USE OF FLUVIAL GEOMORPHOLOGIC KNOWLEDGE TO REDUCE THE COST OF BANK STABILIZATION IN NORTHERN MISSISSIPPI

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ABSTRACT

Rivers in a natural environment establish definite patterns that are the result of the drainage basin's geologic history, the available sediments and the hydrologic input.

If the river engineer will recognize these natural controls, a more economical, more aesthetically acceptable and ecologically adjustable means of improving stability can be constructed.

This paper presents this fluvial geomorphic approach on a Northern Mississippi unstable stream.

INTRODUCTION

Chorley, et. al. (1984) state that geomorphic studies comprise a spectrum of approaches between two major, interrelated conceptual bases:

(1) Historical studies which attempt to deduce from the erosional and depositional features of the landscape evidence relating to the sequence of historical events through which it has passed.

(2) Functional studies of reasonable contemporary processes and the behavior of earth materials which can be directly observed and which help the geomorphologist to understand the maintenance and change of landforms.

Chorley, et. al. (1984) further state that applications of geomorphology can be divided broadly into two classes:

(1) Man as a geomorphic agent, in times of his inadvertent and planned effects on geomorphic processes and forms.

(2) Geomorphology as an aid to resource evaluation, engineering construction and planning.

The Streambank Erosion Control Evaluation and Demonstration Act of 1974, Public Law 93-251, Section 32, afforded an opportunity to experiment with a wide variety of methods of stream bank and bed stabilization methods. Researchers in this field have believed for a long time that incorporating natural controls and geometry with manmade controls could produce less expensive and more effective methods of river stabilization. Too often the methods of channel straightening and forced malalignment have resulted in more problems than those experienced in the natural stream.

Stream channels and drainage basins in Northern Mississippi have been subjected to many alterations that have changed both the water load and the sediment load and because of the easily erodable alluvum in their beds and banks have reacted in a deteriorating manner.

Johnson Creek (Figure 1) is a sixth order tributary of the Peters, Yocona, Coldwater, Yazoo, Mississippi System in Northern Mississippi. It has a 19.1 square mile drainage basin totally composed of rural-agricultural lands.

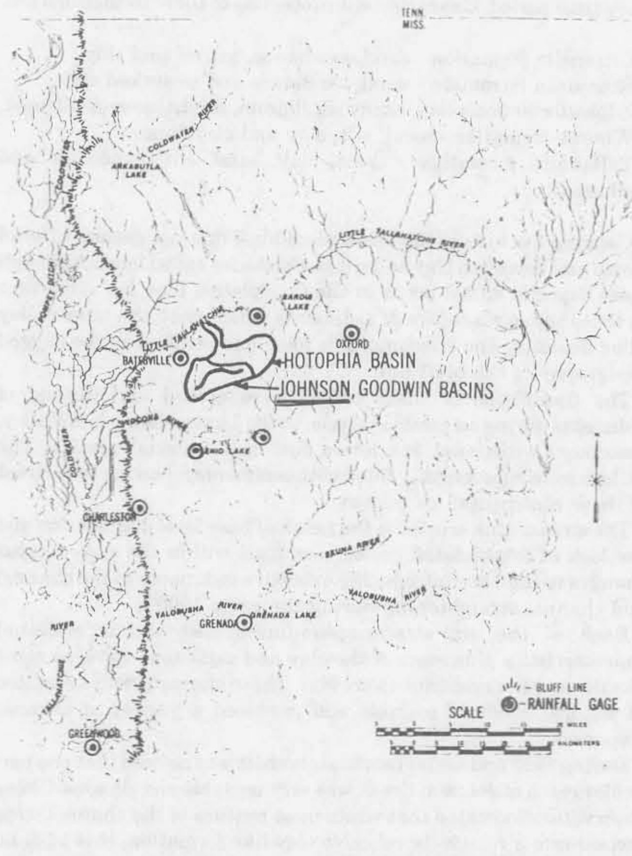

Figure 1–Location of rainfall gages

GEOMORPHIC ANALYSIS

The Section 32 report states that the geology of a drainage basin is one of the most significant factors in the analysis of channel stability. The physical properties of each stratigraphic unit are directly related to the response of a stream as varied hydraulic forces are imposed upon the system. The strength and corresponding erodibility of each unit varies with the grain size, cohesion, compaction, and consolidation of the materials which are deposited. To be able to accurately assess and predict the stability of a stream, a complete knowledge of the geological variations within the basin must be gained.

The geology of this basin consists of Eocene sands and clays in the uplands with a complex alluvial fill in the floodplain. The valley fill is the depositional area of upland erosion which occurred following the Wisconsin glaciation.

Mississippi State Geological Survey Bulletin No. 81, Vestal, (1956), presents the generalized geologic outcrops in this watershed. Four geologic units of Eocene Age outcrop occur within these watersheds. Through a cooperative agreement with the ARS Laboratory in Oxford, Mississippi, recent investigations within this area have shown that the outcrops may be the result of variations in the composition of younger deposits. For a complete description of these deposits, the reader is referred to Appendix E of the ARS Report (1981) to Vicksburg District.

Five formations influence this basin, the Citronelle, Kosciusko, Zilpha, Winona, and Tallahatta. The Citronelle was probably deposited during the Pliocene-Quaternary time period, while the latter four were laid down during the earlier Eocene Epoch of the Tertiary time period. Characteristic properties of these formations are:

Citronelle formation - sand, sandstone, gravel and clay.
Kosciusko formation - sand, sandstone and reworked clay.
Zilpha formation - clay, sandy silt, lignite, sandstone and siltstone.
Winona formation - sand, silt, clay and claystone.
Tallahatta formation - shale, clay, sand, silt, sandstone and siltstone.

Capping the hills of the Mississippi bluff line is a deposit of wind blown and deposited clay and silt size particles called loess. Although these deposits do not occur in the floodplains, they are important in that they are a source of sediments which were the later valley filled deposits. The erosion of this loess has resulted in the rugged topography of the bluff line.

The floodplains of these basins were eroded and flushed of sediments during an erosional cycle, in the Lower Mississippi Valley, associated with lower sea levels during the glacial periods. The valleys were subsequently filled with sediments following the retreat of these continental ice masses.

The streambank erosion is the result of base level degradation and the lack of consolidated geologic controls within the system, plus changes in land use introducing excessive sediments to the channel and channel straightening during the early 1900's.

Each of the six stratigraphic units had varied erosional characteristics plus some of the clay and sandstone were, at some locations, quite resistant to erosion. These characteristics resulted in natural gradient controls and produced a variety of channel responses.

During field and aerial reconnaissance it was noticed that one particular reach of Johnson Creek was very unstable and sinuous. Closer observation indicated that while most reaches of the channel were incised into a relatively cohesive clay-like formation, this 14-bend reach had excessive lateral migration over a more cohesive formation.

Historical evidence of this basin parallels that of similar basins in the Yazoo system. The 1834 maps show no settlement in the basins but do indicate extremely sinuous rivers, which would result from excessive sediment loads of relatively coarse material.

As evidenced by 1935 to 1944 photos, extensive land clearing had occurred and though the stream banks were vegetated, there is evidence of recent excessive bank caving. More land clearing occurred early in the lower, downstream portion of the basin than in the headwaters, but by 1957 much of this early farm land had been vegetated. And by 1976, much of the rowcrop land in the lower end of the basins was being converted to pasture land; also, many wooded acres in hills were being cleared for pasture.

This stream is an excellent example of a channel's geometric adjustment to land use changes, channelization, hydraulic and hydrologic alternatives and variations in sediments. Poor agricultural practices created excessive erosion; local landowners, as well as Federal agencies, altered channel geometry; stream flow conditions were changed by impondments; and the basin's geologic history deposited sediments with a range of erodibility as well as transportability. The end result is the individualized channel reaches occurring in the stream.

Figure 2 shows the reaches that were straightened out from a period prior to 1937 through 1963.

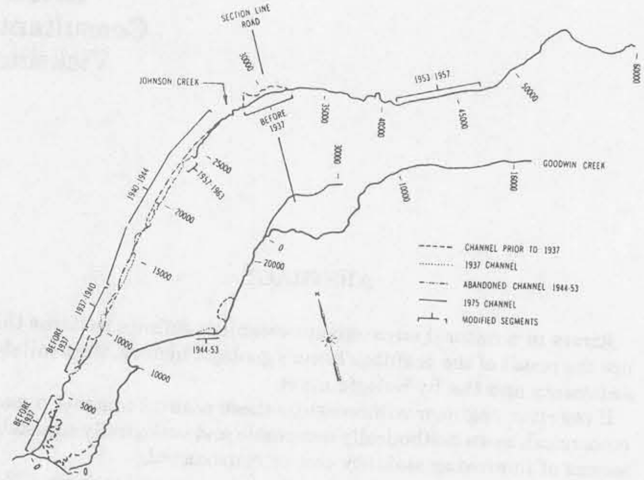

Figure 2–Johnson Creek channel changes (Grissenger, 1981)

Figure 3 locates the knickpoint migration resulting from straightening of the channel as shown in Figure 2 and from base-level lowering. The author realizes that there could be other causes of this bed degradation but these are the most obvious.

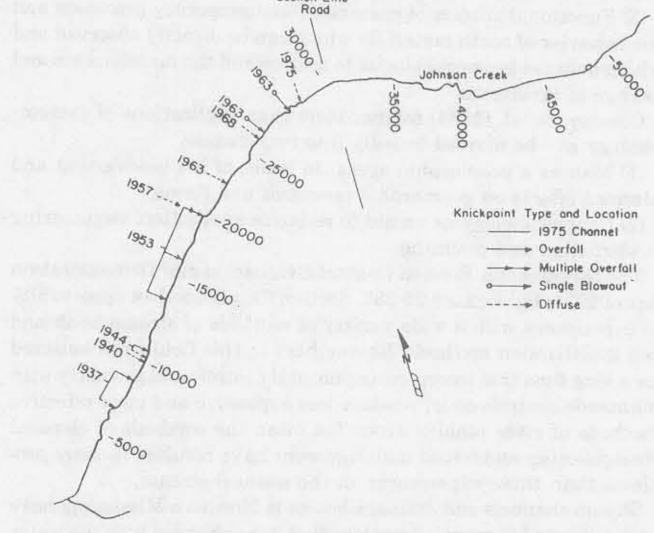

Figure 3–Knickpoint migration in Johnson Creek (after Ethridge, 1979)

Width/depth ratios are shown in figure 4. Upstream of bed degradation, the ratios are consistent indicating that the channel has adjusted to a dynamic equilibrium. Downstream a wide range of width/depth ratios result from variation in stratigraphy and cohesiveness of the bed and bank material plus variation in energy gradient, (Figure 5).

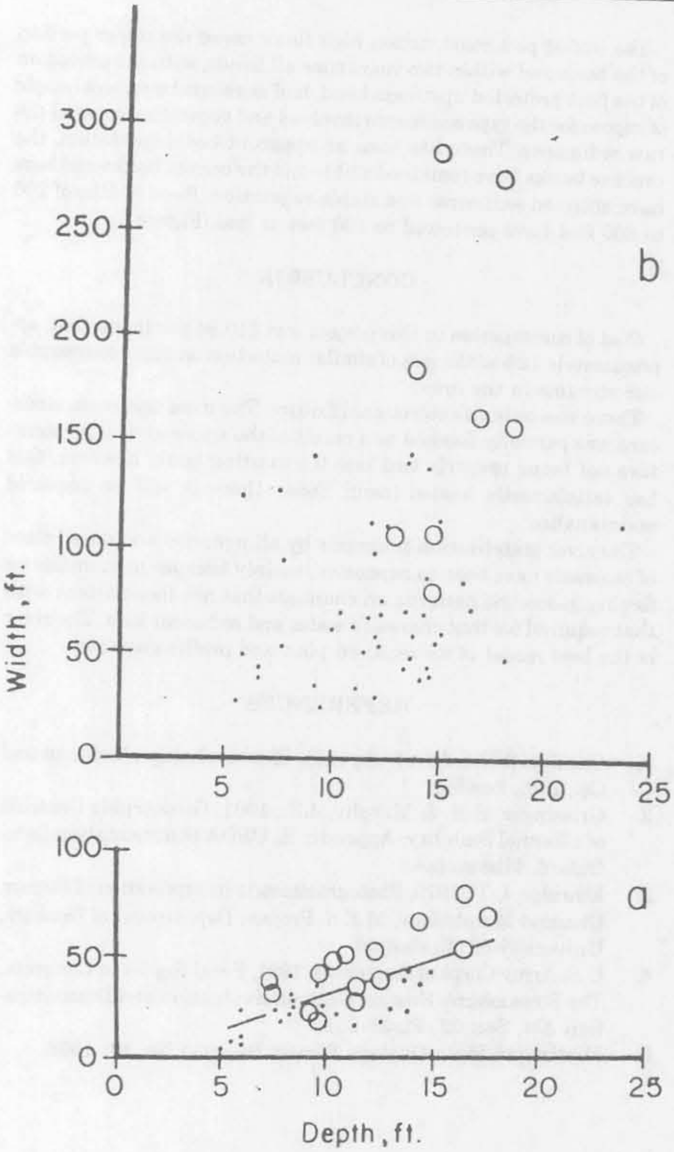

Figure 4 – Width-to-depth ratios for Johnson Creek upstream (a) and downstream (b) of the knickpoint, from stereoscipic analysis of ASCS aerial photographs for the years 1937, 1940, 1944, 1953, 1957, 1963 and 1968 (identified by dots) and for the year 1975 (identified by circles)(Ethridge, 1979).

Four rain gages (Figure 1) were available with records varying from 30 to 48 years. Monthly and annual precipitation are consistent over the area; however, the period of reconnaissance and construction was wetter than normal.

Land use changes as indicated on aerial photos suggested possible sediment surges during historic periods. Sinuosity versus valley slope suggested that the reach to be stabilized has a geometry compatible with other regime reaches over the historic record.

No measured sediment data was available, only visual analysis during the field trips.

HYDRAULIC-GEOMETRIC ANALYSIS

The 14 bends on a 4300-foot reach of Johnson Creek were chosen to demonstrate that by using geologic control plus the hydraulic-geometry of the channel, an effective, less costly means of stabilization could be constructed.

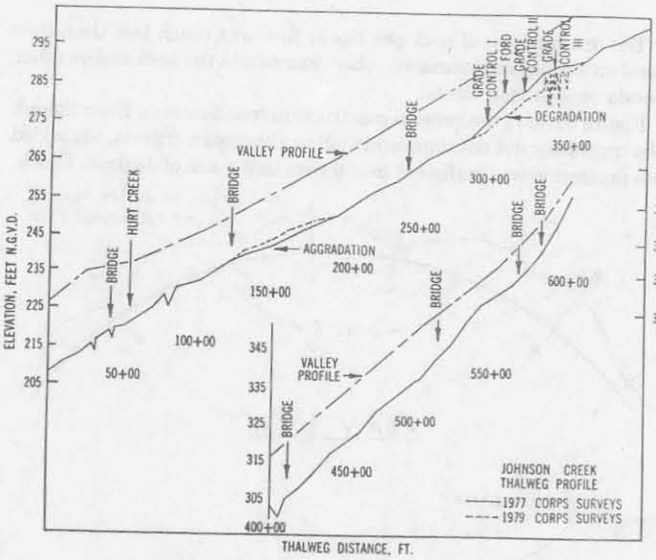

Figure 5 – Valley and Thalweg Profiles

Reconnaissance trips indicated that the present geometry was compatible with natural geometry and also that the thalweg was being stabilized by a cohesive material acting as a bedrock. Channel changes were only in the lateral direction. Channel geometry, measured from topographic maps, aerial photos and two thalweg surveys, was determined to be within the acceptable limits of the probable extremes of hydrographs that would be imposed on the stream. This acceptable geometric pattern was then superimposed on a survey of the channel and the following criteria specified: (1) channel geometry that would accommodate all flows; (2) the shape of the structure in each bend must be an arc of a circle with no deviations; (3) the width of the low water channel at each crossing must remain constant throughout the reach; (4) the distance between the end point of control of the lower end of the upstream structure and the beginning of the control of the opposite downstream structure must be one channel width; (5) the upper end of each structure must be tucked into the local topography in such a manner that the stream will not flank that structure; (6) the lower end of each structure should streamline into the local topography in such a manner that it would not create unnecessary turbulence; (7) the elevation of the top of the rock on each bend be constant; and (8) the side drainage be treated as if it did not exist. The structures were to be one-half ton per linear foot of limestone riprap, place peaked or against the bank to effect an arc of a circle. More rock was to be used if necessary to effect a constant top elevation through any depressions. The bank and streambed were not to be disturbed in any manner.

Every other bendway was planted with "water elm", the alternating bends were left to re-establish natural vegetation. No significant variation in response could be determined from either method, possible because the natural vegetation was so prolific it immediately took over the raw areas as soon as bank caving ceased.

Because of poor construction control, many of the original concepts were not incorporated into the actual construction; therefore, the project resulted in: (1) bends with reverse curves; (2) uneven elevations of structures; (3) crossing too wide as well as too narrow; (4) structures overlapping; (5) inadequate tie into the local topography; and (6) radii different than designed.

Even with the above deficiencies, the structures appear to be working very well. Several high flows were experienced during the first two years after construction and then a long period of relatively dry weather followed. Since then there have been several overbank events. Except for a short straight reach left unprotected, the total reach is adjusting very well. Banks have caved to a natural angle of repose and the channel has developed a look of stability with no raw caving banks.

The one-half ton of rock per linear foot was much less than that used on similar structures on other channels in the area and on other bends on Johnson Creek.

Figure 6 shows the general construction specifications. Even though the contractor did not completely follow the design criteria, the added toe protection was sufficient to stabilize this reach of Johnson Creek.

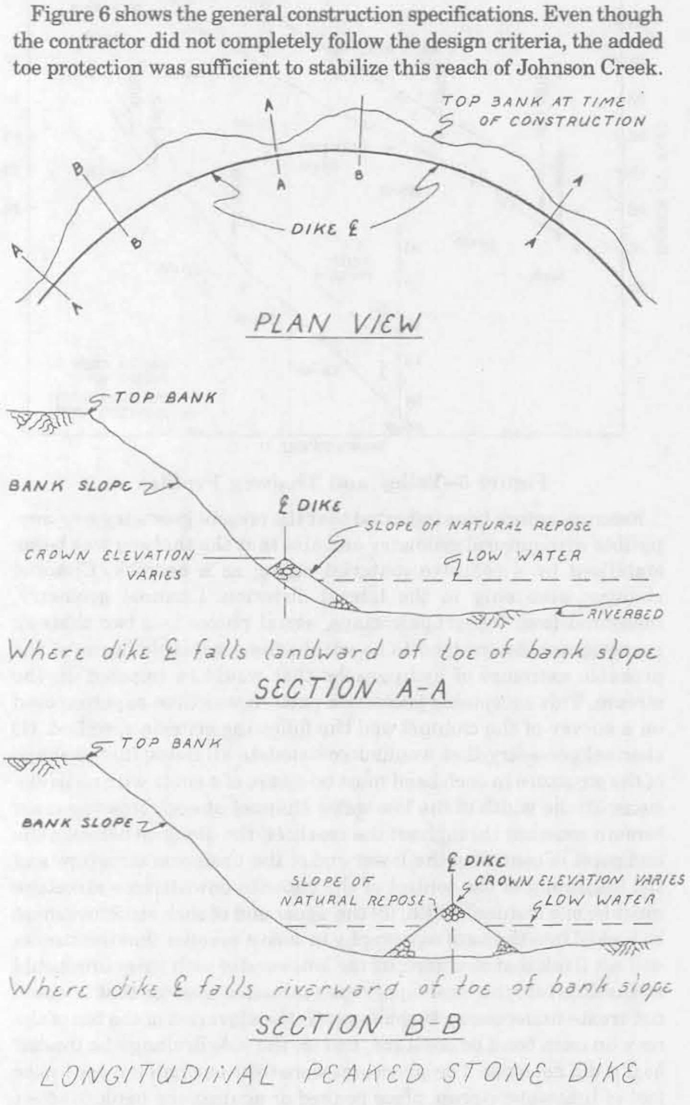

Figure 6.

The initial post-construction high flows caved the upper portion of the bank and within two years time all bends, with the exception of the first protected upstream bend, had developed a natural angle of repose for the type sediments involved and vegetation covered the raw sediments. There has been no apparent bed degradation, the concave banks have remained stable and the convex banks and bars have accreted sediments and stable vegetation. Bend widths of 200 to 300 feet have narrowed to 100 feet or less (Figure 4).

CONCLUSION

Cost of construction in this project was $10.94 per linear foot, approximately 12% of the cost of similar protection on other comparable size streams in the area.

There was only one objectional failure. The most upstream structure was partially flanked as a result of the upper end of the structure not being properly tied into the existing bank; however, this has satisfactorily healed itself. Today there is still no required maintenance.

The river stabilization programs by all agencies and on all sizes of channels have been to expensive, mainly because man insists on forcing geometric patterns on channels that are inconsistent with that required for that channel's water and sediment load. The river is the best model of its required plan and profile geometry.

REFERENCES

1. Chorley, Richard J. et. al., 1984, Geomorphology, Methuen and Co., Ltd., London.
2. Grissinger, E.H. & Murphy, J.B., 1981, Geomorphic Controls of Channel Stability, Appendix E, USDA Sedimentation Lab., Oxford, Mississippi.
3. Ethridge, L.T., 1979, Photogrammetric Interpretation of Stream Channel Morphology, M.E.S. Project, Department of Geology, University of Mississippi.
4. U.S. Army Corps of Engineers, 1981, Final Report to Congress, The Streambank Erosion Control, Evaluation and Demonstration Act, Sec. 32, PL 39-251.
5. Mississippi State Geology Survey Bulletin No. 81, 1956.