historical and current trends in the system. Evolutionary trends and current stability were identified with the streams being divided into geomorphic reaches based on the channel evolution model (Schumm et al. 1984).

The hydraulic stability of the channels in the Hickahala Creek watershed was evaluated using four separate techniques:

- comparative thalweg surveys
- equilibrium slope analysis
- average bed shear stress at the channel forming discharge
- long-term sediment routings.

The first three methods were used early in the study to establish the overall stability of the various reaches in the basin and to assist in the development of alternative rehabilitation strategies for the basin. If the goal had simply been to provide erosion control, then these simple assessment techniques may have been sufficient. However, because of the complex goals in the Hickahala Creek watershed, a long-term sediment routing model was developed to analyze the impacts of potential alternatives.

Bank stability assessments in the Hickahala Creek watershed were performed based on stability relationships developed by Osman and Thorne (1988). These relationships were developed using data from incised channels in northwestern Mississippi.

The data in Table 1 summarize the hydraulic and geotechnical stability assessments for the channel reaches within the Hickahala Creek watershed. This is, effectively, a tabular summation of the systems approach as applied to the Hickahala Creek watershed. As the data in Table 1 indicate, there is not always agreement between the various methods used. For this reason, engineering judgment must be applied. Therefore, overall assessment of the geotechnical and hydraulic stability of each geomorphic reach are based on a subjective comparison of the results of all the geomorphic assessment techniques, tempered by the information obtained in the field investigations.

Plan Formulation. Once the geomorphic assessment was complete, alternatives were identified that would address the project goals of correcting the system-wide bed and bank erosion, reducing the aggradational problems in the lower basin, protecting riparian infrastructure, providing flood control to the lower channels, and enhancing the environmental aspects of the channels.

Plan Evaluation and Preliminary Design. Figure 3 shows the steps in the plan evaluation and preliminary design sequence. Biedenharn (2004) discusses the plan evaluation and preliminary design sequence in detail.

Table 1. Summary of Stability Assessment Using Geomorphic Assessment Techniques of System Approach.

Creek	Reach	Thalweg Surveys	Sediment Routing Analysis	Equilibrium Slope Analysis	Average Bed shear Stress at Dominant Discharge	Overall Geotechnical Stability Assessment	Overall Hydraulic Stability Assessment
Hickahala	1	A	A	A	A	S	A
	2	D	A	A	A	S	S
	3	D	A	S	A	N	S
	4	D	D	D	D	N	D
	5		D	D	D	U	D
Billys	1	A	A	A	A	S	A
	2			S	D	N	S
Thornton	1	D		A	A	S	A
	2			D	A, D	N	S
Steammill	1			A	A, D	N	S
Whites	1	D	S	A	S	N	S
	2			S	U	D	
	3			A	S	S	
Beards	1	D		A	A	N	S
	2			D	D	N	D
	3			A	A, D	N	S
West Ditch	1	S		A	A	S	A
	2			D	A, D	N	S
Basket	1	S	A	A	A	S	S
	2	D	A	A	A, S	N	S
	3			A	A, D	U	S
James Wolf	1	D	A	S	A	S	S
	2		D	D	A	N	S
	3		D	D	A, S	U	D
	4		D	D	A, D	U	S
Martin Dale	1			D	S, D	U	D
	2				S, D	U	D
Cathys	1			S	A, D	N	S
	2			A	A, D	U	D
South Fork	1			D	N	S	
Hickahala	2				U	D	
Sentatobia	1	A	A	A	A	S	A
	2	S	A	A	A	S	S
	3		S	S	A, S	N	S
	4		S	D	S	U	S
Mattic	1		A	A	S	N	S
Nelson	1			A	S	N	S
	2			A	A, D	U	S
Tolbert-Jones	1			A	A, D	N	S
	2			A	A, D	U	S

NOTES:
A = Aggrading channel bed
S = Stable channel bed or stable channel bank
D = Degrading Channel bed
U = Unstable channel bank
N = Unreliable channel bank

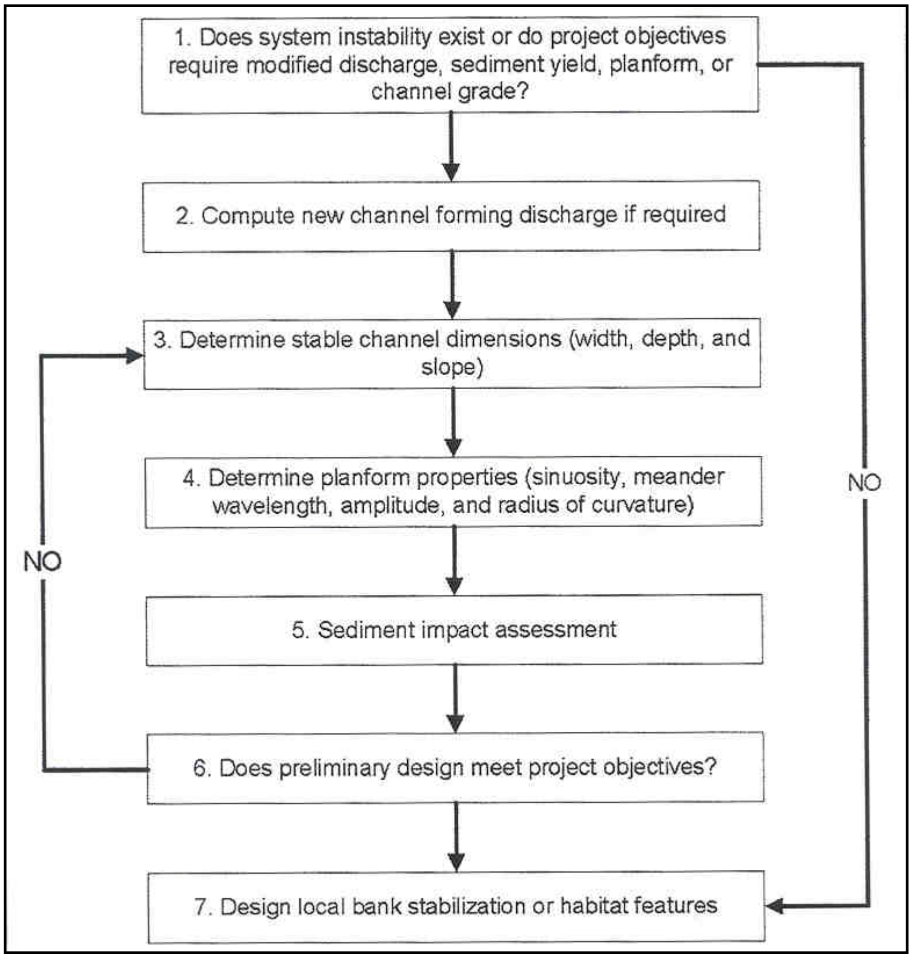

Figure 3. Plan evaluation, and preliminary design sequence.

The first step in the design sequence shown in Figure 3 asks a critical question: "Does system instability exist or do project objectives require modified discharge, sediment yield, planform, or channel grade?" Based on the geomorphic assessment, it was found that system instability did indeed exist in the form of severe channel degradation in the upper portions of the watershed, with channel aggradation along the lower reaches of Hickahala and Senatobia Creeks. It was also apparent that project goals of a sustainable flood control channel along lower Hickahala and Senatobia Creeks might require changes in the sediment yield, discharge, and channel grade. Therefore, it was necessary to proceed to Step 2 in the design sequence.

The second step in the plan evaluation and preliminary design sequence is the determination of the channel forming discharge, which is often used in the initial calculation of stable channel dimensions. The channel forming discharge was calculated for each geomorphic reach. Based on bank-full indicators and effective discharge calculations it was decided to select the 2-year recurrence interval flow to represent the channel forming discharge. The use of the channel forming discharge in this study was limited to the calculation of the average bed shear stress in the geomorphic assessment of the channels.

Computation of stable channel dimensions (width, depth, and slope) is the third step in the process and can be accomplished by a number of empirical and analytical methods. A major component of the Hickahala Creek Watershed plan was the channel improvement in the lower portion of the basin to provide improved flood control. This plan called for approximately 22.5 km of channel improvement along the lower Hickahala and Senatobia channels. This work was intended to restore the conveyance lost due to historic aggradation. Initial channel dimensions (width, depth, and slope) were calculated for the channel using empirical relationships, tempered with engineering experience gained from work in similar watersheds and the geomorphic assessment.

Past experience had shown that channel improvement of the lower portions of Hickahala and Senatobia Creeks would not be successful without reducing the upstream sediment supply. Therefore, it was determined that for the downstream channel improvement project to be successful, a comprehensive erosion control and land treatment program must first be implemented in the upper watershed. A critical component in the erosion control plan was the construction of grade control structures to prevent further channel degradation. The determination was made to stabilize the channel systems along existing straightened planform rather than to restore them to some previous meandering pattern because of existing infrastructure and land use. Consequently, a complete design of new channel dimensions (width, depth, and slope) was not required. Rather, a stable slope for each reach was calculated using equilibrium slope methods, and grade control structures were designed to meet the stable slope requirements. Other erosion control features included bank stabilization, drop pipes, and land treatment measures. The location for these measures was based on field determinations of areas of severe erosion and sediment delivery.

The fourth step in the design sequence is the determination of the meander planform properties. As previously noted, the decision was made to stabilize the channel along the existing alignment. Therefore, no analysis of stable planform properties was required.

The fifth step in the process was the completion of a sediment impact assessment to assess the long-term impact of the proposed erosion control measures in the upper watershed on sediment transport and flood control. The evaluation was made by conducting a long-term (30-year) sediment routing simulation to define aggradation/degradation trends along the channel system using the KUWASER model (Simons, Li & Associates 1988). The results of the long-term sediment routing indicated that the channel improvement of the lower Hickahala and Senatobia Creeks produced increased and more consistent sediment transport capacities which, when combined with the reduced sediment supply from upstream, would result in reduced aggradation trends.

Plan Selection. The data in Table 2 summarize the selected plan for the Hickahala Creek watershed. Figure 2 shows the limits of the channel improvement work, and the location of proposed grade control structures and the general areas requiring bank stabilization.

Implementation. Construction of the erosion control features began in 1986, while construction of the channel improvement project was not initiated until 1993. The channel improvement project was completed in 1994.

Monitoring and Feedback. A comprehensive monitoring plan was implemented for the Hickahala Creek watershed. The monitoring is being conducted by the ERDC Coastal and Hydraulics Laboratory (CHL), and CSU.

Table 2. Summary of Improvements for Hickahala Creek Watershed.

Feature	Unit	Constructed (as of 2003)	Remainder to Construct
Low Drop Grade Control Structure	each	21	0
Riser Pipes	each	158	100
Riprap Sills	each	3	0
Bank Stabilization	meters	11,270	21,560
Debris Basins (Rehab)	each	0	40
Intermediate Dam (Rehab)	each	0	20
Debris Basins	each	0	10
Intermediate Dam	each	0	10
Channel Improvement	kilometers	22.5	0
Bridge Replacement	each	5	15
Box Culvert Grade Control Structures	each	1	9
Overfall Pipes	each	280	200
Critical Area Planting	hectares	324	810
Strip Cropping	hectares	8	12
Terraces (Parallel)	meters	0	4,830
Diversion Terraces	meters	305	7,315

CHANNEL RESPONSE TO IMPLEMENTED PLAN. The channel improvement work on Hickahala and Senatobia Creeks was completed in 1994. Figures 4 and 5 show the effects of the project, including the minimum stage from 1960 to present at the Hickahala and Senatobia Creek gages, respectively. These gages are located near the upper limits of the channel improvement project (Figure 2). Figures 4 and 5 also show the response to the earlier channel improvement work in about 1967, as well as the response to the present project.

As shown in Figure 4, the 1967 channel work lowered stages on Hickahala Creek about 2.3 m, from about 74.6 m to about 72.3 m. However, stages immediately began to increase and by the early 1990s, stages were once again approaching 74.5 m. The response to the 1994 channel improvement work is much different from the earlier response. The 1994 channel improvement project initially lowered stages from about 74.5 m in March 1994 to about 72.8 m in January 1995 (Figure 4). Post-project aggradation occurred immediately following the 1967 work. However, no aggradational response to the recent work has been observed through September 2002. Field observations also confirm the absence of any significant aggradation.

Figure 5 is similar to Figure 4, and indicates the minimum elevation of Senatobia Creek through time. On Senatobia Creek, the rebound from the 1967 channelization was immediate and most of the flood level reduction was lost within 3 years. The data from the present channel work indicate that falling stages began in February 1995 at a stage of about 74.4 m, and continued to fall to a low of about 72.5 m in September 2001. No aggradation is shown at this time and the channel continues to increase in flood capacity.

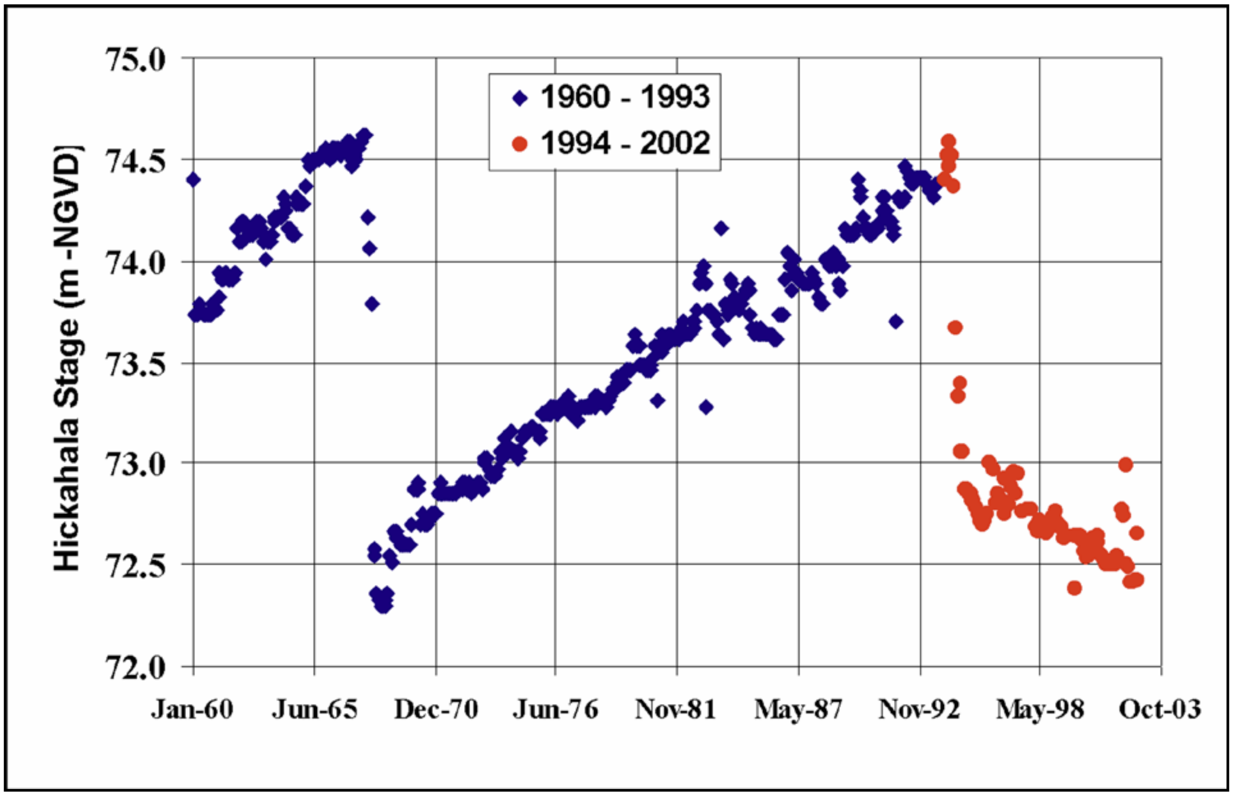

Figure 4. Minimum monthly elevation of gage readings on Hickahala Creek.

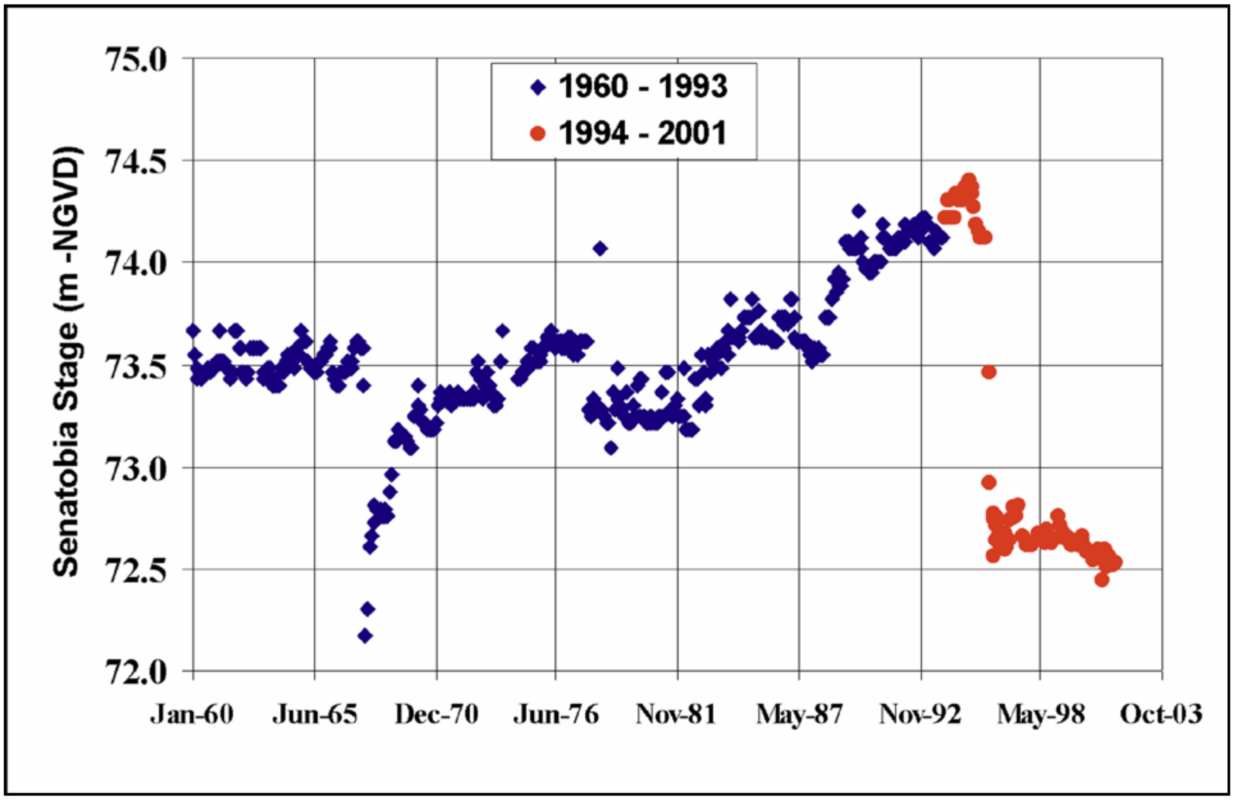

Figure 5. Minimum monthly elevation of Senatobia Creek Gage Readings.

An important component of the channel improvement project was the construction of the erosion control features in the upper watershed. Perhaps some of the most important structures, at least in the short term, were the two riprap sills constructed just upstream of the upper limits of the project on Hickahala and Senatobia Creeks. These sills were initially constructed at the existing bed elevation with no drop across them (Figure 6). However, a 2003 field inspection of these structures revealed about 1 m of drop across each structure (Figure 7). Had these structures not been built, approximately 1 m of additional bed lowering would have advanced upstream for many kilometers resulting in accelerated sediment supply to the downstream project area. This increased sediment load would have severely impacted the longevity of the project. Additionally, riprap sills were also constructed near the mouths of all tributaries entering the project area.

Figure 6. Initial riprap sills.

Figure 7. Riprap sill during 2003 field inspection.

By using equilibrium slope analysis and empirical relationships for channel widening as functions of bed lowering, an estimate was made of the sediment and soil loss if incision and widening continued to an ultimate equilibrium condition for the streams in the Hickahala Creek watershed. This analysis was conducted for both with and without the DEC project features in place. The results estimated that the DEC project in the Hickahala Creek watershed would decrease the volume of sediment introduced into the channel systems by about 64%. While these results are strongly supportive of beneficial reductions in sediment yield, the benefits presented are limited to only the extent of streams surveyed. Not all streams in the watershed were surveyed and no streams were surveyed to the upstream extent of the channel. Therefore, the long-term sediment yield reduction could be even greater than 64% if the impacts to these first- and second-order streams were to be considered.

The time required for the sediment yield reductions to be realized in the downstream reaches of the watershed is unknown. It could take anywhere from 10 to more than 100 years, depending upon a number of factors such as bed and bank materials, and hydrologic factors. Based on the temporal series of cross-section data, a relation of the future thalweg depth as a function of time was obtained based on an exponential decay function developed by Simon (1989). Based on these results, an adjustment time of approximately 50 years was calculated. While it is difficult to quantify the exact impacts of the erosion control features on the downstream reaches, these features have undoubtedly contributed to the short-term success of the project, and will continue to provide tremendous benefits to the project and the system as a whole in the long term.

Although the channel improvement project has performed as designed with no loss of channel capacity over the past 6 years, it must be recognized that the area in the vicinity of the reservoir boundary is a natural deposition area. Therefore, aggradation of the channel should be expected to occur at some point in time. The purpose of the systems approach in the Hickahala Creek watershed was not to totally eliminate the erosion and sedimentation processes, but rather to minimize these impacts and prolong the life of the channel improvement project. Thus, the systems approach applied to the Hickahala Creek watershed illustrates the importance of effective regional sediment management to satisfy complex water resources goals.

CONCLUSIONS. As water resources projects grow in complexity, the need for effective regional sediment management has begun to be recognized. Unfortunately, there is little guidance for conducting this type of investigation, and even less documentation exists of the successful application of regional sediment management. A systematic and organized approach for channel rehabilitation and sediment management has been developed and applied through the DEC project in northern Mississippi. The success of applying the regional sediment management approach is illustrated in the performance of the Hickahala Creek watershed project. By applying a comprehensive regional sediment management approach to the Hickahala Creek watershed, the Corps has been able to prolong the life of a channel improvement project within a historically severely aggrading zone.

ADDITIONAL INFORMATION. This Coastal and Hydraulics Engineering Technical Note (CHETN) was written by Drs. David S. Biedenham, Chester C. Watson, Lisa C. Hubbard, and John B. Smith, all of the Coastal and Hydraulics Laboratory, US Army Engineer Research and Development Center (ERDC), Vicksburg, MS. The work described herein was supported by the Regional Sediment Management (RSM) Demonstration Program (DP). Additional information

pertaining to RSM can be found at the Regional Sediment Management web site http://rsm.usace.army.mil

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