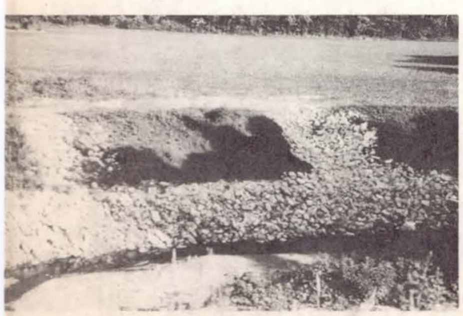
US Army Corps of Engineers

December 1981

FINAL REPORT TO CONGRESS

THE STREAMBANK EROSION CONTROL EVALUATION AND DEMONSTRATION ACT OF 1974 SECTION 32, PUBLIC LAW 93-251

Appendix F - Yazoo River Basin Demonstration Projects



Rock Toe With Tie-Backs

Precast Block Paving

Board Fence Dikes

FINAL REPORT TO CONGRESS

THE STREAMBANK EROSION CONTROL EVALUATION AND DEMONSTRATION ACT OF 1974 SECTION 32, PUBLIC LAW 93-251

APPENDIX F

YAZOO RIVER BASIN DEMONSTRATION PROJECTS

Consisting of

A COMPREHENSIVE SUMMARY REPORT ON STREAMBANK EROSION CONTROL DEMONSTRATION PROJECTS CONSTRUCTED IN EIGHT WATERSHEDS OF THE YAZOO RIVER BASIN

U.S. ARMY CORPS OF ENGINEERS

December 1981

PREFACE

The Streambank Erosion Control, Evaluation and Demonstration Project was enacted as Section 32 of the Water Resources Development Act of 1974, Public Law 93-251, and amended by Public Law 94-587, Section 155 and 161, October 1976. The Vicksburg District portion of the project was conducted under the direction of Mr. John E. Henley, Chief, Engineering Division, and Mr. Roy O. Smith, Chief, Hydraulics Branch.

The report preparation and data analysis was conducted under the leadership of Mr. Brien R. Winkley, Chief, Potamology Section, VXD, by David S. Biedenharn, Jean M. Bishop, John H. Brooks, Caroline Dungan, Lloyd T. Ethridge, James V. Hines III, Robert E. Rentschler, and Donald R. Williams.

The design of bank protection features was under the direction of Mr. Charles M. Elliott, Chief, River Stabilization Branch, and the grade control structures were implemented by personnel of the VXD Design Branch. Coordination within VXD was accomplished by personnel of Project Management Branch. Final revision of this report reflects the combined direction of the Project Management Branch and the Hydraulics Branch. Assistance in the preparation of the report was given by Sandra Ford and Karen Buehler of Drafting Section. The word processing center, under the direction of Hilda McGuffee, was most helpful and patient in preparing the numerous drafts of the report.

The District Engineers of Vicksburg District during the course of study were Col. Gerald E. Galloway, Col. John H. Moellering, and Col. Samuel P. Collins.

APPENDIX F

Yazoo River Basin Demonstration Projects

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APPENDIX F

YAZOO RIVER BASIN DEMONSTRATION PROJECTS
SECTION 32 PROGRAM

I. INTRODUCTION

The United States contains nearly 3.5 million miles of rivers, creeks, and other such streams. Erosion is occurring on over half a million miles of bank lines along these streams. The resulting total annual damages of about $270 million are a serious economic loss to both private and public interests located along these streambanks. The U. S. Congress has recognized this problem and the potential benefits to be derived by controlling bank erosion. Legislation has been enacted to develop low-cost-effective bank protection guidelines for both public works and private citizens. A developmental program has been conducted by the U. S. Army Corps of Engineers.

A. Authority

The River and Harbor Act of 1968 (Title 1 of Public Law 90-483, Section 120) authorized and directed the Secretary of the Army, acting through the Chief of Engineers; ". . .to make studies of the nature and scope of the damages which result from streambank erosion throughout the United States. . . ." The ensuing Report of the Chief of Engineers to the Secretary of the Army, A Study of Streambank Erosion in the United States, August 1969, indicated that total annual damage resulting from streambank erosion in the United States amounted to approximately $90 million. In comparison, the estimated total annual cost of conventional bank protection required to prevent the damage was estimated to be $420 million, which emphasized the importance of developing low-cost methods for eliminating most streambank erosion problems. The 1969 report recommended a vigorous research and development effort, under existing agency authorities, to improve and develop the required low-cost remedial measures and to more fully understand the erosion process and its effects.

In recognition of the serious economic losses occurring throughout the Nation due to bank erosion, the U. S. Congress passed the Streambank Erosion Control Evaluation and Demonstration Act of 1974, Section 32, Public Law 93-251 (as amended by Public Law 94-587, Section 155 and Section 161, October 1976). This legislation authorizes a five-year program consisting of an updated analysis of the extent and seriousness of streambank erosion, research studies of soil stability and hydraulic processes to identify cause of erosion, an evaluation of existing bank protection techniques, and construction and monitoring of demonstration projects to evaluate the most promising bank protection methods and techniques. The program thus established will hereinafter be referred to as the "Section 32 Program."

B. Location and Watershed Description.

The Yazoo drainage system was an extremely complicated network as a natural system. The valley below the confluence of the Ohio and Middle Mississippi River at Cairo, Illinois, was deltaic and subjected to shifting water courses as it adjusted to the ever-changing sediment and water loads. Many parts of the Yazoo Basin were 30 feet below the banks of the present Mississippi River and acted like a large reservoir absorbing as much as 50 percent of the Mississippi River flows and then slowly releasing them back into the Mississippi River at Vicksburg.

Main line levees built along the Mississippi River shut off these distributory flows and left many of the Yazoo Basin channels as underfit streams adjusting their channel size to reduced local flows. Subsequent channel straightening, diversions, impondments and land use changes further altered the water and sediment loads into the channels. Continued modification of the channels and their water and sediment load even caused cyclic aggradation and degradation, channel enlargement and reduction.

Watersheds along the eastern bluff line of the Mississippi River alluvial plain (or "Delta" as it is locally called) all have a number of characteristics in common. Physiographically they are similar, located in either the Loess Hills (Bluff Hills) physiographic subprovince which is typified by deep windblown silt (Loess) deposits overlaying coarse-grained terrace deposits of sands, gravels, and some clays, or in the North Central Hills subprovince which is typified by more shallow windblown silt deposits overlaying finer sands and clays, some of which are fluvial and some of which are marine in origin. The valleys are all filled with coarse-grained lag deposits capped by 10 to 20 feet of reworked silt. The entire landscape consists of a sometimes thick, sometimes thin marginally cohesive mantle of material overlaying totally uncohesive sands and gravels. With this geologic stratigraphy and with the tendency of loess to erode vertically, the topography is steep where the loess is thick and is rugged and gullied where erosion has breached the thin loess mantle. Sediment production from the loose underlying sands and gravels is prolific. Where upland erosion was not held in check, many upland channels and Delta streams choked with sand. Where upland erosion was held in check, some upland channel beds and banks eroded and many Delta streams showed signs of aggradation.

Since the material beneath the loess consists of terrace deposits, it is not uncommon for the watersheds to have similar average maximum elevations and similar amounts of relief around 300 feet. At the bluff line where the loess and terrace deposits join the alluvial plain, about 200 feet of the relief occurs very abruptly. At this point streams exiting the bluff line change from a slope averaging 5 to 15 ft/mile to a slope closer to a half a foot a mile. A slope change this abrupt tends to promote deposition of the sediment carried by the hill streams and results in numerous alluvial fans along the toe of the bluff line. A similar tendency toward dropping sediment loads is observed when the hill tributaries join the main trunk streams such as the Tallahatchie, Yocona, or Yalobusha Rivers whose average slopes are around 1-1/2 to 3-1/2 ft/mile. In these cases, however, it is the main trunk river that receives the deposition of the sediment load. Characteristically, gravels and coarse sands plug the tributary mouths at these points of slope change, and the finer fraction of the sediment load plugs the main stream channels below.

The Yazoo Drainage Basin (Figure 1) extends from the Tennessee-Mississippi state line south-southwesterly to Vicksburg, Mississippi. It is roughly shaped like a hickory leaf or an overcup oak leaf and historically has always drained into the Mississippi River near Vicksburg. Its width varies from a few miles at its effluent to 85 miles wide at the northern end of the Basin. The central portion on a line through Cleveland and Grenada is about 115 miles wide.

Basically it is divided into two portions: (1) the Delta (6600 sq. miles) with three principal subdrainage basins; (a) the Steele Bayou; (b) the Sunflower, and (c) the Yazoo-Tallahatchie-Coldwater, (Fig. 1); and (2) the hill drainage (6800 sq. miles) with six principal drainage basins, (a) the streams draining into the Yazoo River below Greenwood, (b) the Yalobusha, (c) Tallahatchie, (d) Yocona, (e) Little Tallahatchie, and (f) Coldwater above the hill line. The delta is relatively flat with a slope of about 6 inches per mile. The hills rise 150 to 200 feet above the delta, and the various basins and subbasins have slopes varying from 1 foot per mile to over 50 feet per mile--thus an extreme variation in potential sediment transport.

C. Summary of Vicksburg District Activities.

A joint venture was undertaken with the Science and Education Administration--Federal Research, USDA Sedimentation Laboratory at Oxford, Mississippi, to define and monitor amounts, sources, direction, and time of travel of sediments. This includes a complete analysis of the drainage basin morphology, geology, soils, land use, vegetation, basin stratigraphy, hydrology, climatology, and stream hydraulics. Particular emphasis is given to the Goodwin Creek Basin, and the results will be used to determine the performance of selected channel stabilization methods and to determine influence of grade control structures on channel stability.

A program to test a wide variety of vegetation controls, both on the floodplain and on the beds and banks of the streams, has been initiated with the combined efforts of the USDA Soil Conservation Service (SCS) agronomy teams from an 11-state area.

A complete inventory of SCS bank stabilization efforts for the past two decades has been compiled. This includes location, type, and purpose of stabilization; results and maintenance; and effects on geology and soils, stream and basin hydraulics and hydrology; and land use.

During the program data has been collected from over 60 different streams. One drainage basin has been completely instrumented to monitor water and sediment movement through the entire system. Additionally, a complete weather station was installed with rain gages scattered throughout the basin, and many farm lands were monitored for sediment management. All of these data are being fed to a computer through a telemeter system.

Eight additional basins have been studied and monitored on a more restrictive basis. In these eight basins, 220 different bendways with a wide range of flows and geometry were stabilized using 21 different methods of protection. Costs of these structures varied depending on local conditions and needs of protection. These costs are summarized in Table 1.

Additionally, 26 grade control structures were constructed with the same basic design, but with variations in geometry and material, in order to assess the stream's ability to re-establish stability and to field-test lab-flume tests and design criteria.

D. Extent of Investigation.

1. Purpose.

Section 32 of the 1974 Water Resources Development Act (Public Law 93-251) authorizes construction of demonstration projects in "the delta and hill areas of the Yazoo River Basin generally in accordance with the recommendations of the Chief of Engineers in his report dated September 13, 1972."

The investigation is being conducted in response to the Report of the Chief of Engineers to the Secretary of the Army on A study of Streambank Erosion in the United States, 91st Congress, 1st Session, October, 1969, pp. 10-11.

Paragraphs 12 and 13 of the above report are herein repeated. Under-lining emphasis has been added to indicate statements more pertinent and important for this project.

> "12. Research Needs- During the past 50 years, extensive research has been conducted in certain areas relevant to streambank erosion, such as the determination of suspended and bed load transport capacities and their effects on stable, alluvial stream regimes. But activities to develop bank protection methods have been slanted toward large alluvial streams. This study, however, indicates that an additional threepronged research effort is urgently needed if the damages which result from streambank erosion are to be effectively reduced. Research should be directed toward (1) better understanding of the mechanics of erosion processes and of stream morphology-long-term channel development and behavior; (2) developing new lost-cost methods of preventing bank erosion; and (3) determining better techniques for the evaluation of damages due to streambank erosion and the benefits from its control. The research would involve a literature search, theoretical and laboratory analyses, and field investigations and tests. Most of the required basic facilities and key personnel are presently available, but additional funds would be required.

"13. Summary and Conclusions - For the first time, data have been obtained and presented on the nature and scope of streambank erosion damages throughout the United States. In areas where data were not previously available or where no significant erosion was thought to exist, a closer examination revealed that substantial damages occur.

"Streambank erosion is an extremely complex subject from the point of view of its genesis, its effects, and its prevention. Whether or not erosion occurs depends upon the resistance of the soil composing the bank, as determined by its composition and condition, and the erosive ability of the stream. Why some banks erode and similar ones do not is not fully known. A number of variables are involved in the process and may exert their influence individually. More often, however, streambank erosion is the result of a complex combination of variables, making it extremely difficult to understand, to predict, and to treat. Precise quantitative analysis and evaluation of damages from bank erosion are also very difficult and, in some cases, impossible. Some benefits, such as increased channel capacity and nourishment of coastal beaches, do occur from bank erosion but they are even more obscure than the damages and could not be meaningfully estimated for this report.

"Streambank erosion is widespread. Of the 19 water resource regions, only Hawaii can be considered as substantially unaffected. An estimated 549,000 miles of bank or 8 percent of the Nation's total, is undergoing some degree of erosion. Of this, 148,000 miles or 2 percent, merits further examination to determine if some form of treatment is justified. Damages, estimated for the 148,000 miles, are categorized as stemming from land loss, sedimentation, and other detrimental effects such as undermining structures and the reduction of esthetic appeal, and total $90 million in damages annually. Of these damages, almost one-half is due to sedimentation from bank erosion. This damage estimate reflects, in part, the growing awareness of adverse effects of sediment influence on marine ecosystems and the quality of the environment as well as the more tangible damages from siltation.

"The annual cost of treatment for the prevention of the reported $90 million damages is estimated to be $420 million, indicating that many of the areas suffering damages cannot be economically treated. The stream reaches meriting treatment will, for the most part, be widely scattered.

"A substantial investment of about $1.8 billion has already been committed in bank protection facilities wholly or partially under Federal sponsorship. Most of this investment was made in projects for flood control, navigation, irrigation, and other purposes although a very small investment has been made in projects for the sole purpose of bank protection.

"Effective streambank protection measures are costly to install and to maintain. For this reason, a substantial research program is needed to develop cheaper and more effective methods of treatment. Such a program should also include efforts to improve our understanding of the mechanics of stream channel behavoir and bank erosion, our evaluation of damages and benefits, and our ability to predict adverse results that may occur from installing remedial measures.

"The nature, extent, and cost of prevention of streambank erosion damages indicate that a case by case approach is best suited for Federal efforts to deal with streambank erosion problems. Present Federal authorities and institutional arrangements are generally adequate to carry out this type of program. However, since bank erosion is but one element to be considered in conservation, development, and management of our water and land resources, adequate data should be included in comprehensive framework plans, now being accomplished under the aegis of the Federal Water Resources Council, to provide continuing, coordinated assessment of the overall problem. The importance of such attention will increase as demands of the Nation's streams grow, as urban areas and public facilities increase in number along the waterways, therefore making less tolerable the adverse effects of streambank erosion."

Authority for this current study is contained in Section 32 of the Water Resources Development Act of 1975, Public Law 93-251 (Streambank Erosion Control Evaluation and Demonstration Act of 1974). Portions of Section 32 are quoted below:

"(a) This section may be cited as the "Streambank Erosion Control Evaluation and Demonstration Act of 1974".

"(b) The Secretary of the Army, acting through the Chief of Engineers, is authorized and directed to establish and conduct for a period of five fiscal years a national streambank erosion prevention and control demonstration program. The program shall consist of:

"(1) An evaluation of the extent of streambank erosion of navigable rivers and their tributaries.

"(2) Development of new methods and techniques for bank protection, research on soil stability, and identification of the causes of erosion.

"(3) A report to the Congress on the results of such studies and the recommendations of the Secretary of the Army on means for the prevention and correction of streambank erosion.

"(4) Demonstration projects including bank protection works.

"(c) Demonstration projects authorized by this section shall be undertaken on streams selected to reflect a variety of geographical and environmental conditions, including streams with naturally occurring erosion problems and streams with erosion caused or increased by manmade structures or activities. At a minimum, demonstration projects shall be conducted at multiple sites on:

"(1) The Ohio River.

"(2) That reach of the Missouri River between Fort Randall, South Dakota and Sioux City, Iowa.

"(3) That reach of the Missouri River in North Dakota at or below the Garrison Dam.

"(4) The delta and hill areas of the Yazoo River Basin generally in accordance with the recommendations of Chief of Engineers in his report dated 23 September 1972.

"(d) Prior to construction of any projects under this section, non-Federal interests shall agree that they will provide without cost to the United States lands, easements, and rights-of-way necessary for construction and subsequent operation of the projects; hold and save the the United States free from damages due to construction, operation, and maintenance of the projects; and operate and maintain the projects upon completion.

"(e) There is authorized to be appropriated for the five-fiscal-year period ending June 30, 1978, not to exceed $25,000,000 to carry out sub-sections (b), (c), and (d) of this section."

The Chief of Engineers report dated 13 September 1972, referred to in paragraph (c) (4) above states: "...that a pilot program to test various types and combinations of structures in prototype should be implemented and carefully analyzed as a basis for developing a comprehensive bank stabilization program for the entire Yazoo Basin. ...This pilot program would consist of prototype construction, data collection, planning, and analysis of results."

2. Scope.

The Yazoo River System had a unique relationship with the Lower Mississippi River before settlement of the Yazoo Basin, Figure 1. The Yazoo Delta acted as a flood storage reservoir, while the river system acted both as a distributary for the Mississippi River flood overflow as well as for some intermediate flows. This second function enhanced navigation on many of the basins streams. The system also served as a tributary for local runoff. This relationship was permanently changed with the confinement of the Mississippi flood flows between its levees. This reduced the flows in the Yazoo River and caused a concomitant decrease in channel cross-section and plan geometry. The inter-basin flows between the Sunflower Steele Bayou and the Yazoo-Tallahatchie System were also eliminated. All this changed the flow duration and magnitude in most of the basin streams. These delta streams were base level controls for many of the hill streams. The hill streams began adjusting to the imposed slope changes and hydrologic variations. The complicated geologic history also added variations that effected the streams response. Many hill streams flowed through as many as nine different geologic formations in the drainage basin plus the reworked deposits of these erodible soils. Because some of these geologic formations resisted erosion to various degrees, many streams developed profiles that were convex instead of concave. This produced unusual hydraulic conditions, thus wide variations in sediment movement and deposition.

Historically the Yazoo Basin has experienced problems initiated by poor farming practices that exposed the soils to erosion which were further complicated by uncoordinated early channel modifications by local owners, levee and drainage districts, railroad and highway departments, Soil Conservation Service and the Corps of Engineers. Many of these early activities had compensating effects, others were cumulative in their reactions.

In an effort to alleviate this complex situation the Vicksburg District directed most of its efforts under this program toward determining the causes of bank instability and the most effective methods of correcting the sediment problem. It was determined that the project would be more successful if treated as an interdisciplinary and intraproject problem with all agencies furnishing all knowledge of their projects and experiences. The final product is developing into a Sediment Management Program which will involve the cooperation of all local, federal and state agencies, and enviromental groups.

The Vicksburg District initiated a program with the USDA Soil Conservation Service to accomplish an inventory and assessment of cause, cure, and response of their work within the state of Mississippi and with the SCS agronomy team from an eleven state area to begin a program of studying the best vegetation to use on and in stream channels for potential stabilization. A program was also initiated with the USDA Sedimentation Lab at Oxford, Mississippi, to learn the cause of instability in the basin's streams as well as to track the source and movement of sediments through the system. The District also selected eight river systems to demonstrate stabilization techniques and an additional 60 streams to monitor for comparative data.

E. History of Area Development.

Land use is a result of a basins geologic history, and an analysis of a basin's history usually exemplifies land use and drainage alterations that have influenced the water and sediment loads of its streams.

In this report the historical settlement of the Yazoo Drainage Basin has been divided into five periods based on activities that may have had an influence on the quantity of water and sediment in the streams. History divides settlement into four (4) periods according to land development activities: (1) The pre-Civil War, with the struggle to establish an agricultural organization in spite of the tremendous land-clearing task, frequent floods, and malaria (Harrison, 1961). (2) Settlement from 1865 to 1900 can best be described by Harrison: "The building of levees as a protection against the Mississippi River floods has been so intimate a part of the economic and social life of the drainage basin that any study of the levee program tends to become a history of land settlement and the economic development of the land." (3) The expansion from 1900 to 1930 was made possible by the reclaiming of wet and poorly drained land. It is this work that initiated many of today's problems with the rivers. (4) The period from 1930 to the present was one of population changes, shifts in land use and in farm organizations.

1. Pre-Settlement by White Emigres.

The Yazoo Delta portion of the Mississippi Alluvial Plain is one of the most fertile and productive regions in the world. Prior to occupation by the white European emigre, the earliest clues to human habitation are found in the "mounds" occurring in both the delta and the hills. The Mound Builders came into the area around 1500 B.C. Originally strictly hunters, by 600 A.D. they had adopted a more sedentary existence; farming became life's mainstay, soon supplemented by trading (Reuss, 1980). The original occupants of the basin did little to disturb the natural movement of water and sediments; however, the stream characteristics, both in the delta and in the hills, had a sinuous geometry that suggested a high sediment movement at that time or at some recent geologic time period. Many of the channels flowed in flood plains that were at a considerably lower elevation than the present Mississippi River meander belt. High flows were overbank and the streams did not build channels that would contain even the 1-year events. For example, the Mississippi had yearly high flows of 1,350,000 c.f.s. or greater, but a top bank capacity of only 900,000 to 1,200,000 c.f.s. and the Little Tallahatchie River, in the short 8 years of record prior to construction of Sardis Dam, had 25 overbank flows. Other streams show similiar geometry. Normally, an alluvial river will build a top-bank geometry that will contain the 2.3 year event (Leopold 1969).

2. Period 1800-1860.

The first permanent white settlements occurred around 1800. These first white settlers in the Yazoo Basin encountered the anopheles mosquito, and during the next century as plantations were established malaria or swamp fever remained one of the two problems in this area. The other was the flooding. During the first half of the nineteenth century, floods covered half of the Yazoo Basin 4 to 5 months of every year. It was possible to paddle a skiff from the Mississippi River across the delta and up into the hills past the east end of our present flood control reservoirs (Reuss, 1980). DeSoto had to wait several months in 1500 for a flood to subside (Harrison, 1961).

During relatively dry periods of each year, the delta and many of the flood plains in the hills were almost impassable swamps. The Mississippi River and the main rivers of the Yazoo Basin were practically the sole means of access to the new cotton plantations. Roads were few, and Indian trails were still in use. The early settlers of the Yazoo

Basin occupied the higher lands immediately adjacent to the rivers. These natural levees were available to river commerce and were above water except during the intermittent higher floods. The basin developed primarily into large plantation type of farm units because of numerous physical, economic, and historical factors which made this type of organization advantageous. The difficult task of clearing the dense forest and underbrush, combating insects, and serious flood and drainage problems made it practically impossible for a small operator with little capital to settle and maintain himself. Because of these problems in the lowlands, many of the early settlers who could afford only the smaller type of operation chose the loessial hills for homesites. Flooding was less of a problem, but the large undissected flats in the hills were easily eroded when cleared of natural vegetation. Within a very short period, the flow of sediments began to cause problems in the hill streams and valleys and add to the problems in the delta.

Between 1832 and the general financial collapse of 1837, Mississippi lands were bought and sold on a large scale. Settlers were willing to pay the standard price of $1.25 per acre. Land speculation reached alarming proportions, with few eastern developers ever actually seeing the land. When the collapse came, Mississippi alluvial lands were offered for $0.25 an acre, but there were few bidders. From 1837 to 1847, land development was at a standstill in the Yazoo Drainage Basin. After the close of the Mexican War, settlement became more rapid, reaching a peak in 1850 (Harrison, 1961). This development was aided by the Swampland Act of 1849 and 1850, when the overflow lands were turned over to the State, and the proceeds from their sale were to be used for flood reclamation.

3. Period 1860 to 1920.

Early flood protection was done by reparian landowners. During the Civil War most of these early flood control efforts were either destroyed or they deteriorated due to lack of maintenance. Between 1865 and 1885, land development was slow because of title confusion and because of lack of coordination of adequate drainage and levee systems. In 1880 only 11.5 percent of the basin's land was classed as improved. By 1900 improved land had increased to 27.9 percent.

After the Civil War, the hill lands were mostly settled by small landowners, "when everyone was given 2 acres and a mule" (Harrison 1961). Extensive land clearing initiated extreme sediment problems, and many flood plains and deltaic deposits at the hill line accumulated 10 to 15 feet of sandy sediment over the once rich soils. The expansion of development between 1900 and 1930 was made possible by the reclaiming of wet and poorly drained land. Beginning in 1890 the railroad and lumber companies conducted land-selling campaigns to attract small farmers. From 1900 to the beginning of World War I, clearing of land for agriculture increased rapidly. By the beginning of the 1900's, many of the major streams in the hills as well as the delta were severely reduced in flood capacity. Drainage districts began organizing for a collective effort at solving the flooding problem. Extensive channel straightening began in this period and aggravated the situation on many streams. Because of the wide variations in erodibility of the different bed and bank material of these channelized water courses and also the variation in energy slopes, some channels remain today almost exactly as constructed while others have incised themselves into a clay-like strata but maintain their redesigned plan view, yet are responsible for increasing sediment problems. Others have both degraded and meandered, trying to establish a stable slope and in doing so have moved tons of sediment into the delta portion of the basin.

4. Period 1920 to 1937.

Organized drainage districts began during this period; however, most operated independently, as did many individual landowners, and in many cases the upstream and downstream lands developed more problems than they had originally.

Large plantations became dominant in the delta while the number of small farms increased in the hills. The larger operators brought in experts to help solve the many problems and began cooperating with other landowners on a subdrainage basin basis that insured better results. Unfortunately, the smaller independent landowner's activities in the hills added to an ever-growing sediment problem, resulting in the loss of flood control as well as valuable farmland. Beginning in the 1920's and 1930's farming operations began to show some profits, particularly in the delta. This resulted from the following changes: (1) the operation of Federal Government programs, (2) shifts in land use and farm organization, and (3) increased mechanization. However, even many of these benefits were short lived. Natural drainage systems were grossly altered and began to react on a scale of time and magnitude that was directly related to type and erodibility of the local sediments and to the hydraulic gradient (slope) of channel. The need for drainage and flood control was recognized and programs were implemented without proper attention to the problems of sediment movement. Many channels were widened and straightened, with the main object being to drain the lands and hasten the passage of flood waters.

Sediment moves as a power function of the discharge, so by increasing discharge even a relatively small amount, the potential sediment movement is increased a large amount. Sediment also moves as a power function of velocity and slope. Straightening a sinuous channel increases the slope in direct proportion to the decrease in length. The natural geologic process is to wear down the hills and build up the lowlands. The combination of increasing discharge, velocity, and slope increased the geologic processes by a very large portion. The result was land alteration occurring within a single generation that naturally may have taken thousands of years.

5. Period 1937 to 1980.

During this period, the Federal agencies did much to minimize erosion, reclaim land, improve drainage, and flood control. Soil erosion from well vegetated land is usually less than 1 percent of that from exposed land surfaces. Clearing forest and swamp lands for agriculture has had a big impact on the amount of sediment eroded into the rivers. Thus the record of historic sediment problems is directly related to land clearing. Originally, both the delta and hill portions of the basin were 100 percent forest and swamp. The following table shows the rate of land clearing.

Percent of Land in Forest

	Originally	1860	1880	1900	1930	1940	1950	1980
Delta	100**	88**	78*	72*	44*	39*	35*	10**
Hills	100**	88**	78*	72*	30**	36**	41*	50**

* - Source U. S. Census of Agriculture

** - Estimated by authors

Clearing operations continued in the delta during this period but because of the flat gradient and improved farming practices, the amount of sediment produced was low. The soil that was lost, however, was the top soil that can no longer be replenished by flooding and is of the silt-clay sizes which are easily suspended in moving water that finally ends up in the Gulf of Mexico. During the past three decades, land improvement measures and revegetation in the hills have reduced the sediment problem; however, today extensive land clearing is again in progress. This renewed clearing adds to the total sediment problem, and in many cases the methods of handling the felled trees produces excessive erosion in the channels, endangering bridges and other structures. Sediment must be managed if we are to be able to sustain ourselves and reap the benefits of our natural resources.

F. General Geology of the Yazoo Drainage Basin.

An analysis of any drainage basin should include a fluvial geomorphic analysis of the entire drainage basin and should be divided into geologic sequences and time periods. The geologic controls in a basin denote the type of erosion, thus the runoff and also the land use resulting in the type and location of agriculture. Geology influences channel geometry, and thus hydraulic and sediment movement and deposition. The evolution of habitation is, therefore, a direct result of the geologic history of the basin. The time sequence of the study can be gleaned from a specific gage record. Major changes that will influence the water and sediment load will be shown by the reaction of the stage-discharge relations. Man's history in the basin indicates the land use patterns and thus changes in the basin streams water and sediment loads.

The geology is similar for all drainage basins evaluated in this SECED Demonstration Project. These streams flow through a valley alluvium and layers of mixed silts, sands, clays, and gravels. Out of the 86 geologic formations that have been identified in Mississippi, nine are included in the stream channel and surface geology of these basins. This does not include duplicate or substitute formation names or terms used for geologic "Group" or "Member" (i.e., formations are made up of members, and groups are made up of formations).

The oldest formation known to Mississippi is dated as Late Cambrian (approximately 500 million years ago) and is not found in the surface geology. The formations influenced by the streams in these study areas are no older than Mid-Eocene (approximately 46 million years ago). In general, these formations represent a little less than 10 percent of the geologic time recorded in Mississippi's stratigraphy, and are thus very young.

An apparent stratigraphic time gap can be found between the Eocene and Pleistocene Age formations (Figure 2). This 35.5 million year gap remains unexplained but probably represents an erosional surface or a period of no deposition. The time gap is not unique to any particular watershed but has been reported in many borings and outcrops in north Mississippi, although the areal extent of its occurrence has not been determined. There are 12 formations in Mississippi that have been age dated during this missing time period between Eocene and Pleistocene but are not found in the watersheds being examined. There is some doubt as to whether the geologic formations in these areas are chronologically correct or if they are in fact correctly named. According to a recent SCS report by Harvey, Schumm, and Watson (1981), "the use of the generally recognized time stratigraphic units in northern Mississippi has been questioned by Grissinger, et al (1980). Drilling evidence obtained in Panola County suggests that while many of the units are lithologically equivalent to the mapped formations, they should at this time be referred to without time-stratigraphic connotations."

Figure 2 represents an attempt to identify the characteristics of the formations influenced by the streams under investigation using the Unified Soil Classification and is idealized. The purpose of this chart is to relate the geologic formations to engineering terms by use of the Unified Soil Classification. The diagram does not imply that the Old Paleosol, for instance, is always a ML or CL or that the Citronelle is always a SW or GC. These symbols represent the most common Unified Soil Classification description that closely represents the formation. In some cases, the geologic nature of a formation is too complex for the soil classification, even with the use of modifiers. However, the soil classification does qualify the material for foundation and construction purposes.

The character and order of stratigraphic sequence is highly variable between one area and another and the boundary between formations is not always clearly distinguishable. Modifications used by the Unified Soil Classification are assigned to the entire formation and not to particular letter symbols where more than one symbol is used. Geologic descriptions are condensed from descriptions published by the Mississippi Geological, Economic, and Topographic Survey (Childress, 1973). Standard geologic symbols have been combined and modified to represent a particular formation according to its physical characteristics.

The erodibility of each formation, due to stream action, has not been qualified in absolute terms but can be expressed relative to the order of increasing erosion resistance as follows:

Formation	General Characters
Loess	Unconsolidated silt
Alluvium	Low-strength sands, gravels, and clays
Kosciusko	Loose sands with traces of silt and clay
Tallahatta	Loose sands interbedded with clays and shales
Citronelle	Mixed sand and clay with gravel lenses
Young Paleosol	Semiconsolidated clays
Old Paleosol	Dense, consolidated silty, clayey sands
Winona	Consolidated clay, shales, and chalks
Zilpha	Dense clay and clay shales

It should be emphasized that this is a generalization based on intuitive knowledge and field observations. Local variations in lithology can change the erosive quality of some geologic materials. A particular formation may have a preferred orientation of resistance to erosion or a tendency toward block failure rather than a gradual wearing away with time. Shales of the Tallahatta, for example, may be highly resistant to erosion when oriented horizontally with stream flow but become unstable when tilted against the flow. Internal hydrostatic pressures may also affect the strength of resistance for a material between effluent and influent reaches of a stream.

Figure 3 is an illustration comparing the hill stratigraphy to the valley stratigraphy that is typical of the stream basins under consideration. The major difference between the two stratigraphic sequences is that the hill deposits usually include a loess cap that is lacking in the valley sediments. The valleys contain a recent alluvium, underlain by the Young and Old Paleosols. In general, it is believed that the Paleosols are derived from the loess material (Harvey, Schumm, and Watson, 1981), although the mode of deposition is debatable. The valley stratigraphy underlying the Paleosols, beginning with the Citronelle and progressing downward, is generally the same as in the hills, although some units may have been removed by previous erosional events.

The valley alluvium is composed mostly of sand, gravel, silt, and clay which is more or less sorted into lenses or irregular bodies vertically, longitudinally, and laterally. In general, the alluvium is sandy nearer the stream and grades from silt to clay away from the stream and nearer the valley walls. However, this generalization does not consider rock debris carried by the tributaries from the bordering uplands and deposits along the outer margins of the main valley. The thickness of the floodplain alluvium varies but is usually thicker nearer the stream and thins progressively toward the valley walls. As a general rule, thickness also increases in the direction of stream flow. There are local variations in sediment thickness due to the slight relief and irregularity of the surface of the alluvium and also of the valley floor on which the alluvium lies.

The streams considered in this study often expose portions of the stratigrahic column depicted in Figure 3 for the valley. Where a stream runs up against a hill line, these formations are commonly found. The stratigraphic order depicted in Figures 2 and 3 will not be found in every location in the hills or valley due to the nature and areal extent of each formation and due to local pinching out of strata. Also, an unpredictable, discontinuous nature is a characteristic of the upper stratigraphy in northern Mississippi.

The geologic interpretation presented here is an oversimplification of the complex conditions revealed by borings and field observations in the study areas. Although a uniform, "layercake" type of stratigraphy rarely occurs in nature, some degree of constancy is expected since it is a continuous and persistent nature of strata defines a geologic formation. According to the American Geological Institute, a formation is defined as having "some character in common" and as being "a large and persistent stratum." It also defines a sedimentary formation as a "lithologically distinctive product of essentially continuous sedimentation selected from a local succession of strata as a convenient unit for purposes of mapping, description, and reference."

Many so-called "formations" of the upper surface geology in northern Mississippi do not fit this criteria as well as most of the remaining strata across the state. However, electrical logs of water wells and test holes on file at the Bureau of Geology and Energy Resources indicate deeper strata (1000+ feet) in this area that can be recognized as continuous formations.

The stratigraphy found in the streambanks and beds within the study basins do not appear to be very continuous or persistent in nature, nor do they necessarily possess a common character from one location to the other, and are usually not convenient for purposes of mapping, description, and reference. The same materials that characterize a formation can be found in all the basin areas but in a very scrambled and haphazard manner. In this sense, the geology for each basin is basically the same.

Information obtained from E. H. Grissinger (1980) indicates that the formations discussed herein could actually be "valley-fill" (on the scale of Mississippi Valley Embayment). The Citronelle, for example, may actually be reworked material from the original "Citronelle Formation" and the Tallahatta material in the area may actually be reworked from the original "Tallahatta," etc. Grissinger and others often use terms such as "Kosciusko-like," "Tallahatta-like," etc., for some of the strata in northern Mississippi. This could explain the lack of continuity in the strata from one location to another as well as the lack of consistency in stream erosion through a particular formation that has heretofore been attributed to interfingering layers and lenses between and within formations. Interfingering does exist but when found in excess, tend to challenge the existence of a discrete and unique formation.

Despite this random existence of geologic materials, there are several features that appear at regular intervals, the occurrence of which is too orderly to have been the result of chance.

In some streams, Perry Creek for example, a series of resistant clay silts can be found in the channel bed and banks at nearly regular intervals. These clay silts usually act as a natural weir in the streambed. Headcuts also appear in many of these streams with overfalls consistently measuring approximately 4 feet, regardless of the stream of watershed they occur in.

Many streams in Mississippi, as viewed from the air, appear to flow in nearly parallel, step-like patterns (Figure 4). This could be the result of fault or joint patterns but could also be the result of a system of curvilinear ridges or terraces. Vestal (1956) recognized a series of near parallel terraces that decrease in elevation from north to south and east to west in northern Mississippi and trend more or less parallel to the bluff line. Shaw (1918) identified four main terraces in this area and reached the conclusion that they are surface expressions of the Mississippi Valley terrace deposits, some so eroded that they are now scarcely recognized as terraces.

These study basins, as well as other portions of the state, contain enormous quantities of sugar-white sands. The abundance of clean, well-worked, beach-like sands appear to be in excess of the amount that could have been derived from the local stream systems. An example of such an excessively sandy system is Batupan Bogue. This interpretation is based on the fact that such clean sands can only be the result of repeated agitation of sediments in a manner which removes everything but the more resistant quartz material.

The streams being examined in this study, as well as other streams throughout the state, typically transport and rework sands, silt, gravel, and clay that is mostly of local origin. However, individual pieces of rounded granite and other igneous and metamorphic rocks can be found in some stream systems, but are generally thought of as having been transported from the Appalachian regions.

Generally speaking, the geology of these stream areas and of the rest of Mississippi can be described as, "sedimentary." Four basic types of sedimentary rocks are native to Mississippi; (1) limestone, (2) sandstone (includes ironstones), (3) shale, and (4) claystone. Petrified wood is also found in Mississippi but probably does not qualify as a naturally formed rock. Some chert nodules are associated with the base of the Kosciusko formation (Figure 2).

A complete analysis of Mississippi geology is beyond the scope of this report. It is important to note, however, that the present geological setting of the Yazoo Basin is a result of repeated episodes of deposition, erosion, and reworking of sediments during pleistocene glaciation. The confused stratigraphy in northern Mississippi is the result of one event reworking and partly destroying the composition of another. Each glacial episode, with its high volume of melt-water caused sea level to rise and encroach inland as far as the Yazoo Basin area.

A more complete understanding of the geology of an area will allow for the most efficient and economic treatment of a problem and increase the chances of success in the control of streambank erosion and other instability problems. In light of the diverse geological conditions that exist, it seems necessary to examine the geology of each stream reach separately when considering channel modifications and construction works.

G. Problem Analysis.

1. Sedimentation and Deposition.

In the original assessment of streambank erosion, the Vicksburg District inventoried project streams only. Recently, a more complete survey was made of the streams within the drainage basin and the erosion problems associated with all the smaller tributaries and drainage channels. This second inventory indicated that the number of miles of bank caving in the original assessment was too low by 900 percent and that the amount of sediment produced by these caving banks was underestimated by approximately 300 percent. The production of sediment is a natural process and evidence indicates that the process has been active for most of geologic history. Sedimentary rock as old as 3.8 billion years has been identified. Almost all of the sea floor is covered with sediments as well as most of the land surfaces. Cyclic changes in weather patterns have resulted in a wide variation in sediment production during geologic times. The lower Mississippi River Valley has accumulated over 40,000 feet of sediments in less than 10 percent of the total life of the earth.

Periods of erosion are documented in the Yazoo Basin which occurred roughly 2,000, 5,000, and 10,000 years ago, with aggradation following each period of degradation. Deposition in the Yazoo Hills of 50 to 60 feet of sediment in the past 10,000 years or after the most recent glacial activity is evident as well as deposits of about 30 feet during the last 2,000 years. In all river valleys in the Yazoo Hills, post-settlement (up to 170 years old) deposits of a few inches up to 10-15 feet are extensive throughout the area with occasional deposits of over 60 feet of postsettlement alluvium. This adds up to an average of one-half foot per 100 years of sedimentation for the period since the last major climate change, and at least 6 feet per 100-year average sedimentation since farming operations began. Most of the latter probably occurred between the end of the Civil War (1860's) and pre-World War II (1930's). Since that time period, better land-use practices have minimized the sediment problems. However, recent land clearing and construction activities, as well as other activities, have initiated a new cycle of erosion and sediment movement.

Because sedimentation is a natural process, it cannot be eliminated. However, the problems it causes can be effectively minimized. The methods incorporated into the total analysis are the proper "management" of the sediments. Sediments can be both an asset and a liability. Nature does not remain in a constant condition; therefore, an intelligent method of management of the sediment problem and a continual program of balancing sediment sources and sediment sinks is necessary. Sediments will continue to move; however, it is necessary to keep them as close to the supply source as possible and to effectively transport the sediments that get into our waterways to either the first available storage area or to move them through the system to the next best storage place. In doing this, additional wetlands to replace those that were filled through management of the previously displaced sediments should be created.

This type of program will require the complete cooperation of the Federal agencies, all environmental concerns, as well as local land-owners. The eventual program should be directed toward a combined water, sediment and floodplain management program for all the nation's drainage basins. Increasing delays on implementing such a program will result in more difficult and costly improvement programs.

2. Variation in Stream Characteristics.

The hill streams in the Yazoo Drainage Basin flow through a total nine or more basic geologic sedimentary deposits. Some individual rivers are shaped by as many as eight different sediment deposits. In addition, the renewed alluvium of these original deposits adds several more heterogenous environments that influence a stream's geometry. This wide variation of bed and bank material, the varying slopes from less than half a foot per mile to over 50 feet per mile, and a varying groundwater elevation that may be affecting bank stability anywhere from topbank to below the thalweg results in numerous streams that are all basically the same but are individually much different. Each stream attempts to build a local geometry that is compatible with its hydrograph but is strongly influenced by its varying bed and bank material and its energy slope.

All of the channels prior to settlement were the result of their geologic past. Some were very stable in time, others were highly transitional attempting to adjust to a wide variety of natural influences. Land-use changes altered the drainage pattern as land was converted from its natural forested state to other use. Many channels were treated similarly regardless of their slope or of their local bed and bank material. The results filled the entire spectrum from complete stability as rebuilt to wildly unstable. Any future stabilization attempts should consider these individual local variations, which can be water and sediment and a highly varying discharge over any period of time, flowing on an energy platform (slope) that is ever-changing and flowing through sediment that could be any combination from a highly cohesive stable clay that acts like a bedrock, to very erodible silts and sands that move with the slightest influence, to gravels that can cause complete instability or a stable armoring environment.

Each reach of each stream must be analyzed and treated on a location-by-location basis. Stabilization techniques must be designed to accommodate the different characteristics as well as to the type of bank failure resulting from local stratigraphy.

II. DEMONSTRATION PROJECTS

A. Perry Creek Watershed.

1. General Overview.

Perry Creek's geometry was severely altered during the early 1900's. This along with changes in land use and a series of headcuts had produced bank caving problems in the urban section of the stream. The extremely sandy, erosive banks were an excellent location to demonstrate stabilization techniques. Six variations of bank stabiliztion were demonstrated with costs ranging from $11.61 to $28.42 per linear foot of bank. Total cost of bank protection was $432,000. In addition, two grade control structures were built with costs of $597,407 and $104,675 each. Excessively high rainfalls created damage in 7 of the 37 bendways that had been stabilized. Repairs totalled $103,600 or 24 percent of the original cost. Where the work was most successful, some or all of the following conditions were present:

a. Relatively smooth channel alignment, with no abrupt changes in flow direction.

b. Adequate toe protection to allow for localized scour and/or bed degradation.

c. Structural protection (i.e., stone paving) to top bank in areas of greatest attack and/or where bank or fill material was easily erodible and difficult to vegetate.

d. Upper bank vegetation left undisturbed where existing growth was adequate.

e. Accurate prediction of beginning (upstream) and ending (downstream) points of erosion.

Conversely, less success was acheived where one or more of the above conditions were not present. Also, less damage would have occurred if high flows had not occurred before vegetation was well-established.

2. Watershed Location and Description.

Perry Creek, a tributary of Batupan Bogue is located in the North Central Hill region of Mississippi. Its watershed has a dendritic shape and drains approximately 19 square miles in Northeast Carroll County and South Central Grenada County of Mississippi (Figure 5). Flow is generally north for about 2 miles, then northeasterly to its confluence with Batupan Bogue (Figure 6), a total length of 9 miles.

Perry Creek was straightened and shortened several decades ago but now has a fairly sinuous channel. Evidence of this earlier channelization is indicated on aerial photograph as abandoned channel scars in the lower reaches. In the upper and central portion of the basin, the main stream flows to the left side of the valley against the hill line, then flows to the right just before confluencing with Batupan Bogue (Figure 7).

Headcutting has been a problem on Perry Creek. Degradation on the order of 8 feet has progressed upstream to a box culvert under Highway I-55 and exists as a discrete headcut. Degradation has resulted in an increase in depth and width and littering of the streambed with trees and other debris.

Perry Creek flows mainly through thin loess material, typical of northern Mississippi. Ridge tops are narrow with moderate to steep slopes. The topography is relatively low at the confluence as the stream enters the floodplain of Batupan Bogue and approaches the urbanized area of Grenada. Maximum elevations at the headwaters of Perry Creek Basin are around 400 feet, NGVD, while minimum elevations approach 160 feet, NGVD.

Most of the demonstration project stabilization work was accomplished in the lower 2 miles of Perry Creek where it flows through an urban area which includes a local ballpark, golf course and seven bridges.

3. Problem Analyses of Perry Drainage System.

Bed degradation is the primary concern in the Perry Creek watershed, and is the major cause of bank instability. This degradation is the result of the interaction of the geologic and hydrologic variables of the drainage basin. In addition, the upstream migration of degradation on Perry Creek was complicated by local channelization of the stream.

To fully analyze the problem, one must first understand the regulation procedure of Grenada Dam. The primary purpose of Grenada Dam is flood control of the Yalobusha River. When a high intensity rain occurs in the watershed, the gates are closed so that the outflow from above the dam will not add to the tributary flows that enter the Yalobusha River below the dam. The gates are gradually opened following rains and after flood crests from the tributary floods have occurred. This flood-regulating procedure has reduced the backwater effect of the Yalobusha River on Batupan Bogue, the first tributary below the dam. The reduction of this backwater causes the energy grade line and water surface slope of Batupan Bogue to steepen creating a perched-stream situation at its confluence.

The drainage pattern of Batupan Bogue and Perry Creek was held in a relatively stable profile by a natural weir consisting of a well-consolidated formation, containing sandstone and ironstone, located upstream of Hwy. 8 bridge east of Grenada, Mississippi, until the early 1970's. However, subsequent hydraulic action finally eroded this natural weir and a significant head-cut proceeded upstream.

Perry Creek, the first major tributary of Batupan Bogue (Figure 6) immediately began to degrade. A series of clay outcrops in the streambed restricted the time and the magnitude of the bed degradation. These clay outcrops are evident in the bed of Perry Creek intermittently throughout its entire length (Figures 8a and 8b). This severe erosion and bed degradation made Perry Creek an ideal location to evaluate both grade controls and bank protection methods while providing protection to urban development.

4. History of Perry Creek Watershed.

Very little history of man's influence on this basin is available. Aerial photos have been taken at various widely spaced intervals from 1935 to the present. These photos are the best and in this case the only available documentation of man's activities. The 1935 photos show evidence of a much narrower and more sinuous channel than the present channel. Meander scars and the type of sediment deposits in the floodplain, indicate that, at least during man's occupation of the basin (possibly up to 150 years) the stream pattern has not changed.

The exact date is uncertain, however, possibly in the early 1920's, the stream was straightened in a series of straight doglegs. The 1935 photos showed evidence that vegetation had gained a foothold on the banks and the stream had regained sinuosity, indicating that the stream responded quickly after straightening. A period of 10 to 15 years of relative stability followed, as evidenced by the photos very little change occurred in land use between 1935 and 1980 with farming well established prior to 1935. Since 1935 some acreage returned to natural forest, particularly in the hill sections, resulting in decreased sediment input to the system. Currently, about 70 percent of the basin is wooded, 5 percent is in row crops, and about 5 percent is urban and commercial uses, with the balance in pasture lands.

The influence of urbanization during the period of record has been minimal and scattered. The type of urban land use evident in the recent photos would probably enhance stability rather than encourage deterioration. Possible causes of recent stability problems are the loss of natural grade controls (clay in the channel bed), through time, plus the influence of reservoir control on the downstream portion.

5. Geology of Perry Creek.

The geology of a drainage basin is one of the most significant parameters in the analysis of channel stability. The physical properties of each stratigraphic unit have a direct relationship 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 thorough analyses of the geological variations within the basin must be made.

The geologic formations present in Perry Creek watershed consists of Eocene sands and clays in the uplands with a complex valley fill in the floodplain. The valley fill is the depositional area of upland erosion which occurred following the Wisconsin glaciation. The Eocene deposits consist of the Tallahatta, Zilpha-Winona, and the Kosciusko. (See Section B in the introduction for a more complete description of geological formations and their engineering characteristics).

The Tallahatta consists of interbedded sands and clays and attains a maximum thickness of 200 feet when the entire unit is present. This unit is the oldest formation exposed at the surface of the basin and is found in the floodplain in the lower portion of the drainage, underlaying the valley fill deposits. The Zilpha-Winona overlays the Tallahatta and is exposed at the surface on the lower hill slopes and in the streambed in the headwater regions of the basin. Winona, the lower portion of the unit, consists of up to 25 feet of sand and the upper Zilpha member may consist of up to 50 feet of clay, which acts as a natural temporary weir when it is exposed to the streambed. The Kosciusko Formation caps the hills in the upland regions of Perry Creek and consists of up to 150 feet of sand and sandstone with interspersed quartzite and clay or shale. It is not present in the floodplains of Perry Creek. The Citronelle Formation and loess deposits overlay the Kosciusko. These formations are the source of some of today's valley sediments. The Citronelle is a mixture of gravel, sand and clay and is the probable source of any gravel in the Perry Creek Basin. The loess, an Aeolian (wind-blown) silt-clay, blankets the hilltops along the eastern bluff line of the Mississippi Embayment. This material is highly erosive and is the source of the fine-grained deposits within the valley fill sequence in the lower floodplain.

The valley fill stratigraphy is probably the result of massive upland erosion and redeposition following the melting of the last continental glacier. During the maximum extent of this glaciation, the tributary valleys of the Mississippi River would have been flushed of sediments due to the lowering of sea level. With the influx of massive amounts of coarse sediments into the Mississippi River from the glacial meltwater, the mouths of many tributaries would become obstructed and lakes would form in the tributary valleys.

The result of a plugging of the mouths of the main tributaries would be an extensive valley fill deposit in the floodplain of the streams. Due to the large amounts of sand in the upland portions of the Perry Creek-Batupan Bogue drainage system, the fill in these basins is sandier than in the other basins in the area. This is one of the causes of channel instability in Perry Creek.

The deposition and stratigraphy of this valley fill is rather complicated. For simplicity, there can be considered two major periods of activity. The first period is the time in which a unit termed the "old paleosol" was deposited. Radiocarbon dating done on organics found at the base of this unit indicated that it was deposited about 10,000 years ago. The unit is characterized by a massive dark-gray to dark-brown silt ranging up to 8 feet in thickness. The lower portions of this unit have a well developed polygonal cracking. This produces a weakness which, when exposed, results in a block-type failure. The remaining portions of the unit do afford a temporary restraint to bed degradation, but when subject to the extensive degradation which has occurred in this area, it is quickly removed.

At the bottom of the "old paleosol" unit is a layer of organics ranging in thickness from 6 to 48 inches. It has little or no strength, is easily eroded, and probably originated from vegetation killed during the initial rise of the lakes, which could have been formed when the tributary mouths were plugged. When this portion is exposed to stream action, bank instability increases rapidly. It is probable that this entire unit is the sediment that settled in these low energy systems.

The "young paleosol" is the second unit of deposition. It is basically a channel fill deposit in abandoned stream courses within the "old paleosol." This unit is a sandy silt of a lighter color brown than the "old paleosol." It has no internal structure and is easily eroded. Due to extensive sand in the Perry Creek area, this unit has more sand and less erosion resistance than the paleosols in other study areas. When the channel slope is too steep and this unit is exposed by stream action, bank widening and deepening advances upstream.

Overlaying this older valley fill is a layer designated the post settlement alluvium. This is the result of poor farming practices by the early settlers. The unit has no erosion resistance and is a source of large amounts of sediment in the stream.

The bank and bed of Perry Creek are very unstable except for intermittent outcrops of clay. In the lower 6 miles of the stream, the clay outcrops are probably of the "old paleosol" formation and offer some resistance to degradation only if the bed slope is stable. The clay outcrops in the upper portion of the valley are probably of the Zilpha formation and are more resistant to erosion. Figures 8a and 8b are thalweg profile of Perry Creek. Every break in the profile slope has clay exposed in the bed. The best method for stabilization of this stream is to regain a stable slope by properly placed grade control structures and then to allow vegetation to restabilize the banks.

6. Hydrology.

a. Rainfall. There are two rainfall gages in the vicinity of Grenada, Mississippi which may be used to estimate precipitation on the Perry Creek drainage basin. These gages are located at Grenada Dam and at the town of Elliott, Mississippi (Figure 6). The average annual total rainfall at these stations is as follows: Grenada Dam, 53.56 inches and Elliott, 53.31 inches. The monthly average rainfall for these stations is given in the following table:

Month	Average Precip (in.) Grenada Dam	Elliott	Month	Average Precip (in.) Grenada Dam	Elliott
Jan	5.32	5.25	Jul	4.44	4.79
Feb	5.62	5.66	Aug	3.15	3.05
Mar	6.45	6.11	Sep	3.36	3.29
Apr	5.30	5.04	Oct	2.48	2.64
May	4.17	4.17	Nov	5.22	4.92
Jun	2.88	3.38	Dec	5.17	5.01

During the period 1970-1980, the annual rainfall varied between 49.20 inches (1971) and 78.72 inches (1973), with an average for this period at Grenada of 62.68, or approximately 9 in/yr more than the annual average for the period of record. This data was not available for the station at Elliott.

During the period 16 June 1976 to 23 November 1979, a number of significant rainfall events occurred over the Perry Creek Basin. These are shown in the following table, with the antecedent conditions as total rainfall for the 5 days preceding the given date.

Date	Grenada* Dam		Elliott*	
	Antec.	1-Day	Antec.	1-Day
16 Jun 76	0	1.87	0	1.38
25 Oct 76	0	1.10	0	1.22
4 Mar 77	.07	4.45	.09	4.51
4 Apr 77	.19	3.79	.34	3.00
10 Jul 77	.55	.93	.81	1.95
9 Oct 77	.53	2.71	.43	3.10
25 Oct 77	0	3.22	0	2.77
21 Nov 77	2.18	4.21	1.16	4.30
30 Nov 77	2.16	2.03	1.03	2.11
4 May 78	0	2.74	0	2.00
8 May 78	3.88	2.52	3.49	2.75
2 Jun 78	.83	2.80	.35	1.10
8 Jun 78	.38	1.52	.45	1.05
9 Dec 78	2.35	1.81	3.80	.60
1 Jan 79	1.61	2.30	1.55	2.35
20 Jan 79	.76	3.10	7.5	3.05
12 Apr 79	.93	5.31	1.50	2.55
5 May 79	3.03	.43	1.85	1.15
12 Jul 79	2.02	1.99	1.25	2.95
20 Sep 79	.68	2.57	.56	2.70
23 Nov 79	.30	3.14	.15	3.25

*All units are in inches.

b. Stage Information. Prior to the installation of a stage recording gage for the purpose of this study, no stage data was recorded for Perry Creek. The existing gage was installed at structure 6B2 (Figure 7) in 1979. This was subsequent to a period of channel enlargement due to degradation of the bed and bank caving, and therefore, these gage readings should not be used for comparison with stages or discharges associated with earlier runoff events because the stage discharge relations were altered by the hydraulic effects of the structure.

c. Discharge Information. No records of measured discharge data have been found for Perry Creek. However, a comprehensive report for this area has indicated that an average annual discharge for streams originating in this area is approximately 1.3 cfs/sq. mi.(USACE 1973).

For the Perry Creek Basin with a drainage area of 19.0 sq. miles, this would indicate an average discharge of about 25 cfs. Based on the average rainfall for this area, this would be reached if two-thirds of the rainfall was intercepted before reaching the stream, which is not unreasonable.

d. Velocity Range. No measured velocity data is available for Perry Creek; however, the normal wide range of velocities in any cross section or between high and low flow can be expected. A few bank full flow average velocities can be found in following table.

e. Bank-Full Information. Information for bank-full flow characteristics may be obtained through the use of Manning's Equation with data obtained from thalweg surveys and cross sections. Manning's Equation is given as:

$$V = \frac{1.486}{n} S_f^{1/2} R^{2/3}$$ where,

V = mean velocity in ft/sec

n = Manning's "n" value

S_f = Slope

R = Hydraulic Radius

For this purpose, the slope of the energy grade line, (S_f), is assumed to be approximately equal to the mean thalweg slope. Manning's "n" value for a channel with steep, vegetated banks and significant, exposed sandy point bars is estimated at .050 (Chow 1959). In the lower reaches (below I-55 bridge), the channel is less restricted by vegetation and an "n" value of .035 can be used; however, conditions at high flows and between stations can have extreme variation. The following table illustrates typical bank-full flow characteristics for these conditions at a few specific stations:

Bank-Full Flow Characteristics

Station (ft. above mouth)	X-Sec. Area (ft^2)	Hyd. Rad. (ft)	Slope (ft/mi)	"n"	Velocity (ft/sec)	Discharge (cfs)
8+00	1,628	9.63	9.6	.035	8.19	13,300
60+00	1,190	11.02	7.2	.035	7.76	9,234
143+00	814	8.39	10.5	.035	7.82	6,360
309+00	1,154	8.42	10.6	.050	5.51	6,360

Since the channel geometry varies greatly between the stations in the table, it would be unreasonable to think of the discharges as occurring simultaneously during a single runoff event. Although 40 percent of the drainage basin lies below the I-55 bridge (Sta 300+00), there are no significant tributaries to the main channel, indicating large quantities of runoff are being imponded or conducted as overland flow to the main channel.

In an effort to correlate the above rainfall and flow information, simple volumetric relations can be used as follows: Aproximately 60 percent, or 10.8 sq. mi. of the drainage basin lies above I-55. For this area to maintain a bank-full flow of 6,000 cfs at the bridge, a runoff of .9 in/hr, or 21 inches in 24 hours would have to be maintained continuously. It would be highly unlikely that a flow of this magnitude would be maintained for more than a few hours. However, rainfall intensities that are adequate to produce this runoff for short periods do occur. For example, the storm of 21 November 1977 produced overbank flows of 3 to 5 feet deep at the Vance Road bridge, located near Station 50+00. This would have been representative of a discharge of approximately 10,000 cfs. The center of this storm was located in the Batupan Bogue (Figure 6) headwaters and has an estimated return period from 100 to 500 years.

f. Sediment Information. No sediment transport data has been measured for Perry Creek. However, during the past 15 years, large amounts of sediment have been introduced to the system as a result of bank caving. Aerial photographs show extensive areas of aggradation and bar buildup. The exact effect of this on roughness has not been discerned, but the additional value of the form roughness due to large bars is probably of the same order of magnitude as the reduced value of roughness from the loss of trees and other vegetation as the banks caved. After one particularly active period of degradation and caving left a large number of overturned trees in the channel, the Corps of Engineers and local interest groups conducted efforts to clear much of this debris from the channel. The periods of degradation and bank caving led to a steeper but larger channel thus leaving the flow velocities, depths, and sediment transport capabilities indeterminate.

7. Channel Changes.

Perry Creek has been undergoing stream channel alterations since the 1940's throughout its length in response to channelization, land-use changes and subsequent increases in sediment production, base-level lowering, and loss of geologic bed controls. Most of the significant stream modifications presently occurring can be related to alterations of the entire Yazoo Basin drainage system for the past 40 years. Perry Creek is currently experiencing degradation along most of its length. This process has been evolving at least since the 1950's and appears to have resulted from the base-level lowering on the Yalobusha River concurrent with the construction of Grenada Lake in the early 1950's. Perry Creek is tributary to Batupan Bogue, a stream with temporary geologic controls which appear to have delayed the impact along Perry Creek by providing a time lag from the base-level lowering of the Yalobusha River to the degradation occurring on Perry Creek. Figure 9 is presented to show the streambed lowering which has been occurring on both Batupan Bogue and Perry Creek from 1954 to 1977 (Whitten & Patrick 1980).

Batupan Bogue, Figure 9 reveals a bed level lowering of approximately 5 feet along the first 2 miles and approximately 7 feet continuing for the next 7 miles of stream length. Perry Creek reveals approximately 1 to 5 feet of aggradation for the first 2 miles upstream with approximately 5 to 10 feet of degradation continuing upstream. This process is expected to continue with various degrees of severity along this stream depending primarily on the success and frequency of bed stabilization efforts installed.

Morphologic changes at four study sites P1 thru P4 (Figure 10) along Perry Creek were described by Whitten and Patrick (1980) as follows:

"Site P1 is located at the mouth of Perry Creek and includes 1 mile of the channel. Bank erosion has been actively widening the channel since pre-1937. The banks were generally vertical with a raw, fresh-cut appearance. The rate of bank erosion or retreat was relatively slow with no noticeable rapid or sudden width increases from 1937 to 1963. Channel width increased less than 20 percent from 1937 to 1963. However, from 1963 to 1977 the channel width more than doubled. There was a noticeable increase in channel width at the mouth of Perry Creek in 1963. The lower 1/2 mile of the channel had increased approximately 50 percent in width. There were also numerous slumps and cave-ins along this section of channel.

"Hanging tributaries and isolated segments of previous streambeds at elevations higher than the present channel in the 1954, 1963, and 1977 streams show that channel degradation had been active since at least the 1950's. Point bars were common in all of the channels.

The upper three sites (P2, P3 and P4) are located above the demonstration project sites. However, a study of the sites is warranted for an evaluation of the response of the entire system. Relative to the upper three sites Whitten and Patrick (1980) found:

"Site P2 is located 3.7 miles (1954 stream distance) above the mouth of Perry Creek and includes approximately 1 mile of the channel. Bank erosion was very actively eroding the outside banks of the meander loops in 1935 and 1941 but did not appear to have been very active in other areas. The channel width had nearly doubled by 1954. Hanging tributaries and isolated segments of previous streambeds at elevations higher than the 1954 bed show that the channel had been deepened. The steep, vertical banks had a raw, fresh-cut appearance. Continued bank and bed erosion since 1954 has widened and deepened the channel but at a much slower rate than during the 1941-54 period. Bank erosion has removed most of the small bends and meander loops and appears to be most active on the outside banks of the larger meander loops.

"Site P3 is located 5.6 miles (1954 stream distance) above the mouth of Perry Creek and includes approximately 1 mile of the channel. The 1941 channel was lined with vegetative growth. There was no observable erosion in the channel. The vegetative growth along the channel had been removed by 1954. The channel appeared to be rapidly widening and deepening in 1954. The beds of several meander loops, cut off since 1941, were at elevations higher than the 1954 channel bed. The lower segment of the channel had nearly doubled in width since 1941, and all of the banks in this site have a fresh-cut appearance. The 1963 channel was two to three times as wide as the 1941 channel, and bank erosion still appeared to be very active. Channel depth had also increased. Bank and bed erosion were still very active in the 1977 channel. However, the construction of the Interstate 55 Highway bridge in 1965 had altered the channel erosion above the culvert-type bridge. There is a more detailed discussion of the effects of the bridge on channel erosion later in this section.

"Site P4 is located 6.6 miles (1954 stream distance) above the mouth of Perry Creek and includes approximately 1/2 mile of the channel. This segment of Perry Creek was channelized prior to 1941. Channel erosion at this site appears to have occurred at a slow, relatively uniform rate since 1941. The most noticeable bank erosion occurred in the upper segment where the meander loops have been slowly straightened as the curves were eroded away. The hanging tributaries show that depth has also increased since 1941. The thalweg is presently cutting in Quaternary clays. Channel erosion directly below site P4 has increased channel depth and widths in the same manner seen at site P3."

Geomorphic changes for Perry Creek are summarized in Table 7 as observed on the chronological sequence of aerial photos and from field observations. Whitten and Patrick (1980) additionally observed:

> "The chronological sequences of aerial photos of each of the four sites of Perry Creek show there has been a very significant increase in channel depth and width since 1935 and that these increases have advanced upstream with time. The knickpoint on the 1954 longitudinal profile is located between sites P2 and P3 (Figure 10). Interstate Highway 55 bridge, built at site P3 in 1965, acted as a grade control structure, preventing any further degradation from advancing past this point after 1965. The prominent knickpoint on the 1977 longitudinal profile shows the effectiveness of the culvert-type bridge as a grade control structure. (The 8 ft of degradation at the culvert caused severe problems to the culvert and the highway which have been repaired by the Highway Department). The channel downstream from the culvert had degraded 6 to 8 ft by 1977. The banks are steep with frequent cave-ins, slumps, and undercut trees. The channel directly upstream from the bridge appears stable. Cross sections of Perry Creek show bank erosion has been more extensive downstream from bridge than upstream (Figure 11)."

A study of the stream prior to highway construction could have prevented expensive repairs.

> "Figure 12 shows the changes in channel area and length at each of the four sites since 1937. There has been a general decrease in channel length at all the sites, except for P4, which has changed very little. Bank erosion cut away the meander loops and bends, thereby straightening and shortening the channel. Channel area either increased or decreased as the channel was widened. The combination of channel geometry changes determined whether there was increase in channel area. Channel area increased at site P4 as the length decreased, while just the opposite effect occurred at site P2."

Recent profiles in 1979 show degradation continuing along sections of Perry Creek. From the confluence with Batupan Bogue upstream about 1 mile, there has been an average degradation of nearly 2 feet. This process is expected to stop once it nears grade control structure

6B-1. Approximately 1/2 mile further upstream (1-1/2 mi from confluence), a second creek section is experiencing degradation of near 5 feet. Grade control structure 6B-2 is located at the upper limit of this degradation and is expected to stop this process. Continuing upstream above structure 6B-2, no significant degradation is obvious until the intersection of I-55 is reached (approximately mile 6). At this location, it is apparent that approximately 8 to 10 feet of degradation has moved through the system up to I-55. Above I-55 several head cuts of approximately 4 ft each are moving upstream at varying rates (Figure 8b).

8. Construction of Protection Works.

a. Need for Protection. Bank caving throughout the entire Yazoo Basin could be as much as nine times higher than established in 1969. Loss of land, maintenance of man-made river bank structures, navigation and flood control problems further downstream in the system, as well as the associated environmental problems, all point out a dire necessity to improve sediment management. Streambed and bank stabilization techniques are one portion of improving the total sediment problem.

Following degradation of the streambed, the banks tend to fail for two reasons: (1) gravitational and hydrostatic forces are increased as the streambed is lowered to a point where the strength of the bank materials is exceeded and the banks fail, (2) increased sediment load accelerates bar building and lateral movement of the channel.

The alluvial valley within the floodplain of Perry Creek is composed of a high proportion of sand derived from the upland regions of the watershed during a past erosional cycle. The thickness of this deposit averages about 30 feet for the lower portion of the valley. This sandy material has very little strength. Degradation lowers the streambed elevation and oversteepens the bank slopes. The increased bank height and weight of exposed bank material then reaches a point where the internal strength of the material is exceeded and gravitational slip failures result.

This process is further complicated by the hydrostatic pressure head increase due to increased bank height. As the elevation of the streambed is lowered, the height of the ground water table and imponded overbank water remains the same. This increase in head then translates into increased pressures against an already unstable condition and enhances the possibility of bank failure due to the increased weight of unsupported material. Lubrication of the friction surfaces within the internal structure of the soil mass also occur.

The channelization of Perry Creek several decades ago has accelerated the degradation and bank instability process within the basin. When a sinuous reach of stream is straightened, the reduction in sinuousity is accomplished by an increase in thalweg slope of the same magnitude.

The channel instability of Perry Creek probably reflects the varied activities that result from settlement and use of the land compounded by changing of the streams base level at its mouth by the flood control operation of Grenada Dam.

b. Protection Techniques. Longitudinal and tranverse stone dikes, wire cribs, tire post retards, longitudinal peaked stone dikes and grade control structures were constructed in 1978 to control the bed and bank erosion. Perry Creek demonstration structures are located in Figures 13 thru 15. Type of construction techniques are illustrated in Figure 16. Typical construction details are shown in Figures 17 thru 21.

c. Construction Cost. The total cost of bank stabilization measures on Perry Creek, Item 6A, was $432,000. The following is a list of the cost per linear foot of streambank protected for each of the bank protection methods used on Item 6A.

Type Structure	Cost per Linear Foot
Longitudinal Stone Dike, Type I	$18.95
Longitudinal Stone Dike, Type II	28.42
Longitudinal Peaked Stone Dikes, 2 Tons/L.F.	28.42
Stone Paving	23.45
Used Tire Post Retards	11.61
Wire Crib Retards with Tire Fills	21.85

The total cost of grade control structures 6B-1 and 6B-2 was $597,406.56 and $104,675.00, respectively.

9. Maintenance.

a. Significant Events Contributing to the Need for Maintenance. Between time of construction and the spring of 1980, seven bendways were damaged to the extent that rehabilitation work was planned for 1981. Recent photographs of damaged areas are shown in Figures 22 and 23. High runouts in May 1978 and March 1980 concurrent with active streambed degradation and alignment problems may be responsible for the bank failures.

b. Description of Construction or Repairs to Existing Work.

(1) Reach 10 (Figure 22).

(a) Type Structure - Longitudinal stone dike and vegetative treatment.

(b) Reason for Repairs - Initial vegetative treatment on upper bank did not become well established, allowing upper bank scour behind the stone dike. The proximity of grade control structure 6B-1 dictated that further erosion be prevented.

(c) Corrective Measures - grade bank, construct stone bank paving, and vegetative treatment.

(d) Cost Estimate - $16,750.

(2) Reach 14 (Figure 22).

(a) Type Structure - Longitudinal stone dike and vegetative treatment.

(b) Reason for Repairs - Following construction, the upper banks experienced some damage; however, the banks have since become relatively stable with the exception of two large trees which are in danger of sloughing into the stream. The root systems of these trees contribute significantly to bank stabilization, and loss of the trees would result in additional bank recession.

(c) Corrective Measures - Fill pocket and construct stone paving at the base of trees.

(d) Cost Estimate - $1,800.

(3) Reach 15 (Figure 22).

(a) Type Structure - Longitudinal stone dike, stone paving, and vegetative treatment.

(b) Reason for Repairs - The original construction consisted of complete upper bank paving in the upstream portion of the reach, due to the proximity of a golf green, and only stone toe protection and vegetative treatment below the apex of the bend where the main attack of the stream is concentrated during high flows. The vegetation did not become well-established because the bank material was easily erodible, infertile sand. Therefore, the upper bank treatment was inadequate to withstand higher flows. Another factor contributing to the failure of the bank may be the eddy action formed at the downstream edge of the upper bank protection.

(c) Corrective Measures - Restore the bank slope by filling with point bar sand and construct stone paving.

(d) Cost Estimate - $14,050.

(4) Reach 16 (Figure 22).

(a) Type Structure - Longitudinal stone dike and stone paving.

(b) Reason for Repairs - This structure consists of complete upper bank paving in the upper reach, due the proximity of an overbank drainage structure structure, and only stone toe protection below the apex of the bend where the main attack of the stream is concentrated during high flows. The straight alignment of the streambank does not provide a smooth curvilinear path during high flows. Another factor contributing to the failure of the bank may be the eddy action formed at the downstream edge of the upper bank protection.

(c) Corrective Measures - Excavate, fill, rearrange existing stone, and construct stone tieback, and vegetative treatment.

(d) Cost Estimate - $11,800.

(5) Reach 19 (Figure 23).

(a) Type Structure - Longitudinal stone dike with vegetative treatment of upper bank slope.

(b) Reason for Repairs - Upper bank vegetative treatment inadequate for high flow, resulting in approximately 30 feet of bank recession.

(c) Corrective Measures - Restore bank slope with fill, rearrange existing stone, reinforce longitudinal stone dike and tieback and place stone paving.

(d) Cost Estimate - $31,600.

(6) Reach 23 (Figure 23).

(a) Type Structure - Wire crib retards with riprap toe protection.

(b) Reason for Repairs - Misalignment during construction of the tire cribs resulted in the middle portion of the structure protruding into the stream, resulting in scour of the stone toe, damage of the tire cribs and upper bank failure behind tire cribs.

(c) Corrective Measures - Construct tire post retard tiebacks behind existing wire crib retards and place sandfill.

(d) Cost Estimate - $10,638.

(7) Reach 33 (Figure 23).

(a) Type Structure - Tire post retards.

(b) Reason for Failure - Structure was placed in a tight bendway without toe protection, and failed soon after construction.

(c) Corrective Measures - Remove existing tire post retards as required and construct tire post retard, fill, and stone toe.

(d) Cost Estimate - $16,961.

10. Performance Observations and Conclusions.

a. <u>Monitoring Program</u>. Monitoring of the demonstration projects on Perry Creek included surveys, photographs, aerial photography, visual inspections, and a recording gage installed in 1979.

b. <u>Observations and Conclusions</u>. Of the 37 reaches stabilized, only seven are in need of immediate repair. All three of the tire post retards have experienced some structural damage and upper bank failure; however, only one reach is scheduled for rehabilitation work. Of the four tire cribs with riprap toe, only one suffered significant damage. This failure is a result of improper alignment at the time of construction. Five of the 30 stone dikes are in need of repair. There has been some minimal bank erosion on several other structures; however, the damage is not severe enough to warrant rehabilitation work.

The tire crib retards with riprap toe protection seem to withstand the erosional effects as well as the longitudinal stone dikes; however, it should be noted that the tire crib retards were placed in moderate to long radius bendways; therefore, their effectiveness in tight radius bends could not be determined. Many of the longitudinal stone dikes were placed in tight radius bends and have performed satisfactorily. The success of these structures may be attributed to the toe protection which induced sedimentation and vegetative growth, where soil conditions allowed good growth, and channel alignment did not cause severe erosive forces.

The tire post retards were not effective as a bank stabilization measure on Perry Creek. Since the toe of the bank was not stabilized, the accumulation of sediment behind the structure was minimal. It is possible that if riprap toe protection had been provided, then these structures could have been as effective as the wire cribs. Obviously, the cost would be much greater then.

At several of the bendways the channel alignment resulted in excessive bed and bank scour. It is imperative that the structure alignment provides a smooth and orderly transition between bendways for both high and low flow periods. Otherwise, full bank structural protection may be necessary.

Scour pockets were observed at the downstream end of several structures as a result of the eddy action of the water flowing over the stone tiebacks. Similar eddy action at the downstream edge of the complete upper bank protection on reaches 15 and 16 may have contributed to the upper bank failure. Careful consideration during design is needed to prevent bank erosion where stabilization measures are terminated.

At several of the sites which experienced bank failures, the natural vegetation had been removed and the banks graded during construction. This was done because the existing vegetation was considered inadequate for permanent stabilization, and sloping the banks and revegetating was specified. Whenever a good growth of natural vegetation is present, the existing banks and natural vegetation should be left undisturbed. This is exemplified on reaches 12 and 13, which are located in the same bendway but on opposite banks. On reach 13, which is on the inside of the bendway, the existing vegetation was removed, the bank was sloped and revegetated, and a longitudinal stone toe dike was constructed. The natural vegetation was left intact on reach 12 and the banks were stabilized with a peaked stone dike. Although reach 12 is on the outside of the bendway, the bank has remained relatively stable, whereas the banks on reach 13 have receded approximately 5 feet.

The success of vegetative treatment is totally dependent on three factors which are generally not controllable by the designer, therefore is subject to great risk. These are: (1) soil conditions; (2) season of the year that construction is performed; (3) severity of flow conditions immediately after construction.

Both grade control structures have been effective in halting the migration of headcuts. Several feet of bed degradation has been halted by the upper grade control structure (6B-2). Bank erosion just upstream of 6B-2 and overbank drainage are jeopardizing the integrity of the structure. If corrective measures are not taken soon, the structure may be flanked and the bed degradation may proceed upstream; migration of the headcut would endanger several bridges upstream. Stabilization of the upstream approach to the structure is limited because of the inability to obtain the necessary right-of-way.

An overbank drainage problem at the upper grade control structure was deleted from the plans during construction. The drainage includes not only the nearby pond, but also about 1 square mile, or about 5 percent of the total Perry Creek drainage area. The drainage was to be diverted from upstream of the sheetpile weir to just downstream of the scour hole. The deleted drain has now caused severe bank scour, resulting in several trees falling into the creek. Corrective measures are needed to protect this drain before the grade control structure is severely damaged.

During construction of the lower grade control structure (Item 6B-1) a decision was made to provide full bank paving for an additional 500 feet on the right bank downstream of the structure and to increase the width of the structure. This added bank protection resulted in significant increases in the cost of the structure. The resulting geometry of the structure is no longer compatible with the channel conditions.

The accumulation of sediment and subsequent vegetative growth on the side of the pre-formed scour hole on the lower grade control structure (6B-1) indicates that the scour hole as constructed is oversized. However, this vegetative growth is not a potential hazard to the structure, unless the flow is diverted to one side of the structure instead of directed through the center of the structure. This action could cause damage to the structure and loss of adjacent lands.

At the present time, no significant impacts on stream regime are evident, with the exception of a possible reduction in sediment input due to reduced bank caving. No significant adverse effects on the environment were observed. In addition, bank protection has created a more aesthetically pleasing stream.

11. Summary and Recommendations. The majority of the stabilization works on Perry Creek have been successful to some degree in preventing streambank erosion. Present evaluations indicate that proper structure alignment, toe protection, prevention of streambed degradation,

and leaving existing vegetation and banks undisturbed have contributed to the success of the stream stabilization measures. Effective evaluation and definite conclusions as to the future success or failure of the stabilization works will require another 5 to 10 years of monitoring.

B. Batupan Bogue.

1. General Overview. This stream was subjected to local straightening and channelization several decades ago. Recent erosion of a rock outcrop in the bed, one and a half miles upstream from the mouth, has aggravated instability problems throughout the basin. Excessively sandy erodible banks, plus the need to protect several bridges and urban developments, made this steam an excellent location to demonstrate a variety of bank stabilization methods.

Twelve different protective techniques were built, ranging in cost from $18.41 to $108.90 per foot of bank, with a total cost of $1,511,000. Excessively high rains in November 1977 produced a runoff that was estimated to be between the 100 year and the 500 year event. At that time construction was incomplete and vegetation controls were nil. The result necessitated immediate rehabilitation work costing $562,000. Final repairs are being added in 1981 at a cost of $345,000.

The work on Batupan Bogue was less sucessful than that on other streams in the Vicksburg District due primarily to two reasons: (1) This stream was undergoing significant regime changes, and (2) Unsually high flows during and shortly after construction. Where the work was most successful, some or all of the following conditions were present:

(1) Relatively smooth channel alignment, with no abrupt changes in flow direction.

(2) Adequate toe protection to allow for localized scour and/or bed degradation.

(3) Structural protection to top bank elevation.

(4) Mimimum clearing of vegetation where existing growth was incorporated into structural design.

(5) Accurate prediction of beginning (upstream) and ending (downstream) points of erosion.

Conversely, less success was achieved if any or all of the above conditions were lacking. The majority of the failures were dramatic examples of the severe stress created by high flows on the downstream end of bank protection in a bend.

2. Watershed Location and Description. Batupan Bogue Watershed drains a 233 square mile area in the North Central Hills region of Mississippi (Figure 24). The watershed covers portions of southeast Grenada County, north Montgomery County, and a small portion of Webster County. Batupan Bogue forks into two main channels near the center of the watershed; Big Bogue to the southeast and Little Bogue to the east. The watershed drains in a northwest direction and flows into the Yalobusha River at Grenada. In addition, Batupan Bogue is the first tributary to the Yalobusha River below Grenada Dam, and is strongly influenced by the reservoir releases, as well as hydraulic conditions of the Yalobusha River.

The entire Batupan system is highly sinuous along the main channel, as well as along its tributaries. Meander bends have a tendency to be contorted with sharp angle bends. Channelization has been extensive throughout the basin, particluarly along Little Bogue Creek. Many abandoned channels and meander scars are visibly depicted on topographic maps and can be seen on aerial photographs. Drainage on Batupan appears to be evenly distributed on both sides of the basin with the main channels approximately centered about the basin (Figure 25).

The demonstration project stabilization work which will be described in a later section of this document was done in the lower 5 miles of Batupan Bogue in rural areas, where two bridges and two small residential areas are exposed to the stream's actions.

3. Problem Analysis of Batupan Bogue Drainage System.

Research data indicate that Batupan Bogue was historically a fairly stable stream until its natural stability was affected by changes in the Yalobusha River. Geologic controls in the stream bed, consisting of clays, held the stream bed in a stable condition in historic times, producing a convex rather than concave valley profile. This stability is evidenced in aerial photos taken in 1935 and 1941. However, beginning in 1954, changes were evident in the aerial photos of the stream.

Increased hydraulic gradient eroded the stream's natural controls resulting in severe channel response. Changes in the stream included bed degradation, as well as gross width increases. Both these actions tended to lower flowlines creating instability in the upstream reaches and on all tributaries.

4. History of Batupan Bogue Watershed.

Historic data of this basin are not abundant, but the navigating activities on the Yalobusha River as well as quantities of farm produce shipped from Grenada, Mississippi, attest to land use practices, thus probable sediment production in the basin.

In the 30-year period prior to the Civil War, the farm population grew from practically no farming to extensive farms throughout this section of the Yazoo Basin. An 1833 map shows only a handful of settlers in the entire watershed, and by 1860 all usable land had been cleared for agriculture.

In 1879, navigation on the Yalobusha between Greenwood and Grenada was possible for boats having a capacity of only 600-800 bales. Prior to 1860, boats carrying 1,500 bales could navigate that reach. Bank width in 1879 ranged from 120 to 240 feet. Today the top bank varies from 150 to 550 feet wide. By 1922 the river was so choked with sediments that no navigation was possible. By 1941 the discharge capacity of Yalobusha River had decreased to 25 percent of its 1879 capacity, which, according to navigation reports, was considerably less than it was in pre-Civil War years.

This wide fluctuation in channel size of the Yalobusha River in 80 years obviously controlled the characteristics of Batupan Bogue and its tributaries. Additionally, the Yalobusha was reacting to land use problems in its drainage basin, so the farming practices beginning in the 1830's must have eroded extreme amounts of sediments into all of the streams.

The 1833 map indicates the Batupan Bogue was relatively straight and apparently locked in by geologic controls. Meander scars in the floodplain are either residuals of previous (pre-1833) high sediment movement or a result of poor farming practices between the 1833 map and a 1935 aerial photo. Documented evidence on other rivers in the Yazoo drainage basin indicates that the meander scars in the plains are mostly much older than 1833. They were probably formed 2,000-3,000 years ago when the Young Paleosol soils were deposited. Post-settlement deposits appear to be of the over-bank type and not channel deposits, indicating that during the 100-year period before 1935 the Batupan Bogue was more of a transport stream than a depositional stream.

Recent sediment production by the stream is evidenced in the Yalobusha River. Between Grenada Dam construction in 1954 and a 1970 survey, comparisons indicate that the Yalobusha River had 1 to 4 feet of aggradation just downstream of the confluence of Batupan Bogue, and 6-10 feet of aggradation near the bluffline (12 to 14 miles downstream) where a slope change is evident. This aggradation on the Yalobusha River, if continued, could eventually reverse degradation reaction in all tributaries and start a cycle of channel filling.

Early maps indicate few settlers and very little farming; however, by 1860 all the useable land had been cleared. Apparently the

150 years of initial land clearing produced excessive sediments in the basin streams. However, by 1935 over 75 percent of the basin had reforested with only the floodplains still in agriculture, and more of the agricultural lands had been reforested by 1974. Currently there is evidence of renewed land clearing efforts.

Photos indicate that the geometry of the river in the mid-1930's would allow a higher discharge than the geometry of the old meander scars indicated. This was probably a result of excessive runoff due to land clearing. However, the 1935 bank widths are as narrow as those of the earlier scars and the channel, at that time, seems to be incised into the floodplain, further indicating a higher discharge in recent historic past. The stability of pre-1930 to the early 1950's river indicates a possible underfit stream incised into a consolidated clay formation which held the bed profile constant but allowed the banks to fill in, creating a narrow, relatively smaller river in a larger river's meander path. Current instability activity is reverting this stream to the same historic condition with a larger channel. Future changes in base level controls and land conservation practices will effect the stability regime of Batupan Bogue.

5. Geology of Batupan Bogue.

The geology of a drainage basin is one of the most significant parameters in the analysis of channel stability, with the physical properties of each stratigraphic unit having a direct relationship 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. Accurate assessment and prediction of stream stability requires a complete analysis of the geological variations within the basin.

The geologic formation present in the Batupan Bogue Basin consists of Eocene sands and clays in the uplands with a complex valley fill in the floodplain. The valley fill is the depositional area of upland erosion which occurred following the most recent glaciation.

In general, Batupan watershed flows through thin loess material typical of the area. Ridges are relatively narrow with moderate to gentle slopes, with topography over the basin varying in elevation from around 450 feet, NGVD, at the headwaters to 160 feet or less at the confluence, as the stream enters the floodplain of the Yalobusha River. Sediments found in the channel consist mainly of silt, sandy silt, and a low plasticity clay.

Above the Highway 8 bridge, the creek flows against a hill exposing a high bluff along the right bank. The near-vertical bluff appears to be a Tallahatta-like material. The hill appears to be the result of tectonic activity, such as uplift and/or folding. The exposed bluff exhibits a jointed and faulted structure with small displacements.

The areal geology of Batupan Bogue Watershed is shown on Figure 26. Data for preparation of this map were taken from Mississippi Geological Survey Bulletins 48 and 55, from a USGS state areal geologic map, from Bicker's (1969) MGS State Geological Map, and from field investigations. Data for the eastern portion of the map was taken from Brown (1943), and the western area was compiled from other large scale mapping projects and adjusted to fit this smaller area using reported contact elevations and regional dips of the various formations.

Foundation borings near Vance Road on Perry Creek revealed Eocene material at an average depth of 38 feet below the surface. Silty sand and gravel overlays the Eocene material and 2 to 9 feet of post-settlement alluvium overlie the sandy, gravelly terrace deposits. These deposits are usually saturated to within 12 feet of the surface. On Perry Creek a layer of organic material roughly follows the thalweg elevation on down to Batupan Bogue. Borings near the golf course south of Grenada revealed up to 13 feet of post settlement alluvium at this location overlaying coarser alluvium. The water table at the time the holes were drilled stood at about 187.5 feet, NGVD, 12-1/2 feet below the surface, at the approximate thalweg elevation. One sample of Sassafras wood taken at a depth of 15 feet a hundred feet or so downstream from I-55 was dated at 4830± 100 years B.P. A mile further up channel, wood at a depth of 9 feet was only 270± 80 years old.

The scour into the Eocene material is of indeterminate age and considerable reworking of the valley alluvium has occurred in the top 15 feet of sediments in the last 5,000 years; however, reworking of the upper half of this deposit has been more active in the last 270 years. In the lower reaches, the channel has done considerable meandering in the last 2000-3000 years.

The floodplain of Batupan Bogue was eroded and flushed of sediments during the 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 stratigraphy of these valley fills is discussed in the general geology section in the introduction of this report.

The banks and bed of Batupan Bogue are very unstable, except where either the Eocene or Paleosol clays are present. Frequently, however, the stream will migrate laterally when this clay is encountered, caving additional banks. The best method for stabilizing this stream in terms of its geologic characteristics is to maintain an acceptable thalweg slope and provide sufficient bank protection to prevent the lateral migration.

6. Hydrology.

a. Rainfall. The rainfall gages providing data for Batupan Bogue are located at Grenada Dam and Elliott, Mississippi. See paragraph II-5-a, "Perry Creek," for detail.

b. Streamflow Information. Very little measured streamflow data is available for Batupan Bogue. During the period 1954 through 1977, 32 discharge measurements were taken at the Mississippi Highway 8 bridge, east of Grenada. Data for these measurements are presented as a "rating curve", Figure 27. These data form a fairly well-defined curve, which is somewhat unusual since Batupan Bogue underwent major channel enlargements during this period. Channel enlargement usually indicates a significant downward shift of the stage-discharge curve. Until the recently installed protection works become fully effective in stabilizing the banks, the downward-shifting trend may be expected to continue.

During the period of record, mean velocity for all flows ranged from 0.74 fps to 6.49 fps. Maximum velocities ranged from 1.06 fps to 12.09 fps. Measured discharge for these velocities varied from 15.5 cfs to 34,400 cfs. Flow information for several of the more significant runoff events is given in the following table:

	Precipitation (in., 5-Day Total)		Gage (ft, NGVD)	Mean. Vel. (ft/sec)	Max. Vel. (ft/sec)	Discharge (ft^3/sec)
	Grenada	Elliott				
3-24-75	1.50	1.02	171.48	2.04	3.32	3,040
2-3-56	3.64	3.26	173.05	2.65	7.72	4,500
4-6-56	3.77	3.66	175.33	3.93	5.34	5,740
5-3-54	10.50	11.25	175.01	4.86	9.31	6,800
12-13-56	4.67	4.78	174.99	4.18	9.11	7,600
12-17-59	3.38	3.25	177.50	5.13	10.57	14,100
11-13-61	9.94	8.07	180.37	6.49	11.09	25,500
11-13-61	9.94	8.07	181.52	5.75	12.09	27,200
3-16-73	8.85	7.19	182.35	6.42	10.92	34,400

During the storm of 21 November 1977, for which approximately 7 inches of rainfall were recorded, no streamflow measurements were taken. Crest gages at Highway 8 bridge indicated a maximum water surface elevation of 181.23 ft, NGVD. Since the channel is now larger, it is likely that this runoff surpassed the previous record discharge of 34,400 cfs. Observations by several Vicksburg District personnel in the area during and immediately after this storm state that the rainfall began late in the evening and continued for 7 or 8 hours at a very heavy rate, producing the flow data noted above.

The results of this storm remained visible following the return of flow conditions to normal levels. The most noticeable of these was the collapse of the Mississippi Highway 8 bridge. This bridge was less than 10 years old, the previous bridge also having been a victim of severe flows. Following the storm, the bridge span was visible and positioned in a manner which indicated that the pier footing had been swept downstream or the streambed could have become fluid and incapable of supporting a load.

Another result of this storm occurred in the vicinity of Station 230+00. A cultivated field occurs at this location. Aerial photos indicate an old abandoned channel. Following the November 1977 storm, at the point where the old channel leaves the existing channel, a sand wave was created in the field. At the top of the bank, the sand wave was about 20 feet wide, with a near-vertical downstream face about 15 inches high and tapered down in size as it extended 200 to 300 feet into the field. The sand wave was formed with sediments subject to the forces of secondary flow. It is estimated that overbank flow depths of 5 to 6 feet were necessary to produce a sand wave of this extent.

c. Bankfull Information. Since the period of channel enlargement began, insufficient data has been taken to provide accurate bankfull flow information. Manning's equation can be used to estimate these characteristics through the use of available cross-section and thalweg profile surveys.

To evaluate Manning's "n" value, or roughness coefficient, a reference (Chow, 1959) which shows different channels and their assigned "n" values may be consulted. Batupan Bogue, within the study area, has a wide channel with large vegetation-free sandbars with steep banks, especially in bendways. Most banks have vegetation ranging from grasses to trees, with normal amounts of underbrush. Flow resistance in a channel of this type is due primarily to form roughness. An "n" value of .035 is considered appropriate for Batupan Bogue, below the upper end of the project. This value varies with stage, however, and based on information from the available discharge data, it can be shown to range from .08 at mid-bank flows, to .028 at overbank flows at the Highway 8 bridge. This variation depends on the actual channel geometry at a given location.

From this type analysis, the following values can be estimated for bankfull flows:

STATION	Area (ft^2)	Wetted Perimeter (ft)	Radius (ft)	Slope (ft/ft)	Assumed "n"	Avg. Vel. (fps)	Discharge (cfs)
31+00	2,370	266	8.91	5.000×10^{-4}	.028	5.1	12,100
					.05	2.86	6,800
108+68	1,646	220	7.48	6.147×10^{-4}	.03	4.71	7,750
					.06	2.35	3,875
170+00	1,432	171	8.37	6.147×10^{-4}	.035	4.35	6,200
					.07	2.17	3,100
190+69	1,942	239	8.13	6.147×10^{-4}	.035	4.27	8,300
					.07	2.13	4,150

It should be noted that portions of the available data are of questionable validity since alterations have been made to the channel after discharge measurements were last taken. These changes include increased roughness in the form of rock cribs, groins, and toe protection and also channel contractions such as caused by the landfill placed on the left top bank just upstream of the Highway 8 bridge.

In a report prepared for the Mississippi Research and Development Center on the flood hazards at Grenada, estimations of the Intermediate Regional Flood and the Standard Project Flood were given (C of E 1970). These are shown in Figure 28.

d. Sediment Information. No measured sediment data is available for Batupan Bogue. It may be concluded, however, that based on channel changes, sediment transport capacity of the stream has decreased during the period of enlargement which followed the construction of Grenada Dam. This is deducted from the fact that slope has remained essentially constant and stage has decreased as a result of channel widening. The increased number and size of sand bars in the channel is evidence that the stream is unable to transport the available load at any but the highest flows. It is possible that the volume of sand in the bars is approximately equivalent to the material entering from the caving banks, but there is not accurate means of measuring these quantities or the amount of sediment that has been flushed from the reach during the widening period. Another possibility is that slope and velocity have increased in some locations, thus increasing average transport capability, but that sediment input exceeds this capacity. Future monitoring is necessary to determine the degree to which these processes are occurring, and their effect on sediment transport.

7. Channel Changes.

The Batupan Bogue stream channel has undergone major modifications throughout its length, beginning in the early 1950's and continuing to the present. Aerial photography reveals a very stable stream channel from its mouth at the Yalobusha River upstream through the entire drainage system of this watershed. Typically, the streams of this watershed in the 1935 photos indicate that the basin stream time period were characterized by long radius, tree-lined channels producing minimal sediments, with little evidence of active aggradation or degradation. The undesirable characteristic for channels of this period, if any, would be the relatively undersized channels as compared to the drainage basin which resulted in more frequent flooding.

The aerial photography of the early 1950's shows extensive channelization of the Yalobusha River. The channelization of the Yalobusha River and the controlled river flows through Grenada Lake coupled with land use changes, reduced the normal water levels at the mouth of Batupan Bogue. The photography of 1952 and 1954 indicates clearly the initial channel alterations in the lower 1-1/2 miles of channel with an increased bank width of 70 percent by 1952. The 1954 photos indicate that the channel meandering process had resumed with a natural cutoff forming 1/4 mile upstream of its confluence with the Yalobusha River. Additionally, large sand deposits appear on all point bars below State Highway 8 bridge with smaller sand deposits on point bars an additional 2 miles upstream.

The 1974 aerial photography indicates the channel has undergone significant modifications throughout its length, since 1935. The degradation has progressed upstream resulting in (1) width increases averaging 100 percent or greater; (2) unstable vertical banks; (3) meandering to the point of natural cutoffs below State Highway 8 bridge; and (4) large sediment deposits appearing in all natural deposition locations along the channel. These observations along with several bridge failures over this drainage basin further substantiates extensive stream channel degradation moving through the system.

Figure 29 is presented to show the relative magnitude of stream width and length alterations for Batupan Bogue from the Yalobusha River confluence to Tie Plant Bridge (5 miles) for the period 1935 to 1974. This figure shows channel width increases of 100 percent from the Yalobusha River confluence upstream 1-1/2 miles and 200 percent continuing upstream from this point. Length variations have remained relatively unchanged with a 500-foot increase for this period over the 5-mile reach.

Figure 30 shows a bed-level lowering from 1954 to the late 1970's of 2 to 5 feet for the stream channel up to the Perry Creek confluence (2 miles) and over 7 feet continuing upstream. The later profiles of this figure show aggradation of 2 to 3 feet from the Yalobusha River confluence upstream approximately 3 miles. Little change is noted for the next 1-1/2 miles with 2 feet of degradation continuing upstream.

Figure 31 shows the large scour and fill processes for the thalweg which have occurred since 1972 over the lower 2 miles of stream channel. Summarizing these data, the thalweg has generally aggraded 2 to 3 feet over this stream reach.

Further indication of continuing stream channel alterations for Batupan Bogue is apparent due to random bank failures during high runouts. The bank failures occurring in the 1970's have been primarily concentrated along the channel above State Highway 8. Documentation of these failures is presented in Section 8 entitled "Maintenance" in this report.

These data clearly show the continuing regime changes in this stream. Channel widening is continuing upstream of State Highway 8 with each major storm event. Various types of bank stabilization measures have been installed to reduce this problem. These measures have met with varying degrees of success. These adverse channel changes are expected to continue until this system has time to adjust to the base-level changes imposed on the system and has established a stable slope.

8. Construction of Protection Works.

a. Need for Protection. Bank caving throughout the entire Yazoo Basin could be as much as nine times higher than established in 1969. Loss of land, a maintenance of man-made river bank structures, navigation and flood control problems further downstream in the system, as well as the associated environmental problems, all point out a dire necessity to improve sediment management. Stream bed and bank stabilization techniques are one portion of improving the total sediment problem.

Following the bed degradation, the banks tend to fail for two reasons: (1) gravitational and hydrostatic forces are increased as the streambed is lowered to a point where the strength of the bank materials are exceeded and the banks fail, and (2) increased sediment load accelerates bar building and lateral movement of the channel.

The alluvial valley within the floodplain of Batupan Bogue is composed of a high proportion of sand derived from the upland regions of the watershed during past erosional cycles, with thicknesses averaging 30 feet for the lower portion of the valley. This sandy material has very little strength, and degradation lowers the streambed elevation and oversteepens the bank slopes. The increased bank height and weight of exposed bank material then reaches a point where the internal strength of the material is exceeded and gravitational slip failures result.

This process is further complicated by additional hydrostatic pressure head due to increased bank height. As the elevation of the streambed is lowered, the height of the ground water table and imponded overbank water remain the same. This increase in head then translates into increased pressures against an already unstable condition and enhances the possibility of bank failure due to the increased weight of unsupported material. Lubrication of the friction surfaces within the internal structure of the soil mass also occurs.

The channel instability of Batupan Bogue probably reflects the varied activities that result from settlement and use of the land compounded by changing of the stream's base level at its mouth by the flood control operation of Grenada Dam.

b. Protection Techniques.

The following presents a brief summary of protection techniques used in Batupan Bogue demonstration projects. See Figures 32 and 33 for the project plan and location, Figures 34-38 for typical construction details, and Figures 39-44 for photographs of typical structures.

The lower reach of Batupan Bogue below Highway 8 bridge was stabilized in 1974 under Work Item FY 74. Construction was not funded under the Section 32 Program; however, evaluation of the protective methods was performed under Section 32. Four types of bank protection were used: (1) transverse stone dikes; (2) traverse board-fence transverse dikes; (3) longitudinal board-fence revetment with tiebacks; and (4) longitudinal stone dikes with tieback. Work Item 4A was constructed in 1977 upstream of the Highway No. 8 bridge. Four types of bank protection were used: (1) longitudinal stone dikes with upper banks graded and vegetated; (2) used-tire revetment; (3) sand-cement sack revetment; and (4) peaked stone toe dikes with no upper bank protection.

c. Construction Cost. The initial bank protection measures on Batupan Bogue were constructed under Work Items FY 74 and 4A costing $565,000 and $946,000, respectively. Rehabilitation work was performed under Work Items 4A-1 and 4A-2 costing $498,000 and $64,000, respectively. The total cost estimate for the 1981 rehabilitation work is $345,000. The following is a breakdown of the cost per linear foot of streambank protection for each work item:

Type Structure	Cost Per Linear Foot Per Work Item FY-74	Item 4A	Item 4A-1	Item 4A-2
Transverse Stone Dike	22.87	33.00		
Longitudinal Stone Dike w/Tieback	108.90	38.00		
Type II Longitudinal Stone Dike w/Tieback			33.00	
Type III Longitudinal Stone Dike w/Tieback			55.00	
Longitudinal Peaked Stone Dike Type II		30.00	33.00	
Longitudinal Peaked Stone Dike Type III			66.00	
Stone Paving			38.00	
Used Tire Revetment		28.00	18.41	
Sand Cement Sack Revetment		62.00		
Board Fence Transverse Dike	26.08			
Longitudinal Board Fence Revetment	115.80			
Vegetative Treatment				9.22

9. Maintenance.

a. Significant Events Contributing to Maintenance. During the extremely high runouts in November 1977, 7 of the 13 bank stabilization structures on Batupan Bogue (Item 4A) were damaged to the extent that reconstruction measures were needed. This event occurred during construction, with most of the upper bank protection incomplete. Rehabilitation work was performed in the summer of 1978 under work items 4A-1 and 4A-2. During the high runouts of 1980, three structures were again severely damaged and are scheduled for rehabilitation work in the spring of 1981. None of the structures under Item FY 74 were damaged enough in 1977 or 1980 to require any rehabilitation work. See Figures 45-53 for photographs of rehabilitation areas.

b. Description of Construction or Repairs to Existing Work.

(1) Reach 4.

(a) Type Structure. Longitudinal peak stone dike.

(b) Reason for Repairs. During the high runouts of November 1977, the upper bank experienced some minor erosion. Following this event, the banks became re-vegetated and were relatively stable. During the high runout of 1980, this structure was totally flanked with a bank recession of over 100 feet. The landowner estimates his land loss at 5 acres. This structure was placed in a relatively straight reach with no curvilinear alignment. The alignment of the channel upstream was such that during high flows, the main thread of current was directed nearly perpendicular against the structure, resulting in the excessive bank recession. At the present time, the remains of the original structure lie across the inside of the new point bar.

(c) Corrective Measures. Clear and grade bank, construct longitudinal stone dike and tieback, used tire revetment, and vegetative treatment.

(2) Reach 5.

(a) Type Structure. Longitudinal stone dike and vegetative treatment.

(b) Reason for Repair. This structure is located in a relatively short radius bendway. There has been upper bank scour throughout the reach most noticeably near the apex of the bend. Of more concern, however, is severe toe scour (12 feet) which occurred during the high flow of November 1977 because of the short bend radius (Figure 54). There is little vegetaion growing along the upper bank, and it appears that the soil type is not suitable for good vegetative growth. However, the denseness of the soil has also limited the rate of erosion. Rehabilitation work is scheduled for 1981.

(c) Corrective Measures. Clear and grade bank, fill, construct longitudinal stone dike and vegetative treatment.

(3) Reach 7.

(a) Type Structure. Sand-cement bag revetment.

(b) Reason for Repair. The lower end of this structure was destroyed during the high runouts of November 1977. This failure may be attributed to the alignment of the structure not being compatible with the high water channel. During high water, the main thread of current was directed across the lower end of the structure, resulting in excessive bank scour. It should be noted that during construction, there was extensive clearing of vegetation within the right-of-way of the top bank.

(c) Corrective Measures. Rehabilitation work, which was performed in the summer of 1978, consisted of the construction of eight transverse stone tiebacks extending from the sand-cement bag revetment back to the new bank line and the addition of longitudinal peaked stone.

(4) Reach 8.

(a) Type Structure. Used tire revetment.

(b) Reason for Repairs. During the high runouts of November 1977, the lower end of this structure experienced excessive bank scour. This failure may have been aided by the failure of the lower end of the structure just upstream (Reach 9); the failure of the lower end of Reach 9 allowed the high flows to cut across the point bar and impinge on the lower end of Reach 8.

(c) Corrective Measures. Rehabilitation work was performed in the summer of 1978. This reinforcement consisted of the construction of a longitudinal stone dike and a transverse stone tieback on the lower end and reinforcing the toe of the used-tire revetment with stone to prevent additional toe scour.

(5) Reach 9.

(a) Type Structure. Sand-cement sack revetment.

(b) Reason for Repair. During the high runouts of November 1977, the downstream end of the revetment was flanked, and upper bank scour occurred on several hundred feet of the upstream end. Once again, upper bank protection of the downstream end was not sufficient for high flows. The damage to the upstream end is due to saturated fine-grained soil, underlain by impervious clay. This soil condition is subject to slumping and rapid erosion.

(c) Corrective Measures. During the summer of 1978, the lower end was repaired by extending three transverse stone dikes from the original revetment line to the new bank line, adding longitudinal peaked stone at the bank toe, and reinforcing the upper bank with stone paving. The upper end of this reach was not repaired at this time, but rehabilitation work is scheduled for 1981. The repair work for the upper end will include the following: slope bank, construct longitudinal stone dike, used tire revetment, and vegetative treatment.

(6) Reach 10.

(a) Type Structure. Longitudinal stone dike (Types II and III).

(b) Reason for Repair. During construction, fill material was removed from the point bar and used to bring the banks to grade. The erodibility of this material, the lack of vegetation on the bank slope prior to the November 1977 flood, and strong overbank flows all combined to cause the lower end of the structure to be flanked. It is important to note that the overbank at this location is a cultivated field which presented little resistance to overbank flow.

(c) Corrective Measures. Rehabilitation work in the summer of 1978 consisted of the construction of eight transverse stone tiebacks and a Type III longitudinal stone dike.

(7) Reach 11.

(a) Type Structure. Longitudinal peaked stone dike and longitudinal stone dikes (Types II and III).

(b) Reason for Repair. During the high runouts of November 1977, the lower end of the bendway experienced excessive scour and bank recession. It should be noted that bank failure occurred even though the lower end was stabilized with a Type III longitudinal stone dike, which is the strongest design used on Batupan Bogue. This indicates that even the strongest design may be ineffective during extremely high events particularly if these events occur before vegetation is established, if vegetative treatment is incorporated into the design.

(c) Corrective Measures. During the summer of 1978, five transverse stone tiebacks were installed on the lower end. Following this repair work, the space between the tiebacks began to accumulate sediments and grassy vegetation began to take hold. However, the high runouts in March 1980 caused severe bank scour and loss of vegetation. The work is still functional and there is no additional repair work scheduled at this time.

(8) Reach 12.

(a) Type Structure. Longitudinal peaked stone dike.

(b) Reason for Repair. During the storm event of November 1977, the lower end of the structure was flanked and the banks receded approximately 40 to 50 feet. More vegetation was cleared from the bank during construction than was anticipated, leaving the upper bank vulnerable to high flows.

(c) Corrective Measures. Nine transverse stone tiebacks were constructed in the summer of 1978, extending from the original stone revetment back to the new bank line. Additional peaked stone was also added to the original structure. Since reconstruction there has been little sedimentation or vegetative growth, but no further channel migration has occurred.

(9) Reach 13.

(a) Type Structure- Used Tire Revetment.

(b) Reason for Repair. During the high runouts of November 1977, this structure was completely destroyed, and the bank receded approximately 40 feet. Excessive toe scour and lack of vegetation on the bank slope resulted in total failure.

(c) Corrective Measures. Repair work in the summer of 1978 consisted of the construction of a longitudinal stone dike, three stone tiebacks at the lower end, and used-tire revetment vegetated with willow sprouts. At the present time, the bank is in good shape and has a good vegetative cover of grass, although there has been little, if any, growth of willows. The success of the reconstruction is attributed to adequate toe protection and extending the elevation of the used-tire revetment to top bank rather than relying on vegetative treatment for the upper portion of the bank slope.

10. Performance Observations and Conclusions.

a. Monitoring Program. Monitoring of the demonstration projects included surveys, photographs, aerial photographs and visual inspections.

b. General Observations and Conclusions. All stabilization measures under Item FY 74 have been successful in accumulating sediments and protecting the banks. The longitudinal board fences with stone toe protection were the most effective, and the most expensive, of all bank stabilization measures on Batupan Bogue. This structure combines the effects of flow retardence and toe protection. Another factor contributing to the success of the Item FY 74 work is that degradation and subsequent channel widening had proceeded upstream through the area prior to construction of the stabilization measures. Comparison of the 1976 and 1979 thalweg profiles indicate that the lower end of Batupan Bogue below Highway 8 has localized areas of aggradation and degradation. There has been significant accumulation of sediment and vegetative growth behind the structures. This accumulation of sediments has continued for several years, which is evidenced by the well-developed growth of willows behind the structures. Moderate to low rainfall from 1975 to 1977 also may have contributed to the increased sedimentation and vegetative growth.

With the exception of a few reaches, the Item 4A work has generally had little launching of the stone toe protection due to scour, even where massive bank failures have occurred. According to comparative thalweg profiles (Figure 54), the streambed between Reach 1 and Reach 9 has remained relatively stable with only localized areas of scour and fill. This indicates the presence of a consolidated streambed which the stream cannot penetrate; therefore, during high flows the banks are scoured rather than the bed. Because of the consolidated bed material, the bank failures are due to the erosive forces of the stream impinging on the upper banks, rather than as a result of an oversteepening of the banks following a lowering of the streambed. In areas where geologic bed controls exist, complete upper bank protection with minimal toe protection may be the most suitable design. This design differs considerably from actively degrading streams such as Perry Creek where toe protection is essential to providing adequate bank protection. It is important to recognize that a complete study of the area is necessary to insure that the optimum stabilization techniques for the stream are selected. Several factors such as alignment, incomplete upper bank protection, and extensive clearing of existing vegetation for construction access may have contributed to the bank failures on Item 4A. During construction of the Item 4A work, approximately 40 feet along the upper bank was cleared for construction operations. This extensive clearing left the banks extremely vulnerable to erosion. Had the existing vegetation been left undisturbed, then the channel width increases may have been reduced. However, this would require that construction operations be conducted from the streambed, increasing the difficulty and cost of construction. During extreme high flows the point of attack on the bendway is shifted downstream. Most of the damages to the structures occurred at the downstream end of the bendway, indicating that the channel alignment was attempting to adjust to the extreme high flows.

However, despite the factors described above, the storm event of November 1977 is the major reason for the bank failures. Even under the best design conditions, bank stabilization measures may be ineffective when subjected to extremely high runouts. Had it not been for the November 1977 storm, most of the structures may have performed satisfactorily.

The majority of the 1978 rehabilitation work consisted of the construction of transverse stone tiebacks connecting the structure to the new bankline. This was an attempt to provide a structure compatible to all flows. At the present time, channel migration has stopped, although there is not a great deal of sediment accumulation between the dikes. However, given several years of normal flows, these structures may prove effective. Consideration was given to protecting the new bankline rather than attempting to preserve the original structure alignment. This would provide an alignment that is more compatible with the high flows. The radius of any bank on any stream must conform to all flows and can be determined only by data from that stream. The design of the rehabilitation work was based on allowing a portion of high flows to pass over the tops of the stone tiebanks, without allowing channel migration, and at the same time preserving the original structure alignment for more moderate flows.

Although many of the Item 4A structures were severely damaged, three of the sites (Reaches 2, 3, and 6) were not significantly affected.

Reaches 2 and 3 were constructed of longitudinal peaked stone on a long radius bendway. Reach 2 is downstream of the mouth of Perry Creek, and it is possible that the sediment input from Perry Creek may be protecting the upper end of the structure from direct attack during high flows. Reach 3 is a very short structure just upstream of the mouth of Perry Creek and is not subjected to severe attack during high flows. Both of these structures have experienced little structural damage or upper bank failure.

Reach 6 has experienced only minor erosion since its construction. This structure is located in one of the larger radius bendways in the study area and consists of full bank paving throughout most of its length, with stone toe protection and upper bank vegetation on a portion of the upper third and on the lower third of the bendway. Comparison of 1976 and 1979 thalweg profiles indicates that Reach 6 has aggraded with the exception of one area of localized scour at the upper end. The high degree of bank protection, coupled with the relatively long radius bendway and aggradation, may account for the success of Reach 6.

11. Summary and Recommendations.

Stabilization measures on Batupan Bogue were constructed under Work Item FY 74 and Item 4A. The success of the FY 74 work and the failure of much of the 4A work exemplifies the fact that certain areas in a stream may be more susceptible to bank protection measures than others.

The FY 74 work was placed in an area where the channel was already adjusting to the degradation and subsequent bank widening. The extreme storm event in November 1977 did not significantly alter this previously widened and well protected channel. However, the Item 4A work was constructed in an area which had not been seriously affected by degradation and bank widening due to the presence of geologic controls. Because the channel geometry had not been significntly enlarged as in the FY 74 area, the channel was unable to accommodate the November 1977 flows, and many of the banks were drastically widened and the structures severely damaged. It is doubtful if any economically feasible engineering techniques in the 4A area would have provided adequate bank protection against this extreme event which has been estimated as at least a 100- to 500- year frequency event.

Perhaps the most critical factor affecting the future performance of the Item 4A work is the geologic controls in the streambed. These controls have essentially stabilized the streambed with the exception of a few areas of localized scour. If these controls are relatively thin and are eroded away in the near future, then the subsequent bed degradation and channel widening could be disasterous to the stabilization structures. Therefore, a geologic investigation is needed to determine the thickness and erodibility of the controls. The results of this investigation would be used to determine if any future work such as construction of grade control structures or reinforcement of existing structures is needed.

C. Tillatoba Drainage Basin.

1. General Overview. During the early 1900's, the reach of river between the hill line and it's confluence with the Tallahatchie River was straightened out by local interests. This action, coupled with land use changes and the lowering of the rating curve on the Tallahatchie River, initiated a series of headcuts that worked their way upstream creating instability problems. An unpublished report by local interests indicated that 50 percent of the farmable land could be eroded by the early 2000's if instability problems were allowed to continue. S.C.S.

built a series of several flood-retarding structures in the upper portion of the watershed and stabilized a reach of the stream in the late 1960's. This initial work offered a good basis to continue stabilization of the drainage basin.

Eighteen variations in bank protection were constructed, varying in cost from $18.28 to $99.00 per foot of bank with a total cost of $2,320,324. In addition, two grade control structures were built on the North Fork, Tillatoba Creek, at a cost of $213,901 and $128,420, respectively. Rehabilitation work costing $80,100 is scheduled for FY 1981.

The bank stabilization work in the Tillatoba Basin was generally successful, with the exception of the wire crib retards. These structures provided neither adequate toe protection nor adequate height for upper bank protection. Where the work was most successful, some or all of the following conditions were present:

(1) Relatively smooth channel alignment, with no abrupt changes in flow direction.

(2) Adequate toe protection to allow for localized scour and/or bed degradation.

(3) No active channel degradation occurring.

(4) Accurate prediction of beginning (upstream) and ending (downstream) points of erosion.

(5) Relatively low stream flows immediately after construction.

Conversely, less success was achieved if any or all of the above conditions were lacking. Some problems on Item I, North Fork, and Item 5-C, South Fork, were caused by an unstable channel meander pattern, which made accurate assessment of structure location difficult.

2. Watershed Location and Description. Tillatoba Creek, a tributary of the Tallahatchie River, is located in the North Central Hills and the Loess Hill physiographic regions of Mississippi. Tillatoba Creek Watershed is located in the central third of the eastern half of Tallahatchie County, Mississippi, a small portion of the north central edge of Grenada County, and in the southwestern quarter of Yalobusha County (Figure 55). The watershed enters the Yazoo Delta 7 to 8 miles east of its confluence with the Tallahatchie River. The hill drainage portion is 17 miles long and has a relief of 330 feet, giving it an average drainage slope of 19 feet per mile. The total drainage of Tillatoba Creek is 174 square miles, of which 172 square miles are hill area and 2 square miles are in the leveed floodway stream below the hill line. South Fork has a drainage area of 119 square miles and North Fork has a drainage area of 53 square miles (Figure 56). Hunter Creek, a tributary of South Fork, has a drainage area of about 11 square miles and a relief of about 200 feet.

3. Problem Analysis. Residual evidence, as shown on maps and aerial photos, indicates that man's influence on erosion and sediment production has been extreme at times but compared to nature's past performances it has been insignificant. However, it is possible that man has sped up the geologic timetable and, by locking in the plan geometry of the streams, we are creating an irreversible problem. In this drainage basin, as the headcuts moved upstream, the channel straightened out and widened, altering the system's energy and the movement and deposition of sediments. SCS and the Corps of Engineers stabilized the banks of the straightened out, higher energy system. As sediments filled in the old abandoned meander loops, the efficiency of the new channel increased. In time, the process increased the rate of headcut movement upstream, thus increased bank caving and stability problems upstream and converted slow-moving bed sediments to faster-moving suspended sediments. These sediments produce further stability problems downstream

where the energy slopes are not high enough to convey the channel-forming bed sediments. Establishing stable thalweg slopes may be the key to stabilizing this system. The sediments, particularly the sands and gravels, must be held at or near their source through better land-use programs and control of the stream's bed gradients. There are numerous geologic controls on all of the basin's streams which will aid in promoting stability, provided sediment loads and downstream hydraulic conditions do not further deteriorate the river's present regime.

4. History of Tillatoba Watershed. Geologic reports, maps and aerial photos show that this drainage system had a very complex base level history. Mississippi River braided stream deposits are still evident just south of the channel in the delta reach, and are now partially covered by the delta cone of Tillatoba Creek. Also, the Mississippi River meander scars extend to the western edge of the cone near the mouth of today's creek at the Tallahatchie River. The Mississippi River over recent geologic times was the base control for this system and as indicated by the residual scars in the Yazoo Delta near the mouth of the Tillatoba system, this base control varied in its hydraulic influence on the system, producing a varied but high productive sediment output. At least 12 meander belts of the Tillatoba Channel are still etched into the cone, radiating from NNW to SSW. The cone at the North and South Forks' confluence is 45 feet higher than the elevation at the creek's mouth. During the past 10,000 or less post-glacial years, the delta plain of the Mississippi River was at least 45 feet lower at the hill line. Add to this about 50 feet of its channel depth and Tillatoba Creek could have had a base control 100 feet lower than at present.

The current surface of the deltaic cone, with its many meander scars, was probably deposited 2000-3000 years ago, which would be the same period that present topography of the Tillatoba Drainage Basin was formed. Since then, the system has been quite stable until changes in area land use for agriculture influenced the stream's characteristics.

The 1833 maps indicate no settlement or farming activities in the basin. However, the 1937 photos show extensive agricultural activities. In 1937 the streams were very sinuous, indicating recent large sediment movement; however, tree growth on banks indicated stability at that time. In comparison 1833 streams were relatively straight, indicating small amounts of sediment moving and a stable system. The 1937 photos also indicate a recently-built levee system below the hill line. Thereafter, the river either occupied the borrow ditch, or the channel was straightened to follow the levees. This straightening, coupled with lowering of the base control on the Tallahatchie River in the 1940's, initiated a headcutting action that progressed almost to the top of the hills destroying usable land and causing severe stream instability. During the 1950's and '60's, a large amount of land was allowed to return to forests; however, reclearing of land has begun. Considering the method of stabilization in the main channels and the effects of the headcut, sediment production should increase considerably in the next decade or so. The river below the hill line could continue to aggrade and this could breach the levee diverting flow into the Ascalmore-Tippo System. The land between river bank and levee toe has already aggraded 4 to 8 feet and, in some reaches, the river has caved into the levee toe.

5. Geology of Tillatoba Drainage Basin. The geology of a drainage basin is one of the most significant parameters in the analysis of channel stability, with the physical properties of each stratigraphic unit having a direct relationship 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. Accurate assessment and prediction of the stream stability requires a complete analysis of the geological variations within the basin.

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

The generalized geologic outcrops in Tillatoba Creek Watershed are shown in Figure 56. The map was compiled from maps and data from the Mississippi State Geological Survey (MSGS) Bulletin No. 50 (Priddy 1942), MSGS Bulletin No. 76 (Turner, 1952), and field investigations.

The geologic units, which are exposed at the surface, are the Winona, Zilpha, and Kosciusko units which were deposited during the Eocene epoch of the Tertiary Period. Overlaying these older units are deposits of wind-blown loess and a clay/gravel unit of the Citronelle formation. These two formations were deposited simultaneous with the retreat of the glaciers to the north and are the depositions associated with the massive reworking of large amounts of material moved by wind and flowing melt-waters from the glaciers.

Very little well-consolidated materials exist within the watershed which are capable of stopping stream bed degradation. The Eocene units consist of sands, clays, shales, and an occasional iron-cemented sandstone. The cemented sandstone, which occurs at the top of Zilpha formation, offers a temporary control but is eventually eroded by stream action when the stream gradient is unstable.

The Winona formation consists of a 30- to 40-foot thickness of sand which has a greenish color when unweathered but, when exposed, is stained an intense Indian red color due to the oxidation of iron minerals within the sand. This unit offers no resistance to stream bed degradation, and when encountered the streams are free to meander.

Overlaying the Winona is the Zilpha formation. This unit is a gray-white and chocolate-brown clay having a thickness of about 60 feet. When outcrops of Zilpha are exposed in the bed of a stream, the erosional processes are slowed, but not halted. Eventually degradation will proceed upstream. At the top of the Zilpha is an iron-cemented sandstone, and it usually has a thickness of 1 to 2 feet. The distribution of this layer is irregular and discontinuous. This sandstone of the Zilpha does afford some additional erosion resistance but, due to the thinness and random distribution, offers little permanent stream bed control. The Kosciusko formation is the uppermost Eocene exposed within the Tillatoba Watershed. This unit is composed of a heterogenous mixture of sand, iron-cemented sandstone, and quartzite. The Kosciusko is exposed in the upper reaches of the streams within the Tillatoba Watershed. The extensive sandy nature of the formation, along with the lack of consolidation, is the cause of extensive upland erosion and in-channel sediment deposition.

Above these deposits, extensive sand and gravel deposits were laid down. These deposits, the Citronelle, blanket the hilltops overlaying the Eocene formations and underlaying the loess deposits. This unit is the source of the gravels which are present within the watershed.

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

The floodplain of the Tillatoba Watershed was eroded and flushed of sediments during the 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 stratigraphy of these valley fills are discussed in the general geology section of the introduction to this appendix.

The streambank erosion of the Tillatoba Creek Watershed is the result of base level degradation and the lack of consolidated geologic controls within the system. Two grade control structures were constructed on North Fork Tillatoba, and numerous bank protection devices were installed on North and South Fork Tillatoba Creeks and Hunter Creek. An analysis of these structures is presented in a subsequent section of this document.

6. Tillatoba Creek Basin Hydrology.

a. Rainfall. Several rainfall gages in the vicinity of the Tillatoba Creek Drainage Basin were used to estimate the flows of North and South Forks of Tillatoba Creek and Hunter Creek at Charleston, Mississippi. These are located at Charleston, Grenada Dam, Enid Dam, and Water Valley. The average annual total rainfall is as follows: Charleston, 52.12 inches; Grenada Dam, 53.56 inches; Enid Dam, 50.37 inches; and Water Valley, 52.7 inches. The monthly average rainfall for these stations is given in the following tables:

AVERAGE MONTHLY RAINFALL (INCHES)

MONTH Period of Record	GRENADA 1954-Pres.	CHARLESTON 1910-Pres.	ENID 1941-Pres.	WATER VALLEY 1950-Pres.
January	5.32	5.18	4.73	5.08
February	5.62	5.32	5.02	5.29
March	6.45	6.28	5.75	6.08
April	5.30	5.73	5.72	5.89
May	4.17	4.24	4.16	4.07
June	2.88	3.58	3.12	3.55
July	4.44	3.85	3.86	4.06
August	3.15	2.56	2.95	2.98
September	3.36	3.36	3.52	3.71
October	2.48	2.49	2.35	2.62
November	5.22	4.85	4.40	4.86
December	5.17	4.68	4.79	5.11

AVERAGES FOR PERIOD 1970-1980

	GRENADA	CHARLESTON	ENID	WATER VALLEY
Max. Annual (in)	78.52	73.56	73.96	80.89
Min. Annual (in)	49.18	45.57	37.96	39.15
Av for Period (in)	62.19	59.43	56.20	61.85
Departure from Period of Record (in)	+ 8.63	+ 7.31	+ 5.83	+ 9.15

During the period 16 June 1976 through 23 November 1979, a number of runoff-producing rainfall events occurred over the Tillatoba Creek Basin. The 1-day rainfall and antecedent conditions, in the form of total rainfall in the preceding 5 days, are given below:

SIGNIFICANT RAINFALL EVENTS

	GRENADA DAM		CHARLESTON		ENID DAM		WATER VALLEY	
DATE	Antec	1-day	Antec	1-day	Antec	1-day	Antec	1-day
4 Mar 77	0.07	4.45	0.00	4.06	0.05	3.75	0.00	4.39
9 Oct 77	0.53	2.71	1.21	1.13	1.01	0.22	0.98	0.33
25 Oct 77	0.00	3.22	0.00	0.79	0.00	0.83	0.00	2.14
21 Nov 77	1.18	4.21	1.87	2.43	2.07	0.45	2.25	2.23
30 Nov 77	2.16	2.03	3.78	1.90	4.17	1.89	2.03	2.58
8 May 78	3.88	2.52	3.12	1.32	3.62	1.76	2.50	2.13
1 Jan 79	1.61	2.30	1.47	3.02	1.54	2.58	1.97	2.75
20 Jan 79	0.76	3.10	0.44	1.65	0.65	2.17	0.87	1.78
12 Apr 79	0.93	5.31	1.94	2.37	0.86	2.94	0.76	2.76
20 Sep 79	0.68	2.57	0.41	2.38	3.04	1.80	2.55	2.25
21 Mar 80	4.64	1.42	4.86	0.90	4.70	0.71	6.32	1.01
14 Apr 80	4.19	1.37	3.69	1.28	2.85	1.00	5.13	1.15
30 Sep 80	6.25	0.98	7.58	0.87	5.38	0.84	5.19	0.98

The above rainfall gage locations are shown in Figure 57. These gages are located at the four points of a diamond-shaped figure, with sides ranging from 12 to 21 miles in length. An effort was made to determine why Enid Dam consistently recorded lower rainfall than did the other three gages. According to the U. S. Weather Service and Corps of Engineer sources, no apparent explanation is available.

b. Flow Information. Several projects have been undertaken in the Tillatoba Creek Basin since 1940, which have affected the stages on the main tributaries. The most significant of these was a reaction to the construction of the main flood control reservoirs at Grenada and Enid. There has been a significant decrease in the rating curve (stage-discharge relation) at the Swan Lake gage on the Little Tallahatchie River. This trend is also visible at Lambert, with a slight upward shift at Locopolis in recent years. This is partially due to sediment inflow from Panola-Quitman Floodway and Tillatoba Creek, which enter upstream of the gage. These rating curves are shown in Figure 58.

Other significant projects in the basin are the construction of 15 small, flood-retarding structures in the upper portions of the South Fork Watershed by the USDA-Soil Conservation Service controlling approximately 25 sq mi, or 14 percent, of the total drainage basin runoff and 21 percent of South Fork runoff. These small reservoirs have drainage areas ranging from 447 to 2,440 acres. The construction of these works is now in its final stages of completion and the total effect on flows near Charleston is not known. The sub-basins being controlled are shown in Figure 59.

c. Stage Information. The U. S. Geological Service maintains a bridge gage on both the North and South Forks of Tillatoba Creek. The infrequent available data is presented.

(1) South Fork Tillatoba Creek. The period of record dates from January 1941 to the present; however, very little flow information was gathered on South Fork Tillatoba in recent years. The highest recorded stage on South Fork was 181.33 feet, NGVD, at the Highway 32 bridge at Charleston, on 29 May 1974. Other stages are shown on the rating curve in Figure 60, and are listed in the following table.

SOUTH FORK TILLATOBA CREEK FLOW MEASUREMENTS

Date	Width ft	Area sq ft	Mean Velocity fps	Max. Velocity fps	Stage ft, NGVD	Discharge cfs
1-20-41	20	13	1.50	1.92	159.12	19.5
3-14-41	30	53	0.81	1.21	159.45	43.0
3-24-41	65	232	1.68	2.79	161.28	389.0
3-17-47	50	129	0.53	0.73	157.35	8.5
4-12-47	88	1,100	1.27	3.33	161.54	1,400.0
2-20-53	201	1,860	2.28	4.48	171.84	4,240.0
4-7-53	31	68.4	2.19	3.20	158.22	150.0
4-29-53	205	2,050	2.32	4.29	172.94	4,750.0
5-14-53	123	692	2.27	3.62	164.47	1,570.0
9-17-53	8	2.2	0.91	1.25	156.33	2.0
9-20-53	5	1.3	0.85	1.26	155.94	1.1
2-15-53	17	9.5	0.88	1.35	156.45	8.4
1-27-56	11	7.6	1.58	2.10	155.91	12.0
2-4-56	190	2,100	4.73	6.85	173.06	9,930.0
11-15-56	12	5.5	0.59	0.72	155.39	3.2
7-1-57	223	3,460	3.38	6.59	180.17	11,700.0
7-2-57	166	1,540	2.82	4.73	170.95	4,350.0
2-13-66	85	493	2.96	4.37	162.92	1,460.0
3-7-73	97	570	3.00	4.59	163.72	1,710.0
3-15-73	174	1,930	4.63	7.10	173.60	8,940.0
11-27-73	208	2,190	5.07	8.50	175.88	11,100.0
8-23-77	30	12.8	0.70	1.23	157.54	8.9
3-17-80	169	1,620	5.09	6.96	176.10	8,240.0

(2) Hunter Creek. No stage records are available for Hunter Creek.

(3) North Fork Tillatoba Creek. Flow data, similar to that taken for South Fork, is also available for North Fork Tillatoba at the highway bridge west of Charleston. The maximum recorded stage was 180.37 feet, NGVD, on 1 July 1957. A rating curve prepared from the available data is presented in Figure 61 along with the actual data listed in the following table.

NORTH FORK TILLATOBA CREEK FLOW MEASUREMENTS

Date	Width ft	Area sq ft	Mean Velocity fps	Max. Velocity fps	Stage ft, NGVD	Discharge cfs
1-17-41	22	10	1.45	1.81	165.42	14.5
3-14-41	20	13	1.85	2.43	165.77	24.2
3-17-47	42	26	1.48	1.79	162.44	39.9
4-12-47	41	51	2.87	4.51	164.89	147.0
4-7-53	49	43	1.20	1.64	162.65	51.3
4-29-53	154	1,690	3.29	6.95	174.31	1,560.0
5-14-53	114	711	4.36	7.67	168.45	3,100.0
9-17-53	19	4	0.81	1.20	161.75	3.5
7-1-57	193	2,230	5.51	8.13	180.37	12,300.0
7-2-57	129	1,180	5.13	6.26	172.20	6,050.0
2-13-66	77	214	2.54	3.31	163.29	544.0
3-7-73	71	125	2.18	2.66	163.03	273.0
3-15-73	130	1,190	3.01	4.24	173.45	3,580.0
11-27-73	144	1,500	3.04	4.35	175.47	4,570.0
8-23-77	19	4	0.79	1.06	160.38	3.3
3-17-80	120	983	1.46	2.37	169.62	1,440.0

When grade control structure 3-A was completed on North Fork, an automatic stage recorder was installed, along with rainfall recorder. The stage hydrograph, plotted in Figure 62, indicates the "flashy" nature of the small drainage basin hill stream. In the 30 days prior to the 24 June 1980 storm, almost no rainfall fell; therefore, the volume of runoff was somewhat decreased by infiltration. The stage and corresponding accumulated rainfall are given in the following table.

TIME-DEPTH OF FLOW FOR EVENT OF 24 JUNE 1980,
TILLATOBA CREEK STRUCTURE 3A

(Date) Time Hours	Cum. Rainfall Inches	Flow Depth Feet	(Date) Time Hours	Cum. Rainfall Inches	Flow Depth Feet
0100	1.85	0.05	1000	9.15	10.60
0130	2.13	0.06	1015	9.15	10.11
0145	2.15	1.00	1030	9.16	9.80
0200	2.17	4.15	1045	9.20	9.45
0215	2.21	4.96	1100	9.25	9.18
0230	2.25	5.40	1115	9.34	8.85
0245	2.30	5.66	1130	9.35	8.45
0300	2.70	5.80	1145		8.20
0315	3.03	5.90	1200		7.95
0330	3.35	5.97	1215		7.60
0345	3.55	6.01	1230		7.20
0400	3.70	6.10	1245		6.65
0415	3.90	6.80	1300		6.10
0430	4.20	7.15	1315		5.50
0445	4.80	7.50	1330		4.80
0500	5.45	7.65	1345		4.15
0515	5.65	8.15	1400		3.64
0530	5.80	8.61	1415		3.21
0545	6.20	9.00	1430		2.95
0600	7.25	9.35	1445		2.79
0615	7.50	10.10	1500		2.54
0630	8.00	10.65	1515		2.37
0645	8.12	11.25	1530		2.28
0700	8.20	11.88	1545		2.11
0715	8.25	12.27	1600		2.00
0730	8.27	12.62	1615		1.90
0740	8.35	12.71*	1630		1.81
0800	8.50	12.55	1645		1.74
0815	8.95	12.47	1700		1.67
0830	9.04	12.29	1715		1.61
0845	9.05	11.95	1730		1.56
0900	9.09	11.78	1745		1.49
0915	9.10	11.44	1800		1.44
0930	9.14	11.10	1815		1.39
0945	9.15	10.80	1830		1.34

Total Precipitation 9.45 Inches
Begin Time 0030 6-24-80
End Time 1136 6-24-80

* Indicates peak of hydrograph.

(4) A rating curve for Tillatoba Creek proper, about 3-1/2 miles downstream from the confluence of North and South Fork, is given in Figure 63. No change is evident in the rating curves from the sparse data over a 27-year period.

d. Discharge and Flow Information. The only discharge or velocity data available for the Tillatoba Creek Basin is that presented in the accompanying tables. Discharge on South Fork ranges from 0 to 11,700 cfs, as recorded. Mean velocity ranges from 0.6 fps to 5.0 fps, with a maximum recorded velocity of 8.5 fps. On North Fork, recorded discharges have ranged from 3.3 cfs to 12,300 cfs, with mean velocity of 0.8 fps to 5.5 fps. The maximum recorded velocity for North Fork is 8.13 fps.

e. Bank-Full Information. When a lack of flow data exists, it has been customary to estimate bank-full data through the use of Manning's equation. However, this approach is not valid near the mouth of North or South Fork Tillatoba. The basins of these two streams are not very large and rainfall from a given storm is usually consistent over the entire basin. Therefore, it would be unusual for either branch to flow at bank-full stage without the other also at or near bank full. The backwater effects created at the confluence would be so significant that Manning's equation would vastly over-estimate the flow quantities of each stream. Furthermore, due to the extent of channel enlargement on both branches, runoff causing bank-full stages in the uppermost reaches would not closely approach bank full near the confluence.

f. Sediment Information. Sediment data is not available for the streams of Tillatoba Creek drainage area. Modern forestry and agricultural practices have reduced sediment inflow to a rate which appears to be within the streams' transport capability. However, channel changes are still occurring, particularly on South Fork, which are resulting in bank erosion, a significant source of sediment supply. The bed material of South Fork is made up mostly of sand and smaller grain sizes. Gravel is present in small amounts at isolated locations, usually near inflowing streams, forming an armor layer that remains in place during most flows. Based on observation of the present channel, it appears that high flows on South Fork flush much of the excess sediment from the channel. There is, however, noticeable growth of point bars in many areas, indicating that not all the material is carried through the system.

North Fork Tillatoba differs significantly in appearance from South Fork. This stream has much more sediment in the gravel-size range than South Fork and a slightly smaller channel. Most bank erosion is located downstream of grade control structure 3-C, located at Station 406+00, which is the upper limit of this program. Above this point, only isolated erosion has been noted. Downstream of this structure, due to headcut migration, the channel is 1.5 to 3 times as large as the upper reach. Although there are several large point bars in the lower reach, the higher flows are apparently capable of removing most of the surplus sediment from caving banks.

One of the major parameters in sediment transport is the energy slope of a stream. The energy is a product of the topographical relief of the basin and, for relatively uniform channel configuration (i.e., not having numerous expansions and contraction, excessive number of bends of short radius, etc.), the energy slope approximates the average slope of the thalweg over individual reaches. The average slopes of North and South Fork Tillatoba Creek are as follows:

North Fork		South Fork	
Station (ft)	Slope (ft/mi)	Station (ft)	Slope (ft/mi)
0 - 187+00	6.0	0 - 120+00	5.2
209+00 - 400+00	7.4	120+00 - 290+00	4.5
		290+00 - 310+00	4.2
		330+00 - 500+00	6.6

Two conclusions may be drawn from this data. The size range of particles which may be moved by a stream is directly proportional to slope; therefore, North Fork is much more capable of moving gravel-size sediments. Also, the reach from station 120+00 to station 310+00 on South Fork is significantly flatter than the adjacent reaches, and is a possible explanation of the growth of sand deposition areas in South Fork. The greater slope in North Fork also offers at least a partial explanation for the lack of accumulation of sediment in the lower reaches, even though significant enlargement has occurred.

Due to the almost completely vegetated banks and the narrow bed of Hunter Creek, it is difficult to estimate sediment transport. Apparently the sediment introduced in the Hunter Creek channel is carried through to its mouth at the South Fork of Tillatoba Creek.

7. Channel Changes. Ninety-nine percent of the Tillatoba Creek Basin is in the Yazoo Basin hills. The 7.8 miles of channel in the delta were channelized during the 1920's and 1930's (Figure 64). Middle Fork, tributary to South Fork, is the only channel in the basin to be partially channelized.

In the late 1800's and early 1900's, land clearing, farming, and possible channelization of some of the smaller tributaries altered the sediment loads in the basin, and appears to have caused extensive channel changes in the smaller hill tributaries. Several of the first, second, and third order streams more than tripled in width by 1941 as the large influx of sediments increased erosion of streambanks. No observable erosion was apparent for larger channels in 1941. The smaller tributaries appear more entrenched, indicating some erosion since 1937. Conservation practices initiated in the 1930's gradually reduced upland erosion, thereby reducing the sediment load in the streams.

Degradation and bank erosion are presently occurring at an excessive and rapid rate. Figure 65 is presented to show the extent and rate of degradation on the South Fork channel from 1977 to 1979. The active segment begins 8 miles above its confluence with North Fork and continues upstream with a magnitude of variation, generally increasing upstream from 2 to 8 feet. Similarly, Figure 66 shows thalweg profiles on North Fork from its mouth upstream 8 miles. Active degradation begins 1 mile above the confluence with South Fork and continues upstream with a more uniform variation of 1 to 2 feet.

Figure 64 shows the channelization and straightening of the Tillatoba Creek stream channel in the delta flatlands prior to 1937 and the considerable reduction in channel length (Whitten & Patrick, 1980). Photos indicate the channel width doubled from 1937 to 1979. The increase in width may have occurred at a uniform rate, unlike the well-defined erosion locations of degradation in upland channels.

At the confluence of South and North Forks, there was no noticeable channel erosion in the 1937 photos. However, the 1941 photos indicate the width had more than doubled and point bars were well developed and numerous. Also, the tributaries show signs of active degradation.

Photos indicate the channel widths upstream of the confluence of North and South Forks doubled between 1937 and 1954 and have continued to increase since 1954, at a slower rate than the increases from 1937 to 1954. Point bars are more numerous and well developed in all channels from 1954 to the present.

Photos of South Fork taken in 1937 show the channel lined with vegetative growth and no observable channel erosion. The 1941 photos indicate a slightly wider channel than in 1937 channel and bank erosion appeared very active with vertical banks and tributaries eroding near their confluence. The channel of South Fork more than doubled in size from 1941 to 1954 with a very significant increase in channel depth. The channel has continued to widen and deepen since 1954, but not as rapidly as during the 1941 to 1954 period.

Photos taken 11 miles above the mouth of South Fork indicated no active bank erosion in 1937. There were two natural cutoffs by natural meandering between 1941 and 1954. A headcut was advancing just downstream of this area in 1966, with channel widths doubling. The headcut had advanced through this area by 1979, resulting in channel widths of 2 to 3 times the 1954 channel. This degradation eroded away meanders and shortened the channel length. Tributary channels widened rapidly as the headcuts advanced up them.

Photos of Middle Fork reveal channelization 3 miles upstream of the South Fork confluence prior to 1937. No significant channel changes were observed from 1937 to 1977 in this area. In 1977 a headcut is indicated upstream of the mouth with rapid erosion downstream of the headcut.

Further upstream on Middle Fork, 11.5 miles above the mouth, channelization was accomplished in three stages: the upstream segment was channelized before 1941; at this location in the early 1950's; and downstream in 1960's. No significant channel erosion was indicated in the 1937 or 1941 photos; however, significant channel erosion was indicated in the 1968 photos. Degradation had advanced 10 miles upstream, widening the channel, and by 1976, the Middle Fork channel had doubled its width and degraded several feet.

Hunter Creek is a South Fork tributary 2-1/2 miles upstream from the mouth. Photos of Hunter Creek taken in 1937 show the channel lined with vegetative growth with no observable erosion. Photos indicate that by 1941 degradation was advancing upstream near the mouth. The channel more than doubled its width from 1941 to 1954, and the channel continued to widen and deepen from 1954 to the early 1970's. Figure 67 shows the aggradation which occurred for the lower 4-1/2 miles of this channel from 1976 to 1979. This figure shows a generally uniform 2 feet of aggradation for this segment of the channel. 1979 photo coverage shows the channel, as well as its smaller tributaries, continuing to erode as headcuts advance upstream.

1937 photos of North Fork show a vegetation-lined channel with signs of erosion appearing as slow erosion of the outside of the meander loops. The 1941 channel indicated little change in dimensions for the 4 miles of channel above the confluence and the 1954 photos indicate the channel more than doubled its width and bank erosion was occurring at a rapid rate. The bank width tripled from 1941 to 1976. In 1976 the channel had large, well-developed point bars. The thalweg was meandering in wide sediment-filled channels, and tributary headcuts indicate the channel had degraded.

Photos indicated the North Fork channel and tributaries 8 miles upstream of its mouth appeared entrenched in 1937. The banks were vertical with numerous gullies eroding into them. The 1937 to 1941 channel appears entrenched in an older channel 2 to 3 times wider than the 1941 channel. The North Fork channel was eroded rapidly 6 miles upstream from the mouth with little or no erosion evident 9 miles above the mouth.

Chronological sequences of aerial photos and field observations provide the geomorphic changes summarized in Tables 2, 3 4, and 5, with the following text on the Tillatoba Basin (Whitten & Patrick, 1980).

> "The only significant channel erosion in the 1937 Tillatoba Creek Basin was in the small upland channels directly associated with active gullying. All of the channels in the 1941 basin appear to have been eroded to some extent. The only extensive erosion of a major channel occurred in Tillatoba Creek. The channel erosion has been advancing upstream on the major upland channels and their tributaries since 1941. The 1954 longitudinal profiles of the major channels are very irregular, especially in the lower reaches (Figure 68). Comparison of the 1954 and 1976 longitudinal profiles show the channels have degraded as the knickpoint(s) advanced

upstream. The irregularity of the 1976 longitudinal profile shows the channels are still degrading. The convex upward shape of the longitudinal profile of Tillatoba Creek in 1954 and 1976 indicate that further degradation of the upland streams can be expected. Tillatoba Creek is cutting into an erosional resistant clay which is retarding the upstream advance of the knickpoint. The erosional resistant Quaternary and Tertiary clays form rapids and waterfalls in the stream channels throughout the basin.

"The upstream movement of the knickpoint(s) has been slower on North Fork than on South Fork. The fact that the South Fork basin is 2-1/2 times larger than the North Fork basin and, therefore, has more flow, is one factor that could explain the slower upstream advance of the knickpoint on North Fork. The major factor is the more erodible alluvial materials are thinner in North Fork basin than in South Fork basin and have been cut through exposing resistant Quaternary clays in the lower reaches and Tertiary clays in the vicinity of Little Creek. Figure 69 shows the changes in channel area and length through time. Note the extreme bank erosion at site T3. The knickpoint has been hung up on the very erosional resistant Zilpha clay (Tertiary) in this area. The prolonged halt of the knickpoint at this point or general area resulted in extensive bank erosion. The 1954 and 1976 longitudinal profiles of North Fork (Figure 70). The tributaries closer to the mouth of North Fork have been degraded the most."

8. Construction of Protection Works.

a. Need for Protection. Bank caving throughout the entire Yazoo Basin could be as much as nine times higher than established in 1969. Loss of land, maintenances of man-made riverbank structures, navigation and flood control problems further downstream in the system, as well as the associated environmental problems, all point out a dire necessity to improve sediment management. Streambed and bank stabilization techniques are one portion of improving the total sediment problem. Following degradation of the bed, the banks tend to fail for two reasons: (1) gravitational and hydrostatic forces are increased as the streambed is lowered to a point where the strength of the bank materials are exceeded and the banks fail; (2) increased sediment load accelerates bar building and lateral movement of the channel.

The alluvial valley within the floodplain of the Tillatoba Creek Basin is composed of a high proportion of sand derived from the upland regions of the watershed during a past erosional cycle. This sandy material has very little strength. Degradation lowers the streambed elevation and oversteepens the bank slopes. The increased bank height and weight of exposed bank material then reaches a point where the internal strength of the material is exceeded and gravitational slip failures result.

This process is further complicated by the hydrostatic pressure head increase due to increased bank height. As the elevation of the streambed is lowered, the height of the ground water table and impond overbank water remains the same. This increase in head then translates into increased pressures against an already unstable condition and enhances the possibility of bank failure due to the increased weight of unsupported material. Lubrication of the friction surfaces within the internal structure of the soil mass also occur.

The channelization of Tillatoba Creek has accelerated the degradation and bank instability process within the basin. When a sinuous reach of stream is straightened, the reduction in sinuousity is accompanied by an increase in thalweg slope of the same magnitude.

b. Protection Techniques. See Figures 71-78 for project plan and location; Figures 79-86 for typical construction details; and Figures 87-95 for photographs of typical structures.

(1) South Fork Tillatoba Creek. Stabilization measures on South Fork Tillatoba Creek were constructed under work Items FY 72, FY 73, 5A, 5B, and 5C. Construction of the FY 72, FY 73, and 5C work was not funded under the Section 32 program. However, evaluation of the protective measures was performed under Section 32.

Item FY 72 consists of a series of stone dikes with some variation in design and longitudinal toe protection on 12 bendways over 1-1/4 miles of stream. These dikes were mostly transverse groins on the outside of the bend. Work was completed in November 1971.

Four types of bank protection were constructed under Item FY 73: (a) Longitudinal stone toe protection; (b) transverse stone dikes; (c) board-fence dikes; and (d) cable fence dikes. This work begins at the upper end of FY 72 work and extends 1-1/4 miles upstream for 10 bendways. One additional bendway was stabilized with a longitudinal stone dike and two transverse stone dikes just upstream of the Highway 35 bridge. Work was completed in May 1973.

Two methods of utilizing local material and hired labor were used on two bendways under Item 5A: (a) Sand-cement bags placed and backfilled on a graded bank over a city dump with additional bags used as toe protection; and (b) used-tire revetment on a graded bank with willow cuttings. Work was completed in May 1977.

Two methods using local materials were used on eight bendways under Item 5B. Cribs were constructed with treated piles driven into the ground and fenced. The cribs were filled with either baled hay or used tires. The existing bank was left untreated and in a natural condition where possible; however, construction tecniques required clearing and placement of backfill in some instances. Work was completed in July 1977.

Item 5C consists of various types of longitudinal stone dikes with vegetation and modified used-tire revetment with vegetation. This work begins at the upper end of the FY 73 work and extends upstream for 14 bendways. Work was completed in November 1978.

(2) <u>North Fork Tillatoba Creek</u>. Bank stabilization measures were constructed on North Fork Tillatoba Creek under work Items 1 and 2. Item 1 was funded under both the Yazoo Basin Tributaries funds

and the Section 32 program. Both Items 1 and 2 consist of longitudinal and transverse stone dikes with some variation in design. Item 2 begins at the confluence of North and South Forks Tillatoba Creek and extends upstream approximately 2.6 miles. Item 1 begins at the upper end of Item 2 and extends upstream another 2.2 miles. Item 1 was completed in July 1976 and Item 2 in November 1976.

Two grade control structures, Item 3A and 3C, were constructed in an effort to control bed degradation in the upper reaches of North Fork Tillatoba Creek. Items 3A and 3C are located 6.2 miles and 8.7 miles, respectively, above the confluence of North and South Forks Tillatoba Creek. Item 3A consists of a sheet pile cutoff weir, riprap approach and scour hole, and a grout-filled sheet-pile baffle. Although smaller in design, Item 3C is similar to Item 3A with the exception of a hanging sheet-pile baffle. Item 3A was completed in December 1977, and Item 3C in August 1977.

(3) Hunter Creek. Bank stabilization measures on Hunter Creek were constructed under work Items 1 and 1A. The Item 1A work was originally planned as part of Tillatoba (North Fork) and Hunter Creeks, Item 1, but rights-of-way delays required that this work be performed under a separate contract at a later date. Both Item 1 and 1A consist of various types of longitudinal and transverse stone dikes. The stabilization works extend from the mouth of Hunter Creek upstream approximately 2.7 miles. Item 1A was completed in July 1977, and Item 1 in July 1976.

c. Construction Costs. The total cost of construction for each work item on South Fork Tillatoba Creek is: Item FY 72 - $237,664; Item FY 73 - $222,980; Item 5A - $99,400; Item 5B - $161,000; and Item 5C - $456,000. The estimated cost for the Item 5A and Item 5B rehabilitation work is $34,500 and $45,600, respectively.

The total cost of construction for North Fork Tillatoba Creek and Hunter Creek, Item 1, was $625,821. Construction cost for Item 2 on North Fork Tillatoba Creek was $529,879. The total cost of construction for Hunter Creek, Item 1A, was $116,000. The total cost of construction for Item 3A and Item 3C on North Fork was $213,901 and $128,420, respectively. The cost per linear foot for the various protection techniques used in the Tillatoba Creek watershed are given in Table 1.

9. Maintenance.

a. Significant Events Contributing to Maintenance. High water conditions have adversely affected numerous structures on South Fork Tillatoba Creek, particularly in the Item 5B work area. Streambed scour associated with four or five large runouts during the first year of operation of these structures caused severe damage to the majority of the structures. The most severely damaged site was the first left bank wire crib retard (Item 5B) above Highway 35 Bridge where significant upper bank recession occurred. This reach, the left bank retard downstream of the bridge, the sand-cement bag revetment (Item 5A) and one longitudinal stone dike (Item 5C) are scheduled for rehabilitation in 1981. The damage to two of these structures is illustrated in Figures 94 and 95.

There is no rehabilitation work scheduled on Hunter Creek, and only minor repair work at one site on North Fork Tillatoba Creek.

b. Description of Construction or Repairs to Existing Work.

(1) Item 5A, Below Highway 35 Bridge.

(a) Type Structure. Sand-cement bag revetment.

(b) Reason for Repairs. Although the sand-cement bags were placed individually, they acquired the characteristics of a monolithic structure as the sand-cement bags set up and fused together. During the overbank flow in the summer of 1980, a localized slip failure of the upper bank occurred, possibly as a result of a buildup of hydrostatic pressure in the bank. Although the majority of the structure has remained intact and is effectively protecting the bank, rehabilitation work is scheduled for the spring of 1981 to insure adequate bank protection is provided for a nearby housing project.

(c) Corrective Measures. Dress bank, place stone paving in bare area, reinforce toe with longitudinal stone.

(2) Item 5B, First Left Bank Crib Above Highway 35 Bridge.

(a) Type Structure. Baled-hay-filled wire crib retard.

(b) Reason for Repairs. During the high runouts in the first year after construction, the middle portion of the structure was completely destroyed, and the upper banks receded 20 to 30 feet. This reach experienced the most severe upper bank recession of any of the wire cribs; therefore, corrective measures were deemed necessary to prevent any further bank erosion.

(c) Corrective Measures. Clear and grade bank, remove and dispose of existing wire crib retards, fill, construct longitudinal stone dike and tieback, used-tire revetment, and vegetative treatment. Place stone at toe of existing wire crib retards.

(3) Item 5B, First Left Bank Crib Below Highway 35 Bridge.

(a) Type Structure. Tire-filled wire crib retard.

(b) Reason for Repairs. Inadequate toe protection resulted in undermining the cribs to the extent that most of the tires were lost. The low height of the structure allowed high flows to impinge on the upper bank, and the willow plantings behind the crib either died or were washed away before becoming effective.

(c) Corrective Measures. Place stone toe protection and intermittent stone tie-backs.

(4) Item 5C, Reach 14.

(a) Type Structure. Longitudinal Stone Dike with vegetative treatment.

(b) Reason for Repairs. High flows before vegetative treatment became established caused upper bank erosion on the downstream portion of the bend and flanked the tieback at the end of the work.

(c) Corrective Measures. Place stone in key trench to restore tieback bank connection.

10. Performance Observations and Conclusions.

a. Monitoring Program. Monitoring of the demonstration projects included surveys, photographs, aerial photographs and visual inspections.

b. General Observations and Conclusions.

(1) South Fork Tillatoba Creek. Both the transverse stone dikes and the longitudinal stone dikes have been effective in preventing bank erosion in the Item FY 72 work area. Prior to construction in 1971, several of the tighter bendways were cut off following the degradation that had proceeded through this area. Consequently, this reach of the stream is stabilized on a relatively straight alignment and, therefore, the structures are not subjected to as severe erosive forces as those encountered in the tight bendways in the upstream work items (Item FY 73 and 5C). Comparative thalweg profiles (Figure 96) indicate that this reach has experienced only minor degradation since the early 1970's. The absence of severe bed degradation and the substantial accumulation of sediments and subsequent vegetative growth associated with the stabilization structures have resulted in a relatively stable reach.

All the structures under work Item FY 73 have provided effective bank protection; however, there has been some minor scour at the lower end of several of the short radius bendways in the upper reaches. With the exception of these localized scour areas, there has been appreciable sediment accumulation and natural vegetation established. Figure 96 indicates that the lower end of the work area has experienced 2 to 3 feet of degradation; however, the structures do not appear to have been adversely affected.

The upstream reaches of Item 5C are highly sinuous and contain many relatively short radius bendways. There has been some upper bank erosion along several of these bendways. Although the upper banks have experienced some damage, the structures have been successful in protecting the bank toe; therefore, many of the erosional problems may be corrected in time. However, Reach 11 needs to be monitored closely to insure that a nearby public road is not endangered by the migration of this bendway.

It appears from field observations and aerial photography that the upper reaches of Item 5C are in the process of increased meandering. This is evidenced by Reach 13 where the stream has shifted downstream and left the upstream portion of the bendway in a deposition zone. Another example is Reach 6 where the possibility of a chute cutoff exists. During the late 1970's there was severe degradation upstream of the Item 5C work area, shown in Figure 96. Concurrent with this degradation was an increase in the sediment input to the downstream reaches. According to the thalweg profiles of Figure 96 there is a decrease in channel slope near the upstream limits of Item 5C. The valley profiles also indicate a decreased slope through this area. This decreased slope coupled with the increased sediment input may be responsible for the increased bar building and meandering tendancies now showing up in the Item 5C area.

The wire crib retards constructed under Item 5B have not been very successful. As evidenced by the stable streambed (Figure 96), the problems encountered in the Item 5B work area were not the result of degradation, but rather as a result of inadequate toe protection and the top elevation of the cribs being too low. These structures are ineffective as bank protection measures on a stream with the geologic characteristics and drainage area of South Fork Tillatoba. Shortly after construction the backfill, which was predominately point bar sands, was lost and portions of the structures were severely damaged as a result of localized scour at the base of the cribs. Some structures were scoured to the point that cribs were emptied, the outside piles scoured below maximum penetration, and then the entire structure swung up and over the rear piles. Although the cribs were severely damaged, significant bank recession has not yet occurred, except at the first left bank cribs above Highway 35 bridge where the banks receded 20 to 30 feet.

Dike System 1 through 8 under work Item FY 73 consists of a longitudinal stone dike with stone tiebacks just upstream of the damaged wire cribs above Highway 35 Bridge. There has been good sedimentation and woody vegetation established. This structure has been successful in an area where the wire cribs were a complete failure, indicating that the wire crib retards are inadequate bank protection on South Fork Tillatoba Creek.

With the exception of the localized slip failure, the sand-cement bag revetment has performed satisfactorily. Unlike the wire cribs, which protect only a small portion of the upper bank, the sand-cement bags provide complete upper bank protection throughout most of the bendway. Although the majority of the structure has performed satisfactorily, some variations are needed because the sand-cement bags tend to act as a monolithic structure without internal strength. Also, better toe protection is needed to allow launching during scour.

The used-tire revetment (Item 5A) above Highway 35 has been successful in providing complete upper bank protection in a relatively long radius bendway. At the present time the upper bank is completely silted in and a stand of willows is well established. Weather could have been a big factor in the success of this structure as well as a stable bed.

(2) North Fork Tillatoba Creek. Item 2 extends from the confluence with South Fork Tillatoba Creek upstream for approximately 2.6 miles. Below the mouth of Bellamy Creek the channel is relatively narrow and straight with only one large bendway located just upstream of the Highway 35 Bridge. According to Figure 97, channel degradation between 1976 and 1979 has not been as severe below Bellamy Creek as it has upstream. The channel upstream of Bellamy Creek has widened considerably and is characterized by large point bars composed predominately of coarse sands and gravels. In this area the low water channel begins to meander considerably within topbank.

Most of the problems with the Item 2 structures have occurred upstream of Bellamy Creek, and many of these problems are the result of changes in the channel location. This is particularly true of Dike System 67-72. In this reach the stream has completely abandoned the two most upstream dikes and now is directed into the downstream end of the bendway. The two upstream dikes are completely silted in and a good growth of willows is established. At the present time only the downstream end of this dike system is functioning as bank protection. Recent photographs of this area are shown in Figure 99. Most of the erosion at the other structures in this area has been in the form of scour pockets between transverse stone dikes.

The majority of the Item 2 structures downstream of Bellamy Creek performed satisfactorily. However, there has been some scour between the transverse dikes in the tight bendway upstream of the Highway

35 Bridge. The longitudinal stone dike in this same bendway performed satisfactorily. The difference in performance of these two structures emphasizes the importance of toe protection in areas where the stream is degrading.

Work Item 1 begins at the upper end of the Item 2 work and extends upstream approximately 2.2 miles. As illustrated in Figure 97, this area has experienced more bed degradation than the Item 2 work area. Concurrent with the bed degradation were significant width increases, particularly upstream of Highway 782 Bridge where the most severe degradation has occurred. This area is characterized by large point bars consisting of coarse sands and gravels, and a highly sinuous low water channel that meanders considerably within the topbanks. The extreme channel widths coupled with the large inputs of coarse sediments from upstream tributaries (Mitchell and Little Creeks) has resulted in an extremely unstable channel, possibly on the verge of braiding. Prior to construction of the bank stabilization measures the channel meander pattern reversed in a sine-cosine fashion. This reversal was the result of the down-valley migration of the channel. This situation is illustrated in Figure 98. During construction the decision was made to stabilize the banks as found, rather than trying to force the channel back to its previous condition. Since construction the channel has not made any drastic changes, and it appears the bank stabilization structures are providing the necessary protection to establish a permanent meander sequence. However, this area needs to be monitored closely because large inputs of coarse sediments from Mitchell and Little Creeks during future high flows could be extremely detrimental to the channel stability.

All of the Item 1 structures, except Dikes 30 and 36, have performed satisfactorily. Both Dikes 30 and 36 are transverse dikes at the downstream end of stabilized bendways. In both bendways the structures were aligned to accommodate the low flow channel. In this area of the stream, the low flow channel varies considerably from the high flow channel, and during high flows both dikes were completely flanked. This situation is illustrated in Figure 99. This exemplifies the importance of considering both the high and low flow channel during design of stabilization structures.

Item 3A is a grade control structure located approximately 6.2 miles upstream of the confluence of North and South Forks Tillatoba Creek. This structure is functioning satisfactorily; however, it should be noted that degradation below the structure has not been too severe. This may be the result of the downstream geologic control, consisting of a highly consolidated clay in the streambed. The most significant problem associated with this structure is the increase in meandering tendencies upstream. This increase in meandering is shown in Figure 100. During construction the weir invert was purposely placed 2 feet above the existing streambed elevation. It is possible that this raised elevation may have induced the meandering upstream. This situation needs to be monitored closely to insure that the bridge upstream is not endangered.

Item 3C is the upper grade control structure located approximately 2-1/2 miles above Item 3A. This structure is also functioning satisfactorily. Field observations indicate that the structure has not been subjected to significant degradation.

(3) Hunter Creek. All of the stabilization structures on Hunter Creek are a complete success. These structures have been effective in protecting both the bank toe and the upper banks. This is emphasized by the well-established vegetative growth along the banks. At the present time Hunter Creek appears to be an extremely stable stream.

Three factors have contributed to the success of the stabilization efforts on Hunter Creek: (1) At the time of construction it appears that the stream was already beginning to adjust toward a new equilibrium state; (2) the streambed experienced several feet of aggradation since 1976 (Figure 101) which increased the sediment accumulations within the channel; and (3) the stabilization structures were of greater strength in relation to the size of the drainage area than those used on the larger streams such as Batupan Bogue and South Fork Tillatoba Creek.

11. Summary and Recommendations. Stabilization measures on South Fork Tillatoba Creek were constructed under work Items FY 72, FY 73, 5A, 5B and 5C. The upper works (FY 72, FY 73, and 5C) extending 7 to 11 miles above the confluence of the North and South Forks of Tillatoba Creek, have performed satisfactorily with the exception of upper bank scour along several of the tighter bendways. Item 5B, in the lower 1-1/2 miles of the stream, was severely damaged soon after construction. Wire crib retards as stabilization measures have not proven adequate on streams with hydrologic and geologic characteristics similar to the lower end of South Fork Tillatoba.

Bank protection on North Fork Tillatoba Creek consists of a series of transverse and longitudinal stones dikes constructed under work Items 1 and 2. Most of the structures downstream of Bellamy Creek have performed satisfactorily; however, upstream of Bellamy Creek, degradation, channel width increases, and changes in the meander patterns have adversely affected the performance of the structures.

Grade control structures on North Fork Tillatoba Creek were constructed under work Items 3A and 3C. Both structures have performed satisfactorily; however, neither has been subjected to severe degradation. The channel upstream of Item 3A needs to be monitored closely to insure that the bridge just upstream is not endangered by the increased meandering.

Bank stabilization measures on Hunter Creek are a complete success, and the channel now appears to be stable. The streambed aggraded several feet between 1976 and 1979. This is the only Section 32 stream which exhibits a uniform aggradation of the streambed.

Excessive time between design and construction, particularly when channel degradation is in progress, can result in need for redesign and possible relocation of planned work. This occurred on Item 1, North Fork Tillatoba Creek, where the stream reversed its meander pattern in a sine-cosine fashion between the time of design and construction. As a result the location of the structures was based on field conditions. The location and alignment of two of the structures were not compatible with the high flow channel and were completely flanked. Coordination between design and construction personnel is necessary, to avoid unnecessary cost increases, alignment problems, inadequate structures, or overdesigned structures.

In order to effectively evaluate the performance of the bank stabilization and grade control structures in the Tillatoba Creek basin, another 5 to 10 years of monitoring will be required. Monitoring of the system over this extended period should provide valuable information on the effectiveness of the structures in maintaining the stream alignment and providing bank stability. This is particularly true on North Fork Tillatoba Creek, Item 1, where the channel patterns are very unstable. During this extended time period, the effectiveness of grade control structures in maintaining a stable grade by halting headcut migration can be determined.

D. Hotophia, Goodwin, and Johnson Creeks.

1. General Overview.

a. Hotophia Creek was straightened by local interests several decades ago. Because of the type of bank material, bed stability not bank stability, was the main problem above the Little Tallahatchie flood plain. A series of five grade control structures were built to stop degradation and to restore a stable bedslope. Cost of these structures was $238,584. Because of a relatively low rainfall period, these structures have currently (July 1981) only been subjected to small flows;

therefore, no rehabilitation work is needed and no structure analysis is available.

b. Goodwin Creek was not used to demonstrate stabilization techniques. This basin was selected to monitor the movement of water and sediment through an entire drainage basin. The data collection instruments were tied directly into a computer at the USDA Sedimentation Laboratory at Oxford, Mississippi. The monitoring system will be operational in the fall of 1981. The basin can be useful as a prototype model with real-time data of all the variation of soils, geology, hydraulics, hydrology and land use. In addition to actual measurements of water and sediment routing, it can be used to test and verify many math models of discharge and sediments as well as water quality problems. Once the basin and instruments have been calibrated, a variety of stabilization studies can be conducted. One of these could be to learn what stabilization of the Mississippi River might have done to alter the movement and deposition of that stream sediments.

Fourteen super-critical weirs were built at a cost of $1,911,448. A project with the combined efforts the Vicksburg District Corps of Engineers and the USDA Sedimentation Laboratory at Oxford, Mississippi, was formulated at initial cost to each of $2,854,500 and $1,447,100, respectively. These costs included computers, telemeter systems, instruments, monitoring and analysis. This portion of Section 32 project is summarized in Section III of this appendix.

c. Johnson Creek was chosen as a instrumentation site because it had stream characteristics which were amenable to testing conclusions gleaned from some of the early Section 32 work. Three very different stabilization techniques were constructed: (1) grade control with minimum structural installation; (2) bank stabilization using proper hydraulic-geometry; and (3) vegetation control. Grade control structures can be very expensive. If proper hydraulics were incorporated in the design, then these should reach a stability by scouring an energy hole that required minimum structural material. These three grade controls cost a total of $177,000 but have not had enough flow to adequately test them.

Bank protection using miminum toe protection, leaving the banks natural and building in geometry of toe protection that was compatible with the stream hydraulics and instability characteristic, cost a total $177,000. In the minimum protection section 1/2 ton of stone per foot of bank was used with an average cost of $10.94 per foot. The system has been subjected to several high events with no apparent problems.

A variety of vegetation types were planted on the prepared bank to test adaptability and growth under normal stream conditions. Several years of monitoring will be necessary to fully analyze the result.

2. Watershed Location and Description. All three of these streams are located in eastern Panola County, Mississippi.

a. Hotophia Creek is a tributary of Little Tallahatchie River approximately 6.1 river miles downstream from Sardis Reservoir. It has a drainage area of 36.4 miles and a basin length of 11.4 miles and is about 3-1/2 times as long as it is wide. A 395-foot relief exists from a thalweg low of 194 feet, NGVD, at the Little Tallahatchie River, to a high of 589 feet, NGVD, at the summit of Terrapine Hill (Figure 102).

Five flood retarding structures were built on tributaries on the south side of the drainage basin by the SCS between 1950 and 1955 and they control about 26 percent of the basin runoff. However, water with little or no sediment is released from these reservoirs, thereby increasing the potential for accelerated channel bed and bank erosion.

b. Goodwin Creek lies between Sardis and Enid Reservoirs and has a drainage area of 8-3/4 square miles consisting of about equal parts each of cultivated, pastured and wooded land. It is a tributary to

Peters Creek, which flows into the Yocona River below Enid Reservoir. The basin has no urban development and no construction activities (Figure 102).

c. Johnson Creek lies adjacent to Goodwin Creek and is also a tributary to Peters Creek. It has a 19.1 square mile drainage basin totally composed of rural-agricultural lands. Elevations range from 420 feet, NGVD, at the headwaters to 240 feet, NGVD, at the mouth. The stream has been channelized for most of its 11 miles of drainage (Figure 102).

3. Problem Analyses of Basins.

a. Hotophia Creek has been channelized and straightened out for most of its length. Channelized reaches are separated by highly sinuous sections. Numerous meander scars are evident in the floodplains. Both of these characteristics indicate a high degree of sediment movement in its recent history. Today the straightened channel has incised itself into a consolidated clay (old paleosol) that prevents lateral movement but only slightly retards vertical cutting brought on by changes in the hydraulic control of the channel. Bed stabilization seems to be the best approach to stabilizing this stream.

b. Goodwin Creek's channelization history was similar to most other streams on the Yazoo Basin; i.e., channel straightening in an effort to enhance drainage and runoff with the stream reacting to local variations of its sediments. Because this basin was near the USDA Sedimentation Lab at Oxford, Mississippi, and because of its even distribution of land use, along with its wide variation in sediments, it was chosen as the basin in which to fully monitor the movement of water and sediment. A complete weather station along with 14 super-critical weirs were installed. These were hooked by a telemeter system to the computer at Oxford, Mississippi.

c. <u>Johnson Creek</u> was also totally channelized but response varied significantly with local sediments. Some reaches regained stability and remained in a relatively stable condition; while other reaches attempted to adjust to imposed alternatives in stream geometry. A series of grade control structures were installed, a second reach was treated with a variety of vegetative controls and a third reach was established by building a compatible hydraulic geometry.

4. <u>History of the Watersheds</u>. Historical evidence of these basins 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 the 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.

These streams are excellent examples 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 impoundments; and each basin's geologic history deposited sediments with a range of erodibility as well as transportability. The end result is the individualized channels occurring in each stream.

5. <u>Geology of Hotophia, Goodwin, and Johnson Watersheds</u>. 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 these three basins consists of Eocene sands and clays in the uplands with a complex alluvial fill in the floodplain and uplands. The valley fill is the depositional area of upland erosion which occurred following the Wisconsin glaciation.

The generalized geologic outcrops in these watersheds are shown in Figure 103. This map was taken from Mississippi State Geological Survey Bulletin No. 81, Vestal 1956. 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, namely the Citronelle. For a complete description of these deposits, the reader is referred to Appendix E of the ARS Report 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. The sand is coarse to fine, cross-bedded to the southeast, and cemented in places. Gravel is sparse and occurs as stringers to thin beds. Clay is present as lenses or is disseminated in the sand phase as a minor component. The interlayering of the sand and clay within this unit is a source of confusion in the interpretation of the geology of this area. These layers closely resemble the deposits of the older Eocene units. The gravel within this formation is the source of the gravels in the streams within the study area.

Kosciusko formation---sand, sandstone and reworked clay. Sand is fine to coarse and has variable colors ranging from light gray to chocolate or red brown. Clays are pink, yellowish or white and occur as balls, nodules, stringers, or as matrix within the sands. The sand from this unit is the source of the majority of sediment in the streams within this area.

Zilpha formation---clay, sandy silt, lignite, sandstone and siltstone. The fine sediments are shalelike, carbonaceous and brown to black when moist but dry to a gray color. They contain marcasite concretions and have a sulfide smell. They are layered and have laminae of micaceous silt to fine sand. The sands are fine, carbonaceous, gray to black, micaceous and also have a sulfide smell. At the top of this formation, there is frequently an iron-cemented sandstone ranging in thickness from 1 to 2 feet. The distribution of this layer is irregular and discontinuous. This uppermost portion of the Zilpha provides additional erosion resistance, but the thinness and random distribution offers little permanent streambed control.

Winona formation---sand, silt, clay, and claystone. This formation is slightly to very glauconitic, micaceous to very micaceous, carbonaceous, and has variable colors ranging from grayish-tan to greenish-brown to brownish-black. Clay is frequently present as thin stringers, laminae or beds. Outcrops oxidize rapidly to bright red to brown colors. This unit has no erosion resistance and streams which flow in this unit degrade rapidly.

Tallahatta formation---shale, clay, sand, silt, sandstone and siltstone. The Neshoba member is composed of clean to argillaceous fine sand and is usually yellow to gray with some red to brown staining. Clay is present as matrix material, laminae, stringers or thin beds. This member is frequently micaceous and occasionally cemented. The Neshoba member is easily eroded by stream action, while the Basic City member slows the erosion process, but does not stop it.

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 the 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 stratigraphy of these valley fills are discussed in the general geology section in the introduction of this appendix.

The streambank erosion is the result of base level degradation and the lack of consolidated geologic controls within the system. Vicksburg District has constructed 14 grade control structures on Goodwin Creek, 3 on Johnson, and 5 on Hotophia. Fourteen bendways were also protected using minimal stone quantities placed in a compatible stream alignment on Johnson Creek. An analysis of these structures is presented in a subsequent section of this document.

6. Basin Hydrology for Hotophia, Goodwin, and Johnson Basins.

a. Rainfall. Four rainfall gaging stations, which may be used to anlayze the flows of Hotophia, Goodwin, and Johnson Creeks are located in adjacent drainage basins at Enid and Sardis Dams, Batesville, and University, Mississippi, and are shown at Figure 104. The average annual total rainfall for these stations is as follows: Batesville, 53.52 inches; Enid Dam, 50.37 inches; Sardis Dam, 49.97 inches; and University, 53.51 inches. The monthly average rainfall for these stations is given in the following table.

AVERAGE MONTHLY RAINFALL (INCHES)

Month Period of Record	Batesville 1950 - Pres	Enid Dam 1941 - Pres	Sardis Dam 1944 - Pres	University 1932 - Pres
January	5.12	4.73	4.54	5.17
February	5.19	5.02	4.98	5.34
March	6.12	5.75	5.71	5.90
April	5.93	5.72	5.43	5.72
May	4.30	4.16	4.26	4.57
June	3.31	3.12	2.98	3.41
July	3.99	3.86	3.73	3.83
August	3.26	2.95	3.25	3.16
September	3.57	3.52	3.32	3.69
October	2.63	2.35	2.39	2.72
November	4.69	4.40	4.40	4.95
December	5.41	4.79	4.98	5.05

From the period of this study the following data are available:

AVERAGES FOR PERIOD 1970-1980

	Batesville	Enid Dam	Sardis Dam	University
Maximum Annual (in)	75.35	73.96	73.94	73.86
Minimum Annual (in)	36.79	37.96	40.86	46.13
Avg for Period (in)	57.95	56.20	57.29	57.69
Departure from Period of Record (in)	+ 4.43	+ 5.83	+ 7.32	4.18

During the period of construction activity, 16 June 76 through 30 September 80, a number of runoff-producing events occurred. The 1-day rainfall and antecedent conditions, in the form of total rainfall for the 5 days preceding the given date, are given below.

SIGNIFICANT RAINFALL EVENTS

Date	Batesville		Enid Dam		Sardis Dam		University	
	Antec	1-Day	Antec	1-Day	Antec	1-Day	Antec	1-Day
16 Jun 76	0	1.40	0	1.76	0	1.14	0	1.95
4 Mar 77	0.05	3.53	0.05	3.75	0.12	3.59	0.02	3.69
30 Nov 77	2.16	1.92	4.17	1.89	2.21	1.45	3.40	1.95
8 May 78	2.20	1.55	2.50	2.13	0.80	3.83	5.79	2.50
8 Jun 78	1.56	2.33	1.60	2.28	3.19	0.96	1.31	2.01
9 Dec 78	6.11	0	4.06	1.76	3.58	1.68	4.06	1.76
1 Jan 79	-	2.03	1.54	2.58	1.35	0	1.67	2.78
12 Apr 79	0.72	2.79	0.86	2.94	0.38	2.87	0.23	3.23
5 May 79	4.19	0.67	4.01	0.34	4.86	0.41	3.95	0.34
20 Sep 79	0.35	1.85	0.44	1.89	0.39	2.03	0.37	2.32
23 Nov 79	0.51	2.55	0.65	2.67	3.46	1.45	4.25	1.45
21 Mar 80	5.05	0.75	4.70	0.71	6.12	0.68	5.41	0.85
14 Apr 80	3.30	1.16	2.85	1.00	3.90	0.98	5.22	1.03
30 Sep 80	4.87	1.28	5.38	0.84	3.82	0.82	3.55	1.00

In an effort to obtain complete meteorological data for the entire basin, the Goodwin Creek Basin was fully instrumented by the USDA-SEA Agricultural Research Service Laboratory at Oxford, Mississippi. The instrumentation consists of 14 flow measurement stations, numerous rain gages, and a complete climatological data station. Data taken at the flow measurement stations includes flow depth, precipitation, sediment concentration, sediment samples, and air, water and soil temperatures. These stations are located at grade control structures designed to facilitate data measurement. For example, discharge is readily available from stage, and because of the supercritical flow through the structure, the sediment samples represented total sediment load. The climatological station is equipped with instrumentation for obtaining both standard and ground level precipitation, wind speed and direction, humidity and barometric pressure, air temperature, solar radiation, and evaporation pan level, wind speed and temperature. This and many of the flow measuring stations are equipped with telemetry equipment for automatic transfer of information to the laboratory computer system, thus providing real-time data analysis. Complete information on the data collection system can be found in the Appendix of separate reports prepared by the ARS Laboratory.

b. Flow Information. Limited previous data is available from these basins. No stage or discharge measurements have been made previously on Hotophia, Goodwin, or Johnson Creeks. The USGS has made irregular measurements on Peters Creek, the main stream of Goodwin and Johnson Creeks at the Highway 51 Bridge near Courtland, Miss. The annual maximum stage and corresponding discharge are listed in the USGS publication, Water Resources Data for Mississippi. No measurements have been recorded for this station since 1975.

The available data are presented in the form of a rating curve at Figure 105. USGS records indicate that the location of the gage has remained constant and it may be assumed that the upward shift in the rating curve is due to aggradation. Two low-water measurements made in 1979 (not on rating curve) indicate a reverse in this trend, probably as a result of channel enlargement due to headcut migration. Based on the discharge information in Figure 105, a rough approximation of discharge for Johnson and Goodwin Creeks may be found by use of the ratio of drainage areas. Johnson Basin is about 19.1 square miles, or 29 percent of the area above the Courtland gage, and Goodwin Creek Basin is about 8.5 square miles, or 13 percent, of the total basin.

No velocity information is available for the study areas of Hotophia, Goodwin, and Johnson Creeks.

c. Bankfull Information. Measured bankfull flow data for Hotophia, Goodwin, and Johnson Creeks is not available. The use of Manning's equation with known cross section and slope, and estimated roughness factor, or "n" value, is not always appropriate for estimating bankfull information. In the case of these creeks, degradation and channel enlargement have occurred to such an extent that bankfull conditions may never exist again unless an aggradation cycle is initiated.

d. Sediment Information. No measured sediment data is available for Hotophia, Goodwin, or Johnson Creeks. These streams have predominantly sand streambeds, with numerous clay outcroppings, and isolated gravel bars, usually located near the mouths of tributaries. The location of gravel and clay in the streams has remained essentially constant through the period of observation for this study.

In some reaches of these streams, alternating layers of sand and clay lie on a primary slope in the same direction, but slightly less than that of the streambed. The intersection of streambed and clay layer forms the so-called "outcrop" of material. When the clay layer is thin, after a period of time, it will erode completely, exposing a layer of sand. The sand will be carried away more rapidly, especially during higher flows, thus causing severe degradation of the streambed. Streambed degradation normally leads to bank failure adding to the sediment load. When the stream does not experience adequate flows to carry this surcharge of sediment, the excess material on the bed will force the low flow to the opposite side of the channel, thus initiating further bank caving problems.

This process has been observed on Hotophia Creek, with the result that within a reach approximately three miles in length, the cross-sectional area at the lower end is approximately five to six times that at the upper end. The sediment problem is further aggravated by headcuts initiating at the stream mouth and proceeding upstream. Bed degradation of six feet to eight feet at the Highway 6 Bridge required addition of large amounts of riprap bank and bottom protection within one year following construction of the bridge to insure its integrity. The slope of this stream, along with velocity and flow depth, is apparently adequate to transport most of this excess sediment.

Goodwin and Johnson Creeks have also experienced a series of headcuts moving through the channels. Goodwin continues to have uniform channels with steep banks, indicating that most excess sediment from degradation and bank caving is being transported out of the system by flows having a one year return frequency. Johnson Creek developed a number of large, exposed point bars during the enlargement period. These have not vegetated but still show signs of shifting where bank protection is not present. Above the lower grade control structure (station 293+00) the channel is more confined and similar in appearance to Goodwin Creek.

7. Channel Changes. Goodwin and Johnson Creeks experienced both channelization and base level lowerings. Channelization that began prior to 1940 and continued into the mid 1950's (Figure 106). The base levels of these creeks were lowered following the Yocona River channelization, the Enid Lake construction, the flow changes imposed by construction of Panola-Quitman Floodway, and the numerous other alterations to channels in the Yazoo Basin. Prior to 1968, channel erosion was gradual but after 1968 bank erosion was more pronounced. The channel width doubled with very irregular vertical banks and numerous well-developed point bars.

a. Goodwin Creek. The geomorphic changes on Goodwin Creek as observed on the chronological sequences of aerial photos and from field observations are presented in Table 6 (Whitten and Patrick, 1980).

Comparison of the 1954 and 1977 longitudinal profiles of Goodwin Creek shows that the headcut in the lower reaches in 1954 had advanced upstream by 1977 (Figure 107 after Whitten and Patrick, 1980). Channel irregularities, in many instances, reflect erosion-resistant points (clay ledges) that have temporarily halted degradation.

Chronological sequences of aerial photos along Goodwin Creek show there has been an increase in channel width since 1940. The area and length changes are shown in Figure 108 (Whitten and Patrick, 1980).

erosion has generally increased the channel area and decreased channel length.

Thalweg profiles of March and November, 1977 for Goodwin Creek show degradation continuing along the reach from the mouth to station 49+00 and from 56+00 to 125+00 (Figure 109).

b. Johnson Creek channelization occurred prior to 1957. Aerial photos show the alterations of the prechannelized stream. The channelized reaches of Johnson Creek are shown on Figure 106.

The channelized segments of Johnson Creek prior to 1937 were between reaches 77+00 and 96+41 and below reach 41+47. Additionally, a lateral ditch was constructed between reach 290+00 and 326+87 but was not the main channel until between 1940 and 1944. By 1944 most of Johnson Creek had been channelized except for approximately 1/2 mile of channel beginning at sta 27200. The channelized section did not capture the main flow prior to 1944, and segments of both the natural and modified channel were alternately carrying the flow. The 1953 photographs show segments of the channelized section inactive and the natural channel carrying the flow. These inactive segments are indicated in Figure 106 from section 120+00 to 136+17 and 191+22 to 259+75. Additionally, incomplete channel straightening occurred above 410+00.

Photos from 1953 to 1957 show no significant modifications to the channel. The most recent indicated modification of Johnson Creek was completed prior to 1963 and included channel straightening from 233+00 to 240+00.

Johnson Creek channel has and is continuing to undergo channel alterations due to advancing headcuts. These headcuts are migrated upstream at an average rate of 550 ft/yr. Channel width alterations show width increases of 300 percent below headcuts. Thalweg profiles of 1977 and 1979 show degradation with a range of two to eight feet from station 290+00 to 340+00 over this 2-year period (Figures 110 and 111). The only noticeable aggradation for these profiles occurs from station 125+00 to 200+00. The magnitude of variation ranges from less than 1 foot to 1-1/2 feet.

c. Hotophia Creek Channel, except the first 3.3 miles from the mouth, has been channelized. Chronological sequences of aerial photos show the channel changes that occurred before and after the 1958-61 channelization.

For the first one-half mile of the Hotophia Creek vegetation lined the 1935 and 1940 channels, with no apparent bank erosion occurring during this time. By 1949, erosion appears to have been very active. The 1968 photos indicate channel erosion had continued removing all meander loops, except for the large gently curving ones. The post-1968 channel has a straight channelized appearance.

The channel, beginning 3.3 miles upstream from the mouth shows no apparent erosion prior to the 1959-61 channelization. By 1963, two years after channelization, lateral erosion was rapid. Channel width nearly doubled and there were large sediment deposits at the start of the channelized section. Channel width more than tripled from 1957 to 1968. Continued bed and bank erosion had further widened and deepened the channel by 1977. The excess sediments in the 1968 and 1977 channel resulted in a braided thalweg for several locations.

Six miles above the mouth of Hotophia Creek the only noticeable bank erosion, prior to 1957, occurred at State Highway 6 Bridge, and the localized erosion appeared related to the bridge. A short section of the channel downstream of the bridge was channelized prior to 1935 with no noticeable bank erosion in the channel through 1957. The post-1961 channelized segment rapidly degraded and eroded its banks. By 1979, lateral bank erosion altered the straight channelized appearance of the 1963 channel.

Ten miles upstream from the mouth, the pre-1935 channel shows no erosion. The 1953 and 1957 channel shows numerous sediment deposits and debris. The channel width appears relatively constant from 1944 to 1957; however, bank erosion began soon after altering the straight channelized appearance of the 1963 channel to a more irregular shape by 1968. Continued channel erosion widened and deepened the channel by 1977, and the 4- to 5-foot headcut at this location indicates the degree of degradation occurring in the channel.

Channel changes continue along Hotophia Creek as headcuts advance upstream. Thalweg profiles of 1976 and 1979 show the resulting aggradation and degradation as these headcuts advance (Figure 112). Aggradation ranging from 2.5 to 3 feet has occurred from station 489+00 to 525+00 and degradation of up to four feet continues upstream from 525+00 to 555+00.

Geomorphic changes on Hotophia Creek are summarized in Table 7 (after Whitten and Patrick, 1980), as observed on the chronological sequences of aerial photos and field observations.

The following summarization of channel changes for Hotophia Creek from Whitten and Patrick (1980):

> "The only noticeable or significant erosion on the prechannelization photos (pre-1958) was occurring at the mouth of Hotophia Creek. The 1953 longitudinal profile of Hotophia Creek shows a prominent knick-point approximately 2 miles upstream from the mouth (Fig 113). The smooth concave downward shape of the rest of the 1953 longitudinal profile indicates there was no significant channel degradation occurring elsewhere in the channel.
>
> "The 1958-61 channelization shortened the channel length approximately 2.9 miles. The gradient in the channelized stretch was increased from around 7.8 ft/mile to 11.1 ft/mile. A comparison of the 1961 and 1976 longitudinal profiles shows the channel has degraded up to 15 ft (Fig 113). The degradation was

caused by the continued upstream advance of the knickpoint shown on the 1953 longitudinal profile, and subsequent knickpoints. The increased gradient in the channelized section probably increased the rate of speed of upstream movement of the knickpoint. The knickpoint was approaching the lower part at mile 3.3 in 1957. The channel had nearly tripled in width by 1963. The degradation of the tributaries indicates the erosion resulting from the upstream channelization.

"There is a very prominent knickpoint at point A on the 1976 longitudinal profile (Fig 113). The knickpoint is cutting an erosional resistant clay and has formed a 4- to 5-ft waterfall. The steep, unstable banks resulting from the channel degradation are slumping and/or caving in. The channel directly downstream from the knickpoint is 6 to 10 ft wider than the channel directly upstream from the knickpoint. Cross sections of the 1961 and 1976 channels show there is a downstream increase in width and an upstream increase in depth (Fig 114). The downstream increase in width results from the slumping and caving of the oversteepened banks and from bank erosion caused by the increased sediment load. The banks are also being eroded by piping.

"The changes in channel area generally correspond to changes in channel length. Fig 115 shows the changes in channel length and area through time (1940 to 1977). The 1963 data were used as a zero base since channelization (1958-1961) significantly altered the channel morphology. The channel at the mouth and at mile 3.3 was not channelized in 1958-1961. However, the changes in channel morphology of these two locations has been very pronounced. Bank erosion shortened the channel length at both sites. The channel area decreased at the mouth and increased at mile 3.3. The channel at mile 6.0 decreased 74 percent in length and 23 percent in area from 1940 to 1963; but, channel length had not changed since 1963 while the area had increased 39 percent by 1977. The channel at miles 10.5 and 11.5 was channelized prior to 1935, and the channel at mile 10.5 was enlarged in 1958-1961. There has been no change in channel length at either site since 1940; but, the channel areas have increased, especially at mile 10.5. The overall trend has been a decrease in channel length and an increase in channel area or width. There have been some temporary decreases in channel area when the channel has been widened, but also shortened, by bank erosion."

8. Construction of Protection Works.

a. Need for Protection. Bank caving throughout the entire Yazoo Basin could be as much as nine times higher than established in 1969. Loss of land, maintenance of man-made river bank structures, navigation and flood control problems further downstream in the system, as well as the associated environmental problems, all point out a dire necessity to improve sediment management. Streambed and bank stabilization techniques are one portion of improving the total sediment problem. Following degradation of the bed, the banks tend to fail for two reasons: (1) gravitational and hydrostatic forces are increased as the streambed is lowered to a point where the strength of the bank materials are exceeded and the banks fail; (2) increased sediment load accelerates bar building and lateral movement of the channel.

The alluvial floodplain of the Hotophia, Goodwin and Johnson Basins are composed of a high proportion of sand derived from the upland regions of the watershed during a past erosional cycle. This sandy material has very little strength. Degradation lowers the streambed elevation and oversteepens the bank slopes. The increased bank height and weight of exposed bank material then reaches a point where the internal strength of the material is exceeded and gravitational slip failures result.

This process is further complicated by the hydrostatic pressure head increase due to increased bank height. As the elevation of the streambed is lowered, the height of the ground water table and imponded overbank water remains the same. This increase in head then translates into increased pressures against an already unstable condition and enhances the possibility of bank failure due to the increased weight of unsupported material. Lubrication of the friction surfaces within the internal structure of the soil mass also occurs.

Channelization has accelerated the degradation and bank instability process within the basin. When a sinuous reach of stream is straightened, the reduction in sinuosity is accompanied by an increase in thalweg slope of the same magnitude.

b. Protection Techniques. See Figures 116-119 for project plan and location, Figures 120-122 for typical construction details, and Figures 123-126 for photographs of typical structures.

(1) Johnson Creek. Fourteen bendways were stabilized under Work Item 9-A using longitudinal peaked stone dike of 1/2, 2, and 3 tons per linear foot, and construction was completed in November 1978. This work was an attempt at stabilizing a stream with minimum protection. A more detailed discussion of this work is given in Section 7d. Three grade control structures were constructed on Johnson Creek under Item 9B in an effort to halt the upstream migration of headcuts. These structures are simple structures consisting of a sheet pile cutoff weir and a hanging type baffle. The lower grade control structure (Site 9B1) has a riprap lined scour hole, while the upper structures (Sites 9B2 and 9B3) have no riprap protection. The contract for the construction of all three structures was awarded to a minority contractor.

(2) Goodwin Creek. Goodwin Creek has 14 grade control structures that have been instrumented with provisions to measure total sediment load and discharge. One structure was constructed under Work Item 8A, three under Item 8B, and 10 under Item 8C.

(3) Hotophia Creek. Five grade control structures were constructed under Work Item 7 in an effort to control the severe headcuts working up Hotophia Creek. These are simple structures consisting of a sheet pile cutoff weir, and hanging baffle with only minimum riprap protection on two of the structures.

(4) Vegetative Study, Johnson, Goodwin, and Peters Creeks. A variety of vegetative treatments was performed on Johnson, Goodwin and Peters Creeks under Work Items 12A and 12B, this project is explained in Appendix C of the USDA, Sedimentation Laboratory Report. On Johnson Creek, there are four sites: two use vegetation in conjunction with bank shaping and structural materials, the other two sites use vegetation in conjunction with structural devices without bank shaping. The site on Goodwin Creek uses vegetation in conjunction with bank shaping, with and without structural materials. The Peters Creek sites use woody vegetation in conjunction with structural devices without bank shaping.

c. Construction Cost. The total cost of construction for the Item 9A bank stabilization structures on Johnson Creek was $177,000. The Type I, Type II, and Type III longitudinal peaked stone dikes cost $10.94, $43.76, and $65.68 per linear foot, respectively.

The vegetative study was performed by the ARS Laboratory, Oxford, Mississippi, at a total cost of $632,000 (see Appendix C of that report).

The total cost of the grade control structures on Hotophia, Goodwin, and Johnson Creeks was $238,384.00, $1,911,448.00, and $161,917.00, respectively. The cost for the individual structures is presented in the following table.

COST OF GRADE CONTROL STRUCTURES ON
HOTOPHIA, GOODWIN, AND JOHNSON CREEKS

Item No.	Cost
Item 7 (Hotophia Creek)	
Site 1	35,808.00
Site 2	35,315.00
Site 3	65,010.00
Site 4	36,561.00
Site 5	65,690.00
Item 9B (Johnson Creek)	
Site 1	70,286.00
Site 2	44,942.00
Site 3	46,689.00
Item 8 (Goodwin Creek)	
8A, Site 1	349,770.00
8B, Site 2	331,055.00
8B, Site 3	257,487.00
8B, Site 4	147,136.00
8C, Site 5	166,852.00
Site 6	83,426.00
Site 7	93,338.00
Site 8	99,120.00
Site 9	87,556.00
Site 10	20,000.00
Site 11	71,862.00
Site 12	71,036.00
Site 13	63,602.00
Site 14	89,208.00

d. Johnson Creek Minimum Protection. Public Law 93-251, Section 32, states in para (b)(2), "Develop new methods and techniques for bank protection, ..." All methods used for the past several decades, as well as in this program, have endeavored to stabilize rivers with either bank or bed controlling structures that physically held the sediments in place. Johnson Creek was selected to demonstrate and evaluate a method of control with minimum structures that would incorporate a hydraulic-geometry in the design which would accommodate all stages of flow and sediment movement for that stream. This selection was made after a field trip, study of aerial photos, and a hydrographic survey indicated reasonable assurance that the necessary geometry could be designed on Johnson Creek between station 240+00 and 290+00, a distance of almost one mile with 15 bendways.

From the survey and the photos, a range of acceptable channel geometry was established. This acceptable geometric pattern was then superimposed on a survey of the channel. Criteria required for a successful evaluation are the following: (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 was 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, possibly because the natural vegetation was so prolific it immediately took over the raw areas as soon as bank caving ceased.

Many of the original concepts were not incorporated into the 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; (6) radii different than designed; and (7) more rock used than necessary.

Even with the above deficiencies, the structures appear to be working very well. Several high flows were (Section 5) experienced during the first two years after construction and then a long period of relatively dry weather followed. Except for a short straight reach left unprotected, the total reach is adjusting very well. Figure 127 is a series of before-and-after photos of reach number 8. Banks have caved to a natural angle of repose and the channel has developed a look of stability with no raw caving banks.

9. Maintenance. At the present time there is no maintenance or rehabilitation work scheduled on Hotophia, Goodwin, or Johnson Creeks.

10. Performance Observations and Conclusions.

a. Monitoring Program. Monitoring of the demonstration projects included surveys, photographs, aerial photographs and visual inspections. The more elaborate monitoring system on Goodwin Creek is discussed in the ARS Report (1981).

b. General Observations and Conclusions.

(1) Johnson Creek. The minimum protection work on Johnson Creek was an attempt to stabilize the stream through a system of properly aligned longitudinal dikes, providing a smooth transition from bendway to bendway. A detailed discussion of the theory behind the stabilization efforts on Johnson Creek is given in Section 7d. Although the initial design concept called for a system of smooth and orderly structures, several of the bendways were constructed with portions of the structure protruding out into the stream, thereby forming an obstruction to flow. Although these structures were not placed exactly as designed,

they have been effective in protecting the banks. At the present time all 14 bendways are well vegetated and appear stable. However, shortly after construction there were some scouring problems along several of the upper bendways, particularly at reach 14, where the lower end was completely flanked. The comparative thalweg profiles of Figure 128 indicate that this upper portion of the work area was subjected to recent degradation. Figure 129 shows a photo of the headcut in the vicinity of reach 12 just prior to construction. This degradation may be responsible for the initial problems along the upper bendways. Most of the problems were not too severe and the bendways now have become well vegetated and appear to be relatively stable.

Much of the success of the Johnson Creek structures results from an alignment that allowed a well defined pool-crossing sequence to be established. Field observations indicate that this orderly transition between bendways is present throughout most of the work area. After close examination of the crossing locations, three distinct sections within the work area became apparent.

The upper section extending from reach 14 down to the lower end of reach 9 is characterized by a well-defined low water pool-crossing sequence. The average distance between crossings measured along the thalweg is 176 feet.

The middle section extending from the upper end of reach 8 to the lower end of reach 6 has a reduced crossing distance averaging 98 feet. This reduction is most pronounced in the vicinity of reaches 7 and 8 where the low flow channel appears to vary considerably between high flow events. The channel is also straighter and somewhat wider in this area, possibly as a result of the sediment input from a nearby tributary. These factors, coupled with the absence of bank protection between reaches 7 and 8, may be contributing to the random placement of the low water channel. The channel begins to develop a well-defined pool-crossing sequence at reach 6; however, the distance between crossings is still relatively short.

The lower section extends from the upper end of reach 5 down to reach 1. In this section, the pool-crossing sequence is well-established again, with the average distance between crossings increased to 188 feet.

Although there are portions of the stream where the low water channel alignment is highly variable, the structure alignment appears to be compatible with the high flows. The compatibility of the structures with high flows is illustrated by the photo of high flow depositional features shown in Figure 130.

The following is a site by site evaluation of the Johnson Creek minimum protection, starting at reach 14 and proceeding downstream to reach 1.

(a) Reach 14. Shortly after construction a headcut proceeded upstream through this reach which caused the lower end of the structure to be flanked. The bank receded approximately 20 feet at the lower end of this structure and a scour hole formed. The upstream end of this structure was not adversely affected. Present photos and field observations indicate that the scour hole which formed at the lower end has begun to fill in and vegetation is taking hold.

(b) Reach 13. The middle portion of this structure protrudes into the streambed, creating an obstruction to flow. At this protruding section there has been some launching of the riprap. It appears that this launching is the result of placing only a thin veneer of stone on the protruding clay bank (see Figure 131). Although the alignment was not as initially designed, the banks have become well vegetated and appear stable.

(c) Reach 12. Reach 12 has the same alignment problems discussed in reach 13; however, there has been no launching of the riprap and the banks are well vegetated and appear stable. The alignment problems are shown in Figure 132.

(d) Reaches 9, 10, and 11. Prior to construction these banks were extremely raw. These structures were properly aligned and the banks have become well vegetated. A chronological sequence of photographs indicates that there may have been some upper bank erosion shortly after construction; however, sediment has accumulated behind the stone toe protection and later became vegetated.

(e) Reach 8. Reach 8 has similar alignment problems as reaches 12 and 13. Although one portion of the structure juts out into the stream, it is not as pronounced as on reaches 12 and 13. This structure has become well vegetated and the banks are stable.

(f) Reaches 1-7. All the bendways from reach 7 down to reach 1 were properly aligned and have become well vegetated and appear to be stable.

Numerous problems and delays were encountered with the construction of the three grade control structures. Additional improvements are required before the structures meet the design specifications. The structures have not been subjected to high flow conditions at this time, therefore cannot be adequately evaluated.

The following is a list of observations made on the Johnson Creek grade control structures:

(a) Riprap was not placed properly within the scour pocket area at Site 9B1. See Figure 133.

(b) The access ramps to the streambed at sites 9B1 and 9B2 were not backfilled properly and are eroding away. See Figure 134.

(c) At site 9B2 the access ramp at the left bank of the sheet pile cutoff weir was not backfilled properly and is actively eroding and threatening to flank the structure. See Figure 135.

(d) During the construction of site 9B3, a scour pocket developed on the left bank immediately above the sheet pile cutoff weir. This scour pocket extends farther landward than the left bank end of the weir section. This scour pocket will ultimately migrate downstream, and the structure may be flanked. See Figure 136.

(e) At site 9B3, the local landowner dug a field drain which empties into the scour pocket. Left unprotected, this drain may increase the possibility of the structure being flanked.

(f) As a result of construction delays, headcutting progressed upstream of the location of the proposed grade control structures, thereby limiting their effectiveness.

(2) Goodwin Creek. The channel of Goodwin Creek has been subjected to severe degradation in recent years. In order to stabilize the system, a series of grade control structures were constructed throughout the watershed. The structures were also designed to act as flow measuring and sediment sampling sites. Details of construction and instrumentation of the structures are presented in Appendices A, B, and F of the ARS Report (1981).

Although a complete discussion of the performance of the Goodwin Creek structures is not attempted here, several observations from field investigations are included.

All 14 of the structures have been completed, and 11 have been instrumented; however, sediment and discharge data were not being collected as of July 1981.

The structures are structurally sound; however, due to periods of below normal rainfall, they have not been subjected to many large runouts. Another problem associated with the low rainfall has been the excessive vegetation growth in the channels above and below the structures. This is illustrated in the photo in Figure 137. Left unchecked, this overgrowth of vegetation might prove detrimental to the structures.

(3) Hotophia Creek. Construction of the five grade control structures on Hotophia Creek was completed in the summer of 1980. All five sites appear to be structurally sound; however, they have not been subjected to any severe degradation.

A stable grade was selected for the stream from thalweg profile data available and a system of four grade control structures were designated to maintain this grade. A fifth structure was planned upstream to prevent excessive degradation from proceeding to the upstream reaches of the stream. The location and elevations of the structures necessary to produce the desired grade were selected from thalweg profiles. However, when the site surveys were performed, it became apparent that the stream had aggraded several feet in the area of the proposed structures. This aggradation is shown in Figure 138.

This aggradation was the result of a local landowner placing concrete rubble in the streambed below Site 7-1 in an attempt to construct his own grade control structure. Assuming that this temporary dam would be flanked and the imponded sediment flushed out, the grade control structures were built to the original design elevation. This required extensive excavation at the lower three sites in order to place the weir inverts at the design elevation. After placement of the structures, bed sediment filled in the excavations leaving the structures either partially or completely buried in the streambed. Recent photos of the structures are shown in Figure 139.

At the most downstream structure (site 7-1) the sheet pile weir and the baffle plate are completely buried beneath the streambed. It appears from field observations that the stream may have aggraded somewhat since construction. There are no structural problems evident and, unlike the Johnson Creek grade control structures, the access ramps were properly filled and vegetation is re-established.

Approximately 1,000 feet upstream of site 7-1, another local landowner placed concrete rubble in the streambed to form a crossing ramp. This was placed prior to construction of the grade control structures. At the present time there is approximately 2 to 3 feet of fall over the crossing ramp.

Site 7-2 is located approximately 100 yards above the concrete rubble crossing. At this site approximately 6 inches of the baffle is exposed; however, the sheet pile weir is completely buried. There are no erosional problems evident and the structure appears to be in good condition. Site 7-3 is located approximately 2,500 feet upstream of site 2. Approximately 2 feet of the baffle and the upper edge of the sheet pile cutoff weir are exposed. Riprap was placed on the upper bank and designed to launch into the scour hole; however, there has been little, if any, launching as yet. There appears to be no erosional or structural problem with the structure.

Approximately 1,000 feet upstream of site 7-3 is site 7-4. At this location the baffle is completely exposed and there is about 1.5 feet of fall over the sheet pile cutoff weir. At low water there appears to be some ponding of the water upstream of the structure. There is some bank erosion on the upstream right bank; however, the performance of the structure is not affected.

Site 7-5 is approximately 800 feet upstream of site 7-4. A headcut has been halted by this structure and there is approximately 4 feet of overfall at the sheet pile cutoff weir. This structure has the trench filled riprap similar to site 7-3, and some of the stone has launched into the scour hole. With the exception of the anticipated erosion in the scour hole, there are no other problems with the structure.

Further discussion of the Hotophia grade control structures is presented in Appendix A of the ARS Report (1981).

(4) Vegetative Study, Johnson, Goodwin and Peters Creeks. Effective streambank protection has been costly to install and maintain and a research program was needed to develop cheaper and more effective methods of streambank protection. These studies were conducted to determine the feasibility of using vegetation as an economical means of providing streambank protection. Since this type of study requires several years to evaluate, only preliminary results are available. A detailed discussion of the vegetative studies is presented in Appendix C of the ARS Report (1981).

11. Summary and Recommendations. Bank stabilization on Johnson Creek, constructed under Work Item No. 9A, was an attempt to use a minimum amount of bank protection by developing a system of properly aligned structures compatible with the streams' hydrologic and geologic characteristics. These structures have been very effective in accumulating sediments and protecting the upper banks. This is evidenced by the well established vegetative growth along the banks.

Three grade control structures were constructed on Johnson Creek under Item 9B. Numerous problems resulted in delays in the construction of the structures and headcuts proceeded upstream of the proposed site locations, thereby limiting the effectiveness of the structures. During this delay the area of the vegetation study upstream of site 9B1 was severely damaged by the lowering of the streambed.

Fourteen grade control structures equipped with data gathering capabilities were constructed in the Goodwin Creek Watershed. As of July 1981, 11 of the structures have been instrumented; however, discharge calibration is needed and imperfections in the sediment sampling equipment need to be corrected before the system is totally operational.

Construction associated with the vegetative study on Johnson, Goodwin, and Peters Creeks was completed in the spring of 1981. Various vegetative treatments were used as inexpensive alternatives to the more costly traditional bank protection techniques and several more years of monitoring will be required before a complete evaluation can be made.

Five grade control structures were constructed on Hotophia Creek under Work Item No. 7. These five structures were intentionally designed without safety factor in an effort to determine if structures providing minimum protection can be effective. At present there are no structural problems; however, as of May, 1981, they have not been subjected to any large runouts.

A variety of bed and bank protection techniques were constructed on Hotophia, Goodwin, and Johnson Creeks. The evaluation time on most of these structures has been very short and final evaluations have not been made. With 5 to 10 years of monitoring, much meaningful data could be compiled, particularly in the Goodwin Creek Watershed. Collection of the data over this extended time period should provide valuable insight into the most effective means of controlling streambank erosion.

III. USDA SEDIMENTATION LABORATORY (ARS) REPORT

A. Introduction.

As a portion of the Streambank Erosion Control Evaluation and Demonstration Act of 1974, Section 32, Public Law 93-251 (as amended by Public Law 94-587, Sections 155 and 161, October 1976), the Vicksburg District Corps of Engineers and the USDA Sedimentation Laboratory at Oxford, Mississippi, conducted a "Cooperative Study of Streambank Stability."

Basically the study was to: (1) Characterize the channel and flow conditions in the vicinity of major channel stabilization structures; (2) Study the geomorphic features of the study area; and (3) Study the watershed features, including water and sediment sources and their effect on channel stability.

Specifically the study was to: (1) Determine the influence of grade control structures on channel stability; (2) Monitor and evaluate the performance of channel stability methods; (3) Evaluate effects of geology, geomorphology, soils, land uses, and climate on sediment production; (4) Estimate the discharge and sediment production of a watershed and the integrated effect on channel stability; and (5) Evaluate the relation between valley stratigraphy and channel morphology and their combined effects on channel stability.

This report on "Streambank Stability" includes a main report and 17 appendices. Summaries for this report and appendices are included below.

Chapter 1 of the main report is an introduction to the study and the research objectives.

Chapters 2 through 7 are general introductory material that provide the reader with the type information needed to make assessments of channel stability. Chapter 8 is an assessment of the conditions on the study watershed, and Chapter 9 is the Summary, Conclusions, and Recommendations. A summary of the material presented in the chapters follows:

Chapter 2 on River Characteristics and Morphology provides a summary, with references, of major topics in channel morphology. The transport processes responsible for the movement of channel bed material and the bed forms that characterize alluvial channels in both the upper and lower flow regimes are described. Channel roughness, grain, bed form and plan form elements are described as a dynamic system. The turbulence forces responsible for entrainment of sediment particles are described. Physical characteristics of material that normally make up the bed and banks of stream systems are also presented. Flow of water in bendways creates areas of excessive erosion and deposition that are described. Alluvial channels can be classified as straight, sinuous, meandering, or braided. The characteristics of these channel forms and how they relate to sediment transport rates, channel slope, and discharge are described. Finally, the last section of the chapter describes various geomorphic relations of channel size, shape, and sinuosity.

Since the volumes of surface runoff and sediment concentrations have so much impact on the characteristics of an alluvial channel, Chapter 3 on impact of watershed processes on the channel system describes the effect of land-use management practices in the upland watershed on volumes of runoff and sediment production. Sources of sediment production and man's influence on these sources of sediment are discussed. Changes in the climate of a region are also described as they influence runoff and sediment yield. The channels also contribute excessive quantities of sediment from a variety of events that are presented.

Chapter 4 describes processes leading to channel instability and erosion. Included are discussions of fluvial entrainment of bed and bank materials, particle segregation and armoring, the erosion of cohesive materials, weathering of surface materials, processes responsible for sloughing and massive bank failure, liquefaction of silty and sandy soil, and erosion of bank materials caused by seepage and wave action. The latter part of the chapter describes geomorphic processes or mechanisms of channel erosion. These processes include changes in flow rate, sediment load, and channel slope. The effects that these changes have on channel stability are described.

Chapter 5 discusses the many methods of channel protection but concentrates on the use of grade control and vegetation as the two most cost-effective measures. Also described are armor, retards, dikes or jetties, bulkheads, and baffles.

Chapter 6, identification of the processes active in a given situation and evaluation of effectiveness of specific solutions, is written to aid individuals in solution of specific site problems. The concepts of total channel system, reach, and point instability are discussed in depth. An approach to such a study describes the material to be collected, sources of data and aerial photos, use of mathematical models and procedures to use in assessment. Four major causes of system instability, land-use change, climatic change, downstream control, and exceeding of a threshold of stability are described using historic information, the application of geomorphic relations, and hydrologic models. Alternatives to solution of stability problems include "living with the existing channels" if its equilibrium size has already been reached and use of grade control in conjunction with upland watershed treatment measures. Reach and point instability are discussed in less detail because of similarity to specific aspects of material described in the discussion of system instability.

Chapter 7 is a brief discussion of some of the mathematical models that have been developed or are under development for possible use in studying channel stability. The stability of banks has been described analytically for many years by soil mechanics engineers. The first part of this chapter describes some of those models when applied to stream channel banks. The stability of noncohesive, cohesive, and composite banks are discussed. The effect of tensile cracks, which are prevalent in many high steep banks, is included in the discussion. Three hydrologic-type models are described in this chapter. They are a single event model, a continuous simulation model, and a quasi-three-dimensional finite element model. The single event model is physically based and was developed because the bulk of the sediment moves during a few large events. Interception, infiltration, overland and channel water routing, overland sediment routing, channel sediment routing and input data requirements are discussed. The continuous simulation model suggested for use is easier to use and requires less input data. Routing of water and sediment from the model are accomplished using the channel component from the single event model. Procedures used to estimate the volume of surface runoff, percolation, return flow, evapo-transpiration, water balance in reservoirs, sediment yield and input data requirements are discussed. The two-dimensional models discussed were developed to analyze sediment movement at specific sites in a stream channel, for example, at the confluence of two channels or in the vicinity of various stabilization structures such as those presented in chapter 5. The models developed are not yet operational, but the potential for full development is good enough that the concepts are presented in this chapter.

Chapter 8 is an assessment of channel stability problems in Goodwin and Johnson Creeks and a description of the research facilities placed in operation in the Goodwin Creek Watershed. The chapter includes a description of the watersheds including criteria for their selection as a research facility, their land use, soils, climate and climatic history, geology, geomorphic features; hydrologic data collection and data reduction and management system; an assessment of channel stability problems in Goodwin and Johnson Creek watersheds; and a brief discussion of hydrologic model applications.

Chapter 9, the last chapter, is the Summary, Conclusions, and Recommendations. The Conclusions and Recommendations are presented in the order of the five Research Program Objectives. The summarized material is presented in the 14 appendix chapters.

B. Appendix A. "Evaluation of Streambank Erosion Control Demonstration Project in the Bluffline Streams of Northwest Mississippi," Vicksburg District determined that channel stabilization evaluation and demonstration projects funds would be expended on bluffline streams and on streams tributary to the main rivers below the four main flood control reservoirs, Arkabutla, Sardis, Enid, and Grenada. Since these impoundments trap most of the sediment entering them, erosion above these lakes is no longer considered to be a contributing factor to the sedimentation problems in the main rivers below. A search for the study areas was begun in 1976. Areas were sought that, while having both stable and unstable reaches, had the greatest diversity of conditions that could be considered as pertinent variables in the natural processes affecting bed and bank stability.

Four watersheds meeting these criteria were selected for the project. Hotophia Creek, a tributary to the Little Tallahatchie River, had serious degradation problems in its upper reaches, lateral erosion of the banks in its mid-section, filling of the channel in its lowermost reaches, and widely varied land use and geology. Five SCS flood control impoundments already existed along the south rim of the watershed. The main channel had been straightened by SCS in the 1950's, and jacks and slotted board fences were already in use on certain reaches of the creek. Five grade control structures were planned for this project for the upper degrading reaches of the main channel.

Peters Creek watershed, immediately to the south, had sand, gravel, clay, and rock bed streams in its main reach and throughout its various tributaries. In addition it had some tributaries that had been severely altered from their natural state; some that had been just moderately altered; and some that had not been altered at all. Land use was varied. Structural measures in the form of jacks and board fences were already installed by SCS in the lower reaches of the creek, and many drop inlets were under construction. In addition, on the various tributaries of Peters Creek were reaches of straight and meandering channels that were stable, reaches that were unstable, and reaches on the verge of going either way. Goodwin Creek, in the center of the area, was selected to be the highly instrumented, nested set of sub-watersheds, in which most data would be collected. Fourteen combination grade control and flow gaging stations were designed for that area. Johnson Creek, the northern tributary, was chosen as the site for three grade control structures, some bank revetment measures, and a bank vegetation study. Grade control structures were planned for Long Creek, a southern tributary, but were not built because of funding shortages.

Tillatoba Creek watershed, surrounding Charleston, Mississippi, and the area to the east, was chosen as a study area because of the many bank revetment measures that had been employed on its reaches by both the Corps of Engineers and the SCS and because of the varied land use and geology of the area. Two grade control structures were built on the North Fork of the creek by the Corps of Engineers. Concurrently but separate from the Section 32 program, a large straight drop concrete spillway structure was built on the Middle Fork by SCS. A wide variety of bank revetment treatments were designed and built by the Corps of Engineers throughout the entire watershed.

The fourth area chosen was Perry Creek watershed south of Grenada. Degradation throughout all of its reaches had accelerated tremendously since the occurrence of record storms in 1973. Two or three highway bridges and a railroad bridge were seriously threatened, and the need for some type of grade control was urgent. Two grade control structures were built below I-55 and others were considered upstream but, due to landowner refusal to grant right-of-way, none were built. Bank revetment measures were installed at several locations throughout the length of Perry Creek (Item 6A).

The objectives of the study, stated above, were approached from various perspectives, and nine research outlines were prepared and designed to meet the five principal objectives. This Appendix A, "Evaluation of Streambank Erosion Control Demonstration Projects in the Bluffline Streams of Northwest Mississippi" meets objective 2. Presented herein are data useful to the understanding of the problems involved and to planning the future direction that bed and bank stabilization practices in this bluffline area will take.

The following are the ARS conclusions from studying the above streams.

Channel straightening decreases channel length and thereby increases channel gradient. This increase in gradient causes an increase in flow velocity and hence an increase in maximum discharge for in-bank flow.

When a channel is straightened, the channel follows the longitudinal axis of the floodplain and thus maximizes the probability of intercepting older buried meandering channels (paleo-channels or recent channels filled and buried by land clearing or leveling). These older buried channels were likely filled with sands, silts, gravels, logs and other organic debris, were unconsolidated, and highly permeable making them extremely erodible. Erosion will occur first where the newly straightened channel crosses older buried channels creating a disturbance in the flow pattern at that point. Excessively high shear stresses would then propagate a new wave of erosion downstream.

Newly dug channels generally incise into soil strata that are not conducive to plant growth because of high bulk densities, low pH, and low available plant nutrients. These raw banks are then extremely susceptible to erosion.

Lowering of the main channel bottom by dredging or excavation will increase the effective gradient on all tributaries to the channel. This increase in gradient increases flow velocity and sediment transport capacity thus inducing a new wave of degradation in the tributary channels. In the Yazoo Basin, this degradation of channel beds is many times manifested by headcuts working upstream. This problem is compounded since the energy of the flow is concentrated at the overfall. As thesehead cuts move upstream, the channel becomes deeper and the banks steeper, inducing massive gravity failures.

Tailwater elevations in the channels downstream of major reservoirs are lowered by closing the spillways during flood events. Without the reservoirs, flood peaks on the main rivers would be more nearly concurrent with the flood peaks on the tributaries. Reduction of the water level in the main river effectively increases the hydraulic gradient of each tributary causing bed degradation in all tributary channels.

The typical valley alluvial sequence is (from the surface down) (1) Post settlement alluvium, (2) Young Paleosol, (3) Old Paleosol, and (4) Late Quaternary sands, gravels, and organic deposits. The young paleosol is unconsolidated sand and silt and fails by massive slumping caused by formation of gravity-induced tension cracks which run parallel with the banks. The old paleosol is highly consolidated fine material which is severely weathered, has well developed polygonal structure, and fails by individual blocks tumbling into the stream. Bank failures are more often associated with the young paleosol material (in the form of massive slides) and bed failures with the old paleosol material (in the form of headcuts or knickpoints).

As long as the channel bottom is in old paleosol, the channel cross section will be parabolic in shape. As headcuts move upstream and cut through the old paleosol into the underlying unconsolidated sands and gravels, the channel bottom becomes flat and banks recede and become vertical. With the passage of a headcut, the channel flow regime converts from a detachment process (in the parabolic channel) to a sediment transport process (in the rectangular channel).

Any local irregularity not in general alignment with the channel geometry will cause flow velocities to be directed towards one of the banks causing increased erosion stresses at that point. If the bank is vulnerable to erosion, scour will begin on that bank, and the flow will be diverted to the opposite bank inducing meanders downstream. Typical local irregularities are obstructions like toppled trees, trash, and old auto bodies. Misaligned bridge piers or culverts are also common local irregularities. Management-caused irregularities result from cultivation too close to the banks, trash pushed into the channels, cattle crossings, overbank drainage, and clearing of woodland. Natural bank and bed irregularities occur at seepage zones, points of dispersive soils, organic deposits in banks, old buried channels, sand bars, and broken rock sills.

Channel grade control structures are necessary in a degrading stream where headcuts or excessive channel slopes are encountered. The low-drop channel grade control structures discussed in the Appendix Chapter B of this report have been found to be a more economical and effective means of stabilizing degrading streams than treatments previously used.

The primary cause of failure of bank protection measures is channel bed degradation, especially when rigid or semi-rigid revetments are involved. Ten different combinations of structural and vegetative bank revetment techniques on Johnson Creek failed partially because of channel bed degradation. Construction of three channel grade control structures was delayed about 2 years after bank revetments were installed. The bed degraded approximately 4 feet causing partial (at different locations) failure of all treatments. Therefore, we have concluded that drop structures must be installed prior to installation of any bank revetment if bed degradation is expected.

An abundance of organic layers are found at the base of most channels in the Yazoo Basin. These materials are extremely erodible, even at base flows. If there are bendways with exposure of these materials, toe revetments will be essential to prevent lateral migration of the meander belt.

The following recommendations are given presuming that the channel bed is stable (neither degrading or aggrading).

-- Current engineering surveys and aerial photographs are mandatory.

-- Adequate subsurface investigations are mandatory.

-- Once planned, construction of stabilization measures should be started and completed as soon as possible. Otherwise, channel changes may be so rapid that original designs are no longer applicable.

-- Unorganized patchwork treatment of channel instabilities is a dangerous practice. Upstream changes in the meander pattern could transfer stream attack to the opposite bank from the protection measures. If spot treatments are used, they should be placed close enough together to maintain control of the streams' attack from side to side.

-- Many costly drop structures and revetments have been totally destroyed because of a lack of timely maintenance. Agencies responsible for construction work should set aside a maintenance fund for timely repair.

-- Overall problems with a drop structure will be minimized if the upstream approach channel is straight for a distance 10 times the channel bottom width.

-- Design discharge for a structure should be equal to or preferably greater than the 25-year return period. If not practical, provisions should be made for out-of-bank flow to re-enter the downstream channel safely.

-- Care should be taken to ensure that flow over the weir and around the baffle is symmetrical.

-- Permanent vegetation must be maintained on all banks.

-- Uncontrolled lateral inflow over the bank must not be permitted.

-- Vertical drop-inlets have been proven to be an economical means of controlling lateral inflow.

-- If at all possible, revetted bends should be designed and constructed with a constant radius. A long-radius bend should never be followed by a short-radius bend.

-- Laboratory and field studies are needed to determine the location (in plan view) of areas of maximum scour depth in channel bends and the maximum depth of scour anticipated.

-- Additional field studies are needed to determine the effect of a series of low-drop channel grade control structures, in close proximity, on reaches of the channel between the structures. Field studies should also be made of the effects of these closely-spaced structures on the overall hydraulic gradient along the series of structures for a range of discharges from base flow to bank full.

C. <u>Appendix B</u>. "Model Study of the Low Drop Grade Control Structures" is summarized as follows.

Streams and rivers incised and flowing through alluvial valleys many times have little or no natural bed material, such as rock outcrops, to serve as bed control. Such is the case with a majority of the streams located within the Yazoo Basin. These streams originate in the hills of Northwest Mississippi and flow west through the bluffline into the Mississippi Delta. The streams in the hills have steep channel gradients and flow through valleys which are alluvial. During the past 50 years a majority of these streams have degraded seriously. Degradation has occurred as a result of surface erosion of the bed but most often by the upstream progression of headcuts or overfalls. Because valleys of the Yazoo Basin are highly stratified, overfalls are created when the stream breaks through a resistant layer of dense silt or clay into a layer of unconsolidated sand. The erosive energy of the flow is concentrated at the overfall. Headcuts are prevalent throughout the Yazoo Basin, and several headcuts may be active on a stream system simultaneously.

The channel gradient downstream from the headcut is reduced as the headcut moves upstream, thereby increasing the height of the overfall. These headcuts generally range from a few inches where they originate up to several feet as they move upstream. Continued degradation produces higher and steeper banks resulting in massive slump and slide failures and subsequent widening of the channel. Under these circumstances, even bank revetment techniques are ineffective and many times fail completely. One must then reason "a priori" that bed stability is a prerequisite to bank stability.

Grade control structures are needed to halt continued channel degradation. A series of structures carefully spaced throughout the length of a stream is generally required to stabilize the bed. Structures are particulary important at the confluence with larger streams, especially if the larger streams are regulated. Each structure must have a relatively low drop to avoid excessive overbank flow which could breach the structure. Many of the channel grade control structures used by the USDA Soil Conservation Service are of the order of 1 to 4 feet absolute drop height. In the past, these structures have not functioned as intended because no means of energy dissipation at the drop structure was provided. Many of these structures were constructed using riprap to form a rock sill over which the water passed. As a consequence, large scour holes developed immediately downstream of the rock. Many of these structures have been observed to fail as the rock fell into the scour hole. The usefulness of the structure was lost, and, in fact, another headcut was initiated that moved upstream.

The intent of this report is to present a new concept for low drop, channel grade control structures.

A low drop structure is defined as a hydraulic drop with a difference in elevation between the upstream and downstream channel beds, H, a discharge, Q, and a corresponding critical depth, Y_c, such that the relative drop height, H/Y_c, is equal to or less than 1.0. Conversely, a high drop is defined as one with a relative drop height, H/Y_c, greater than 1.0.

Tentative design criteria are given to proportion and hydraulically design the stilling basin for low drops with baffle energy dissipation devices. A method is given to determine the size and placement of a baffle pier or baffle plate to achieve optimum flow conditions in the downstream channel.

Additional model studies are needed using different channel bottom widths to insure that the results are applicable over a wide range of stream geometries and discharges.

D. Appendix C. "Investigation of Vegetation for Stabilizing Eroding Streambanks" is summarized as follows.

Stages in the propagation of vegetation are generally recognized as planting and germination, growth, development, and maturity. The time required to reach maturity or stage of maximum production varies greatly, depending upon the species and growth environment. Under a good environment with a proper balance of soil moisture and plant nutrients, at least two growing seasons are required to establish a dense cover for many of the grasses. More than 5 years will be required to obtain appreciable growth for most woody species. Observations indicate that the shrub types require 4 to 7 years before effective cover is obtained. A number of years are required to properly evaluate most plant material studies. With only two growing seasons for the Peters Creek and part of the Johnson Creek studies, conclusions made at this time would be premature; therefore the following observations are offered.

The checking or elimination of scouring forces creating channel bed degradation is necessary before satisfactory results can be expected from the use of vegetation to stabilize or control bank erosion. In many cases, failure of bank protective work can be attributed to the failure of the bank toe from scour, which in turn creates undercutting and sloughing of the upper bank. The history of the Johnson Creek channel in recent years has been one of a series of progressive headcuts. Prior to selection of Johnson Creek vegetative study reaches Nos. 3 and 4, plans and specifications were developed by the USDA Sedimentation Laboratory and the Corps of Engineers to construct a series of grade control structures to help stabilize the channel bottom. Unfortunately, the awarding of a contract for installing the planned structures was delayed until approximately 2 years after study reach No. 3 was initiated. During this period of time, cross-section surveys of the study reach revealed that the channel bottom degraded 3.1 feet. In a few locations, the rock riprap and cellular concrete block revetment on the lower bank slid down the bank to the eroded toe line and exposed small areas of filter cloth. Most of the displaced material continued to protect the lower bank at the toe line and prevented any bank failure.

All of the No. 3 study reach was subjected to severe hydrologic and plant growth stresses during 1980. Large storm runoff events, occurring early in the year, produced velocities in excess of 12.0 feet per second at the center of the stream and 2.5 to 3.0 feet per second near the bank along both sides of the channel. However, no appreciable damage to the treatment sites was observed. During the growing season, 4.89 inches of precipitation was recorded. Normal rainfall during this period is approximately 15.0 inches. Although plant growth was retarded by the drought, the survival rate for the woody species was considered better than average for the prevailing conditions. The overall survival rate for the 1979 and 1980 plantings of the shrub type bristly locust (Robinia fertilis arnot) and indigo bush (Amorpha fruticosa) was 94 percent and 78 percent, respectively. The 1980 planting of Streamco willow had a survival rate of only 33 percent. Crown vetch on a 7,500-square foot bank area had a survival rate of 83 percent. All of the grassy species responded well and formed a good dense ground cover. Only one treatment site, a formed bank armored with 6 inches of compacted sand clay gravel and over-seeded with Bermuda grass, failed to show good growth and ground cover. However, the survival rate of the Bermuda was considered good. Due to the length of time anticipated for the shrub types to provide adequate cover for protection, grassy species have been interplanted with the shrubs. The most effective mulch materials 1 year after seeding were found to be excelsior erosion control blankets and chopped grain straw anchored with emulsified asphalt. Paper matting was considered to be the least satisfactory.

Species of woody vegetation in conjunction with retards on Johnson and Peters Creek have shown varying degrees of response. A survey was made 2 years after planting to determine the survival rate for each study reach. The results of the survey, made during the latter part of 1980, are as follows: Johnson Creek study reach No. 2, water elm planted between channel bank and riprap - 60 percent survival; Johnson

Creek No. 1, river birch planted between channel bank and wooden fence - 60 percent survival; Peters Creek No. 1, native black willow planted between channel bank and concrete jacks - 75 percent survival; Peters Creek No. 2, Streamco willow planted between channel bank and concrete jacks - 32 percent survival; and Peters Creek No. 3, river birch between channel bank and concrete jacks - 55 percent survival.

Vegetating without bank shaping and no structural measures is usually limited to woody species. Native species such as willows are the easiest to propagate. The degree of success is determined by the size of the channel, height and stability of bank material, maximum velocities and characteristics of flow along the channel banks, the amount and type of material deposited along the bank toe line, and whether or not planting is attempted along a concave bend. The greatest problems exist along concave bends and are the most difficult to vegetate without the support of retards.

Studies to determine the feasibility of vegetating channel banks without bank shaping and without the support of structural materials were initiated in 1976 and 1977 by the USDA Sedimentation Laboratory and the Soil Conservation Service. Plantings of various species of willows were made in 1976 along both banks of a 6,000-foot dredged reach on Pigeon Roost Creek in Marshall County, Mississippi. One bendway was included in the upper reach of the study. The vertical banks averaged 12 feet in height with channel bottom widths ranging from 120 to 130 feet. The channel bed, with a gradient of approximately 7 feet per mile, is slowly degrading. The catchment area above the study reach is approximately 100 square miles. Survival evaluations were made in April 1980 with the following results: native black willow - 32 percent survival; halbert willow (Salix hastata MS-863) - 11 percent; gilg willow (Salix gilgianna MS-859) - 15 percent; and slender willow (Salix gracilis MS-878) - 23 percent survival.

Plantings of various woody species were made in 1977 along both banks of a 330-foot straight reach on Oaklimeter Creek in Benton County, Mississippi. The vertical banks of this natural channel average 15 feet in height with bed widths ranging from 15 to 25 feet. Survival evaluations of the plantings were made in April 1980 with the following results: gilg willow (MS-859) - 12 percent survival; slender willow (MS-878) - 54 percent; Carolina willow (Salix caroliniana MS-4375) - 21 percent; river birch - 54 percent; and hazel alder (Ainus rugosa MS-3516) - 37 percent survival.

Failure of plants to survive in both studies is attributed to high flow velocities (>3.0 feet/second) near the channel banks, bank sloughing due to reduction of shearing resistance from saturation and erosion of the toe, bank slides due to freezing and thawing, and generally poor unproductive soils.

Preliminary results obtained at this early stage of the studies indicate that native species of both grassy and woody plants are preferable over imported varieties. Sprigging is preferred over seeding for crown vetch and the ivies. Good stands of most grasses have been obtained by seeding. Native black willow appears to be superior to the hybrid varieties of willow in both survival and growth. River birch, alders, and water elm show some potential when planted under the right environment. The shrub varieties, indigo bush, and bristly locust have responded well.

A discussion of streambank stabilization work would be incomplete without including maintenance. No stabilization program, regardless of how well designed, will remain effective without some maintenance. Control measures, once installed, are not automatically permanent. Structures installed in conjunction with vegetative plantings will in time deteriorate or they may become ineffective due to changes in hydrologic or physical characteristics of the stream. The plant cover itself is subject to change from destructive physical action and through natural laws of plant succession. Too much plant growth can reduce channel capacity. On-site appraisal of channel conditions is necessary to detect possible weak points and to schedule necessary maintenance and repairs before potential problems reach the acute stage. A regular maintenance program will greatly prolong the useful life of stabilization measures, prevent loss of work previously done, and will safeguard the banks against possible erosion in the future.

E. Appendix D. "Bank Stability and Bank Material Properties on the Bluffline Streams of Northwest Mississippi" is summarized as follows.

Many of the bluffline streams of Northwest Mississippi have degraded very seriously during the last 50 years. This degradation is the result of changes in land use, channel straightening, and lowering of effective base level by trunk stream regulation. Degradation takes place primarily by the upstream movement of a knickpoint, often in the form of a headcut or overfall. This headcut forms where the channel bed breaks through resistant substrata of ironstone or clay. The streams lack any bedrock control and the channels are erodible. Upstream of a headcut, channels appear to be reasonably stable and they conform to regime equations for alluvial rivers. However, downstream of a headcut the channels lose their stability and their coherent hydraulic geometry.

Although the main fluvial response of the channels is to degrade by bed scouring, the channel banks are also seriously affected. Scour of the bed and bank toe increases the bank's height and slope angle, decreasing its stability with respect to mass failure under gravity. Overheightening and oversteepening of the bank continue until a state of limiting stability is reached, when the forces tending to cause failure balance those tending to oppose failure, and mass failure is imminent. The mechanism of failure depends on the size and stratigraphy of the bank and the physical properties of the bank materials.

Slope stability analyses can be applied to streambanks to determine their stability and define the most critical mechanism of failure.

In this study, a literature survey was used to identify possible approaches to the problem of describing and analyzing bank stability in the bluffline streams. On the basis of the survey, preliminary field investigation, and previous experience, it was decided to use Chen's "limit analysis method" to assess bank stability. This requires data on the strength properties of the bank material. Such data usually are obtained from detailed site investigations and laboratory tests on intact samples of soil. However this approach is seldom feasible in the study of bank erosion on a catchment-wide basis, and so another approach must be adopted.

Two relatively new instruments were selected for soil strength measurements. The Iowa Borehole Shear Tester was used to make in situ measurements of the cohesion and friction angle and an Unconfined Compression Tester was modified to conduct both compression and tension tests. The instruments are not widely used and are not well documented, so they are described and discussed in some detail. In this report, the strength measurements are used with bank geometry data from three bluffline streams to test whether reasonable predictions of critical bank heights and slope angles can be made. Finally, the engineering applications are considered and recommendations are made concerning future research.

The most damaging impact of channel instability on a region is in the destruction of floodplain land by bank erosion. There are two primary causes of bank erosion in the bluffline streams of Mississippi. First, progressive bed degradation leading to bank instability (primarily through overheightening) and to widening of the channel. Second, toe erosion and basal scour at the outer bank in bendways leading to bank instability (primarily through oversteepening) and to lateral movement of meandering channels. In the field, evidence suggests that a major phase of bed degradation follows lowering of base level and/or straightening. When the channel longitudinal profile has stabilized, a second phase of meandering and floodplain destruction occurs. Stability is finally re-established when a new floodplain is formed. This is at a lower level than that which was destroyed and is an economically inferior soil. The stability analysis and field techniques developed and presented here could be useful when dealing with bank erosion associated with either phase.

In controlling bank erosion associated with bed degradation, it is essential that a stable bed be established if bank stabilization measures are to be successful, because continued lowering of the bed will eventually result in the undermining and failure of any bank protection structures. With a lack of natural bedrock controls on the bluffline streams, grade control structures are required to establish bed stability. However, a question arises immediately of how many structures are needed and how closely they should be spaced along the channel. To some extent this depends on the critical bank height. The stability analysis can be used here as an aid in estimating the maximum bank height which the bank materials can support. For example, at Hotophia Creek, if the bank height could be limited to about 5 m there probably would not be widespread bank failure due to overheightening. Consequently, grade controls should be positioned along the channel so that the degree of incision below the floodplain does not exceed about 5 m. Of course the bank angle is also a factor, and if some regrading of the steeper banks could be incorporated into the channel stability program, higher banks would be permissible.

In dealing with bank erosion in bendways, the attack on the bank toe is a major problem. The reason for this is easily explained by the concept of basal endpoint control and by the influence of flow in the bend. Therefore it is vital that effective toe protection be established at the outer bank in eroding bendways. Once the toe has been stabilized, the stability analysis can be used as an aid in designing the regraded bank.

The safest approach in redesigning the bank is to grade it so that the bank angle is lower than the worst case friction angle of the bank material. This eliminates tensile stress from the bank and theoretically the bank should be stable to any height. For example, in Johnson Creek the average worst case friction angle is 14.5°. In bank stabilization projects carried out on this creek, a gradient of 1 on 3, or 18° has been used successfully and this is rather close to the worst case friction angle, suggesting that theory and practice may agree.

Often it may not be possible to grade the banks at such a comparatively low angle and in such cases higher angles may be used with a good chance of stability, provided they plot well below the line of critical stability for worst case conditions, in the "stable" zone of a stability chart based on the bank material properties. For example, the results for Hotophia Creek show that banks at angles with the horizontal of less than about 55° were stable with respect to mass failure. This figure could be used as a rule of thumb in regrading unstable banks on Hotophia Creek with a good chance of success.

The surface of any steep, but not vertical, bank in Mississippi must be protected from surface erosion by water running down the slope. Protection is best provided by carefully controlled overbank drainage and suitable vegetation. The role of vegetation in providing surface protection from both downslope and channel flow is well established, but vegetation can also play an important role in improving bank stability through the effect of plant roots in increasing the strength of the soil. The shear strength of soils and the interfaces between layers of contrasting soils can be increased by 200 percent by strongly rooted species such as alfalfa. It is expected that even greater increases in the tensile strength would be recorded, and that the extent of tension cracks behind steep banks could be reduced dramatically by establishing a hedge of strongly rooting species along the bank top. There is great potential for bank stabilization through the use of vegetation in the bluffline creeks if suitable plant species can be discovered. It was intended that part of this study should be devoted to evaluation of some of the plants currently under investigation at the Sedimentation Laboratory, but shortage of time precluded work on this objective. It is recommended that the study be extended to include the effects of vegetation in the future.

The analysis present here deals only with log-spiral toe failure of a bank with a tension crack. It cannot account for other types of failure such as transitional failure associated with a very weak layer in the bank. When a very weak layer is present, most of the failure plane forms in it and the geometry of the failure plane is no longer log-spiral. Such situations must be dealt with individually, depending on the stratigraphy of the bank and the soil properties.

The reasonable results for the soil strength tests, the success of the analysis as applied to the sites on Johnson and Goodwin Creeks, and the good agreement between observed and predicted stability on Hotophia Creek all suggest that the approach developed here could be used to predict bank stability with some confidence in engineering projects in the bluffline streams. There is still much research and development work to be done to refine and improve the analysis; however, this report does offer an engineering approach to analyzing bank caving problems as a means of calculating the necessary stabilization other than experience or intuitive guessing.

F. Appendix E. "Geomorphic Control of Channel Stability" is summarized as follows.

Geomorphology is the science concerned with the nature and origin of the surface features of the Earth. Individual surface features are usually referred to as landforms and a series of landforms constitute a landscape. Inherently, most landforms have been produced by either erosional or depositional processes, or by both. Alternately, some are the product of volcanic or tectonic activity. Landforms within any present-day landscape, however, have been altered by subsequent less-intense processes of deposition and/or erosion and by weathering processes. Rates of landform change in response to changing environmental conditions are not constant but vary between landforms and, for a given landform, vary with its relative position in the landscape.

This rather simplistic introduction belies the complexities involved in integrating this applied geomorphic investigation into the overall study of stream channel stability. Two general conditions are critical in order to maximize the usefulness of results. These two are the line of inquiry and the definition of the system components (the landforms and landscapes).

Three lines of geomorphic inquiry that have been indentified are:

a. The description of existing landforms and landscapes,
b. The changes in landforms and landscapes which progress through time,
c. The identification and quantification of processes responsible for formation and for modification of existing landforms and landscapes.

The latter line of inquiry, termed process or dynamic geomorphology, differs from the preceding two both in technique and in application. The first two are primarily morphometric and frequently tacitly assume a space-time continuum. Landform identification is based primarily on morphometric criteria. Results from such studies are not readily usable in other areas. Process geomorphology assumes no such continuum. It encompasses morphometry and, more significantly, adds a depth component to the study system. This third dimension is surficial geology. The depth dimension pertinent to any given process geomorphic study is axiomatically established as that depth necessary to fully evaluate pertinent processes of formation and of modification. Identification of dominant process controls of landform formation, also referred to as forcing functions, is inherent in this approach and such identification facilitates extrapolation of results to areas outside the study area but subjected to the same forcing functions. Landforms are identified and classified as process units, based on the dominant process controls. Process geomorphology, thus, has many advantages for this study; it has been employed whenever possible. Advantages are:

a. The ease of coupling with standard engineering-type activities,
b. The ease of coupling with process-based simulation models,
c. Continuity with the processes influencing channel bed and bank failure,
d. It is system oriented.

The fluvial system is the dominant feature common to both the channel stability and geomorphic aspects of this study. For this study, it was assumed that the geomorphic system can be defined in relation to the (idealized) fluvial system. Landscapes and landforms within this system have not been formally defined at this time. Units based on formation-controlling and modifying processes have been classified. Ultimately landforms will be identified but these will be based on process units; a morphometric classification is unacceptable due to the subjectiveness of landform definition and the poor interpretative value of landforms identified by morphometric properties only.

Many of the process units are relict elements, produced by forcing functions (dominant processes) different from those of today. Examples of relict elements are:

a. The early Holocene valley-fill units,

b. The fragipan horizon in the loess soils formed by pre-Peoria weathering,

c. The variation in drainage density related to landscape age.

Relict elements may be time-variant or time-invariant for the time span implicit in the investigation and they may or may not be pertinent to the objectives of the investigation.

The assemblage of relict and present-day elements in any given system is, of course, pertinent to current processes characteristic of the system. The representativeness of any given system, or data pertinent to a system, for characterizing a region depends upon the distribution of relict and present-day elements within the system relative to that of the region. Relict elements were produced by forcing functions (dominant process controls) which characterized past ages. Inherently, the present distribution of relict elements was established by the distribution of (past) forcing functions. These (past) forcing functions varied drastically during the Quaternary Period, and similitude with present conditions is unlikely. Identification of forcing functions and definition of their distribution are prerequisite to maximum predictive capabilities.

The fluvial system is common to both the geomorphic system and to channel stability. The following definitions are an attempt to develop terminology which (a) describes channel stability in relation to overall system characteristics and (b) can be used interchangeably for both geomorphic and channel stability investigations.

By themselves, stable and unstable are nebulous, relative terms when applied to channels. All channels are subject to changes which are evaluated as acceptable or unacceptable based on socio-economic and time criteria. If the rate or magnitude of change is unacceptable, the channels are classified as unstable. This classification of stable versus unstable channels is, in essence, independent of stream system characteristics.

An idealized fluvial system has three zones. The headwardmost zone, Zone 1, is the area of sediment and water production. By definition, this is a zone of erosion and temporary storage of sediment. The middle zone, Zone 2, is the transfer zone. Channels in this zone are at grade if sediment input equals sediment output. The lowermost zone, Zone 3, is the area of deposition. Aggradation occurs in this zone. Thus, both aggradation and degradation will occur simultaneously in any one complete system. Channels in the transfer zone will be at grade for a stable system but such channels may be termed unstable based on socio-economic criteria. Several conditions should be noted for this idealized system:

a. Most study watersheds are not complete systems,
b. Zone boundaries are probably stage dependent,
c. Zone boundaries become less well defined as the size of the system is reduced, that is, as variables extrinsic to the system become relatively more significant.

Inherently, the system has a high degree of interdependence between the zones. Changes in either or both sediment and water production and/or routing will induce changes in Zones 2 and 3. Additionally, changes within the system which alter backwater levels and/or peak flow synchroneity may effect changes throughout the system. The forcing function (the dominant control) of such changes may be either intrinsic or extrinsic and may effect changes within existing zones or may cause the boundaries between individual zones to change. An extreme example of this latter type of change is that produced by the concurrent paleoclimatic and base level change at the Holocene-Wisconsin (time) boundary. During Late Wisconsin times, many of the present Bluff Area valleys were Zone 1. Due to vast amounts of glacial debris being flushed down the Mississippi and Ohio Rivers and concurrent rises in sea level from glacial thaw, the Bluff Area valleys quickly changed to Zone 3. Other forcing functions include land use changes, channelization, and water-handling structures which cause peak flow asynchronism.

Secondary systems are frequently imposed upon the simple idealized system. Two types of secondary systems have been observed. Excessive sediment production in Zone 1 may form a large sediment wave. Such waves, equivalent to a micro Zone 3, move downstream effecting channel changes. The second type involves knickpoint migration upstream. The knickpoints, equivalent to a micro Zone 1, similarly effect reach changes; but such changes migrate upstream (the large sediment waves move downstream), ultimately resulting in excessive sediment production. This type of complex response is typical in many Bluff Area streams.

The classes of instability are an attempt to more definitively classify channel changes. This classification also has utility for channel improvement activities. System instability is typified by changes, particularly bed elevation changes, throughout the system, Zones 1, 2, and 3. The system must be modified before bank stability can be achieved. Local bank protection measures will only transfer problems. This system instability represents a total imbalance between hydraulic erosive forces and bank material strength. Point instability, on the other hand, typifies a relatively stable system. The channel bed is stable and bank failure results from atypical local conditions. This type of failure can be alleviated by standard bank protection measures, if such is deemed necessary. Reach instability represents the middle area between the two extremes. The system is marginally stable; some reaches are stable and some are not. If the positions of the stable and unstable reaches are time invariant with respect to the fluvial system, noted as static reach instability, failure most probably is the result of channel morphometric conditions or relatively weak bed or bank materials. Failure mechanisms must be ascertained to evaluate (a) potential rate of change and (b) the probability of natural healing. Unstable reaches which migrate through the fluvial system with time, termed dynamic reach instability, typify complex systems and must be evaluated accordingly. Knickpoint migration is a particularly detrimental type of dynamic instability in that it may result in both static reach instability downstream of the knickpoint and ultimately excessive sediment production from Zone 1 as the knickpoint moves upstream. Such knickpoints are obviously detrimental to long-term stability and must be controlled as the first phase of any stabilization program.

The present conditions of channel stability or instability for Johnson and Goodwin Creeks have evolved from site specific conditions, stratigraphic controls and system characteristics. Bank instability for Johnson Creek is prevalent downstream of a major knickpoint whereas the banks upstream of the knickpoint are relatively stable. The knickpoint has progressed upstream at an average rate of about 525 feet per year for the last 35 years, eroded through the cohesive polygonal-structured paleosol II bed materials and sufficiently lowered bed elevations downstream of the knickpoint to accentuate gravity-induced failure of the banks. Reaches downstream of the knickpoint have sand to gravel beds with transport processes dominating stability relations. This type of instability has been termed dynamic reach instability (the unstable reach moves through the system with time). Goodwin Creek, on the other hand, has undergone appreciably less thalweg lowering due to the presence of iron-cemented sandstone outcrops in the channel bed which function as temporary bed-control sills and due to the large amount of gravel bed material. Excessive lateral movement of the Goodwin Creek channel has occurred at unusually large bendways and this type of instability has been termed static reach instability (the unstable reach remains at the same position within the system).

Gravity-induced failure of paleosol I and postsettlement materials is accentuated by the presence of vertical tension cracks which develop parallel with the bank. This tension crack development results from the relatively unweathered and hence isotropic nature of these materials. Paleosol II materials have a well developed polygonal structure which controls stability. The seam materials between the polygonal blocks are excessively weak, resulting in weakness planes separating individual blocks. Block loading by water leads to block failure. The failure rate is accentuated by the presence of easily eroded toe materials, either channel lag or bog-type deposits.

Bank instability is essentially a three stage process: (a) gravity-induced failure delivers slough to a bank toe position, (b) the slough is continuously disaggregated by weathering forces, and (c) discrete particles are removed by fluid forces. In the study channels, this removal is rapid with little slough remaining in the failure location from 1 year to the next.

Bed failure by headcut movement is extremely complex. Headcuts typically occur in paleosol II materials with a well developed polygonal structure. Failure is initiated by a chute forming through the cohesive materials concurrent with removal of weak seam materials. Individual blocks, thus isolated, roll to the chute and are moved downstream by high velocity flows. The initial chute formation and seam material removal are probably dependent upon low flow conditions.

Goodwin Creek channel is not a true alluvial channel within the time constraints of this study. An additional group should be added to river classification, possibly termed stratigraphic-controlled channels, to more accurately reflect variable dependence or independence with time. The stratigraphic controls, the variation in channel width and depth at point locations, the cemented sills, and the unusually large bendways are probably independent variables affecting flow properties, the dependent variables, for this study of channel stability. The dependent hydraulic properties include the distribution and magnitude of boundary shear stress, secondary flows, and total flow resistance. For longer time periods, these variables will have a reversed role.

The preceding results illustrate the complexity of channel failure processes and the difficulties involved in simulating such conditions in process-based models. Failure occurs in reaches of excessive energy expenditure typically associated with nonuniform flow, necessitating three-dimensional simulation models for accurate representation of field conditions.

The distributions and properties of the valley-fill units (the units imposing stratigraphic controls) and their ^{14}C ages indicate that the dominant process controls of formation for these units was paleoclimate and base level fluctuations. This finding enhances the predictive capabilities for extrapolating results from the study watershed to other locations subjected to similar late-Quaternary paleoclimatic and base level conditions. Similarly, these results illustrate the utility of the valley-fill stratigraphic record as a measure of paleoclimatic conditions.

The geologic studies have established that the presently mapped stratigraphy is not accurate in the study area and probably in a large part of North Mississippi. The surface of the Zilpha is disconformable, representing an erosion surface which we feel has regional significance. Ground water is perched above this surface due to the relative impermeability of the Zilpha material. Additionally, the erosion surface is not congruent with surface watershed definition, creating the possibility of ground water transfer between watersheds. This greatly complexes water budget considerations inherent in the detailed Goodwin Creek study. Resistivity methods appear to have great utility for further defining the relief on the Zilpha surface.

The uncertainty concerning the nature and distribution of the near-surface geologic units limits full development of capabilities for predicting properties of the valley-fill units. The geologic materials are source availability and controlling processes must be accurately defined for full development of predictive landscape models.

This appendix recommends the following.

Relations between valley-fill units, failure mechanisms, and failure rates should be quantified. (This activity will be initiated as soon as gaging station installation is completed.)

The landscape is a complex arrangment of landforms and landform elements in a physical sense but is systematic and logical when defined on the basis of controlling process or processes. A complete understanding of the landscape, based on controlling process or processes, is essential in order to more efficiently manage the present pervasive environmental problems such as those associated with channel instability.

Hopefully, such an understanding would lead to the development of landscape models of sufficient detail to facilitate coupling with application models. We believe that this coupling of models would:

a. Simplify application model requirements,
b. Maximize predictive capabilities with respect to time and space,
c. Result in better definition of the basic processes underlying specific environmental problems.

In order to better understand the landscape, a prerequisite to landscape model development, the following landforms and landform properties should be better defined:

a. Loess - the ages of the loess, the nature of the contacts between individual loess units and the nature of the loess to valley-fill contact.

b. Valley terraces - the distribution and ages.

c. Valley-fill deposits - comparable studies east of the present study area to verify the valley-fill sequence and establish the maximum depth of Quaternary valley erosion, and west of the present study to additionally verify the valley-fill sequence and establish relations of these deposists with those in the Mississippi River valley.

Additionally, geologic studies should be conducted to better define material overlying the Zilpha surface. Secular variation or other paleomagnetic determinations may be a useful tool for dating layered clay bodies in this material. The possibility of a (buried) ancestral Mississippi River channel between the present study area and the bluff line should be evaluated.

Relations between soil map units and valley-fill deposits should be evaluated. To the degree that these are related, the soil map units could be used to infer the general nature of the subsurface deposits.

The dependence of flow properties on stratigraphic and channel morphometric controls should be evaluated. Secondary flow production is extremely important as such flow influences the distribution and magnitude of bed shear stresses and the flow resistance. Full definition of the influences of stratigraphic and morphometric controls may facilitate classification of such controls into functional units which would have direct utility in channel stability evaluations.

G. Appendix F. "Goodwin Creek: Catchment, Data Collection, and Data Management" is summarized as follows.

One phase of a cooperative study on streambank stability between the USDA Sedimentation Laboratory and the U. S. Army Corps of Engineers, Vicksburg District, required the establishment of a research watershed to test concepts developed in the study and provide data to verify models and components developed in the research. The watershed selected was based on four criteria: it should be located in the Bluff Hills draining to the Mississippi Alluvial Plain; it should be suitable for subdivision to meet the research needs of the cooperative study; it should not drain into an existing flood control reservoir; and it should be close enough to the research laboratory to allow effective guidance of the field research.

Goodwin Creek watershed meets the above criteria. It has a drainage area of 8.3 square miles and is equally divided between row-crop, pasture and forested lands with no construction or industry. The basin has 15 sub-watersheds in which a data collection network has been installed. This network consist of 14 super-critical weirs, calibrated to record discharge and total sediment movement. A complete weather station was built with 26 additional rain gages placed throughout the watershed to give complete area coverage. A telemetry system has been installed to furnish real-time data to a computer at the laboratory in Oxford, Mississippi.

Construction was completed in 1980. Instrumentation, calibration, and verification are now (June 1980) about 80 percent complete. ARS and Vicksburg District intend to continually monitor this basin. The data are brought from the field to the laboratory in a variety of forms, as traces on a chart, map notations, radio messages, or observations in a notebook. To be readily usable, the data must be converted to digital form, reduced, edited, and stored on a computer. Much of the data comes directly from the field in digital form, as radio signals. Data from non-telemetered rain gages are obtained as charts. These data are converted to digital form on a digitizer. Data from water level recorders and from rain gages at telemetry sites are also recorded on charts as backup for the radio-transmitted data. These charts are also digitized as needed to fill in any gaps when the telemetry system is not working. Some data such as field surveys are keyed directly from field notebooks into the computer.

The goal of any data collection system is use of the data for some benefit. To facilitate that use, the data which have been collected, converted, and edited are stored in a data management system. This system is composed of several data bases and supporting software.

The data base is a collection of interrelated data stored together with controlled redundance to serve one or more applications in an optimal fashion. The data are stored so that they are independent of programs which use the data. A common and controlled approach is used in adding new data and modifying and retrieving existing data within the data base. Two concepts are used in guiding the development of the Goodwin Creek data bases. These are the concepts of logical and physical independence of data. The concept of logical data independence means that different users can see different logical organization of the data without requiring different actual logical organizations. This allows new programs and modifications of old ones to see different data organizations. Thus the data requirement for one program can change without disrupting data organization for other programs. The concept of physical data independence means that change in how the data are stored will not affect the overall logical organization of data or the application programs which use them.

Two broad categories of data have led to two different sets of data bases. One category is data which vary slowly with time or are considered time invariant. Examples include the locations of divides, drainage network, field boundaries, land use, soils, etc. These data are stored in a spatial information system with locations based on the Mississippi Plane Coordinate System. Definition of most features in this data base is by straight line segments or polygons. The second broad category is data which may vary rapidly with time. This category includes water level records, streamflow rate, precipitation, sediment transport rate, etc. The major characteristic of these data is many observations for each sensor at a location.

The data management system consists of the collection of data and the programs for retrieval and maintenance of the data. Some types of requests occur fairly frequently. Examples include availability, maximum, minimum, range, mean, standard deviation, etc. A user can obtain these directly without the need for his own software. A user can also write his own application programs and retrieve the data for it.

The Vicksburg District Corps of Engineers has its own data base system, the Yazoo Basin Data Management System. The Goodwin Creek data can also be put into the Yazoo Basin System for use. The system of the laboratory is designed and oriented toward a small area, an area of a few square miles, while the Yazoo Basin System is designed to handle data for hundreds of square miles.

H. Appendix G. "Soil Erosion and Sediment Characteristics of Typical Soils and Land Uses in the Goodwin Creek Catchment" is summarized as follows.

Much of the sediment moving through major streams originates as eroded soil from contributing agricultural areas, particularly those that are intensively cropped (Figure 1). Such sediment is detached and transported by the rainfall and runoff that result from moderate to intense rainstorms on upland areas that are not adequately protected from the erosive forces of raindrops and flowing water. Different soils may vary considerably in their rate of erosion due to inherent textural and structural differences. Such differences may also affect sediment characteristics, particularly size distribution and density, which in turn affect the transportability of the sediment once it is detached. In addition to soil differences, the type and amount of vegetative cover on the land and the topographic characteristics of the land can greatly influence the rate of sediment production and transport during rainstorms. The research conducted during this study was designed to investigate the range of erodibilities for the various soils in the

Goodwin Creek Watershed, the effect of different land uses and cropping systems on erosion, the change in erosion rates at different soils and soil conditions, and the sediment transport capacities of runoff along crop rows of various lengths and steepnesses for different sediment sizes.

Data were obtained from 156 runs. Three replications of all treatment combinations were studied. Two types of sediment motion were observed: the dune type of motion and the ribbon motion, which was actually a strip of sediment flowing through the channel. These two types of motion were more observable when slope was changed and the other two variables were held constant. The transition from dune to ribbon motion came between slope steepnesses of 1 and 2-1/2 percent. This phenomenon can be related to discharge, depth, slope, Froude number, and Reynolds number, particle size, settling velocity, and shear velocity.

The steepness of the furrow slope had a tremendous effect on the capacity of the furrow to transport this sand-sized sediment. The amount of sediment trasported per unit of time for a furrow steepness of 1 percent was generally 50 to 100 times the amount that could be transported at 0.2 percent. The amount transported at 2.5 percent was generally 500 to 1,000 times that at 0.2 percent, and the transport at 5 percent furrow slope was generally more than a 1,000 times that at 0.2 percent. Furrow steepnesses of 0.2 percent are seldom found on upland fields, although they are a common steepness on land that is formed for drainage in the Mississippi Delta. Furrow slopes of 1 percent are much flatter than most furrows on upland fields except on slopes that are contoured or on bottomland fields along streams. Furrow steepness of several percent and greater is common on sloping land that is not contour farmed or terraced.

Increased furrow length, as simulated by increased flow rates, also affected the rate of sediment transport greatly. The amount of sediment transported per unit of time generally increased more than the relative increase in amount of flow. The results indicate that doubling furrow length will more than double the capacity of the furrow to transport sediment at the lower end. The maximum flow studied during this research was equivalent to that for furrows less than 100 meters long, yet furrow lengths of several hundred meters often occur on flatter fields.

Sediment size also affected the sediment transport capacity. Considerably more very fine sand could be transported for a given flow condition than coarser sand sizes. Further research has not yet been possible to evaluate the transport of finer silt-sized sediment. However, the effect of sediment size on transport capacity found during this research indicates that more silt-sized sediment per unit of flow for a given flow condition would be transported than the sand-sized sediment that was studied. Most of the soils in the Goodwin Creek Watershed have predominantly silt-sized sediment, so very high sediment transport rates can be expected for sediment eroded from those soils where furrow slopes are about 1 percent and steeper.

The presence or absence of rainfall did not affect the transport of sand-sized sediment very much. Earlier research on cohesive soils indicated that rainfall would double the rate of erosion from rills of 6 percent steepness.

The results of this research show that the transport of sediment along crop row furrows can be greatly influenced by row steepness, row length, and sediment size characteristics. Such influences can therefore greatly affect the amount of sediment delivered to the ends of cropped agricultural fields and into the stream systems where the runoff flows. Since the rates of interrill erosion are very high for the soils of the Goodwin Creek Watershed and since the sediment sizes of the Watershed soils are predominantly the easily transported silts, the potential for delivery of large rates of sediment to the stream system is very high. To reduce the delivery of such sediment, soil conservation practices on intensively cropped fields and/or sediment basins at the ends of such fields to trap the sediment are commonly recommended methods. They certainly seem desirable for intensively cropped land in this watershed. The loss of such sediment is a problem both downstream where it may deposit in locations where it is not wanted, and on the upland fields where its loss reduces the productive potential of the land from which it was eroded.

From this study, it can be concluded that:

1. Different soils may vary considerably in their rate of erosion due to inherent physical and chemical characteristics.
2. For the Goodwin Creek watershed soils, the difference in interrill erodibility decreases with increased rainfall duration.
3. The amount and type of vegetative cover greatly influences the rate of erosion from all soils.
4. Prior land use affects the erodibility of a given soil. In particular, soils that have been tilled are more erodible than those that have no recent history of tillage.
5. Apparently, a soil's susceptibility to erosion decreases through the cropping season because of physical or chemical change within the soil.
6. The rate of erosion from woodland or good pasture is very small compared to cultivated areas.
7. The effect of rain intensity (I) on erosion rate (E) can be expressed as $E = aI^b$ for a wide range of soil and cropping conditions. The exponent b is near 2 for soils with low clay contents, so the equation $E = cI^2$ represents these soils quite well.

8. Sizes of sediment eroded from row sideslopes varied considerably from soil to soil.
9. Much of the sediment eroded from cohesive soils was in the form of aggregates, and some of the aggregates were much larger that the primary particles of which the soils were composed.
10. Sediment size characteristics did not vary directly with those of the primary particles. Finer soil usually produced coarser sediments due to greater aggregation.
11. Sediment size characteristics did not seem correlated with the interrill erodibility rates of soils.
12. Sediment size distributions varied only slightly with major differences in rainfall intensity.
13. Sediment size distributions changed relatively little with continued erosion, at least over a period of a few days.
14. Sediment size distributions changed relatively little with the presence or absence of crop canopy.
15. Soil with a history of cultivation produced finer sediment than the same soil that had not been in cultivation for many years and finer still than for the same soil with no history of cultivation.
16. The relatively small changes in sediment size distributions with major changes in rainfall intensity, storm duration, and canopy suggested that the size distribution of sediment from interrill erosion is a fairly distinct characteristic of a given soil in a given condition.
17. The capacity of runoff to transport sand-sized sediment along crop row furrows and other flow channels increases rapidly as furrow steepness increased. At steepnesses greater than 1 percent, large amounts of sediment could be transported.

18. Transport capacity also increased as the flow rate increased, but the effect was less than for furrow steepness.
19. Transport capacity decreased as particle size increased.
20. Generally, rainfall did not affect the rate of sediment transport for the conditions, devices, and techniques studied.

I. Appendix H. "Hydrologic Measurements on Typical Soils in the Goodwin Creek Catchment" is summarized as follows.

Large scale denudation of the bluffs along the Mississippi River during and following settling in the nineteenth century led to significant changes in the surface hydrology of bluffline watersheds. The increased volume, rates, and peak discharges accelerated many times over the then prevailing geological soil erosion and sediment transport rates. Headcuts and bank failures widened and deepened the channels in the process of accommodating increased flow rates. This particular chapter deals with the impact of the soil water regime, of major soils in the bluffline watersheds, as it relates to internal drainage, infiltration, and thus the discharge rate of excess rainwater into the existing channel system.

Numerous factors influence the rate and amount of excess rainwater and its discharge into channels for subsequent conveyance to larger rivers. They include rainfall, rainfall rate, antecedent conditions, cover, topography, soils, etc. At a given location the excess water available for runoff is determined by the balance of rainfall, surface storage, and infiltration. The latter process depends on such factors as soil type, soil water antecendent conditions, rainfall history, and evapotranspiration demand by the prevalent canopy. Often, the summer periods are characterized by a net water loss because of evapotranspirational processes, whereas the late fall, winter, and early spring usually yield water surplus. Therefore, it may be concluded that soil type and the hydraulic characteristics will significantly affect the surface water regime.

In transecting the bluffline region from east to west, three land resource areas are encountered. Each of these land resource areas has its own soil groupings. At the foot of the bluffs is the Mississippi Delta. Its soils consist of alluvial material, which was deposited either by the Mississippi River or represents wash-in from tributaries draining the watersheds on the bluffs. The soils of the bluff region itself belong to the Brown Loam (thick loess) belt and are mostly of aeolic origin. They are over 120 cm (4 feet) thick and high in silt content. They are, therefore, subject to severe erosion hazards. Hard pans or impervious layers are common occurrences. Soils, having hard pans, are usually classified as fragiudalfs. Farther to the east, the third land resource area is encountered. It is made up of soils belonging to the Thin Loess area. Its soils are generally less than 120 cm (4 feet) thick and silty in composition. They represent a transitional belt between the soils of the Brown Loam to the west and the Coastal Plain soils to the east. The underlying coastal plain material has significantly influenced soil profile development in this belt. Erosion hazards are severe with gully erosion being a serious problem. Many of the unit source watersheds draining the bluffs originate in this belt. The major part of the Goodwin watershed is located in the Brown Loam land resource area.

In assessing the role of soils in the Brown Loam land resource area on the surface hydrology of the Goodwin Basin, the hydraulic characteristics of typical profiles need to be examined. Several major soil series found in this basin were selected for an in-depth study. The soils selected consisted of three upland soils (Grenada, Loring, and Memphis) and one bottomland soil (Vicksburg). The Grenada (Fragiudalf) is considered to be a moderately well drained soil with a genetic pan at about 55- to 60-cm (22- to 24-inch) depth. The Loring (Fragiudalf) is a deep soil with a weak pan at about 67 to 72 cm (26- to 28-inch) depth. The Memphis (Hapludalf) is a deep, well drained soil without a pan. Vicksburg is a well drained bottomland soil without a genetic pan. However, as a bottomland soil, it has usually been in cultivation, mostly in cotton or soybeans, and thus may have developed a plow pan. Except from general physical principles, the impact of this pan on infiltration and water movement has not been clearly established. Grenada, Loring, and Memphis are, as upland soils on rolling slopes, usually seeded to pasture. Unless occasionally tilled, they may possess a compacted top layer due to cattle traffic.

Research objectives as implemented under this project were two-fold: (i) to examine the hydrologic behavior of the aforementioned soils either under evaporative or drainage conditions, (ii) to follow the soil water regime in bottomland watersheds during the crop growing season. These objectives deviate from those of the original proposal in that they represent a significant expansion of the original scope of the project. This report, also, indicates how the information can be used to compute in situ values of hydraulic conductivities in the near saturated region. This information, under certain conditions, may be necessary in determining ponding times during rainstorm events. On some soils (Loring, Memphis, Vicksburg) preliminary infiltration studies were conducted; however, more significant efforts in this regard will be conducted during the 1981 and 1982 summer season.

As part of an effort to evaluate the hydrologic response of unit source watersheds in the Goodwin Creek catchments, limited research was conducted to follow the soil water regime for selected fields in uniform land use. The original objective was to measure the various components in a water budget relationship for a given area with special emphasis on the runoff and subsurface components. It was thought that a proper characterization of these components for the various land uses, management practices, and topographic conditions would supplement channel flow measurement in the Goodwin catchment. Unfortunately, the information on the soil water regime reported in this section cannot be supplemented with runoff measurements conducted by other research units. Also, limited basic data were collected for computation of evapotranspirational losses for the research sites studied. Only during the 1980 crop growing season was ample meteorological data collected to estimate evapotranspiration losses using existing prediction models. However, plant data and meteorological information from surrounding weather stations may provide a basis for close estimates of 1979 transpiration losses.

Various forms of a budget relationship exist. However, all relationships can be reduced to one which has the following general form.

$$S = RF + I - RO - ET - SE$$

where S is the change of water storage in the soil, RF is rainfall, I is inflow (surface and subsurface), RO is runoff, ET is evapotranspiration, and SE is seepage. Seepage and subsurface inflow are usually the most difficult parameters to evaluate. However, to determine, over time, seepage losses to deeper soil horizons and/or lateral inflow and outflow (seepage out of channel wall), a continuous assessment of the soil water storage component is necessary. With this objective in mind, the water regime of several fields was followed during the 1978 through 1980 crop growing seasons. The specific objectives were: (1) to determine the variability of the soil moisture content within a row cropped bottomland field, and (2) to provide a data base for evaluating the soil water component in a water budget equation for a typical unit source watershed.

Soil moisture measurements in unit source watersheds of cotton cropped bottomland showed appreciable decreases in soil water storage during the crop growth season. Soil water loss during this season was mostly by evapotranspiration. The decrease in the soil water storage was very appreciable during the drought of 1980. The soil profile was rapidly replenished with rainwater following a series of storm events in the fall of 1979. Also a 3-day storm event of 145 mm precipitation in the early fall of 1980 increased the soil water storage component by about 75 mm.

The presence of a pan was apparent from direct sampling activities as well as water content data. The surface hydrology of the watersheds appeared to be affected through low infiltration rates and increased runoff dates during storm events, with high antecedent moisture conditions. However, this conclusion could not be corroborated with independent runoff measurements. Secondly, it was surmised that lateral subsurface flow and seepage at channel walls may be experienced in those cases where channels or gullies intersect flow restrictive layers.

Water loss to deeper horizons was examined for three upland soils of aeolic origin and one alluvial bottomland soil, developed from wash-in soil material in bluffline watersheds of northern Mississippi. Studies consisted of isolating a block of soil from the surrounding soil mass by vertical trenches with a cement coat applied to the vertical walls to prevent lateral water movement. The soil block was ponded with water and infiltration and was allowed to proceed until a thoroughly wetted profile was obtained. The objective was to determine the internal drainage characteristics of these soils. In some cases, evapotranspiration was allowed to take place to permit a greater depletion of the soil water content for computations of hydraulic conductivity. The following conclusions can be drawn:

1. The upland soils showed extremely slow drainage characteristics. Little internal drainage was apparent in the Loring and Grenada sites. The presence of a fragipan was very apparent in the Grenada site as noted from tensiometer data. Such a pan was not detected with tensiometer information obtained for the Loring plots. On the other hand,

the relatively small shift in tensiometer readings over the entire profile of the Loring plots made it impossible to detect differences in hydraulic gradients between horizons. In any case, both sites showed evidence of perched water tables for a sustained time period. Latter evidence was apparent from both pressure head data and standpipes.

The presence of fragipans or slowly draining soil horizons of loessial upland soils, therefore, has several consequences relative to channel stability. First, the poor or nonexistent internal water movement within the soil profile leads to a rapid filling up of the storage capacity of the profile. Runoff will take place quickly, surface flow will concentrate on specific locations on the upland slopes and conditions for rilling or gulley formation are enhanced. Secondly, lateral movement of infiltrated water or interflow in horizons above flow restrictive pans may lead to seepage at locations where channels or gulleys intersect with pans. At those points the possibility for a further deterioration of channel walls is enhanced.

2. The Memphis site did not have a fragipan. In fact, an increase in the hydraulic gradient was noted in the bottom part of the profile. On the other hand, water loss to deeper parts of the profile was small. Therefore, impact of this soil on the hydrologic response of watersheds and channel system will mainly be through runoff once precipitation has exceeded the infiltration rate and surface storage capacity.

Most of the Memphis soils are found in the Brown Loam land resource area bordering the Mississippi Delta. There, the slopes are often steep and severely eroded, which is usually indicative of poor agricultural management in the past. Under these conditions, the greatest hazard, on this type soil, is sheet erosion and the potential for rilling and gullying by concentrated surface flow in the upper reaches of watersheds. Stabilization can best be met by proper land management, that is, pasture and forestry.

3. The Vicksburg soil showed good internal drainage characteristics. On the other hand, there are other post-settlement alluvial soils which are less well drained. However, most of these soils are found on bottomlands and are ideally suited for row cropping. Because of the flat slopes, erosion hazards are small and sediment movement into channels may be inconsequential. Since this type soil usually is found at the base of steep slopes or along side channels (floodplains), its potential hazard results from overflow during severe weather conditions. Protecting the channel banks can best be accomplished by 10- to 20-foot border areas with controlled limited exit points for excess surface water.

J. Appendix I. "Single Event Numerical Model for Routing Water and Sediment on Small Catchment" is summarized as follows.

Alluvial streams are dynamic systems that continuously change their configuration and state in response to either changes in the natural environment, or perturbations introduced by man's activity. Frequently, these changes conduce to alteration of the stream-channel stability, which often results in channel migration and shoaling.

Among the leading causes of channel instability are several that are intimately associated with land management and conservation practices carried out on the upland areas. They are (a) clearing of land that removes the soil-protective and flow-retardant ground cover, which in turn leads to increased erosion and flood peaks; (b) installation of reservoirs for flood protection and irrigation control, which upset the water-sediment equilibrium downstream of those structures; and (c) excessive soil erosion resulting from uncontrolled sources. The combined effect is an aggregate flow of water and sediment coming from a variety of point and non-point sources within the upstream catchments. This aggregate yield acts as a time- and space-dependent loading on the streams draining the catchments. If this loading becomes quite different from that which the streams have adjusted to, the result is a breakdown in the stability of the channel system.

The catchments contributing to the loading of any given channel system exhibit in general a great variety of soils, vegetation, and land uses. In order to effectively assess the impact of these catchments on the loading of the channel system, it is necessary to develop improved methods for predicting the effects of alternative land managements of those catchments. There is, therefore, a need for the development of mathematical models so that the hydrology of a catchment can be simulated and the effects of various management practices understood and predicted. In response to this need, the goal of the present study is the development of a prediction model for estimating sediment yield from agricultural catchments. In developing the model, the following specific objectives were considered: (i) estimate the amount of soil loss from specified soil-source units with homogeneous characteristics; (ii) estimate the amount of water and sediment transported out of the catchments through the principal drainage networks; and (iii) estimate the rate of channel aggradation and degradation along the flow system. The model is oriented towards the needs of the Corps of Engineers for better means of assessing the impact of land-management practices on stream channel behavior.

Because the physical processes governing catchment behavior are very complicated, many past studies have utilized regression models.

However, it is difficult to predict the response of a catchment to different land-management activities using regressional methods, because these methods are based on the assumption of time and space invariability. This assumption almost always fails to be valid in the case of natural catchments.

A second type of models includes lumped parametric simulation methods, such as the TVA Continuous Daily-Streamflow Model. These models simulate the response of a given catchment by adjusting a number of coefficients with little physical significance, using data collected under certain environmental conditions. The impossibility of relating those coefficients to a different set of environmental conditions seriously restricts the use of these models for predicting the response of ungaged catchments.

A different class of models embodies the distributed process simulation methods. These techniques use mathematical descriptions of the basic hydrologic processes being modeled, and their interaction. In addition, this approach tends to minimize the number of adjustable parameters and, whenever possible, to relate them to physical quantities that can be readily measured in the field.

The Stanford model was one of the first general models developed to simulate runoff from a catchment. It is basically a lumped-parameter model, although large, heterogeneous catchments can be subdivided into subcatchments if sufficient data are available to define model parameters. The model has gained widespread use and as a result has undergone numerous modifications. Although this model is basically lumped, a heterogeneous catchment can be broken down into smaller homogeneous areas. An attempt is made to incorporate spatial variability by dividing the catchment into land capabilities' classes that correspond to uplands, hillslopes, and bottomlands. This model has been reasonably successful in predicting daily streamflows.

A continuous distributed model is not yet available. However, several single-event distributed models that include part of the hydrologic cycle have been introduced. The reductionist approach to watershed simulation was introduced employing a square grid for decomposing a complex catchment into elemental surface units. Most physically based overland flow models used simplified lumped-system infiltration models. A distributed infiltration model, derived from soil moisture flow theory, to calculate point infiltration rate, and therefore rainfall excess rate has been used. The foregoing concepts have been incorporated, in one way or another, into more detailed models using flow routing techniques based on the kinematic-wave approximation of the flow governing equations. The kinematic wave approximation has received extensive application to catchment runoff modeling. This approximation is restricted by the assumption that the friction slope equals the stream bed slope, but it has been found to be applicable in many stream flows and in most overland flow situations. In addition, the kinematic-wave formulation admits an analytical solution by the method of characteristics. This analytical solution has two main advantages over other numerical solutions. It eliminates the wave-celerity-damping and phase lag usually induced by numerical schemes; and, in addition, results in faster computational procedures. In spite of these advantages, applications of this analytical solution have been restricted in the past to catchment models with a high degree of geometric abstraction. The reason is the formation of kinematic shock waves. Formally, innumerable shock waves can be generated during the routing process, as a result of the time and spatial discretion of precipitation and the physical characteristics of the catchment. In the past, the existence of these shocks has frequently been ignored by using approximate numerical techniques. This practice, however, may not be considered as valid particularly when the foundation and the physical relevance of the kinematic wave approximation is under investigation. It is well known that shock formation is intrinsic to the hyperbolic equation governing kinematic theory. Further, shock formations are considered to be the manifestations of higher order effects such as formation of monoclinal flood waves, bores, etc. These discontinuities play important roles in the dynamics of hydraulic systems and an ad hoc smoothing by numerical means does not necessarily make the theory look better. The model described in the present report introduces a new solution to the kinematic approximation, which retains the dynamic effects of the shocks by routing the discontinuities as they appear. Certain simplifying assumptions are made which permit closed form solutions and an efficient numerical algorithm, based on the method of characteristics. The resulting procedure, called an approximate shock fitting scheme, preserves the effect of the shocks without the usual computational complications and compares favorably with existing finite difference solutions.

Different types of sediment production models have appeared widely dispersed in the technical literature. Several regression equations for predicting gross soil erosion have been proposed. The most commonly used among these is the so-called universal soil loss equation (USLE). In these equations, the soil loss rate is correlated with storm, land, and vegetation characteristics. Such equations are applicable on seasonal basis or longer. Also, they do not take advantage of the physical processes occurring within the catchments; hence, it is not possible to use them on large, complex basins.

The first physically based sediment yield model uses the Stanford model for the water phase and takes into consideration rainfall soil splash, entrainment by overland flow, and rilling and gullying, along with separate channel transport of fine and coarse sediment. Sediment production is evaluated in terms of power functions of water discharge containing a number of parameters that must be calibrated. A modified version has been incorporated in the Agricultural Runoff

Management (ARM) model. The aforementioned models also incorporated the capability of describing sediment movement on a catchment as a time- and space-distributed process. The structures of these two models are similar; however, there are differences in numerical techniques and functional relationships. The sediment movement is described by linking the excess rainfall flow equations to the sediment continuity equation, with relations describing sediment detachment and transport capacity at any point on the surface or in a channel. A similar structure has been incorporated in the erosion and sedimentation component of the present model. In addition, sediment is routed using a sediment characteristic scheme that takes advantage of the efficient analytical solution mentioned above.

Part 2 of this report provides a detailed description of the model. Part 3 discusses the validation of the model on sets of laboratory and field data. Input data and coding details are given in Addendum 1.

This study states that it has accomplished the following

1. A numerical model for routing water and sediment on small catchments has been developed. The model accepts any single rainfall hyetograph and produces runoff and sediment hydrographs for the modeled catchment.

2. The model is developed on a general basis so that it may be applied to any agricultural catchment by changing only the input data. The approximate range of basins over which the model is applicable is from a few acres to about 5 square miles.

3. The model is based on the physical processes governing the mechanics of water and sediment movement and requires the calibration of four parameters.

4. The model can be used to simulate the effect of different land uses on the water and sediment yields from the modeled catchment.

5. The model predicts the surface component only. It does not presently predict subsurface and ground water movement.

6. The applicability of the model is restricted to streams where the channel geometry does not change significantly during a storm event and in which the kinematic-wave approximation for flow routing is valid.

7. The present model simulates single storm events; the user must estimate the initial conditions for the storm. The model can still be applied to a sequence of rainfall events if the user can make satisfactory estimates of the initial soil moisture conditions. In this case the model can be used to predict a sequence of surface runoff and sediment transport events.

8. The model has been validated with several data sets including data from the natural catchments W-5 in northern Mississippi and R-5 near Chickasha, Oklahoma. The shape of water and sediment hydrograph and total water and sediment yields of a number of events were satisfactorily simulated.

The study recommends that:

1. The model be put to work on real systems. The evaluation and continuous updating of the model are essential to its credibility and effectiveness.

2. The model be further developed, or modified, to permit continuous simulation over long time spans (20 to 50 years). This is essential in evaluating the long term response of a catchment, or stream network, which is dependent not only on the history of management practices, but also on the sequence of storm events.

3. The model be further developed to track the channel geometry of streams that become unstable due to bank erosion and deposition.

4. Data gathering efforts be continued to provide an adequate base for further model development and validation.

K. Appendix J. "Numerical Model for Routing Graded Sediments in Alluvial Channels" is summarized as follows.

This report describes a one-dimensional numerical model designed to simulate sediment transport in natural channels. The physical processes associated with the sediment movement are reproduced using a variety of algorithms. These algorithms incorporate sets of equations that operate on input data in a predetermined sequence to generate output data reproducing the actual physical process. A satisfactory model must include the more relevant aspects of that process.

Sediment moves driven by hydrodynamic forces exerted by flow of water which in many instances is highly time dependent. The sediment transport model must, therefore, account for unsteadiness in sediment movement.

The dependence of sediment motion on flow conditions makes it also dependent on the longitudinal variations the flow experiences as a result of stream boundary irregularities. These variations are reflected in the spatial variability of the sediment load distribution. Depending on particle size, some particles may be carried primarily in suspension, while others move entirely as bed load. In addition, depending on flow conditions, particles moving in suspension at one place may be moving as bed load farther downstream. Whether a particular size fraction moves primarily as suspended load or bed load determines to what extent that fraction of the sediment load will lag behind the flood wave and therefore determines what the magnitude of longitudinal sorting will be. This means that the transport model must reflect the dependence of the sediment load lag on the material properties of the sediment as well as on hydraulic conditions. Whenever the bed material consists of a mixture, its transport involves the motion of a multitude of particles of diverse sizes. Some particles may deposit on the streambed while others are scoured away, resulting in a size composition of the material in transport different from that of the bed. A realistic model must account for the interchange between the bed surface material and the moving sediment load and should simulate the residual transport capacity of the stream. The latter is a measure of the ability of flow to further entrain material of a given size fraction in the presence of all the fractions already in motion.

During the above particle interchange, the bed material particle size composition changes continuously and, in the process, the bed may experience a net amount of aggradation or degradation. For certain flow conditions the bed degradation in a reach may be limited by the formation of an armoring layer, over which sediment may move either in suspension or as intermittent bed-load waves. The armoring layer may be destroyed during high flows and reformed at subsequent low flows. A model must therefore be capable of tracking the streambed profile evolution and the changes in bed material size distribution.

The proposed model is designed to meet the above criteria. It can simulate the unsteady transport of sediment mixtures through a network of nonbifurcating channel reaches, and it can be used in tandem with a suitable sediment yield model, which simulates the supply of water and sediment runoff from adjacent upland areas. At present the model is restricted to consideration of noncohesive bed materials only. It is also restricted to down channel streamflow and cannot consider the effect of transverse currents.

Parts 2 and 3 of this report provide a detailed description of the model. Part 4 discusses the validation of the model on sets of laboratory and field data. Coding details are given in Addendum 3.

The report concludes that:

1. A one-dimensional numerical model has been developed for simulating the movement of well graded sediments through a stream network.
2. Hydraulic routing is performed by using any acceptable algorithm supplied by the user because the water movement is assumed uncoupled from the sediment process. The model can be used in conjunction with any suitable sediment yield model to supply the water and sediment runoff from lateral areas.
3. The sediment routing scheme is based on the physical processes governing the mechanics of sediment movement in alluvial channels. The model recognizes the effect of bed and suspended load interaction on the total load movement, can simulate bed armoring, changes in bed elevation, and longitudinal sorting of eroded material.
4. The applicability of the model is restricted to noncohesive materials, relatively stable channel geometries, streams with negligible in- and out-of-bank transport, and flows in which transverse currents may be ignored.
5. The model gave satisfactory results when tested on laboratory data from flume armoring study and field data from San Luis Valley Canal, Colorado, and the East Fork River, Wyoming. These tests tend to indicate that the model adequately simulates the transport of graded cohesionless sediments, including the effect of armoring.

The report recommends that:

1. The channel model be further tested against a variety of real situations with special emphasis on the scour, deposition, and transport of noncohesive materials.

2. The model be further developed and refined to include the following capabilities: (a) improve the one-dimensional representation by separating flows in the incised channel from flows over floodplains; (b) account for in- and out-of-bank transport, and lateral distribution of bed-material properties and hydraulic conditions; (c) predict the variation of lateral bed slope and lateral sediment sorting around channel bends; and (d) simulate sediment retention by grasses and other vegetative covers.
3. The channel model should be tested using hypothetical situations to confirm that the model does respond in a realistic manner. For instance, these tests may include the following channel-stability related applications: (a) Consolidate the channel model with continuous sediment yield and bank-stability models. Run the consolidated models for a period of a few years, and predict the size and grade of channel needed to maintain a bank height-slope that is stable for a given stratigraphic condition. (b) Run the consolidated model for a combination of unstable bank and steep grade and observe what combination of bed armoring and/or grade-control structures are predicted to stabilize the channel. (c) Select a range of storm events and use the consolidated model to study slough of bank material and find channel width and/or armoring coat that is needed to prevent erosion of slough material.
4. Data-gathering efforts be continued to provide an adequate base for further model development and validation.

L. Appendix K. "Two-Dimension Finite-Element Model for Routing Water and Sediment in Short Alluvial Channel Reaches" is summarized as follows.

The objective of this study is to develop a new methodology for modeling the phenomenon of sediment movement in irregular alluvial channels, scouring around obstructions, etc. The basic physical principles of conservation of mass and momentum are used to describe the fluid flow. The conservation of mass and semi-empirical equations governing sediment particle movement are adopted to establish the interaction between the sediment movement and the fluid flow. The resulting mathematical model is, unfortunately, highly nonlinear and complex. It is impractical, if not impossible, to solve it analytically. Therefore, the numerical methods of finite element and finite difference are used to obtain approximate solutions of this model.

The application of the finite element method (FEM) to model fluid flows has progressed rapidly in recent years from the simplest linear inviscid fluid flow problems to slow viscous flows and finally to the solution of the full Navier-Stokes equations. However, this latter area represents an extremely large and complex field. As such, the research, although very active, can only be referred to as being in its beginning stage. A complete review on FE Modeling of Open Channel Flows and directly related works is presented.

A variational principle for an ideal fluid flow with a free surface under gravity was developed by others using potential function formulation. It was modified using the stream function formulation and the different expressions of free surface boundary conditions to compute the flows by a vertically two-dimensional model and over a spillway, etc. Although the problem is only one-dimensional, the equations are kept nonlinear and unsteady.

A two-dimensional quasi-linear FE Model for Open Channel Flow near Critical Conditions was reported recently. It successfully demonstrated the capability of FEM to simulate a supercritical floodwave. The truly three-dimensional finite element modeling of viscous flows in an open channel with and without the existence of obstructions was carried out using three-dimensional linear hexahedral, isoparametric elements to obtain very slow viscous laminar flows in open channels of varying cross section and around an isolated obstruction. Although results obtained were physically sound and mathematically reasonable, the requirement of computer storage and computing time were prohibitive. One of the most effective alternatives is the depth-averaging scheme. It has been used primarily in the simulation of currents and water waves in lakes, estuaries, and shallow coastal water. More recently the utilization of the depth-averaging models in the finite element simulation of flows in open channels and rivers was reported. Because the distribution of hydrodynamic properties in the vertical direction of a shallow water flow are usually better understood, appropriate functions can, thus, be chosen to yield adequate approximation in this direction. Therefore, the governing differential equations can be integrated vertically from the channel bed to the free surface resulting in differential equations, containing vertically averaged properties, which are only two-dimensional in a horizontal reference plane. Even if the time derivatives are retained in the equations to model unsteady flows, the requirement of computer storage as well as computing time to simulate an open channel flow is greatly reduced. Besides, this approach not only gives reasonable results with adequate accuracy, but allows better resolution in horizontal directions by using the computer storage saved from reducing three-dimensional to two-dimensional formulation to add more nodes on a horizontal plane. Furthermore, the computer code developed based on this approach has the potential of wider acceptance by users with limited computing resources. The simulation of sediment transport is discussed below.

In recent years one-dimensional, mathematical models of sediment routing, morphological transients, and sediment deposition, etc., were developed. Although they do not provide the time-varying configuration of the sand bed in a horizontal plane, these models contribute a great deal in understanding the basic characteristics of morphological transients as well as in estimating the sediment discharge at various locations of waterway system. A large number of contributions in the area of sediment transport in suspension has been published in recent years using the numerical techniques to solve the sediment convection-diffusion equation in a vertical plane. Approaches have been adopted in the present study to develop two different finite-element schemes. One uses a two-dimensional vertical domain; the other employs a two-dimensional depth-averaging solution. Detailed information on Mathematical Formulation, Numerical Modeling and Solution, and Simulation Results are presented in Parts 2, 3, and 4, respectively. A complete computer program listing is given in the addendum 2.

The report concludes that:

1. A two-dimensional numerical model has been developed to predict water and sediment movement and water surface and bed elevation changes in channel reaches with complex boundary geometry.
2. The model is based on the conservation laws of water and sediment continuity, and momentum equations. The water continuity and momentum equations are solved first. The predicted flow variables are then introduced into transport formulas and the sediment continuity equation to compute sediment load rates and changes in bed elevation, respectively. The equations of motion are solved using a finite-element scheme.
3. The model has been validated by simulating laboratory data obtained from a trench scour and fill study. The model predicts satisfactorily the evolution of the water surface and bed elevations. In another test the model was used to simulate bed scour around a spur dike. The shape of the

predicted scour hole is in qualitative agreement with observations reported in the literature. However, the deviations observed in the predicted locations of maximum scour and deposition point out a limitation in the model when simulating situations dominated by regions of flow separation. Further research is needed to correct this deficiency.

The report recommends that:

1. The model be further developed and tested on real systems to ensure its accuracy and credibility. Work should continue on the computer code to improve its flexibility and efficiency. Carefully designed laboratory experiments should be conducted to investigate the accuracy and range of applicability of transport algorithms used in the model (i.e., turbulence closure schemes, two-dimensional sediment transport functions, etc.). Two-dimensional models have a great potential to study in detail sediment-related problems in irregular stream reaches with significant flow components in more than one direction.
2. Verification and validation of two-dimensional models require data with a degree of detail and spatial resolution that is practically nonexistent. It is thus recommended that laboratory data be collected in scaled-down physical models reproducing conditions observed in the field. Laboratory studies can provide, at a reasonable cost, velocity, sediment transport, and cross-sectional data with the high degree of resolution needed in model validation. Then, a few carefully selected prototype measurements in the field will suffice for model verification.

3. Hypothetical situations be used to confirm that the model responds in a realistic manner. To this effect, the two-dimensional model can be linked to one-dimensional channel and sediment yield models to investigate the dynamic response of local bank stabilization structures to changes in upstream land management practices, and to series of intense storm events. These consolidated models could be used, for instance, to look at (a) bed and bank response in the vicinity of toe armor, hard points, fences, etc.; (b) degree of bank destabilization caused by proximity of point bar, etc.

M. Appendix L. "Stochastic Properties of Turbulent Tractive Forces in Prismatic Channels" is summarized as follows.

The beds of streams are composed of aggregates, the component particles of which can range in size from boulders and cobbles down to silt and clay. These streambed particles experience forces that are exerted on them by flowing water, and which tend to set them in motion, thus disturbing the stability of the streambed. This is the source of erosion in natural channels, and of damage to canals and irrigation ditches. Knowledge of those forces acting on the streambed is essential for the proper design of a stable channel cross section. It was thought for several years that turbulent velocity fluctuations produce intermittent periods of high boundary shear stress, during which most sediment motion is initiated. Flume experiments established that such fluctuations in shear stress do, indeed, produce intermittent episodes of bed material movement. Entrainment of bed material can take place at values of time-averaged shear stress well below the value of critical stress defined by Shield's function. This observation can also be interpreted to indicate that different entrainment rates can be expected for bed shear stress distributions with different variances but equal mean values.

In spite of the foregoing facts, all the existing tractive-force models for the initiation of sediment motion have been based on the estimation of the time-average boundary shear stress distribution, and little progress has been made toward a sediment entrainment model incorporating stochastic properties of boundary shear stress. This is mostly due to the scarcity of adequate data on which to base the models. Some statistical properties of the turbulent hydrodynamic forces acting on discrete roughness elements have been reported. This report presents new measurements of some stochastic properties of boundary shear stress taken at points spaced over half the wetted perimeter of a smooth open channel, under conditions of essentially constant aspect ratio and Reynolds number. The effects of position along the wetted perimeter on the statistical moments and the probabilistic distribution of the instantaneous boundary shear stress are discussed.

This report presents recent measurements of the statistics of the instantaneous boundary shear stresses in a smooth-wall open channel flow. These measurements were made along the wetted perimeter of a channel flow with an aspect ratio of about 4.4 and a Reynolds number of about 1.7×10^5. The results reveal the following information:

1. The wall and bed distributions of relative intensity of the shear stress fluctuations (standard deviation per unit average tractive force) follow trends similar to those exhibited by the relative local mean shear. This suggests that the mean secondary flow affects the cross-sectional distribution of relative intensity of boundary shear.
2. The coefficients of skewness and kurtosis are dependent on the transversal boundary position, differ significantly from their Gaussian limiting values, and were found to exhibit quasiperiodic variations along both bed and wall perimeters.
3. The probability density function estimates from the boundary shear stress are positively skewed, with instantaneous

standardized values ranging from -2.5 to 10.00 along the bed and from -2.5 to 7.7 along the wall. The measured density functions are well fitted by the theoretical (two parameter) gamma-density distribution only near the corner. In the remainder of the channel perimeter, neither the gamma nor the lognormal functions provide a good fit, although the gamma function approaches a better fit than the lognormal in all cases. The shape of the probability density estimates are suggested to be the result of large-scale flow structures oriented towards the wall.

The measurements reported above were confined to turbulent flows over smooth beds, using sensing devices suitable only for laboratory practice. There is obviously a need for (a) extending these type of measurements to fully rough bed conditions usually encountered in the field and (b) developing tractive-force measuring techniques appropriate for this type of environment. In order to accomplish these goals, implementation of the following experimental program is recommended:

1. Adapt a commercially available force transducer to measure instantaneous unit tractive-forces acting on discrete roughness elements. This technique will complement that already in use for smooth beds, thus permitting direct measurement of the mean and probabilistic properties of turbulent tractive forces acting on boundaries ranging from smooth to fully rough.
2. Implement hot-film anemometry techniques for measuring the turbulent flow characteristics in the proximity of the channel bed. This will require setting up into operation existing equipment designed for the calibration of hot-film velocity sensors.

3. Investigate the relationship between the bed tractive forces and the turbulent velocity field from space cross-correlation measurements of those variables. This should be done over the entire range of bed roughnesses and for a wide variety of flow Reynolds numbers and aspect ratios. This information will permit engineers to estimate the tractive-force distributions from direct measurements of the velocity field in the proximity of the bed. Such techniques could be used by field workers to measure point tractive forces in alluvial streams where it is not possible to install any sensing device at the stream bed for direct measurement of those forces.

N. Appendix M. "Large Scale Model Studies of Bed Material Transport" is summarized as follows.

Sediment transport processes of alluvial streams are important aspects of channel stability. Channel instabilities result from erosion of sediment from or deposition on the stream's bed or banks. This erosion or deposition occurs because of an imbalance between the capacity of the flow to transport sediment and the sediment supply rates from upstream reaches. Any rectifiction of the channel system must balance the transport capacity of a new set of hydraulic variables and the sediment supply rates to the channel.

Relationships between the transport capacity and the hydraulic variables are necessary if a successful design is to be developed. Valid relationships have been quite elusive. Numerous equations and calculation procedures have been proposed, but their results differ widely under similar applications. The variability of estimates may be due to a number of factors among which are the temporal and spatial variations in the flow and transport rates; and the difficulty of assessing the generality of experimental relations, when the variables upon which the transport rate is considered to depend, are themselves interrelated.

To overcome the problems of unsteady flow and to facilitate measurement of the transport rates, a number of flume investigations have been conducted. Any one of these may still manifest the estimate difficulties mentioned above and some may still present nonvalid results because of an imbalance in sediment capacity and supply. However, combinations of a number of valid investigations have suggested general relationships between the transport rate and the flow variables. Unfortunately, almost all controlled flume experiments have been for fairly small flows relative to those of streams for which rectification designs are needed. Transport similarity may not exist between flows of greatly different scales, so additional experimental investigations are needed for larger, controlled flows to verify or revise the transport similitude relationships from small-scale experiments.

This study of total bed material transport in the 250-foot outdoor test channel at the USDA Sedimentation Laboratory was designed to obtain accurate measurements of the sediment load and hydraulic characteristics of the flow to test the generality of existing transport relationships. The experiments were designed to provide not only estimates of average flow and transport properties but also temporal and spatial records of the bed forms and temporal records of the sediment transport rate. From these records time and distance scales should aid in assessing the significance of the average quantities and define measures of the bed roughness, which is important in establishing the regime of a channel.

The statistical analysis of the sediment load and bed forms is considered to be an important aspect of this investigation because the expected long periods of significant deviations from the mean may result in short-term means that may deviate significantly from the long-term mean. Also, the selective erosion and deposition of dunes induces variations in the sediment transport rate, so that the perturbations in the concentration and bed-form records should be coupled. A comparison of the results form large-scale experiments with comparable data from smaller flumes should aid in assessing the generality of transport relationships.

The overall goal of the investigation is the development of transport relationships that can be used to estimate the average transport rates in existing, equilibrium reaches of stream channels and to provide the hydraulic variables for redesign of an unstable reach. The results should also provide an estimate of natural deviations from the average that may be accommodated by different flow rates in the channel.

Over some long time period, a stable stream may be considered to have adjusted its geometry in response to the valley slope so that the transport capacity for both water and sediment equals the runoff and erosion quantities delivered to it from the watershed. Not just one set of "design" variables but a spectrum of different flows, sediment quantities, and different sediment sizes are delivered to the channel. These complexities are compounded by natural statistical perturbations of constant flow, and even more so by local instabilities within nonuniform channel reaches wherein local disturbances and high erosivities, such as on the outside of a bend, may interrupt the transport balance. Some distance downstream may be required to re-establish the transport balance, and for fine sediments, no balance may ever be achieved.

The question may then be asked whether a design can be accomplished in view of the deviations in the mean transport rate from the average, upon which the design is proposed to be based. The bed material of a stream provides the degrees of freedom whereby the range of flows and transport rates, as well as perturbations from the average, may be accommodated. A stream can adjust to small deviations between the sediment supply and capacity by depositing sediment on or eroding it from the stream bed. The sediment storage is quite limited but the stream bed imparts another degree of freedom to the transport processes through variation in bed roughness. Bed roughness can change appreciably and it will have an appreciable influence on the hydraulic resistance and, consequently, the velocity and depth of flow for a given flow rate. When the sediment concentration is low, the bed forms may be large with high flow resistance giving a greater depth, lower velocity, and a lower transport capacity. When the concentration is high, the bed forms tend to be obliterated leaving a rather smooth bed with low hydraulic resistance and a shallower depth, higher velocity, and higher transport capacity.

The preceding adjustments occur naturally in a stream channel and are predicated on the assumption that the blanket of bed material is preserved. If the blanket of sand or gravel is removed, not only are the transport adjustments that rely on this blanket of material no longer present, but also the underlying alluvium is exposed to the erosion action of the flow. If the boundary material is erodible, an unstable channel is likely to develop. Thus design criteria should be predicated on preservation of the bed material through equilibrium transport of the sediment fractions represented therein.

In summary, the results of the large-scale flume studies indicate mean concentrations that are significantly larger than those for published small-scale studies for the same bed material size. The standard deviation of the bed surface relative to the flow depth was similar to that of small-scale tests, but the wave lengths were relatively longer over much of the Froude number range. The Froude number remains the primary independent flow similitude number controlling alluvial channel processes, but the question of sediment size similitude is yet to be resolved. The longer wave lengths relative to flow depth suggest similarity with coarser sediments, but the higher sediment concentrations are more consistent with finer sediments.

Temporal spectral calculations revealed dune periods that were not short relative to the length of record. Hence, the reliability of estimates based on the temporal records, including the mean concentration, should be considered low. An additional test series is planned to include longer temporal records encompassing at least 5 and preferably 10 dune periods.

Additional experimental work will be needed to explain the unexpected deviations of the data from the relationships defined by small-scale investigations. Until these deviations can be explained as artifacts of the particular investigations or accounted for by alternate methods of prescribing sediment-size similitude, the quest for a reliable, generally applicable sediment load predictor will not be finished.

O. Appendix N. "Alluvial Channel Flow Resistance: Stochastic Properties" is summarized as follows.

The concept of head loss, energy dissipation, or flow resistance is fundamental to applying physical laws to the design of man-made channels, or to understanding and predicting the behavior of natural channels and rivers. The head loss or resistance concept originated from efforts to understand flow in pipes; its application in this context is so well understood that the design of pipe runs ranging in size from domestic plumbing systems to very large hydraulic power penstocks or oil pipelines has been reduced to a series of fairly standard procedures. The situation is not well defined with regard to the application of the resistance principle to open channels, where little agreement exists even about how such principles should be applied in the relatively tractable case of channels with rigid linings. In the case of alluvial channels, the situation is so complex that at least one worker concluded that alluvial channel flow is hydraulically indeterminate, and that relations between flow depth, velocity, energy gradient, sediment discharge concentration, etc., are artifacts of unrecognized implicit constraints in specific alluvial channel systems, or the results of unrecognized covariances between two or more independent variables. It is certain that every aspect of alluvial channel flow has a stochastic component of relatively large magnitude, and it is undoubtedly this fact that has led to the extreme difficulty experienced by every hydraulic technician who has ever attempted to understand alluvial channel flow resistance.

This report describes a series of experiments that were performed in a laboratory flume that was adapted to allow computer control of the independent experimental variables and computer acquisition of data during experiments. The object of the study was to relate the Darcy-Weisback resistance coefficient of an alluvial channel flow to the bed roughness as expressed by the standard deviation of bed elevation records (a measure of the dune and antidune roughness height). Since the Darcy-Weisbach coefficient in an alluvial channel shows considerable time variation even in supposedly steady uniform flows, and since the bed roughness, as measured from the time records of the bed elevation, is a stochastic quantity, time records of the Darcy-Weisbach coefficient and of the bed elevation were analyzed to obtain probability density functions, which were typified by mean values and standard deviations of the relevant quantities. Autocorrelation functions of the time records were also computed and plotted. From these functions, time constants for variation of the resistance coefficient and for the propagation of bed forms were obtained.

The Darcy-Weisbach resistance coefficient is of importance in the development of mathematical models of streamflow for predicting floodwave propagation, channel bed and bank modification, and the intensity of fluvial attack on channel protection or river training structures.

A total of 112 experiments were completed in this study without stoppages due to instrument failure. Of these experiments, 39 displayed simultaneous stationary records of the resistance coefficient and the bedform roughness σ_D.

Although data scatter was large, tentative time-mean resistance functions could be defined for the subcritical and supercritical flow regimes. These functions were of the Nikuradse form, in which an expression for relative roughness was the independent variable.

The ratio $(4R/\sigma_D)$ was found to be a usable expression for bedform relative roughness if it was weighted by the nondimensional integral time constant I_D of sand bed fluctuation to form the relative roughness ratio $(4RI_D/\sigma_D)$.

For individual time records, only a hint of a relation between σ_f and σ_D was found. If this relation indeed exists, its form will depend on the Froude number.

No evidence of coupling could be found between I_f and I_D, which are, respectively, the integral time constants of the resistance coefficient of the study reach and the propagation of bedforms down the study reach.

The temporal variation of instantaneous values of f around the mean value $\langle f \rangle$ was found to be not related to the relative roughness of the study reach in a given flow.

IV. SCS INVENTORY AND EVALUATION REPORT

A. Introduction.

This report furnishes an inventory and evaluation of bank stabilization measures installed by the Soil Conservation Service (SCS) in North Mississippi. The study was performed under the authority of the Streambank Erosion Control Evaluation and Demonostration Act of 1974, Section 32, Public Law 93-251, (as amended by Public Law 94-587, Sections 155 and 161, October 1976).

B. Description of Area.

The bank stabilization measures discussed in this report are located on streams within the Yazoo, Little Tallahatchie and small portions of the Tombigbee and Big Black Watersheds in North Mississippi.

The Soil Conservation Service, in cooperation with the Mississippi Agriculture and Forestry Experiment Station, has designated areas of distinctive geological and topographical characteristics in Mississippi as part of a national inventory of major land resource areas. The soil resource areas within the study region are described in Exhibit 3 of the report.

In 1886 the first drainage law was enacted in Mississippi and, in 1888, the Chiwappa Creek Bottom Swamp Land District was the first district organized under that law. Subsequently, more than 300 districts were organized statewide, most of them prior to 1925. By 1941, more than 1400 miles of drainage ditches had been constructed. Under the drainage laws, the degree of success improved, but, on the whole, the improvement was of limited duration. Inadequate initial planning and lack of maintenance led to rapid deterioration of the work and return of the land to a nonproductive status.

The bottomland drainage problems, together with the demand for cotton, led to intensive clearing of hillside forest land. In DeSoto, Panola and Tate Counties, clearing was almost total and in the other counties in the study area more than half of the woodland was cleared and converted to cropland. The remaining woodland was often used for grazing with resultant damage to the humus cover. Forest fire control was minimal. Thus, the highly erodible hillside soils were exposed, which resulted in almost total loss of topsoil and the formation of deep, narrow gulleys. Millions of tons of silt and sand were washed from the hillsides into floodplains and channels, and the frequency and severity of flooding increased. As the eroded fields became nonproductive, they were abandoned.

Under the authority of the Flood Control Act of 1944 (P.L. 534, 78th Congress), a program to control soil erosion and flooding was implemented by the USDA Soil Conservation Service, the U. S. Forest Service and the Corps of Engineers in cooperation with the private land owners. Fundamental to that program was the Watershed Work Plan wherein the requirements of the watersheds with respect to erosion and flood control were analyzed and specific remedial measures documented.

Two categories of remedial measures were considered, land treatment and structural. Land treatment measures included reforestation of uplands, conversion of some row crop land to pasture, terracing, contour plowing, surface water runoff control, pond construction and woodland fire and grazing control. Structural measures were primarily for flood control and included the construction of floodwater detention ponds, grade stabilization and sediment control structures and the installation of cantilever overfall pipes. Stream channels were cleared, widened and straightened to accelerate runoff of flood waters.

Following implementation of the land treatment and structural measures under the watershed work plans, erosion control and reduction of flood frequency and severity were rapidly realized. Effective drainage of bottom land adjacent to streams was accomplished and those fields became productive.

Between the early 1930's and 1947, forest land in North Mississippi increased from 3.1 to 3.7 million acres and by 1957 to nearly 4.0 million. A further increase of more than 81,000 acres was recorded in the study area counties between 1957 and 1967. In 1977, an average two percent decrease in forest acreage was recorded in the statistics, attributed primarily to land clearing for soybean production. During the period 1949-1974 (the last year for which published data are currently available), total farm acreage in Mississippi decreased from 20.71 to 14.30 million acres. However, cropland and pasture acreage decreased only ten to twenty percent, indicating that a major portion of the overall change represents transfer of woodland and idle acreage to non-farm interests and the removal of many small, unproductive farms from the inventory.

The most significant changes in land use have been in the restoration of idle, abandoned fields to pasture or forest and improved agricultural practices on cropland. Those formerly abandoned fields were generally hillside acreage. In the areas bordering the study streams, the combined cropland and pasture acreage has remained fairly constant and the proportionality between the two has varied with economic factors, primarily soybean and beef cattle prices. In 1974, cotton and soybean acreage were nearly equal in the study area. Currently (1980), soybean cultivation is predominant.

The erosion and flood control measures contributed, to some extent, to the problem of streambank erosion. Erosion control measures reduced the amount of soil washed into the streams and channel improvements resulted in greater stream velocities. These factors increased the erosive potential of the streams. At locations where hydrologic, hydraulic and/or geological factors rendered the banks more susceptible to erosion, valuable farmland was lost, and bridges and other structures were endangered. Measures to protect and stabilize the banks were therefore required.

C. Bank Stabilization Measures.

There are three principal types of streambank stabilization measures used by SCS: slotted wood fences, concrete jacks and rock riprap.

In addition to these three major forms of streambank stabilization, other protective measures have been employed, including wire fences, crossed board fences, vegetative planting, old automobile bodies, automobile tires, and wooden posts. With the exception of wire fences, these materials were used on a trial basis and their use discontinued on the basis of effectiveness or aesthetics.

A general summary of bank stabilization measures is tabulated in the following table.

GENERAL SUMMARY OF SCS BANK STABILIZATION MEASURES

Type	Total Number	Number By Evaluation Category			
		Good (1)	Fair	Poor	Other
Concrete Jacks	152	139	4 (2)	7 (2)	1 (3); 1 (4)
Slotted Wood Fence	101	91	5	2	2 (4); 1 (5)
Riprap	38	37	-	1	-
Welded Wire Fence	22	21	-	1 (4)	-
Poles or Posts	4	4	-	-	-
Steel Jacks	4	3	-	-	1 (6)
Automobile Bodies	2	1	-	-	1 (4)
Automobile Tires	1	1	-	-	-
Crossed Board Fence	1	1	-	-	-
Vegetative Planting	1	-	-	-	1
Total	326	299	9	11	7

(1) Includes sites where the stabilization measure is in less than "Good" structural condition but where the measure was effective for a period of time sufficient for development of a stable bank.

(2) Jacks have been displaced and/or have settled excessively.
(3) Partially disturbed by construction of a grade control structure.
(4) Rendered ineffective by changes in channel alignment.
(5) Replaced by riprap.
(6) Replaced by concrete jacks.
(7) Maidencane died off and was replaced by volunteer vegetation.

D. <u>Detailed Inventory and Evaluation.</u>

Analysis of bank stabilization measures on all 44 streams is contained in report. Unfortunately, a detailed look or accurate analysis was not furnished. Also, the necessary before-and-after look is missing. The report presents a one-time data point for more than a decade of constantly changing channels. In order to use the data as furnished, the initial and intermittent data available must be added and/or the study carried into the future.

V. SUMMARY AND CONCLUSIONS

A. Types of Bank Failure and Erosion Problems Encountered at the Demonstration Project Sites.

1. Summary and Range of Streambank (Geotechnical) Characteristics. A wide variation in stream pattern characteristics occurs in the eight Yazoo Basin hill line streams that were selected for study under the Section 32 Program. The major reason for these differences is the varying geologic formations the streams flow through. The erosion resistance varies considerably between the formations, as well as within the individual units themselves. Therefore, it is difficult to quantitatively describe the erodibility of the formations; however, a relative comparison among them is possible. The following is a list and brief description of geologic formations found in the Yazoo Basin study area arranged in order of increasing resistance to erosion.

MAJOR GEOLOGIC FORMATIONS INFLUENCING YAZOO HILL LINE STREAMS

Loess	Unconsolidated silt
Alluvium	Low-strength sands, gravels, and clays
Kosciusko	Loose sands with traces of silt and clay
Tallahatta	Loose sands interbedded with clays and shales
Citronelle	Mixed sand and clay with gravel lenses
Young Paleosol	Semiconsolidated clays
Old Paleosol	Dense, consolidated silty, clayey sands
Winona	Consolidated clay, shales, and chalks
Zilpha	Dense clay and clay shales

2. Summary and Range of Flow (Hydraulic) Characteristics. The drainage areas of the eight watersheds selected for study range from 8 to 230 square miles, and there is a wide variation in the channel geometry

and hydraulic characteristics. Rainfall data collected at various locations in the study area indicate an average annual rainfall of approximately 53 inches with a range of 35 to 78 inches. Limited stage or discharge data were available for the study areas; however, discharges were estimated using relations between precipitation and runoff.

3. Causes of Failure and Erosion. The major causes of bank erosion and the failure of protective measures in the Yazoo Basin have been:

a. Bed degradation due to a variety of reasons (channelization, cutoffs, loss of geologic control, flood control activities, and changes in base level) and the subsequent channel widening.

b. Natural meander tendencies of alluvial rivers.

c. Bank failures caused by hydrostatic pressure.

d. Overbank drainage.

e. Man's activities.

f. Instability in the streambed and banks due to localized geology.

g. Extreme storm events.

h. Structure alignment problems.

4. Significant Problems Encountered During the Program.

a. Local cooperation is essential to the success of the SECED program. A majority of the landowners supported efforts to protect their property; however, a few landowners refused and work was deleted from those ownerships.

b. Excessive time between initial concept and construction, particularly on the actively degrading streams resulted in the need for redesign and relocation of planned work.

c. Some streams were in transition states and had a geometry that upset sediment movement. This significantly limited the effectiveness of the stabilization efforts.

d. During the extremely high runouts in November 1977, seven of the bank stabilization structures on Batupan Bogue (Item 4A) were damaged to the extent where reconstruction measures were needed. This event occurred immediately after placement of the structures; however, upper bank protection was incomplete. Bed degradation (especially in the form of local scour), absence of upper bank protection, and the unusually large runouts (100- to 500-year frequency event) contributed to the excessive bank failures.

e. The funding sequence was not compatible with construction needs. Too many funds were scheduled late in the program leaving inadequate time to monitor results.

f. Limited geologic and soil stratigraphy information was available to adequately incorporate into designs.

B. Types of Protection Installed at the Demonstration Projects.

1. General Physical Descriptions. The general physical descriptions of the protective structures used in the Yazoo Basin are as follows:

a. Longitudinal Stone Dike. Riprap stone placed parallel to the toe of the streambank and used to deflect the streamflow and provide toe protection. Areas of the upper bank not covered by stone are sometimes protected by various vegetative treatment methods.

b. Peaked Stone Dike. Riprap stone placed parallel to the toe of the streambank and allowed to slope to natural angle of repose. Used to control the erosion of the toe and induce sedimentation behind the stone.

c. Board Fence with Peaked Stone. Peaked stone dike along toe of streambank reinforced with a treated wood piling and timber fence constructed near top bank height. Used to deflect and separate the direct flows on the bank and induce sedimentation between fence and bank.

d. Transverse Stone Dike. Riprap stone structure protruding from streambank as a "hard point," providing some degree of flow deflection, and used as a tieback for longitudinal stone dikes to prevent flanking of structure and provide areas of sedimentation.

e. Transverse Board Fence Dike. Treated wood piling and timber fence protruding from bank to deflect flows and provide areas of sediment deposition.

f. Transverse Cable Fence Dike. Concrete piles with 3/8-inch cables strung between the piling to catch debris and thereby deflect the flows and induce sediment deposition.

g. Tire Revetment. Used tires tied together with steel banding to form a flexible mattress. Used to protect the bank from scouring forces of direct flows.

h. Sand-Cement Bag Revetment. Degradable bags filled with a sand-cement mixture and placed in layers to various bank heights to protect the bank against direct flows.

i. Wire Cribs Retards, Tire Filled. Light piling and wire fence cribs placed parallel to the bank and filled with used tires. Used to deflect flows away from bank and to induce sedimentation between the cribs and banks. Used with a stone or sand-cement bag toe protection.

j. Wire Crib Retards, Hay Filled. Similar to tire cribs but filled with hay bales.

k. Tire Post Retards. Light piling driven through the center of a stack of used tires, capped with a board railing, and placed parallel to toe of streambank. Used to divert flows from the bank and induce deposition.

l. Vegetative Treatment. Seeding with various types of grasses and mulch and/or planting of woody vegetation.

m. Grade Control Structures. Consists of a sheet-pile weir, with an energy-dissipating baffle and a naturally occurring or preformed riprap-lined scour hole. The purpose of these structures are to halt the migration of head cuts. Structures built early in the program have scour holes lined with various sizes of graded riprap, but later structures have only the sheet-pile weir and baffle allowing the forces of the stream to size the scour hole. The Goodwin Creek Watershed grade control structures were specifically designed to measure total sediment load and discharge, concurrent with the control of bed degradation.

2. Construction Costs. Table 8 lists the relative construction costs per linear foot of streambank protected for the various protection techniques used in the Section 32 Program.

C. Monitoring of Demonstration Projects. Monitoring and observation of the projects consisted of the collection of thalweg and cross-sectional surveys, aerial photography, onsite field inspections and site surveys. The limitations of the program consist of manpower shortages; the funding sequence which left a relatively short evaluation period since the construction of a majority of the stabilization measures; and the limited amount of historical, hydrologic, and geologic data of the study area.

D. Maintenance and Rehabilitation of Demonstration Projects. Several periods of high runouts (November 1977, March 1978, and May 1980) have caused varying degrees of damage to the demonstration projects. Much of the damage is minor in nature and will require no corrective measures. However, three structures on Batupan Bogue, seven on Perry Creek, four on South Fork Tillatoba Creek, and one on North Fork Tillatoba Creek are severely damaged and are scheduled for rehabilitation work. Some of the rehabilitation work has been completed and the remainder is scheduled for completion in 1981. Some structures have not been tested by a major runout, and other failures will undoubtably occur with time. The contributing factors to the bank failures are bed degradation, misalignment, buildup of hydrostatic pressure in the banks, inadequate toe protection, high runouts, and lack of vegetation on upper bank slopes.

E. Observations.

1. Over 220 bendways in eight different drainage basins were stabilized and/or evaluated under the Section 32 Demonstration Program using a variety of different types of stabilization structures. Among the drainage basins considered, there is wide variation in drainage area, stream characteristics, geology, hydrology, and land use applications. The short period of time since the construction of the stabilization measures limits the opportunity to observe their effectiveness. However, certain factors related to the construction, design techniques, and the general stream characteristics are apparent. Table 9 is a summary of the type, cost as of October 1980, and status of the various stabilization techniques used during the Section 32 Program in the Vicksburg District. It should be noted that the cost in Table 9 represents contract construction cost only and does not include, engineering and design, contract supervision, rehabilitation, or special study contracts with the USDA Science and Education Administration Lab and the Soil Conservation Service.

2. A variety of vegetative treatment measures was applied. In cases where existing vegetation was left undisturbed, the effectiveness of bank protection was increased. This was especially true in cases where woody vegetation existed. In some cases it was necessary to use vegetative treatment to help stabilize banks which had been graded or banks which were void of vegetation. The effectiveness of these

vegetative treatments generally depended on whether or not the vegetation had been given time to take hold prior to the high water season. The use of woody vegetation such as willow seemed to provide a more effective bank protection than nonwoody vegetation. It is important to note that in some cases the soils (Paleosols, Zilpha, etc.) are not conducive to vegetative growth.

3. Since bed degradation is very widespread in the Yazoo hill streams, the protection of the bank toe appears to be an important factor in the design of bank stabilization measures. The longitudinal stone dikes which provided effective toe protection were the most successful bank stabilization measures studied, particularly in degrading streams. In many cases the absence of toe protection (tire post retards on Perry Creek) contributed to the bank failures. Bank stabilization measures without toe protection were successful in some instances; however, if bed degradation is apparent or anticipated, or in bends having more than slight curvature, then toe protection is needed, or structures must be designed to accommodate expected channel deepening.

4. Numerous usable geologic controls (consolidated clays in the streambed, outcrops of ironstone, quartzite, etc.) were encountered during the study. In general, the presence of geologic controls has a stabilizing effect on the stream by halting the headward migration of headcuts; however, there are times when a well consolidated streambed may actually contribute to the erosion of the upper banks. This was the case on Batupan Bogue (Item 4A) where the streambed consisted of a well consolidated clay. During the extreme runout in November 1977, the stream skated over the resistant clay bed and scoured the upper banks to over twice their original width.

5. The grade control structures have proven quite effective in halting streambed degradation although there have been some minor erosional problems encountered at a few sites. In some instances (Perry

Creek upper structure), it appears that the degradation has been halted by the riprap key downstream of the pre-formed scour pocket. At other locations in the study area, degradation has been temporarily halted by box culverts and the placement of concrete rubble in the streambed by the local landowner; however, it sould be emphasized that these techniques are only temporary and should not be considered as a method of halting bed degradation permanently.

6. Even under the best design conditions, the effectiveness of the stabilization measure may be nullified due to construction delays. During the study, several instances of changes in stream patterns and bed elevation occurred from the time of design survey to construction. This was the case on North Fork Tillatoba Creek (Item 1) where the low water thalweg pattern reversed in a sine-cosine fashion. On Johnson Creek a headcut had already progressed upstream of the site of the proposed grade control structure thereby severely limiting the effectiveness of the structure.

7. Monolithic type bank stabilization structures prevent the seepage of water through the bank, thereby creating hydrostatic pressures in the banks. If pressure release is not provided, mass bank and structural failures may occur. This was the case of the slip failure that occurred on South Fork Tillatoba Creek where sand-cement bag revetment was installed. After placement of the sand-cement bags, the structure acquired the characteristics of a monolithic structure and a slip failure of the bank occurred, possibly due to the buildup of hydrostatic pressure following a bankfull event.

8. Scour pockets were observed at the downstream edge of some structures as a result of the eddy action of the water flowing over the downstream stone tiebacks. Similar scour was observed at the point of transition from complete upper bank paving to longitudinal stone toe protection. Careful consideration during design is needed to minimize this scouring action where stabilization measures are terminated.

9. It is noteworthy that none of the bank protection works, except at grade control structure, included a filter layer or filter cloth. With a few exceptions, this lack of a filter did not significantly affect the performance of the works. These few exceptions, of course, occurred where strata in the bank material were relatively impermeable, the ground-water level was high, and/or the revetment structure tended to act as a monolith (sacked sand-cement). The significance of this observation is that the designer of bank protection works should not automatically specify expensive filter material if the risk and consequences of loss of minor amounts of bank material through the protective covering is small. Where the bank material is pervious, ground-water level is low, the duration of high stages is short, and the revetment material is flexible and pervious (i.e. riprap), a filter may not be cost-effective.

10. Throughout the program it became apparent that some streams responded more effectively to bank stabilization measures than others. This phenomenon may be attributed to the rapid rate of change of the morphologic parameters (width, depth, etc.) in the unstable streams. Streams which have been significantly altered due to bed degradation undergo a rapid rate of change in width, depth, and other channel parameters. After a certain period of time, this rate of change decreases as the stream begins to adjust to a new state of relative equilibrium. It is during this period of adjustment toward a new equilibrium state that bank stabilization measures have the greatest chance of success. Construction to stabilize the stream during the rapid transition state will require more massive and costly protective works to compensate for the increased threat.

F. <u>Significant Participation by Other Organizations</u>.

1. A joint venture was undertaken with the USDA Science and Education Administration Sedimentation Laboratory (SEA) at Oxford,

Mississippi, to define and monitor amounts, sources, direction, and time of travel of sediments. Research included complete analyses of the drainage basin morphology, geology, soils, land use, vegetation, basin stratigraphy, hydrology, climatology, and stream hydraulics. Particular emphasis was given to the Goodwin Creek Basin, and the results will be used to determine the performance of selected channel stabilization methods and to determine influence of grade control structures on channel stability.

2. The SEA and the USDA Soil Conservation Service (SCS) have cooperated in a program testing the effectiveness of a wide variey of vegetation control on streambank stability.

3. The SCS inventory and evaluation of bank stabilization measures in North Mississippi lists 326 sites that were stabilized. Of these, SCS lists only 11 percent as having failed to some degree. However, photos and surveys furnished with this report indicate a much higher percent with problems. Prior to using this SCS report to substantiate erosion problems and stabilization measures in the Yazoo Basin, a more thorough analysis of the SCS work is needed.

G. Recommendations

1. The alignment of the structures is critical. During periods of high and low flows, the location of the major point of attack will vary. It is therefore necessary to define the limits for this point of attack in order to provide adequate bank protection for both high and low flows. The design should provide the highest degree of protection within the limits of the point of attack of high flows with a reduced level of protection upstream and downstream. The most common oversight in design is to extend bank protection too far upstream and not far enough downstream; since bends migrate down valley, the downstream end of the protection is more critical, therefore care should be taken in establishing the lower limits of protection.

2. The alignment of the structures should provide a smooth transition from bendway to bendway. Both the high water and low water paths should be considered in alignment design for development of an orderly transition between bendways, thereby preventing the structures from creating an obstruction to flow. In instances where the structure alignment was not compatible with the high water flows (upper seven structures on Item 1, North Fork Tillatoba Creek), the structures were subjected to erosive forces which resulted in upper bank failures. On the other hand, the minimum protection on Johnson Creek was designed to create a smooth transition between bendways for both high and low flows, and the structures have effectively stabilized the banks.

3. In streams where the streambed consists of a well consolidated clay or other geologic control, the stabilization measures should be designed to provide complete upper bank protection with only minimum toe protection. This differs from the design on actively degrading streams such as Perry Creek where toe protection is essential to the success of the structure.

4. It is essential that all possible measures be taken to expedite the time between design and construction. An effective way to do this is to advertise and award the contract based on approximate quantities and locations, then furnish detailed site layouts immediately prior to construction.

5. Close coordination between design and construction personnel while work is underway is very important. This is exemplified on Johnson Creek (Item 9A) where a protruding clay plug in the bank was encountered during placement of the stone toe protection. Rather than removing the obstruction and aligning the structure as designed, the stone was placed along the protruding bankline, thereby creating a point of discontinuity in the structure. Onsite changes by construction personnel are sometimes necessary, but should be closely coordinated with the designers.

6. Where possible, natural levees along top bank should be left undisturbed by construction activities. Manmade replacements may not be adequate and may alter the overbank drainage patterns. Engineering techniques to control overbank drainage are necessary to prevent damage to the structure.

7. Before any stabilization measures are planned, as much data as are available should be analyzed. This may be accomplished through a research of old plan maps, surveys, topo maps, aerial photographs, field investigations, discussions with local residents and historical documentation of the area. This will assist designers to understand how the system has responded to changes in the past and how it may respond in the future.

H. Concluding Remarks. The Yazoo River system had a unique relationship with the Lower Mississippi before the valley was settled and flood control measures were instigated. The Yazoo Basin acted as a flood storage reservoir and the Yazoo River system acted both as a distributary for Mississippi flood overflows as well as intermediate flows and as a tributary for local runoff. This relationship was permanently changed with the levee confinement of Mississippi flood waters. Reduced flows in the Yazoo River, caused a concomitant decrease in channel cross section and plan geometry.

The Yazoo drainage system was an extremely complicated network as a natural system. The Mississippi valley below the confluence of the Ohio and Middle Mississippi River at Cairo, Illinois, was deltaic and subjected to shifting water courses as it adjusted to the ever-changing sediment and water loads. Many parts of the Yazoo Basin were 30 feet below the banks of the present Mississippi River and acted like a large reservoir absorbing as much as 50 percent of the Mississippi River flows and then slowly releasing them back into the Mississippi at Vicksburg.

Mississippi main line levees shut off these distributory flows and left many of the Yazoo Basin channels as underfit streams adjusting their channel size to reduced local flows. Subsequent channel straightening, diversions, impondments and land use changes further altered the water and sediment loads into the channels. Some of these alterations had compensating effects, while others only compounded the problems.

Continued modification of the channels and their water and sediment load even caused cyclic aggradation and degradation, channel enlargement and reduction, further complicating the whole picture.

In the course of this study we have been able to document periods of erosion in the Yazoo Basin roughly 2,000, 5,000, and 10,000 years ago, with aggradation following each period of degradation. deposition in the Yazoo Hills of 50 to 60 feet of sediment in the past 10,000 years or after the most recent glacial activity is evident as well as deposits of about 30 feet deep during the last 2,000 years. In all river valleys in the Yazoo Hills, post-settlement (up to 170 years old) deposits of a few inches up to 10-15 feet are found. This adds up to one-half foot per 100 years of sedimentation for the period since the last major climate change, and six feet per 100-year average sedimentation since man began using the land. Most of the latter probably occurred between the end of the Civil War (1860's) and pre-World War II (1930's). Since that time period, better land-use practices have minimized the sediment problems. However, recent land clearing and construction activities as well as various federal agency activities on our streams have initiated a new cycle of erosion and sediment movement.

Because sedimentation is a natural process, we cannot eleiminate it. We can, however, effectively minimize the problems it causes. The methods we should be incorporating into our total analysis are the proper "Management" of the sediments. Sediments can be both an asset and a liability. Nature does not remain in a constant condition. What is necessary is a method of management of the sediment problem; a continual program of balancing sediment sources and sediment sources and sediment sinks. Sediments will continue to move; the secret is to keep them as close to the supply source as possible; to effectively transport the sediments that get into our waterways to either the first available storage area or to move them through the system to the next best permanent storage place. In doing this we can also create additional wetlands to replace those that were filled through management of the previously displace sediments.

This type of a program would require the complete cooperation of the Federal agencies, all environmental concerns, as well as local land owners. The eventual program would be a water, sediment, and floodplain management of all the nation's drainage basins. It should be emphasized that since this project was somewhat experimental, failures were expected. Some structures were designed with marginal strength in an effort to determine the minimum amount of protection required to demonstrate that using inexpensive measures can in some cases be false economy. There is a difference between "inexpensive" work and "cost-effective" work. This is a most important point. "Cheap" solutions to significant erosion problems are not possible. However, an understanding of the streams behavior allows the most effective use of funds, even though the amount of funds required may be significant or even prohibitive.

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TABLE 1

GEOMORPHIC CHANGES IN PERRY CREEK

CHANNEL CHARACTER	SITE	1935	1941	1949	1954	1963	1970
BANK EROSION	P1 (MOUTH)	NOTICEABLE EROSION IN BENDS	EROSION ALONG ENTIRE CHANNEL; BUT MORE NOTICEABLE ON OUTSIDE BANK OF BENDS	OUTSIDE BANKS OF SOME BENDS APPEAR TO BE ONLY ACTIVE AREAS	OUTSIDE BANK OF SOME BENDS	ACTIVE EROSION IN LOWER 1/2 MILE; MORE LIMITED IN REST OF CHANNEL	VERY ACTIVE EROSION ALONG ENTIRE CHANNEL
	P2	NOTICEABLE EROSION IN BENDS	VERY NOTICEABLE ON OUTSIDE BANK OF BEND	--	VERY ACTIVE ALONG ENTIRE CHANNEL; BENDS ARE MEANDER LOOPS BEING STRAIGHTENED	MOSTLY ALONG OUTSIDE BANK OF BENDS	ACTIVE EROSION ALONG ENTIRE CHANNEL, BUT MORE NOTICEABLE IN BENDS
	P3	--	NOT DETECTABLE, TREE LINED CHANNEL	--	ACTIVE EROSION ALONG ENTIRE CHANNEL	CHANNEL WIDTH DOUBLED; BENDS AND MEANDER LOOPS STRAIGHTENED	ACTIVE EROSION ALONG ENTIRE CHANNEL, BUT MORE EXTENSIVE BELOW INTERSTATE #55 INTERSTATE BRIDGE
	P4	--	EROSION IN BENDS	--	ACTIVE ALONG ENTIRE STRETCH BUT MORE NOTICEABLE IN BENDS	SOME EROSION IN BENDS	EROSION IN BENDS
DEGRADATION	P1 (MOUTH)	POSSIBLE DEGRADATION	TRIBUTARIES DEGRADING	BED OF CUT-OFF MEANDER LOOP AT HIGHER ELEVATION THAN PRESENT BED	CONTINUED DEGRADATION TRIBUTARIES RAPIDLY DEGRADING SINCE 1949	CONTINUED DEGRADATION; MORE PRONOUNCED AT MOUTH	CONTINUED DEGRADATION; EROSION RESISTANT CLAYS EXPOSED IN BED
	P2	POSSIBLE DEGRADATION	TRIBUTARIES DEGRADING AT THEIR MOUTHS	--	TRIBUTARIES APPEAR ENTRENCHED; ISOLATED REMNANTS OF RECENT CHANNEL BED AT HIGHER ELEVATION THAN PRESENT BED	TRIBUTARIES DEGRADING HEADWARD; DEGRADATION IN PERRY, BUT NOT AS RAPID AS PRE 1954	CONTINUED DEGRADATION
	P3	--	NOT DETECTABLE	--	RAPIDLY DEGRADING	CONTINUED DEGRADATION	BED DOWNSTREAM FROM HIGHWAY OUT FROM 6 TO 8 FT. SINCE 1965
	P4	--	POSSIBLE DEGRADATION	--	TRIBUTARIES DEGRADING AT THEIR MOUTHS	ISOLATED REMNANT OF FORMER CHANNEL, BED HIGHER ELEVATION THAN PRESENT BED	RAPID DEGRADATION IN LOWER STRETCH

TABLE 2

GEOMORPHIC CHANGES IN DELTA AREA OF TILLATOBA CREEK

	DATE OF IMAGERY				
EROSION	1937	1941	1954	1960's	1970's *
BANK	TREE LINED CHANNEL, NO DETECTABLE EROSION	CHANNEL WIDTH DOUBLED; BANKS APPEAR STEEP AND VERTICAL; SHARP BENDS BEING ERODED; BANKS APPEAR VERY IRREGULAR AND ROUGH	INCREASING WIDTH; SMALL MEANDER LOOPS OR BENDS BEING ERODED	CONTINUED INCREASE IN CHANNEL WIDTH, BUT AT SLOWER RATE; SMALL MEANDER LOOPS AND BENDS STILL BEING ERODED	CONTINUED INCREASE IN CHANNEL WIDTH
BED	NO APPARENT DEGRADATION	ISOLATED REMNANTS OF RECENT** CHANNEL BED INDICATE DEGRADATION HAS AND/OR IS OCCURRING; SMALL TRIBUTARY CHANNELS ARE DEGRADING+	CONTINUED DEGRADATION HAS LEFT ISOLATED SEGMENTS OF THE PREVIOUS BED ELEVATED ABOVE THE PRESENT CHANNEL	DEGRADATION CONTINUING BUT AT MUCH SLOWER RATE	DEGRADATION OCCURRING BUT AT SLOWER RATE THAN IN THE LATE 1940'S AND EARLY 1950'S
CENTRAL	CHANNEL APPEARS STABLE; NO DETECTABLE POINT BARS	POINT BARS COMMON, BUT MORE NUMEROUS NEAR BLUFF LINE	POINT BARS NEAR BLUFF LINE LARGER AND MORE CONTINUOUS; FEWER POINT BARS NEAR MOUTH	THALWEG MEANDERING IN CHANNEL DEPOSITS, CAUSING BANK EROSION	DEGRADATION OCCURRING BUT AT SLOWER RATE THAN IN THE LATE 1940'S AND EARLY 1950'S

* THIS PERIOD INCLUDES DATA FROM IMAGERY AND FIELD OBSERVATIONS.

**RECENT- THIS TERM, AS USED IN THIS TABLE, REFERS TO EVENTS SINCE 1937.

+ THE ERODED APPEARANCE OF THESE CHANNELS IS LIKE THAT OF MODERN ERODING TRIBUTARIES SEEM IN THE FIELD.

TABLE 3

GEOMORPHIC CHANGES IN UPLAND AREA OF SOUTH FORK

CHANNEL CHARACTER	REACH	DATE OF IMAGERY 1937	1941	1954	1960's	1970's *
BANK EROSION	LOWER REACH	TREE LINED CHANNELS WITH NO APPARENT EROSION	NOTICEABLE EROSION ALONG ENTIRE REACH, BUT MORE PRONOUNCED AT MOUTH	CHANNEL WIDTH MORE THAN DOUBLE THAT OF 1937; MEANDER LOOPS AND BENDS CUT OFF BY BANK EROSION, THEREBY SHORTENING THE CHANNEL LENGTH	BANK EROSION IN MEANDER LOOPS, BUT AT SLOWFR RATE THAN PRE-1954	CONTINUED EROSION IN MEANDER LOOPS AS IN THE 1960's
	MIDDLE REACH	VERY LIMITED EROSION, MAINLY IN MEANDER LOOPS	NOTICEABLE BANK EROSION ALONG ENTIRE REACH	EXTENSIVE BANK EROSION IN LOWER STRETCH, DECREASING UPSTREAM; WIDTH TWO TO THREE TIMES WIDES IN LOWER STRETCH THAN IN 1937; MEANDER LOOPS AND BENDS BEING STRAIGHTENED BY BANK EROSION	CHANNEL WIDTH ALONG ENTIRE REACH TWO TO THREE TIMES WIDER THAN 1937; CONTINUED EROSION ESPECIALLY IN MEANDER LOOPS	DECREASED RATE OF BANK EROSION; HOWEVER, MEANDER LOOPS STILL BEING ERODED
	UPPER REACH	VERY LIMITED EROSION	NOTICEABLE BANK EROSION ALONG ENTIRE REACH	NOTICEABLE BANK EROSION ALONG ENTIRE REACH, BUT ESPECIALLY NOTICEABLE IN MEANDER LOOPS, NO GREAT CHANGE IN WIDTH	EXTENSIVE BANK EROSION IN LOWER TWO-THIRDS OF REACH; WIDTH TWO TO THREE TIMES WIDER THAN IN 1937; MEANDER LOOPS AND BENDS BEING STRAIGHTENED BY BANK EROSION	EXTENSIVE BANK EROSION ALONG ENTIRE REACH; WIDTH TWO TO THREE TIMES WIDER THAN IN 1937
DEGRADATION	LOWER REACH	NO NOTICEABLE CHANNEL DEGRADATION	LOWER STRETCH BEING DEGRADED	KNICKPOINT HAD ADVANCED THROUGH ENTIRE REACH; ISOLATED SECTIONS OF PREVIOUS BEDS LEFT AT HIGHER ELEVATIONS THAN PRESENT BED	CONTINUED DOWNCUTTING BUT AT SLOWER RATE; ISOLATED SECTIONS OF PREVIOUS BEDS AT HIGHER ELEVATION THAN PRESENT BED	DEGRADATION OCCURRING, BUT APPARENTLY AT MUCH SLOWER RATE THAN PREVIOUSLY
	MIDDLE REACH	NO NOTICEABLE CHANNEL DEGRADATION	POSSIBLE DEGRADATION BUT VERY LITTLE IF ANY	KNICKPOINT IN MIDDLE STRETCH OF REACH; ISOLATED SECTIONS OF PREVIOUS CHANNEL BED AT HIGHER ELEVATION THAN PRESENT BED	KNICKPOINT HAD ADVANCED THROUGH REACH; ISOLATED SECTIONS OF PREVIOUS BEDS AT HIGHER ELEVATIONS THAN PRESENT BED	DEGRADATION OCCURRING, BUT AT MUCH SLOWER RATE THAN PREVIOUSLY
	UPPER REACH	NO NOTICEABLE CHANNEL DEGRADATION	POSSIBLE DEGRADATION BUT VERY LITTLE IF ANY	POSSIBLE DEGRADATION	KNICKPOINT ADVANCED TO MIDDLE OF UPPER REACH; ISOLATED SECTIONS OF PREVIOUS CHANNELS AT HIGHER ELEVATION THAN PRESENT BED	KNICKPOINT ADVANCED INTO SIMMONS AND DAVIS CREEKS; ISOLATED SECTIONS OF PREVIOUS CHANNELS AT HIGHER ELEVATION THAN PRESENT BED
TRIBUTARIES		POINT BARS IN TRIBUTARIES ASSOCIATED WITH GULLY SYSTEMS	POINT BARS AT MOUTH OF SOUTH FORK, AND TRIBUTARIES ASSOCIATED WITH GULLY SYSTEMS	TRIBUTARIES ASSOCIATED WITH DEGRADING CHANNELS ARE ALSO DEGRADING IN LOWER REACHES, AND WIDENING; DECREASED EROSION IN CHANNELS ASSOCIATED WITH GULLY SYSTEMS	TRIBUTARIES ASSOCIATED WITH DEGRADING CHANNELS ARE ALSO DEGRADING AND WIDENING; VERY LITTLE EROSION IN CHANNELS ASSOCIATED WITH GULLY SYSTEMS	TRIBUTARIES ASSOCIATED WITH DEGRADING CHANNELS ARE ALSO DEGRADING AND WIDENING; NO NOTICEABLE EROSION IN CHANNELS ASSOCIATED WITH OLDER GULLY SYSTEMS

* THIS PERIOD INCLUDES DATA FROM IMAGERY AND FIELD OBSERVATIONS.

TABLE 4

GEOMORPHIC CHANGES IN UPLAND AREA OF MIDDLE FORK

DATE OF IMAGERY

CHANNEL CHARACTER	REACH	1937	1941	1954	1960's	1970's*
BANK EROSION	LOWER REACH	BANK EROSION OCCURRING ON CHANNELIZED STRETCHES; NO EROSION NOTICEABLE ON OTHER STRETCHES	NOTICEABLE BANK EROSION ON ENTIRE REACH, BUT NOT VERY EXTENSIVE	BANK EROSION LIMITED TO A FEW MEANDER LOOPS	LIMITED TO A FEW MEANDER LOOPS	EXTENSIVE BANK EROSION IN THE LOWER STRETCH NEAR MOUTH; CHANNEL WIDTH MORE THAN DOUBLED
	MIDDLE REACH	NO NOTICEABLE BANK EROSION	NOTICEABLE BANK EROSION ON ENTIRE REACH, BUT NOT VERY EXTENSIVE	BANK EROSION LIMITED TO A FEW MEANDER LOOPS	BANK EROSION ON CHANNALIZED STRETCH	BANK EROSION ON CHANNELIZED STRETCH
	UPPER REACH	NO NOTICEABLE BANK EROSION	NOTICEABLE BANK EROSION ON ENTIRE REACH, BUT NOT VERY EXTENSIVE	BANK EROSION IN LOWER STRETCH OF CHANNELIZED CHANNEL	BANK EROSION ON CHANNALIZED STRETCH	EXTENSIVE BANK EROSION ON CHANNELIZED STRETCH
DEGRADATION	LOWER REACH	NOT NOTICEABLE	POSSIBLE DOWNCUTTING, BUT VERY LITTLE IF ANY	SOME DEGRADATION IN SHORT CHANNELIZED TRETCH	SOME DEGRADATION IN SHORT CHANNELIZED STRETCH	KNICKPOINT ADVANCING UP LOWER STRETCH
	MIDDLE REACH	NOT NOTICEABLE	POSSIBLE DOWNCUTTING, BUT VERY LITTLE IF ANY	CHANNELIZED STRETCH DEGRADING	CHANNELIZED STRETCH DEGRADING	CHANNELIZED STRETCH DEGRADING
	UPPER REACH	NOT NOTICEABLE	POSSIBLE DOWNCUTTING, BUT VERY LITTLE IF ANY	CHANNELIZED STRETCH DEGRADING	CHANNELIZED STRETCH DEGRADING	CHANNELIZED STRETCH DEGRADING
TRIBUTARIES		BANK EROSION IN CHANNELS ASSOCIATED WITH GULLY SYSTEMS; POINT BARS IN ERODING CHANNELS	EXTENSIVE BANK AND BED EROSION IN THOSE CHANNELS DIRECTLY ASSOCIATED WITH GULLY SYSTEMS; POINT BARS IN ABOVE CHANNELS	DECREASED EROSION IN CHANNELS ASSOCIATED WITH GULLY; POINT BARS IN ERODING CHANNELS	POINT BARS IN ERODING CHANNELS	POINT BARS BELOW KNICKPOINT AT MOUTH AND IN CHANNELIZED STRETCHES

* THIS PERIOD INCLUDES DATA FROM IMAGERY AND FIELD OBSERVATIONS.

TABLE 5

GEOMORPHIC CHANGES IN UPLAND AREA OF NORTH FORK

CHANNEL CHARACTER	REACH	DATE OF IMAGERY 1937	1941	1954	1960's	1970's *
BANK EROSION	LOWER REACH	TREE LINED CHANNEL WITH NO APPARENT EROSION	NOTICEABLE EROSION ALONG ENTIRE REACH, BUT MORE PRONOUNCED AT MOUTH; STEEP VERTICAL BANKS ARE PRESENT	CHANNEL WIDTH MORE THAN DOUBLED; CHANNEL LENGTH SHORTENED AS BANK EROSION CUT OUT SOME MEANDER LOOPS AND BENDS	OUTSIDE BANK OF SHARPER BENDS BEING ERODED; REDUCED RATE OF BANK EROSION IN OTHER STRESS	CONTINUED EROSION OF OUTSIDE BANKS OF SHARP BENDS, AND LESSER RATE IN OTHER AREAS
	MIDDLE REACH	OUTSIDE BANK OF SOME MEANDER LOOPS BEING ERODED	NOTICEABLE EROSION ALONG ENTIRE REACH, BUT MORE NOTICEABLE ALONG OUTSIDE BANK OF MEANDER LOOPS	CHANNEL WIDTH MORE THAN DOUBLED IN LOWER STRETCH, BANK EROSION INCREASING IN UPPER STRETCH SINCE 1941	CHANNEL WIDTH MORE THAN TRIPLE 1937 WIDTH IN LOWER STRETCH; AND INCREASED BANK EROSION IN UPPER STRETCH	CHANNEL WIDTH INCREASING IN LOWER STRETCH; MAJOR BANK EROSION WAS OCCURRING IN THE VICINITY OF THE JUNCTION OF NORTH FORK AND LITTLE CREEK
	UPPER REACH	OUTSIDE BANK OF MEANDER LOOPS BEING ERODED	NOTICEABLE EROSION ALONG ENTIRE REACH, BUT MORE NOTICEABLE IN MEANDER LOOPS	BANK EROSION IN SOME MEANDER LOOPS	VERY LITTLE DETECTABLE ON IMAGERY	VERY LITTLE DETECTABLE
	TRIBUTARIES	EXTENSIVE BANK EROSION ON THE SMALLER STREAMS ASSOCIATED WITH GULLY SYSTEMS, AND NOTICEABLE EROSION ON THE LARGER STREAMS; NO NOTICEABLE EROSION ON OTHER STREAMS	INCREASED BANK EROSION ON ALL STREAMS ASSOCIATED WITH GULLYING	DECREASED BANK EROSION ON STREAMS ASSOCIATED WITH GULLY AREAS; INCREASED BANK EROSION AT MOUTHS OF STREAMS IN LOWER REACH	VERY LITTLE DETECTABLE EROSION ON STREAMS ASSOCIATED WITH GULLY AREAS; INCREASED BANK EROSION IN LOWER AND MIDDLE REACHES	VERY LITTLE BANK EROSION ON STREAMS ASSOCIATED WITH GULLY AREAS; INCREASED BANK EROSION IN LOWER AND MIDDLE REACHES
DEGRADATION	LOWER REACH	NOT DETECTABLE	DOWNCUTTING AT MOUTH	KNICKPOINT HAD ADVANCED THROUGH REACH; ISOLATED SECTIONS OF PREVIOUS BED LEFT AT HIGHER ELEVATION THAN PRESENT BED	CONTINUED DOWNCUTTING BUT AT SLOWER RATE; ISOLATED SECTIONS OF PREVIOUS BEDS AT HIGHER ELEVATION THAN PRESENT BED	CONTINUED DOWNCUTTING AS IN 1960
	MIDDLE REACH	NOT DETECTABLE	NOT DETECTABLE	KNICKPOINT IN LOWER STRETCH ISOLATED SECTIONS OF PREVIOUS BED AT ELEVATION HIGHER THAN PRESENT BED	KNICKPOINT ADVANCING UPSTREAM	KNICKPOINT IN VICINITY OF JUNCTION OF NORTH FORK AND SANDY CREEK
	UPPER REACH	NOT DETECTABLE	NOT DETECTABLE	NOT DETECTABLE	NOT DETECTABLE	NOT DETECTABLE
	TRIBUTARIES	CHANNELS DRAINING GULLIES EXHIBIT SOME DEGRADATION	CHANNELS DRAINING GULLIES AND THE MOUTH AREAS	CHANNELS DRAINING DIRECTLY INTO NORTH FORK BELOW THE KNICKPOINT	CHANNELS DRAINING DIRECTLY INTO NORTH FORK BELOW THE KNICIPOINT	CHANNELS DRAINING DIRECTLY INTO NORTH BELOW THE KNICKPOINT
GENERAL		POINT BARS IN UPPER AND MIDDLE REACHES, AND IN TRIBUTARIES ASSOCIATED WITH GULLY SYSTEMS	POINT BARS IN UPPER AND MIDDLE REACHES, MOUTH AREA, AND TRIBUTARIES ASSOCIATED WITH GULLY SYSTEMS	POINT BARS IN CHANNEL BELOW KNICKPOINT; THALWEG MEANDERING IN WIDE CHANNELS	POINT BARS IN CHANNEL BELOW, KNICKPOINT; THALWEG DEVELOPING MEANDER PATTERN IN WIDE CHANNELS	POINT BARS IN CHANNEL BELOW KNICKPOINT; THALWEG DEVELOPING MEANDER PATTERN IN WIDE CHANNELS

* THIS PERIOD INCLUDES DATA FROM IMAGERY AND FIELD OBSERVATIONS.

TABLE 6

GEOMORPHIC CHANGES IN GOODWIN CREEK

Channel Character	Site	Date of Imagery: 1940's	1950's	1960's	1970's
Bank	Miles Upstream (Mouth)	Some bank erosion where meandering thalweg deflected against bank	Same as 1940's; gradual bank erosion altering straight appearance of channel	Continued gradual erosion of banks; channel shape more irregular	Channel width nearly doubled from 1968 to 1979; channel attempting to re-establish a meandering type channel
	0.6	Some erosion on the outside banks of meander loops	Some erosion on the outside banks of meander loops	Increased erosion along entire channel, but more extensive in meander loops	Channel width doubled since 1968; channel upstream from bridge more extensively eroded
	2.0	Some erosion in meander loops	Extensive erosion on outside banks of meander loops	Erosion along entire channel, but very pronounced in meander loops	Continued erosion as in 1960's
	4.6	Channel erosion along entire stretch, but more pronounced in meander loops	Some erosion in meander loops	Channel width decreased, no noticeable bank erosion	Some erosion on outside banks of meander loops
Degradation	(Mouth)	Limited downcutting at mouths of tributaries	Not noticeable	Possible degradation	Degradation occurring; erosion resistant clay and limonitic ledges exposed in bed*
	0.6	Downcutting at mouths of tributaries	Tributaries downcutting	Possible degradation	Degradation occurring*
	2.0	Possible degradation	Channel degrading	Tributaries degrading; isolated segment of former bed at higher elevation than present	Channel degrading; erosion resistant only in bed*
	4.6	Tributaries degrading	Tributaries degrading; bed of meander cut-offs at higher elevation than present bed	Beds of meander cut-offs at higher elevation than present bed	Continued as in 1960's
General		The straight appearance of the channelized section is being gradually altered to a more meandering type appearance. Erosion resistant clays and limonitic ledges are exposed in the channel bed throughout the stream.			

*Includes field observations and data.

TABLE 7

GEOMORPHIC CHANGES IN HOTOPHIA CREEK

DATE OF IMAGERY

CHANNEL CHARACTER	SITE	1935 - 1941	1957	1958-1961	1963	1968	1970's*
BANK EROSION	H1 (MOUTH)	NO NOTICEABLE BANK EROSION IN 1935 OR 1940; CHANNEL WIDTH DOUBLED FROM 1940 TO 1949	BANK EROSION CUTTING AWAY MEANDER LOOPS AND INCREASING CHANNEL WIDTH	HOTOPHIA CREEK WAS CHANNELIZED FROM ~3.3 MILES ABOVE ITS MOUTH TO ~1 MILE ABOVE THE MOUTH OF MARCUM CREEK. THE CHANNEL DOWNSTREAM FROM THE CHANNELIZATION WAS CLEARED	CHANNEL WIDENING AND STRAIGHTENING AS MEANDER LOOPS CUT AWAY	CONTINUED BANK EROSION, CHANNEL HAS STRAIGHT CHANNELIZED APPEARANCE	CONTINUED BANK EROSION
	H2	NO NOTICEABLE BANK EROSION IN 1935, CHANNEL TREE LINED	TREE LINED CHANNEL, SOME EROSION ON OUTSIDE BANKS OF MEANDER LOOPS		RAPID EROSION OF CLEARED BANKS	CHANNEL WIDTH NEARLY TRIPLED SINCE 1963; STRAIGHT CHANNELIZED APPEARANCE	CONTINUED BANK EROSION
	H3	TREE LINED CHANNEL, NO OBSERVABLE BANK EROSION	VEGETATION REMOVED, NO OBSERVABLE BANK EROSION, EXCEPT AT BRIDGE		SOME EROSION ALL ALONG CHANNEL	EROSION ALL ALONG CHANNEL, BUT MORE NOTICEABLE DOWNSTREAM FROM BRIDGE	EXTENSIVE BANK EROSION ALL ALONG CHANNEL
	H4	MOSTLY TREE LINED, NO OBSERVABLE EROSION	MOSTLY TREE LINED, NO OBSERVABLE EROSION		LIMITED EROSION ALL ALONG CHANNEL	EROSION ALONG ENTIRE STRETCH, BUT MORE EXTENSIVE DOWNSTREAM FROM MOUTH OF MARCUM CREEK	EXTENSIVE BANK EROSION ALL ALONG CHANNEL
	H5	VERY GRADUAL BANK EROSION ALONG ENTIRE STRETCH OF CHANNEL			CONTINUED GRADUAL BANK EROSION ALONG ENTIRE STRETCH, BUT APPEARS TO BE OCCURRING AT FASTER RATE. THIS SECTION CHANNELIZED PRE-1935		
DEGRADATION	H1 (MOUTH)	NOT NOTICEABLE IN 1935 OR 1940; BEDS OF MEANDER CUT-OFF, AND PREVIOUS CHANNEL BEDS AT HIGHER ELEVATION THAN 1949 BED	BEDS OF MEANDER CUT-OFFS AT HIGHER ELEVATION THAN 1957 BED		CONTINUED DEGRADATION	CONTINUED DEGRADATION	SMALL TRIBUTARIES HAVE HANGING BEDS; LOSS OF PREVIOUS CHANNELS AT HIGHER ELEVATIONS THAN 1979 BED
	H2	NOT DETECTED	NOT DETECTED AT H2, HOWEVER CHANNEL DEGRADATION IS OCCURRING DIRECTLY DOWNSTREAM FROM H2		BEDS OF MEANDER CUT-OFFS AT SUCCESSIVELY HIGHER ELEVATIONS THAN THE 1963, 1968 AND 1979 BED		
	H3	NOT DETECTED	NOT DETECTED		NEW CHANNEL DEEPER THAN PRE-CHANNELIZATION CHANNEL	CHANNEL DEGRADING	10 TO 12 FT VERTICAL DROP IN 100 FT ON PRE-1957 CHANNEL
	H4	NOT DETECTED	NOT DETECTED		NEW CHANNEL DEEPER THAN PREVIOUS CHANNEL	NOTICEABLE INCREASE IN DEPTH	5 TO 6 FT WATERFALL; DRAINAGE CHANNELS ELEVATE 5 TO 11 FT ABOVE 1979 CHANNEL
	H5	NOT DETECTED	NOT DETECTED		CHANNEL DEPTH INCREASED FROM 1963 TO PRESENT, TRIBUTARIES DEGRADING		
GENERAL		THERE ARE NO SEDIMENTS IN THE CHANNEL OF THE MIDDLE AND UPPER REACH. THE STREAM IS CUTTING INTO CLAY. THE LOWER REACH HAS A WIDE SEDIMENT COVERED BED. THERE IS AN 8 TO 10 FT VERTICAL DROP IN ~100 FT AT THE PRESENT MOUTH OF DEER CREEK.					

* INCLUDES FIELD OBSERVATIONS AND DATA.

TABLE 8
RELATIVE CONSTRUCTION COSTS

TYPE OF WORK	BATUPAN BOGUE FY-74	BATUPAN BOGUE ITEM 4A	BATUPAN BOGUE ITEM 4A-1	BATUPAN BOGUE ITEM 4A-2	HIRED LABOR FY-80	HUNTER CREEK ITEM 1A	JOHNSON CREEK ITEM 9	PERRY CREEK ITEM 6A	TILLATOBA & HUNTER CREEK ITEM 1	TILLATOBA CREEK N.F. ITEM 2	TILLATOBA CREEK S.F. FY 72	TILLATOBA CREEK S.F. FY 73	TILLATOBA CREEK S.F. ITEM 5A	TILLATOBA CREEK S.F. ITEM 5B	TILLATOBA CREEK S.F. ITEM 5C
TRANSVERSE STONE DIKE	22.87		33.00			27.46			23.98	23.98	28.81	36.65			
LONGITUDINAL STONE DIKE W/TIEBACK	108.90	38.00							40.64	42.04	77.45	77.34			
LONGITUDINAL STONE DIKE W/2 TIEBACKS									55.61	42.76					
LONGITUDINAL STONE DIKE W/MORE TIEBACKS									65.78	44.26					
TYPE I STONE DIKE									34.53						
TYPE I LONGITUDINAL STONE DIKE W/1 TYPE I TIEBACK						18.26		18.95	20.21						
TYPE I LONGITUDINAL STONE DIKE W/MORE THAN 1 TYPE I TIEBACK						24.47			31.06						
TYPE II LONGITUDINAL STONE DIKE W/1 TIEBACK			33.00			43.39		28.42	48.20						39.00
TYPE III LONGITUDINAL STONE DIKE W/1 TIEBACK			55.00												65.00
LONGITUDINAL PEAKED STONE DIKES II		30.00	33.00				43.76	28.42							52.00
LONGITUDINAL PEAKED STONE DIKES III			66.00				65.68								78.00
STONE PAVING			38.00					23.45		21.00					
USED-TIRE REVETMENT		28.00	18.41										33.00		33.00
SAND-CEMENT BAG REVETMENT		62.00											99.00		
TIRE POST RETARDS								11.61							
WIRE CRIB RETARDS								(TIRE) 21.85						(HAY) 25.00 (TIRE) 25.00	
BOARD-FENCE TRANSVERSE DIKE	26.08											37.80			
BOARD-FENCE LONGITUDINAL REVETMENT	115.20														
CABLE FENCE DIKES												44.55			
VEGETATIVE TREATMENT OR WILLOW PLANTING				9.22	3.30										
LONGITUDINAL PEAKED STONE DIKE I							10.94								

TABLE 9
SUMMARY OF YAZOO BASIN DEMONSTRATION PROJECTS

Fiscal Year	Item	Construction Cost in $1,000	Types of Work	Status of Work
72	South Fork Tillatoba Creek, Item FY 72	237.7	Transverse and Longitudinal Stone Dikes	Structures Performing Satisfactorily.
73	South Fork Tillatoba Creek, Item FY 73	222.9	Transverse and Longitudinal Stone Dikes, Cable Fence Dikes, and Board Fence Dikes	Structures Performing Satisfactorily, Minor Erosional Problem Noted.
74	Batupan Bogue, Item FY 74	565.0	Board Fence Dikes and Board Fence Revetment	Structures Performing Satisfactorily.
76-77	North Fork Tillatoba and Hunter Creeks, Item No. 1	626.0	Transverse and Longitudinal Stone Dikes	Hunter Creek-Structures Performing Satisfactorily, North Fork Tillatoba-Majority of Structures Performing Satisfactorily; Channel Instability Has Caused Some Problems.
76-77	North Fork Tillatoba Creek, Item No. 2	530.0	Transverse and Longitudinal Stone Dikes and Stone Bank Paving	Majority of Structures Performing Satisfactorily; Channel Instability Has Caused Some Problems.
77	Hunter Creek, Item 1A	112.0	Transverse and Longitudinal Stone Dikes	Structures Performing Satisfactorily
77	South Fork Tillatoba Creek, Item 5A (HL)	100.0	Used Tire and Sand-Cement Bag Revetments	Structures Performing Satisfactorily, with Exception of Slip Failure on Sand-Cement Bag Revetment.
77	South Fork Tillatoba Creek, Item 5B	161.0	Wire Crib Retards Filled with Used Tires or Hay	Structures Failed Soon After Construction.
77	North Fork Tillatoba Creek, Item 3C	128.4	Stone Grade Control Structure with Sheet Pile Cutoff Wall and H-Pile Baffle	Structure Performing Satisfactorily.
77-78-79-80	North Fork Tillatoba Creek, Item 3A	210.0	Stone Grade Control Structure with Sheet Pile Cutoff Wall and Sheet Pile Baffle Filled with Grouted Riprap	Structure Performing Satisfactorily.
77-78-79-80	Batupan Bogue, Item 4A	946.0	Longitudinal Stone Dike, Used Tire Revetment, and Sand-Cement Bag Revetment	Majority of Structures Failed During High Runouts in Nov 77; Rehab. Work Performed Under Work Item 4A-1
78	Perry Creek, Item 6A	432.0	Longitudinal Stone Dike, Wire Crib Retards Filled with Used Tires, and Used Tire Post Retards	Majority of Structures Performing Satisfactorily; Degradation has Adversely Affected Performance of Some Structures
78	South Fork Tillatoba Creek, Item 5C	456.0	Longitudinal Stone Dikes with Stone Tie Backs and Used Tire Revetment	Majority of Structures Performing Satisfactorily; Degradation Has Adversely Affected Performance of Some Structures.
78	Perry Creek, Item 6B	702.0	Two Stone Grade Control Structures - One with Sheet Pile Baffle and One with H-Pile Baffle	Lower Structure Is Performing Satisfactorily; Upper Structure Is Endangered by Erosion of Upstream Left Bank
78-79	Batupan Bogue, Item 4A-1	498.0	Used Tire Revetment, Vegetative Treatment and Stone Tie Backs	Majority of Structures Performing Satisfactorily; However Erosional Problems Still Exist.
78-79	Goodwin Creek, Item 8B	736.0	Three Grade Control Structures	Structures Integrity OK; Data Collection System Not Operational
78-79-80	Vegetation, Items 12A & 12ARS Agreement	632.0	Vegetative Treatment	Construction Completed, Spring 1981
79	Vegetation, Batupan Bogue, Item 4A-2	64.0	Vegetative Treatment (Work Performed by Minority Contractor)	Vegetation has been Established; However Some Erosional Problems Noted
79	Johnson Creek, Item 9A	177.0	Longitudinal Peaked Stone Dikes 1/2, 2, and 3 Tons Stone Per Lin Ft	Structures Performing Satisfactorily (Minimum Protection Work)
79-80	Goodwin Creek, Item 8A	286.0	One Grade Control Structure	Structure Integrity OK; Data Collection System Not Operational
79-80	Goodwin Creek, Item 8C	865.0	Ten Grade Control Structures	Structures Integrity OK; Data Collection System Not Operational
80	Johnson Creek, Item 9B	152.0	Three Minimum Grade Control Structures (Work Performed by Minority Contractor)	Numerous Construction Delays; Not Yet Accepted by Vicksburg District
80	Hotophia Creek, Item 7	252.0	Five Minimum Grade Control Structures	Structures Performing Satisfactorily
	TOTAL	9,091.0		

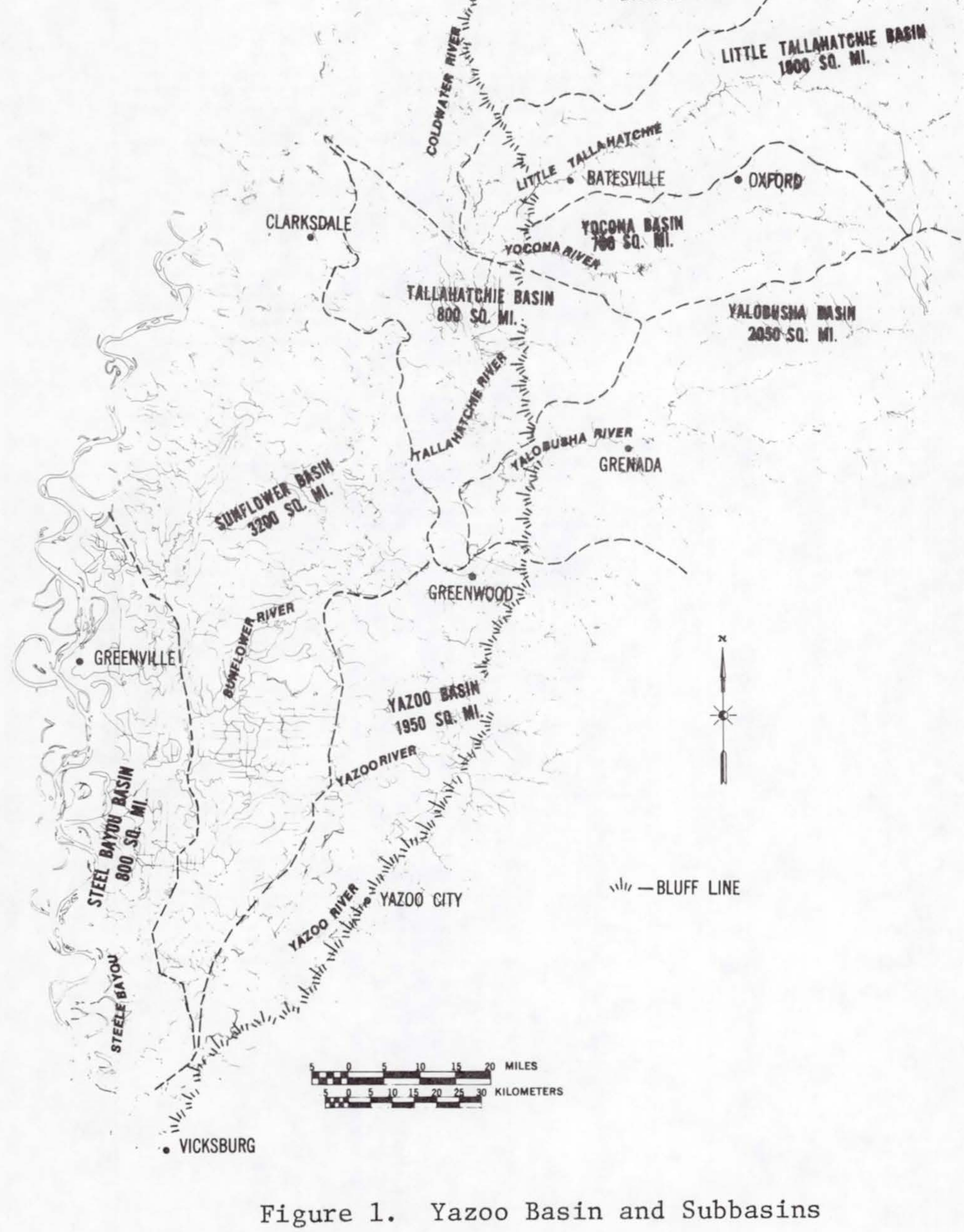


Figure 1. Yazoo Basin and Subbasins

GEOLOGY - VS - THE UNIFIED SOIL CLASSIFICATION

ERA	PERIOD	EPOCH (APPROXIMATE YEAR'S AGO)	AVERAGE THICKNESS (FEET)	FORMATION NAME	USC SYMBOL	MODIFICATIONS USED BY UNIFIED SOIL CLASSIFICATIONS	LETTER SYMBOL	UNIFIED SOIL CLASSIFICATION DESCRIPTION	GEOLOGIC DESCRIPTIONS	GEOLOGIC SYMBOL
CENOZOIC (65 MILLION TO RECENT)	QUATERNARY (2.5 MILLION TO RECENT)	(RECENT) HOLOCENE (5000 YEARS)	0-15 MAX 60	POST SETTLEMENT ALLUVIUM		- SANDY SILT STRATA - SILTY SAND STRATA	ML -	SILTY & VERY FINE SAND, SILTY OR CLAYEY FINE SAND OR CLAYEY SILT WITH SLIGHT PLASTICITY	TAN TO BROWN, MIXED LOAM, SAND, GRAVEL, CLAY, AND SILT WITH FLUVIAL BEDDING FEATURES	
			VARIABLE 0-10	YOUNG PALEOSOL			ML - CL -	SILT & VERY FINE SAND, SILTY OR CLAYEY FINE SAND OR CLAYEY SILT WITH SLIGHT PLASTICITY LEAN CLAY; SANDY CLAY; SILTY CLAY; OF LOW TO MEDIUM PLASTICITY	LIGHT BROWN, SILTY OR CLAYEY FINE SAND	
		PLEISTOCENE (2.5 MILLION)	VARIABLE 0-10	OLD PALEOSOL		- SAND STRATA OR LENSES - CLAY STRATA OR LENSES - MOTTLED	ML - CL -	SILT & VERY FINE SAND, SILTY OR CLAYEY FINE SAND OR CLAYEY SILT WITH SLIGHT PLASTICITY LEAN CLAY; SANDY CLAY; SILTY CLAY; OF LOW TO MEDIUM PLASTICITY	DENSE GRAY, MOTTLED, SILTY OR CLAYEY FINE SAND	
			25-30	LOESS			CL - ML -	LEAN CLAY SANDY CLAY; SILTY CLAY; OF LOW TO MEDIUM PLASTICITY SILT TO VERY FINE SAND, SILTY OR CLAYEY FINE SAND OR CLAYEY SILT WITH SLIGHT PLASTICITY	MASSIVE. TAN COLORED SILTS AND FINE SAND	
			0-125	CITRONELLE		- GRAVELLY	SW - GC -	SAND WELL-GRADED, GRAVELLY SANDS CLAYEY GRAVEL, GRAVEL-SAND-CLAY MIXTURES	VARIOUS SHADES OF RED SANDS, WITH LOCAL LENSES OR LAYERS OF CHERT & QUARTZ GRAVELS WITH INTERMIXED CLAYS	
	TERTIARY (65 MILLION)	MISSING: PLIOCENE (7 M) MIOCENE (26 M) OLIGOCENE (38 M)	0-150	KOSCIUSKO		- CONCRETIONS - SANDSTONE FRAGMENTS	SP - SM -	SANDY, POORLY-GRADED, GRAVELLY SANDS SILT SAND, SAND-SILT MIXTURES	CONSIST OF A BASAL PORTION OF IRON-STAINED, SLIGHTLY LIGNITIC HIGHLY CROSS-BEDDED SANDS AND CLAYS OVERLAIN BY GRAY TO BROWN, CARBONACEOUS LIGNITIC SILTS AND CLAYS. A LIGHT GRAY QUARTZITE CAN BE FOUND AT THE ZILPHA CONTACT	
		EOCENE (54 MILLION)	35-40	ZILPHA		- SANDY - ORGANICS	CL -	LEAN CLAY; SANDY CLAY; SILTY CLAY; OF LOW TO MEDIUM PLASTICITY	CONSIST OF A BASAL UNIT OF GLAUCONITIC SAND, OVERLAIN BY A CHOCOLATE-BROWN TO GRAY CARBONACEOUS SILTY, SHALY CROSS-BEDDED CLAY WITH STRINGERS AND LENSES OF MICACEOUS SANDS CAPPED BY AN UPPER LAYER OF GREEN SAND	
			20-25	WINONA		- ORGANICS	CL - ML -	LEAN CLAY; SANDY CLAY; SILTY CLAY; OF LOW TO MEDIUM PLASTICITY SILT & VERY FINE SAND, SILT OR CLAYEY FINE SAND OR CLAYEY SILT WITH SLIGHT PLASTICITY	INTERBEDDED, PALE-GRAY GLAUCONITIC, SILTY CHALKS AND SANDY MARLS WITH MINOR AMOUNTS OF LIGHT-GRAY AND GREENISH-GRAY, FOSSILIFEROUS, SLIGHTLY CALCAREOUS CLAY AND CLAY SHALES	
		BEGINS 46M	200+	TALLAHATTA		- SHALE FRAGMENTS	SM - SC -	SILTY SAND, SAND-SILT MIXTURES CLAYEY SAND, SAND-CLAY MIXTURES	INTERBEDDED, SHALE, CLAY, SAND AND SILT WITH TRACES OF SANDSTONE AND SILT STONE	

Figure 2. Unified soil classification vs geologic description

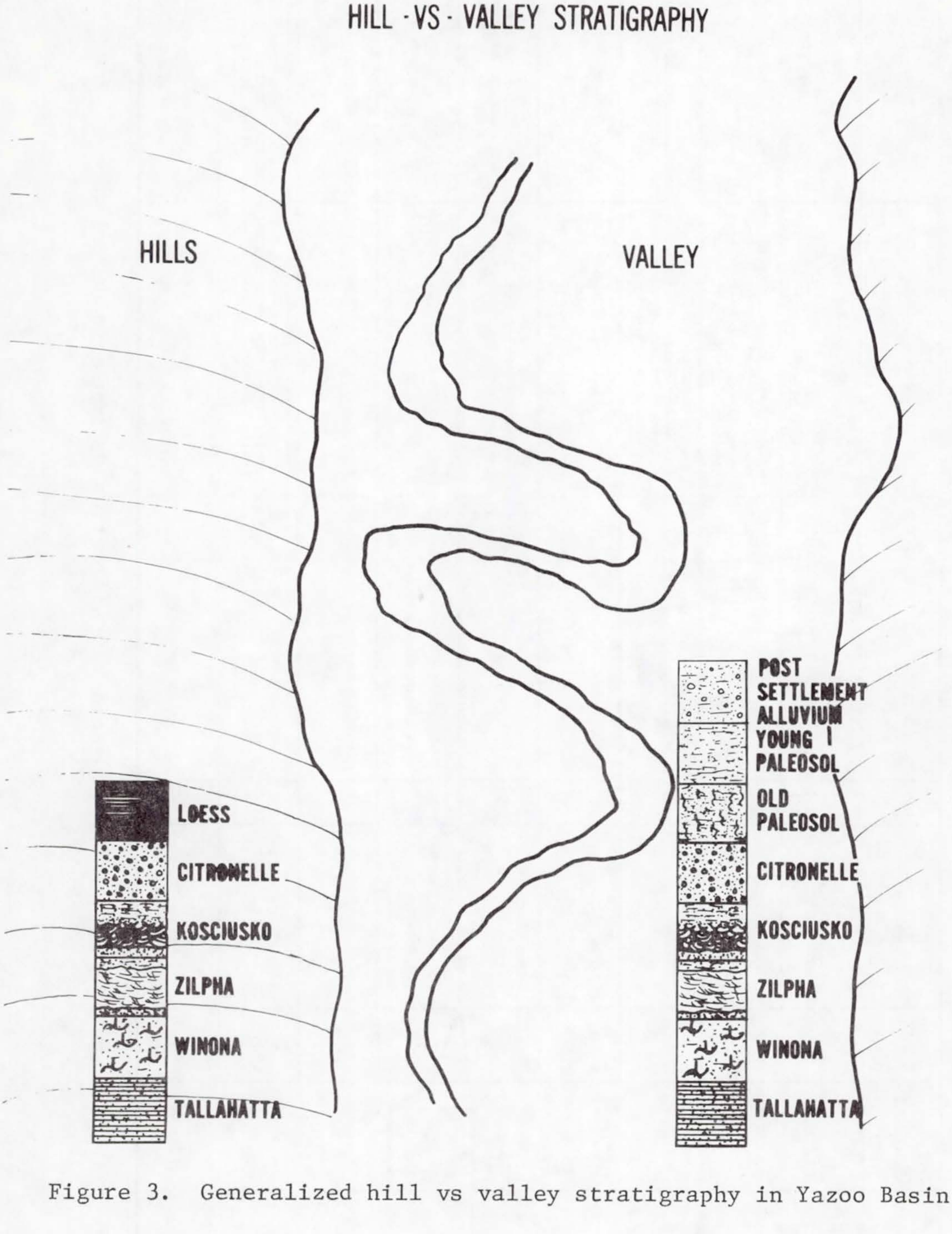


Figure 3. Generalized hill vs valley stratigraphy in Yazoo Basin

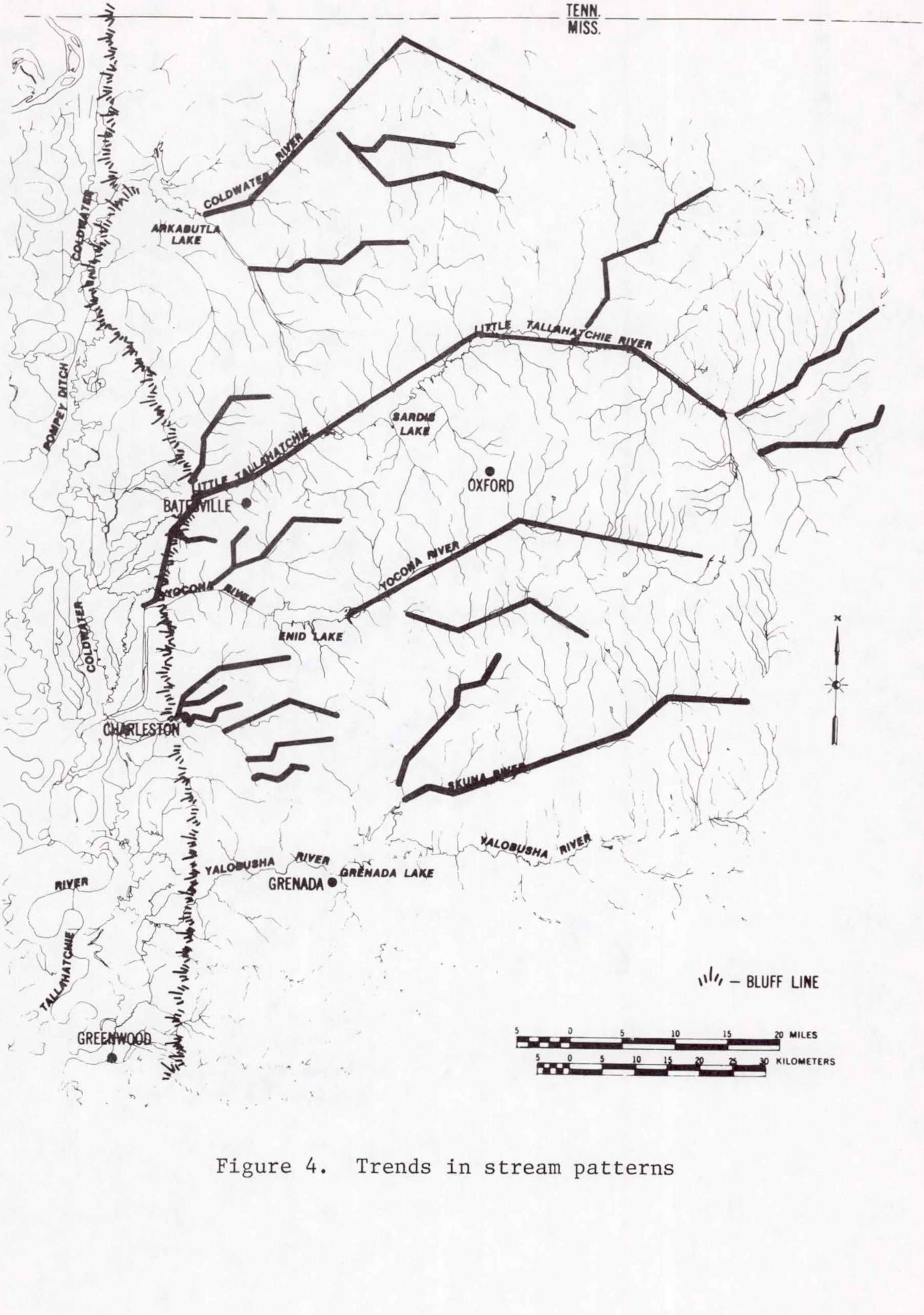


Figure 4. Trends in stream patterns

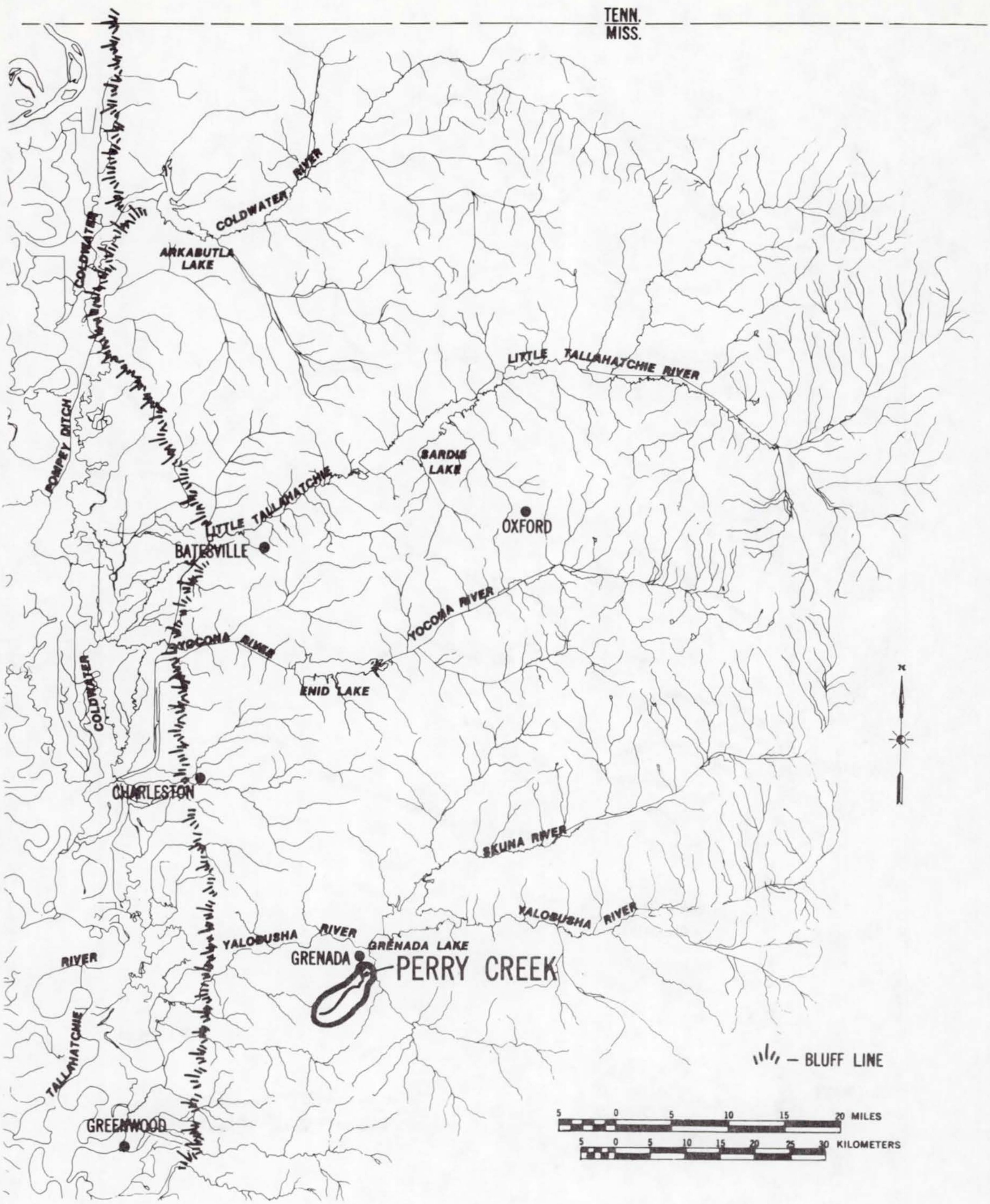


Figure 5. Location of Perry Creek Basin

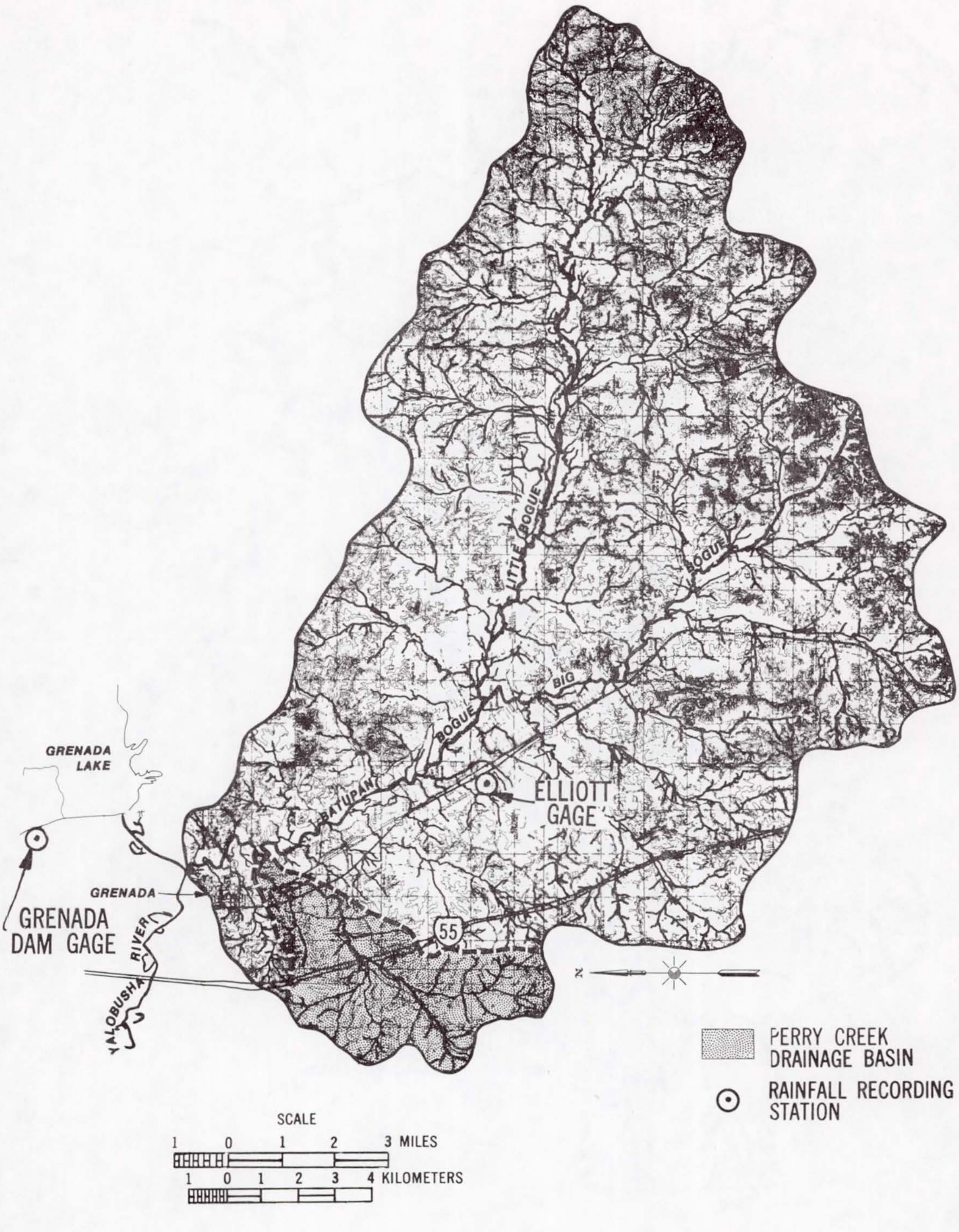


Figure 6. Batupan Bogue Drainage Basin

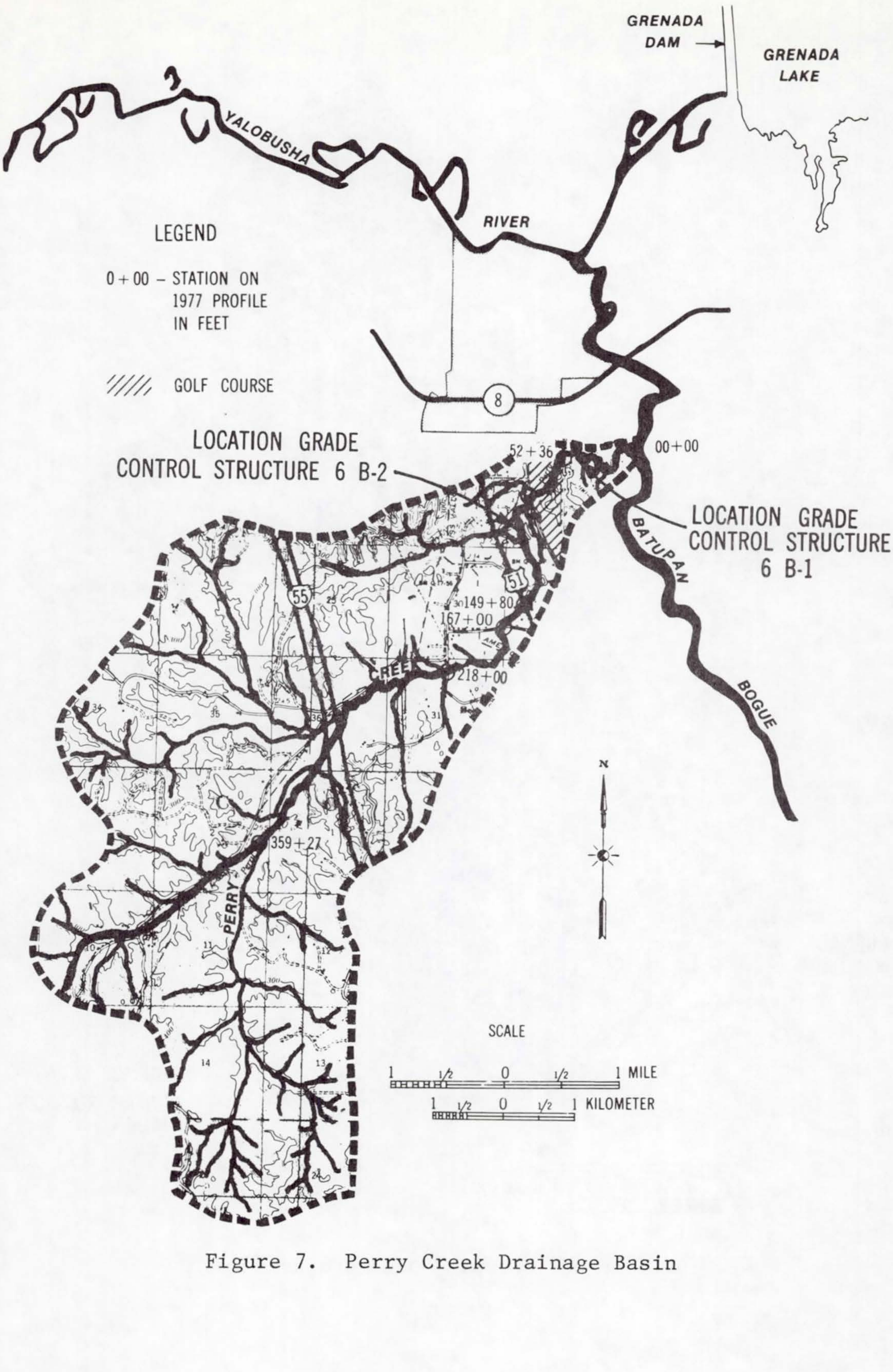


Figure 7. Perry Creek Drainage Basin

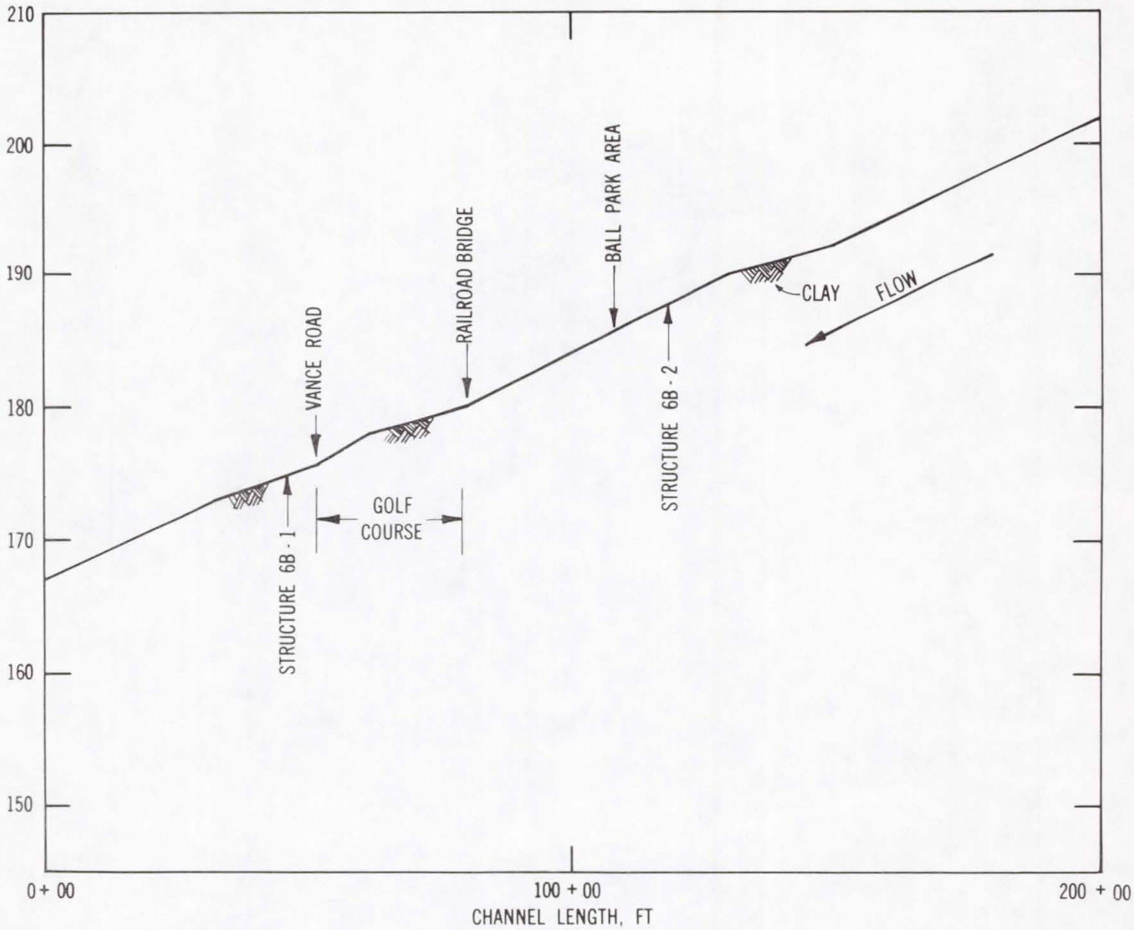


Figure 8a. Perry Creek thalweg profile 0+00 to 200+00

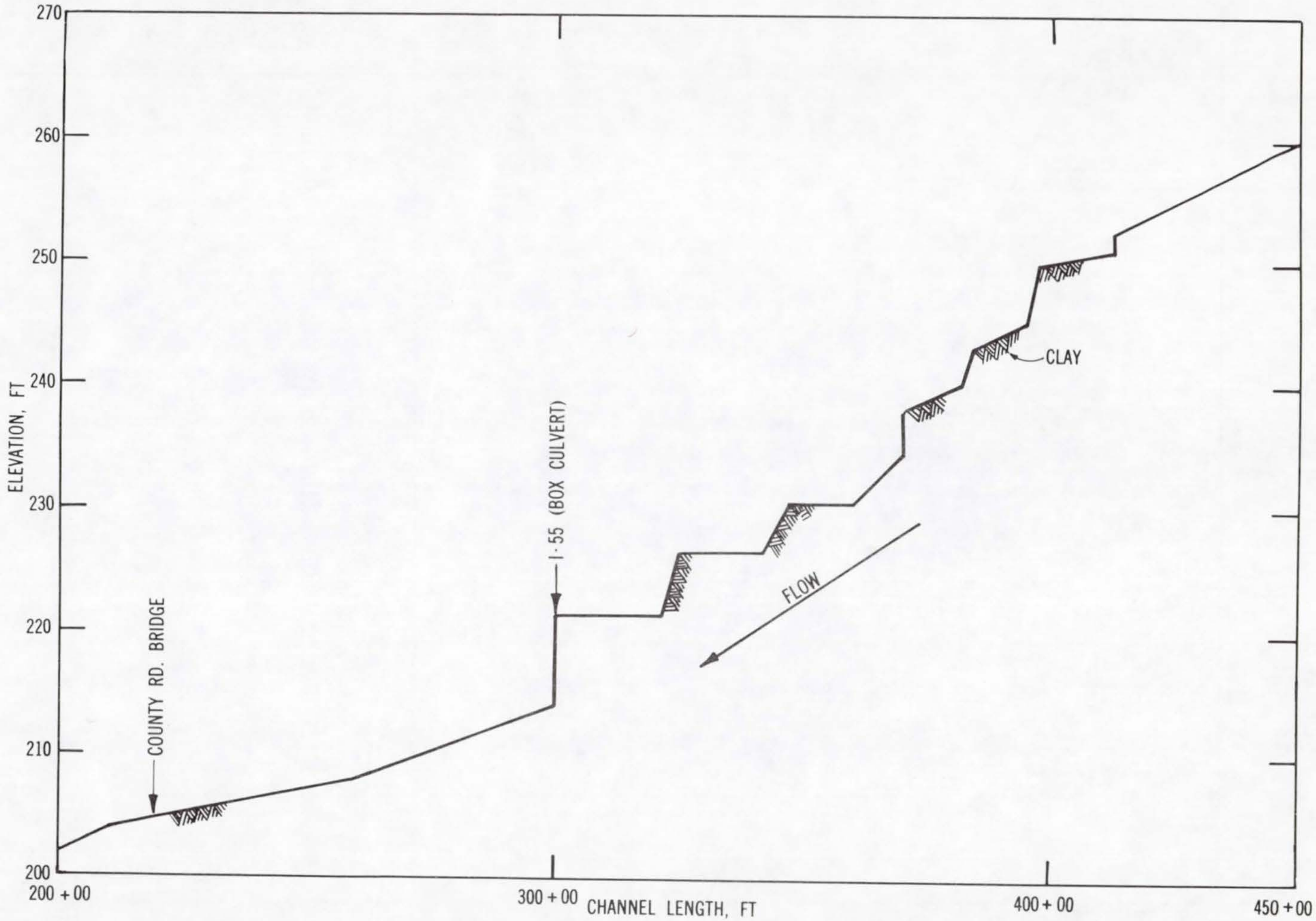


Figure 8b. Perry Creek thalweg profile 200+00 to 450+00

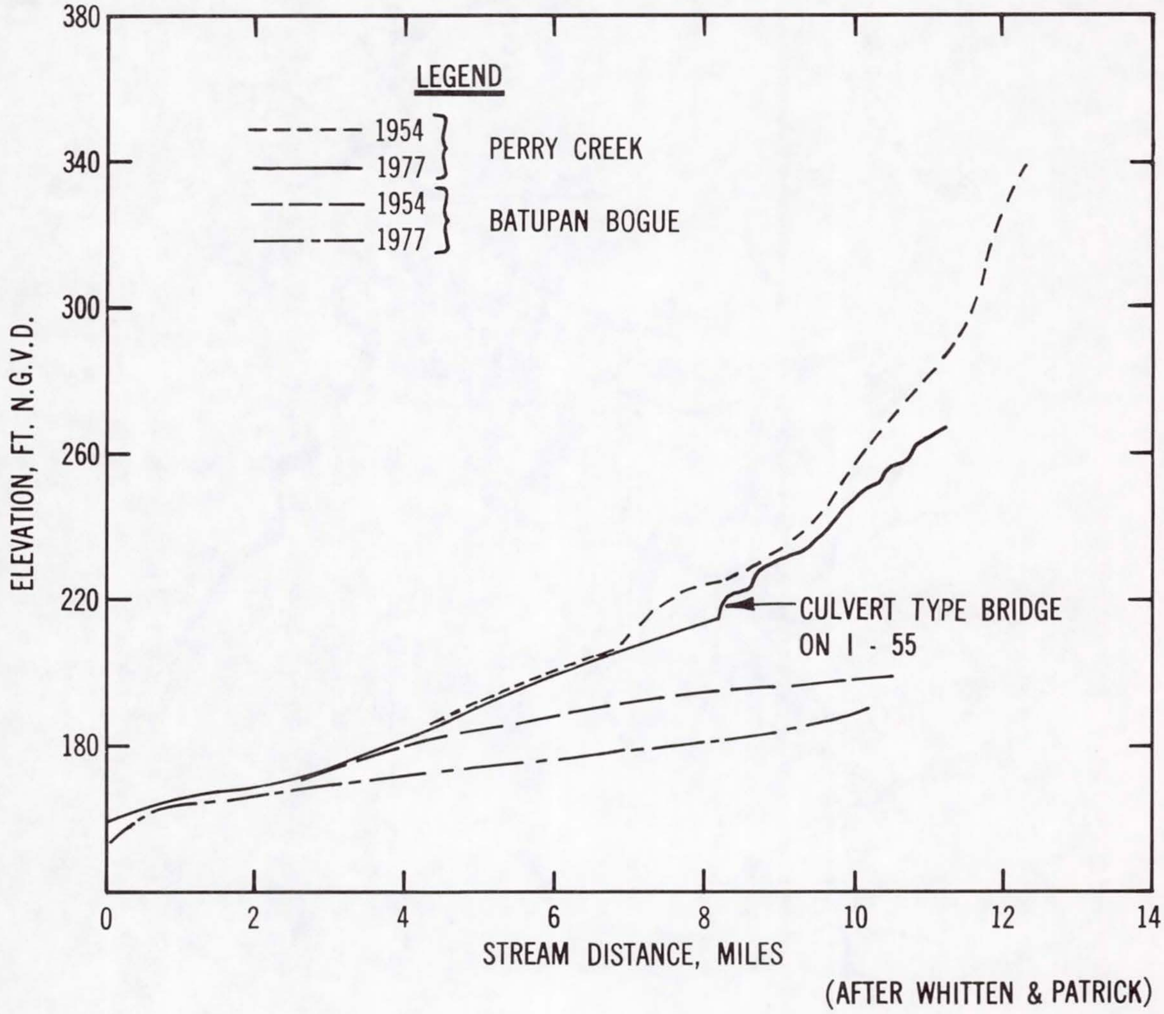


Figure 9. Perry Creek and Batupan Bogue profile comparisons

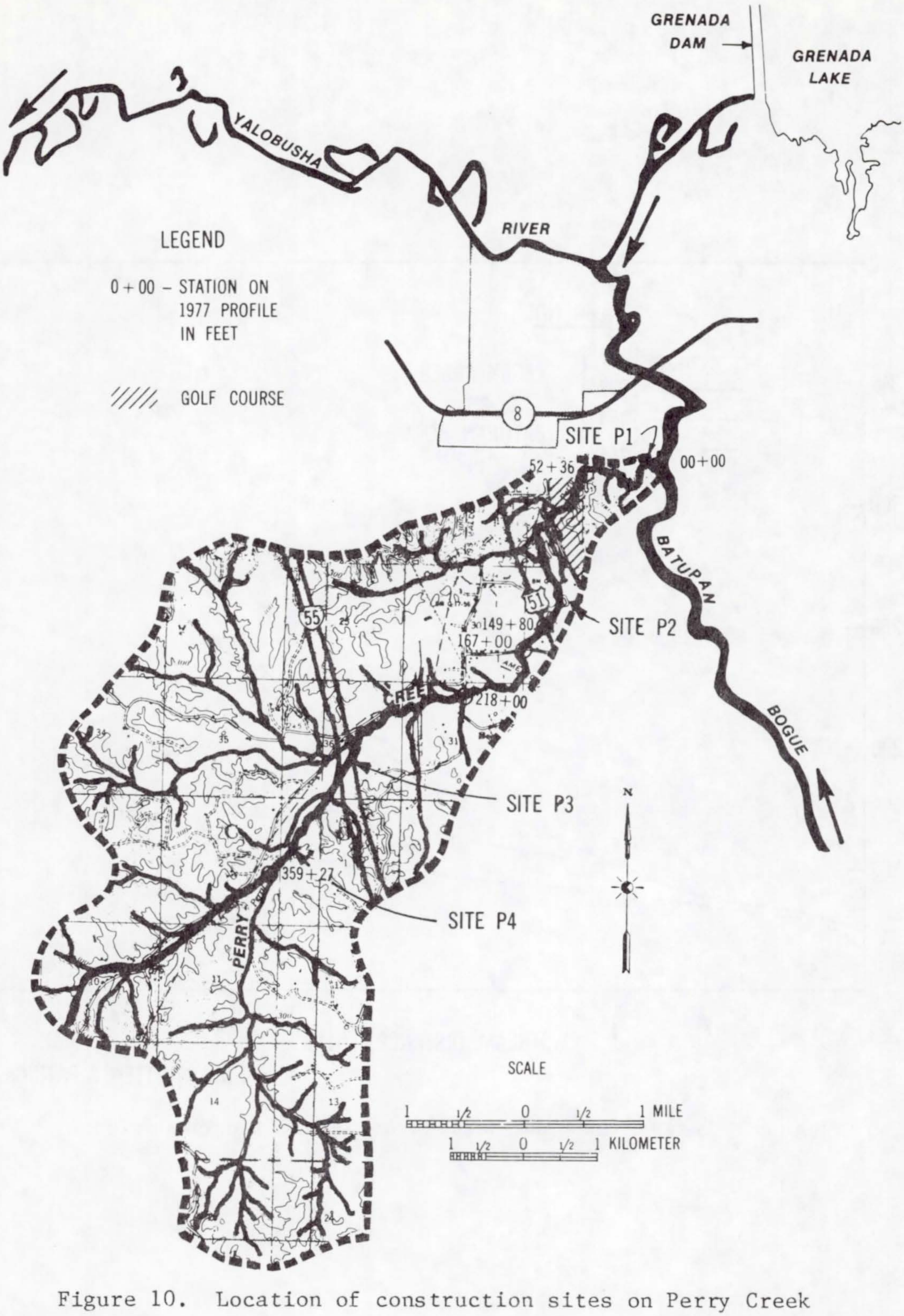


Figure 10. Location of construction sites on Perry Creek

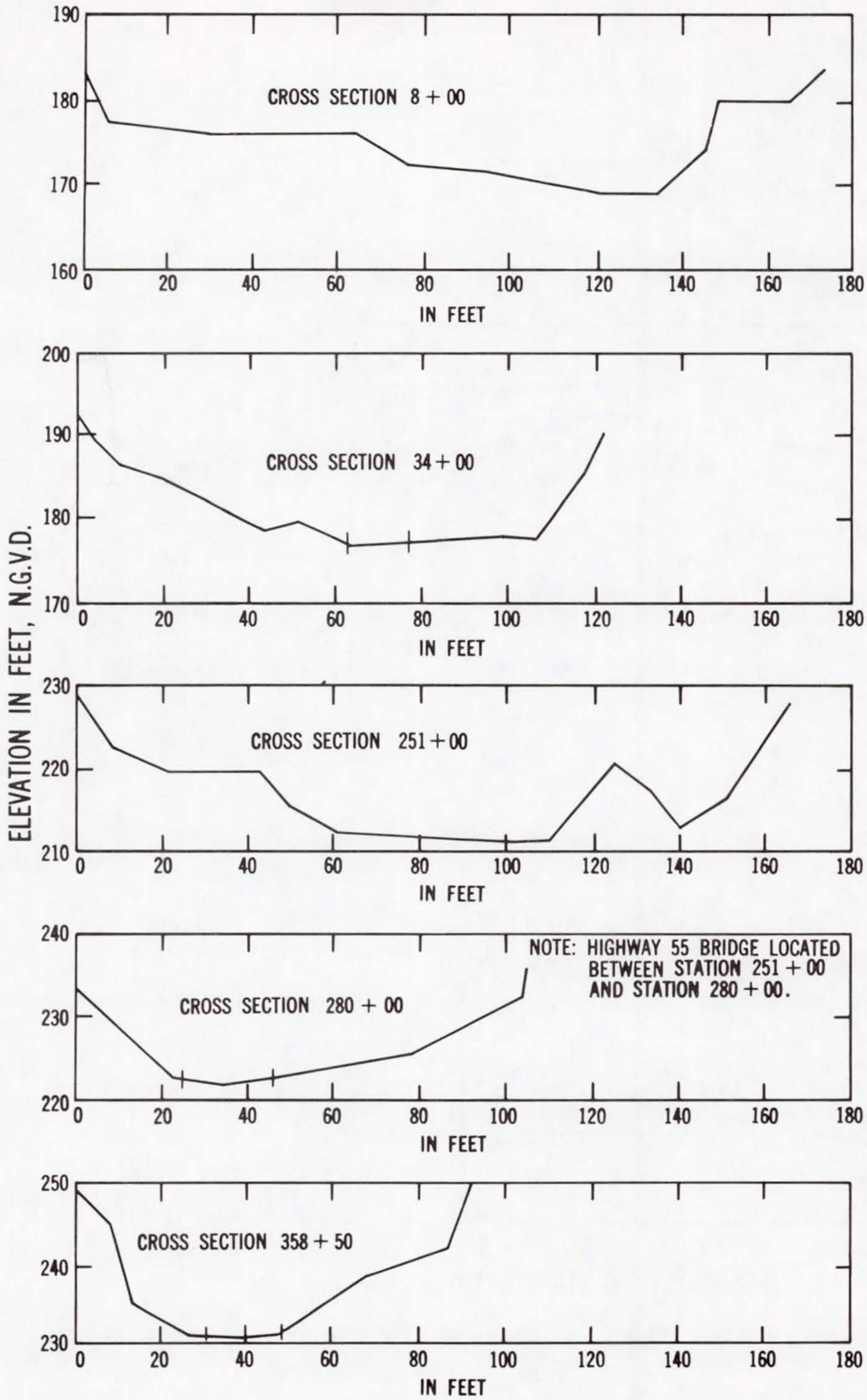


Figure 11. Cross sections of Perry Creek in 1977

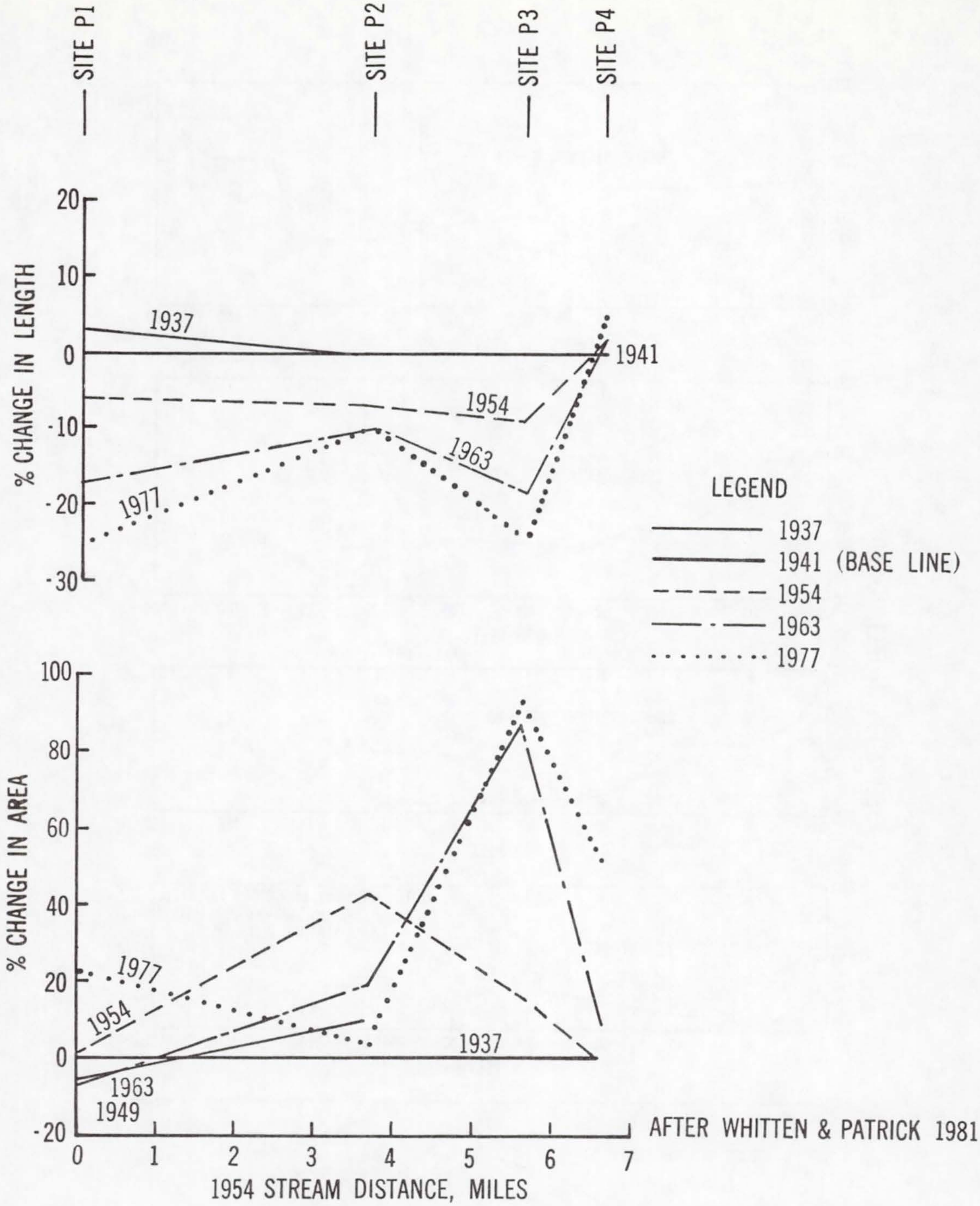


Figure 12. Changes in area and length, Perry Creek

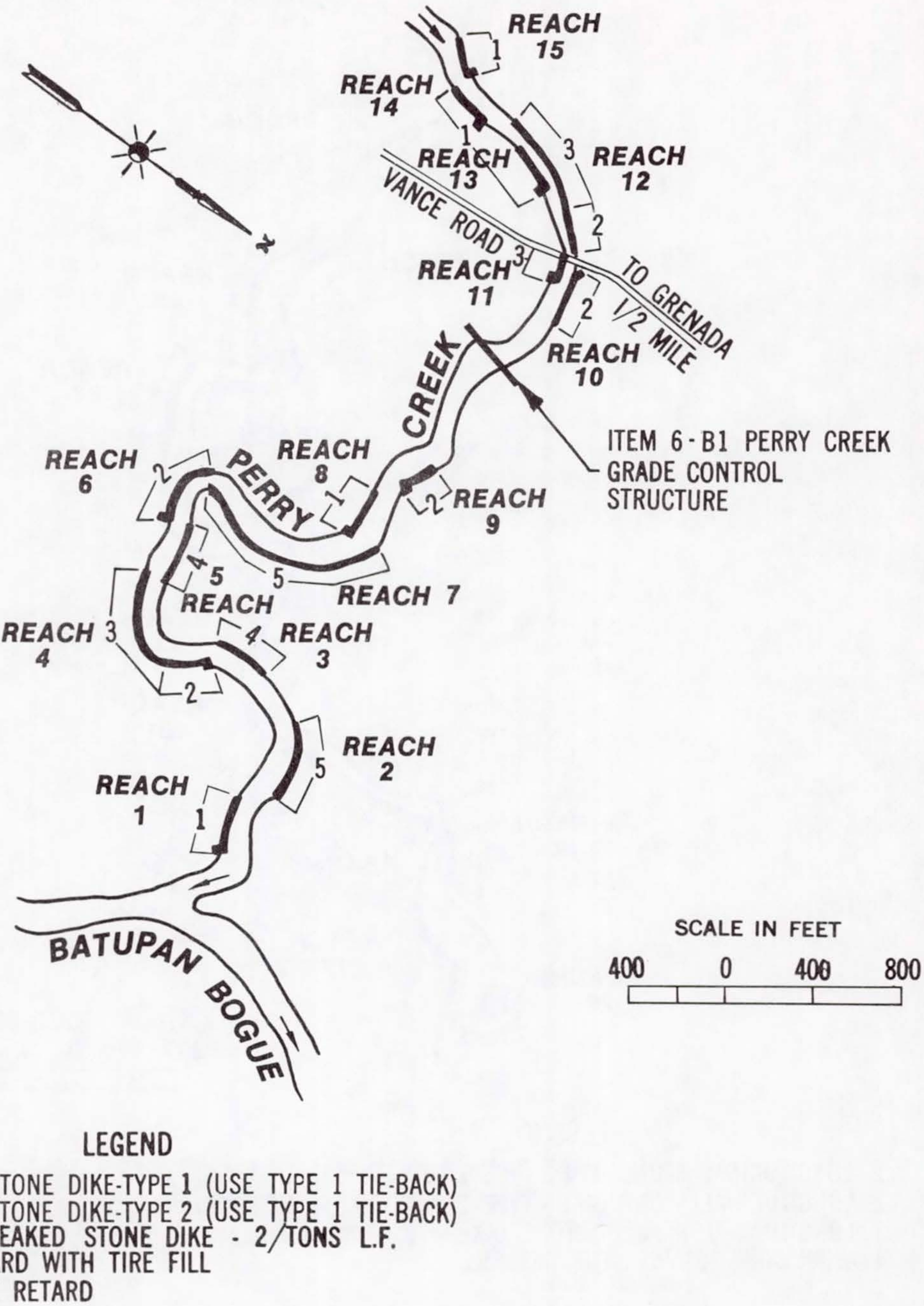
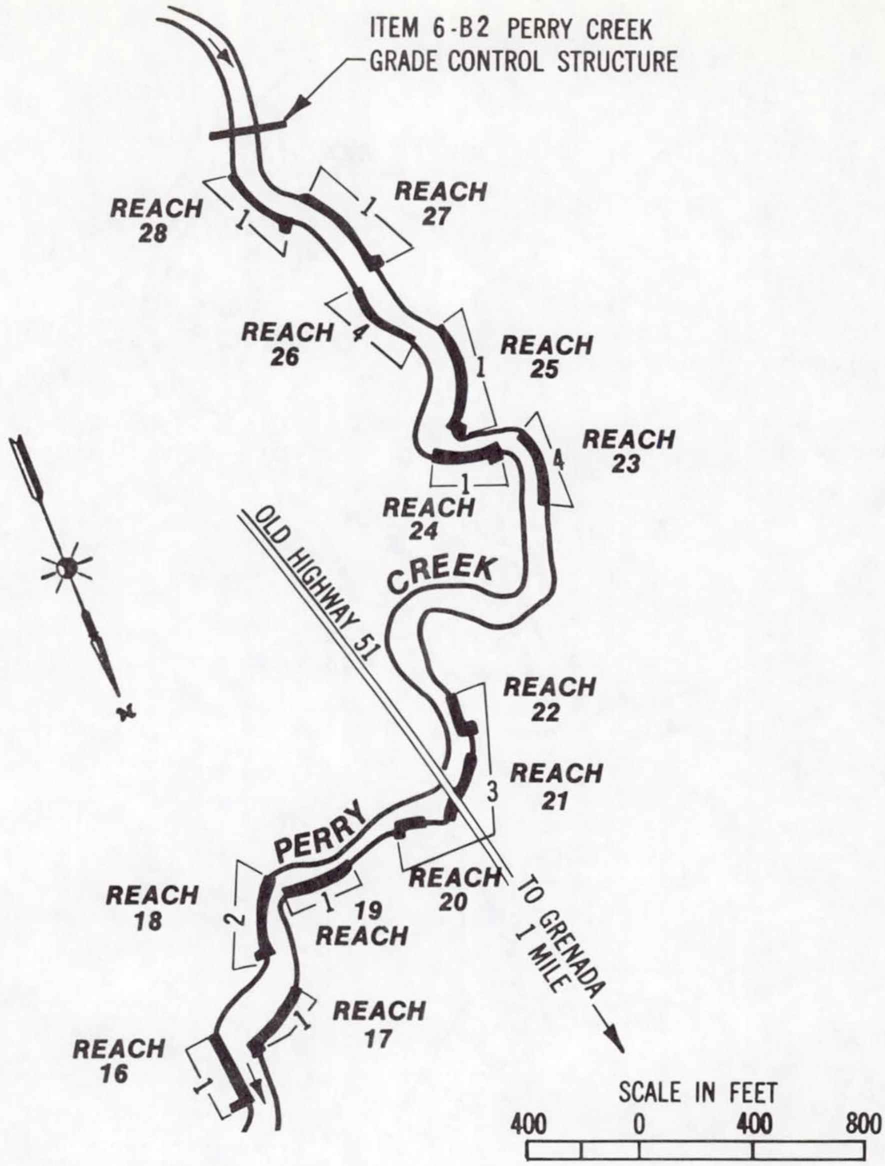


Figure 13. Perry Creek Items 6A and 6B



LEGEND

1 LONGITUDINAL STONE DIKE - TYPE 1 (USE TYPE 1 TIE-BACK)
2 LONGITUDINAL STONE DIKE - TYPE 2 (USE TYPE 1 TIE-BACK)
3 LONGITUDINAL PEAKED STONE DIKE - 2 TONS/L.F.
4 WIRE CRIB RETARD WITH TIRE FILL

Figure 14. Perry Creek Items 6A and 6B

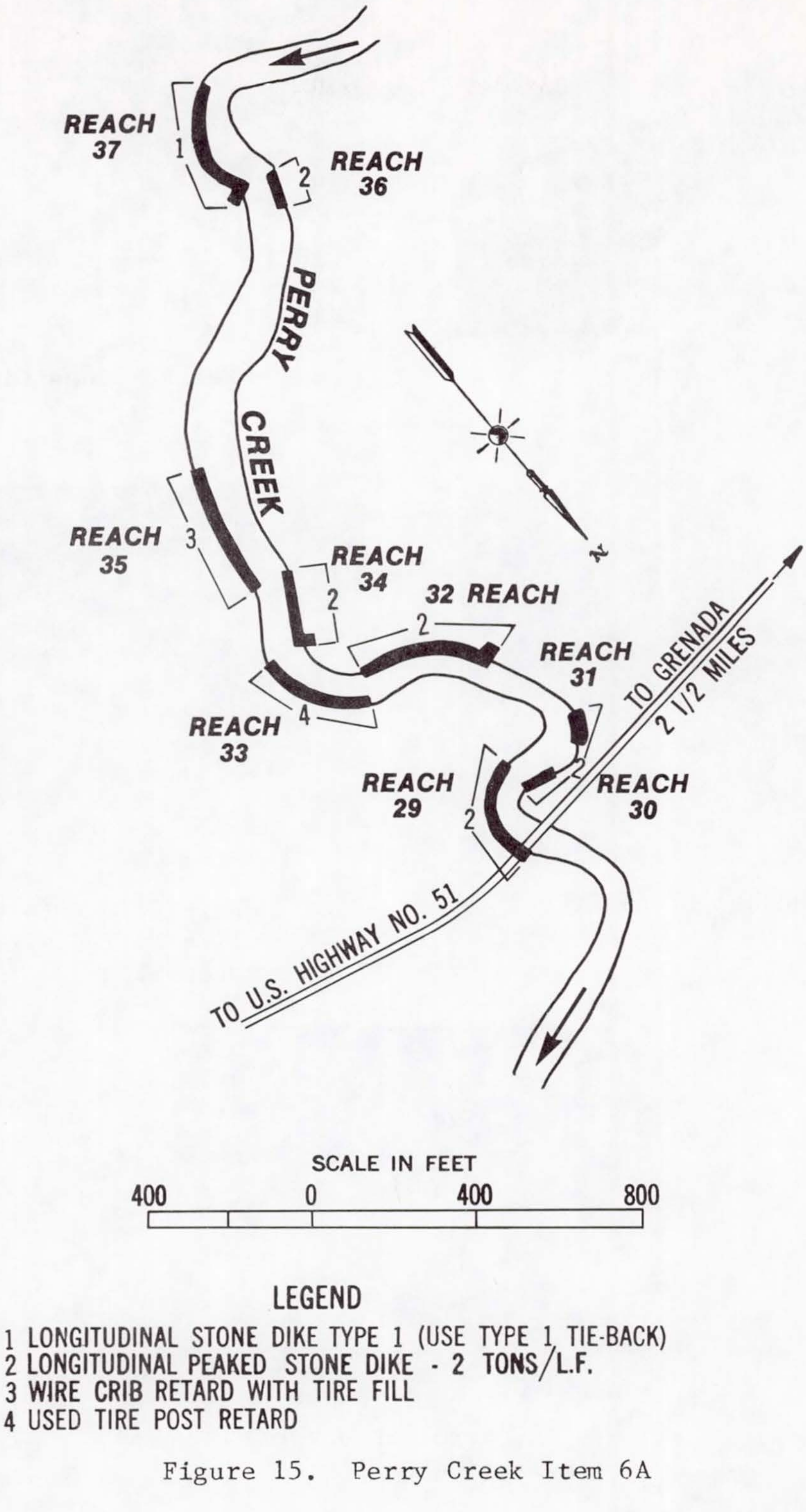
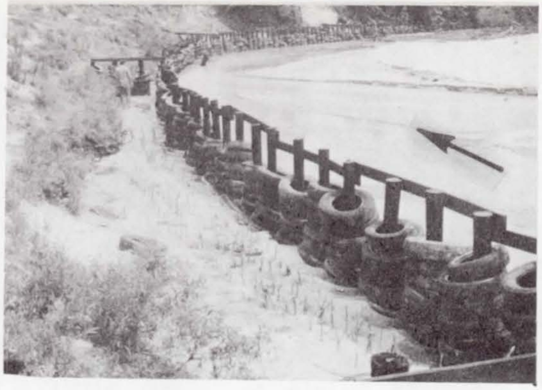
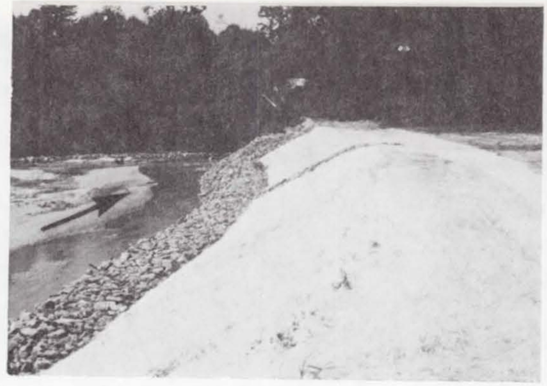


Figure 15. Perry Creek Item 6A



Tire Post Retards



Peaked Stone Dike

Longitudinal Stone Dike

Wire Crib Retards
Tire Filled with
Stone Toe

Grade Control Structure
with Hanging Baffle

Figure 16. Typical photographs of structures on Perry Creek

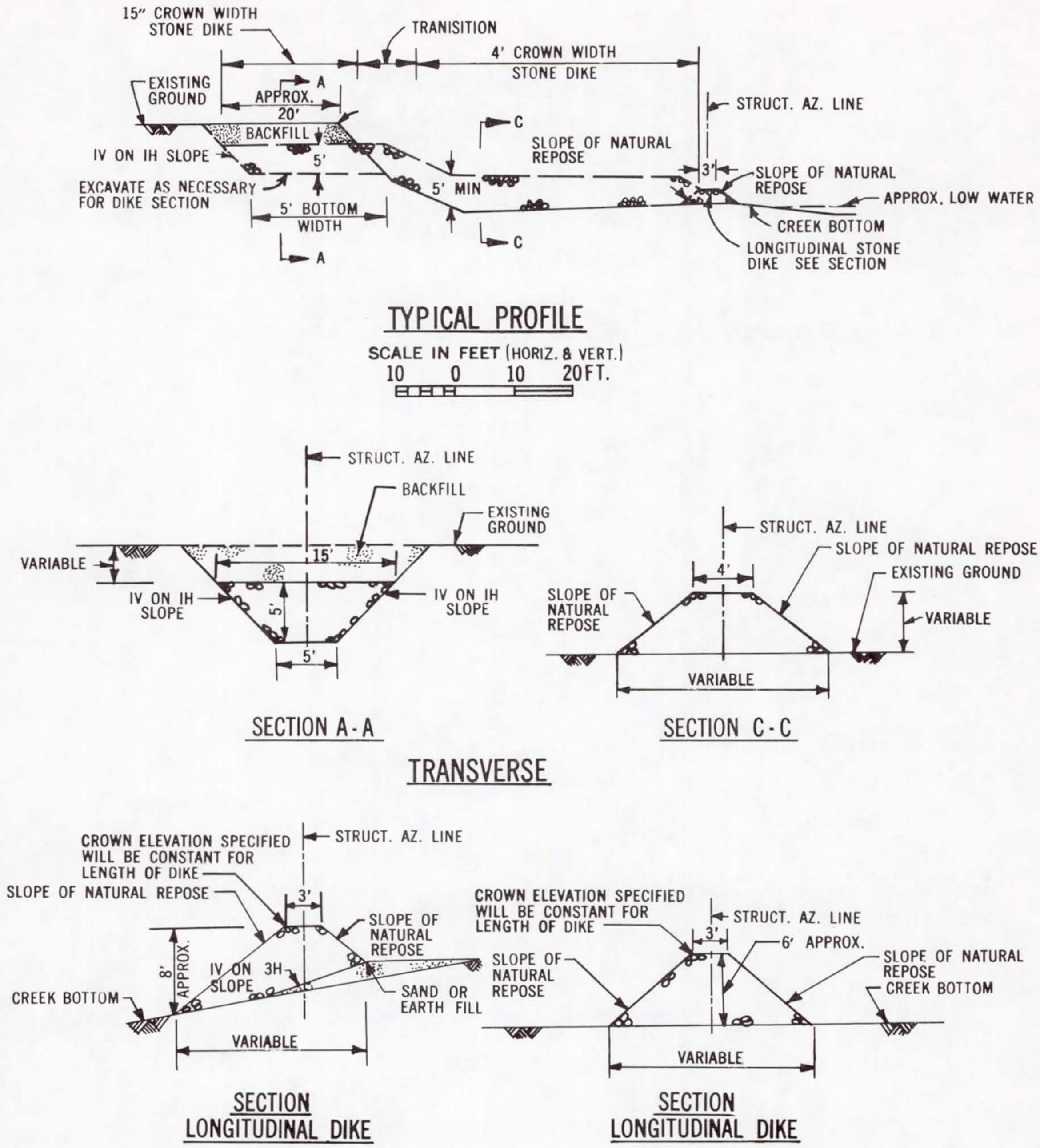


Figure 17. Typical transverse and longitudinal stone dikes

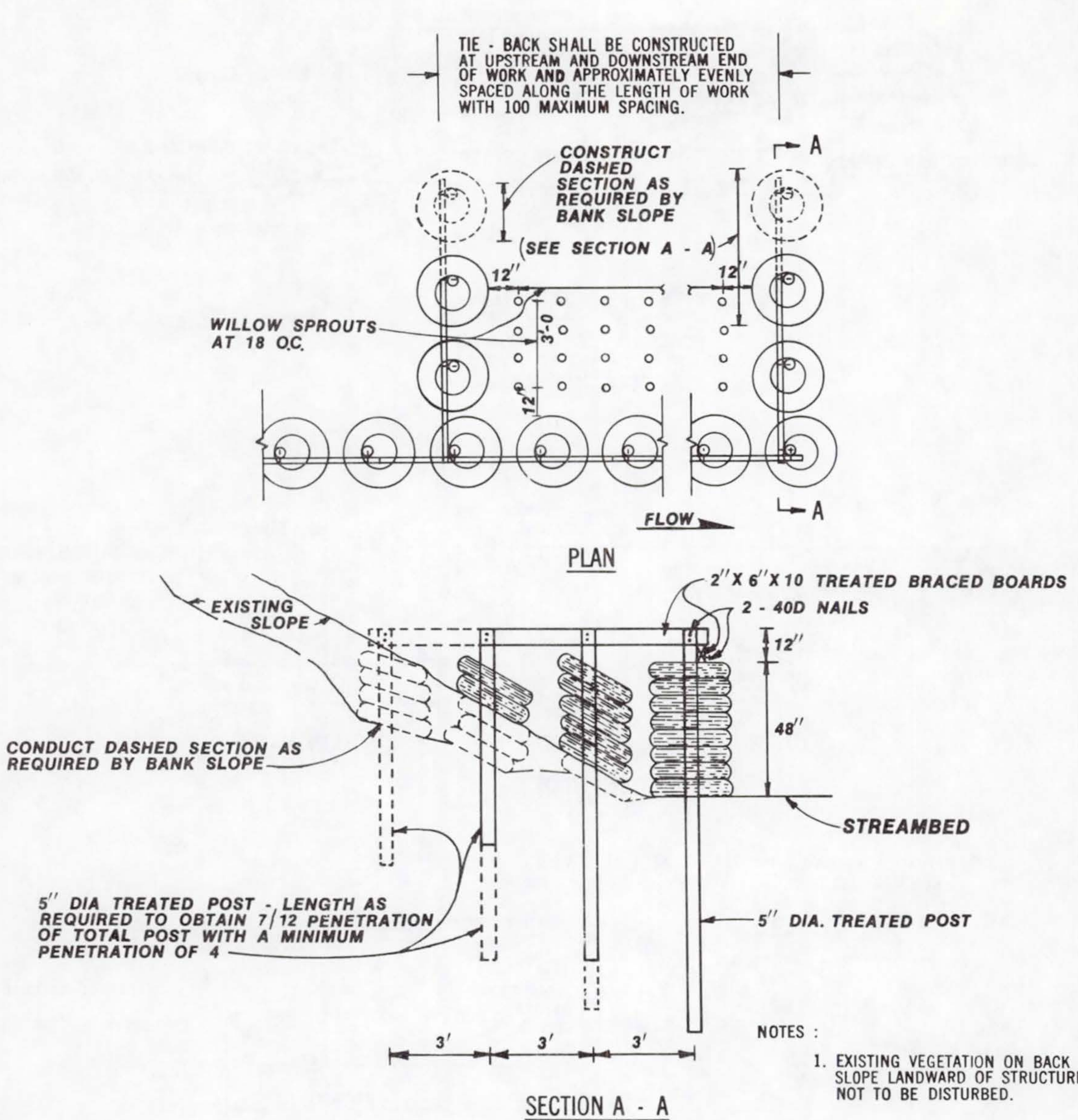


Figure 18. Typical tire post retards

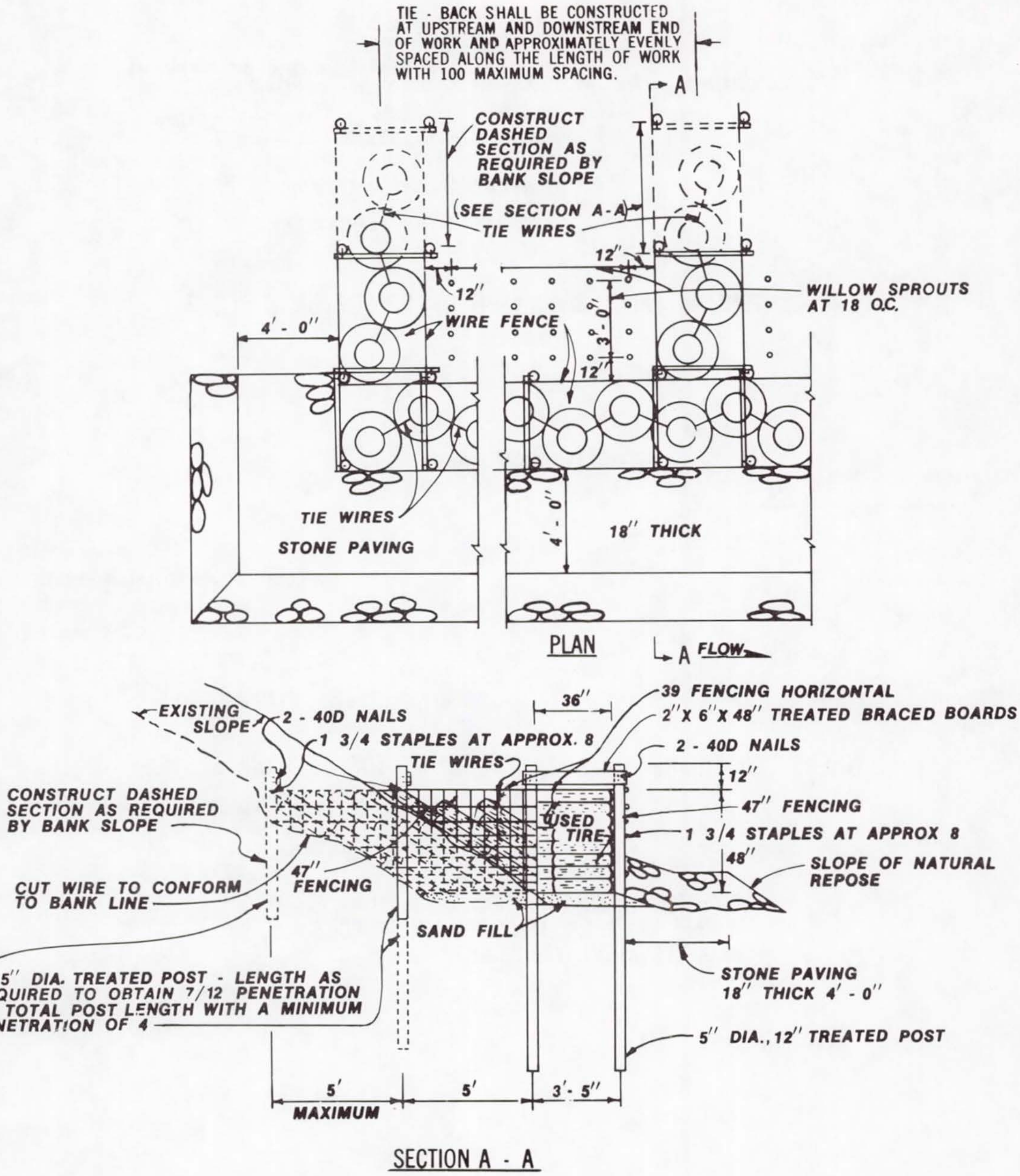
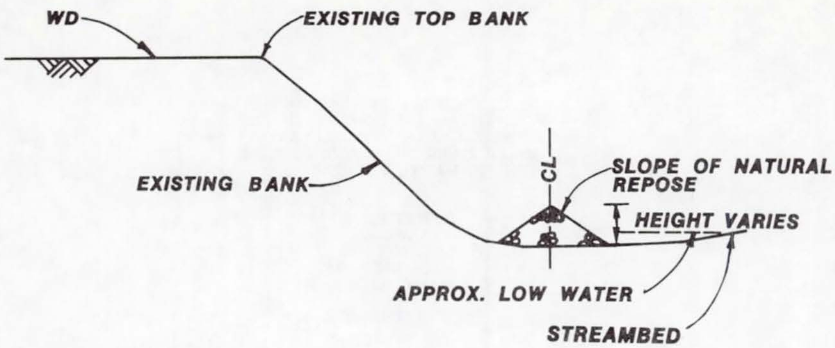
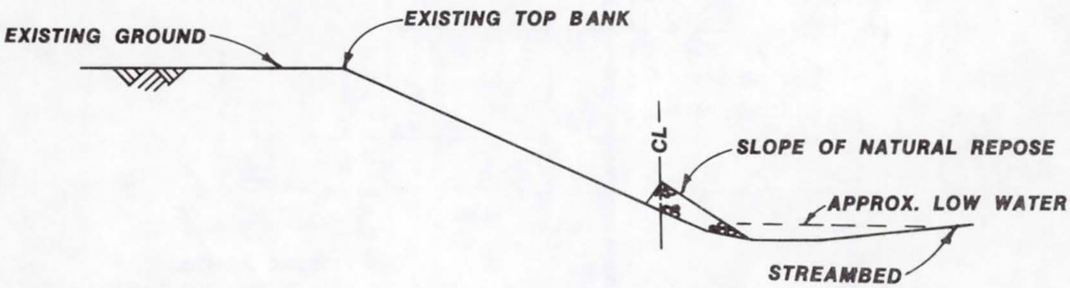


Figure 19. Typical wire crib retards, tire-filled



WHERE CENTERLINE FALLS RIVERWARD OF TOE OF BANK SLOPE



WHERE CENTERLINE FALLS LANDWARD OF TOE OF BANK SLOPE

DIKE TO BE CONSTRUCTION WITH STONE AT
A RATE OF 1-1/2 TONS PER LINEAR FOOT.
PEAK ELEVATION WILL VARY.

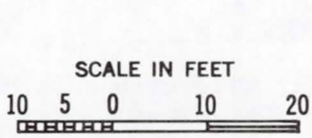


Figure 20. Typical longitudinal peaked stone dike

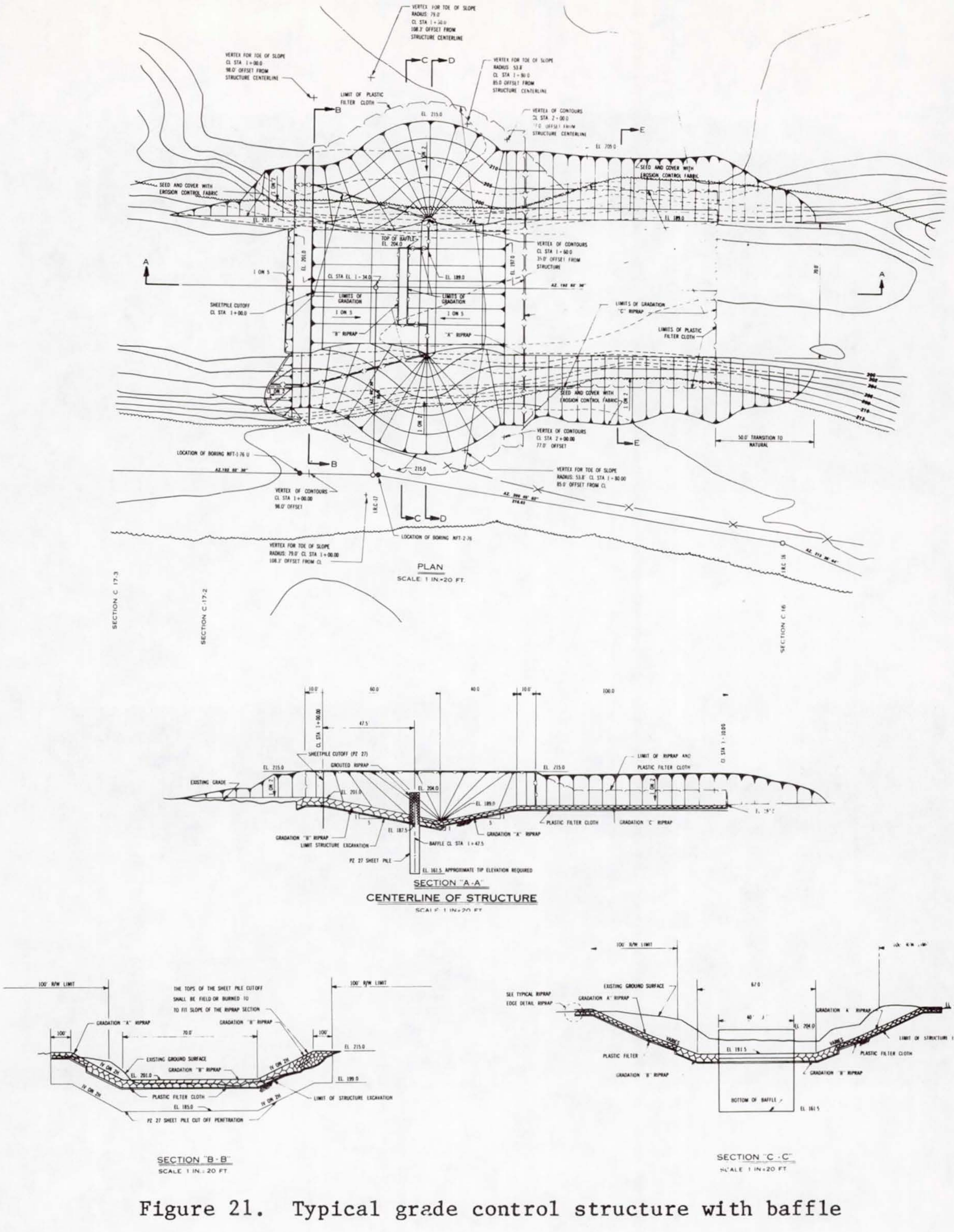
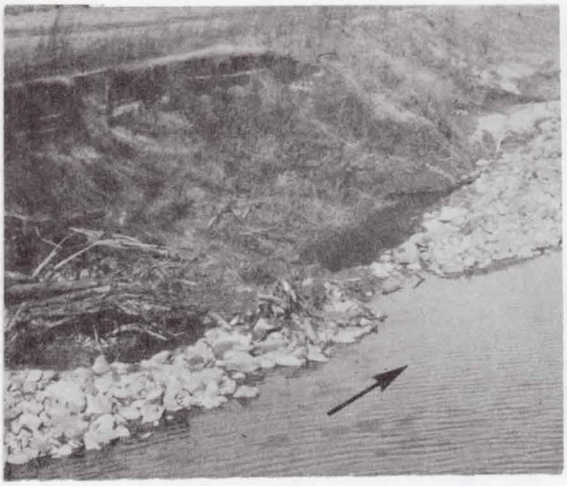


Figure 21. Typical grade control structure with baffle



Perry Creek
Reach 10
Mar 1980

Perry Creek
Reach 14
June 1981

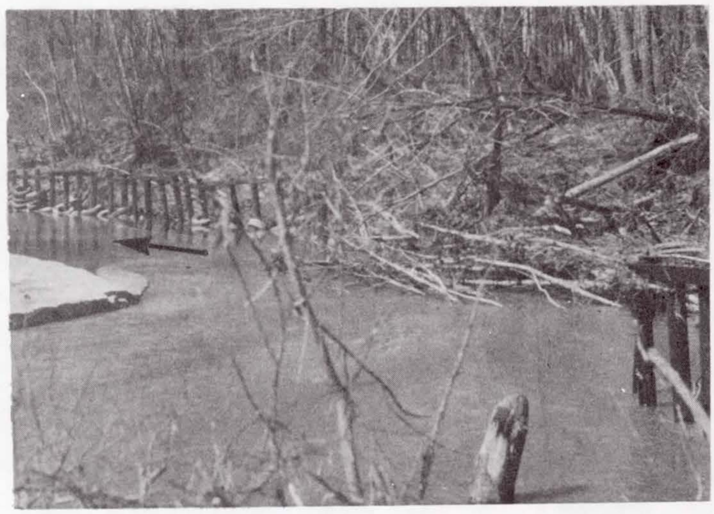
Perry Creek
Reach 15
April 1979

Perry Creek
Reach 16
April 1979

Figure 22. Reaches damaged, Perry Creek

Perry Creek
Reach 19
April 1979

Perry Creek
Reach 23
April 1979



Perry Creek
Reach 33
Mar 1980

Figure 23. Reaches damaged, Perry Creek

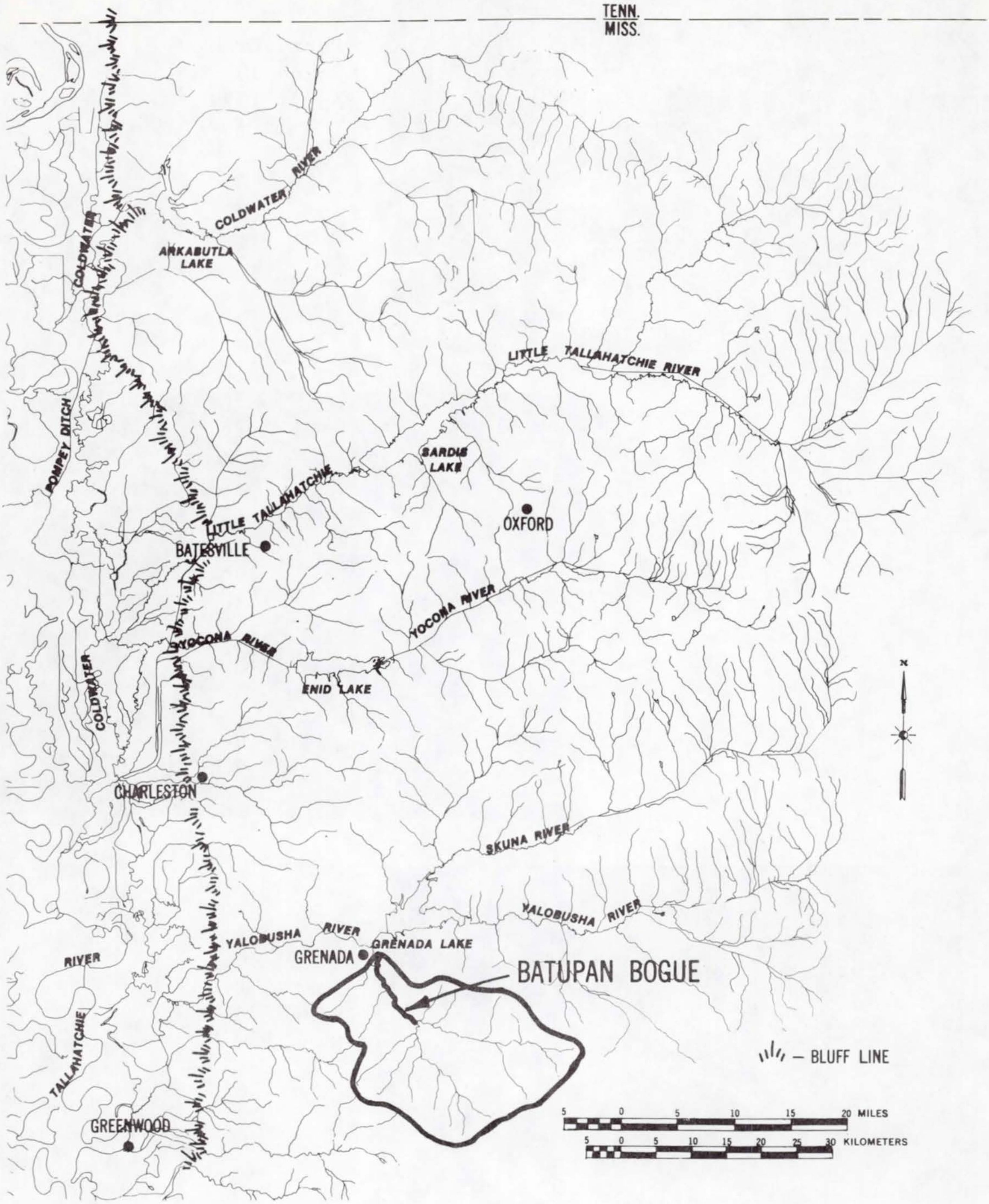


Figure 24. Location of Batupan Bogue Basin

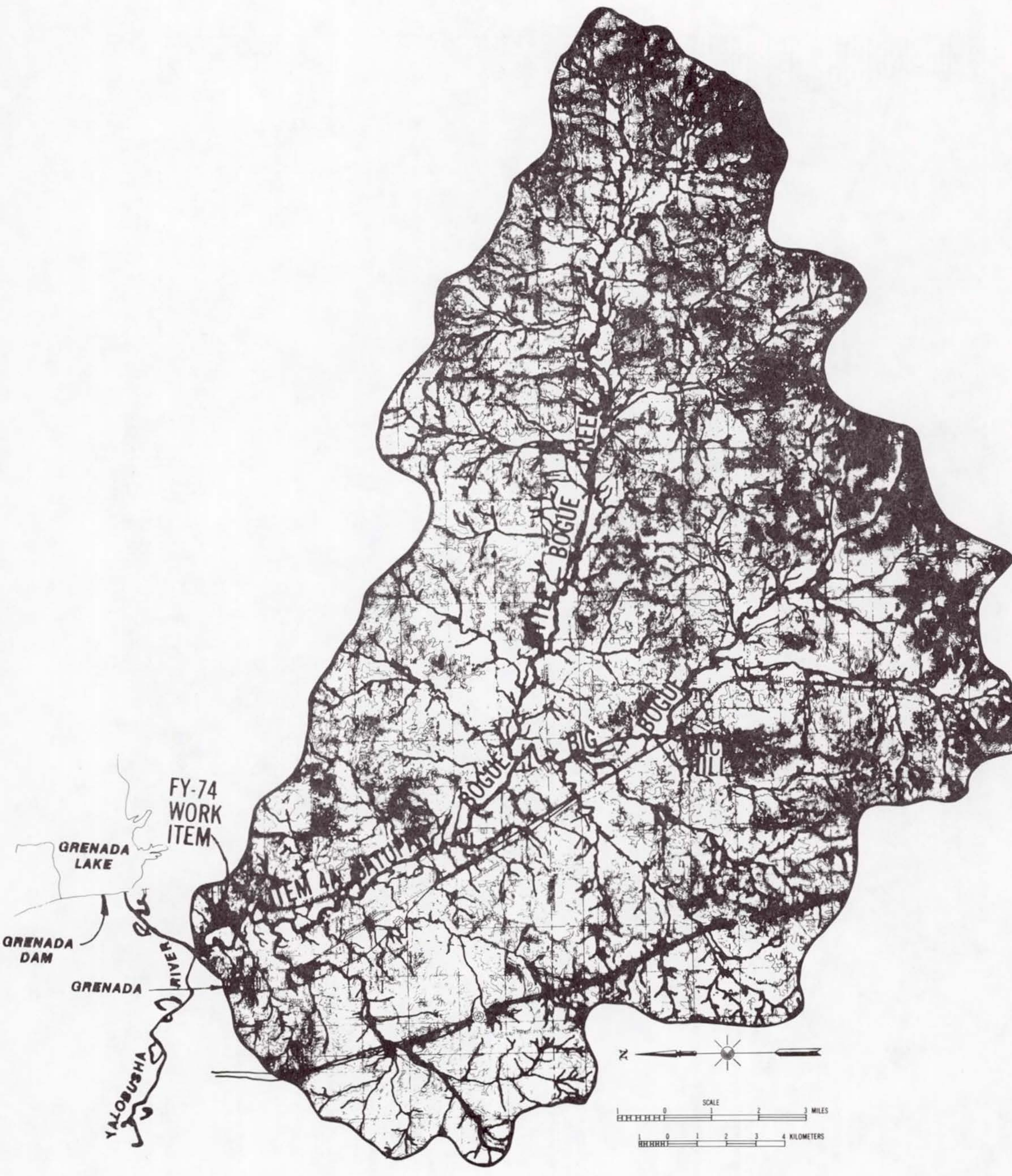


Figure 25. Batupan Bogue Drainage Basin

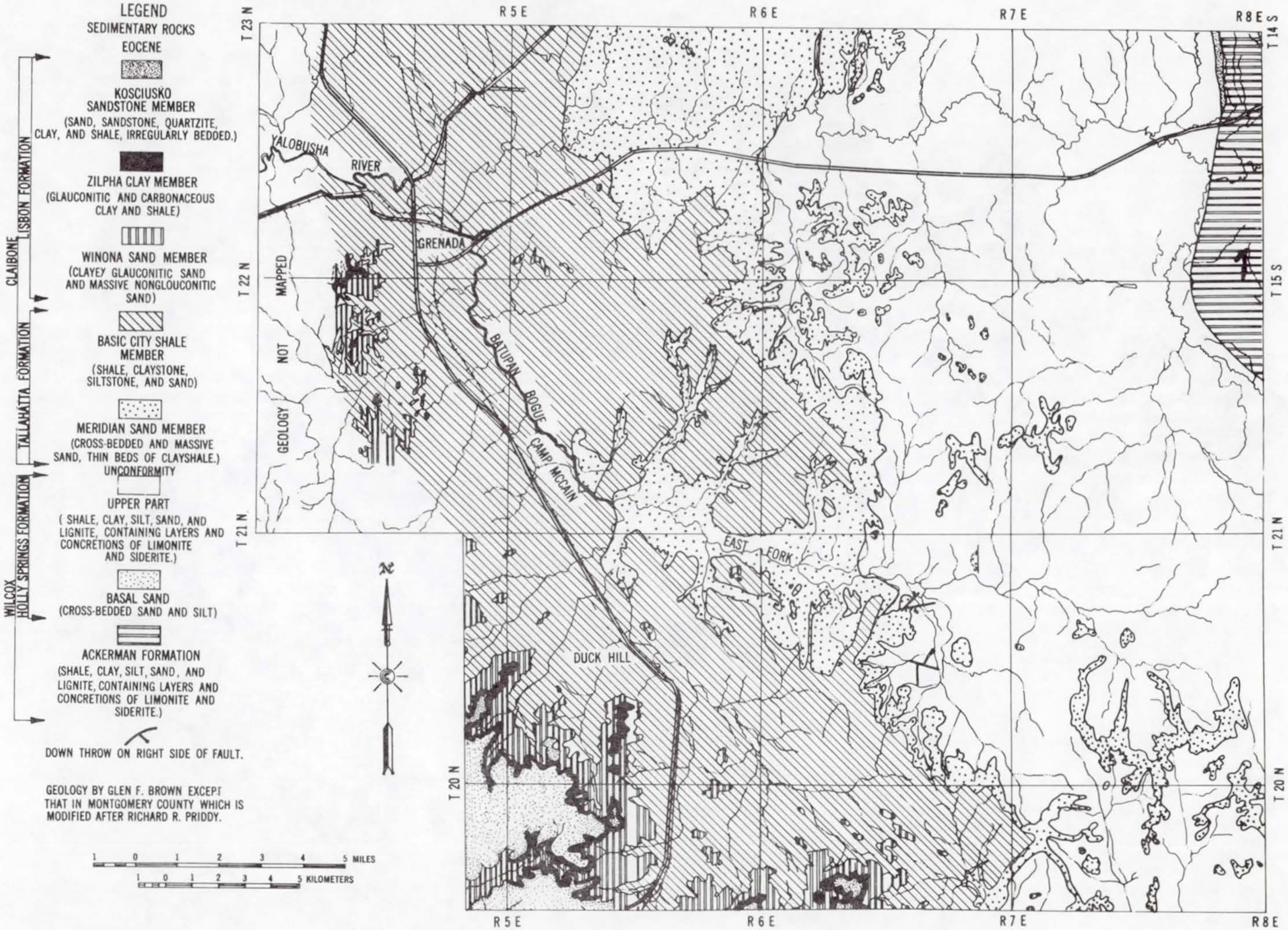


Figure 26. Geologic map of Batupan Bogue

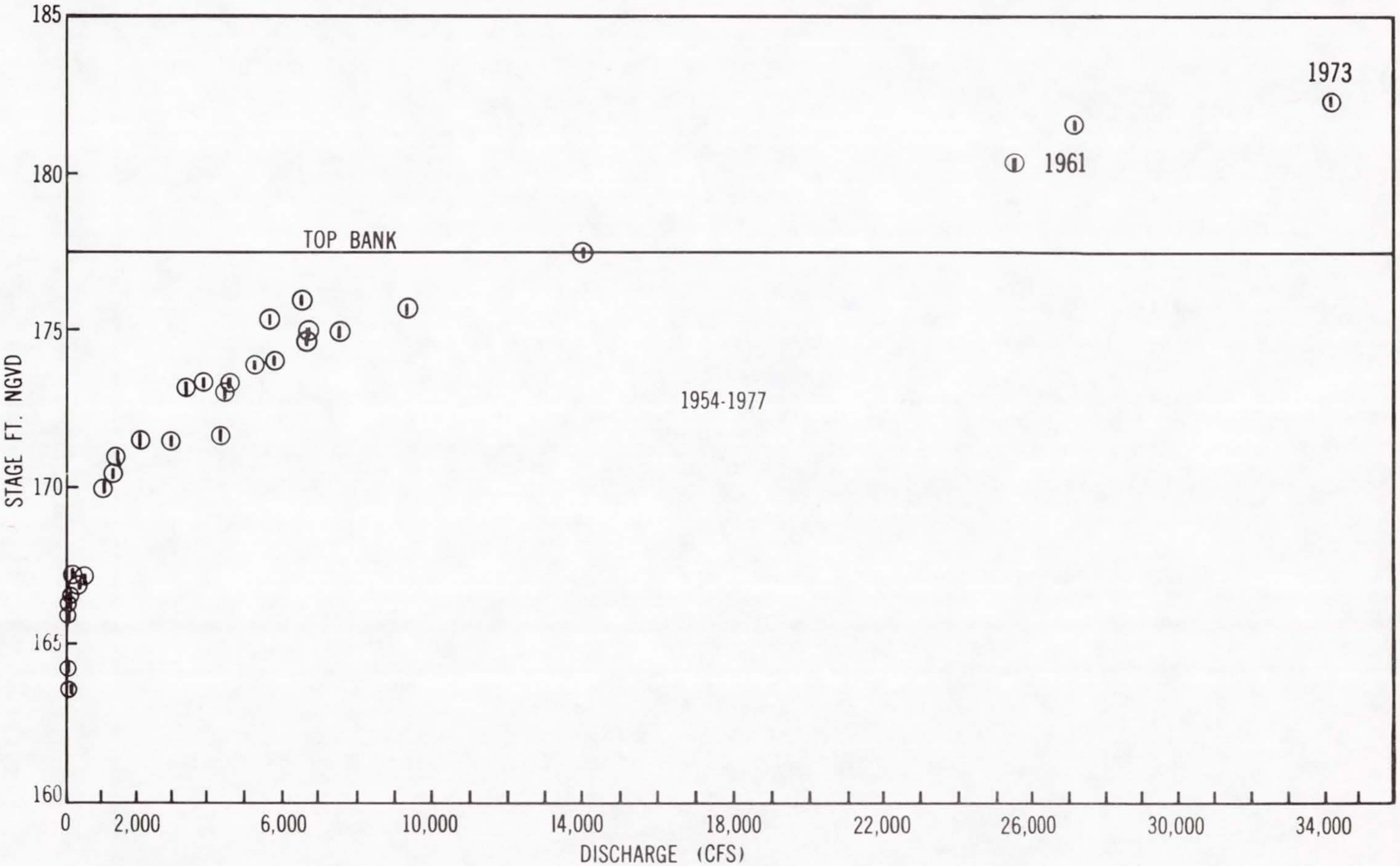


Figure 27. Rating curve Batupan Bogue Highway 8

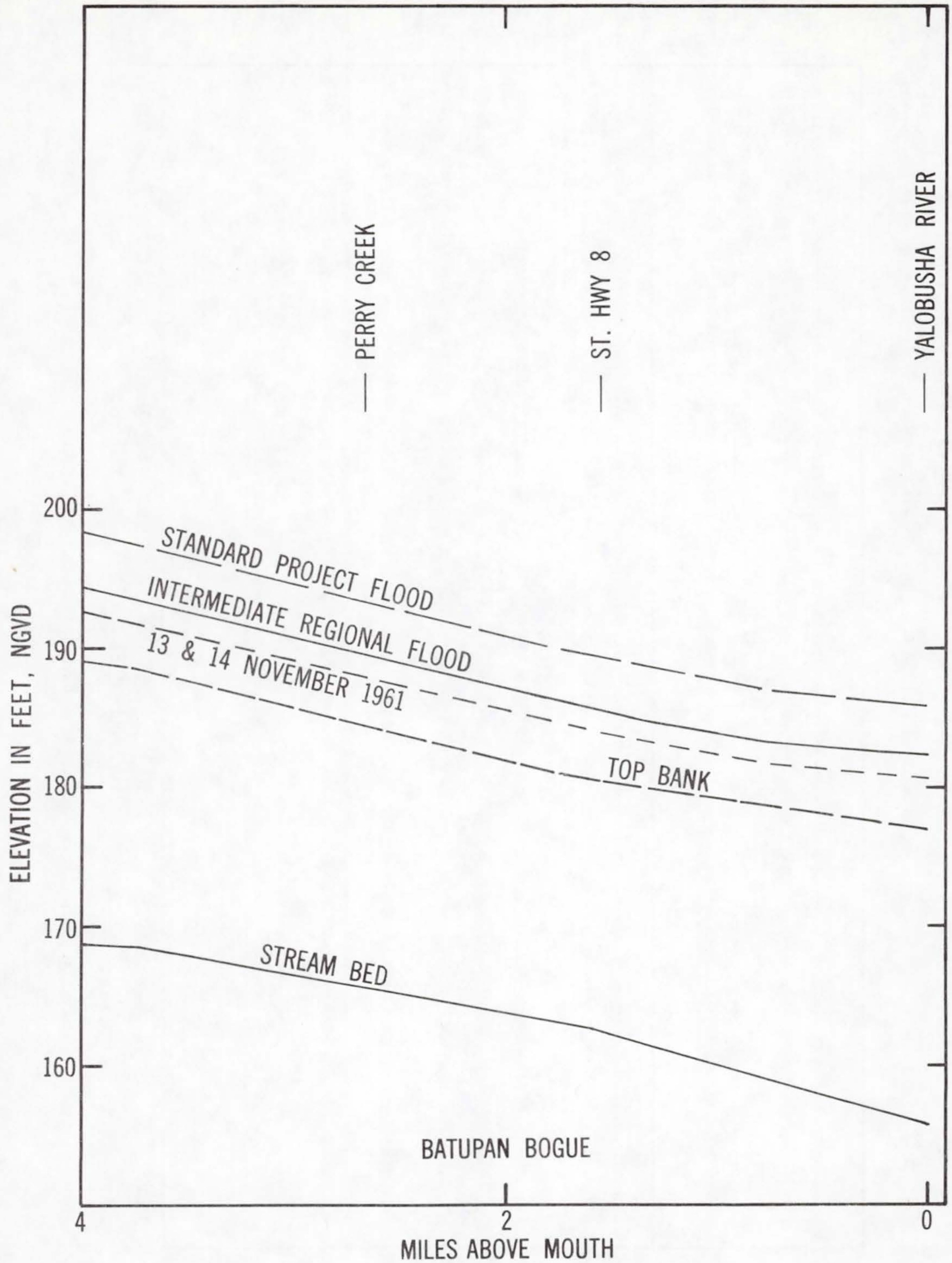


Figure 28. Profile comparisons Batupan Bogue

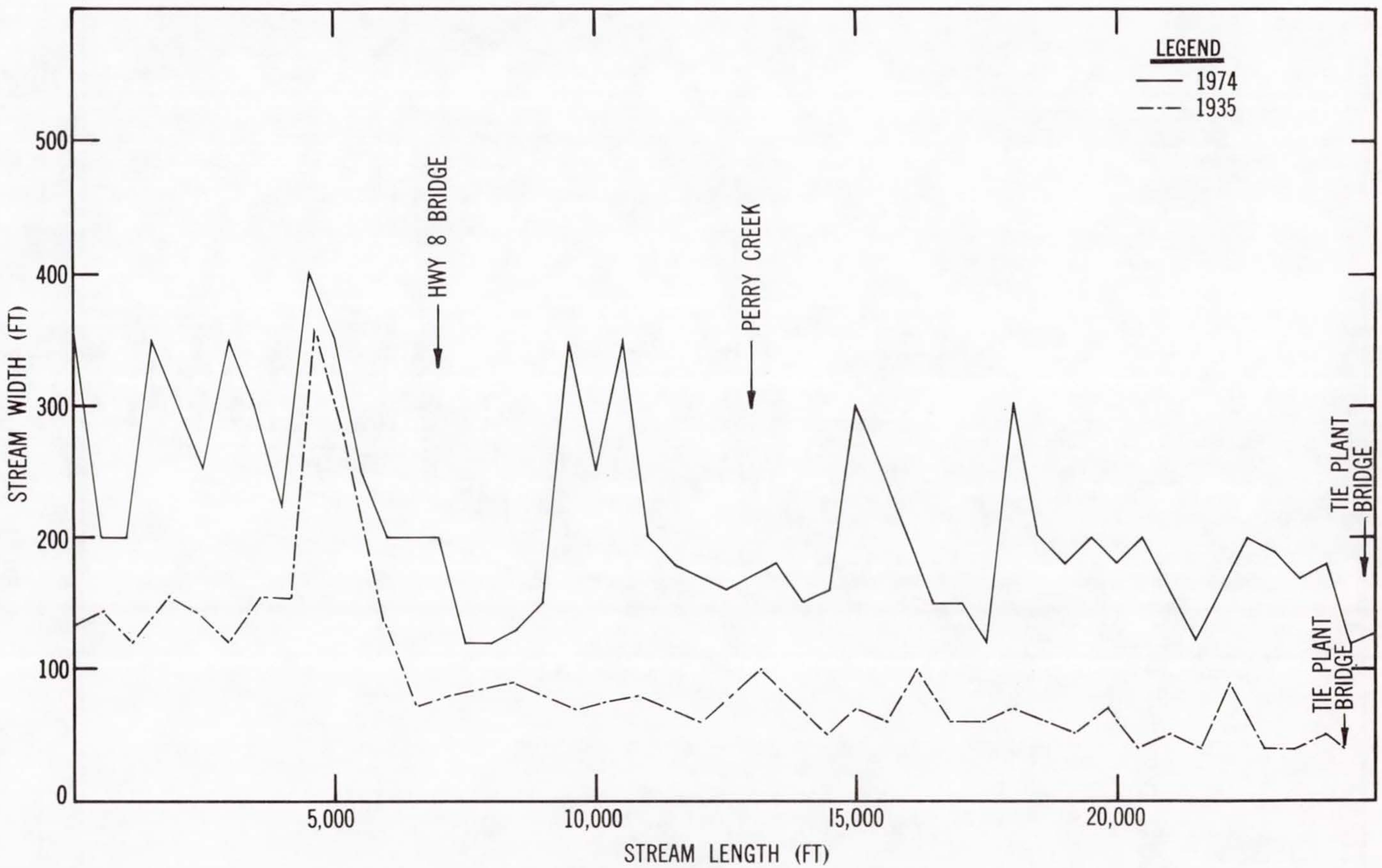


Figure 29. Length-width comparison Batupan Bogue

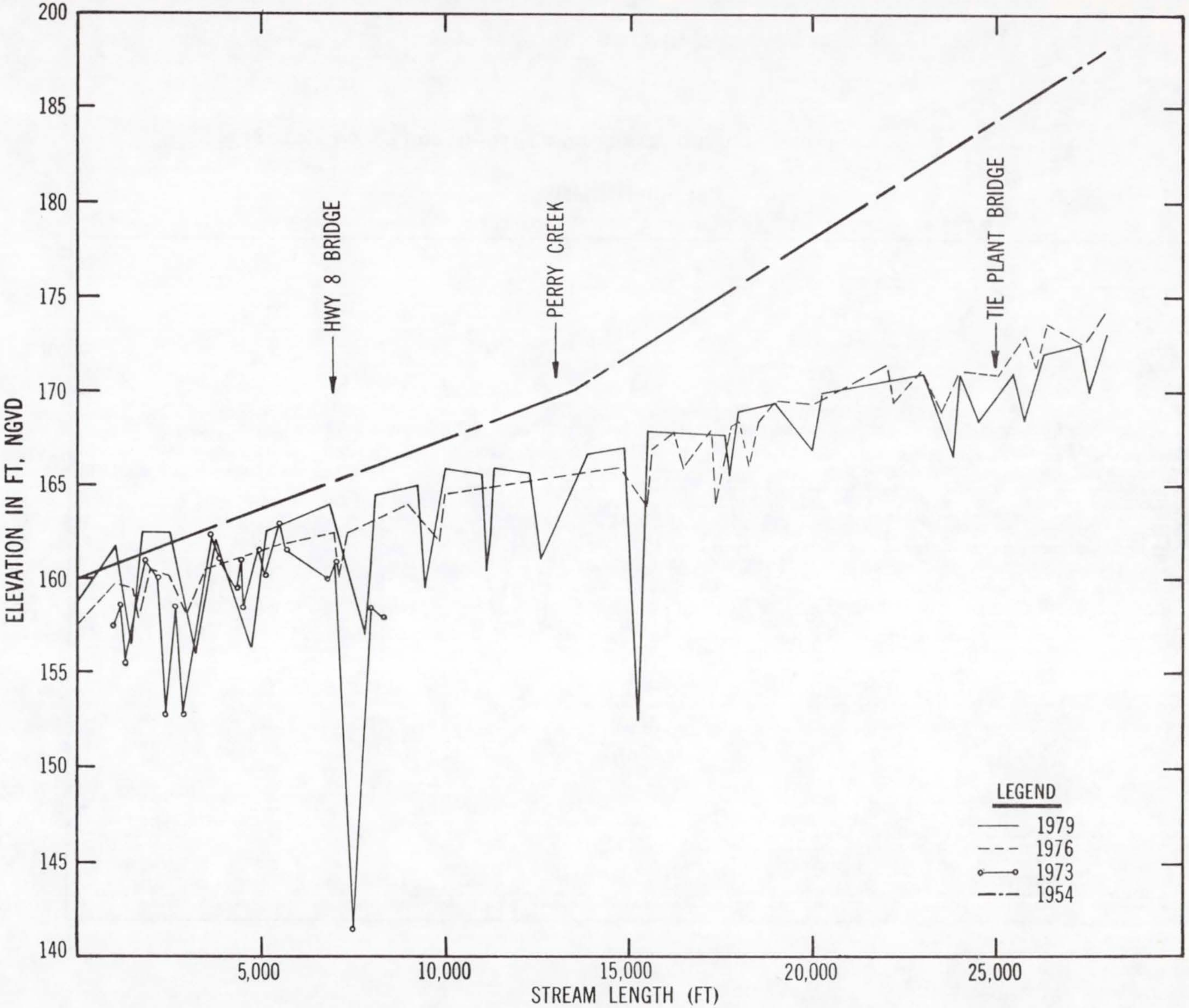


Figure 30. Thalweg profile Batupan Bogue

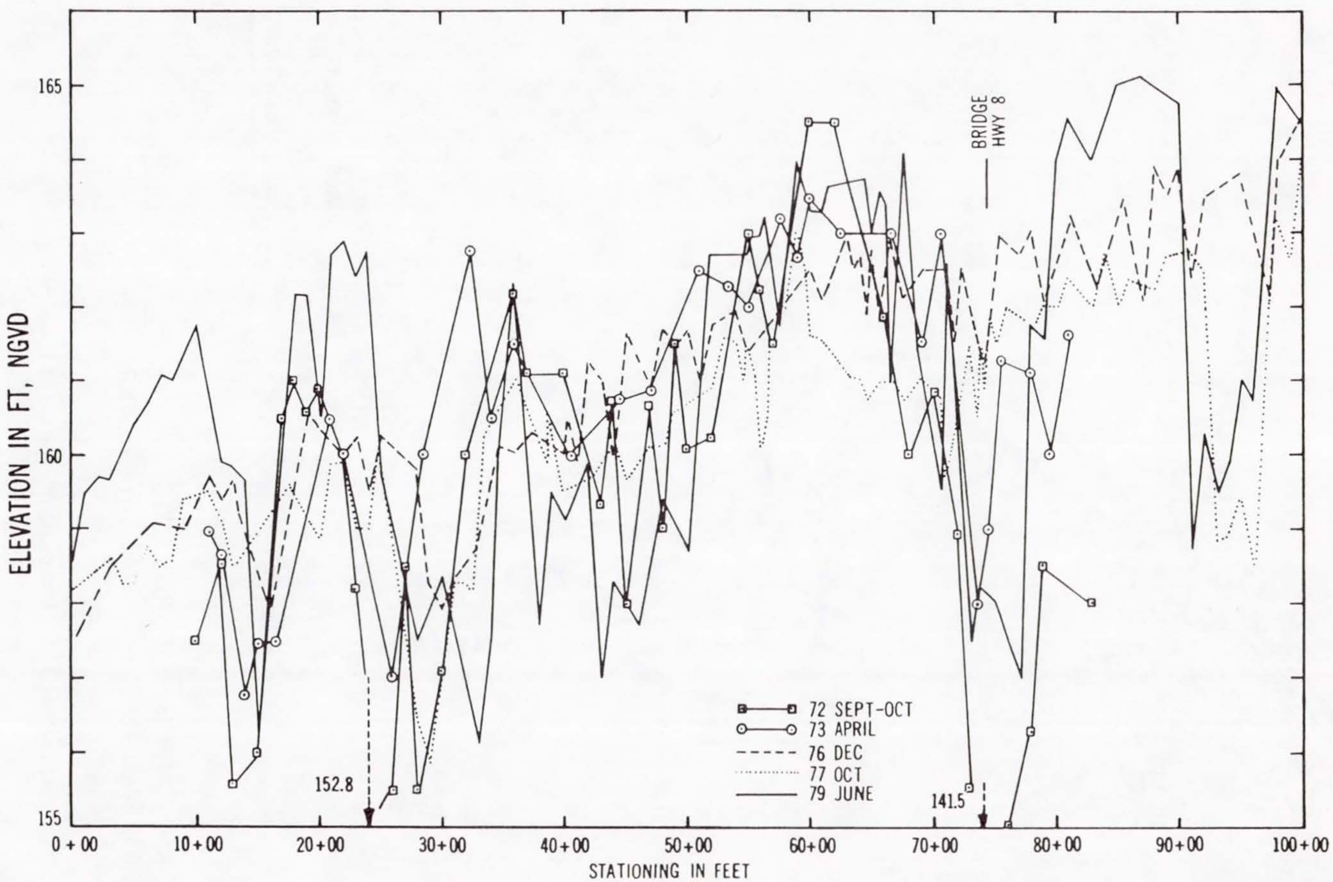
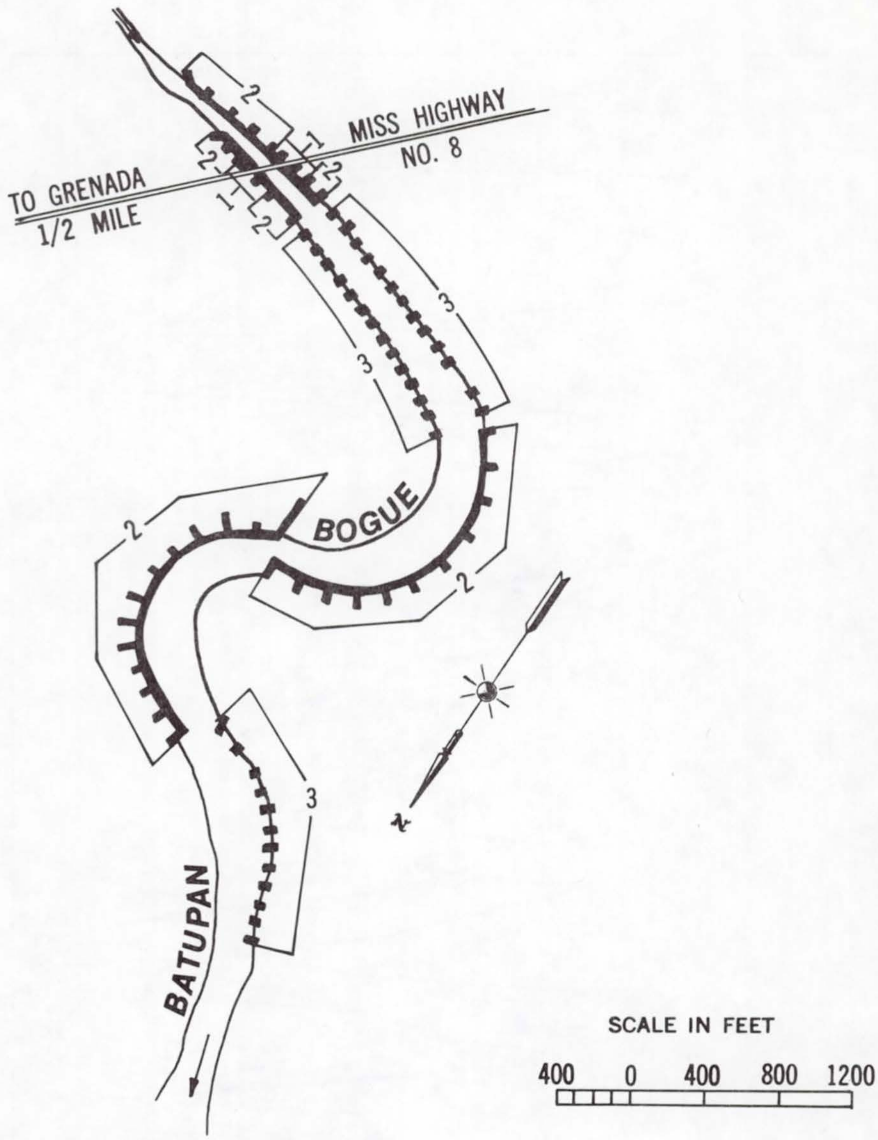
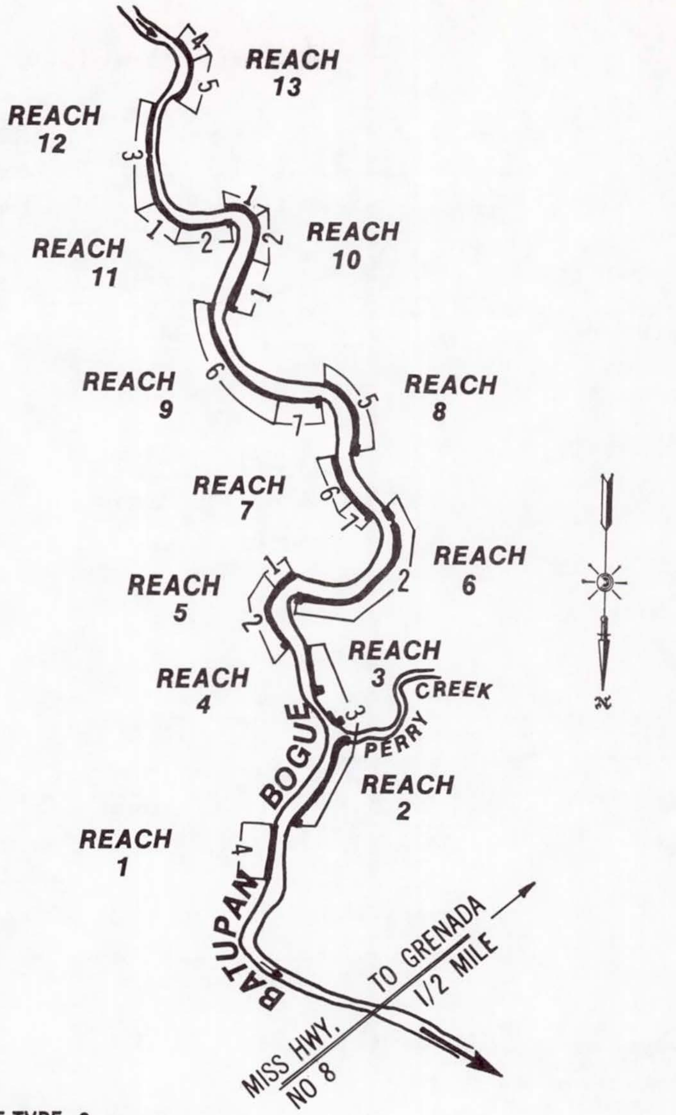


Figure 31. Thalweg profile Batupan Bogue



LEGEND
1 LONGITUDINAL OR TRANSVERSE STONE DIKES
2 LONGITUDINAL BOARD-FENCE REVETMENT (WITH TIE-BACK)
3 BOARD-FENCE DIKE

Figure 32. Batupan Bogue Item FY 74



LEGEND

1 LONGITUDINAL STONE DIKE-TYPE 2 (USE TYPE 1 TIE-BACK)
2 LONGITUDINAL STONE DIKE-TYPE 3 (USE TYPE 2 TIE-BACK)
3 LONGITUDINAL PEAKED STONE DIKE - 2 TONS/L.F.
4 USED TIRE REVETMENT- 1/3 OF TOTAL BANK HEIGHT
5 USED TIRE REVETMENT- 1/2 OF TOTAL BANK HEIGHT
6 SAND-CEMENTS BAGS REVETMENT- 1/3 OF TOTAL BANK HEIGHT
7 SAND-CEMENTS BAGS REVETMENT- 1/2 OF TOTAL BANK HEIGHT

SCALE IN FEET

1000 0 1000 2000

Figure 33. Batupan Bogue Iem 4A

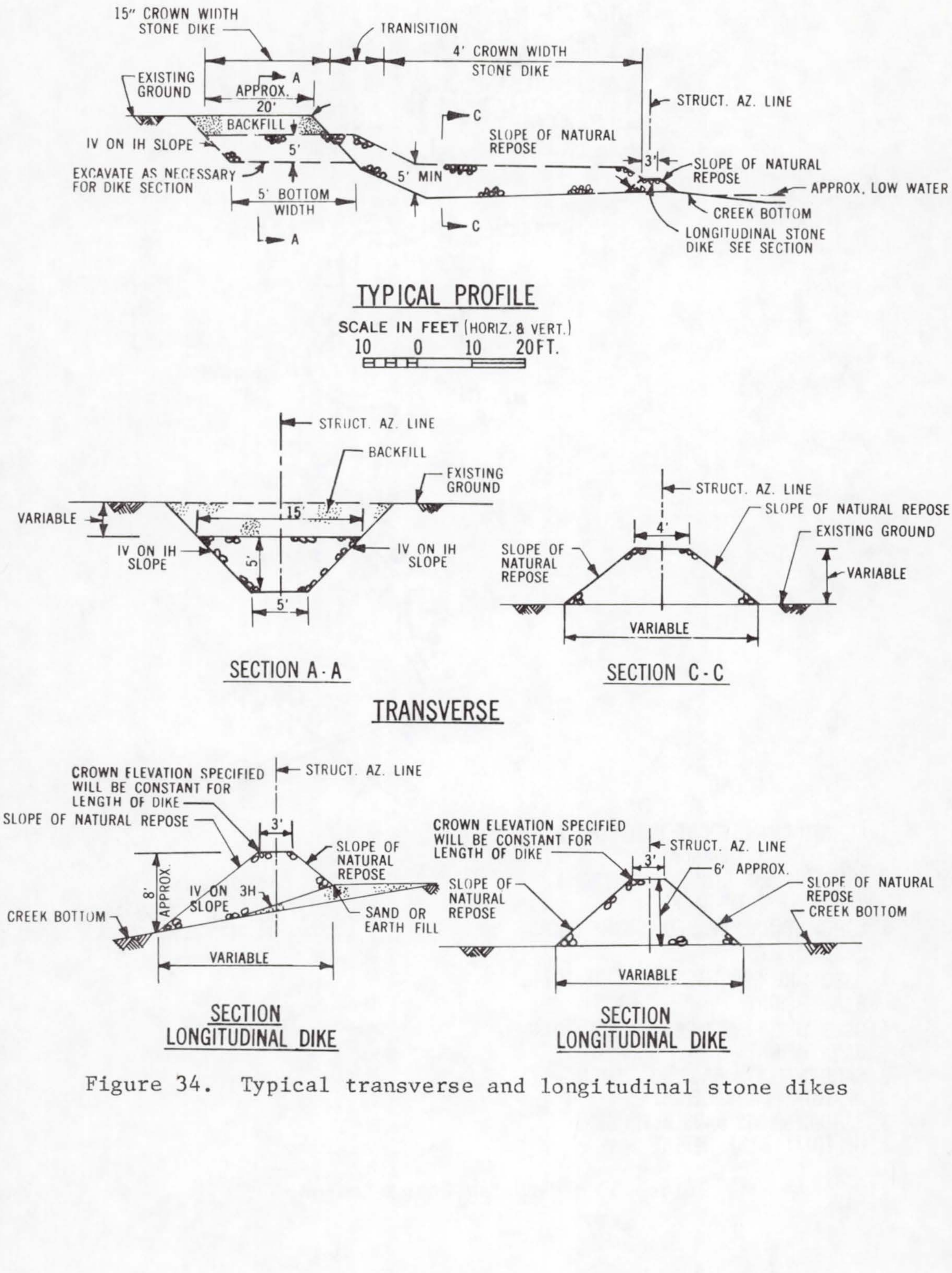
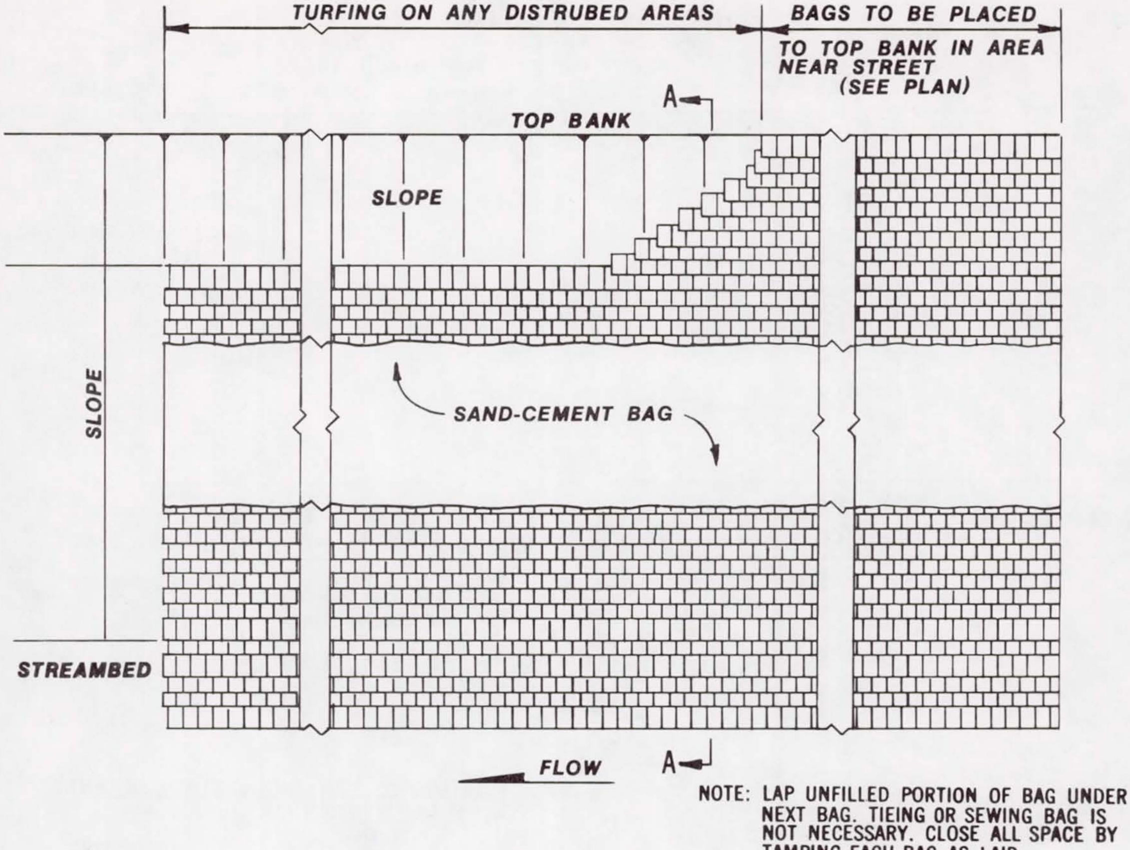
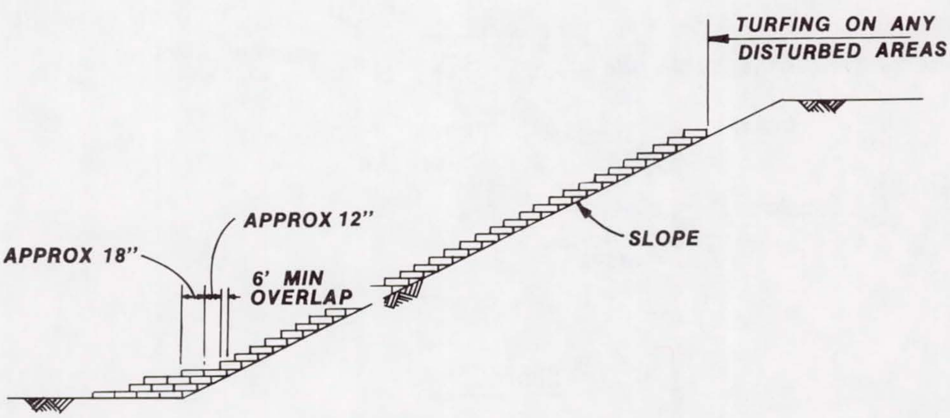


Figure 34. Typical transverse and longitudinal stone dikes

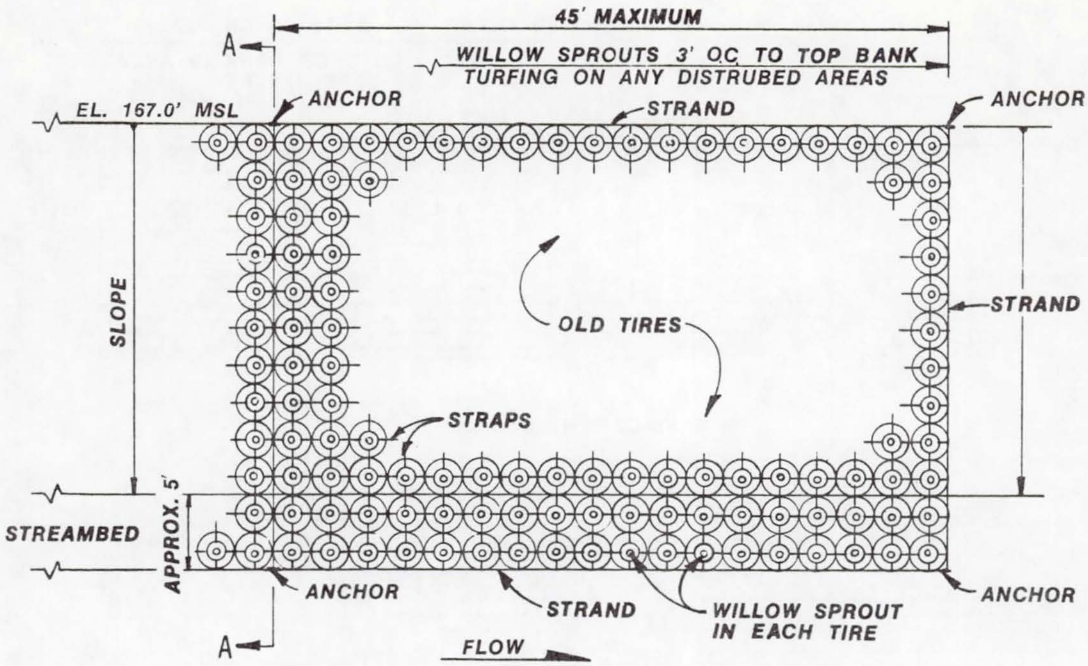


PLAN

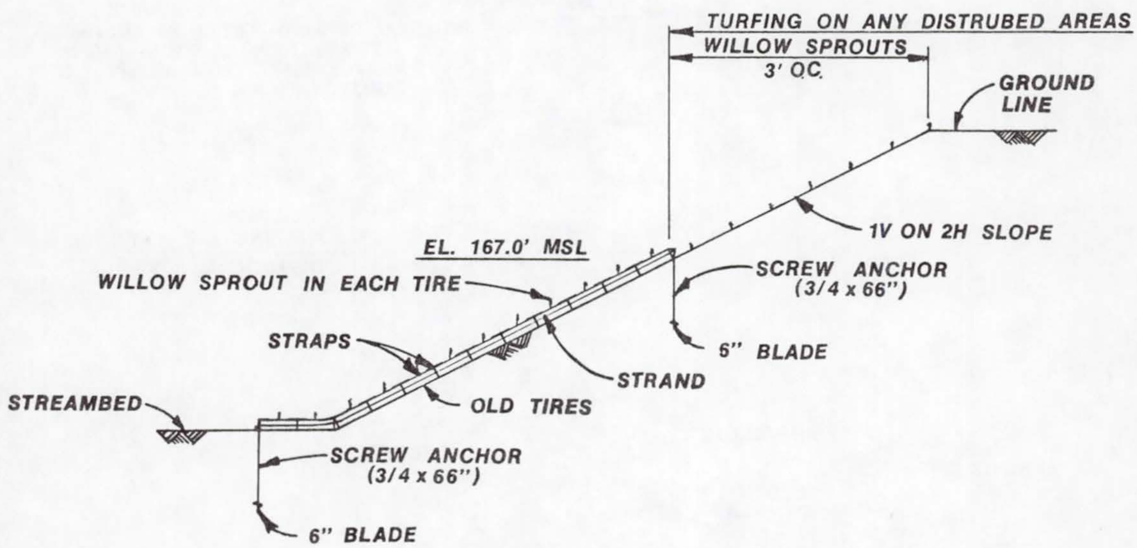


SECTION A-A

Figure 35. Typical sand cement bag revetment

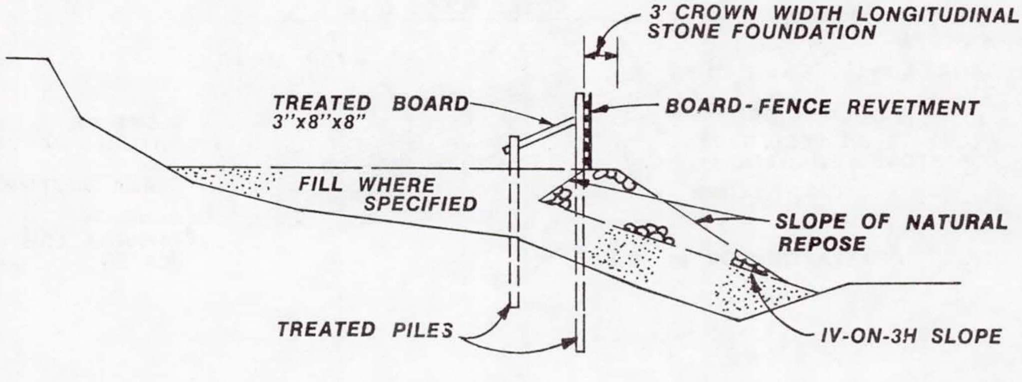


PLAN



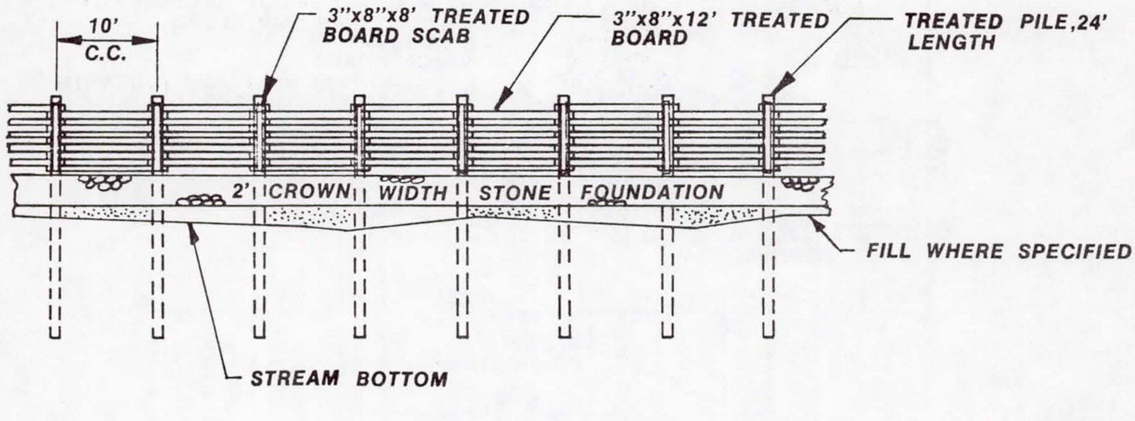
SECTION A-A

Figure 36. Typical used tire revetment



PROFILE

REVETMENT BETWEEN TIE-BACKS



FRONT VIEW

Figure 37. Typical longitudinal board fence

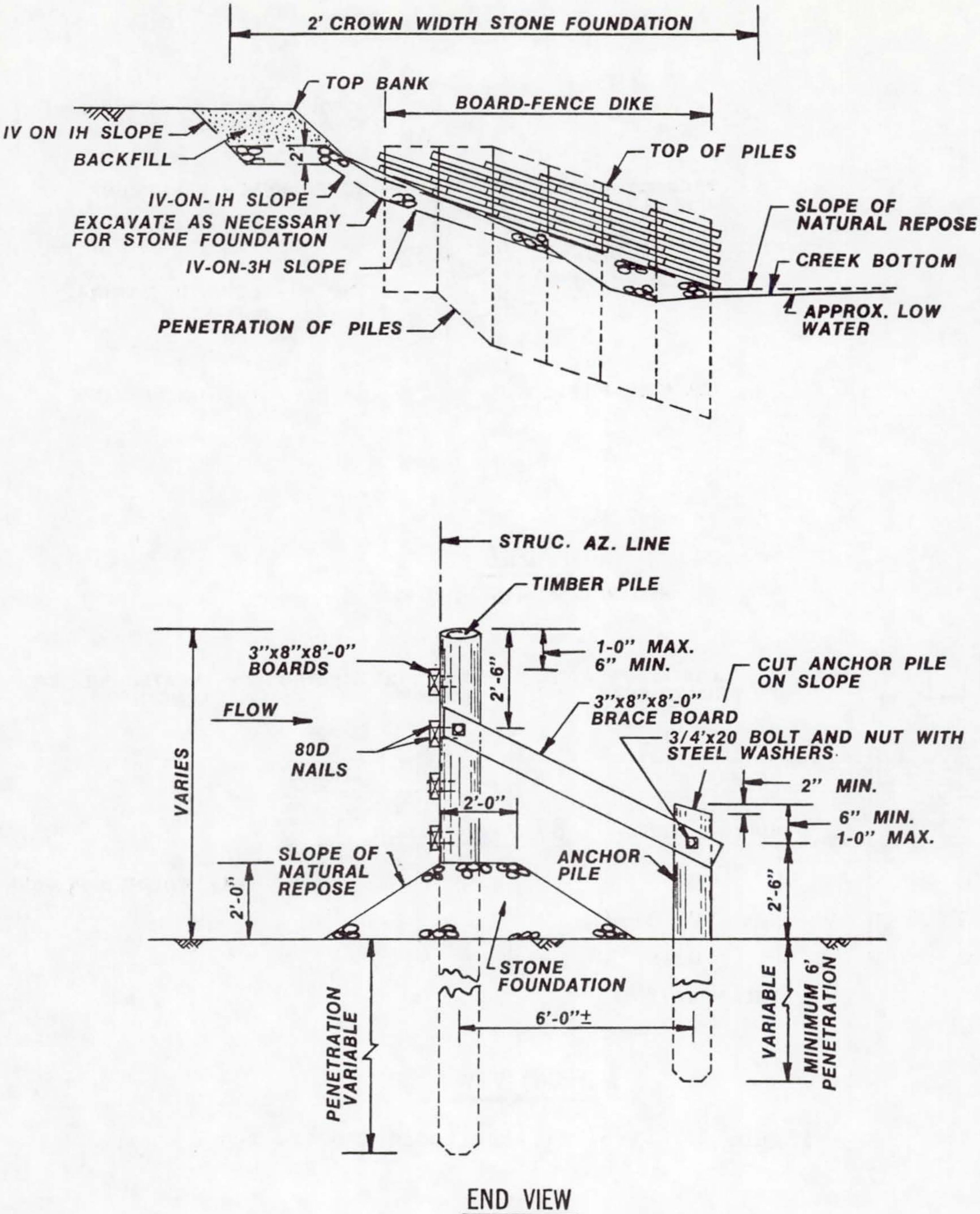


Figure 38. Typical transverse board fence

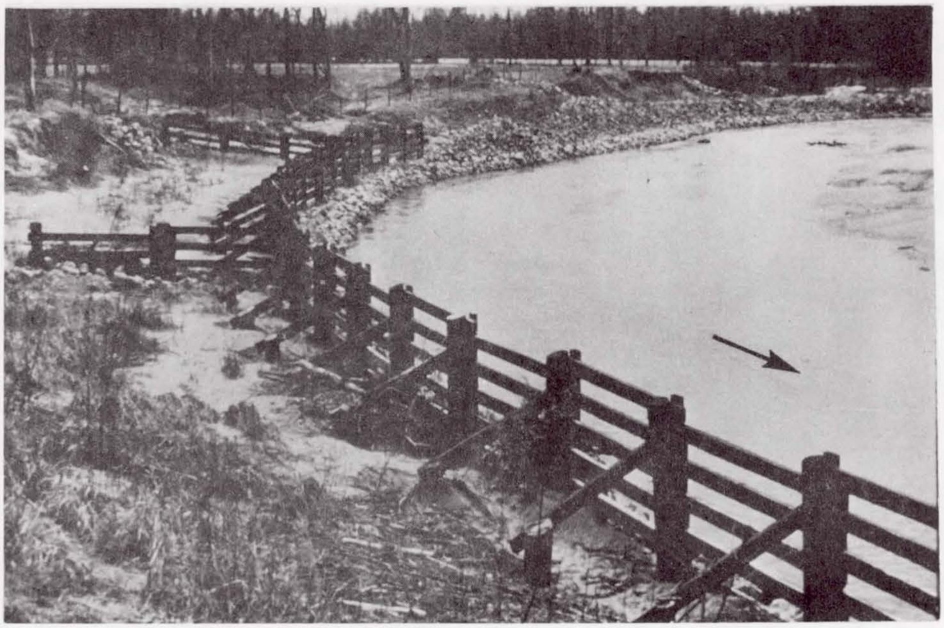


Figure 39. Longitudinal board fence dike with stone toe protection, Item FY-74

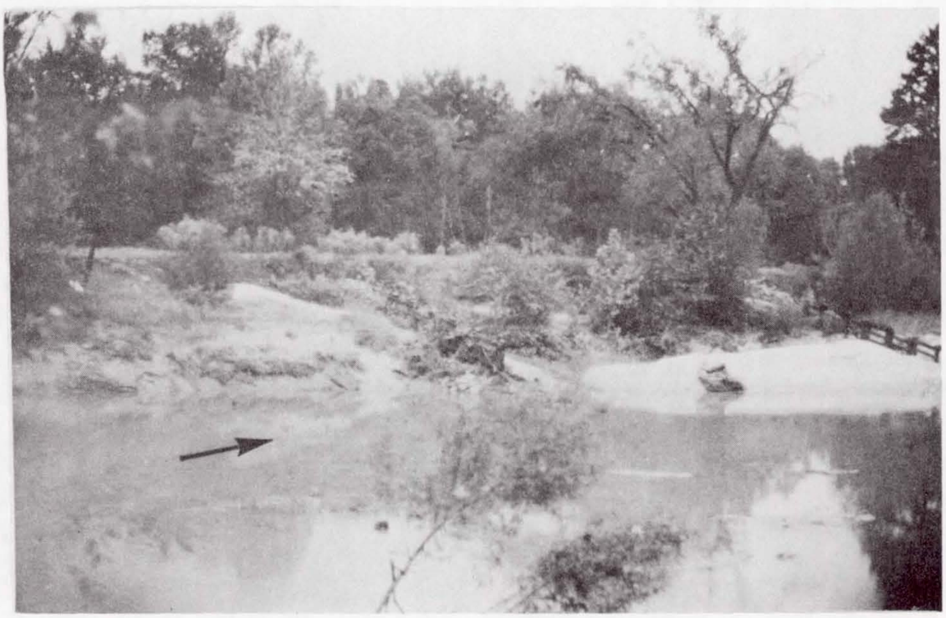


Figure 40. Transverse board fence dike, Item FY-74

Figure 41. Transverse stone dike, Item FY-74, Dike No. 53, Batupan Bogue

Figure 42. Longitudinal stone dike, Item 4A, Batupan Bogue, Nov 1977

Figure 43. Used tire revetment, Item 4A, Reach 13, Batupan Bogue, Mar 1979

Figure 44. Sand cement bag revetment, Item 4A, Reach 9, Batupan Bogue, Nov 1977

After Construction
Jan 1979

After Damage
Looking Downstream
Along Old Dike Alignment
July 1980

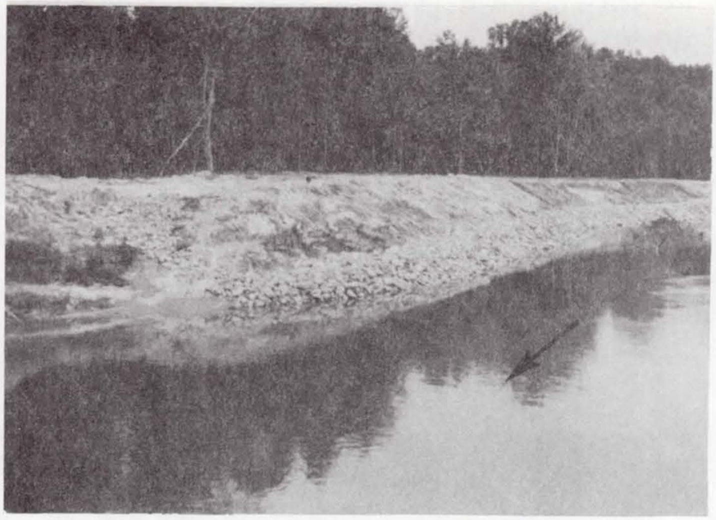
During Rehab Work
Feb 1981

Figure 45. Batupan Bogue, Item 4, Reach 4

After Construction
Jan 1979

Area to be Rehabbed FY-81
Mar 1981

Figure 46. Batupan Bogue, Item 4, Reach 5



After Construction
Nov 1977

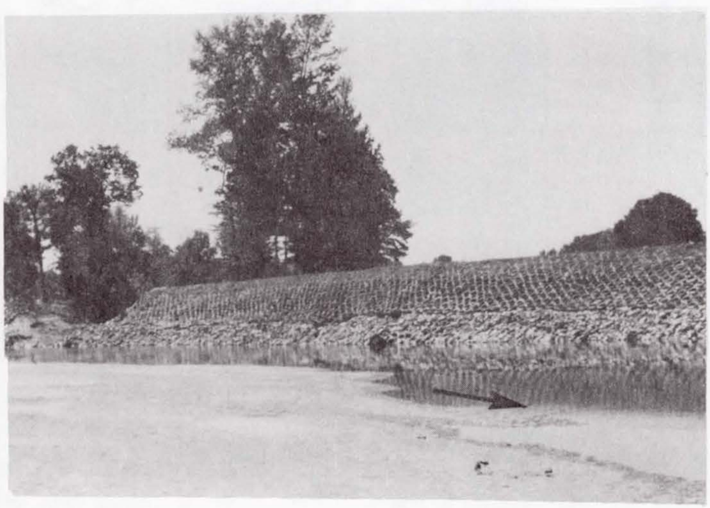
After Damage
May 1978

After Rehab
Mar 1980

Figure 47. Batupan Bogue, Item 4, Reach 7

After Construction
Sept 1977

After Damage
Nov 1977



After Rehab Work
1979

Figure 48. Batupan Bogue, Item 4, Reach 8

After Construction
Item 4A
Nov 1977

After Damage
Item 4A
Dec 1977

After Initial Rehab
Item 4A-1
27 April 1979

Damage Before 1981
Rehab

Figure 49. Batupan Bogue, Item 4, Reach 9

During Construction
Item 4A
Nov 1977

After Damage in Late
Nov 1977

After Rehab Work
Item 4A
Jan 1979

Figure 50. Batupan Bogue, Item 4, Reach 10

After Construction
Nov 1977

After Damage
July 1978

After Rehab
April 1979

Figure 51. Batupan Bogue, Item 4, Reach 11

After Construction
Nov 1977

After Damage in 1977
July 1978

After Rehab with Tie Back
May 1980

Figure 52. Batupan Bogue, Item 4, Reach 12

Tire Revetment
After Construction
Nov 1977

Tire Revetment
After Damage
Mar 1978

Tire Revetment
After Rehab Work
Aug 1978

Tire Revetment
Looking Upstream
Mar 1979

Figure 53. Batupan Bogue, Item 4, Reach 13

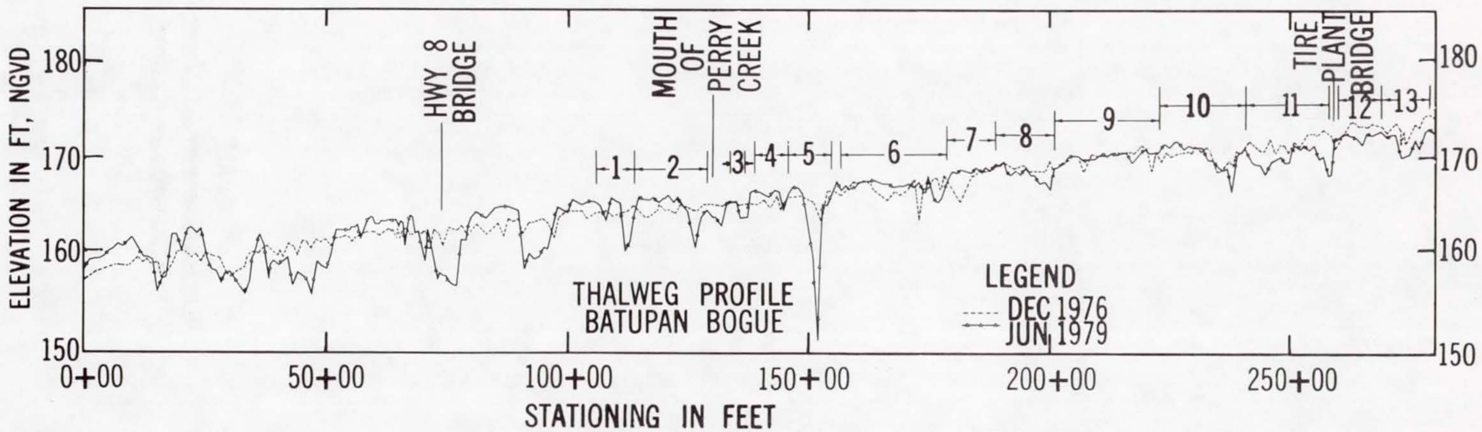


Figure 54. Batupan Bogue Thalweg, 1976 and 1979

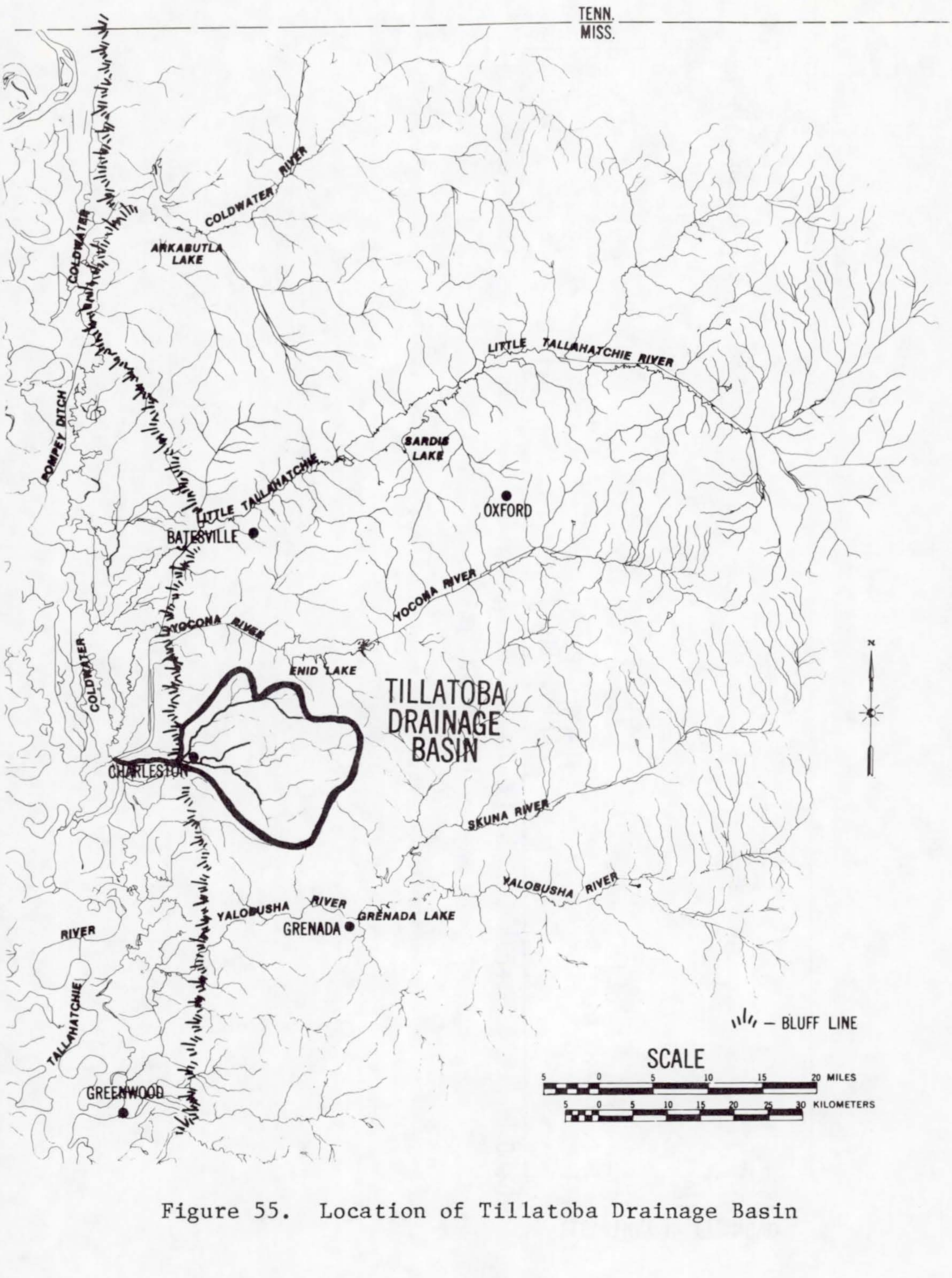


Figure 55. Location of Tillatoba Drainage Basin

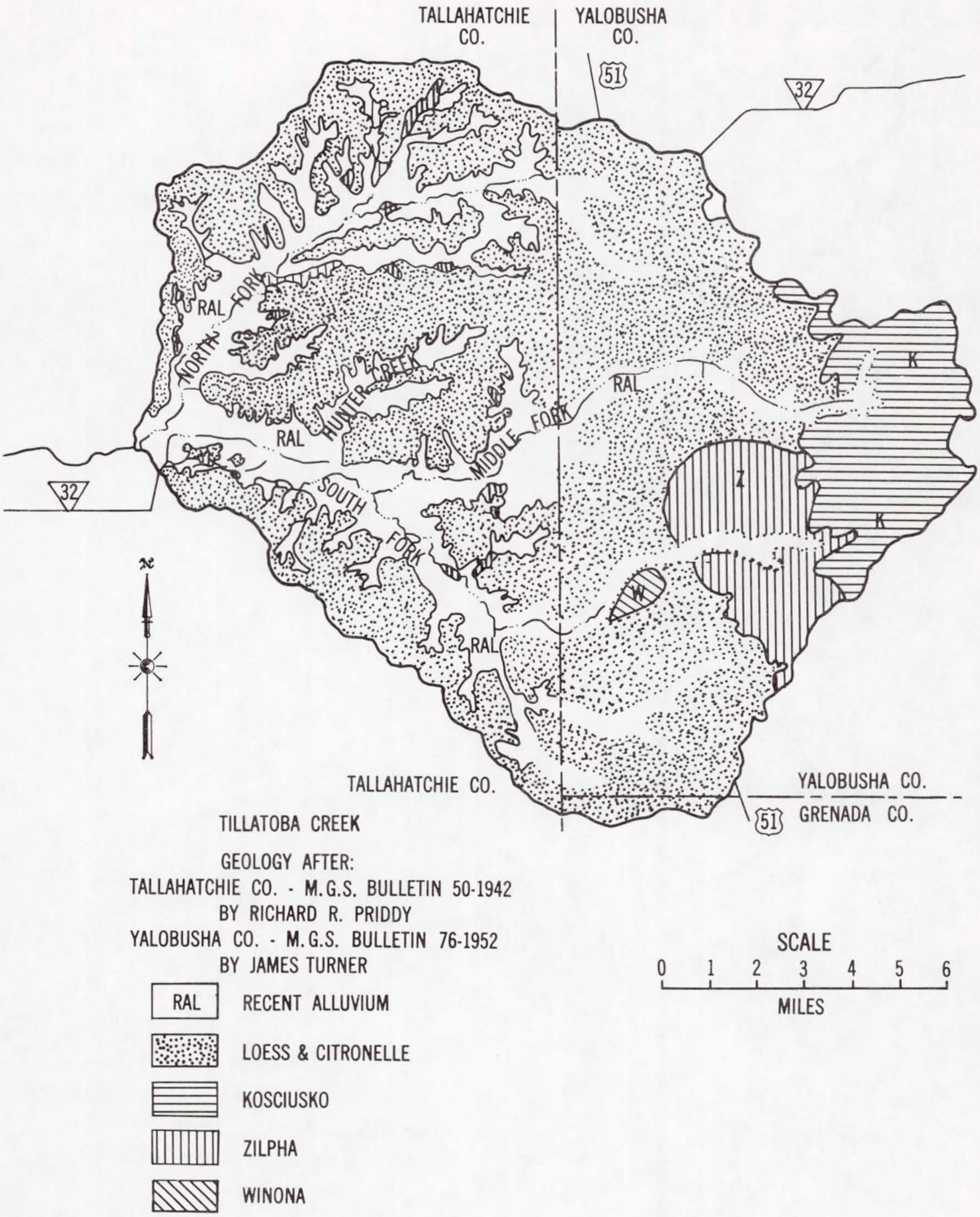


Figure 56. Geologic map, Tillatoba Drainage Basin

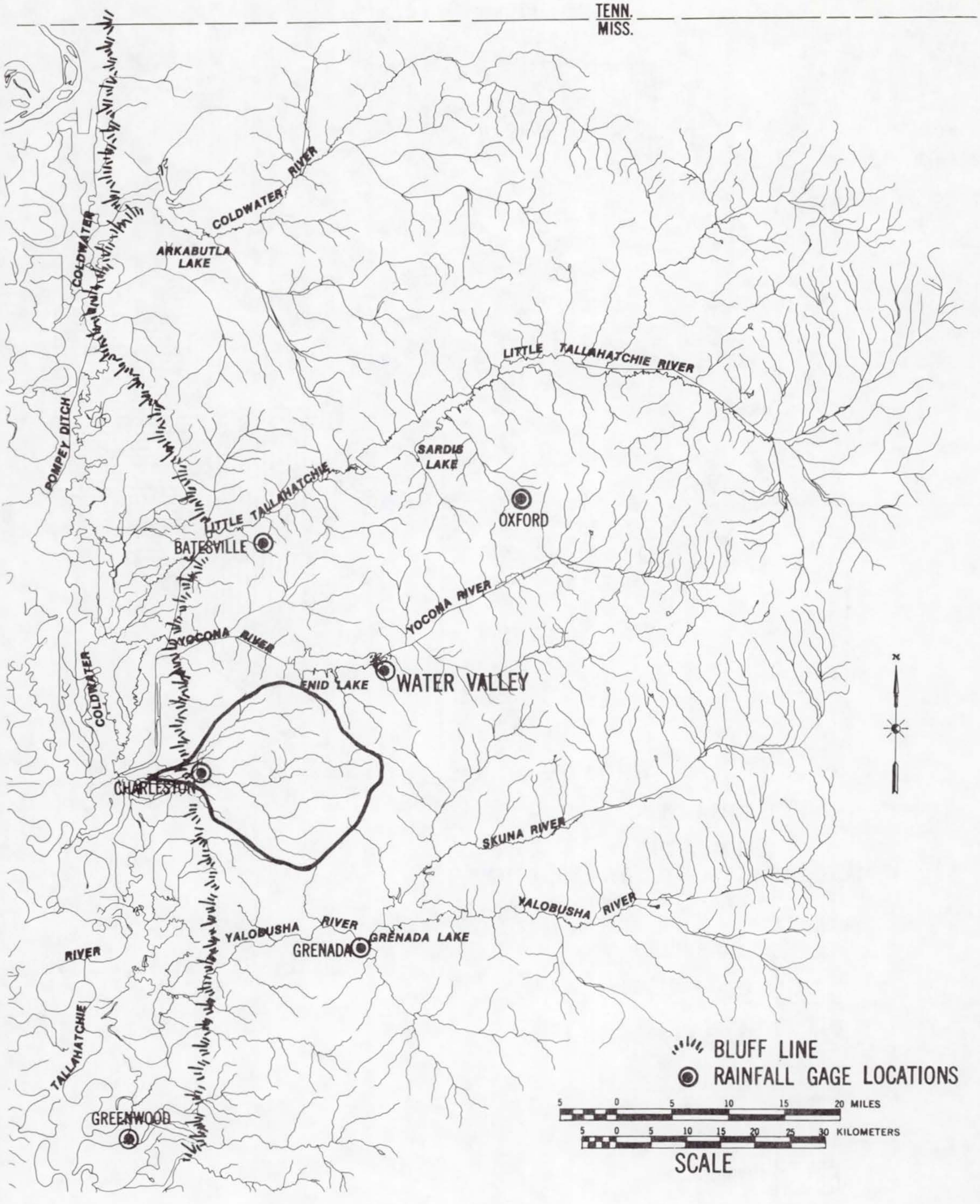
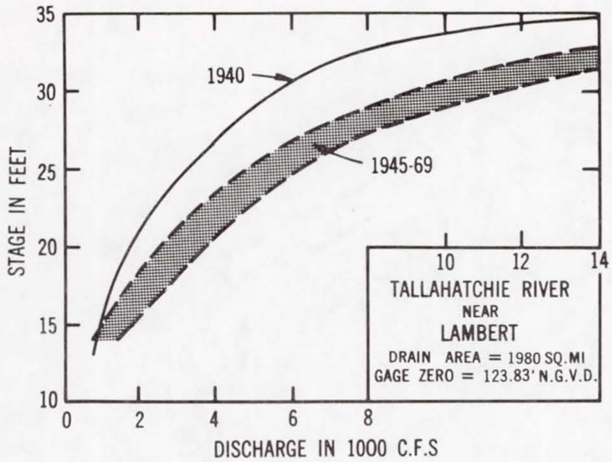
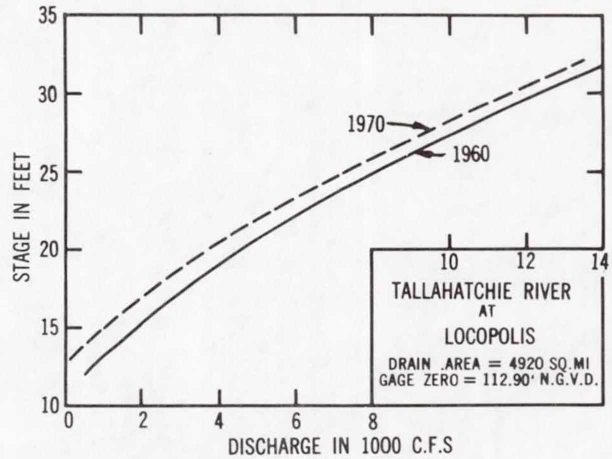


Figure 57. Location of rainfall gages





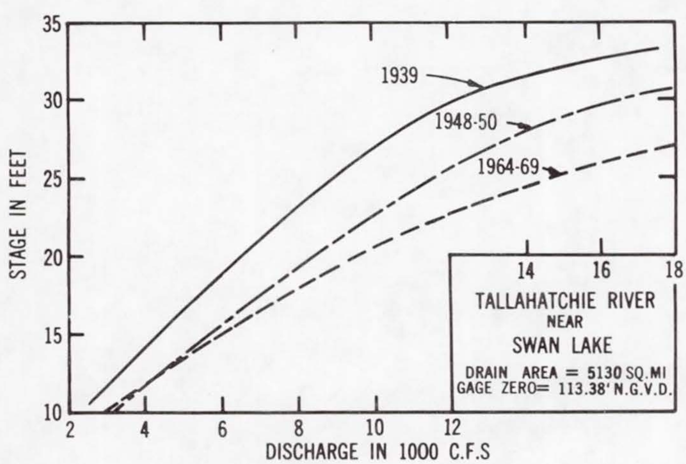


Figure 58. Tallahatchie River rating curves

Figure 59. SCS impoundments in Tillatoba Drainage Basin

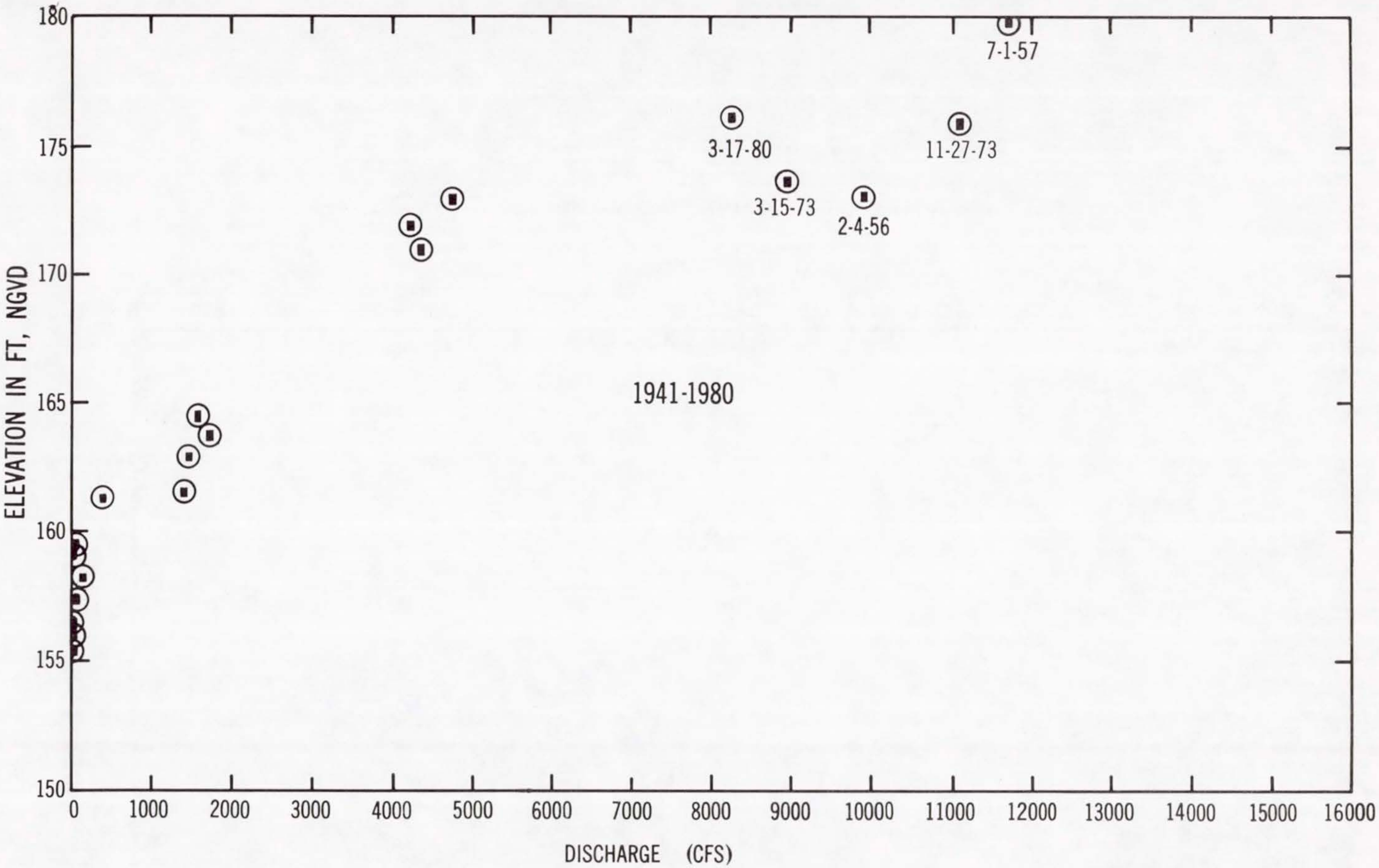


Figure 60. Rating curve, South Fork, Highway 35

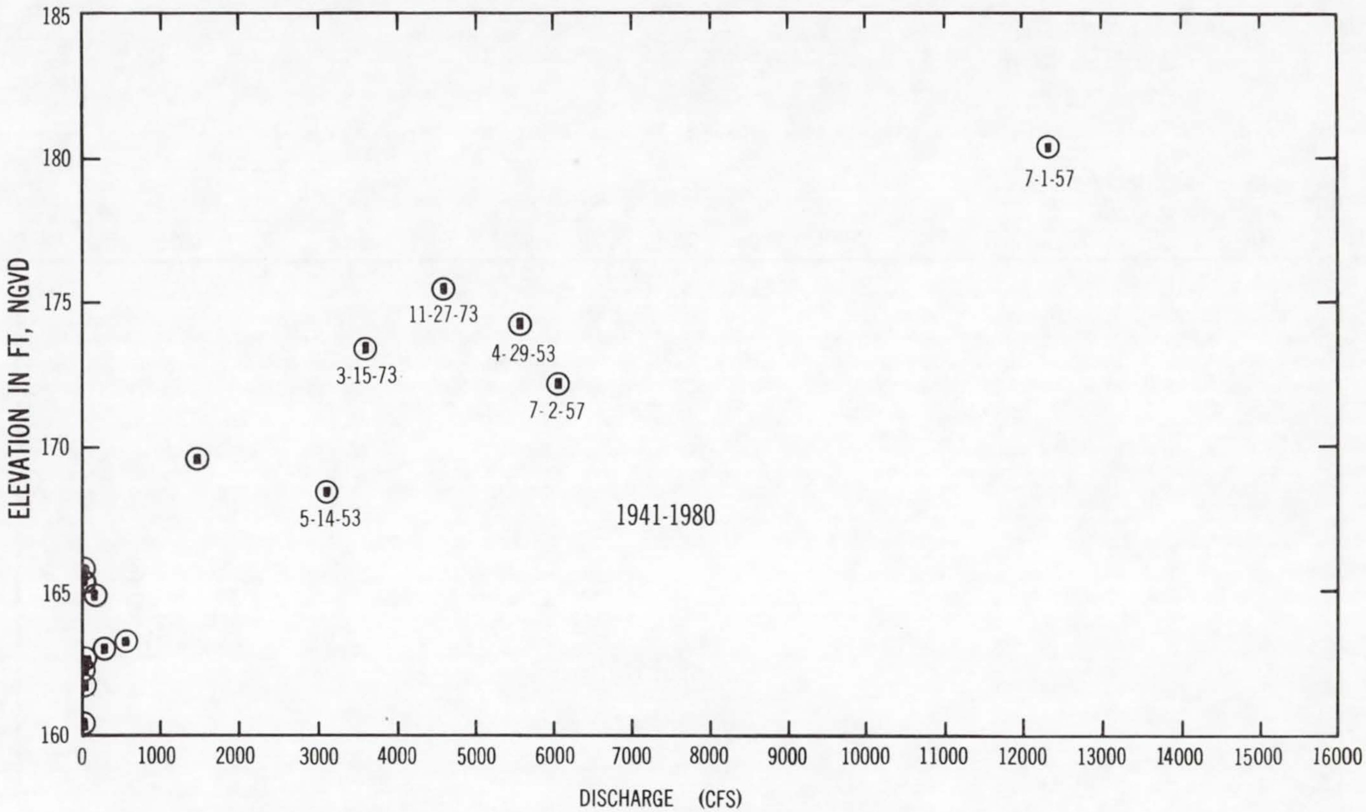


Figure 61. Rating curve, North Fork, Highway 35

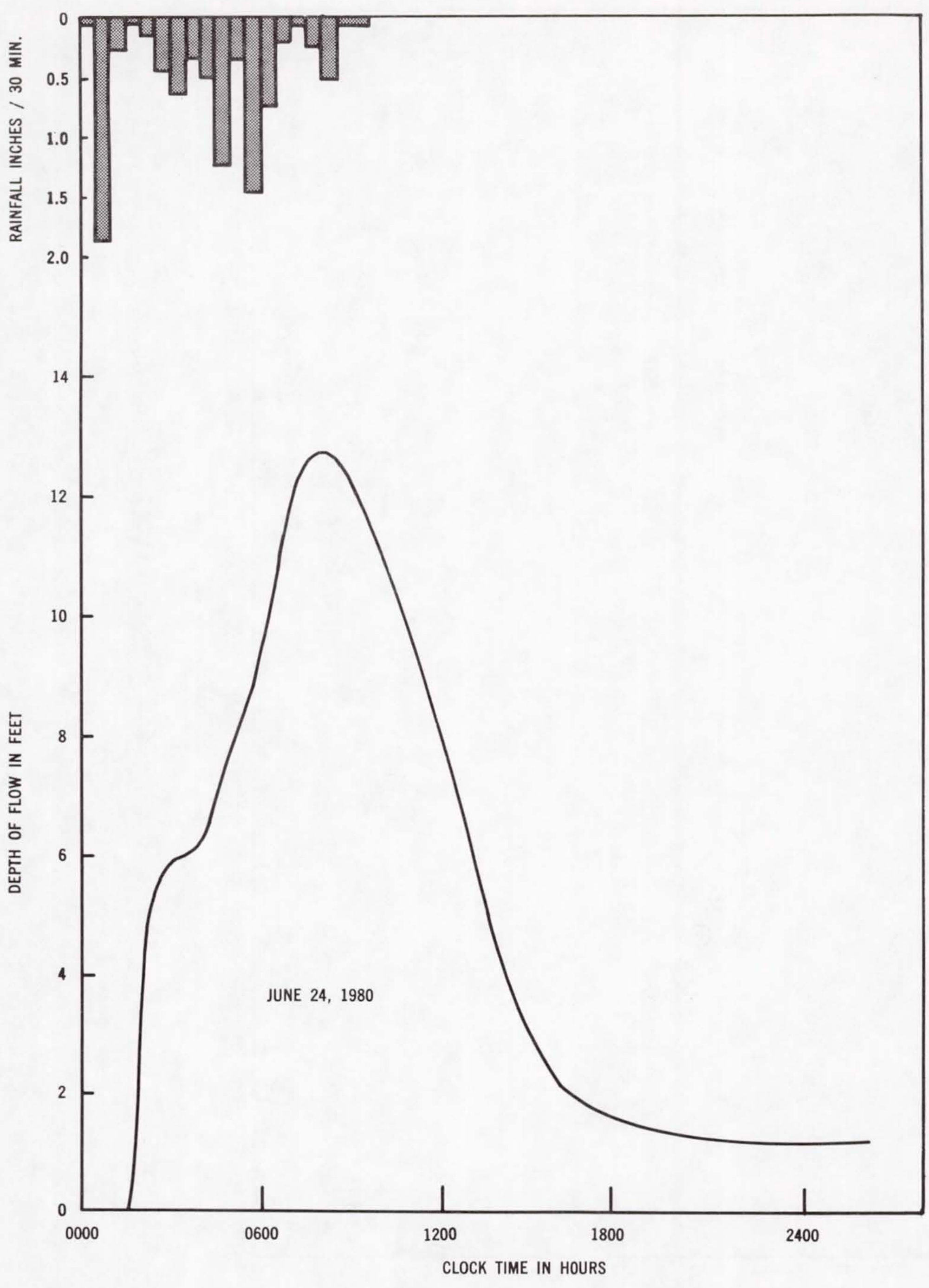


Figure 62. Hydrograph at Item 3A, North Fork, Tillatoba Creek

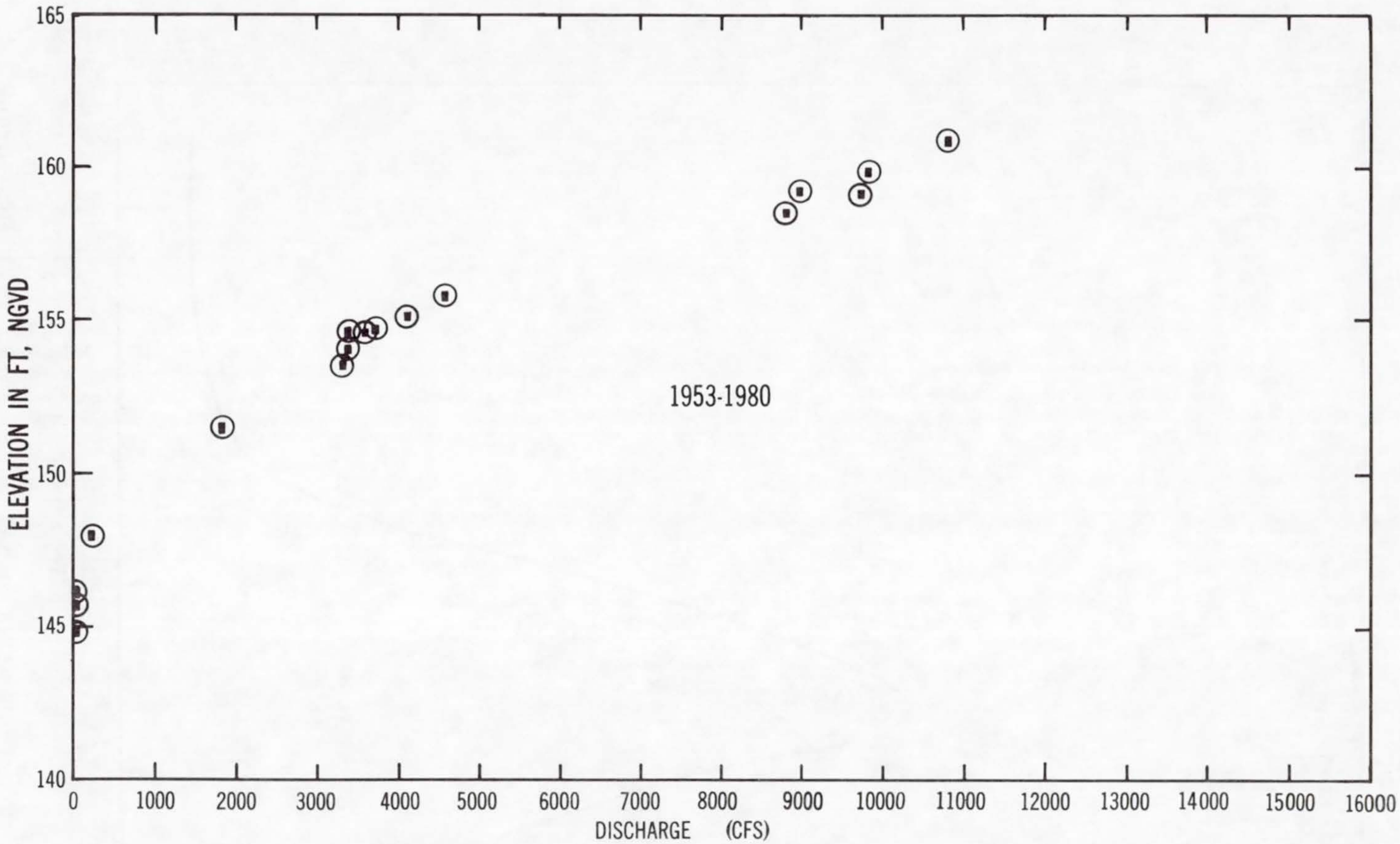


Figure 63. Rating curve, Tillatoba Creek

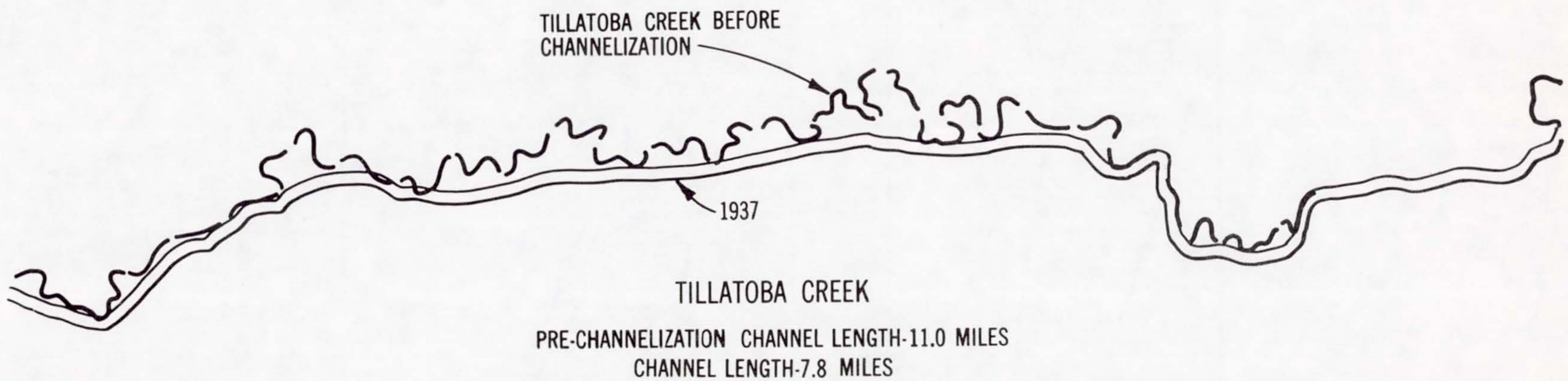


Figure 64. Plan view comparison, Tillatoba Creek after channelization

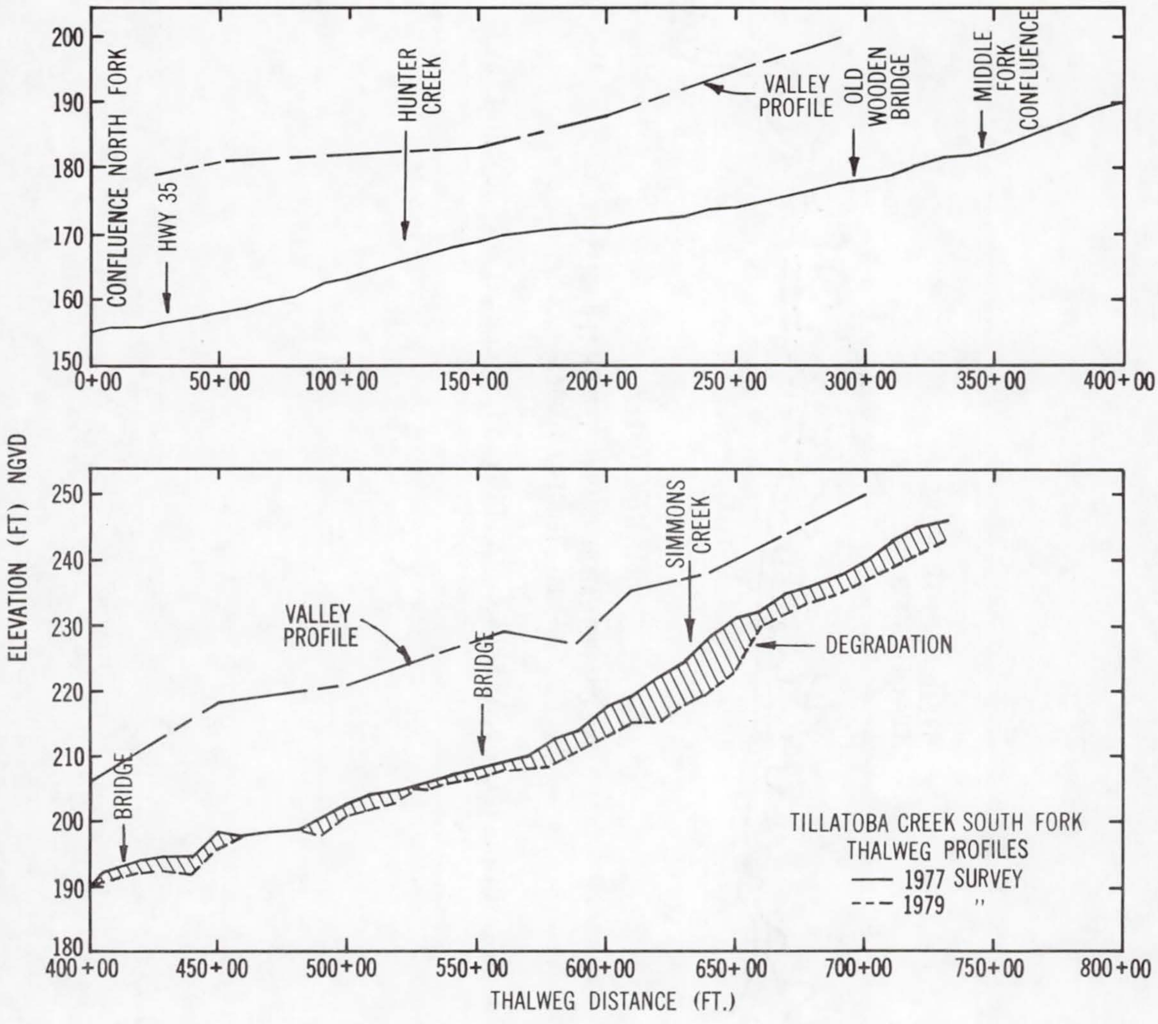


Figure 65. Thalweg profile, South Fork, Tillatoba Creek

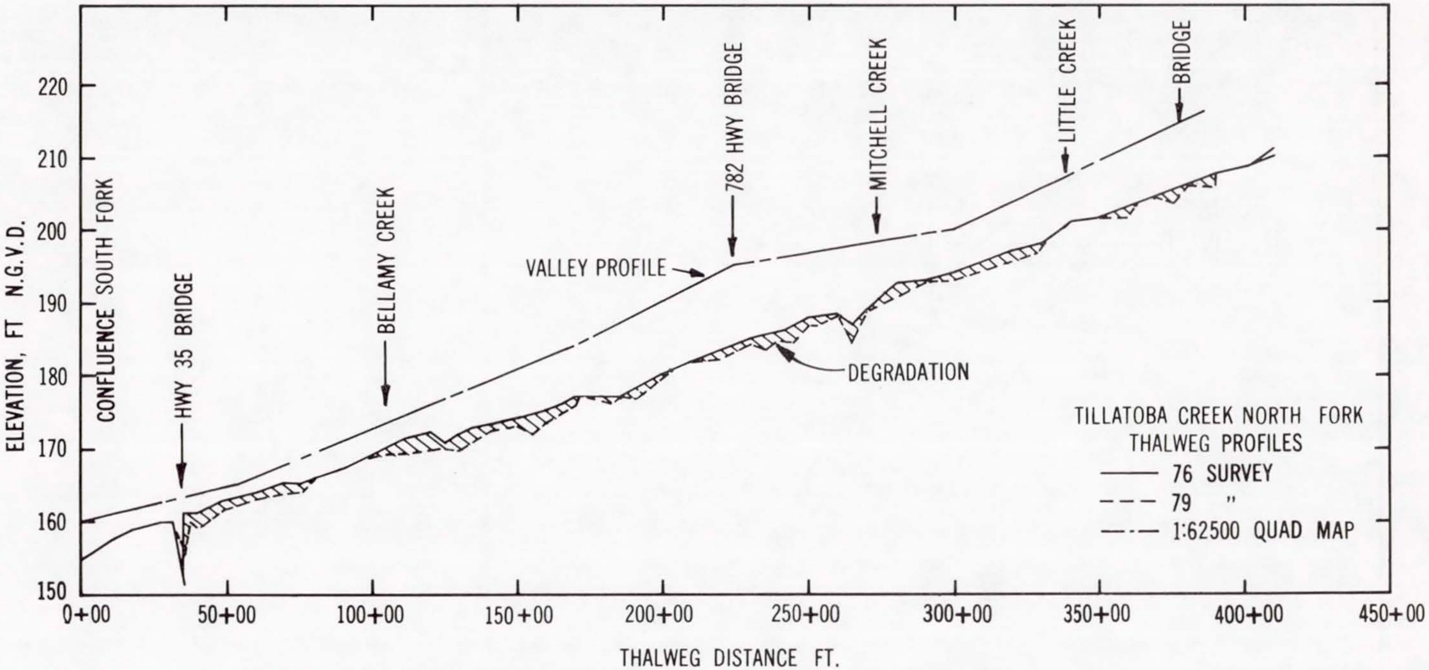


Figure 66. Thalweg profile, North Fork, Tillatoba Creek

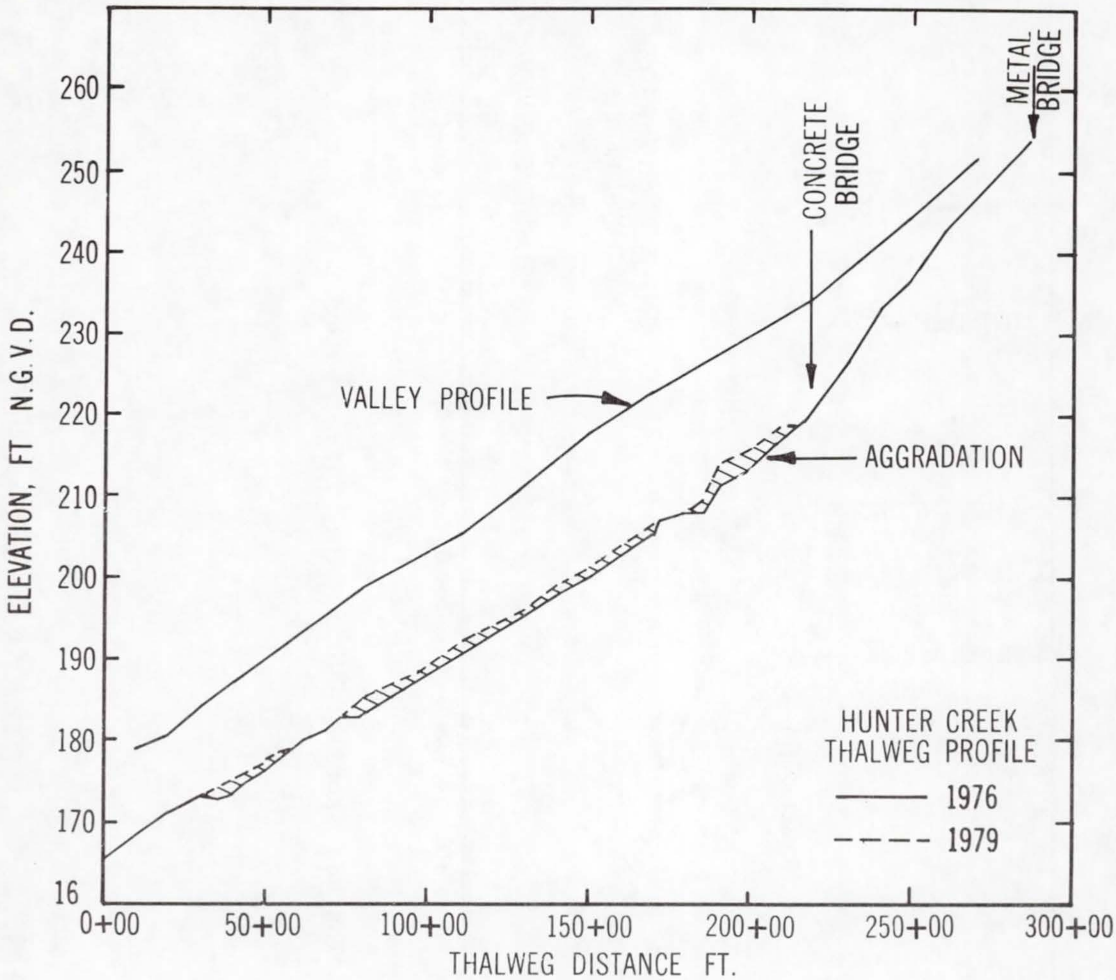
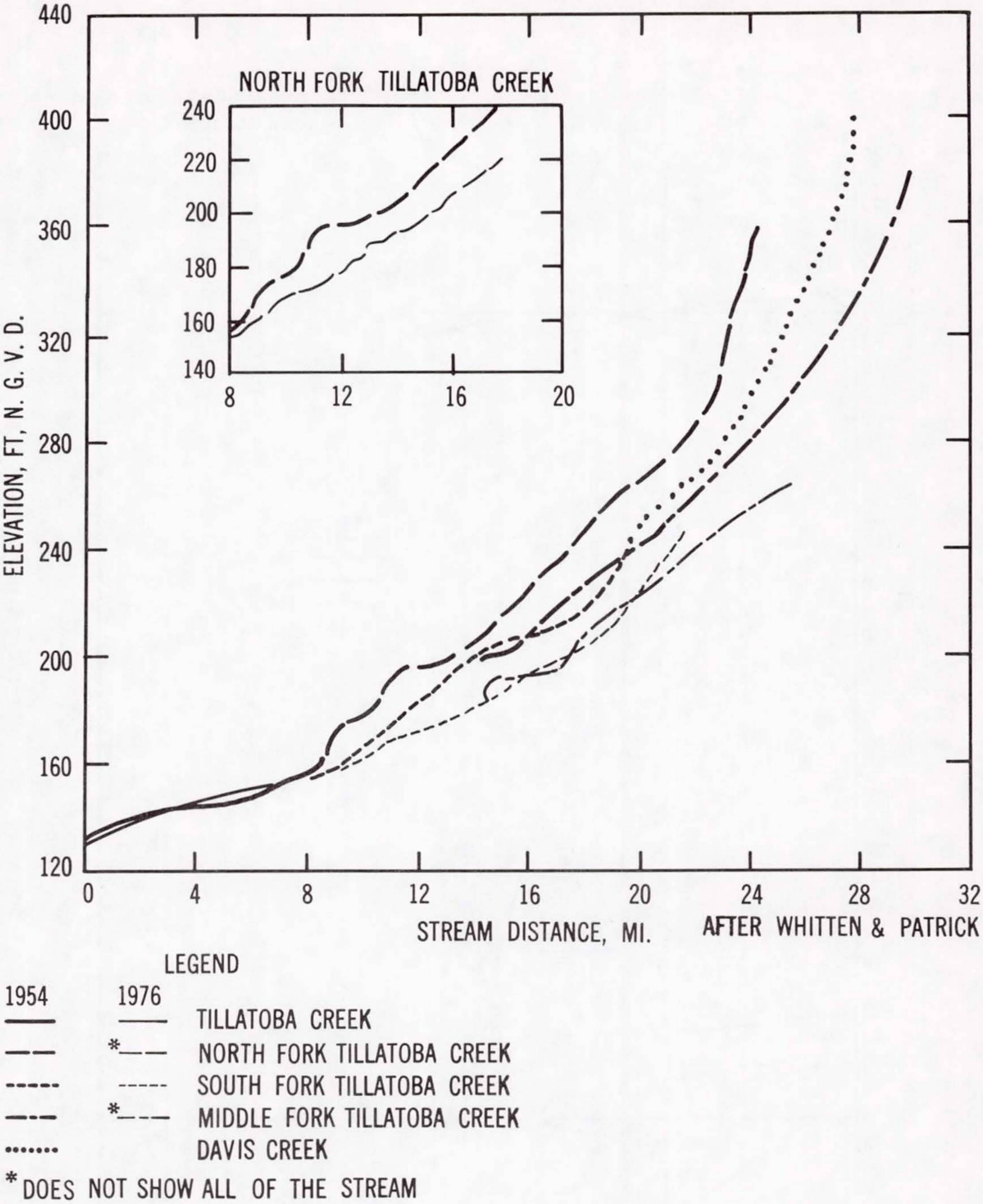


Figure 67. Thalweg profile, Hunter Creek



NOTE: LONGITUDINAL PROFILE OF THE MAJOR STREAMS IN THE TILLATOBA CREEK BASIN(1954 DATA FROM USGS TOPOGRAPHY MAPS, 1976 DATA FROM SURVEY DATA.)

Figure 68. Profile of the major streams in Tillatoba Basin

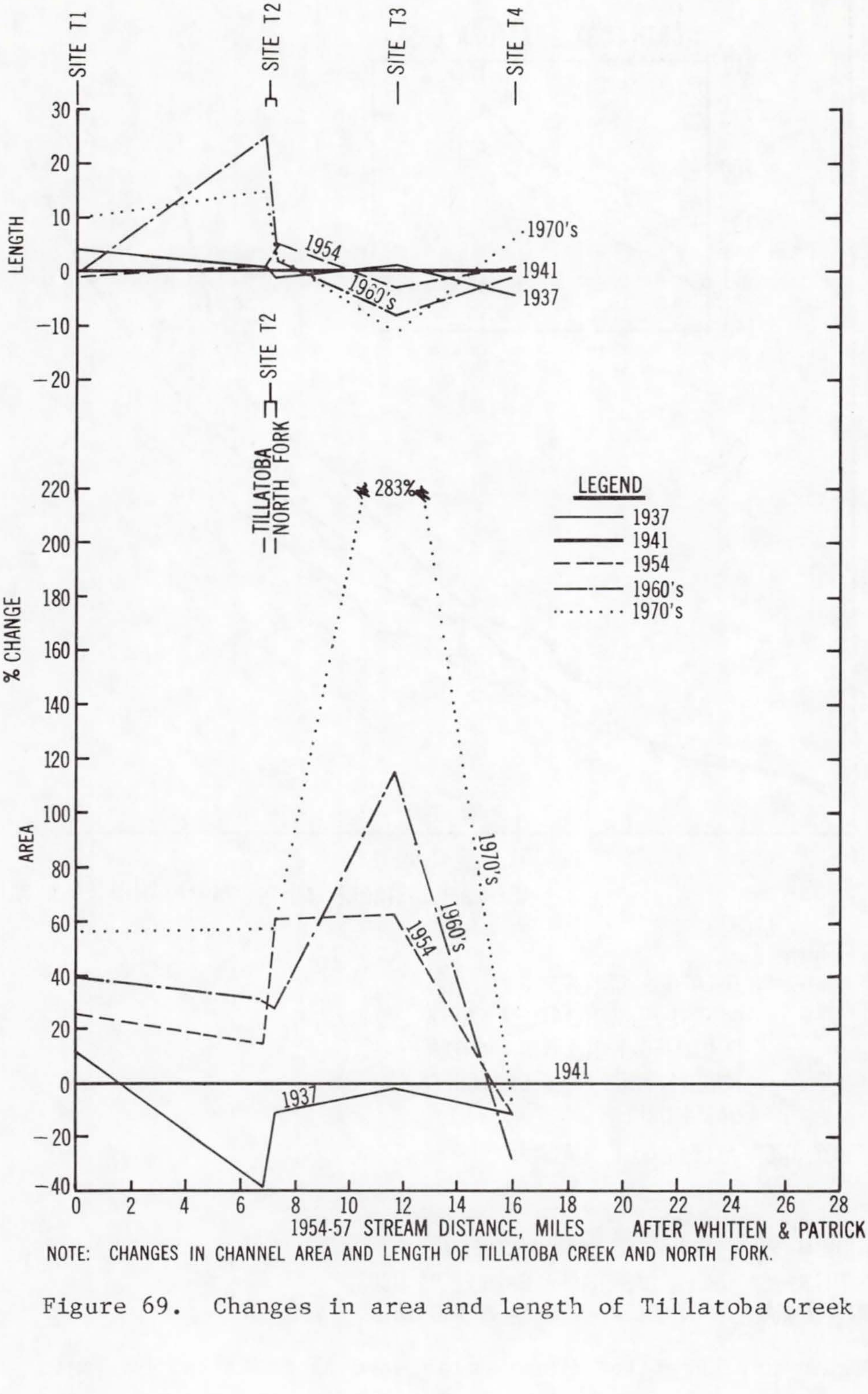
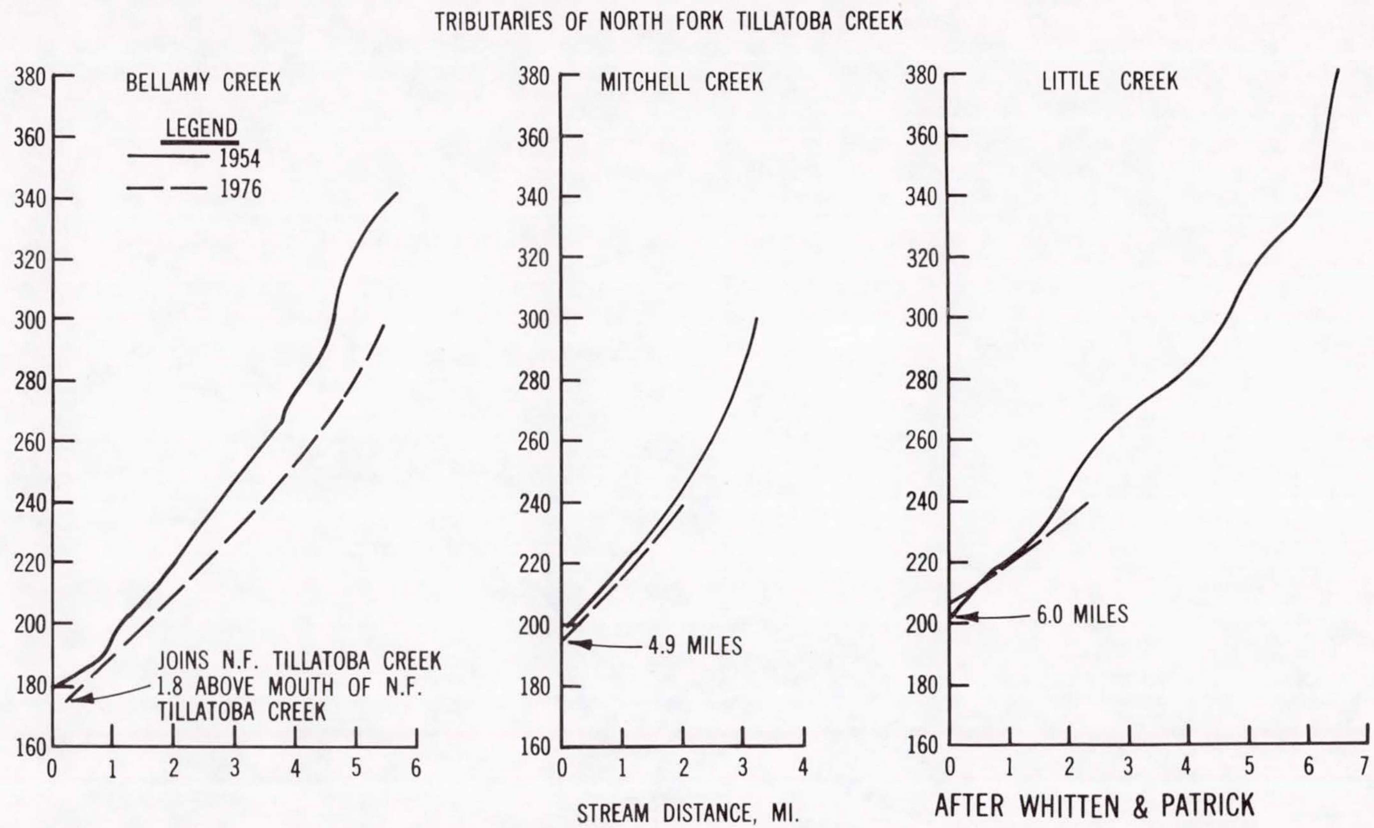


Figure 69. Changes in area and length of Tillatoba Creek



NOTE: LONGITUDINAL PROFILE OF NORTH FORK TRIBUTARIES.

Figure 70. Profile, tributaries of North Fork, Tillatoba Creek

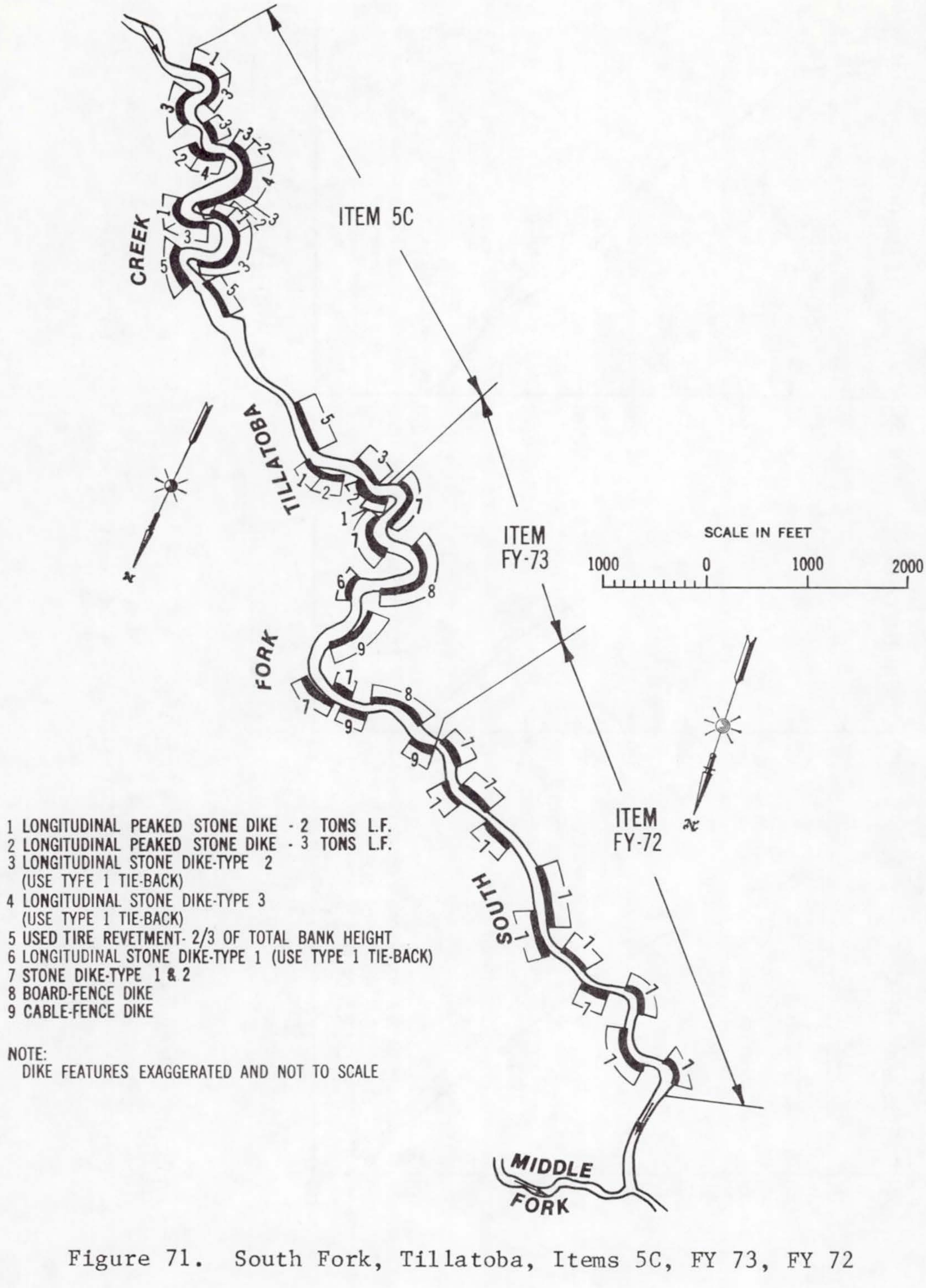


Figure 71. South Fork, Tillatoba, Items 5C, FY 73, FY 72

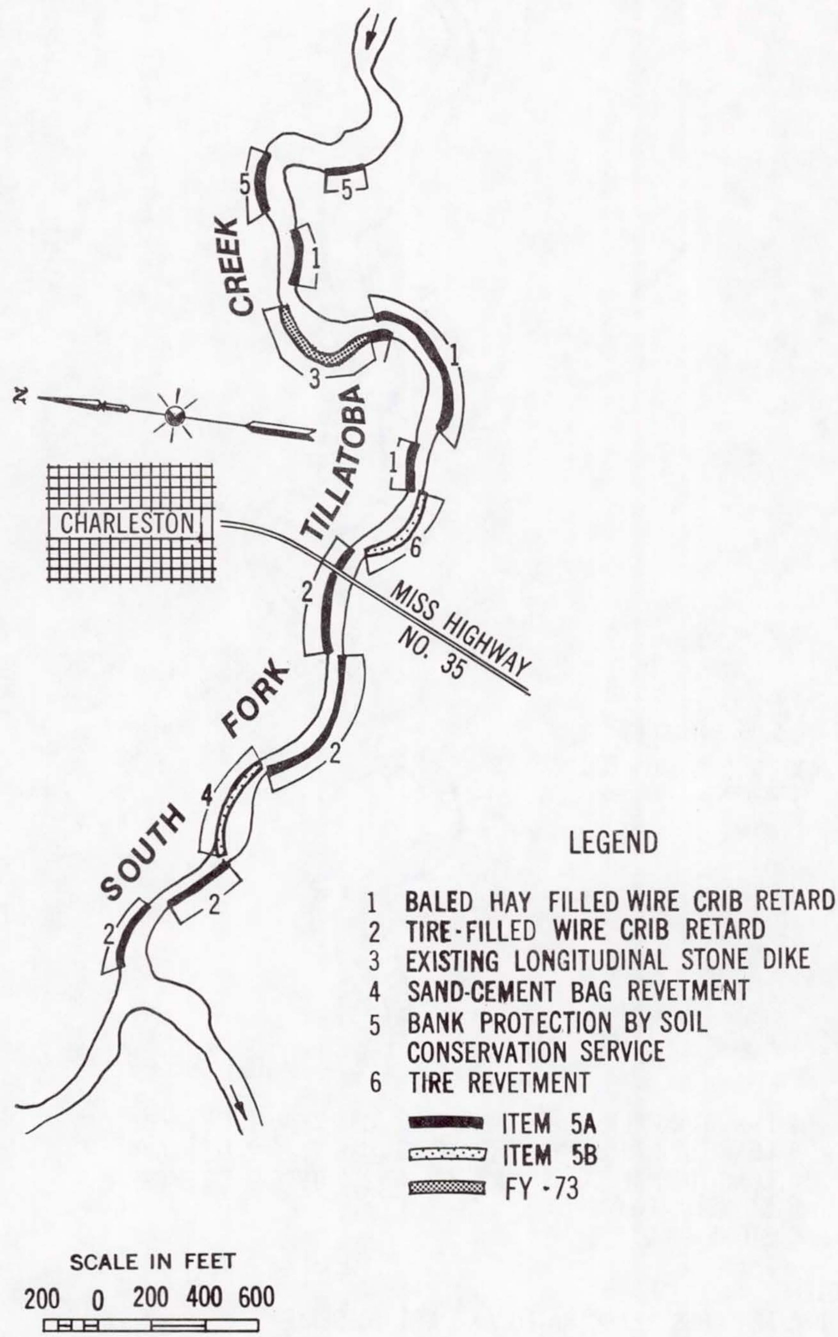


Figure 72. South Fork, Tillatoba, Items 5A, 5B, FY 73

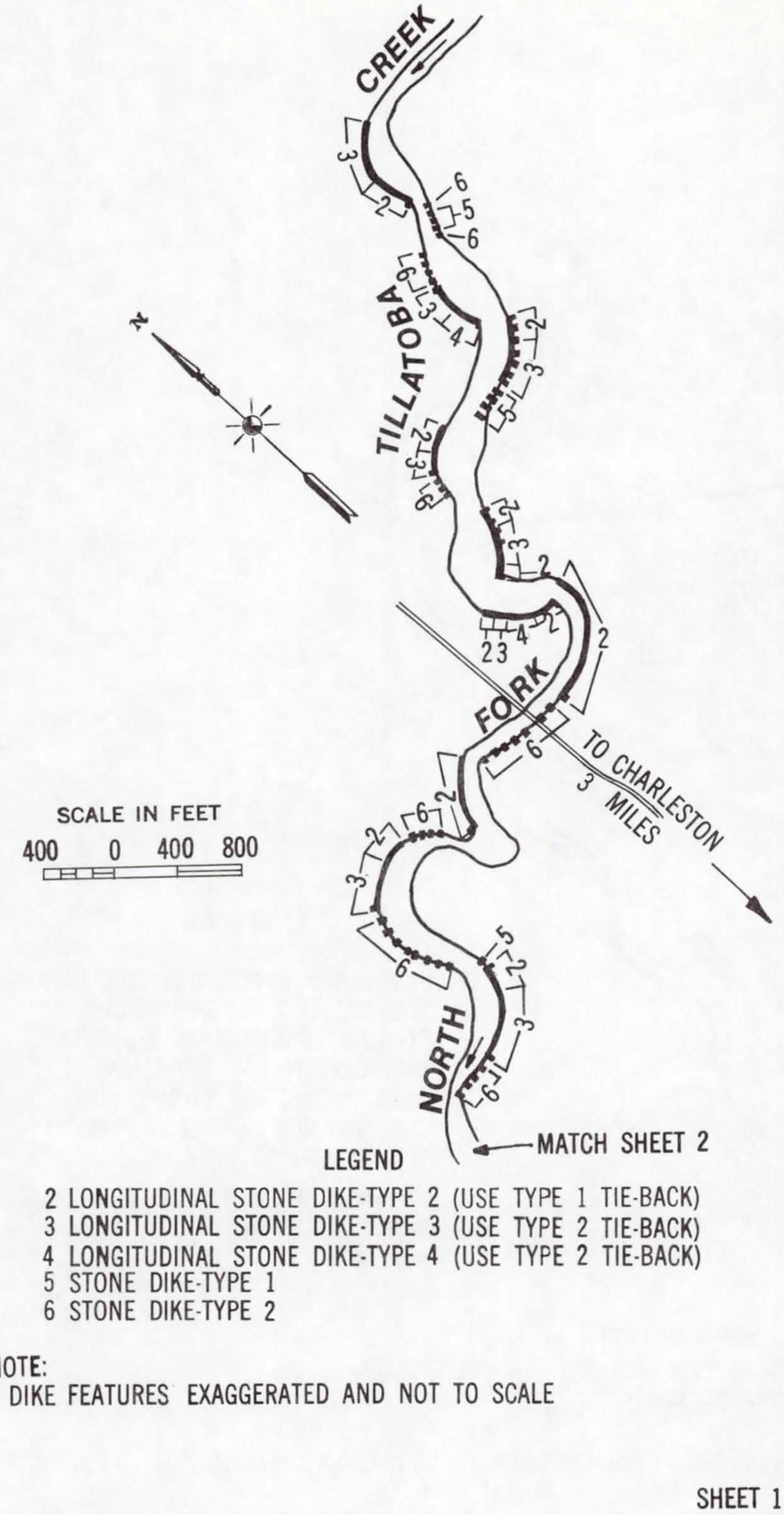
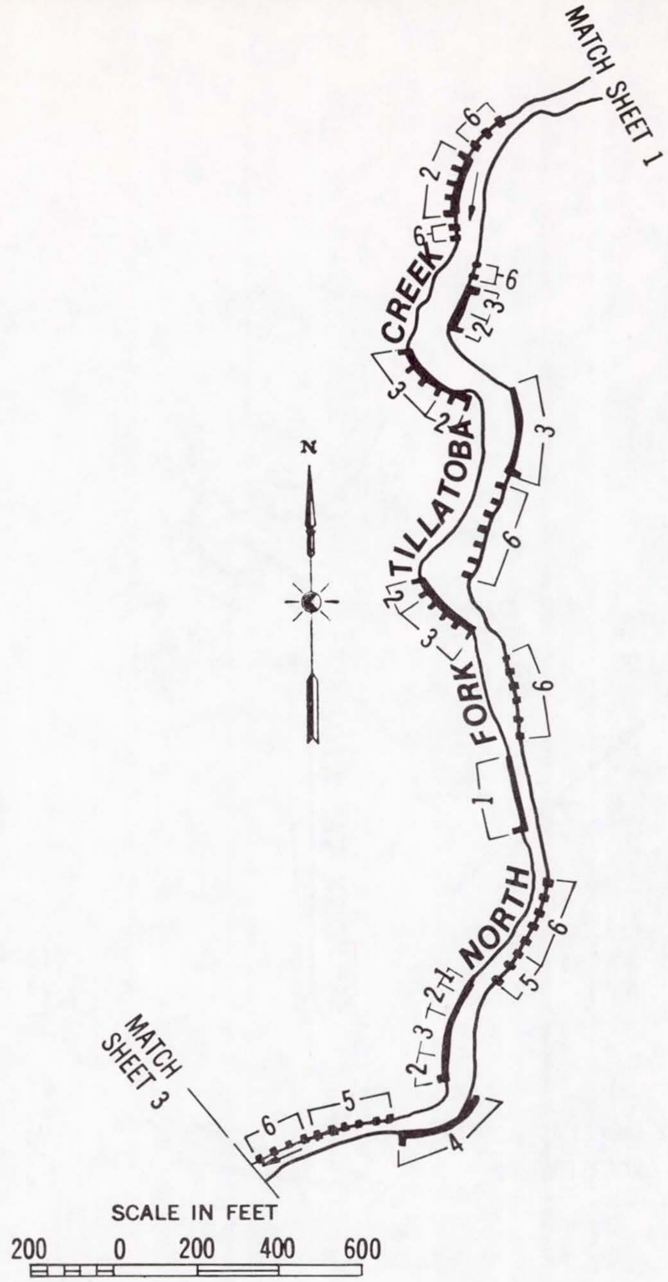


Figure 73. North Fork, Tillatoba, Item 1



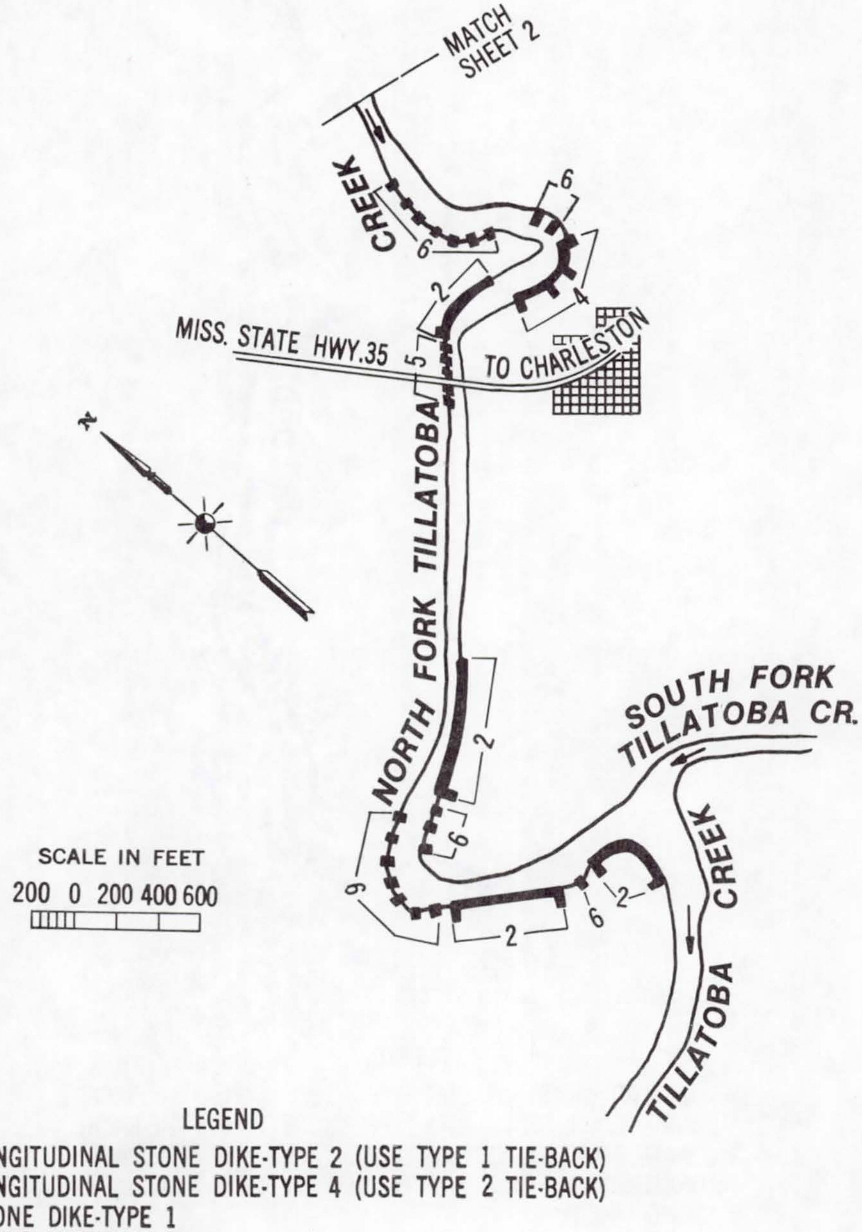
LEGEND

1 LONGITUDINAL STONE DIKE-TYPE 1 (USE TYPE 1 TIE-BACK)
2 LONGITUDINAL STONE DIKE-TYPE 2 (USE TYPE 1 TIE-BACK)
3 LONGITUDINAL STONE DIKE-TYPE 3 (USE TYPE 2 TIE-BACK)
4 LONGITUDINAL STONE DIKE-TYPE 4 (USE TYPE 2 TIE-BACK)
5 STONE DIKE-TYPE 1
6 STONE DIKE-TYPE 2

NOTE:
DIKE FEATURES EXAGGERATED AND NOT TO SCALE

SHEET 2

Figure 74. North Fork, Tillatoba, Item 2



LEGEND

2 LONGITUDINAL STONE DIKE-TYPE 2 (USE TYPE 1 TIE-BACK)
4 LONGITUDINAL STONE DIKE-TYPE 4 (USE TYPE 2 TIE-BACK)
5 STONE DIKE-TYPE 1
6 STONE DIKE-TYPE 2

NOTE:
DIKE FEATURES EXAGGERATED AND NOT TO SCALE

SHEET 3

Figure 75. North Fork, Tillatoba, Item 2

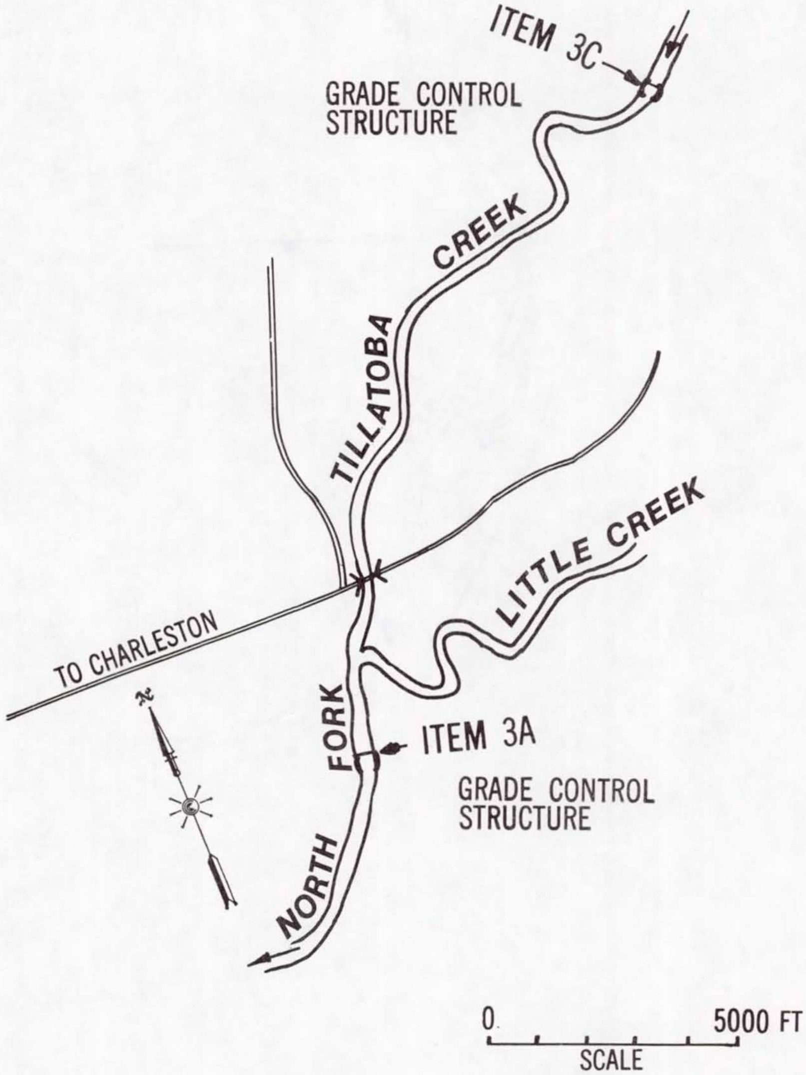
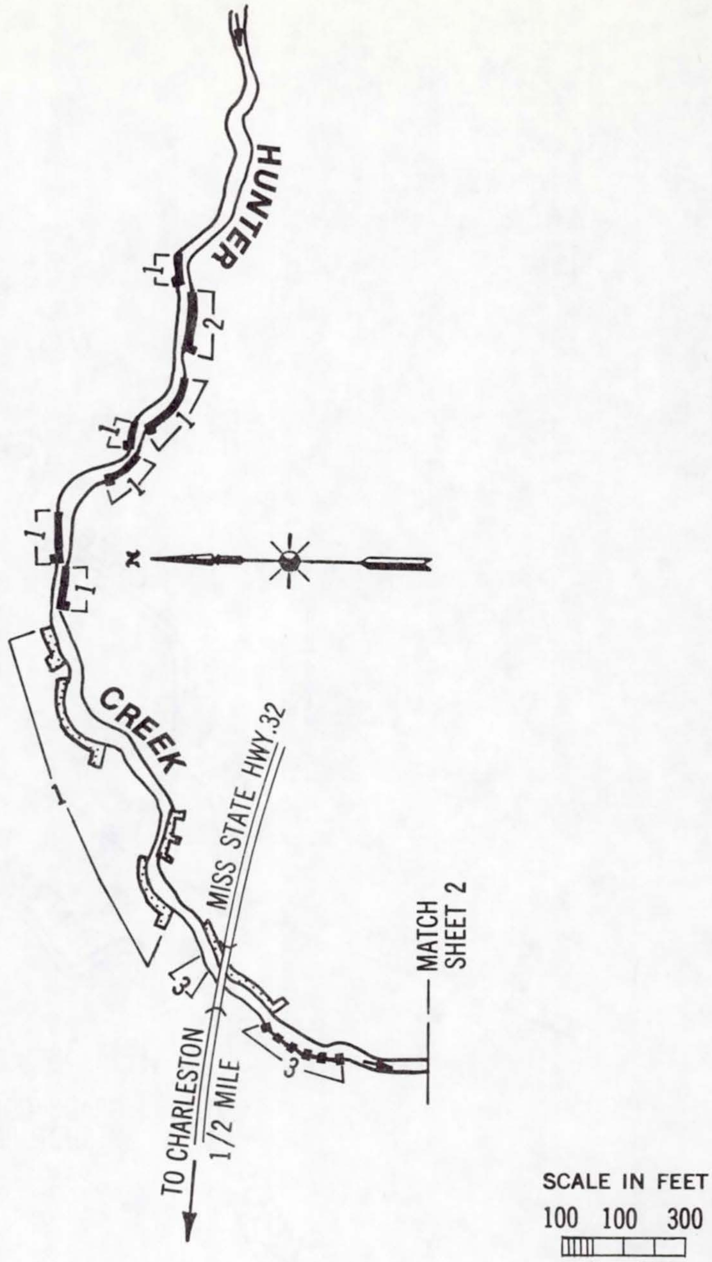


Figure 76. North Fork, Tillatoba, Items 3A and 3C



LEGEND

1 LONGITUDINAL STONE DIKE - TYPE 1 (USED TYPE 1 TIE-BACK)
2 LONGITUDINAL STONE DIKE - TYPE 2 (USED TYPE 1 TIE-BACK)
3 STONE DIKE - TYPE 1

ITEM 1

ITEM 1A

NOTE:
DIKE FEATURES EXAGGERATED AND NOT TO SCALE

Figure 77. Hunter Creek, Items 1 and 1A

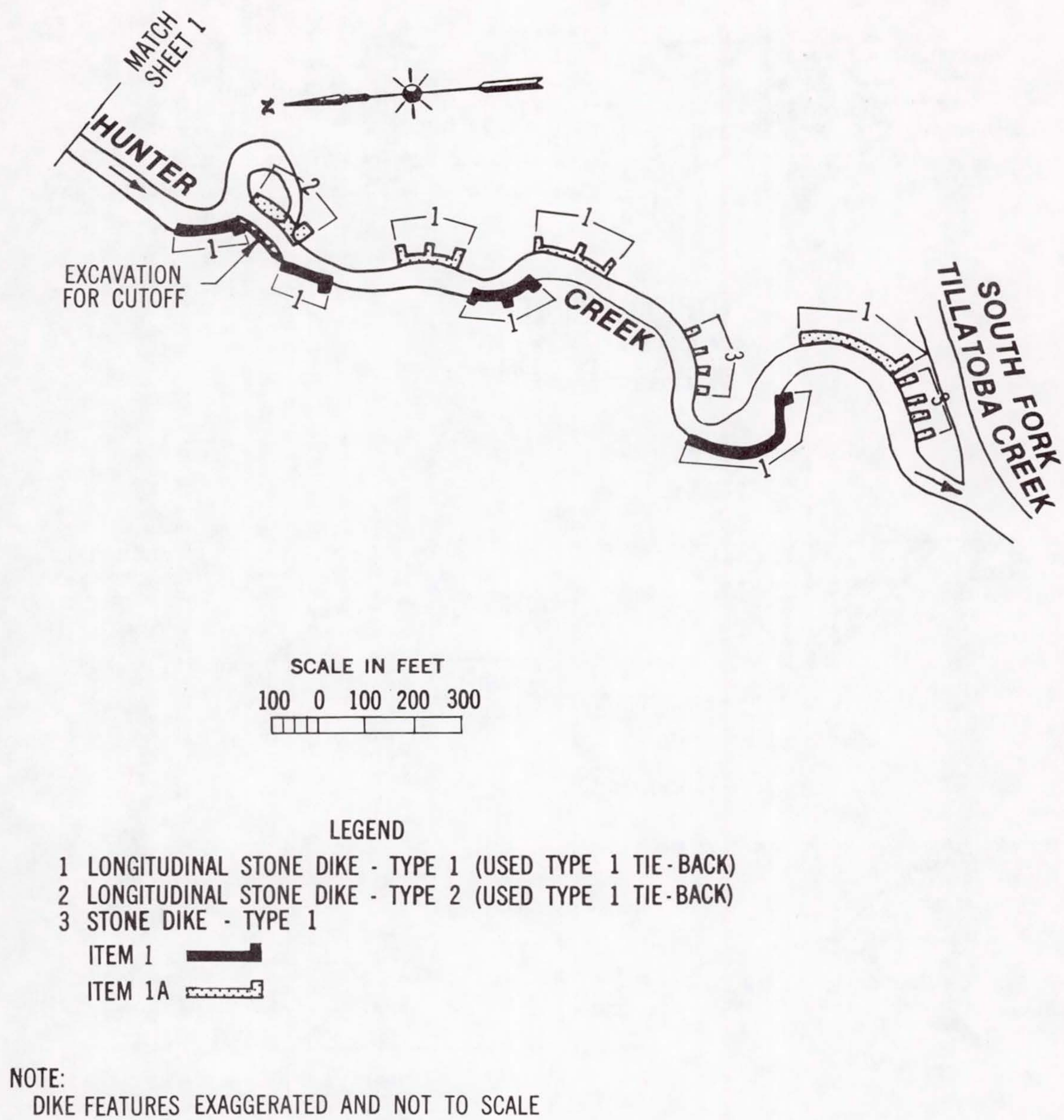


Figure 78. Hunter Creek, Items 1 and 1A

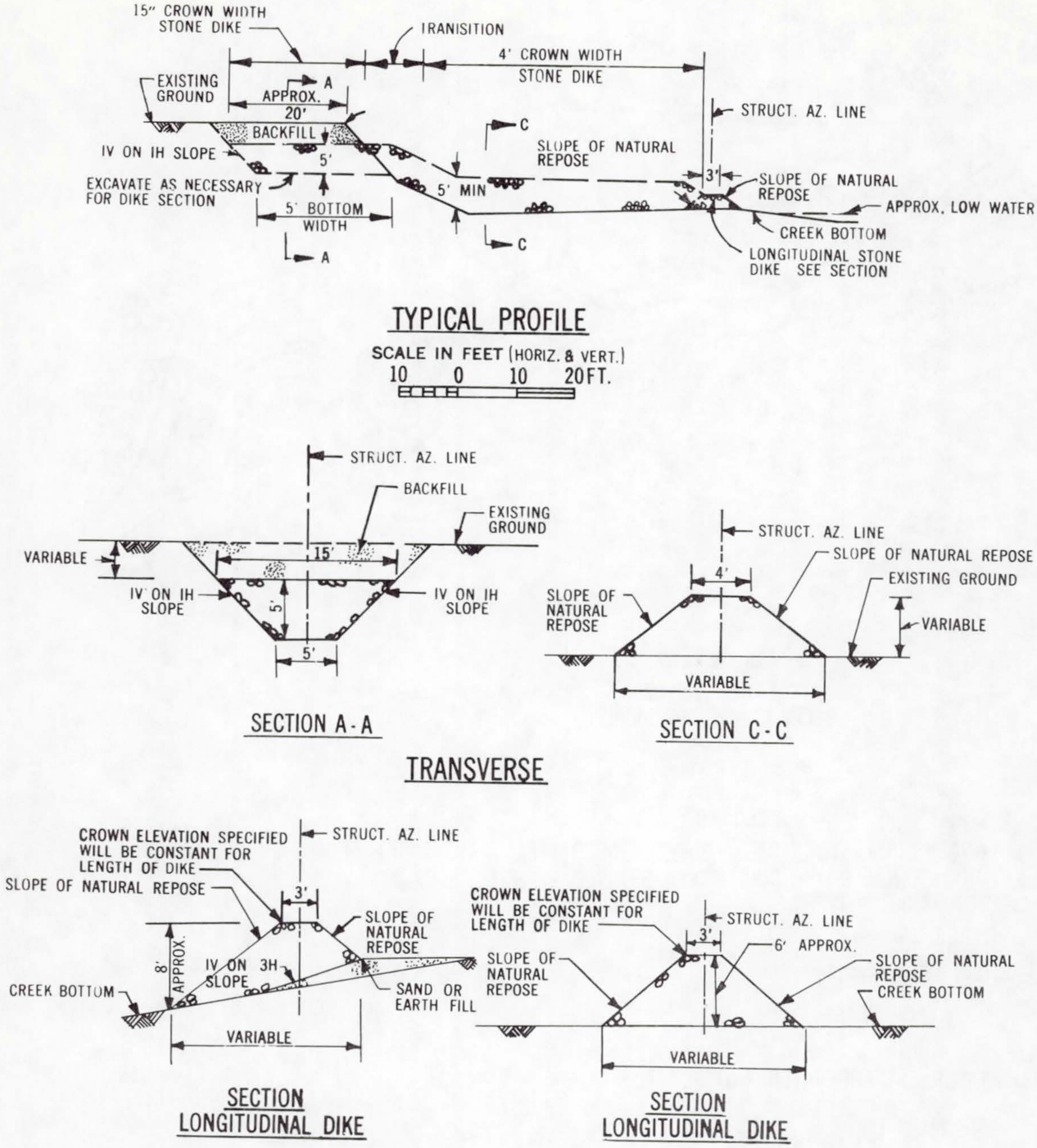


Figure 79. Typical transverse and longitudinal stone dikes, North and South Fork, Tillatoba

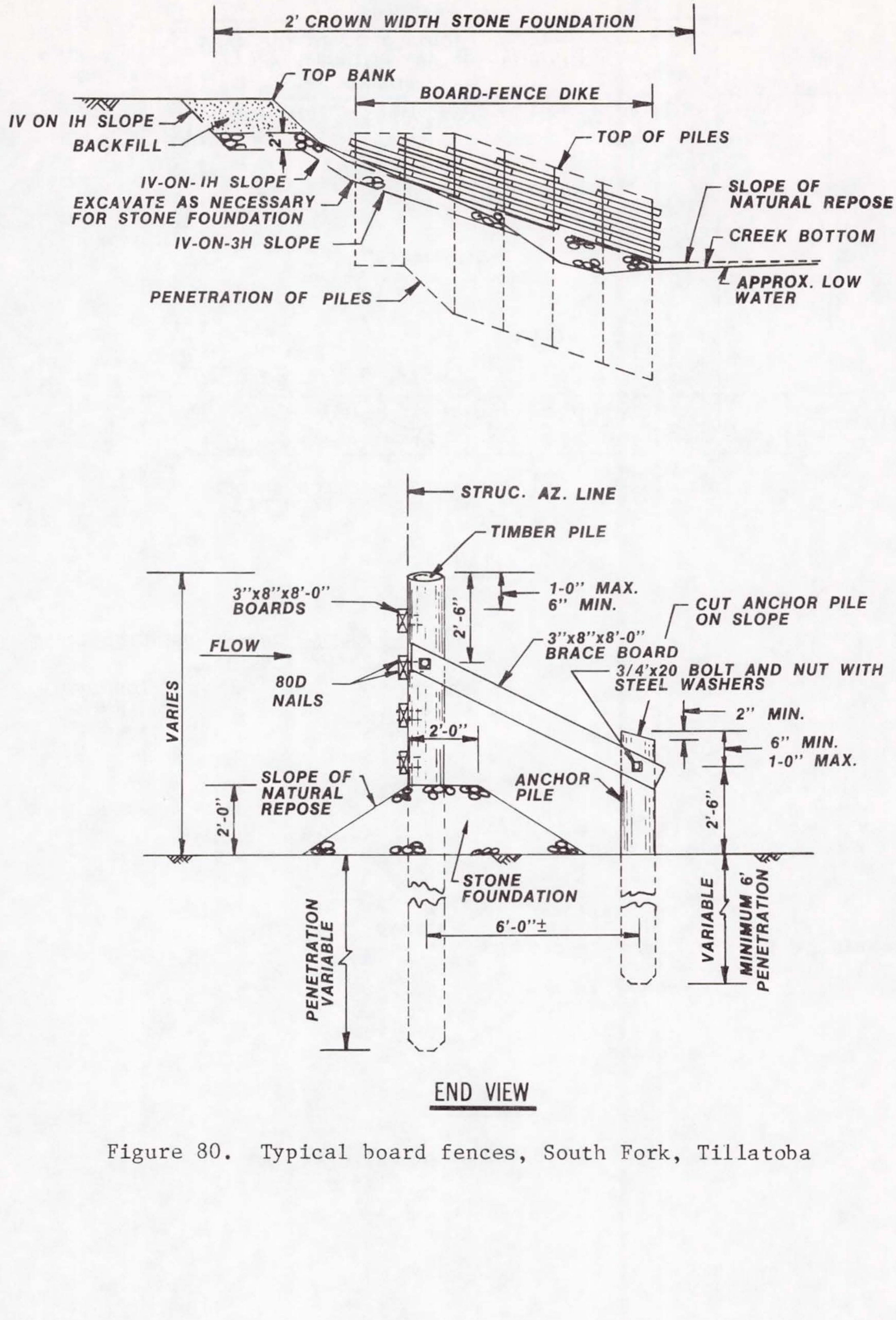
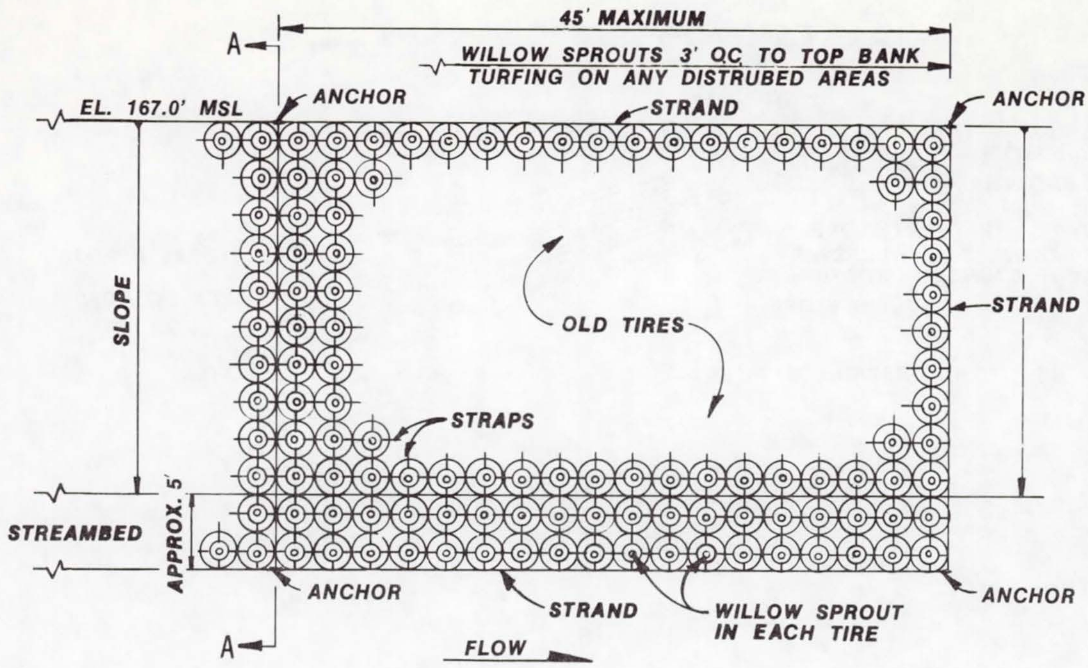
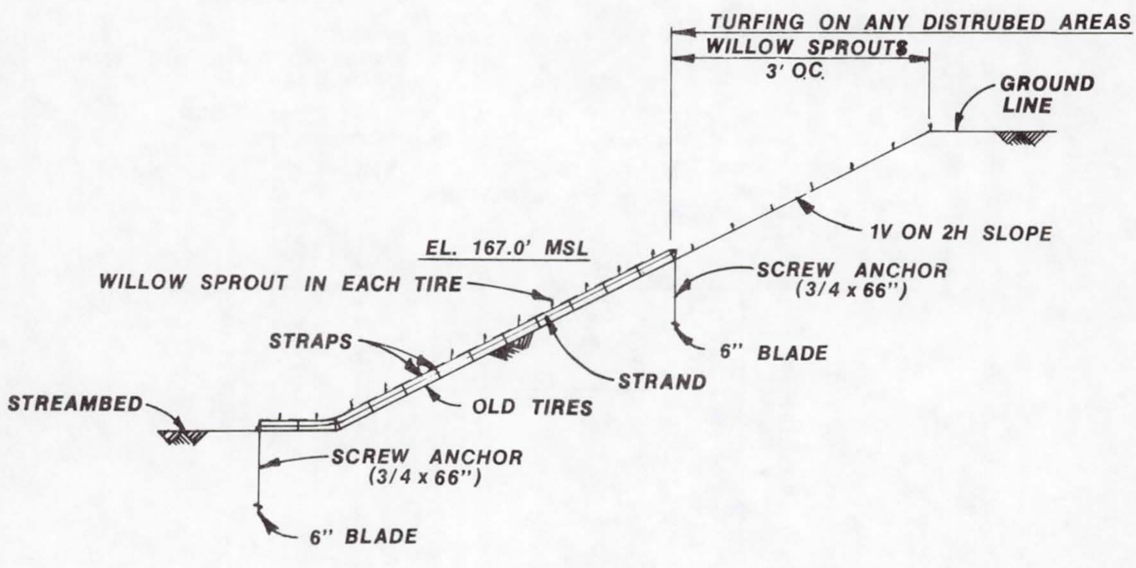


Figure 80. Typical board fences, South Fork, Tillatoba

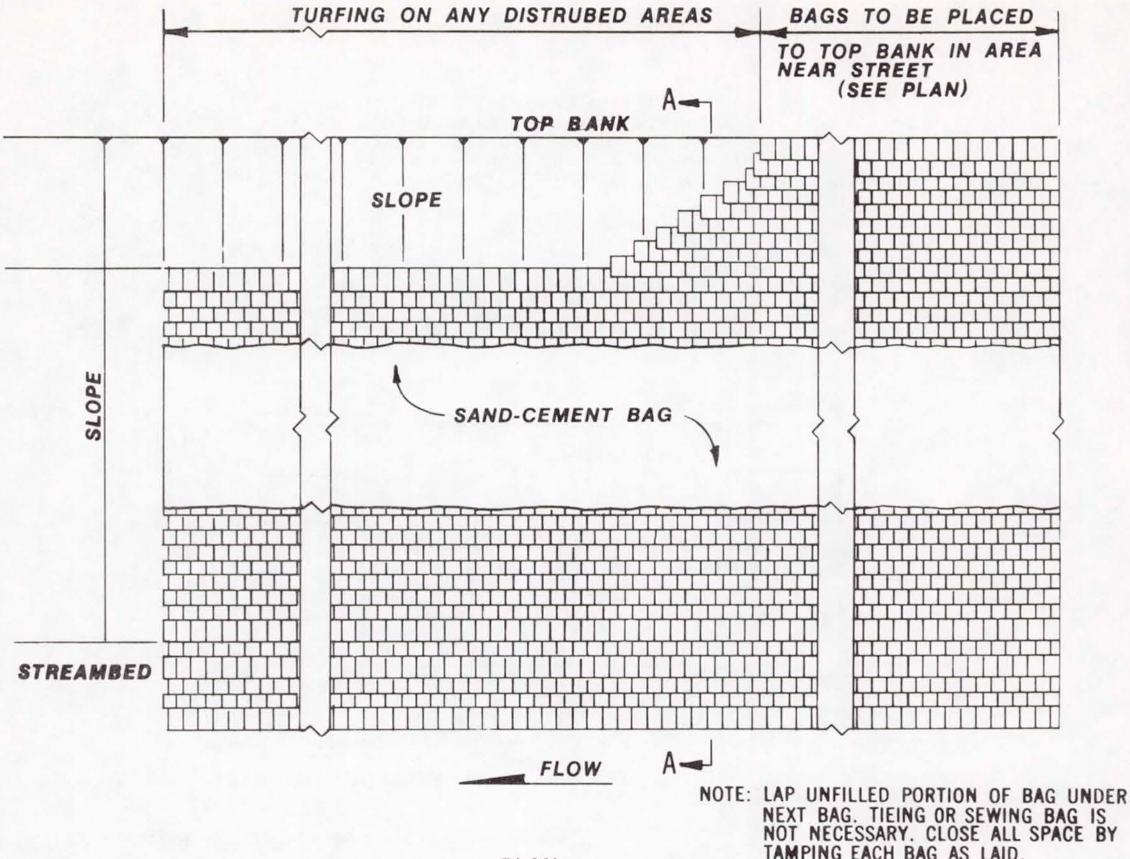


PLAN

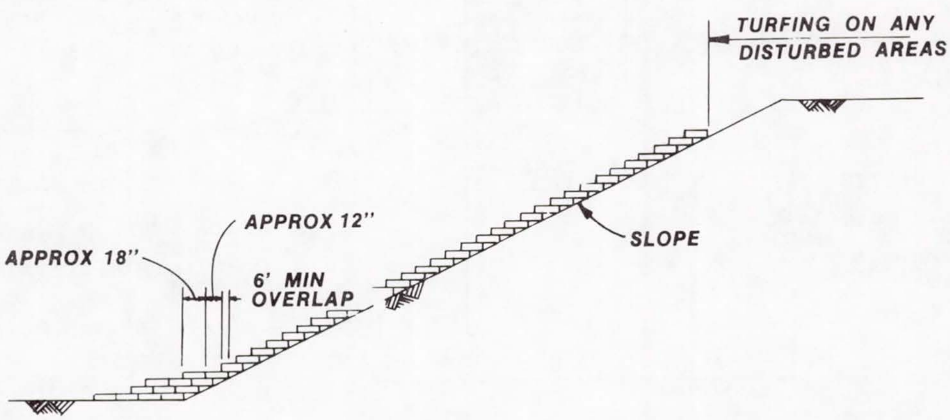


SECTION A-A

Figure 81. Typical used tire revetment



PLAN



SECTION A-A

Figure 82. Typical sand-cement bag revetment

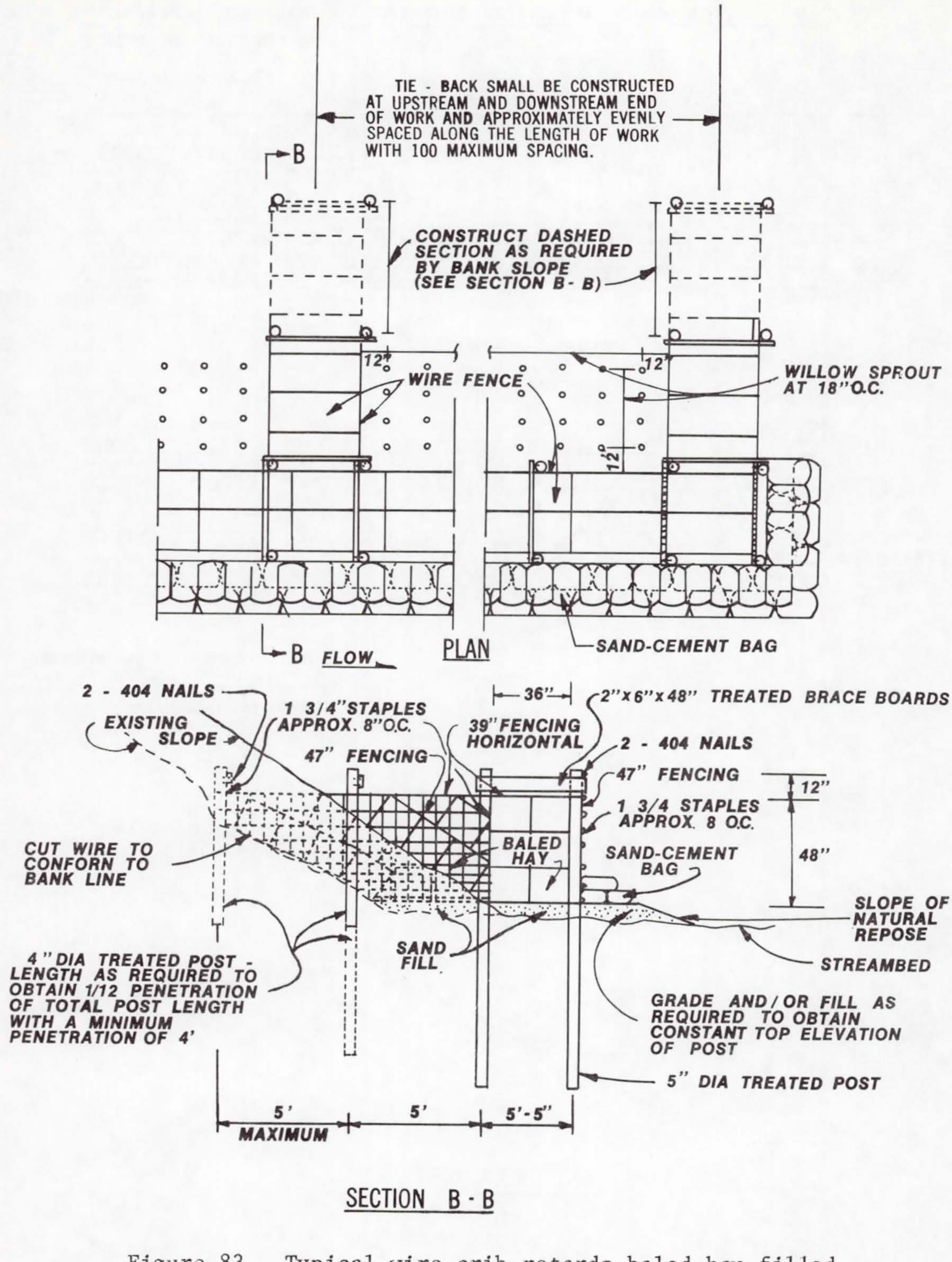


Figure 83. Typical wire crib retards baled hay filled

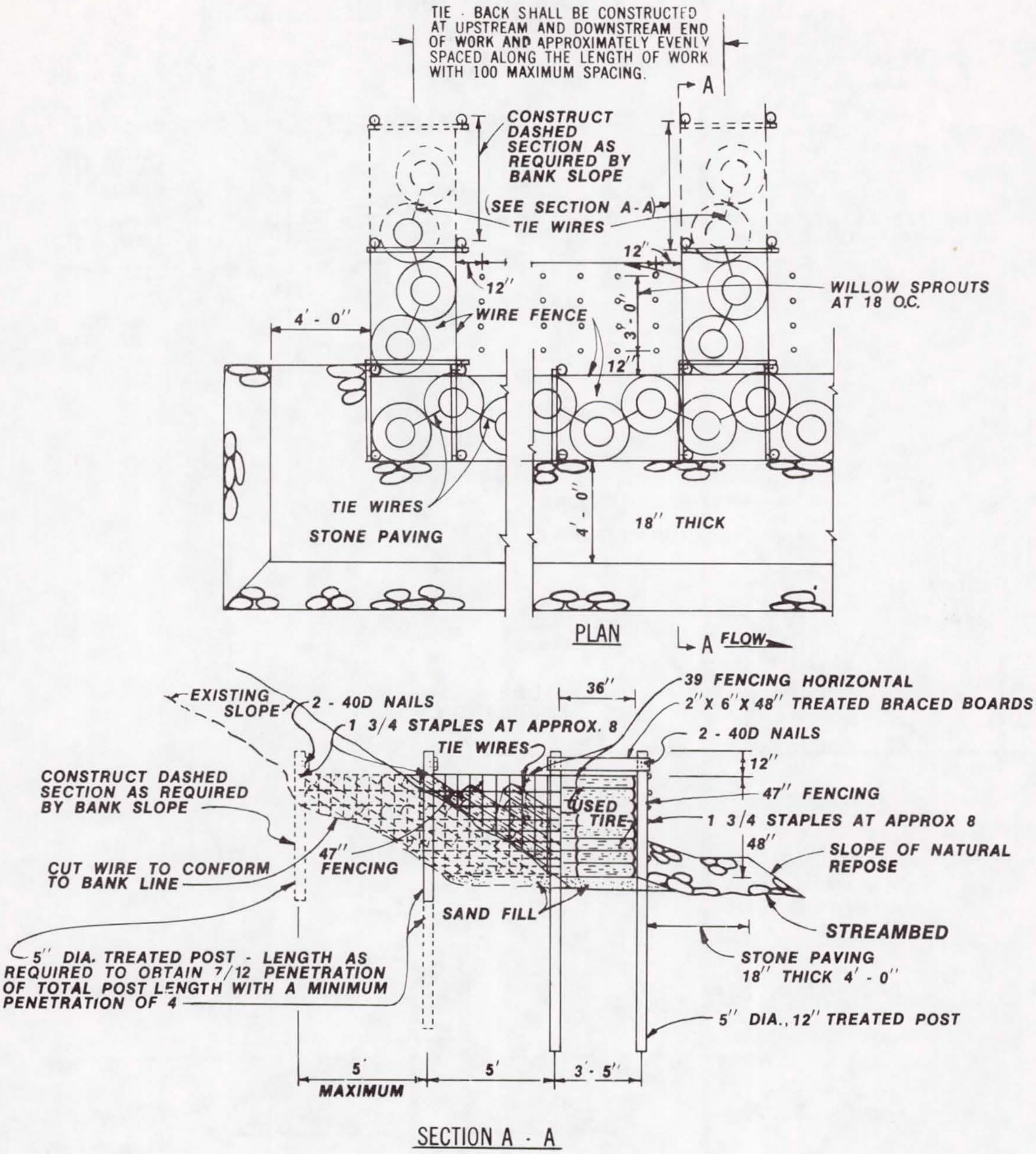


Figure 84. Typical wire cribs, retards tire-filled

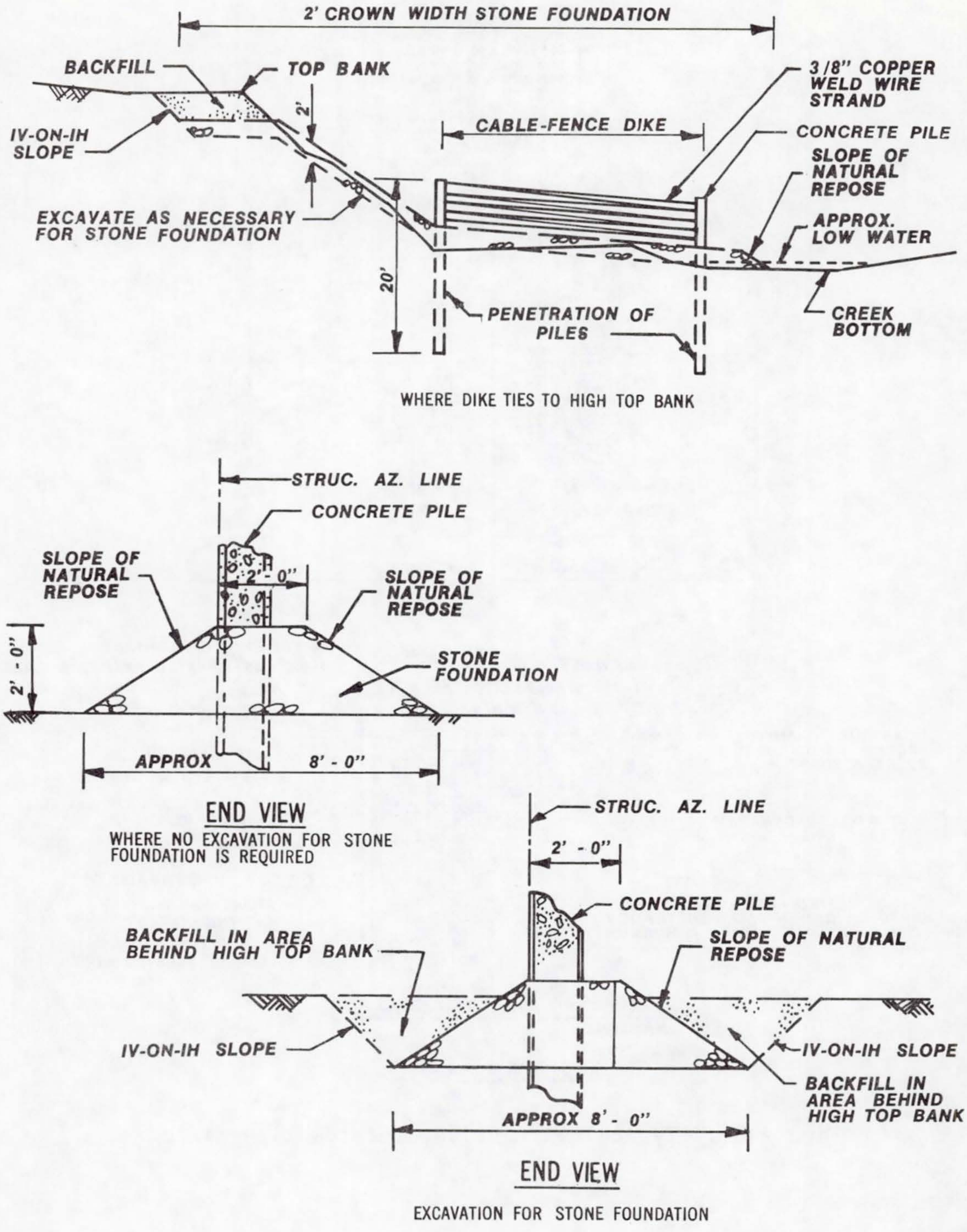


Figure 85. Typical cable-fence dike

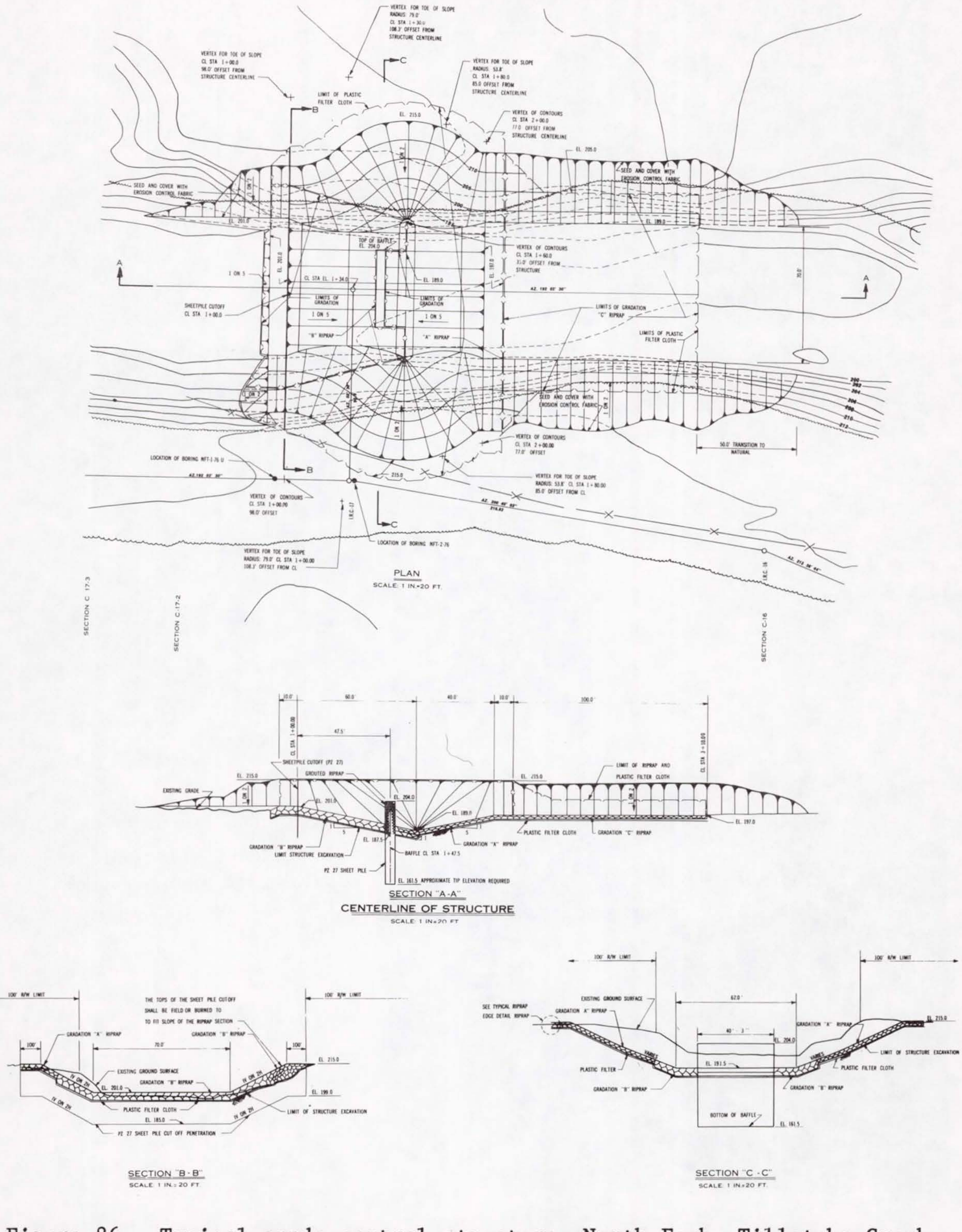
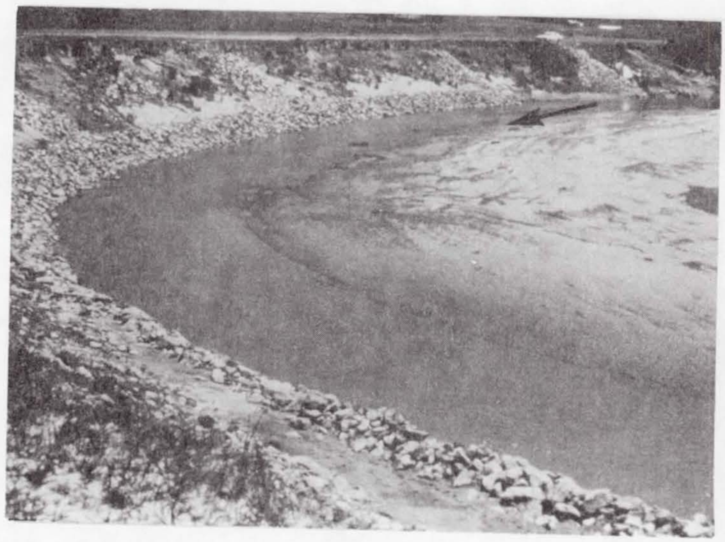


Figure 86. Typical grade control structure, North Fork, Tillatoba Creek

Longitudinal Stone Dike
with Vegetation
Sept 1976

Longitudinal Stone Dikes
with Stone Tie Backs



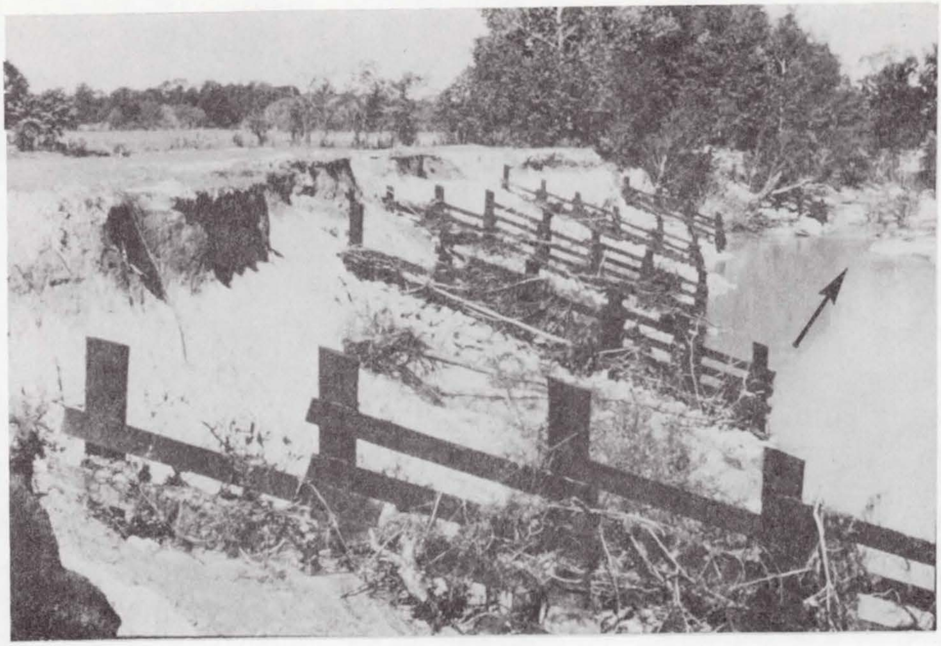
Longitudinal Stone
Dike with Upper Bank
Protection in Place
Feb 1979

Figure 87. Photographs of longitudinal stone dikes

Stone Transverse Dikes in Sharp Bend

Stone Transverse Dikes with Scour
Downstream of Dike North Fork Tillatoba

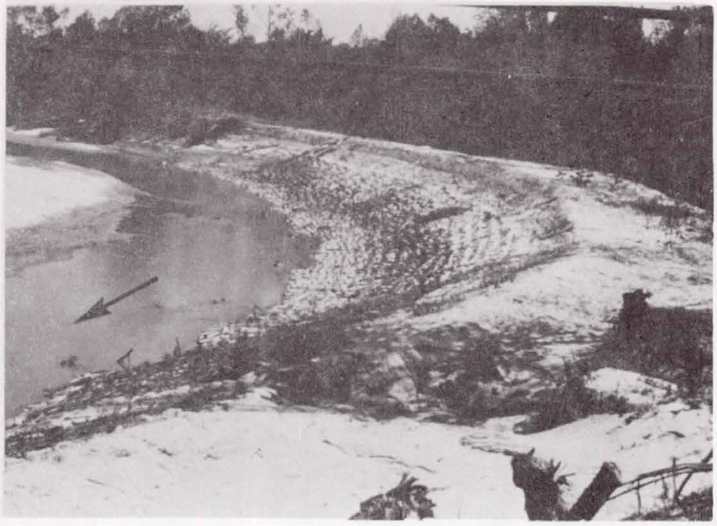
Figure 88. Photographs of transverse stone dikes



Transverse Board Dike
South Fork Tillatoba
April 1974

Transverse Board Dike
South Fork Tillatoba FY 73 Work
Dec 1976

Figure 89. Photographs of transverse board fence dikes

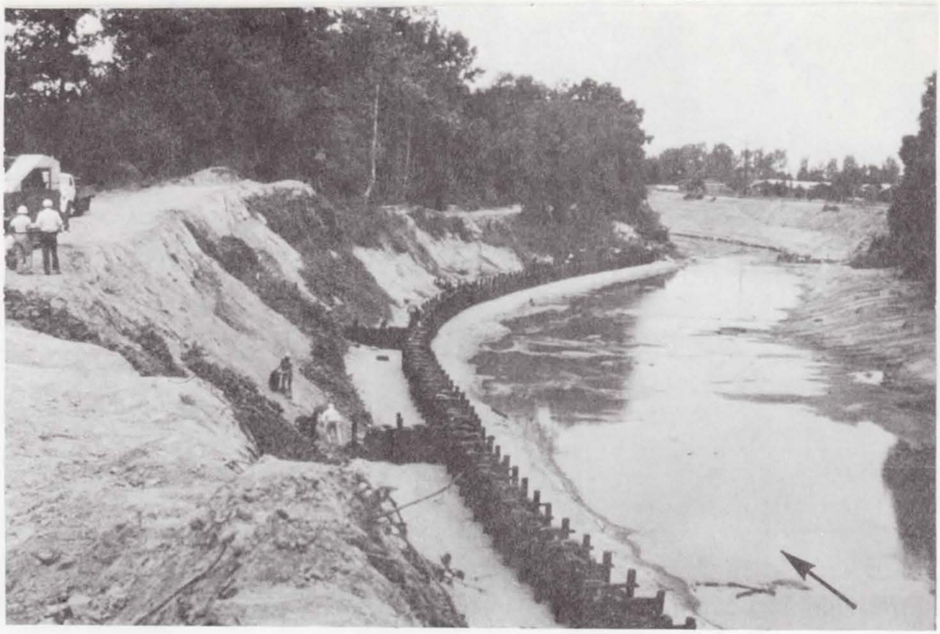


Tire Revetment Looking
Upstream from Bridge
April 1977

Tire Revetment Looking
Downstream with Good
Willow Growth
Aug 1977

Tire Revetment Looking
Upstream with good
Willow Growth
Jan 1979

Figure 90. Photographs of used tire revetment

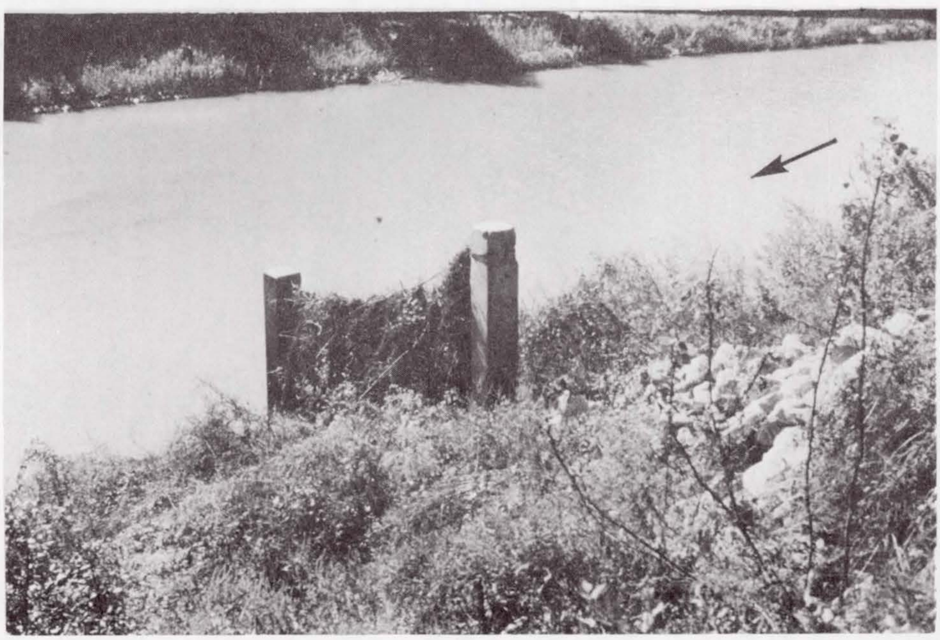


Tire Crib Retards
During Construction
Looking Downstream
July 1977

Empty Tire Crib Retards After
Several High Events
Looking Downstream
Jan 1978

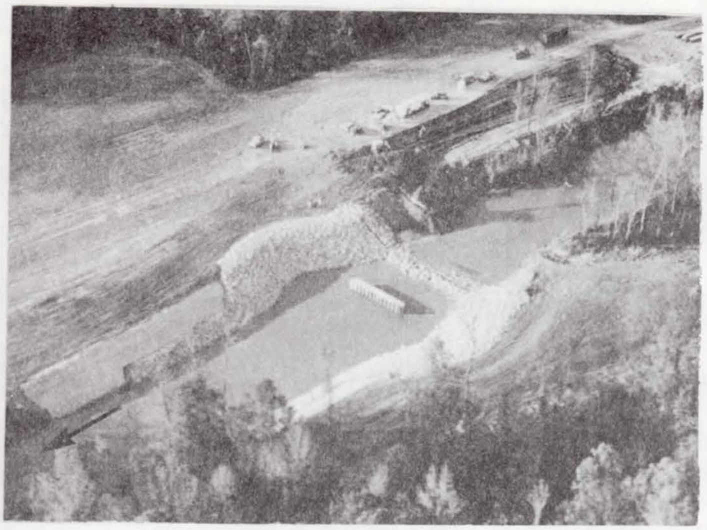
Figure 91. Photographs of used tire wire cribs

Transverse Cable Fence Dike
South Fork Tillatoba Creek
Dec 1976



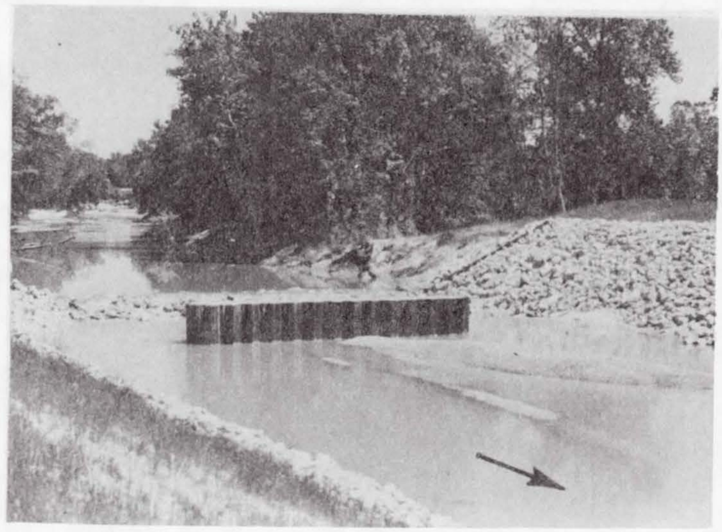
Transverse Cable Fence Dike
South Fork Tillatoba Creek
Oct 1977

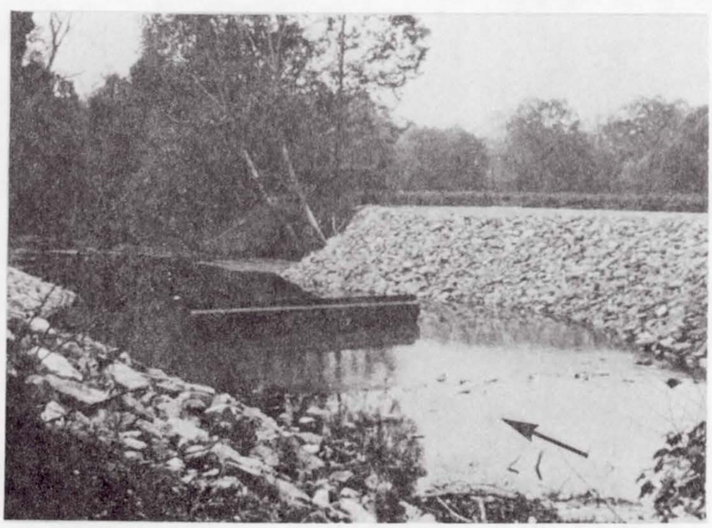
Figure 92. Photographs of cable-fence



Item 3A
North Fork Tillatoba Creek
Scour Hole Shape
& Baffle Location
Nov 1977

Item 3A
Baffle Construction
May 1978



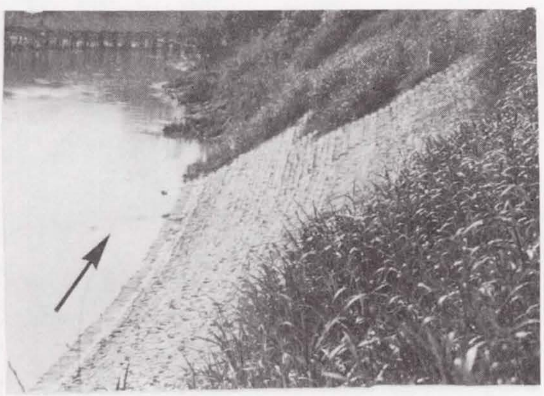


Item 3C
Baffle Construction
July 1978

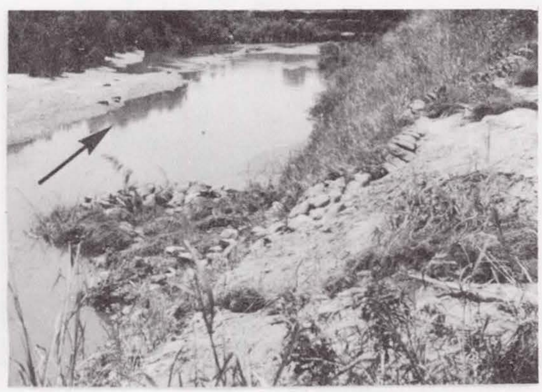
Figure 93. Photographs of grade control structure

Looking Upstream During
Construction
Sand Cement Bag Revetment
Nov 1977

Looking Upstream After
Construction
Sand Cement Bag Revetment
July 1977

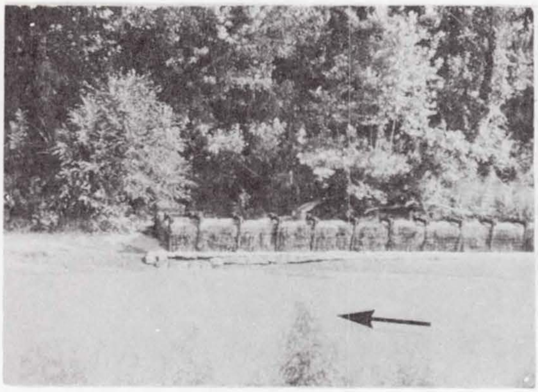


Looking Downstream
Sand Cement Bag Revetment
May 1978

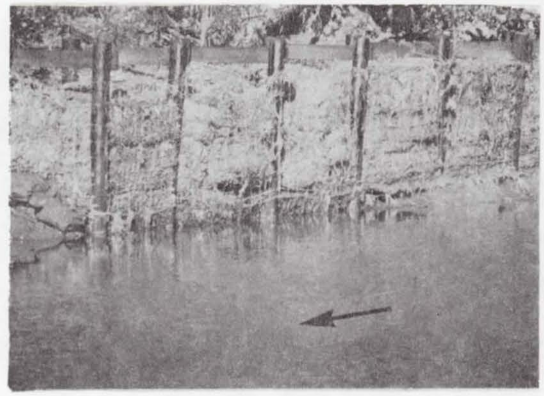


Looking Downstream After
Damaging Overbank Flows
and Slip Failure
Sand Cement Bag Revetment
July 1980

Figure 94. Sand-cement bag revetment



Hay Crib Retards
Sand Cement Bag Toe
Aug 1977



Sand Cement Bags
Toe Starting to Scour
Oct 1977

Empty Hay Crib Retards
Feb 1978

Bank Failure Behind Empty
Hay Crib Retards
Feb 1979

Figure 95. Wire crib hay bale filled

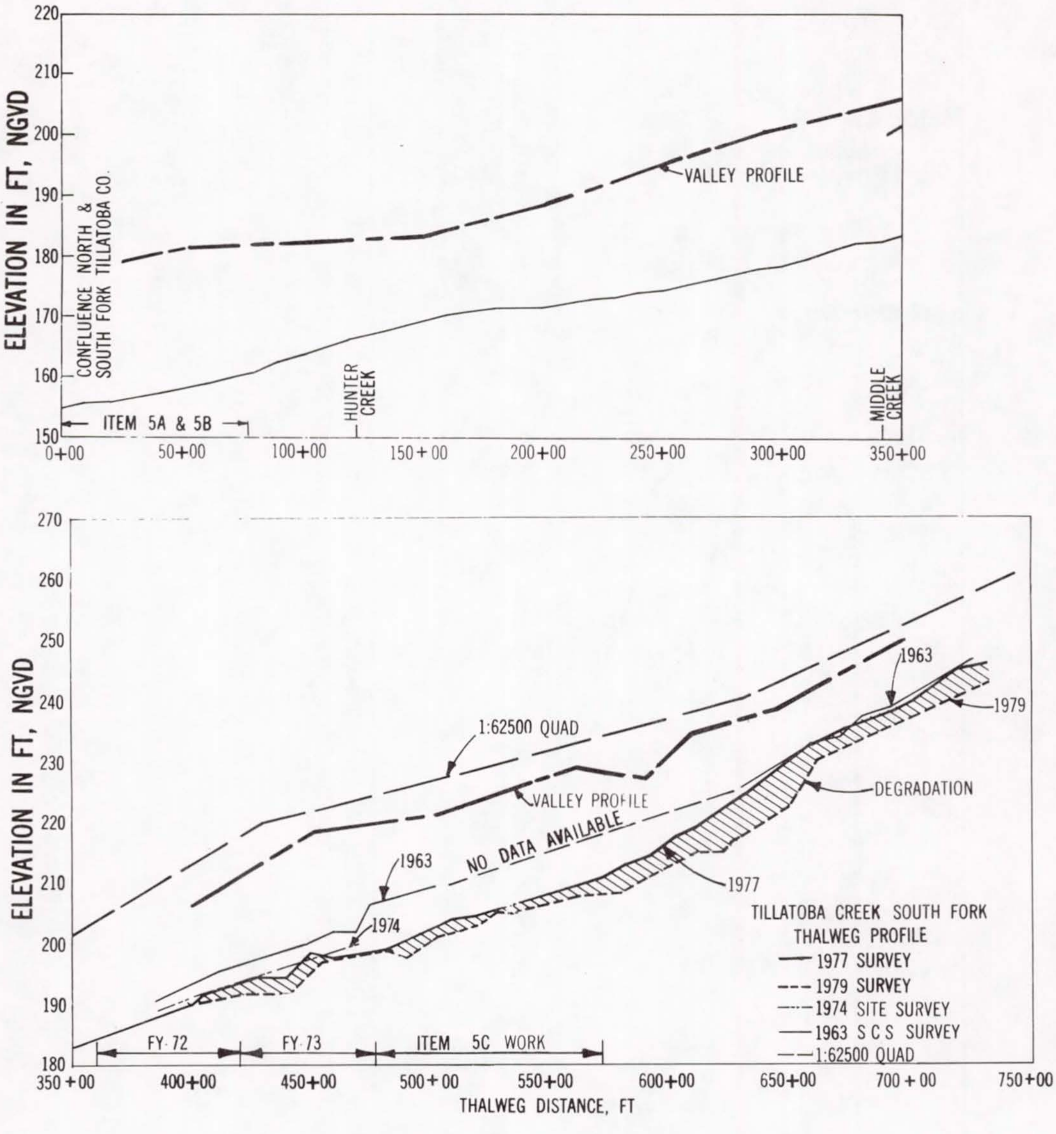


Figure 96. Thalweg profile, South Fork

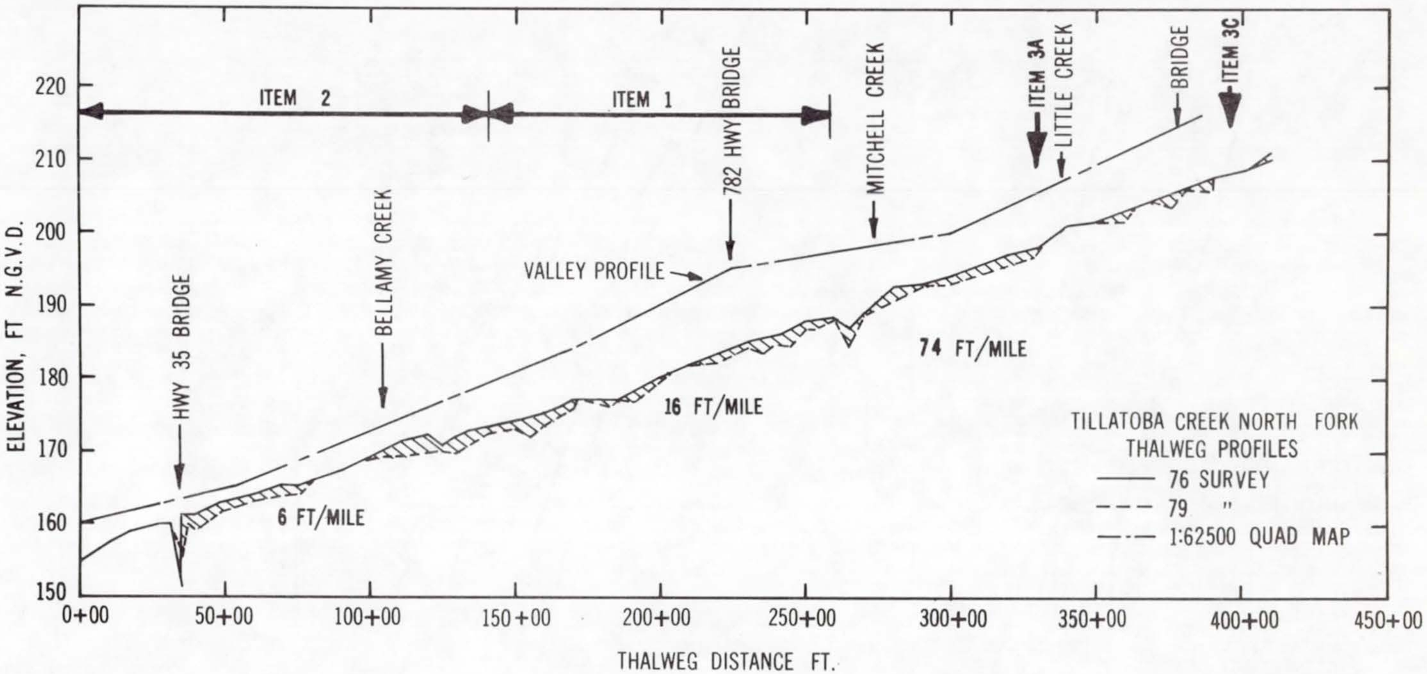


Figure 97. Thalweg profile, North Fork

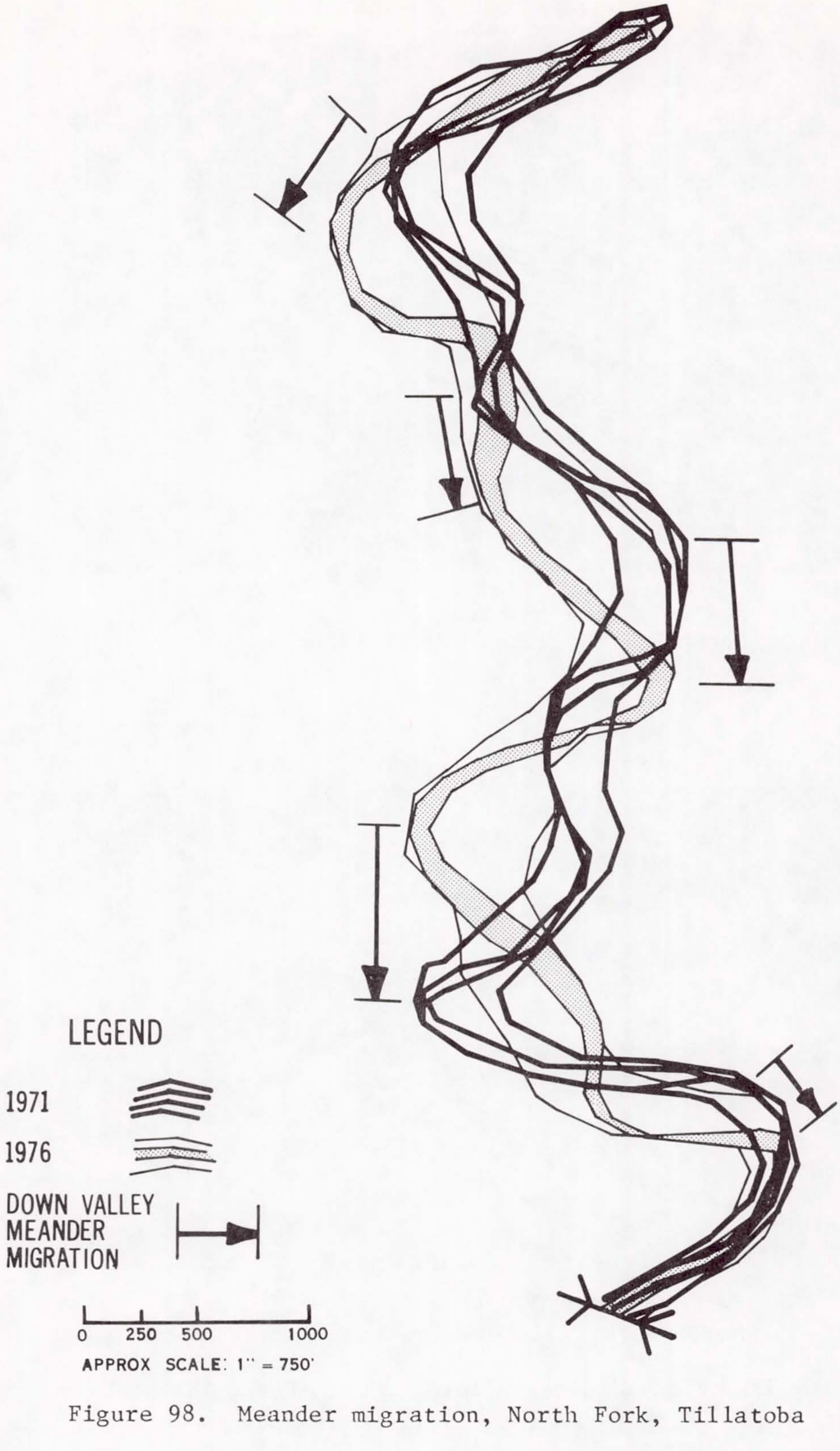
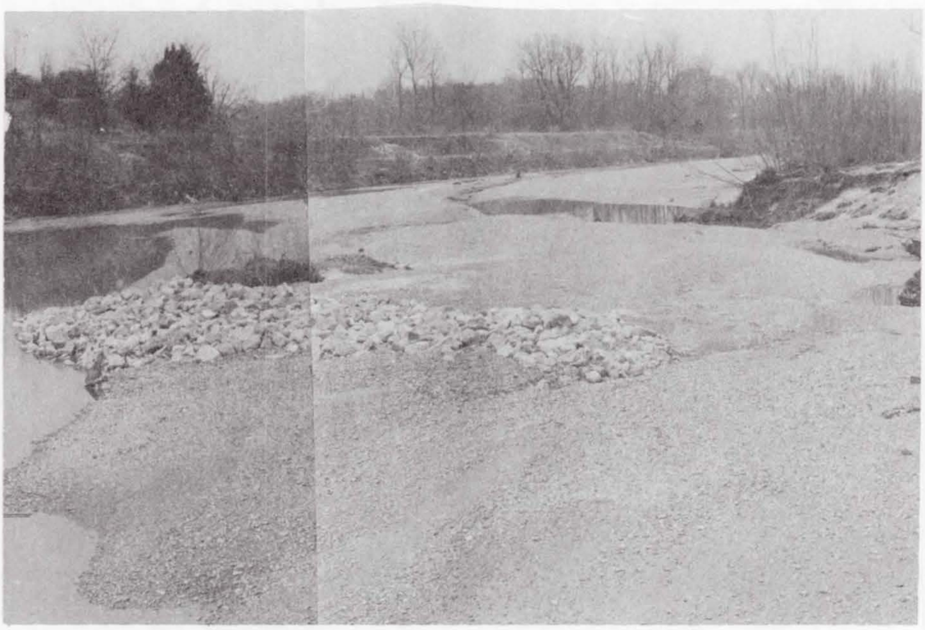


Figure 98. Meander migration, North Fork, Tillatoba

Failure, Dike 36; Item 1
North Fork Tillatoba Creek



Failure, Dike 30; Item 1
North Fork Tillatoba Creek

Figure 99. Flanked dike failures, North Fork, Tillatoba

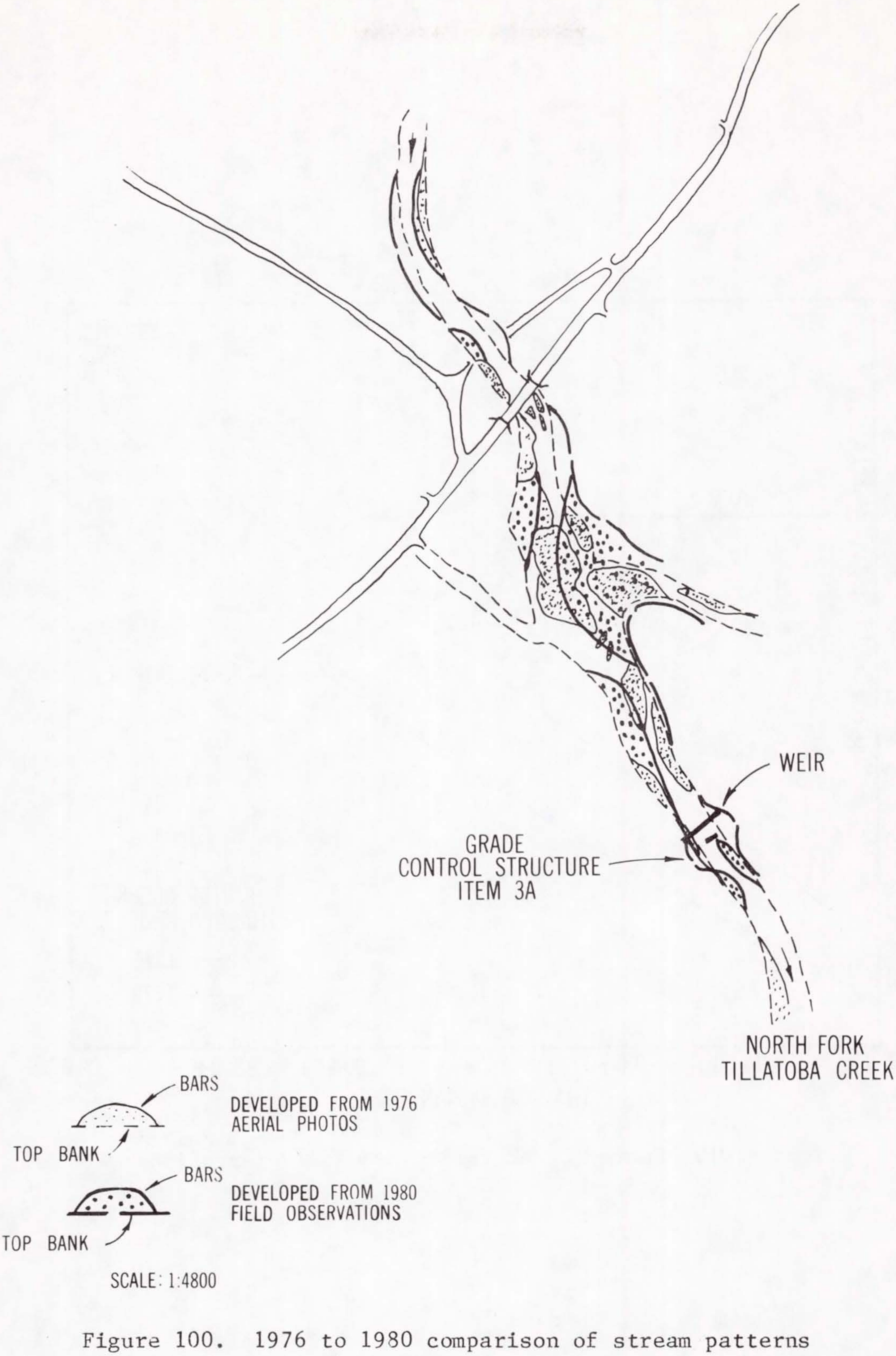


Figure 100. 1976 to 1980 comparison of stream patterns

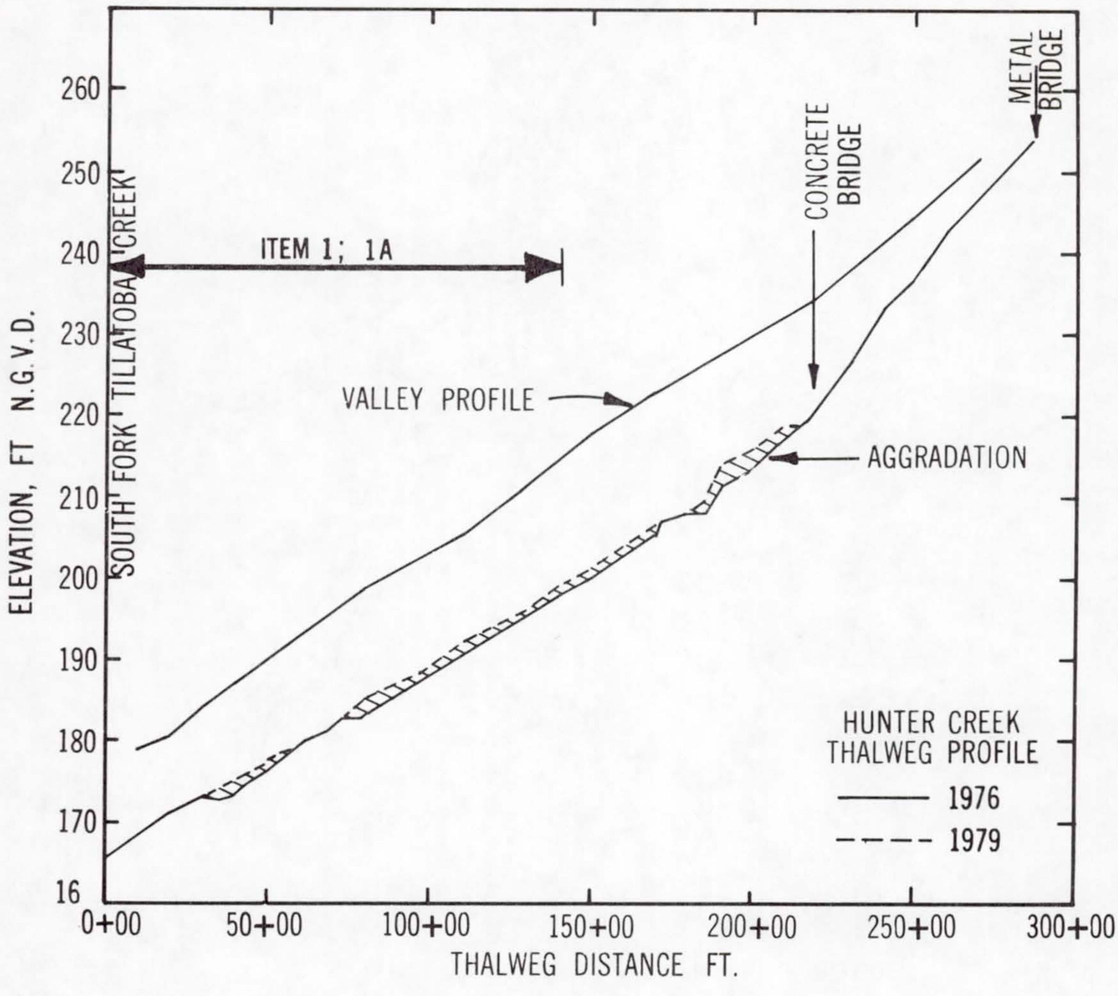


Figure 101. Hunter Creek Valley and Thalweg profile

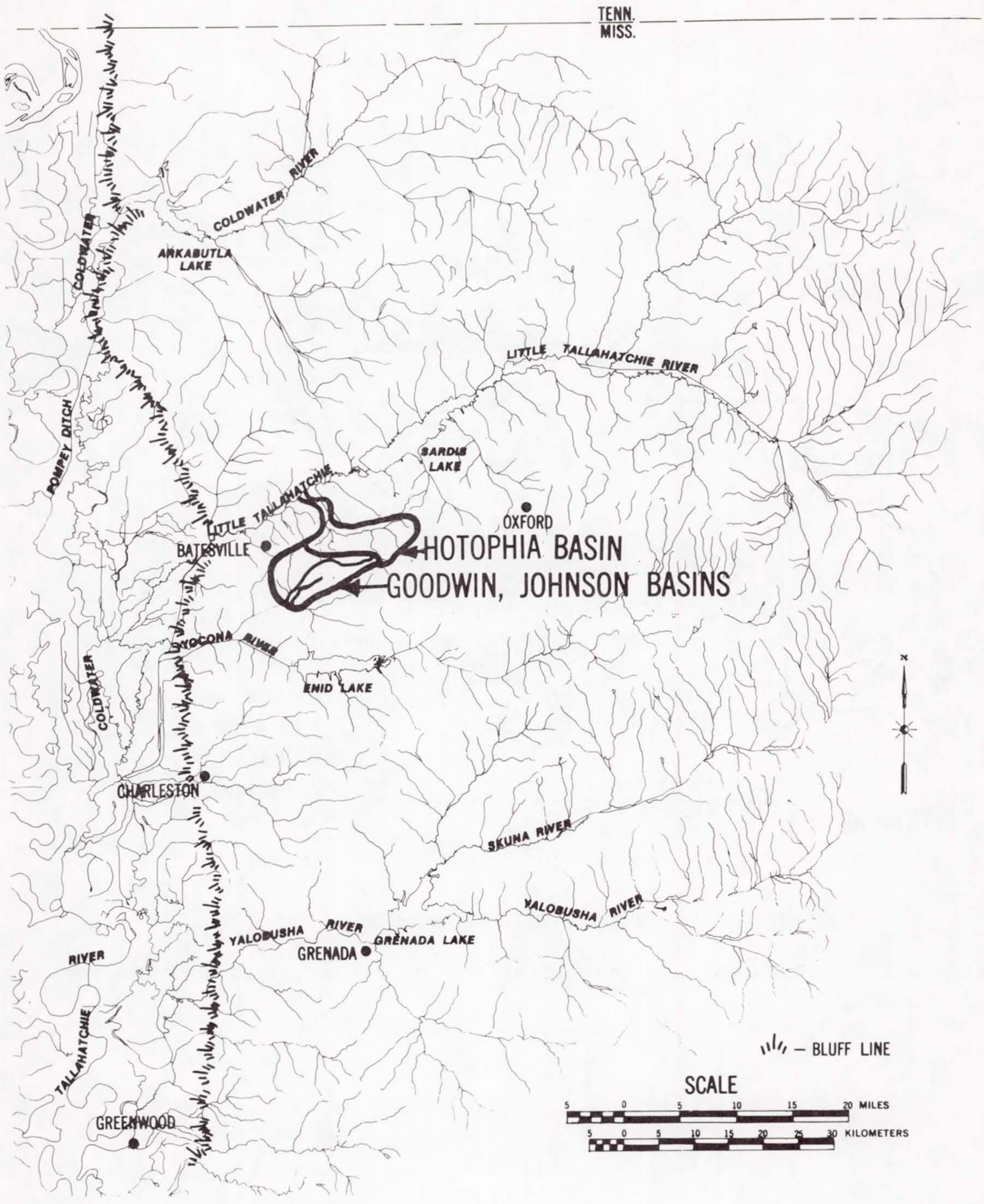
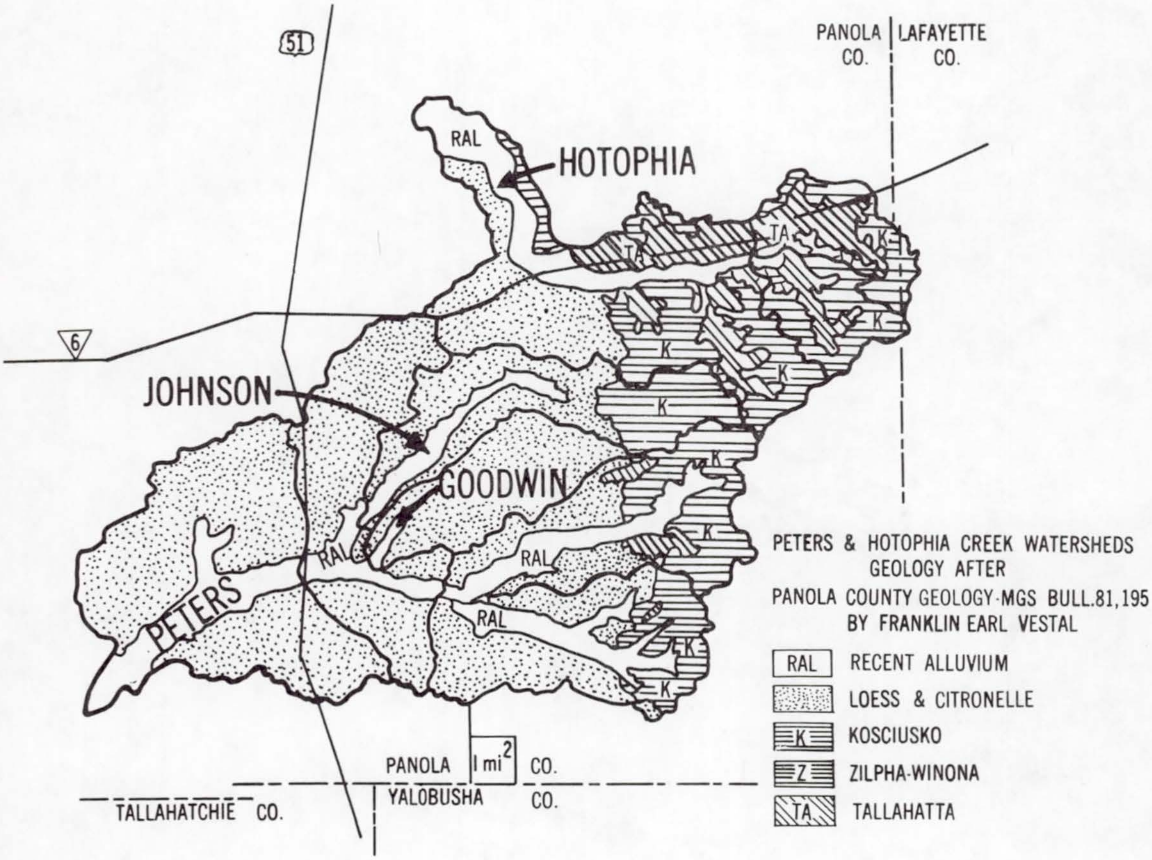


Figure 102. Location of Hotophia, Goodwin, and Johnson Basins



GEOLOGY, PETERS CREEK & HOTOPHIA CREEK WATERSHEDS

Figure 103. Basin map of geology of Peters and Hotophia Watersheds

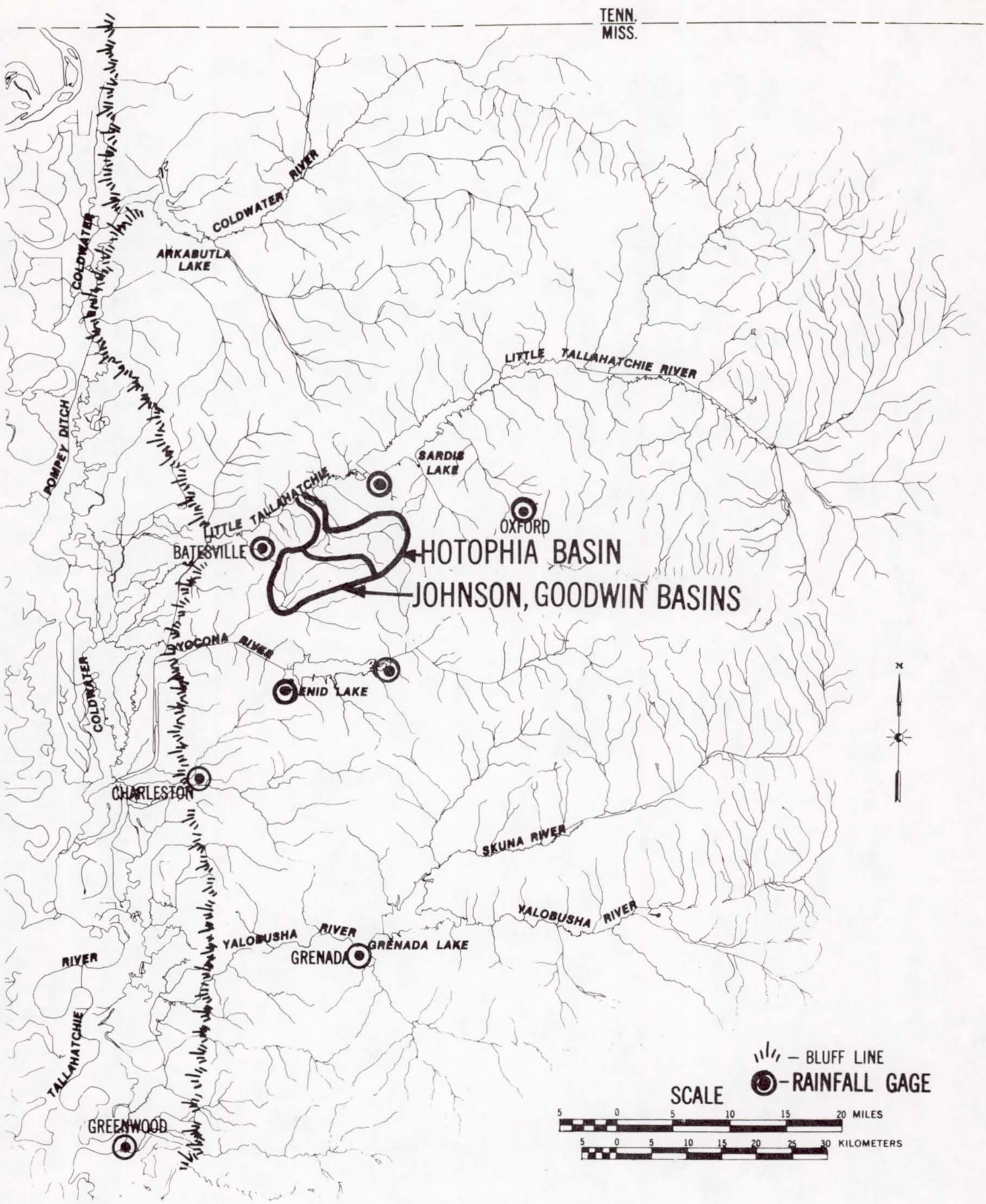


Figure 104. Location of rainfall gages

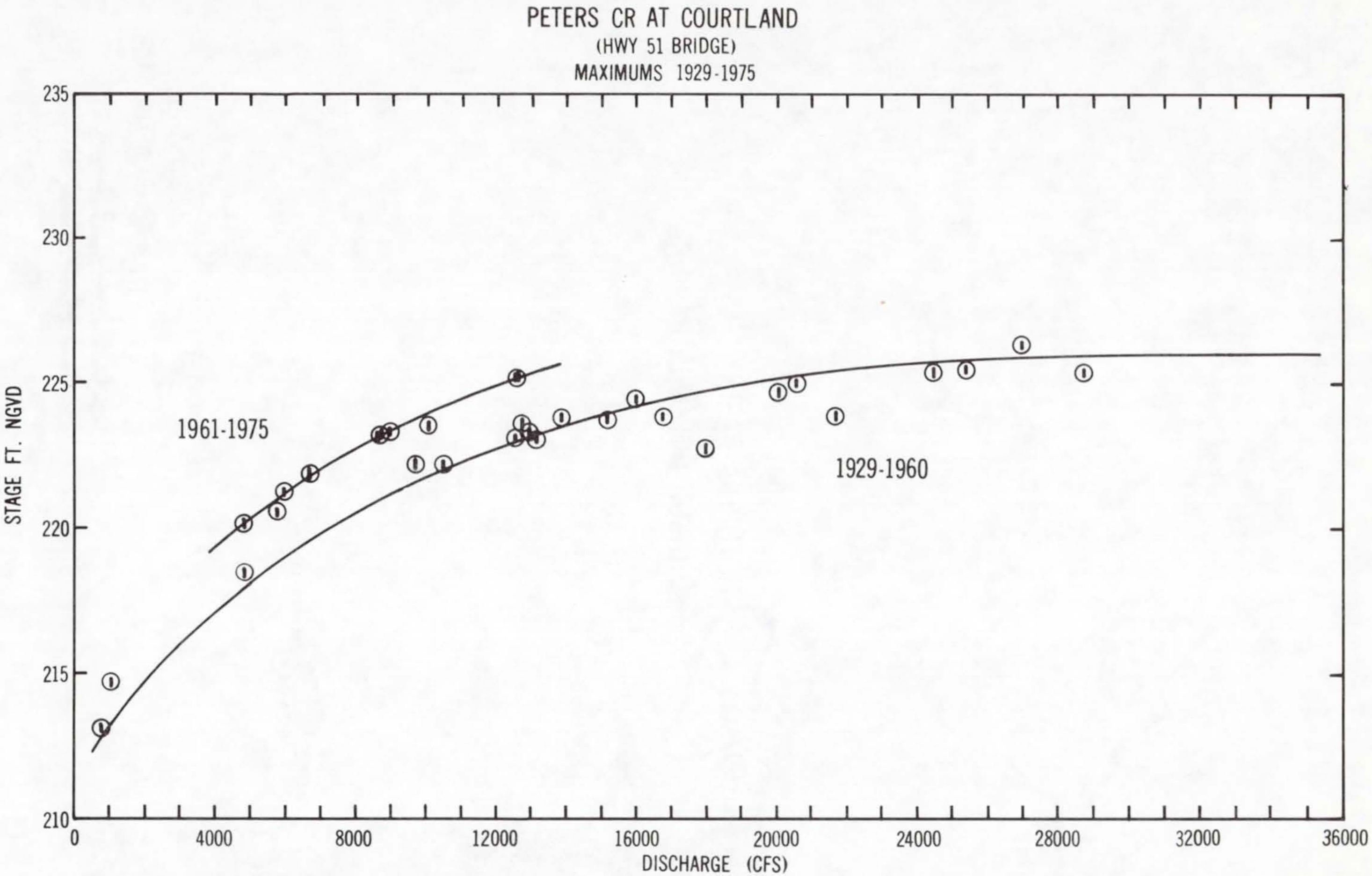


Figure 105. Rating curve, Peters Creek, Highway 51 Bridge

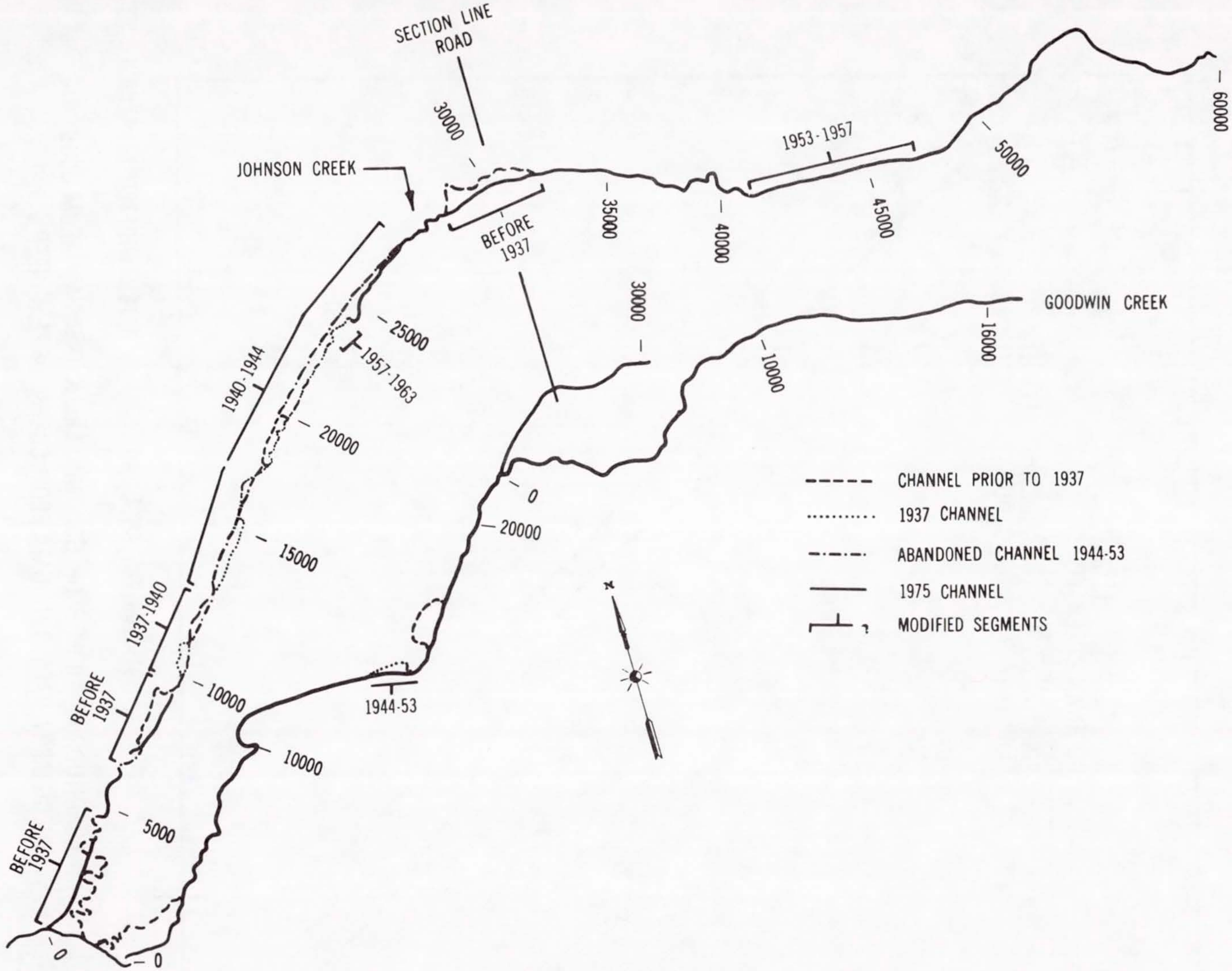
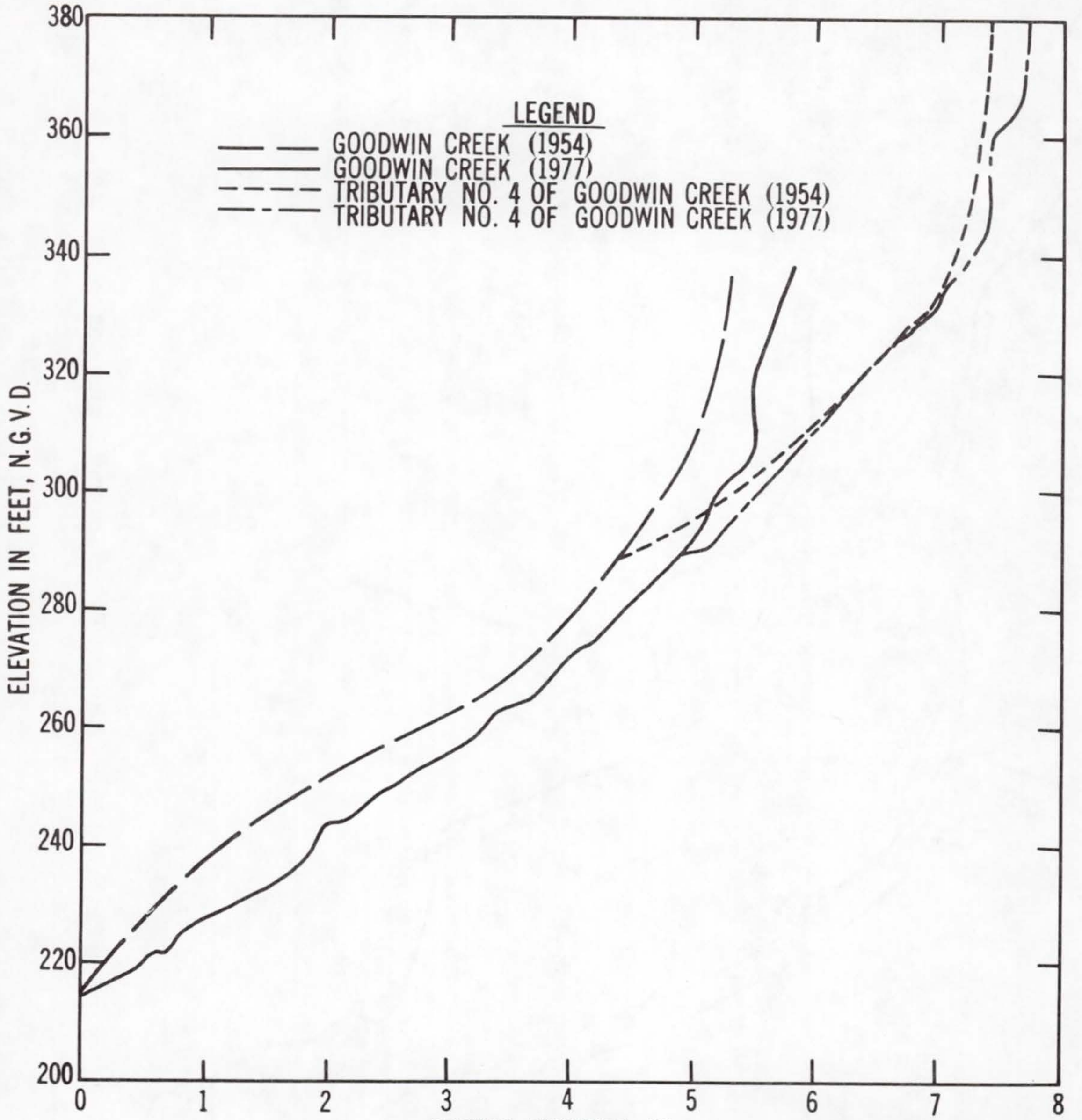


Figure 106. Johnson Creek channel changes



LONGITUDINAL PROFILE OF GOODWIN CREEK (1954 DATA FROM USGS TOPOGRAPHY MAPS; 1977 DATA FROM CORPS OF ENGINEER SURVEY)

Figure 107. Longitudinal profile, Goodwin Creek

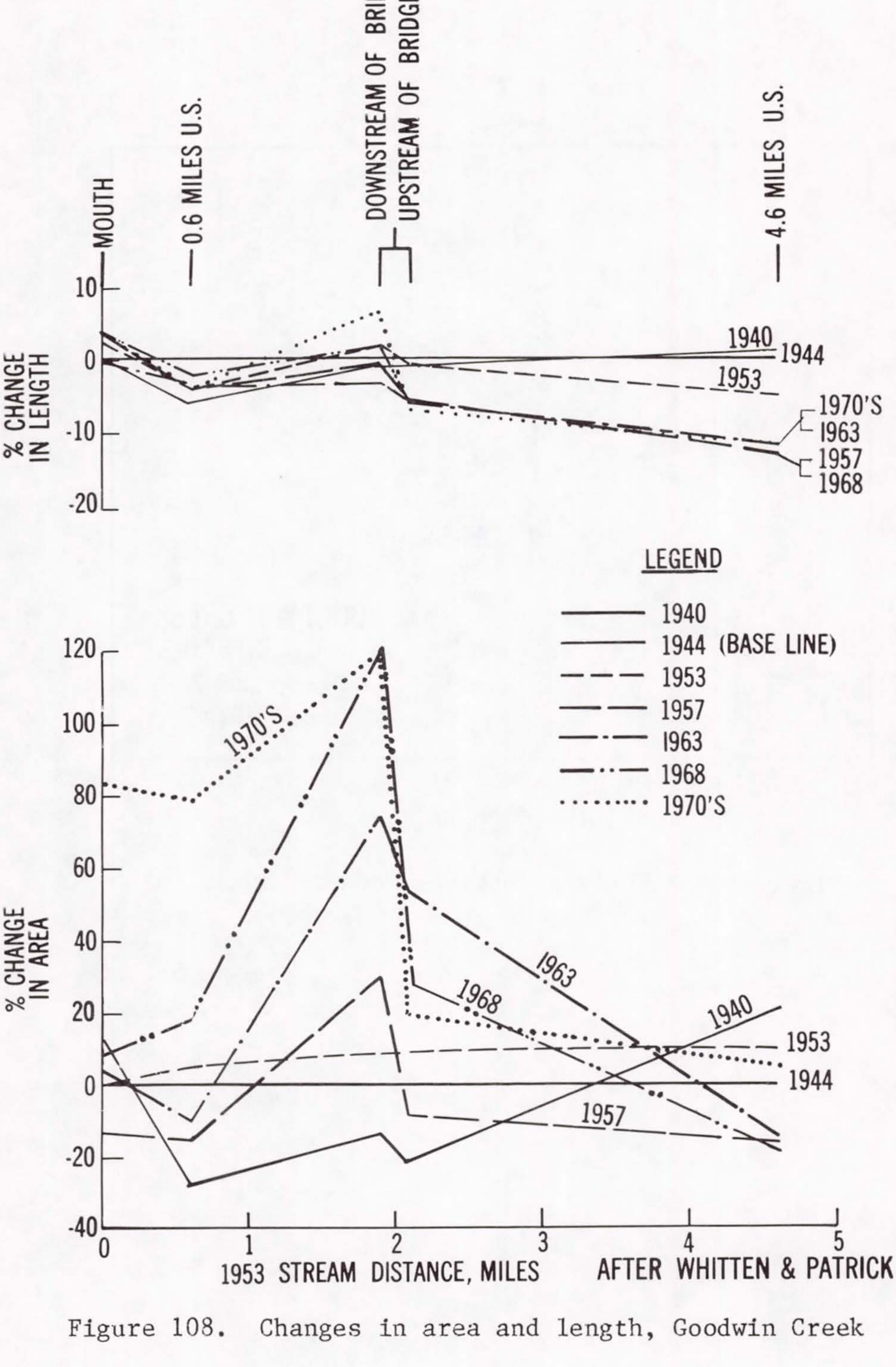


Figure 108. Changes in area and length, Goodwin Creek

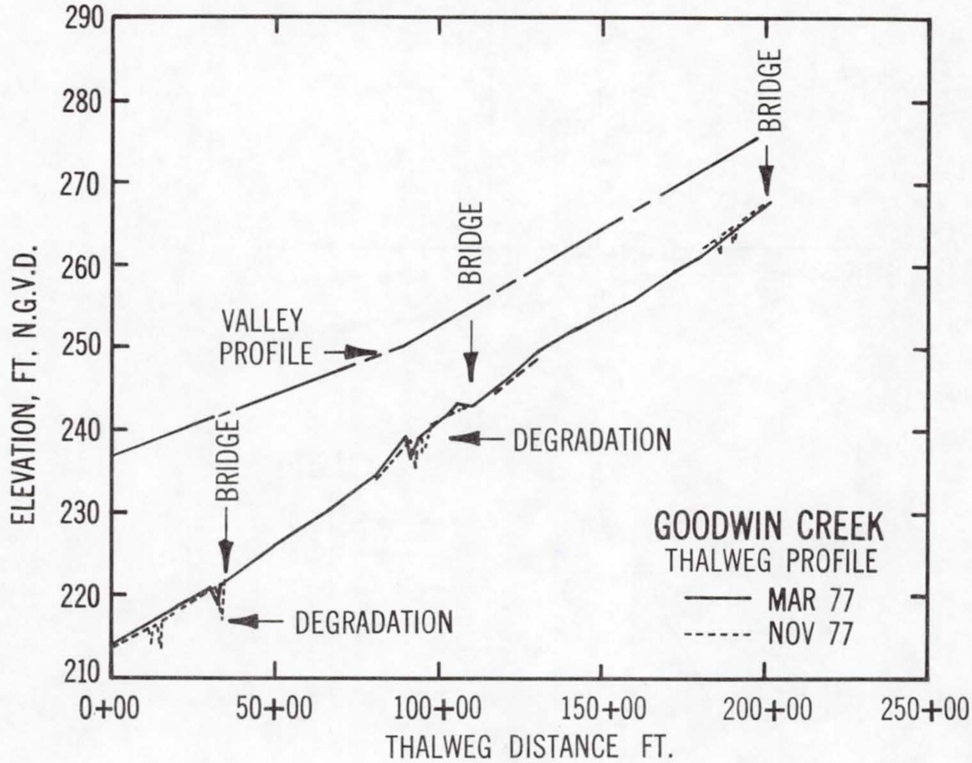
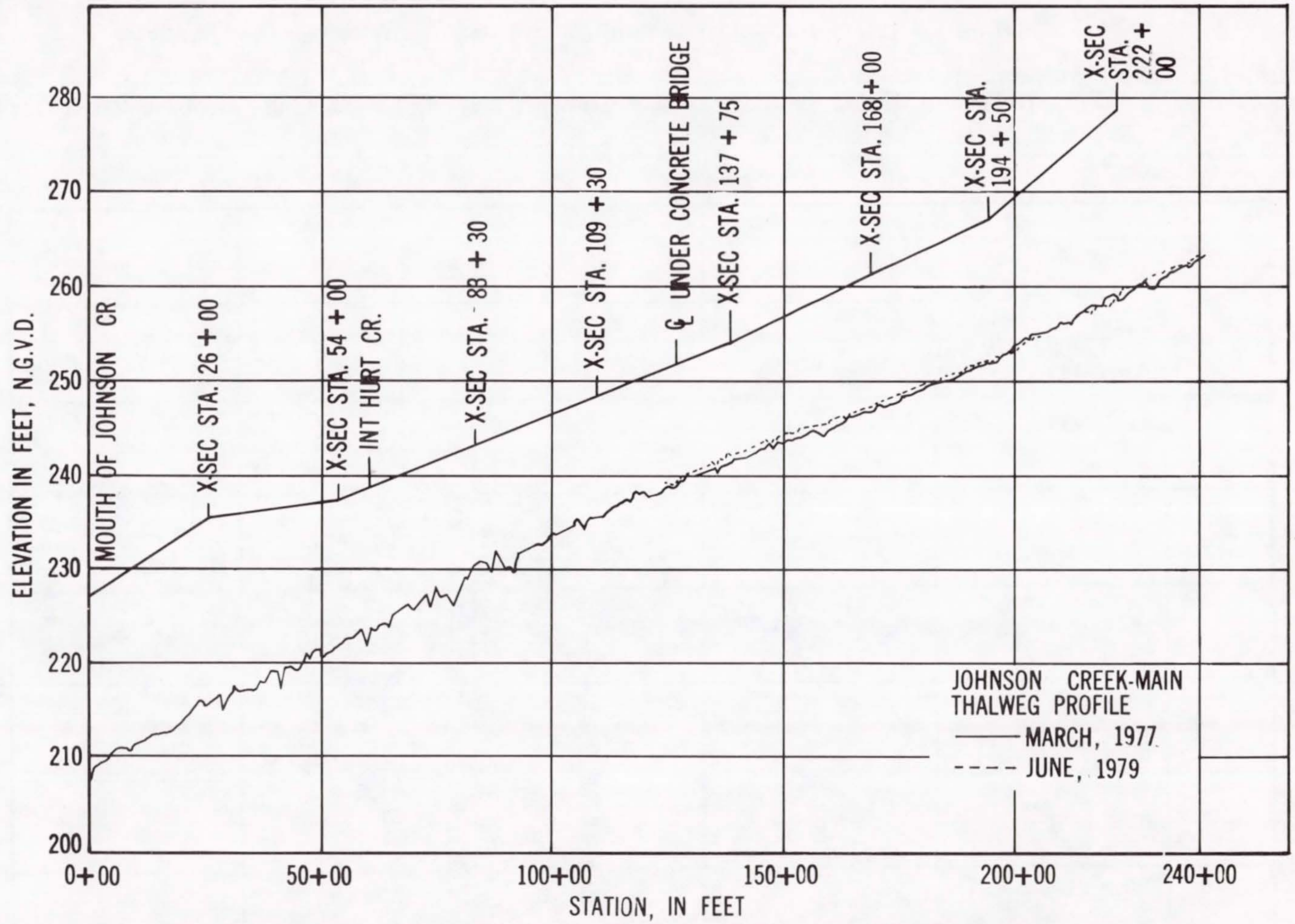
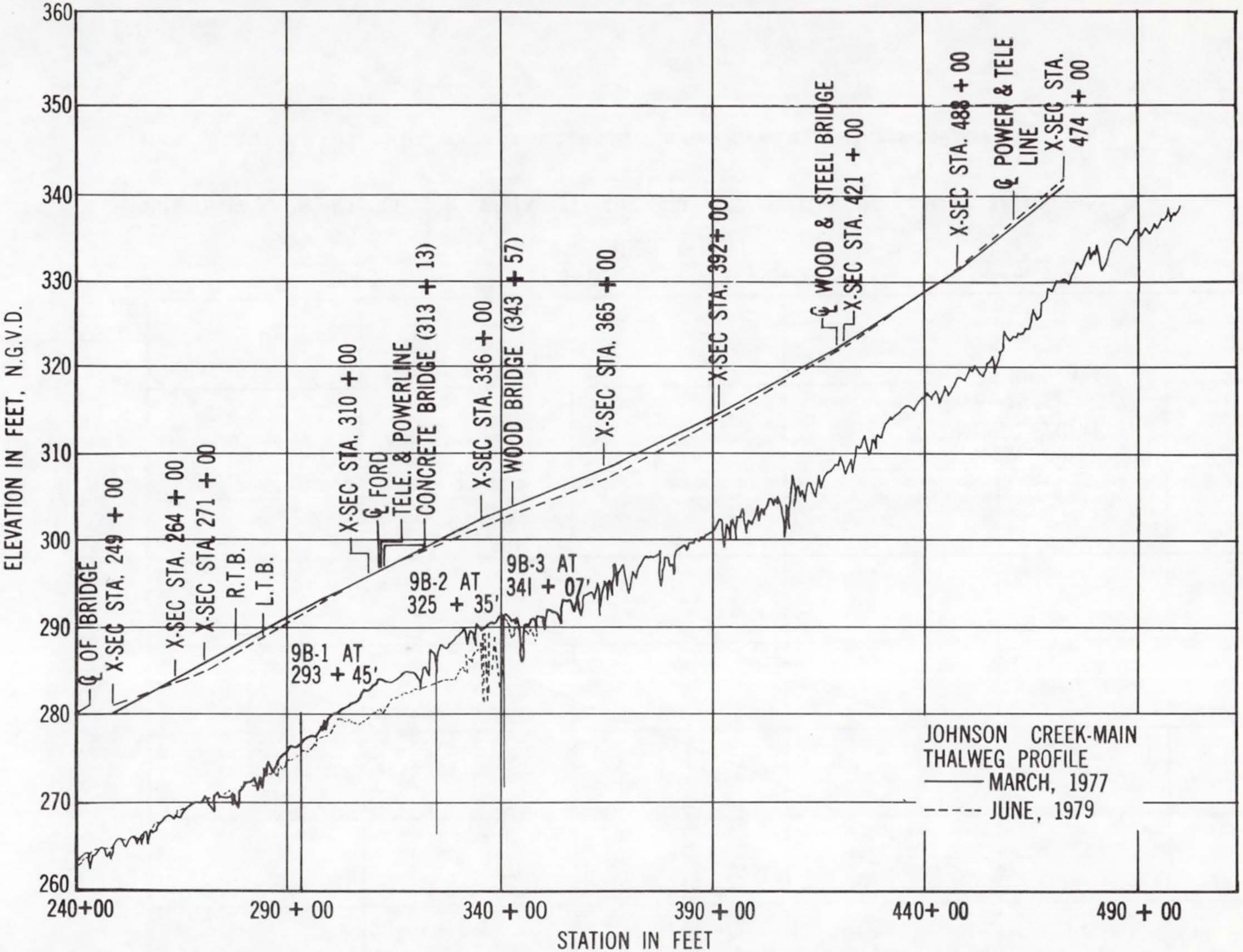


Figure 109. Thalweg profile, Goodwin Creek



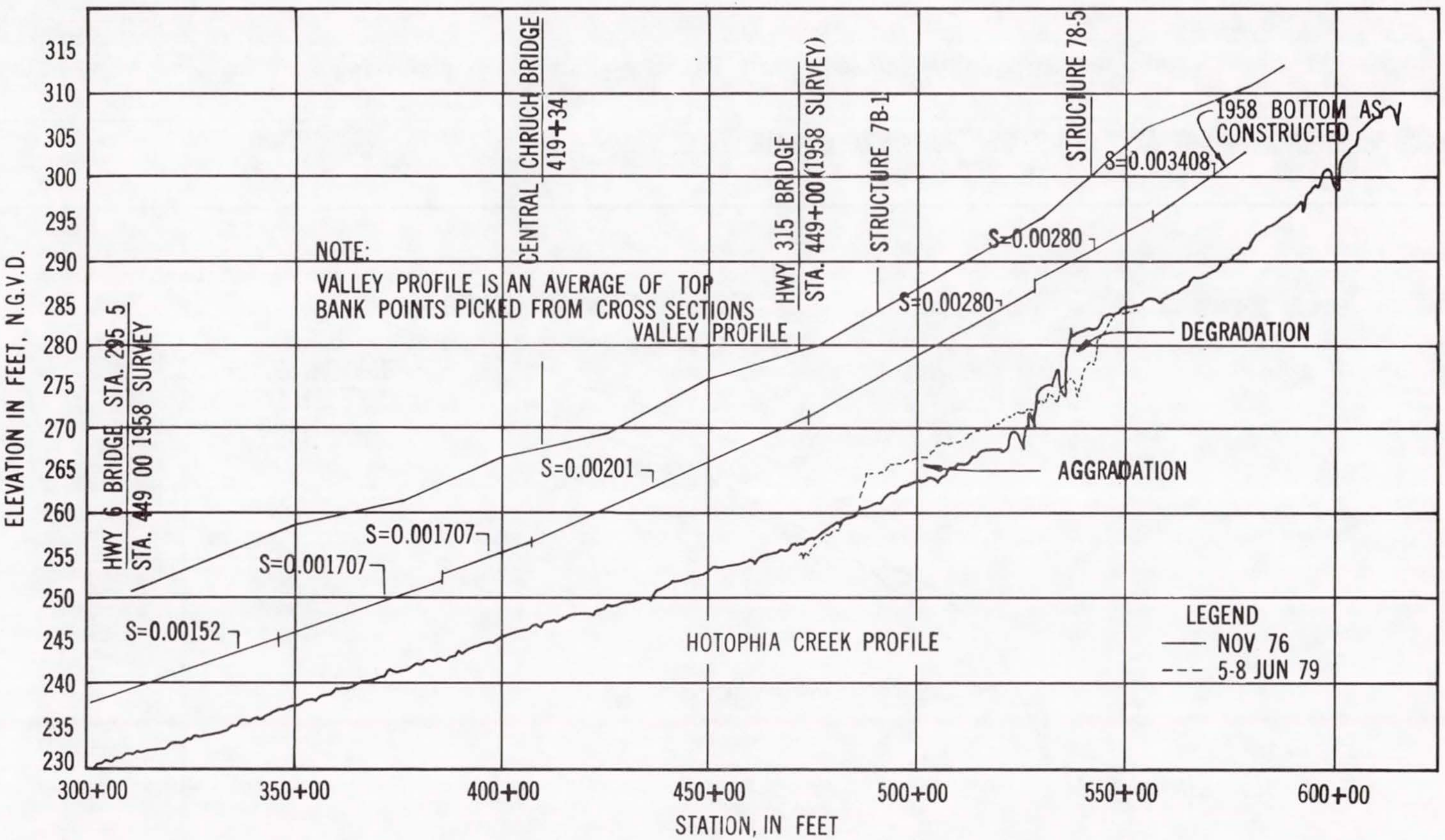
CHANNEL THALWEG PROFILE, JOHNSON CREEK, 1977 AND 1979 SURVEYS, STATIONS 0+00 TO 240+00

Figure 110. Thalweg profile, Johnson Creek, 0+00 to 240+00



CHANNEL THALWEG PROFILE, JOHNSON CREEK, 1977 AND 1979 SURVEYS, STATIONS 240+00 TO 500+00

Figure 111. Thalweg profile, Johnson Creek, 240+00 to 500+00



CHANNEL THALWEG PROFILE, HOTOPHA CREEK 1958 AND 1976 SURVEYS, STATIONS 300+00 TO 600+00

Figure 112. Thalweg profile, Hotophia Creek, 300+00 to 600+00

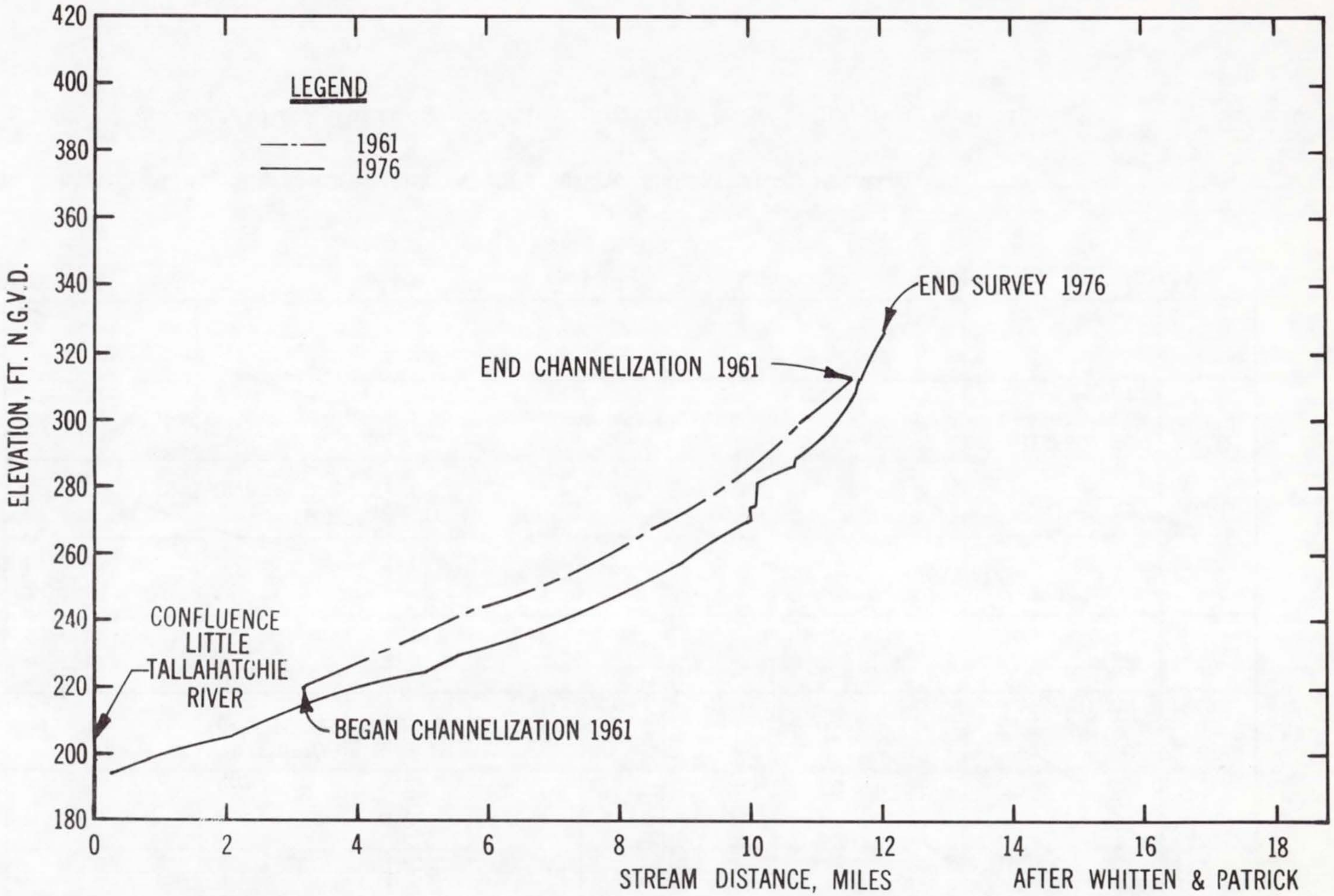


Figure 113. Longitudinal profile of Hotophia Creek

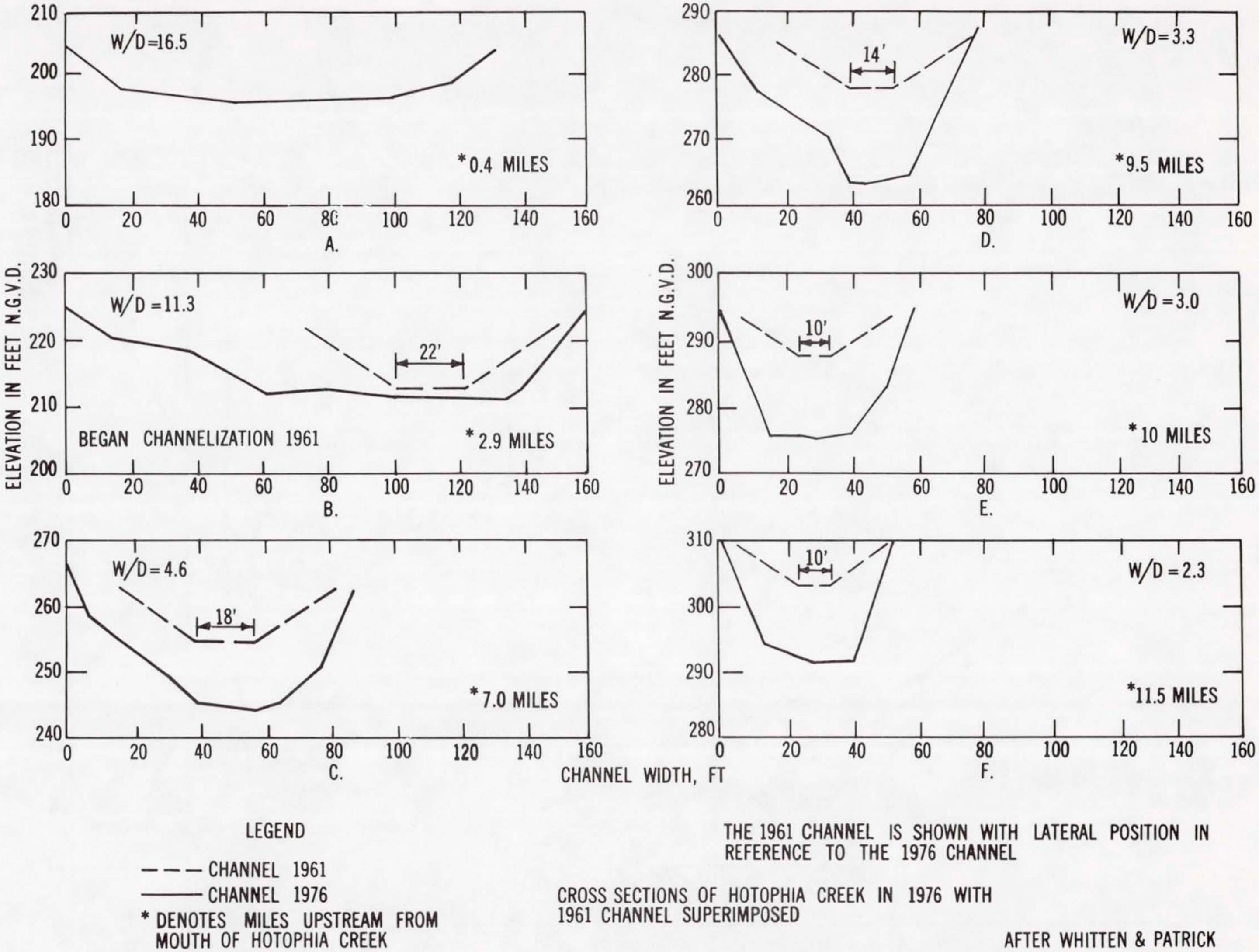


Figure 114. Comparison channel, cross-sectional areas, Hotophia Creek

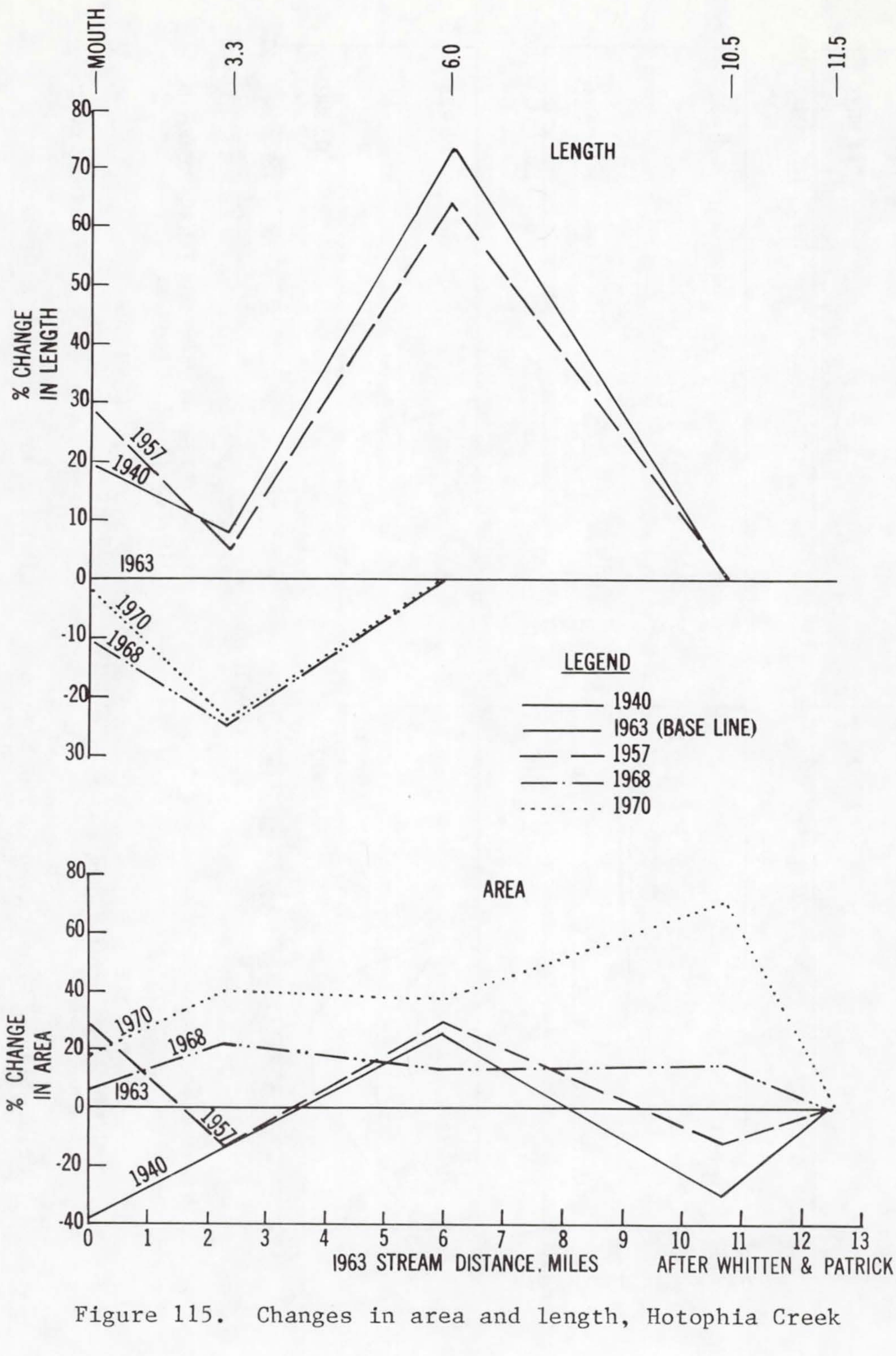


Figure 115. Changes in area and length, Hotophia Creek

Figure 116. Peters and Hotophia Creeks, construction location sites

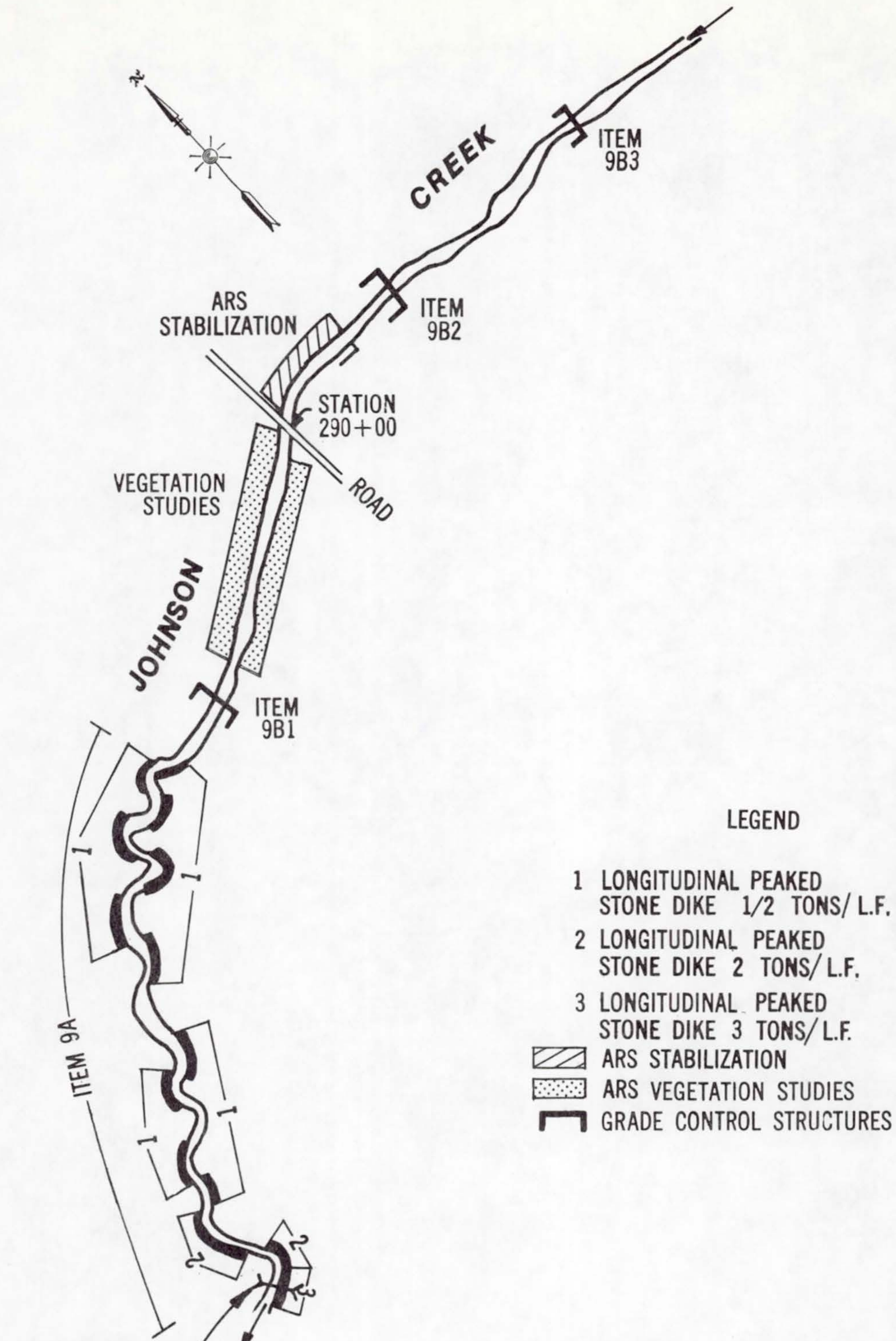


Figure 117. Johnson Creek construction sites

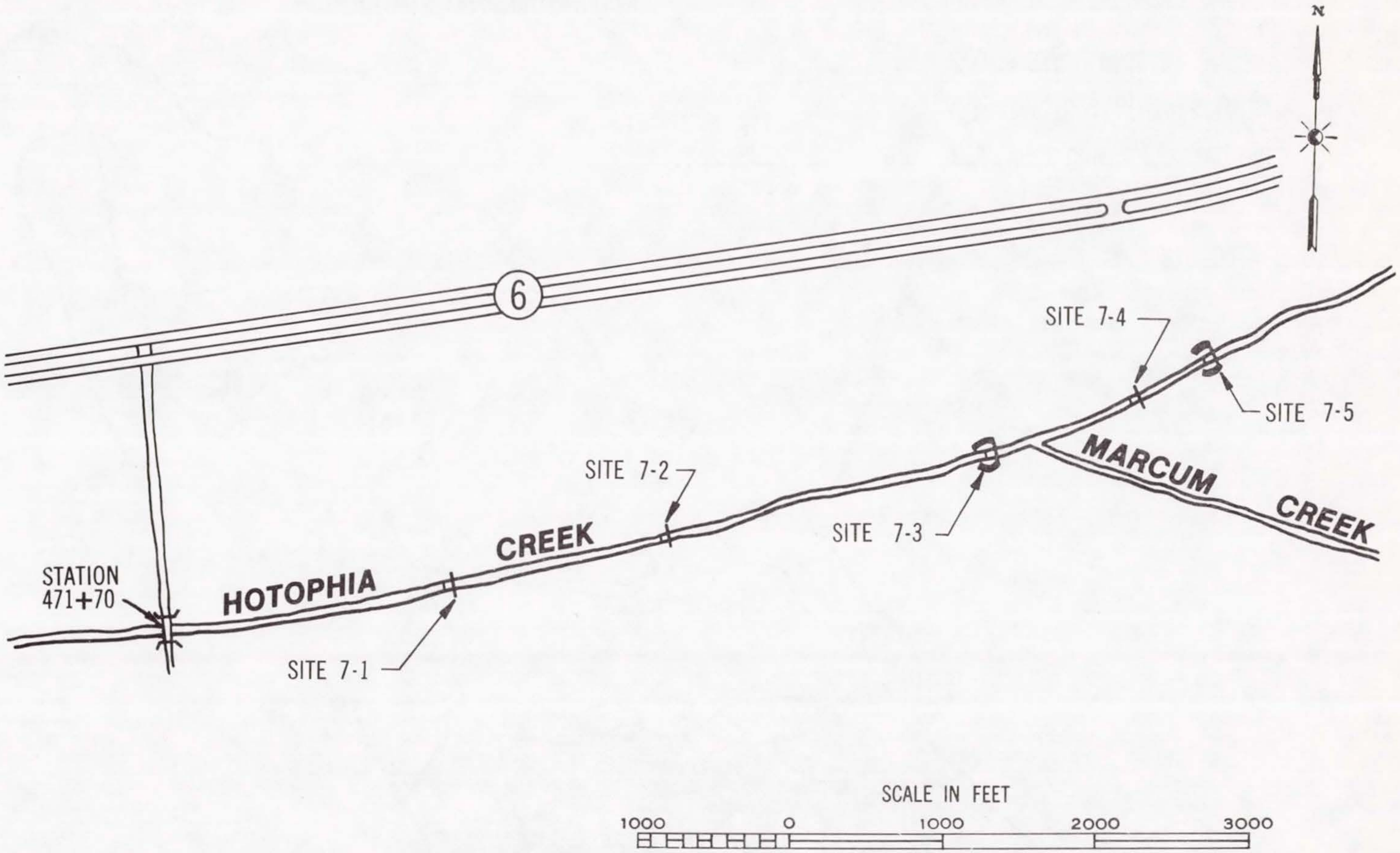


Figure 118. Hotophia Creek construction sites

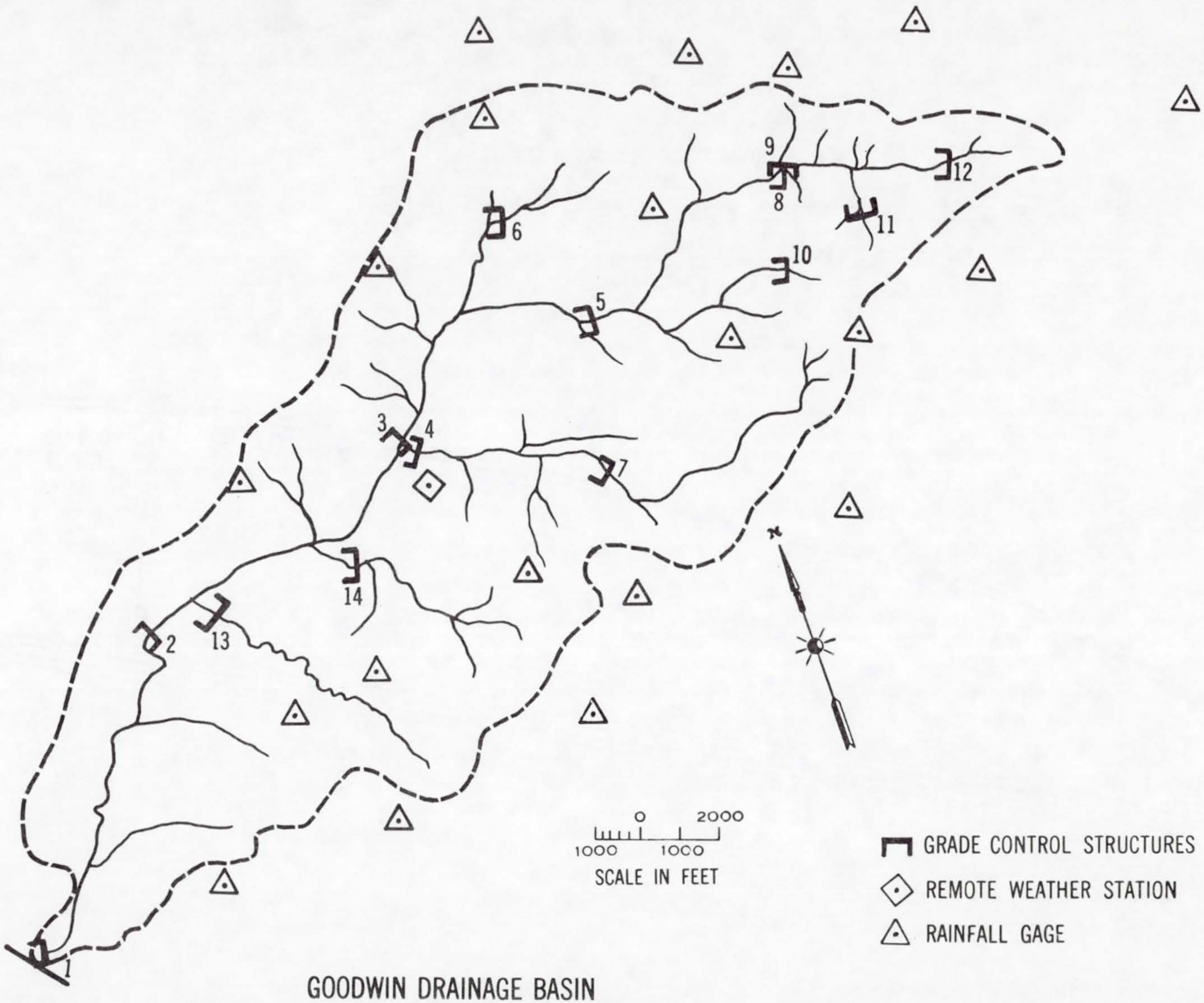
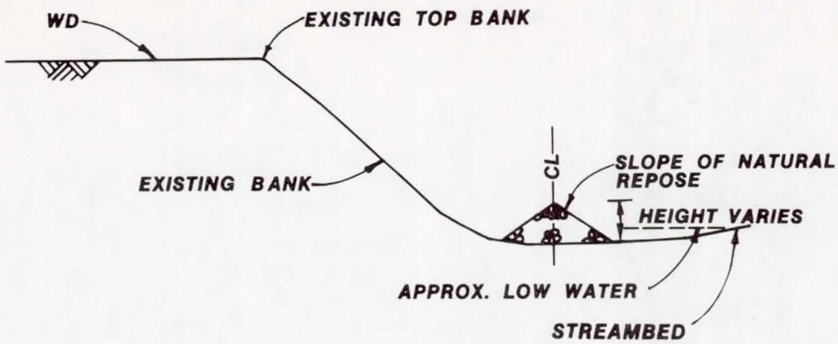
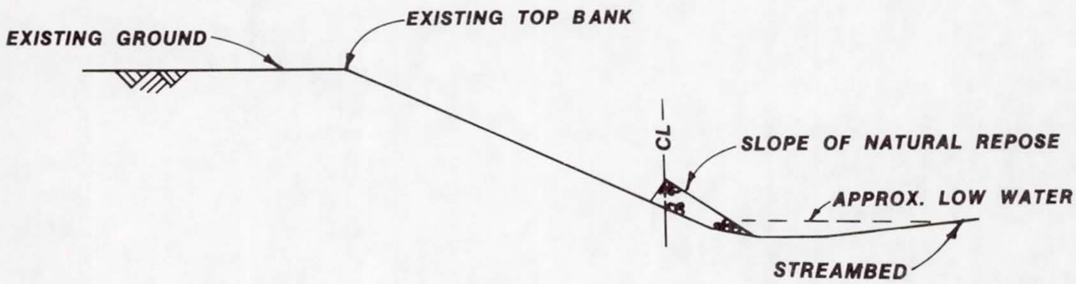


Figure 119. Goodwin Creek construction sites



WHERE CENTERLINE FALLS RIVERWARD OF TOE OF BANK SLOPE



WHERE CENTERLINE FALLS LANDWARD OF TOE OF BANK SLOPE

DIKE TO BE CONSTRUCTION WITH STONE AT
A RATE OF 1-1/2 TONS PER LINEAR FOOT.
PEAK ELEVATION WILL VARY.

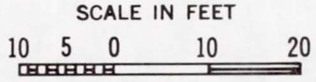


Figure 120. Longitudinal peaked stone dike, Johnson Creek

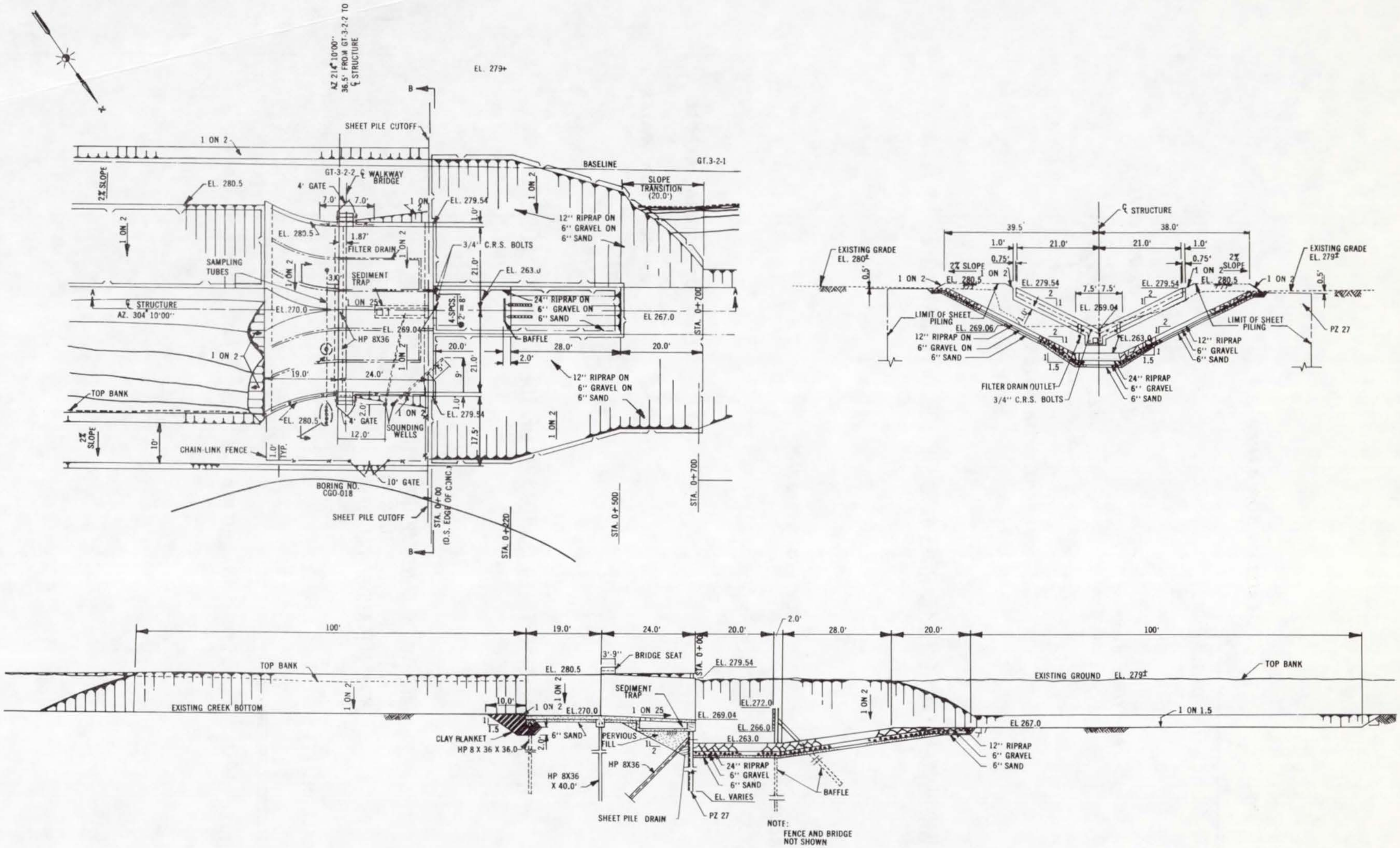


Figure 121. Typical data collection, structures, Goodwin Creek

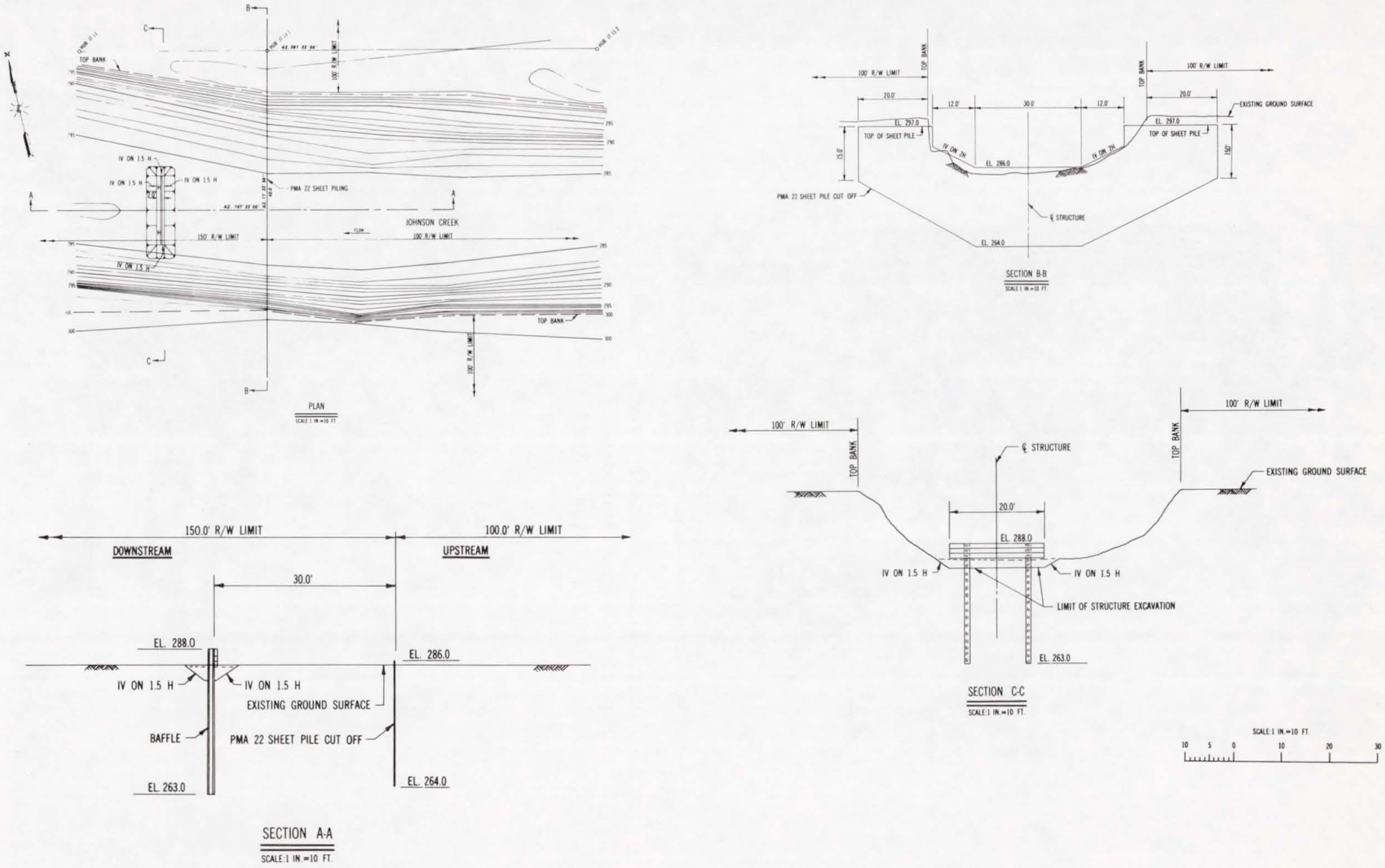


Figure 122. Typical minimum grade control structures

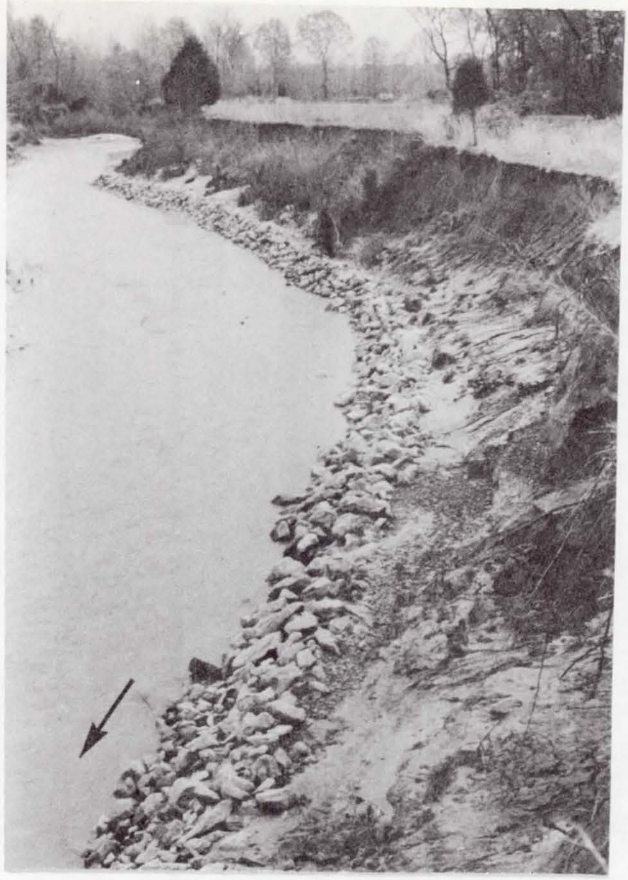


Figure 123. Johnson Creek, Reach 7, typical peak stone dike looking upstream, 12 April 1979

Figure 124. Johnson 6B2, typical grade control, 23 April 1981

Figure 125. Typical grade control site 5, Hotophia Creek, April 1981

Figure 126. Typical grade control site 3, Goodwin Creek, July 1979

April 1978

April 1979

August 1979

March 1980

Johnson Creek Reach 8
Longitudinal Peaked Stone Dike
Showing Minimum Stone Toe with
Vegetation Growth Behind

May 1981

Figure 127. Peaked stone dike, Johnson Creek

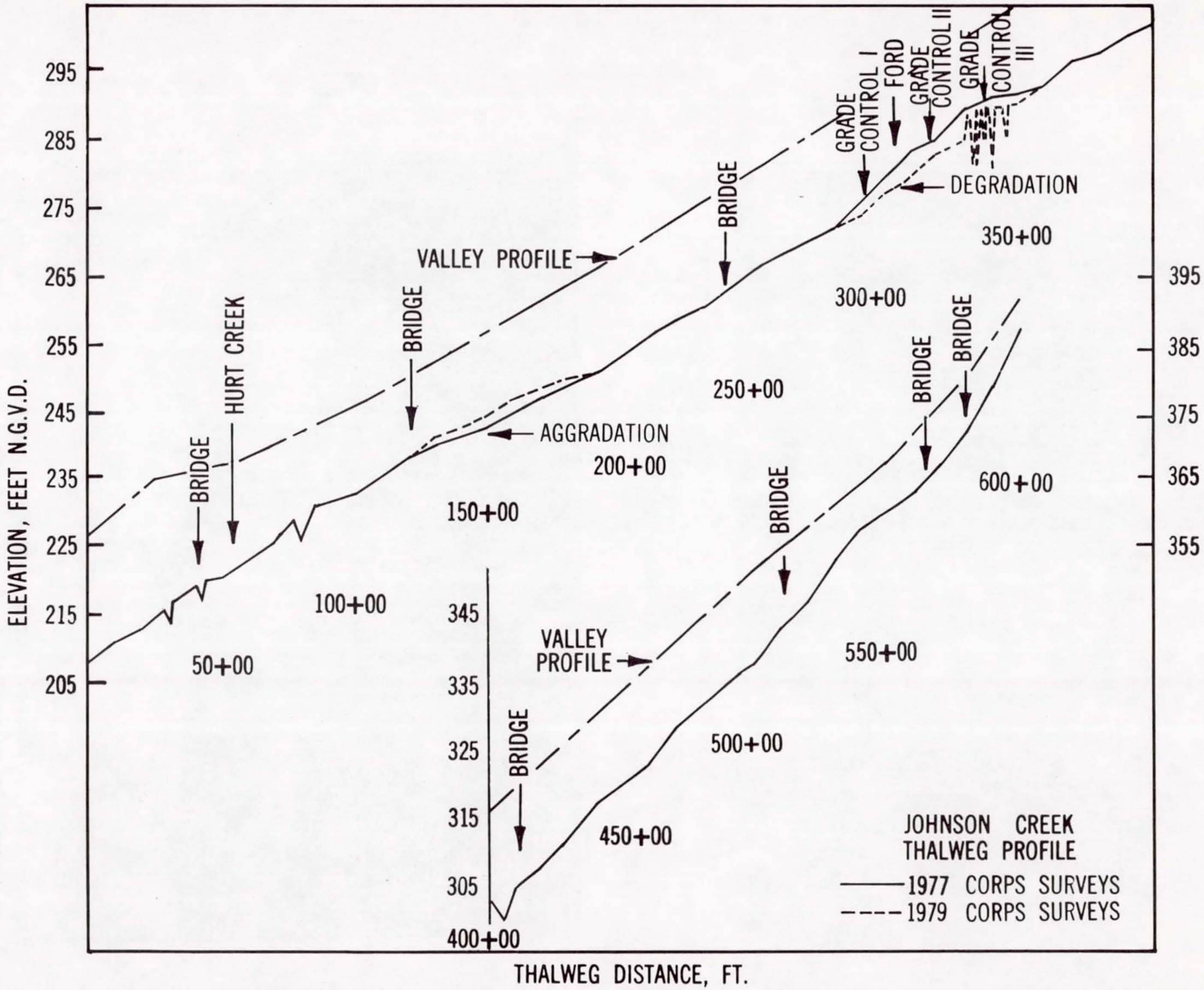


Figure 128. Thalweg profiles, Johnson Creek

Figure 129. Johnson Creek at present day reach, natural grade control of consolidated clay clay in bed, April 1978

Figure 130. Johnson Creek sediment deposits after an event showing alignment of high flow into structure, May 1981

a. Looking upstream, April 1980

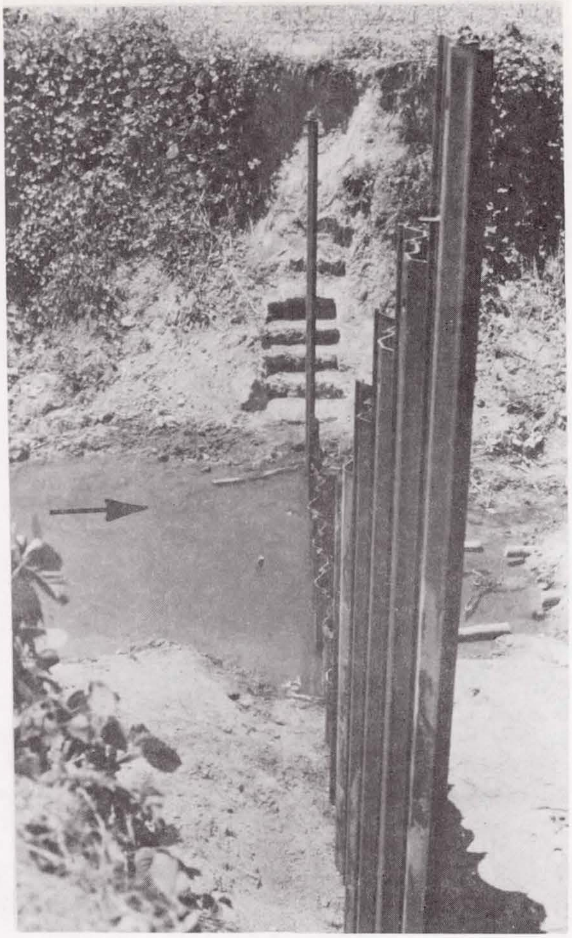
b. Looking downstream, April 1979

Figure 131. Johnson Creek, Reach 13

Figure 132. Johnson Creek, Reach 12, looking downstream, March 1980

Figure 133. Johnson Creek, Site 9B1, riprap scour hole, April 1981

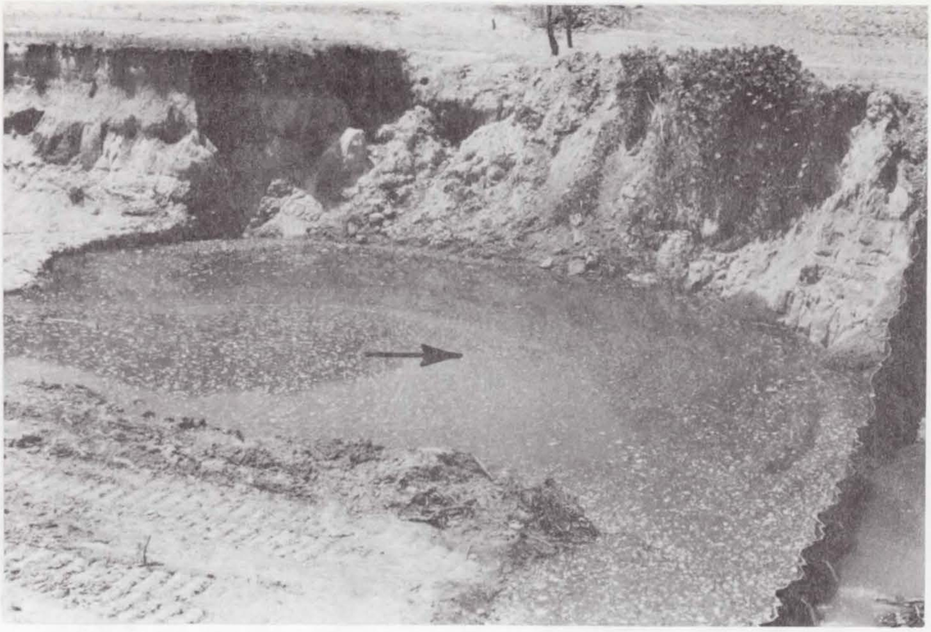
Figure 134. Johnson Creek access ramp 9B1, April 1981



Johnson Creek 9B2
June 1980

Johnson Creek 9B2
April 1981

Figure 135. Access ramp, Site 9B2



Johnson Creek 9B3
June 1980

Johnson Creek 9B3
April 1981

Figure 136. Scour pocket at Site 9B3, Johnson Creek

Goodwin Creek Site 4
Vegetation in Channel
Looking Downstream
May 1981

Goodwin Creek Site 4
Vegetation in Channel
Looking Upstream
May 1981

Figure 137. Vegetation in channel, Goodwin Creek

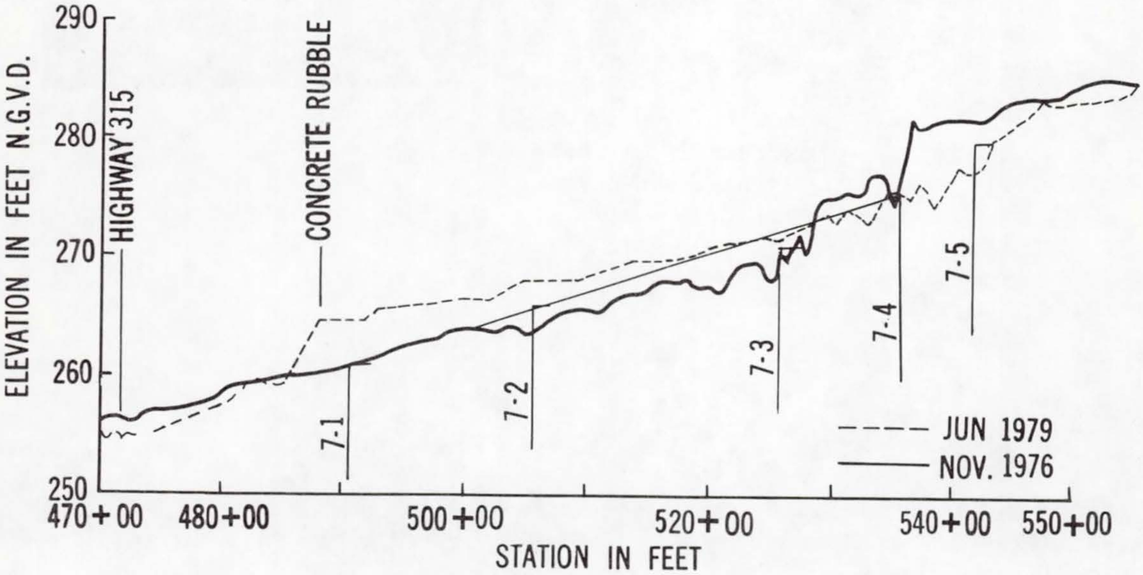
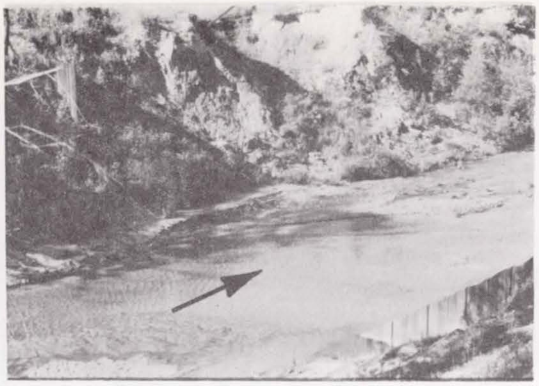
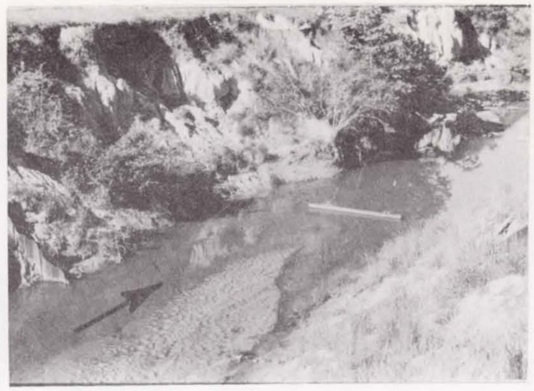


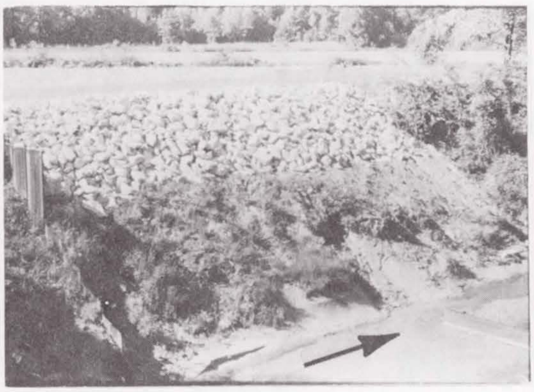
Figure 138. Thalweg profile on Hotophia Creek



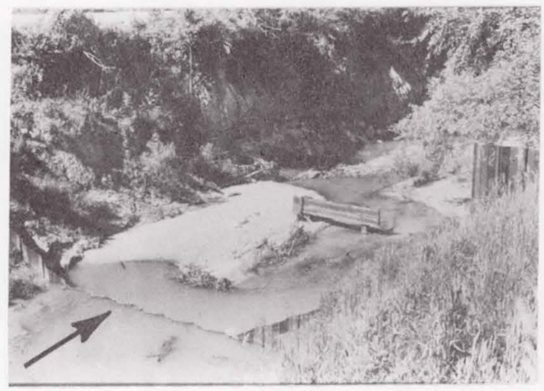
Hotophia Creek Site 1
Sheet Pile Weir and Baffle
April 1981



Hotophia Creek Site 2
Sheet Pile Weir and Baffle
April 1981



Hotophia Creek Site 3
Sheet Pile Weir and Baffle with
Stone Windrows for Scour Hole
April 1981



Hotophia Creek Site 4
Sheet Pile Weir and Baffle
April 1981

Hotophia Creek Site 5
Sheet Pile Weir and Baffle with
Stone Windrows for Scour Hole
April 1981

Figure 139. Hotophia grade control sites