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Sediment Retention in a Bottomland Hardwood Wetland in Eastern Arkansas.

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SEDIMENT RETENTION IN A BOTTOMLAND HARDWOOD WETLAND IN EASTERN ARKANSAS

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

Oceanography and Coastal Sciences

by
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This project was part of a large, multi-disciplinary project undertaken by the US Army Engineer Waterways Experiment Station (WES) to better understand the bottomland hardwood wetlands of the southern United States. Due to the size and complexity of the project, dozens of people have worked on the Cache River, and I have benefitted from discussions and shared data with many of them. Accordingly, these acknowledgments will initially appear extreme, but everyone I mention has played a noteworthy role in the completion of this dissertation.

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ABSTRACT

One of the often-stated functions of wetlands is their ability to remove sediments and other particulates from water, thus improving water quality in the adjacent aquatic system. However, actual rates of suspended sediment removal have rarely been measured in freshwater wetland systems. To address this issue, suspended sediment dynamics were measured in an 85-km^2 bottomland hardwood (BLH) wetland adjacent to the highly turbid Cache River in eastern Arkansas during the 1988-90 water years. A suspended sediment mass balance was calculated using depth-integrated, flow-weighted daily measurements at wetland inflow and outflow points. Over the three-year period, suspended sediment load decreased an average of 14% between upstream and downstream sampling points. To test the hypothesis that the suspended sediments were retained by the adjacent wetland and to determine what part of the BLH forest was most responsible for retaining the suspended sediments, concurrent measurements of sediment accretion were made at 30 sites in the wetland using feldspar clay marker horizons, sedimentation disks, the ^{137}cesium method, and dendrogeomorphic techniques. Sedimentation rates exceeding 1 cm/yr were measured in frequently flooded areas dominated by *Nyssa aquatica* L. and *Taxodium distichum* (L.) Rich. Maximum sedimentation rates did not occur on the natural levee as expected, but in the "first bottom," where retention time of the water reached a maximum. Multiple regression was used to evaluate potential relationships between

sedimentation rates and several physical and biological factors. A combination of distance from the river, flood duration and tree basal area accounted for nearly 90% of the variation in sedimentation rates.

INTRODUCTION

One of the most often-stated functions of wetlands (e.g., Brinson et al. 1995) is their ability to retain suspended sediments and substances sorbed to them. That this function occurs is almost intuitive--water enters a wetland, slows as it comes in contact with wetland vegetation, and sediments in the water fall out of suspension and are deposited in the wetland. There is ample anecdotal evidence for the function as well. In his 1821 visit to the Yazoo Basin, one of the major drainages of the lower Mississippi Valley, John James Audubon journeyed through the extensive swamps of the basin, and described the Yazoo River as ". . . a beautiful stream of transparent water covered by thousands of geese and ducks and filled with fish." During this century, almost all of the forested wetlands in the Yazoo Basin have been cleared for agricultural production. Today, the river is highly turbid, and exhibits the highest concentrations of the insecticides DDT and toxaphene in freshwater fish in the United States (Schmitt et al. 1990). Both insecticides sorb to the surface of sediment particles.

Despite the intuitive likelihood of this function, little quantitative work has been done on the ability of freshwater wetlands to retain suspended sediments. Boto and Patrick (1979) noted that "Little hydrologic data on rates of flow through freshwater wetlands are available. [Therefore] any discussion of the relative efficiencies of . . . forested freshwater wetlands in promoting deposition of sediment by the "filtering" action of plants would be speculative." More than a decade later, in a review of sediment and nutrient retention by freshwater wetlands, Johnston (1991) found only fourteen published reports of vertical and mass accumulation rates for mineral soils and sediments in the entire country. Even in coastal areas, where sediment accretion has been studied much more extensively because of the submergence of coastal marsh and subsequent land loss (Nyman et al. 1993, Cahoon 1994), it is unclear whether the vertical accretion on the surface of the marsh is due primarily to the accumulation of river-borne mineral sediment or autochthonous organic materials.

Study Objectives

The first objective of this study was simply to determine whether the Cache River BLH wetlands retain suspended sediments from floodwaters. The second objective was to determine whether particular parts, or zones, of the BLH system were more effective in retaining suspended sediments than others. The final objective was to determine whether there were any relationships between the retention of suspended sediments and other physical and chemical characteristics of the of the BLH site, such as flood duration and vegetation density. These objectives were accomplished by using a mass-balance approach to measure the sediment load of the Cache River upstream and downstream from a sizable forested wetland system, complemented by *in situ* measurements of sediment deposition and related environmental parameters at sites located along transects within the floodplain forest.

Background Literature

Even casual observations in a wetland system can lead to the conclusion that wetlands can trap and retain sediments. Often there are sediments deposited on tree trunks after a flood recedes, and frequently leaf litter from the previous fall can be seen buried beneath a layer of recently deposited sediment.

Factors controlling the settling of materials suspended in the water column include the density of the water, the fluid viscosity, the size, shape and density of the sediment particles, and floodplain roughness (Ritter 1978:220). If flocculation is ignored, settling velocity of small particles can be estimated by Stokes Law (Simons and Senturk 1977) which is stated:

$$V_s = \frac{gD^2(S_g - 1)}{18\nu}$$

where

V_s = settling velocity (m/sec)

g = gravitational acceleration (9.82 m/sec^2)

D = particle diameter (m)

S_g = specific gravity of the particles and

ν = kinematic viscosity of water at temperature T (m^2/sec).

Kinematic viscosity can be computed from:

$$\nu = \frac{1.79\times10^{-6}}{1.0+0.03368T+0.000221T^{2}}$$

where T is in °C. The settling velocity can range from about 270 m/day for coarse silt (62 μm) to about 0.004 m/day for very fine clay (0.24 μm) and is about 0.1 m/day for medium clay (1.5 μm), which is likely to be common in the Cache River.

For a given settling velocity, the amount of material that is actually deposited on the floodplain is dependent upon the depth of the water column, turbulence in the water column, and the flood duration, that is the length of time the water stays on the floodplain allowing the sediment to travel downward in the water column. Water depth is a factor determined by upstream hydrology and the basin geometry, basically independent of the wetland system. The other two factors, turbulence and flood duration, are in part influenced by the stream velocity of the river. Stream velocities can be calculated by means of the Mannings equation (Dunne and Leopold 1978:592), which states that:

$$V = \frac{1.49R^{2/3}S^{1/2}}{n}$$

where

V = velocity (ft/sec)

R = hydraulic radius (cross-sectional area divided by wetted perimeter, ft)

S = stream gradient (slope of the water surface) and

n = roughness coefficient (experimentally determined, $\mathrm{ft}^{1/6}$)

Velocity decreases with a decrease in hydraulic radius, a decrease in stream gradient or an increase in the roughness coefficient. All three of these parameters can be modified when a river floods a wetland, and the resultant decrease in water velocity makes wetlands likely depositional areas for suspended sediments (Johnston 1991). It is possible that the sedimentation process may be further expedited by the presence of high molecular weight humic acids generated by the decay of organic material on the floodplain which may flocculate clay particles (Akhurst and Breen 1988).

Sediment deposition in wetlands may contribute to the improvement of the water quality of adjacent aquatic systems by reducing the turbidity and suspended sediment of the water. Excess suspended sediments may interfere with reproductive success in aquatic organisms, be esthetically displeasing, and serve as carriers for nutrients and contaminants adsorbed to the surface of the sediment particles (Stall 1972, Mitsch and Gosselink 1993:444).

Mineral Sediment Deposition in Wetlands

Many studies of sediment accretion rates have been conducted in coastal systems, because the rate of vertical accretion is critical to an understanding of the land loss issue associated with relative sea level rise. However, except for measurement methods, these studies have little relation to the deposition of mineral sediments in riverine systems. This is principally because a significant portion of the vertical accretion associated with coastal systems is due to autochthonous organic contribution. In a riverine system, the organic content of the soils is lower due to longer periods of drying which allow for organic matter oxidation and floods that wash leaf litter off the floodplain, and prevent its accumulation. Accordingly, sedimentation in coastal wetlands will not be further discussed here.

Table 1 summarizes several recent studies that addressed mineral sediment deposition in forested wetlands. These studies used a range of measurement methods, ranging from marker horizons and radioisotope dating to flood event sedimentation measurement to the depth to the argillic horizon. The geographic range included southeastern sites in Louisiana, North Carolina, Georgia and northern sites in Michigan and Wisconsin. Only four of the studies measured both vertical accretion and mass accretion. Vertical accretion rates ranged from -0.60 to 2.5 cm/yr, and mass accretion rates ranged from 0 to 7840 $g/m^2/yr$. This variability suggests that understanding sedimentation processes in forested wetlands will require significant study. Figure 1 illustrates the need for sedimentation studies in the wetlands of the Mississippi Alluvial Valley. Even expanding beyond studies done only in mineral, forested systems, there is a glaring lack of studies done between southern Illinois and southern Louisiana, though most of the acres of wetlands in the United States are found in this geographic region.

Table 1. Accretion rates for mineral soils in forested wetlands.

REFERENCE	LOCATION	WETLAND DESCRIPTION	DATING METHOD	VERTICAL ACCRETION (cm/yr)	MASS ACCRETION (g/m^2/yr)
Baumann 1980	Barataria Basin, LA	Cypress swamp	Dust, clay and glitter marker horizons	-0.60	---
Cooper et al. 1987	Cypress Creek, NC	Floodplain swamp	^{137}Cesium and sediment-soil morphology	0.00-0.25	---
Cooper et al. 1987	Cypress Creek, NC	Forest edge	^{137}Cesium and sediment-soil morphology	1.00 - 1.50	---
Cooper et al. 1987	Panther Swamp, NC	Floodplain swamp	^{137}Cesium and sediment-soil morphology	0.00-0.50	---
Cooper et al. 1987	Panther Swamp, NC	Forest edge	^{137}Cesium and sediment-soil morphology	0.75-2.50	---
Johnston et al. 1984	Cecil, WI	Riparian forest levee	^{137}Cesium and sediment-soil morphology	1.30	7840
Johnston et al. 1984	Cecil, WI	Riparian forest backwater area	^{137}Cesium and sediment-soil morphology	0.50	472
Kadlec and Robbins 1984	Pentwater, MI	River bottom	^{210}Lead dating	~0	~0
Kuenzler et al. 1980	Creeping Swamp, NC	Low areas	Flood event sedimentation	---	305
Lowrance et al. 1986	Tifton, GA	Riparian forest	Depth to argillic horizon	0.22	3500-5200
Mitsch et al. 1979	Cache River, IL	Alluvial cypress swamps	Sediment traps	0.80	5600

Adapted from Johnston et al. (1990:52).

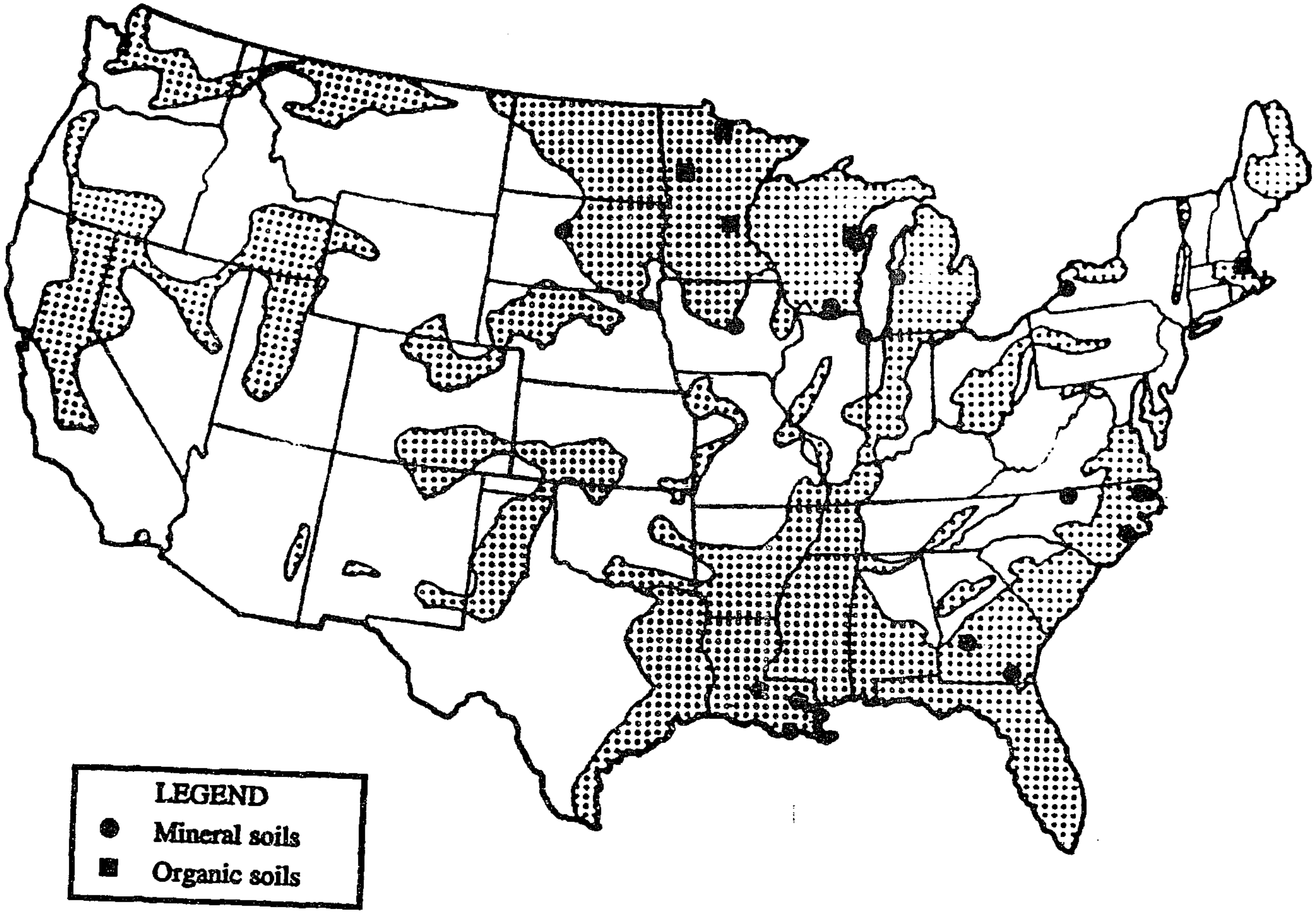

Figure 1. Location of previous sedimentation studies in wetlands compared with the national distribution of wetlands, which are indicated by the stipple pattern. (Modified from Johnston (1991) and National Wetlands Inventory, U.S. Fish and Wildlife Service, St. Petersburg, FL)

Sediment Deposition Associated with Fluvial Systems

Although these studies do not directly address the deposition of sediments in wetlands, there have been some interesting studies conducted which address the deposition of sediment on floodplains of river systems, which address the floodplain more as a geomorphic system than as an ecosystem. Klimas (1988) used the depth to a sand layer deposited by the 1973 flood of the Mississippi River to test the hypothesis that forests inside the Mississippi River levee were associated with high rates of sedimentation, thus indicating that the velocity of the river was diminished. No correlation between forest structure and sedimentation patterns was found. In larger river systems, measurements of sediment on the floodplain from individual flood events are possible. On the Amazon River, Mertes (1994) found vertical accretion rates of 0.3 to 3.3 cm/day, while Kesel et al. (1974) measured deposition ranging from 0.5 to 84 cm from a single flood event of the Mississippi River. Robert Meade has participated in a series of studies (Meade 1982; Milliman and Meade 1983; and Meade and Parker 1984) which have addressed the transport of sediments from the land into rivers, and in turn, into oceans. He suggests that much of the river-borne sediments on the Atlantic coast are trapped by estuaries and coastal marshes, with less than 5% of the total sediment load of the rivers actually going out to the continental shelf or the deep sea. The location of the sediment deposition is moved inland from the estuaries to fluvial systems by Phillips (1989). He said that of sediment reaching streams, 29 to 93% is stored in alluvial wetland or channel environments.

SITE DESCRIPTION

General Background and Sampling Locations

The area intensively studied in this project was bounded to the north and south by two river gages, located at Patterson and near Cotton Plant, AR (Figure 2). These gages are about 49 river kilometers apart. The drainage basin upstream from the Patterson gage is about 2,686 km^2 in size, and the drainage area between the two gages is about 350 km^2. Approximately 85 km^2 of the area between the gages remains in BLH, typical of the wooded wetlands in the region. The forest is dominated by water tupelo (*Nyssa aquatica* L.) and bald cypress (*Taxodium distichum* (L.) Rich.) near the river; overcup oak (*Quercus lyrata* Walt.), water hickory (*Carya aquatica* (Michx. f.) Nutt.), and green ash (*Fraxinus pennsylvanica* Marsh.) in the next higher zone; followed by a zone dominated by Nuttall oak (*Q. nuttallii* Palmer), and willow oak (*Q. phellos* L.); with sweetgum (*Liquidambar styraciflua* L.) and water oak (*Q. nigra* L.) dominant on the highest ground. Much of the forested area is known as the "Black Swamp" and is located within the Arkansas Game and Fish Commission's Rex Hancock/Black Swamp Wildlife Management Area and the Cache River National Wildlife Refuge.

The soils in the project area are primarily Typic Fluvaquents, Typic Ochraqualfs, Albic Glossic Natraqualfs, and Vertic Haplaquepts. All of these are

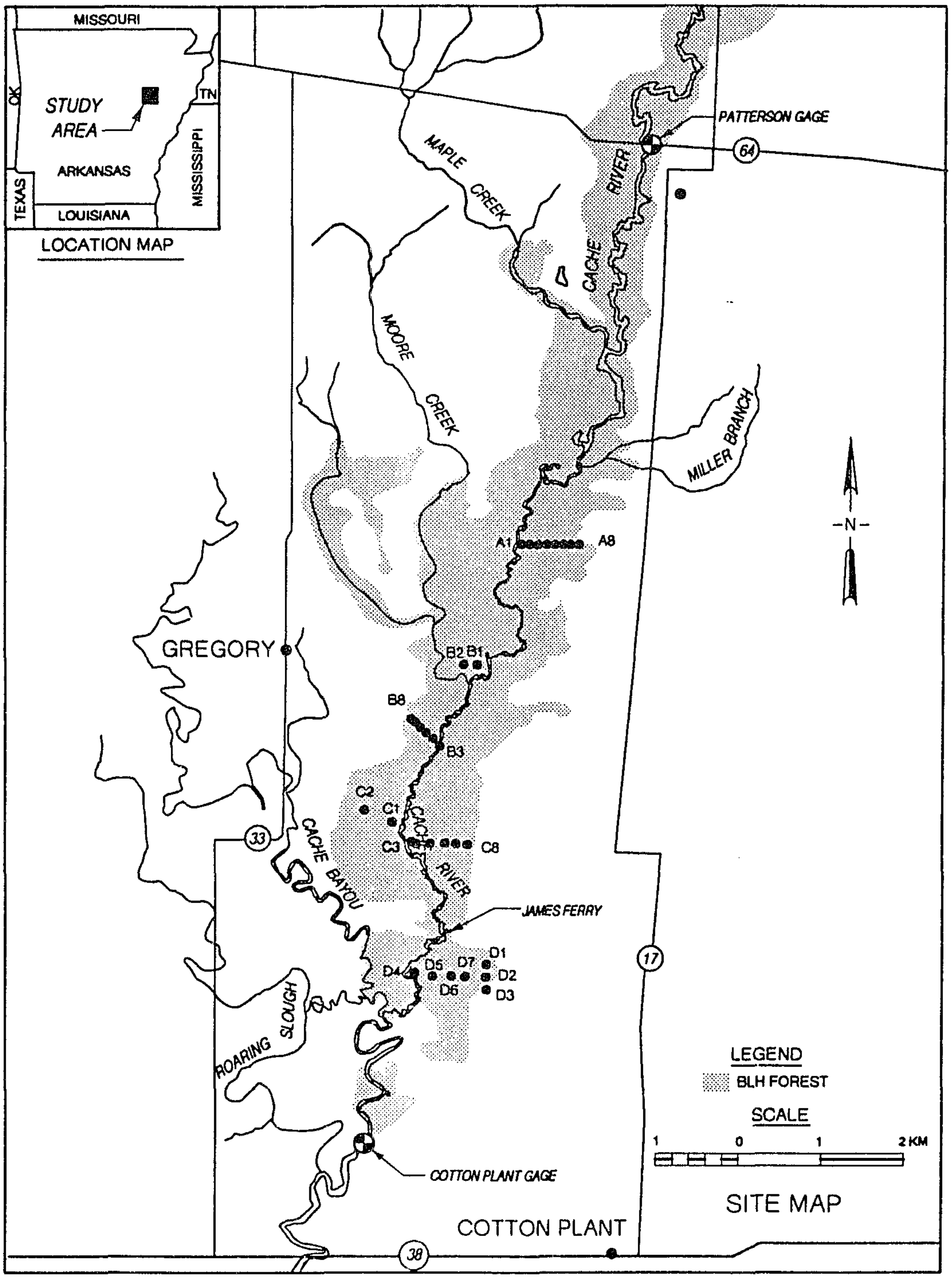

Figure 2. Map of the Cache River project area illustrating the locations of the gaging stations and the sedimentation sites on the floodplain. The remaining forest in the immediate area is shaded gray.

considered hydric soils, that is, soils that are sufficiently wet under undrained conditions to support the growth and regeneration of hydrophytic vegetation.

Four loose transects or study areas were established within the floodplain, running perpendicular to the Cache River (Figure 2). The transects were located to provide reasonable access to the area, and to represent an upstream-downstream gradient. Within each of these transects, eight sedimentation sites were established. These sites were located along the transect prior to surveying the area. Vegetation communities can often be used as surrogates for hydrologic conditions. Therefore, to capture the full range of hydrologic variability the sedimentation sites were located to represent as broad a range of vegetation communities as possible. The cross-section of the floodplain where each of the transects is located is shown in Figures 3, 4, 5 and 6. Five additional sites B1, B2, C1, C2 and D1 were located off of the main transects.

Geomorphological Setting

The Cache River is located in a physiographic region known as the Western Lowlands. During the Wisconsin glaciation, the braided stream of the ancestral Mississippi River occupied the Western Lowlands (Saucier 1974, 1978). The bulk of the valley train deposits were laid down between 50,000 and 70,000 years ago during the waning phase of the Early Wisconsin glaciation (Saucier 1974). During the period of expanding Late Wisconsin glaciation (40,000 to 18,000 years ago) there was still some minor glacial outwash being carried into the Cache River area, but the only active

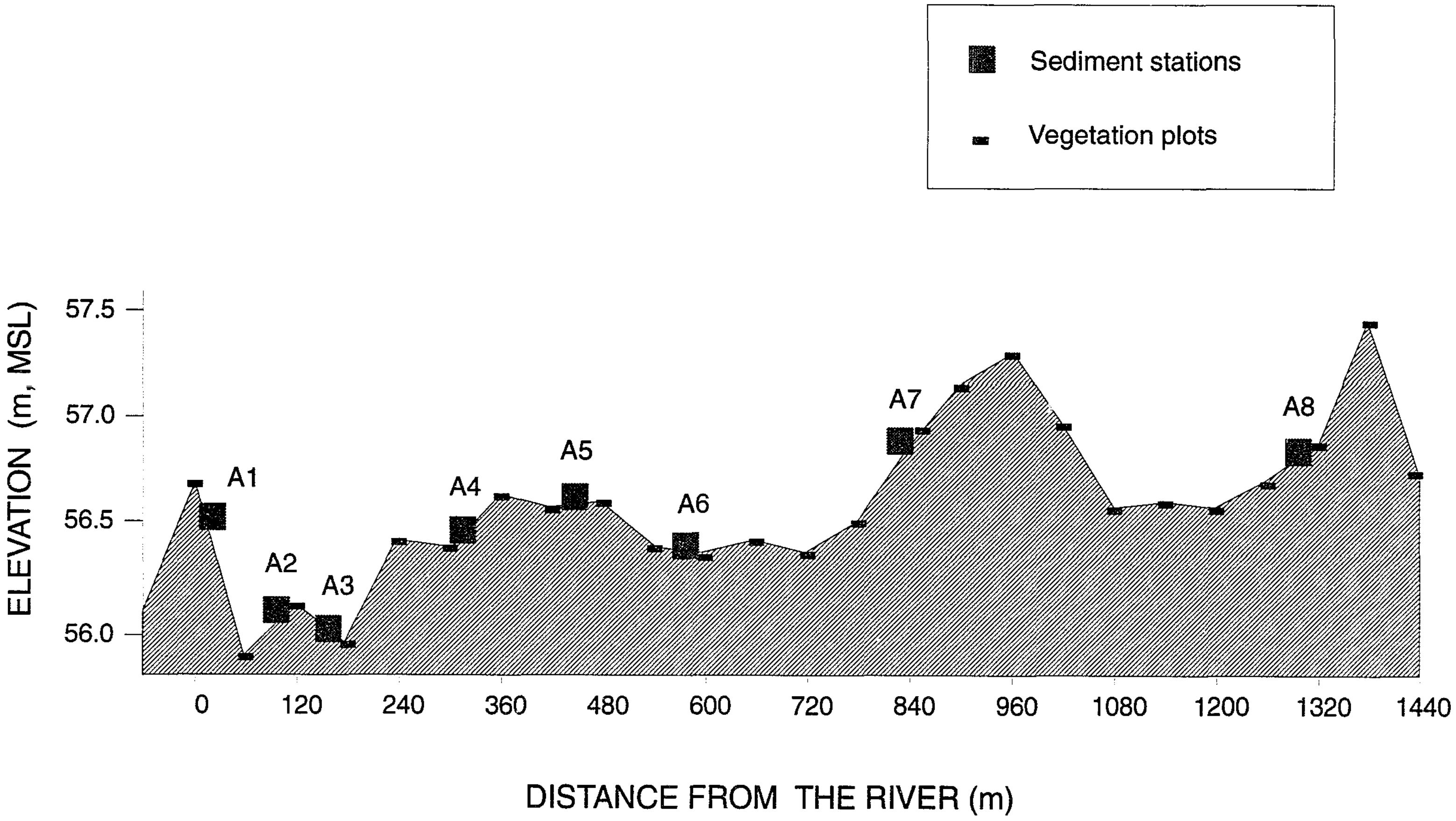

Figure 3. Floodplain cross-section at Transect A, showing the elevation of the sedimentation sites and their distance from the river. Vegetation was described at each of the vegetation plots, and the mid-point of each plot was topographically surveyed.

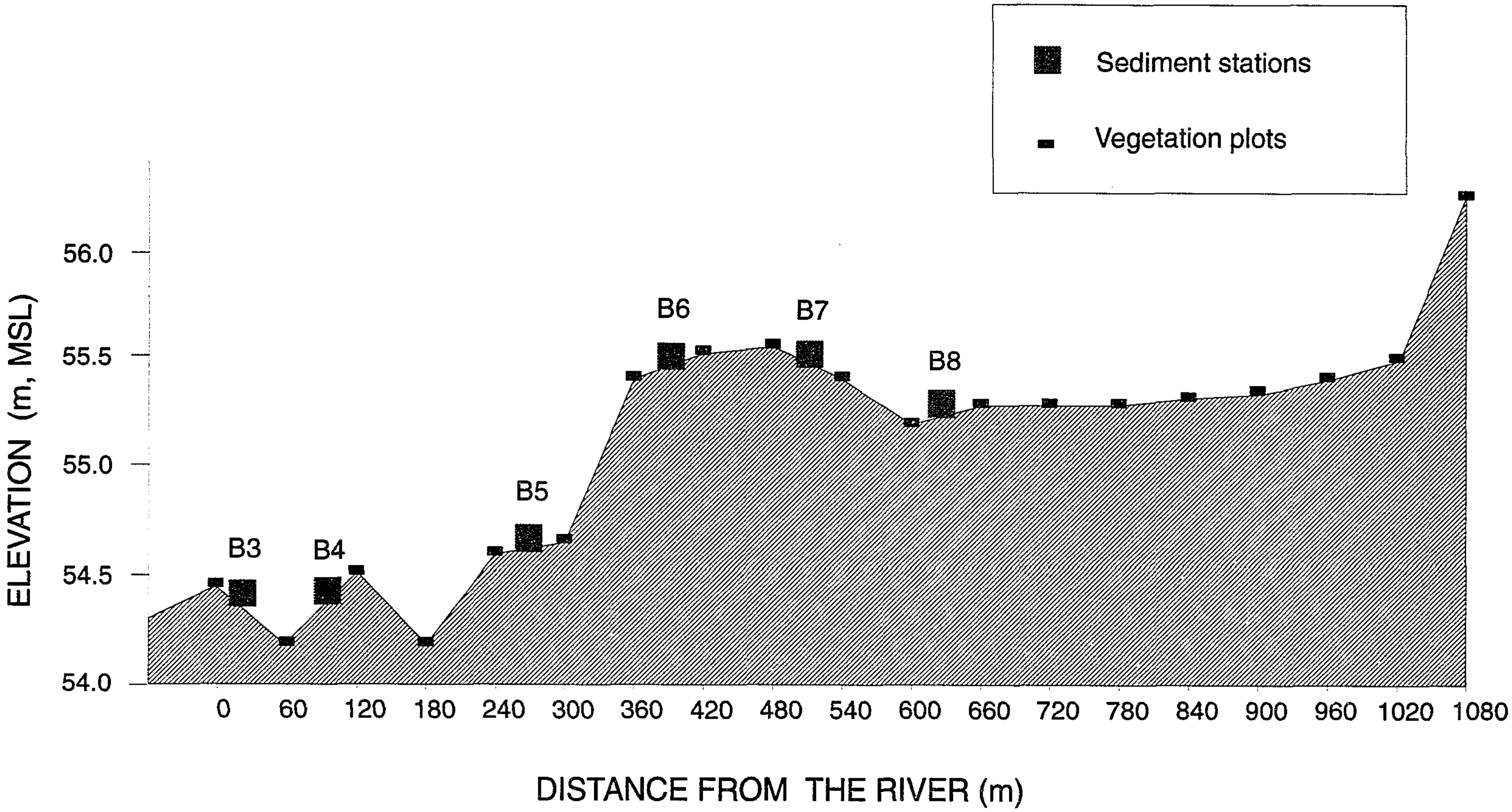

Figure 4. Floodplain cross-section at Transect B, showing the elevation of the sedimentation sites and their distance from the river.

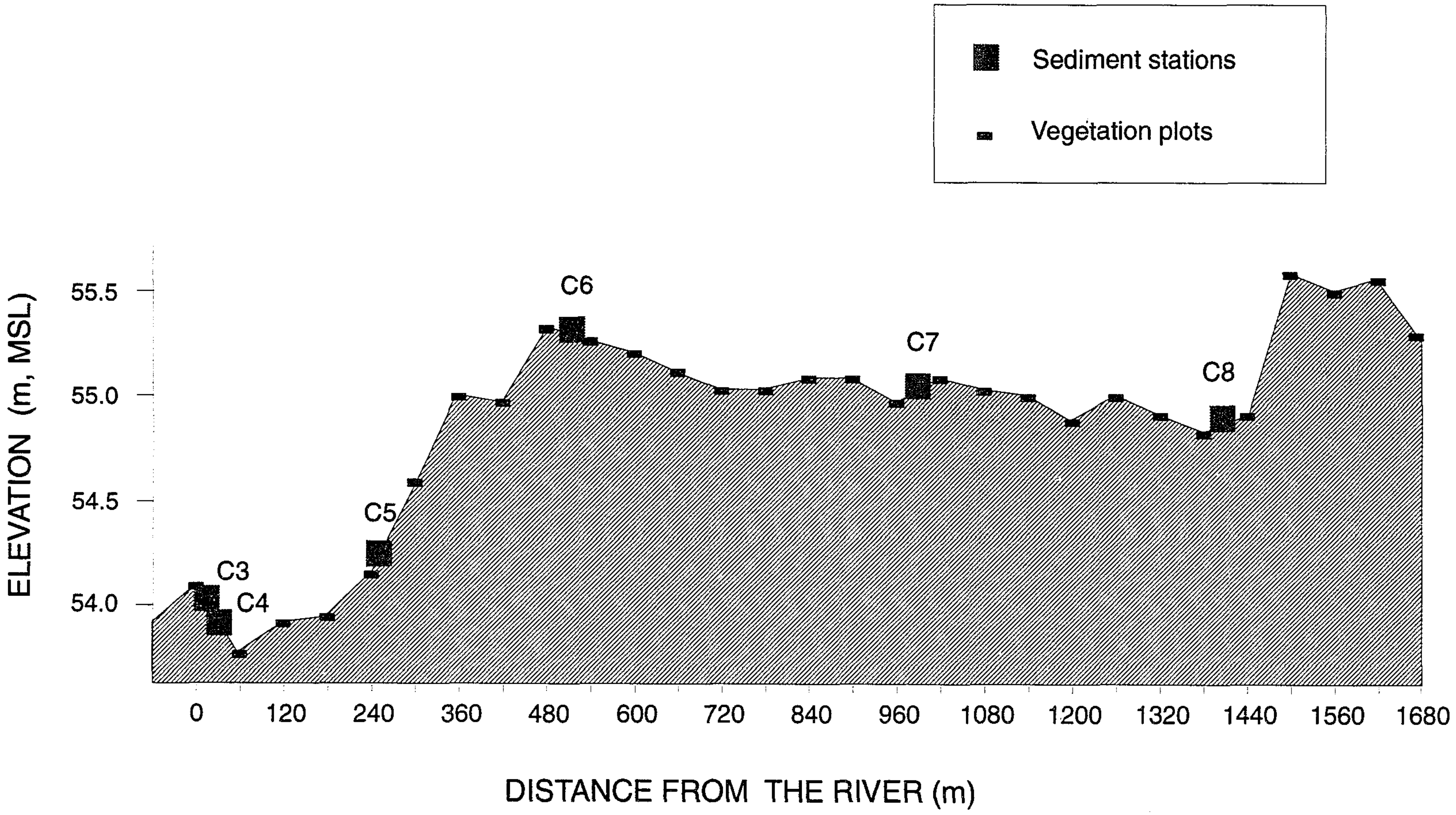

Figure 5. Floodplain cross-section at Transect C, showing the elevation of the sedimentation sites and their distance from the river.

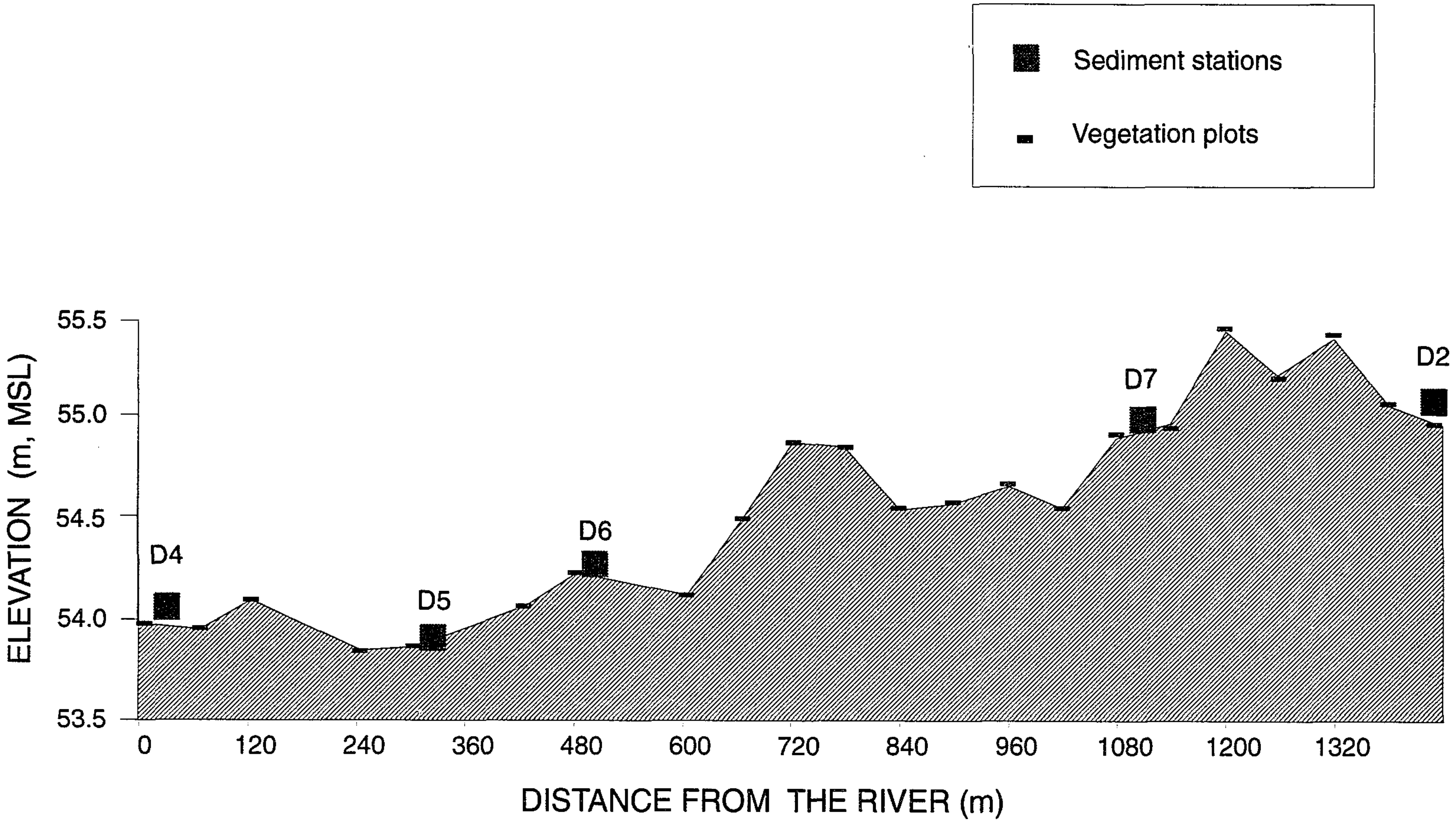

Figure 6. Floodplain cross-section at Transect D, showing the elevation of the sedimentation sites and their distance from the river. Site D1 is located at a right angle to D2 in an oxbow area at an elevation of 54.16 m.

channels apparently were located along the present routes of the Cache and White Rivers (Bennett and Saucier 1988). At about 18,000 years ago, glacial deposition shifted from the Western Lowlands to the eastern side of Crowley's Ridge into the St. Francis Basin. The abandoned braided channels in the Western Lowlands were left to carry only the flow of the local streams such as the Current, White, Black and St. Francis Rivers, which began to develop meander belts. The earliest recognizable meander belt along the Cache River probably dates from between 18,000 and 12,000 years ago and was formed by the combined flow of the St. Francis and Black Rivers and now exists as the Cache River terrace (shown in solid black in Figure 7). The size and radius of the meanders in this meander belt far exceed those developed by the present day Cache River. The abandonment of this floodplain because of the diversion of the two rivers to their present courses has not been accurately dated, but has been estimated at about 12,000 years ago. Since that time, the Cache has been the sole major channel in the floodplain. Accordingly, the Cache can be considered to be a relict, underfit stream in a channel constructed by larger rivers, or as Bennett and Saucier (1988) summarized it, the Cache River valley is a "valley within a valley within a valley."

Two of the apparent tributaries to the Cache River, Cache Bayou and Roaring Slough, are actually large crevasse channels of the White River which were probably formed 4,000 to 7,000 years ago. Roaring Slough is associated with an abandoned

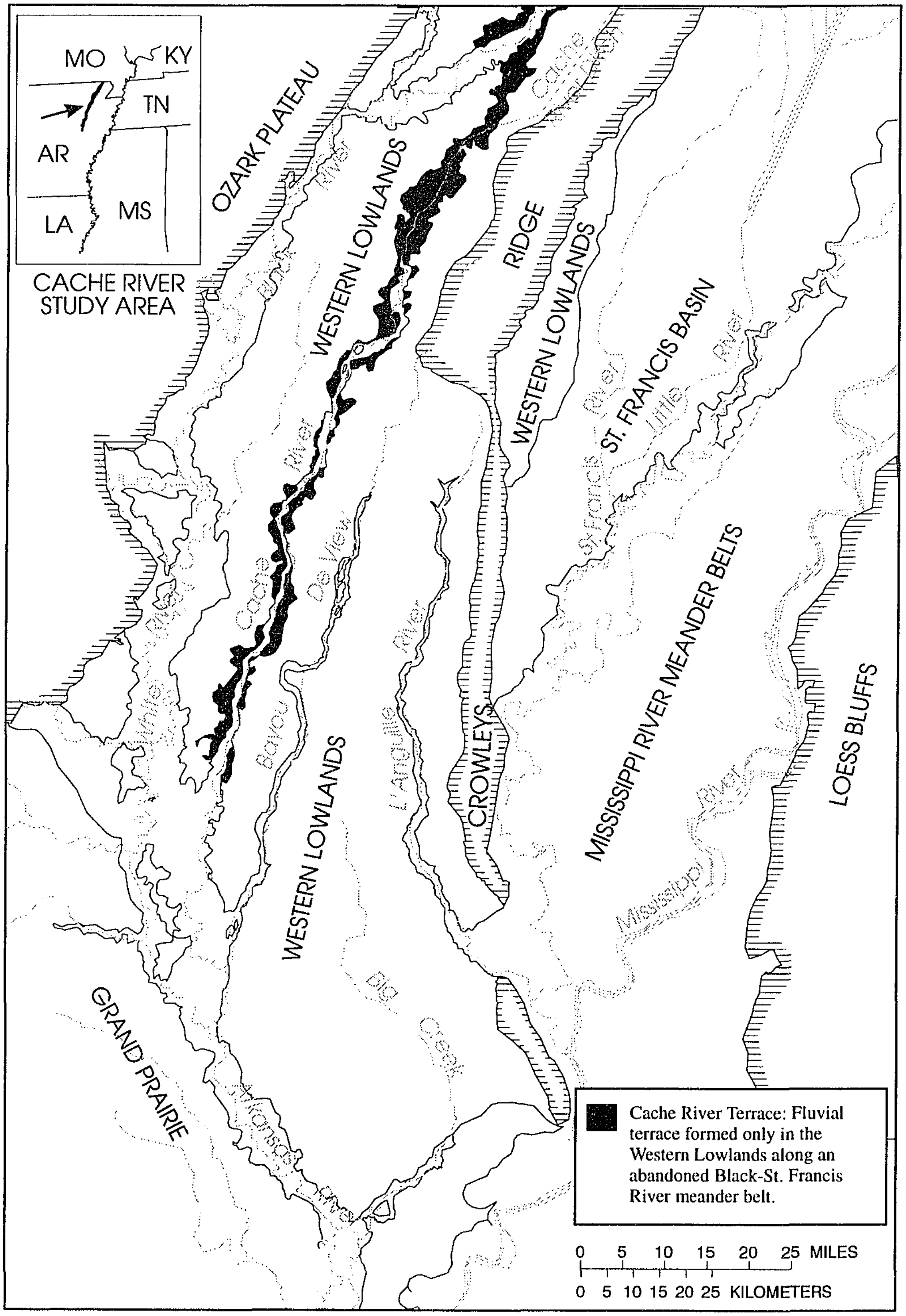

Figure 7. Geological map of the Cache River area (adapted from Saucier and Snead 1989).

White River meander belt, while the Cache Bayou crevasse is associated with the present White River and is probably 1000 or so years younger (Bennett and Saucier 1988). Local residents have indicated that prior to levee construction on the White River, Cache Bayou and Roaring Slough functioned as distributaries for the White River during flood events and actually connected the White River and Cache River basins. This exchange of water apparently has not occurred during recent years, and the two crevasse systems function more as storage areas for backwater flooding from the Cache and traps for the non-point source runoff from their small immediate drainage basins.

Climatic Conditions

Average annual rainfall for the area is approximately 125 centimeters (Freiwald 1985), with frequent, intense frontal storms occurring during the winter and spring months. Water levels in the Cache River commonly fluctuate more than 3 meters during an annual cycle, and discharges can range from no flow to more than 280 cubic meters per second (m^3/s) at the Patterson gage. Average daily temperatures range from about 5.3°C during January to 26.9°C during July. Average annual actual evapotranspiration rates are about 81 cm.

Cultural Background

Kittrell (1983), in her history of the township that is located immediately to the west of the Cache River, noted that although the townships were not surveyed until 1846, the area had been settled, to some extent, earlier. The sale of land from the

United States government to prospective settlers marked the official settlement of the area and began in 1848. However, according to the best available records, the first man-made levee in the area was built during the period between 1820 and 1840, just to the west of the project area, to keep the White River from flooding the area. In 1908, The White and Cache River Levee District was organized and an extensive levee was completed by 1911. This levee system apparently began the widespread clearing of the hardwood timber in the immediate vicinity of the project area. By the time of the historic 1927 flood of the Mississippi River, much of the local area is reported to have been in cultivation.

This trend seems to have been generally true throughout the Cache River Basin. According to an analysis of aerial photography and satellite imagery conducted by Graves and Bourne (in review), the basin was only 65 % forested in 1935. The wooded area declined to only 15% by 1965, and the remaining forest is in small, fragmented blocks. The land clearing in the post World War II era was probably also due to drainage projects, but the loss rate was greatly accelerated by the widespread availability of diesel-powered heavy equipment. The forest has been replaced almost exclusively by row crops, including cotton, soybeans, corn, and rice, although there is a small amount of catfish farming in the vicinity. Accordingly, agricultural runoff is the principal source of sediments and nutrients in the basin. No known point-source contribution of wastewater occurs in the study area.

METHODS

Mass-Balance Study

To address the question "Does the BLH wetland retain sediments from the Cache River?" I initiated a mass-balance study, comparing the mass of suspended sediments flowing into the wetland with that leaving the wetland. To do this, the hydrologic discharge of the river and the concentration of suspended sediments in the water were measured at the upstream and downstream ends of the wetland.

Hydrology

Inflow hydrology was measured at a Corps of Engineers hydrologic gaging station located at the Arkansas Highway 64 crossing, near Patterson, Arkansas (Figure 2). Stage records were first made at the station in 1916 and the gage has more than 50 years of continuous discharge record. During this study, the U.S. Geological Survey maintained the gage and equipped it with satellite telemetry allowing remote access to data on water levels. A new gaging station was established at the downstream end of the project site in 1987 where a county road crosses the Cache River about 7 km northeast of Cotton Plant, Arkansas. The methods used for gage installation and stage measurement can be found in Carter and Davidian (1968) and Buchanan and Somers (1969). Discharge measurements at Patterson and Cotton Plant were made using a bridge crane and a "Price AA" flow meter, except during extreme low flows when a pygmy current meter was used. A stage-discharge relationship was developed for all flow conditions at all sites (Kennedy 1984). Gages were also established early in the study at six minor tributaries: Miller Branch, Cache Bayou, Roaring Slough, Moore Creek, and two small agricultural ditches. After operating the tributary gages for more than a year, measurable flow did not occur at four of the sites, and the operation of the gages was discontinued. A field inspection revealed that water from the remaining two sites, where measurable flow did occur, entered the floodplain and was immediately intercepted by a series of beaver dams. The water was lost from the depressions through either evapotranspiration or infiltration to the shallow groundwater. The water did not reach the Cache River as surface water flow, and could not contribute suspended sediments to the river. Therefore, the operation of these two gages was also terminated.

An automated tipping bucket rain gage was installed near Gregory, Arkansas at a location near the center of the project area to measure rainfall. These measurements were supplemented with records from the nine nearest NOAA weather stations, located in Augusta, Brinkley, Des Arc, Georgetown, Jonesboro, Madison, Marianna, Paragould and Wynne, Arkansas. These measurements were combined with a weighted-average technique based on the distance of the rain gage from the center of the project area.

All hydrologic measurements are presented in water years (WY), which begin October 1 and end September 30. This period of measurement was particularly convenient for this project because annual low flows almost always occur in September or October in this part of the country. Therefore, a WY will usually not split a high flow event between two years or sampling periods.

Suspended Sediments

Water samples for suspended sediments were collected daily during WY 1988, 1989 and 1990 from bridges at the primary inflow point at Patterson and at the outflow point at Cotton Plant (Figure 2). These samples were collected using D-59 depth-integrating suspended sediment samplers with the aid of cable and reel assemblies permanently attached to each bridge. Additional samples were collected during storm events. The relationship between suspended sediment concentration collected by the fixed-station sampler and the concentration of the entire river cross-section was periodically checked by use of the multiple vertical equal-width-increment technique (Guy and Norman 1970). As necessary, an adjustment coefficient was applied to correct for differences between results of fixed-station and cross-section samples. During repeated sampling over a 24-hour period, a mean concentration for the day was determined by the graphical method of Porterfield (1972). Suspended sediment concentration analysis was performed by the evaporation method described by Guy (1969), which treats the filtered sediment with peroxide to yield a measure of inorganic suspended sediments. Mean daily suspended sediment load was calculated by multiplying the mean daily suspended sediment concentration by the mean daily streamflow. Annual suspended sediment loads were generated by summing all the mean daily loads for a water year.

It is possible that additional sediments could have entered the system between the gages through unmeasured non-point source runoff from uplands beyond the perimeter of the wetland, or by tributary flow during extremely high water; but in either case, this would serve to increase the inflow load, resulting in an underestimate of the amount of sediment actually retained by the BLH. Therefore, the sediment retention figures given in this report are conservative, and actual removal may have been somewhat higher if suspended sediments entered the system from other than the gaged upstream source.

Floodplain Study

To determine where within the BLH forest suspended sediments were retained, 30 sediment stations were established within the floodplain (Figure 2). Figures 3-6 depict the elevation of each site and its distance from the river channel.

Sediment Accretion Measurements

I measured sediment mass accretion (kg/m^2/yr) using sediment disks and vertical accretion (cm/yr) using feldspar clay marker horizons, ^{137}cesium and dendrogeomorphic techniques. More details on the sedimentation accretion methods used can be found in Kleiss (1993).

Sediment disks. Sediment traps which use high-aspect ratios are common in limnological studies. These traps are designed to prevent resuspension of material once it enters the hypolimnion, or the depth selected for sampling. However, in forested wetlands, resuspension during flood events is an integral part of the

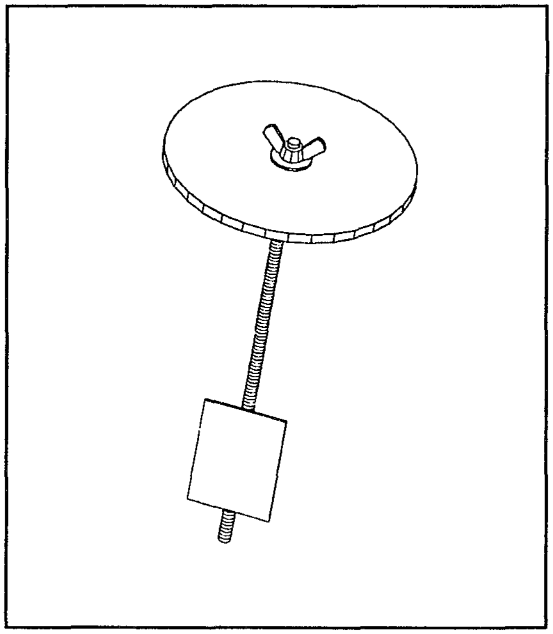

Figure 8. Illustration of a plastic sedimentation disk.

sedimentation cycle. Artificially preventing it would serve to overestimate sedimentation. Therefore, I used "sediment disks" (Figure 8) to allow resuspension of sediments off of the sampling disk during the annual hydrologic cycle. The disks were 15-cm-diameter plastic circles with about a 1-cm hole in the center. The upper surface of each plate was sanded and "roughed up" so that sediments would not be easily washed off. The disks were anchored to the ground surface with a 30 cm threaded steel rod, a washer and wing nut (Figure 9). Three disks were installed at each site and located 1.5 m to the east, west and south of a central stake to aid relocating the disks. Accreted material was scraped and collected from the disks annually during low-flow conditions. The sediments were returned to the lab, dried at 105°C, and weighed. Well-mixed subsamples of the total sediment on each disk were ground and combusted at 500°C to measure loss on ignition.

Feldspar clay marker horizons. Feldspar clay is a white material composed of silt- and clay-sized particles often used for pottery. I spread it at marked locations on the forest floor at a rate of approximately two liters per 0.25 m^2 pad. Sampling consisted of locating the clay pad and taking a small core (about 5 cm in diameter) of the sediments from the surface, down through the marker horizon and measuring the thickness of sediments deposited above the highly visible, bright white marker horizon. Samples were taken in triplicate, once a year, during the low-water period during the fall. Details on this method can be found in Cahoon and Turner (1989).

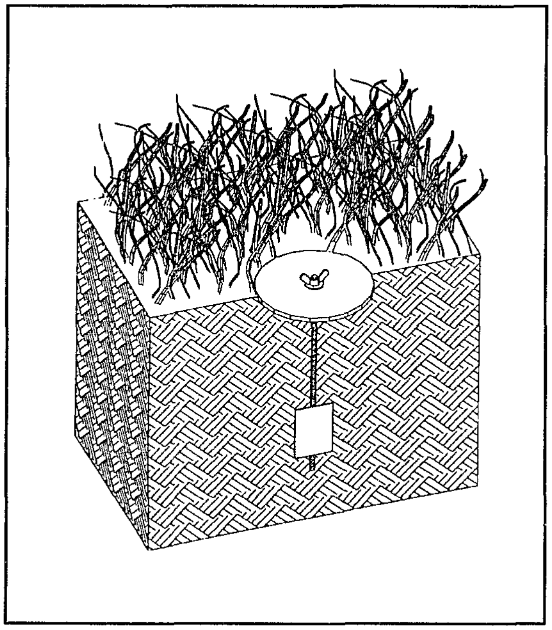

Figure 9. Sedimentation disk anchored into the soil surface.

^{137}Cesium measurements. Sediment cores (0.5 m long by 10 cm in diameter) from a subset of the 30 sites were sliced into 1-cm increments, dried, and ^{137}cesium activity was counted with a lithium-drifted Germanium detector and multi-channel analyzer (DeLaune et al. 1989). In this study, depth to both the 1954 first occurrence of ^{137}cesium and the 1963 maximum detection of ^{137}cesium were used to calculate vertical accretion rates. However, figures reported here are based on the 1963 maximum. ^{137}Cesium may be used to integrate sedimentation rates over a 30- to 35-year period, thereby taking into consideration periods of resuspension or erosion. Ritchie and McHenry (1989) recently reviewed the use of this technique.

Dendrogeomorphic technique. Dendrogeomorphic work in the Cache River basin was done by the U.S. Geological Survey (Hupp and Morris 1990). Sigafoos (1964) and Everitt (1968) showed that historic patterns of floodplain deposition could be described by combining tree-ring analysis with detailed hydrogeomorphic observation. This method assumes that the lateral roots from the trunk of the tree are in the same position as they were at germination, so that any sediment above the root represents sediment deposition during the life of the tree.

An average of five trees, representing a range of ages, near each sedimentation site were cored with an increment corer and partially excavated to expose the trees' lateral roots (Figure 10). Measurements were made of the depth of burial of the lateral roots, from the top of the root to the present soil surface. These measurements were taken 0.5 to 1.0 m away from the tree trunk to assure that measurements avoided the influence of the basal flare. Depth measurements were divided by the age of the tree to obtain a sedimentation rate near the tree. The technique allows the detection of some differences in historic versus more recent sedimentation rates to be made by measuring trees in different age groups.

Other Environmental Measurements

To try to explain how sedimentation rates vary with location on the floodplain, a series of other measurements of the environment surrounding each sedimentation site were taken.

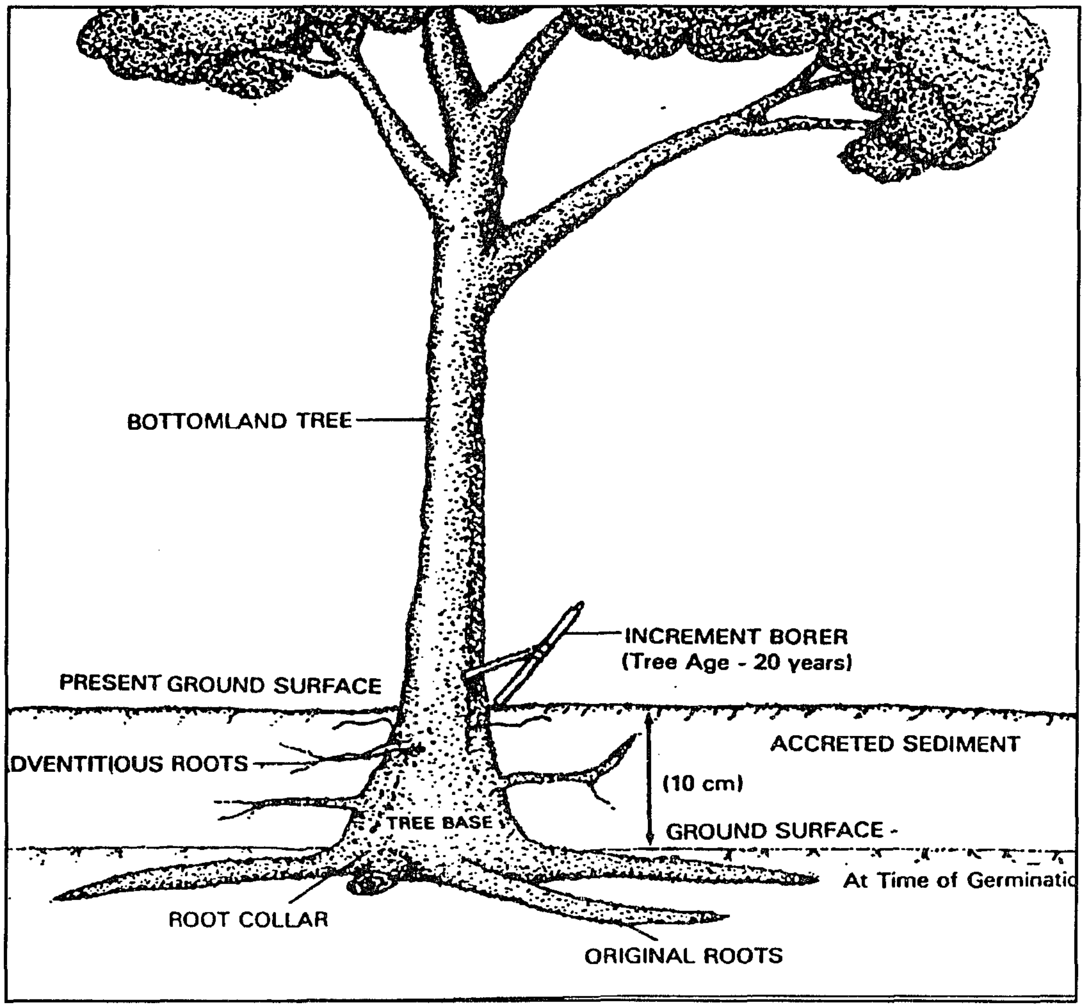

Figure 10. Illustration of dendrogeomorphic sedimentation rate sampling technique. (from Hupp and Morris 1990, used with permission).

Hydrology of overlying water. Flood frequency and duration on each of the 30 plots were calculated for the three-year period using a link-node model called the Wetlands Dynamic Water Budget Model (Walton et al. in review). The link-node grid developed for the wetland system had 66 nodes and 115 links. The model was calibrated to stage recorders installed on the floodplain and compared to field measurements taken during the collection of other samples. Calculations of the elevation of the water surface for each node were made on a daily basis. Then the depth of water and the number of days each site was flooded were determined by subtracting a surveyed elevation for each of the sediment sites from the water elevation at the nearest node. A flood event was defined as any time floodwaters inundated the site, regardless of depth, and flood frequency was the number of times a site was inundated, with a dry period between events.

Water chemistry, suspended sediment particle size and velocity of overlying water. Over a three-year period, 16 water samples were taken of flood water overlying each of the 30 sites (Figure 2) for determination of turbidity and suspended sediment concentration. Standard methods (APHA 1989) were used in gravimetric determinations of solids and nephelometric measurement of turbidity. Particle size of the suspended sediments at Patterson, Cotton Plant, and at the sediment stations along the Transect B was measured using the bottom withdrawal method (Guy 1969). Water velocity during a significant, but not extreme flood event, was measured in the main channel and along Transect B with a Montedoro-Whitney flow meter.

Vegetation survey techniques. All trees (≥ 5 cm in diameter at breast height [dbh]) were identified and their diameters measured within a 0.04-ha circular sampling plot at 60 m intervals along transects. When a vegetation plot did not fall in the immediate vicinity of a sedimentation site, vegetation information from the two nearest sites was averaged (Figures 3-6). Saplings (<5 cm dbh and≥ 1.4 m tall) were identified and counted within two 0.004-ha subplots and woody seedlings (<1.4 m tall) within two 0.0004 subplots. The sapling and seedling categories were combined into a new category called understory density for analysis. The wetland indicator status of the vegetative community was calculated by assigning obligate wetland plants a value of 1, facultative wetland plants a value of 2, facultative plants a value of 3 and facultative upland plant a value of 4, and averaging the sum of the values (Reed 1988). This provided an index of the effect of the hydrology on the vegetation.

Soil characterization. At each of the 30 sites, the soil was described to a depth of about 2 m by soil scientists from the Natural Resources Conservation Service. Horizon breaks were determined and texture, structure, reaction, color, and extent of mottling was noted for each horizon.

Statistics

Data were manipulated with Lotus 1-2-3 ™ and statistical analysis performed with SigmaStat™ Statistical Software (Fox et al. 1994). Suspended sediment loads from the Patterson and Cotton Plant gaging stations were compared using the Mann-Whitney test, and stepwise multiple regression was used to evaluate the relationship between sediment accretion and other environmental characteristics of each of the sites.

RESULTS AND DISCUSSION

Mass-Balance Study

Hydrologic Discharge

The hydrograph for WY 1988, 1989 and 1990 compared to the rainfall is shown in Figures 11, 12, and 13. The difference between the Patterson and Cotton Plant hydrograph was dependent upon antecedent conditions. If conditions were dry, there was a delay between the a rainfall event and an increase in stream flow. However, during wetter conditions, there was an immediate increase in river stage with rainfall. Antecedent conditions also affected the movement of water through the system. When individual flood events were examined, the time of travel for the flood peak varied from 2 to 10 days. During some intermediate events, for example, December and April of WY 1988, the flood crest was dampened and delayed. However, during major events, such as January of WY 1988 and March of WY 1989, the floodplain storage capacity was exceeded and the flood crest was higher at Cotton Plant than at Patterson. On the average about 7% more water left the system at the Cotton Plant gage than entered it at Patterson. This additional water was probably due to rainfall which occurred between the two gages, groundwater inflow from the alluvial aquifer directly into the river bed, shallow groundwater flow, non-point source flow of water across the floodplain, and during extreme events, some tributary flow (Gonthier (in review) and Walton et al (in review)).

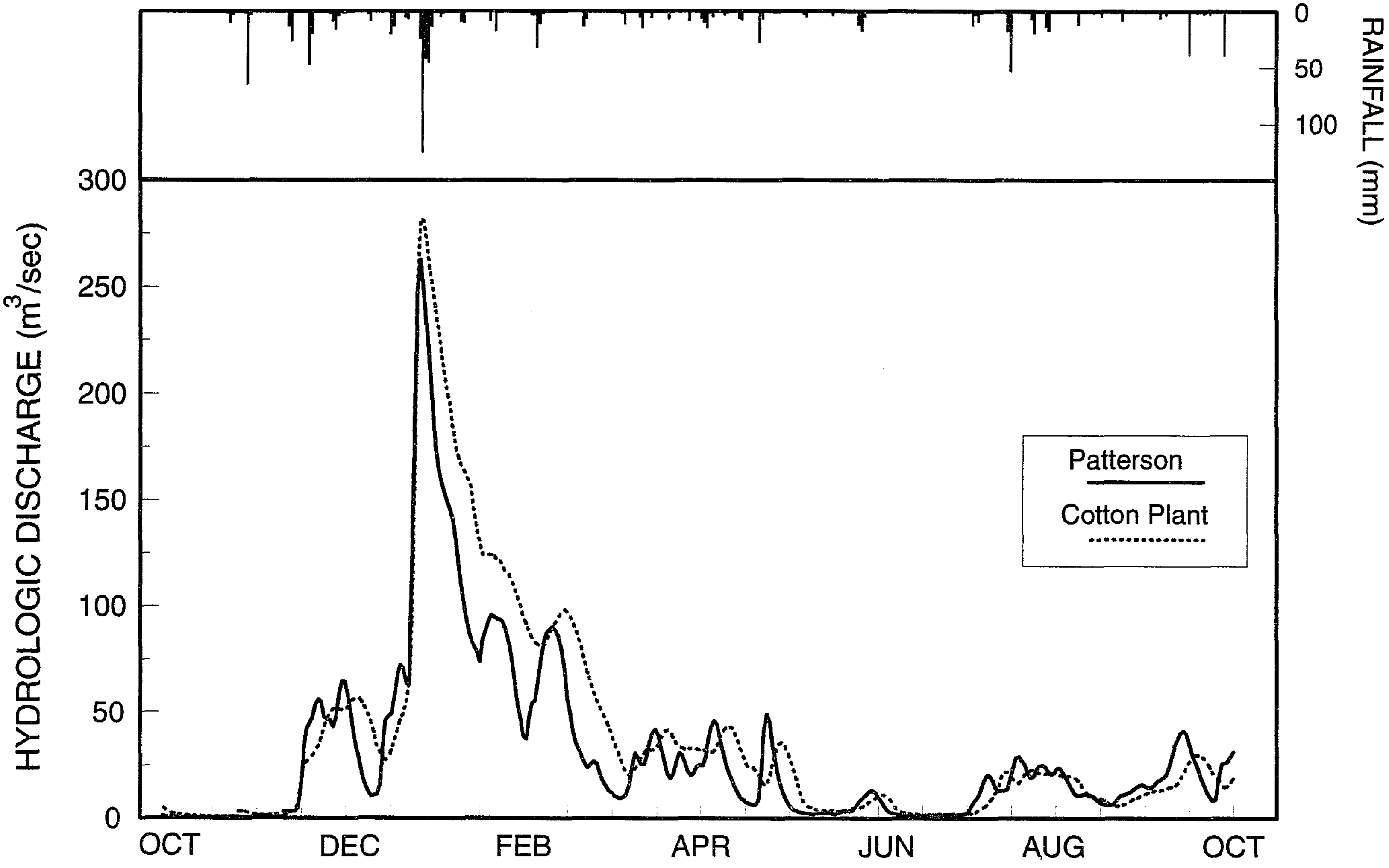

Figure 11. Rainfall and hydrologic discharge for WY 1988.

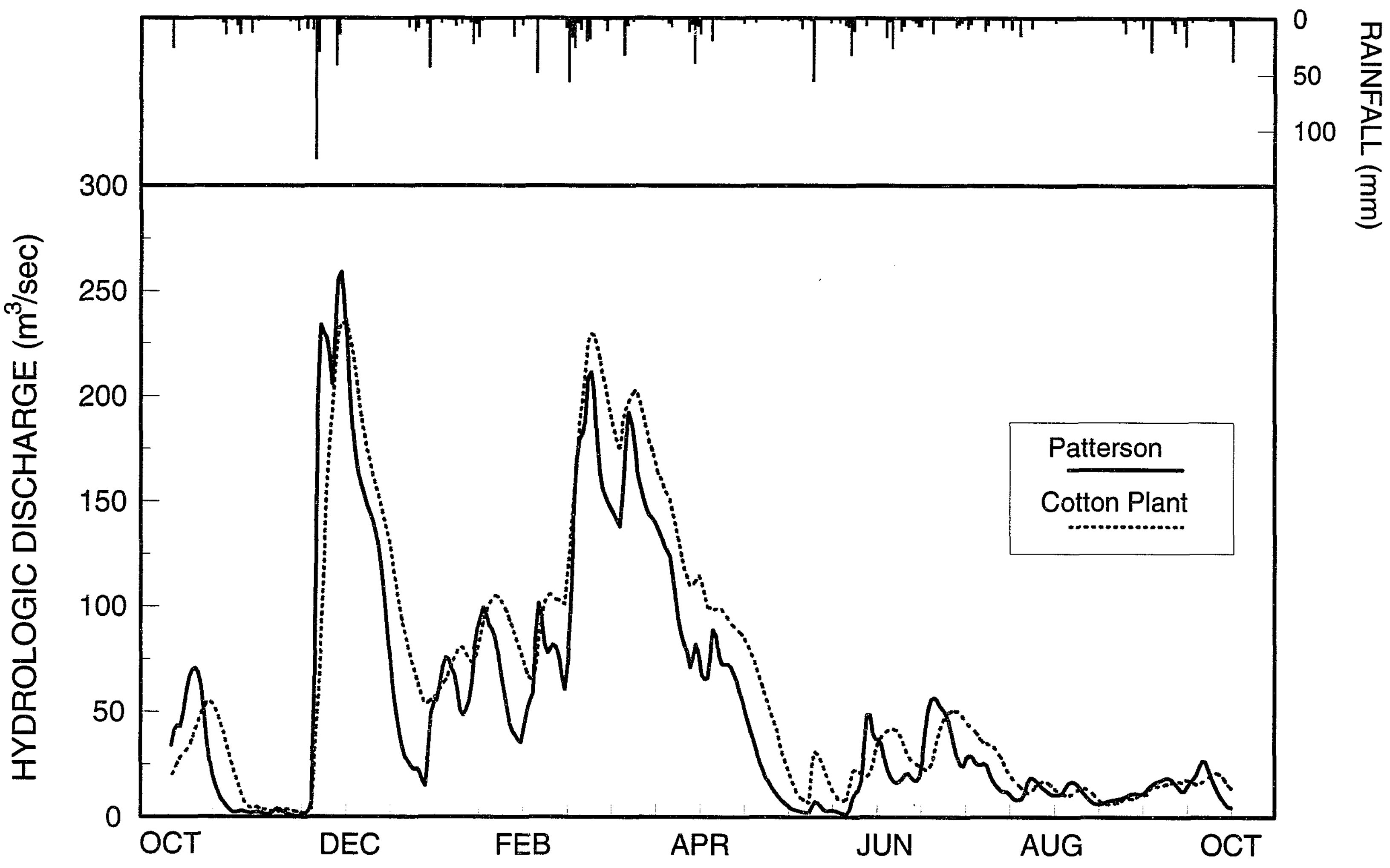

Figure 12. Rainfall and hydrologic discharge for WY 1989.

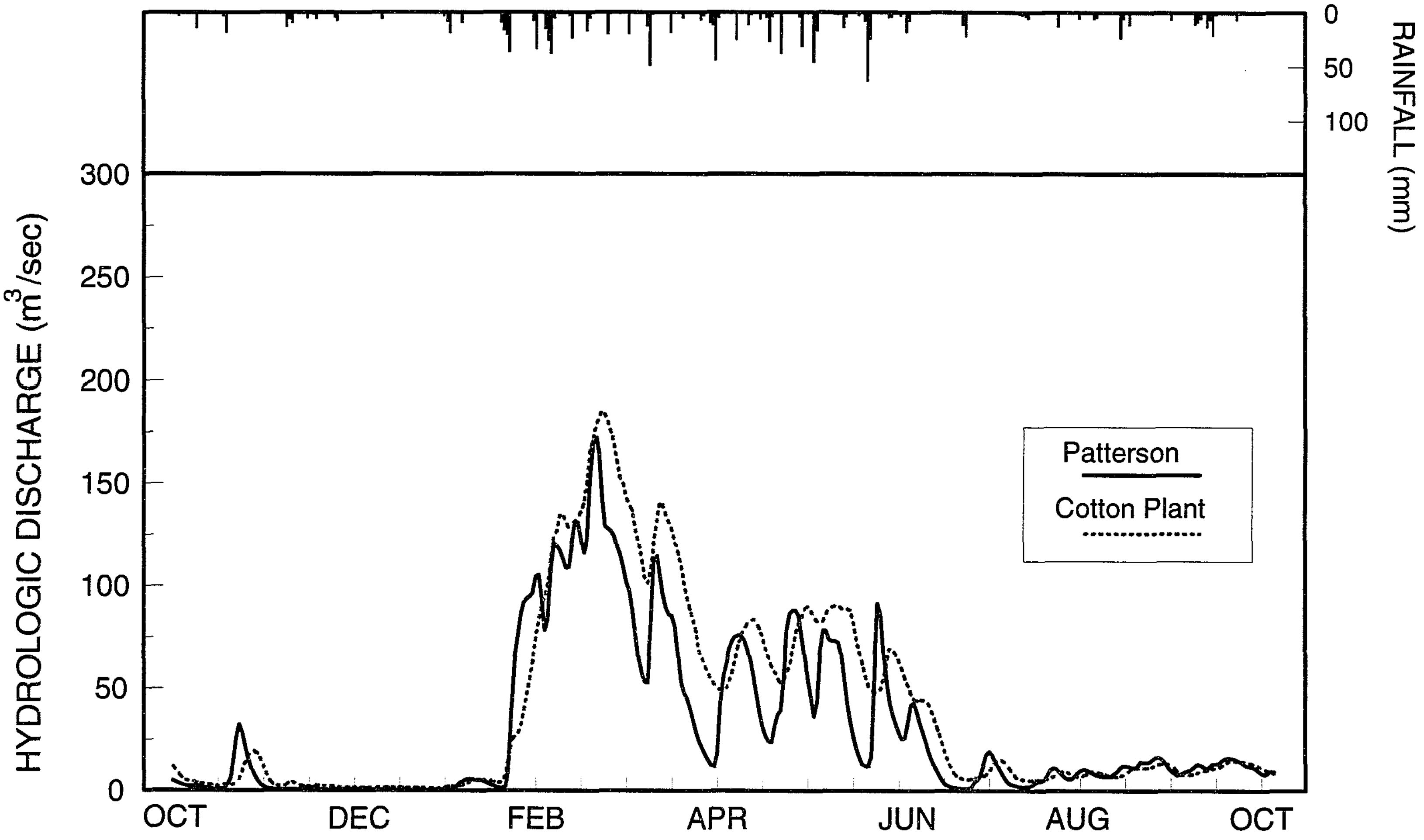

Figure 13. Rainfall and hydrologic discharge for WY 1990.

Wolman and Miller (1960) concluded that for a variety of rivers, the bankfull discharge has a recurrence interval of 1.5 years. The broad, flat floodplain of the Cache River floods much more frequently than that. The river leaves the channel and floods the forest about five or six times a year.

Correlations Between Suspended Sediment and Hydrologic Discharge

Simple, linear correlation between suspended sediment concentrations and the discharge of the Cache River was poor. The correlation coefficient for Patterson was 0.11 and -0.21 for Cotton Plant (Pearson Product Moment Correlation, $p<.0001$, $n=1096$). These coefficients indicate a slight increase in suspended sediment concentration with increased water discharge and a slight decrease in suspended sediment concentration with increased water discharge at Cotton Plant. These correlations changed to 0.40 and -0.03 when both the concentrations and hydrologic discharges were log transformed. The difference in correlation between the two sites was caused by several data points at Patterson with very high sediment concentrations occurring during relatively low flow. These data represented the rising limb of a flood event carrying high sediment loads. By the time the flood wave reached Cotton Plant, an average of 4 to 5 days later, much of the sediment had been removed by the floodplain, causing a lower concentration of suspended sediments for an equivalent discharge at Cotton Plant. The change in this group of samples was enough to change the direction of the correlation.

These results are consistent with those of Irvine and Drake (1987) who said that the "poor correlation between discharge and suspended sediment concentration results from the dynamic of the physical system, including seasonality, antecedent conditions and hysterisis." Fortunately, because the Cache River study used daily suspended sediment data, the lack of correlation between concentration and discharge was not a concern. However, this does cast some doubt on procedures that are dependent on correlations between concentrations and discharge to interpolate between biweekly, monthly or greater sampling intervals.

As expected, the correlation between sediment load (concentration * discharge) and discharge was much better. The log of the suspended sediment load versus the log of the hydrologic discharge resulted in correlation coefficients of 0.96 and 0.91 at Patterson and Cotton Plant, respectively.

Suspended Sediment Discharge

Unlike hydrologic discharge, where the downstream peaks often exceeded the upstream peaks, the inflow peaks of suspended sediment are virtually always delayed and diminished by the time they travel through the wetland system (Figures 14, 15, and 16). The only significant exception to this was the flood event which occurred in May of WY 1989. The best explanation for this event was that a locally heavy rainfall occurred within the basin, which caused the hydrologic discharge and the sediment load of the river to increase at Cotton Plant, while no increase occurred at Patterson. In Figures 17, 18 and 19, the cumulative sediment discharge is illustrated.

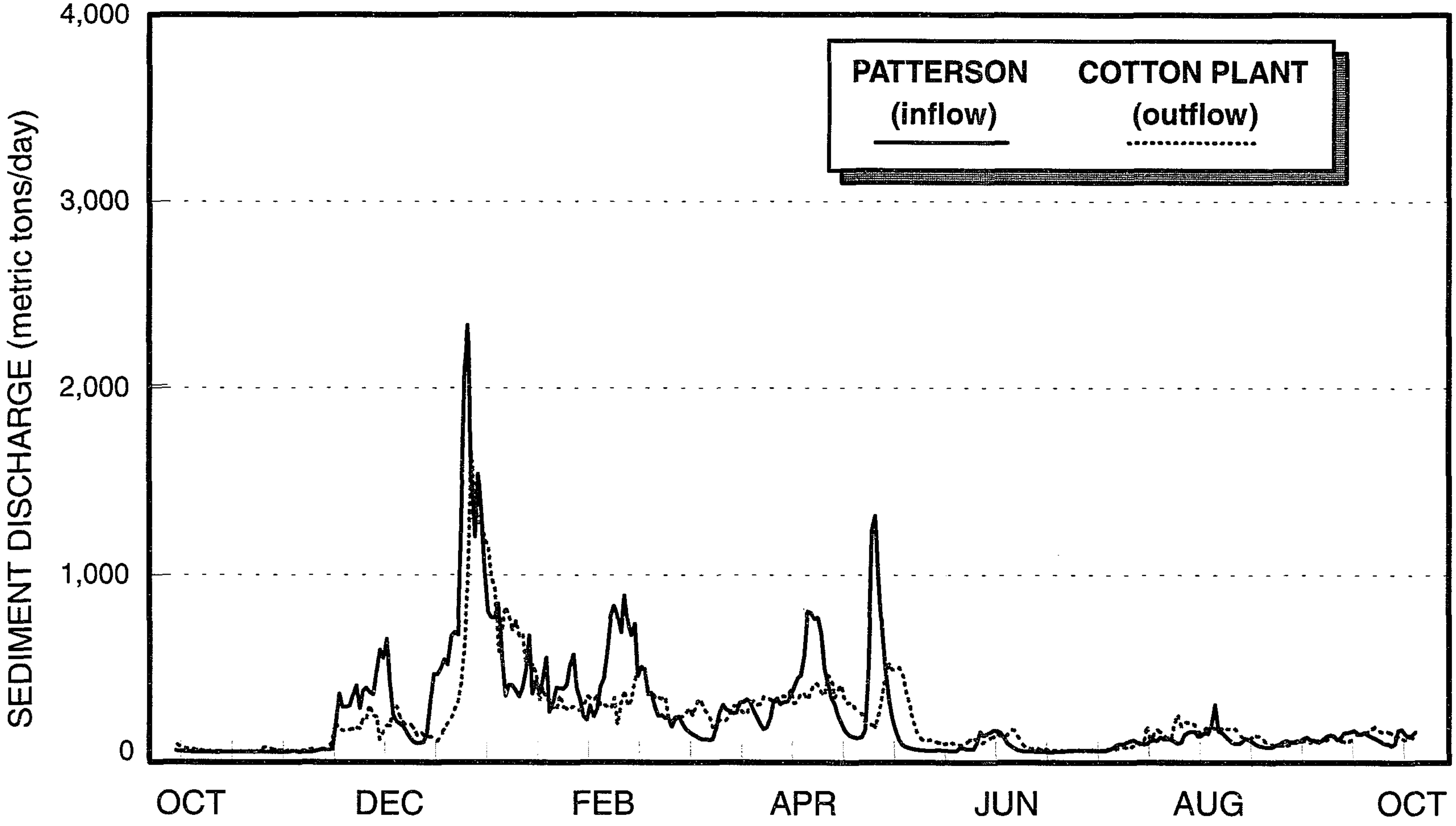

Figure 14. Suspended sediment discharge during WY 1988.

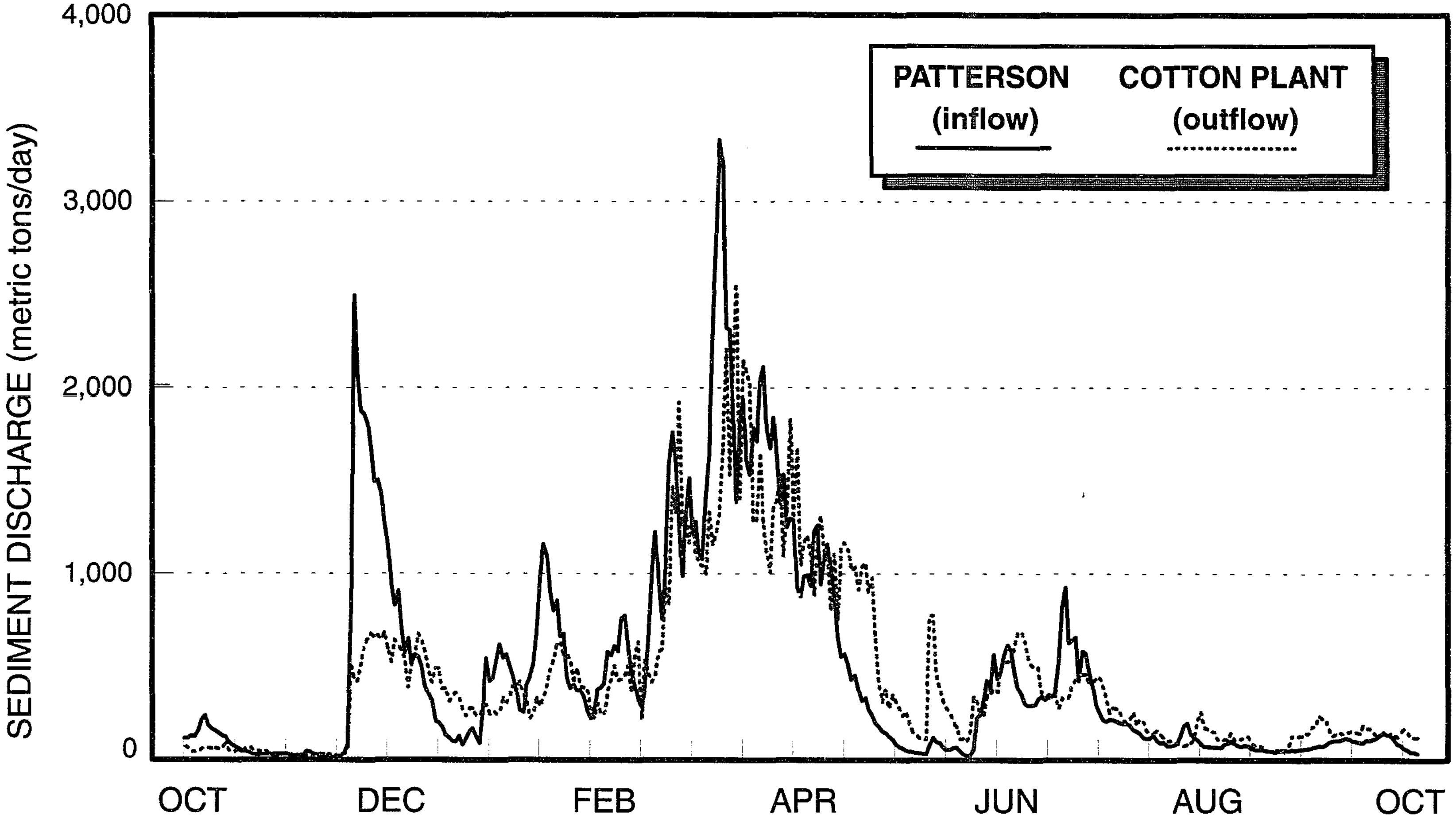

Figure 15. Suspended sediment discharge during WY 1989.

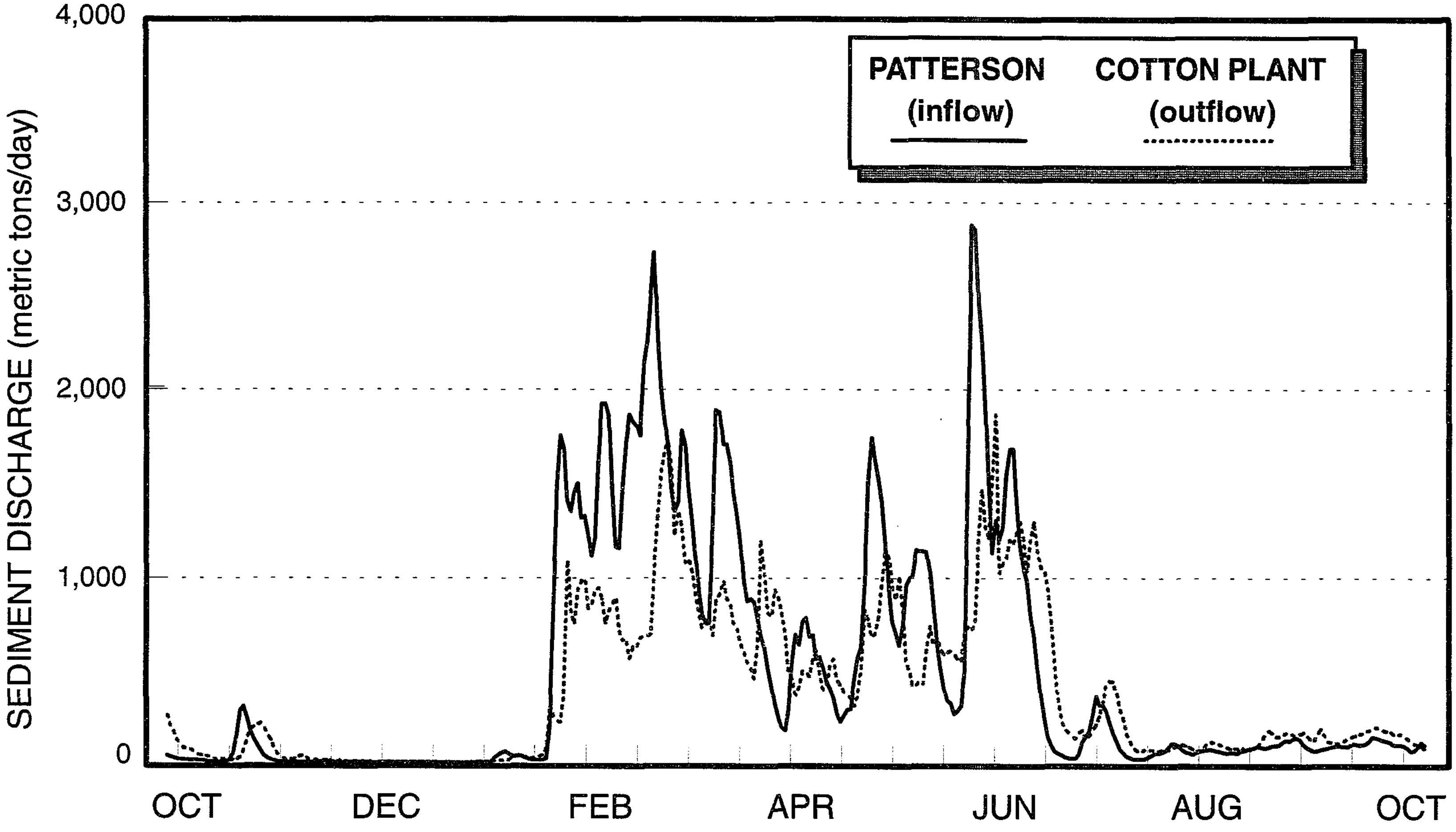

Figure 16. Suspended sediment discharge for WY 1990.

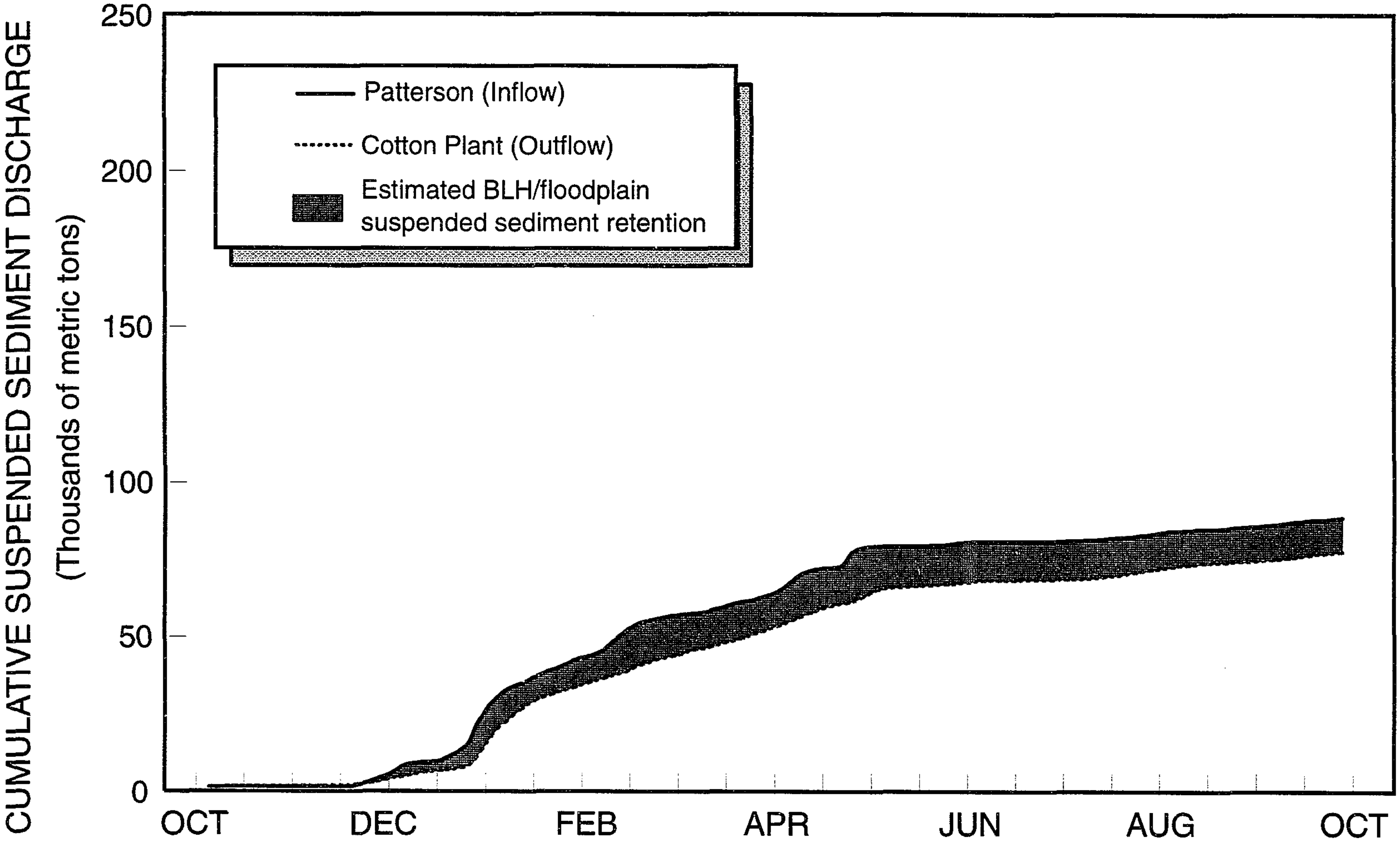

Figure 17. Cumulative suspended sediment discharge for WY 1988.

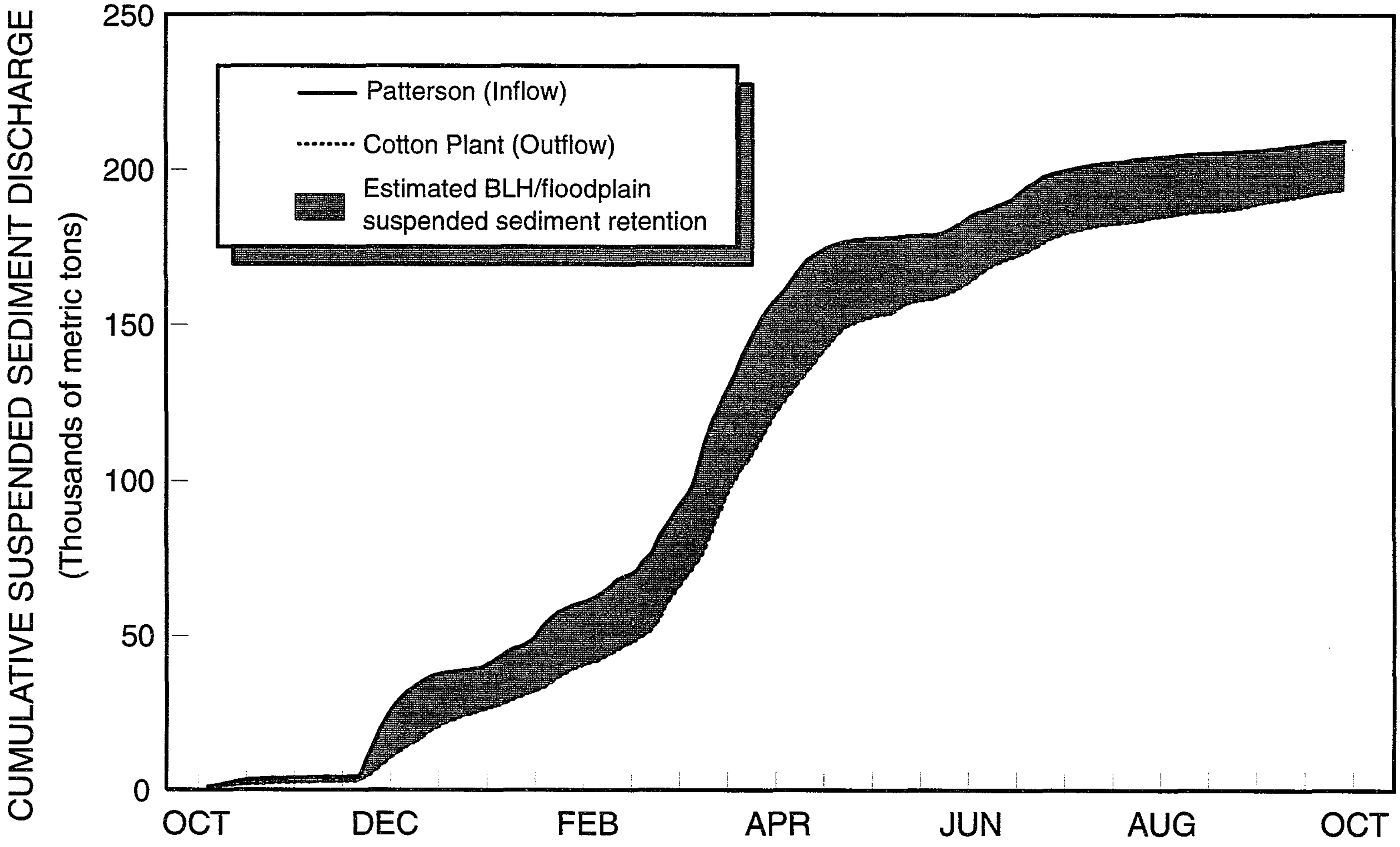

Figure 18. Cumulative suspended sediment discharge for WY 1989.

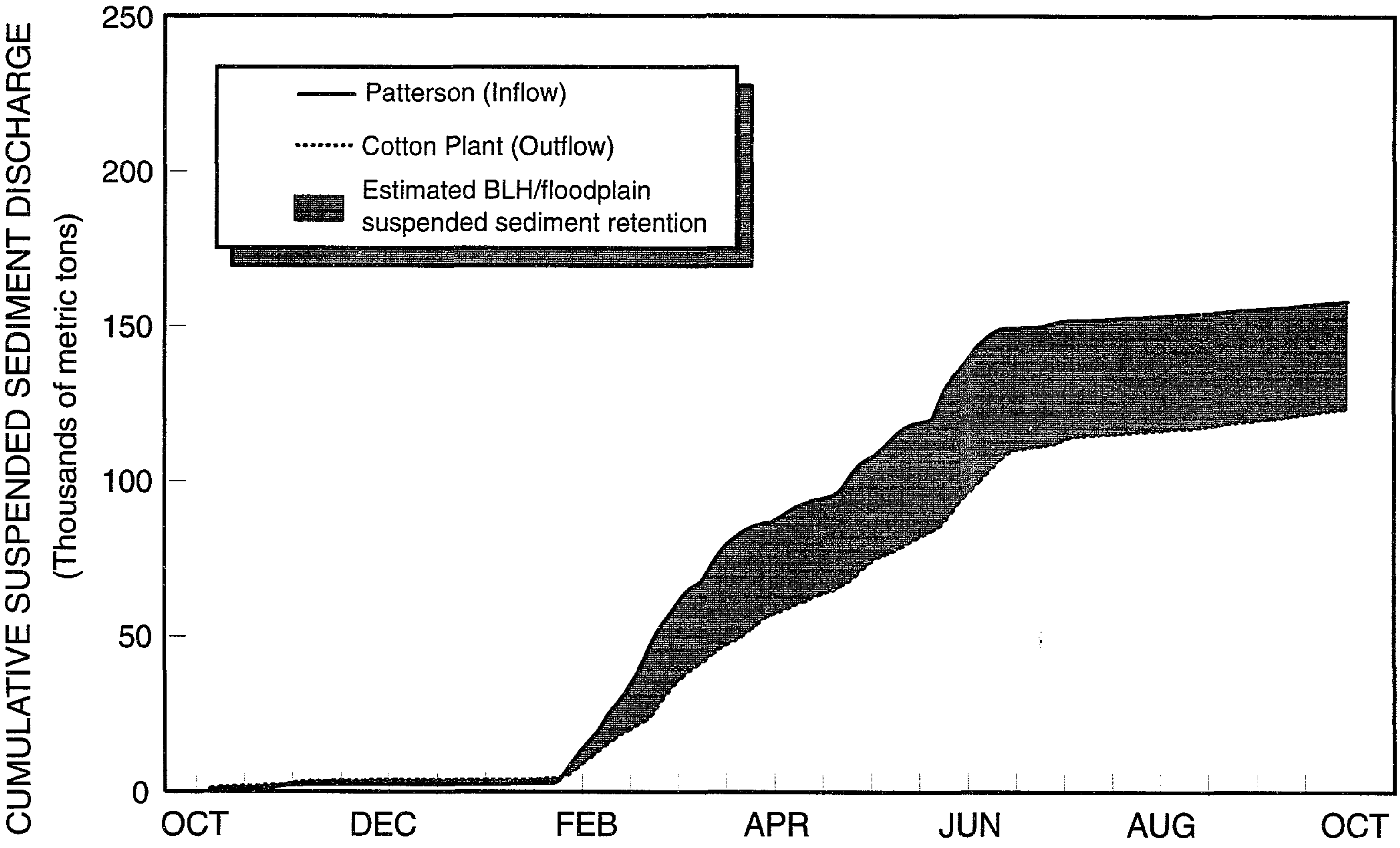

Figure 19. Cumulative suspended sediment discharge for WY 1990.

In these diagrams, the shaded area between the inflow and outflow lines represents the suspended sediment retained by the forested floodplain system. The seasonality of the sediment retention is evident. During the fall low flow conditions, the inflow and outflow lines are together. As the early winter floods occur, the upstream and downstream lines diverge, until sometime in late spring, when the distance between the two lines stays constant.

To minimize the effects of the extreme variability in stream discharge on statistical analysis of suspended sediment loads, the data were segregated into periods of low, intermediate and high flows. Low flow was set at less than 8 m^3/s discharge, intermediate flow, between 8 and 20 m^3/s, and high flow categorized at greater than 20 m^3/s discharge. Field observations showed that at low flow conditions, the flow of the Cache River was entirely within the river channel; intermediate flow conditions flooded the cypress/tupelo zone; and high water conditions caused water to leave the first bottom and enter the part of the floodplain dominated by the wetland oak/hickory community. Descriptive statistics for sediment loads during each of these hydrologic conditions are presented in Table 2.

Daily suspended sediment loads at Patterson and Cotton Plant were significantly different (Mann-Whitney tests, $p<0.001$) for each flow condition. Sediment loads were higher at Patterson than at Cotton Plant during high flows, but for low and intermediate flows the median loads were higher at Cotton Plant than at

Table 2. Descriptive statistics for sediment loads for WY 1988, 1989, and 1990 during low, intermediate and high flow conditions.

HYDROLOGIC CONDITION	LOCATION	MEAN SUSPENDED SEDIMENT LOAD (m tons)	MEDIAN SUSPENDED SEDIMENT LOAD (m tons)	MINIMUM SUSPENDED SEDIMENT LOAD (m tons)	MAXIMUM SUSPENDED SEDIMENT LOAD (m tons)	TOTAL ANNUAL SUSPENDED SEDIMENT LOAD (m tons)	SUSPENDED SEDIMENTS RETAINED (% reduction)	PERCENT OF TOTAL LOAD (calculated at Patterson)
LOW FLOW (< 8 m^3/sec)	Patterson (PT1) n=324	23.9	13.2	0.25	214.5	7751	-29.5 (export)	1.7
	Cotton Plant (CP1) n=285	35.2	22.0	1.65	201.3	10,033		
SWAMP FLOW (>8 and < 20 m^3/sec)	Patterson (PT2) n=267	128.2	92.4	45.1	701.8	34,218	2.2	7.6
	Cotton Plant (CP2) n=229	146.0	137.5	41.8	672.1	33,435		
HIGH FLOW (> 20 m^3/sec)	Patterson (PT3) n=505	813.6	611.6	53.9	4026	410,862	14.3	90.7
	Cotton Plant (CP3) n=582	604.6	461.5	40.7	3091	351,865		

Patterson (Figure 20). During low flows, the river water had no contact with the wetlands on the floodplain, therefore no sediment retention occurred. Disturbance of bottom sediments by bottom-dwelling fish likely added channel sediments to low-flow sediment loads. Furthermore, there is evidence that groundwater discharged into the river through the channel bottom, causing resuspension of fine sediments (Gonthier in review).

It is less apparent why the Cache River exports sediments during the intermediate flow period. As discussed later in this paper, the cypress/tupelo zone is the area of greatest annual sediment deposition, and so it would be logical for a significant amount of sediment to be retained during the intermediate flow regime, when the cypress/tupelo is inundated. Instead, 2.2% more sediment leaves Cotton Plant than enters at Patterson. Perhaps it is because only 7.6% of the total sediment load of the river during the study was carried during this flow regime, so little material was available for deposition.

More than 90% of the total annual sediment load of the river was carried during the high flow period. During this flow regime, more than 14% of the suspended sediments that entered the system at the upstream end were retained by the wetland, which resulted in an average annual retention of more than 19,000 m tons of sediment. At this stage, the greatest extent of the floodplain was inundated, resulting in the greatest water-sediment interface.

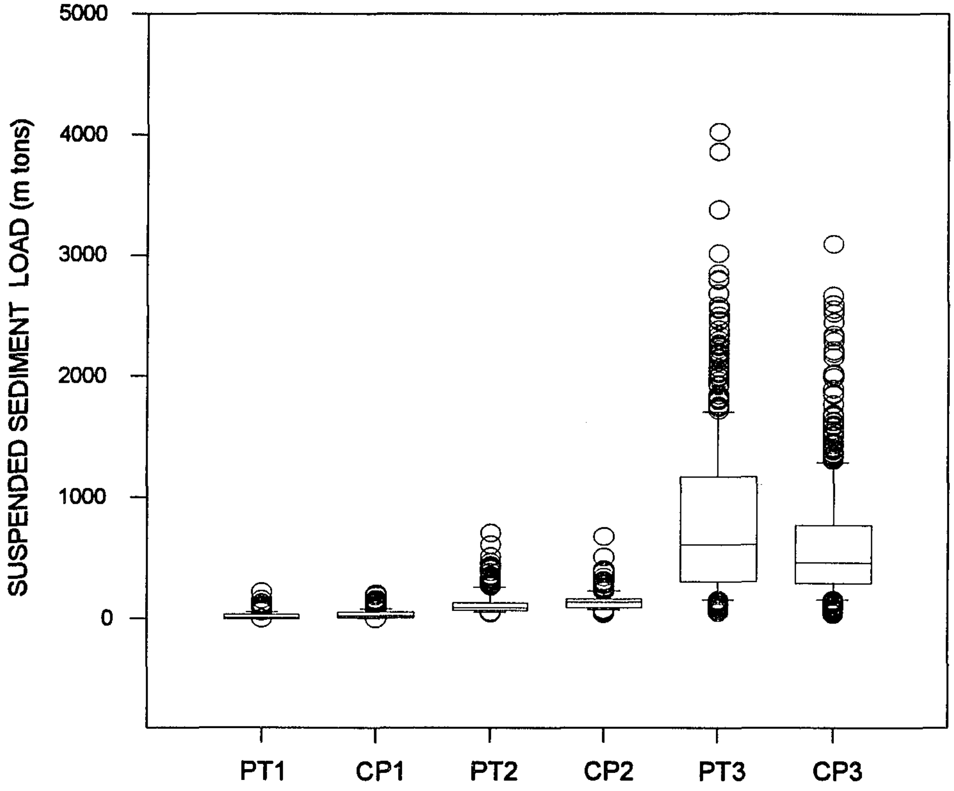

Figure 20. Relation of suspended sediment loads for the three year study period at Patterson (PT) and Cotton Plant (CP) at three discharge levels. Level 1 indicates low flow, Level 2, intermediate flow, and Level 3, high flow. The extent of the box indicates the 25th and 75th percentiles of the data. The line in the center of the box marks the 50th percentile, and the whiskers, the 10th and 90th percentiles. The symbols represent all data outside the 10th and 90th percentile.

In an initial attempt to qualitatively sort out some causal factors, Table 3 lists the mass of suspended sediments retained and the percent reduction in total sediment load between inflow and outflow stations for the three water years with other variables often thought to be related to the sediment retention capacity of wetlands, such as maximum flood peak, duration of flooding, number of flood events, rainfall, total sediment load, and average and maximum sediment concentration. However, most of these results seem counterintuitive. During WY 1988, 13% of the sediment load was retained, in WY 1989 only 6% and during WY 1990 more than 22% of the annual sediment load was retained. However, WY 1989, was by far the wettest year, having the highest maximum flood peak, by far the largest number of days above flood stage, and the most rainfall to bring sediments into the floodplain. The total sediment load for the year was highest, but the mass of sediment retained that year was barely larger than WY 1988, the driest year. At first, it appears as though the maximum suspended sediment concentration may explain part of the situation, but a more detailed look at the data showed that the maximum concentration rates occurred during May and June, when heavy rainfalls occurred soon after spring cultivation of agricultural fields. Conversely, most of the sediment was retained during winter floods, so these peak concentrations had little relation to the overall annual sediment retention rate.

Figure 21 shows inflow and outflow sediment loads for individual flood events during each water year. During all three water years, suspended sediments were exported from the system during low flows. However, during the first flood event of

Table 3. Annual floodplain suspended sediment retention compared with various physical characteristics.

WATER YEAR	SUSPENDED SEDIMENTS RETAINED (m tons)	SUSPENDED SEDIMENTS RETAINED (% reduction)	MAXIMUM FLOOD PEAK (m^3/sec)	DAYS ABOVE FLOOD STAGE	NUMBER OF FLOOD EVENTS	ANNUAL RAINFALL (mm)	TOTAL ANNUAL SUSPENDED SEDIMENT LOAD (m tons at Patterson)	AVERAGE SUSPENDED SEDIMENT CONC. (mg/L)	MAXIMUM SUSPENDED SEDIMENT CONC. (mg/L)
1988	11,025	13%	258	165	6	1359	87,034	74	333
1989	11,738	6%	261	212	5	1645	208,507	96	270
1990	34,735	22%	172	132	4	1278	157,289	109	416

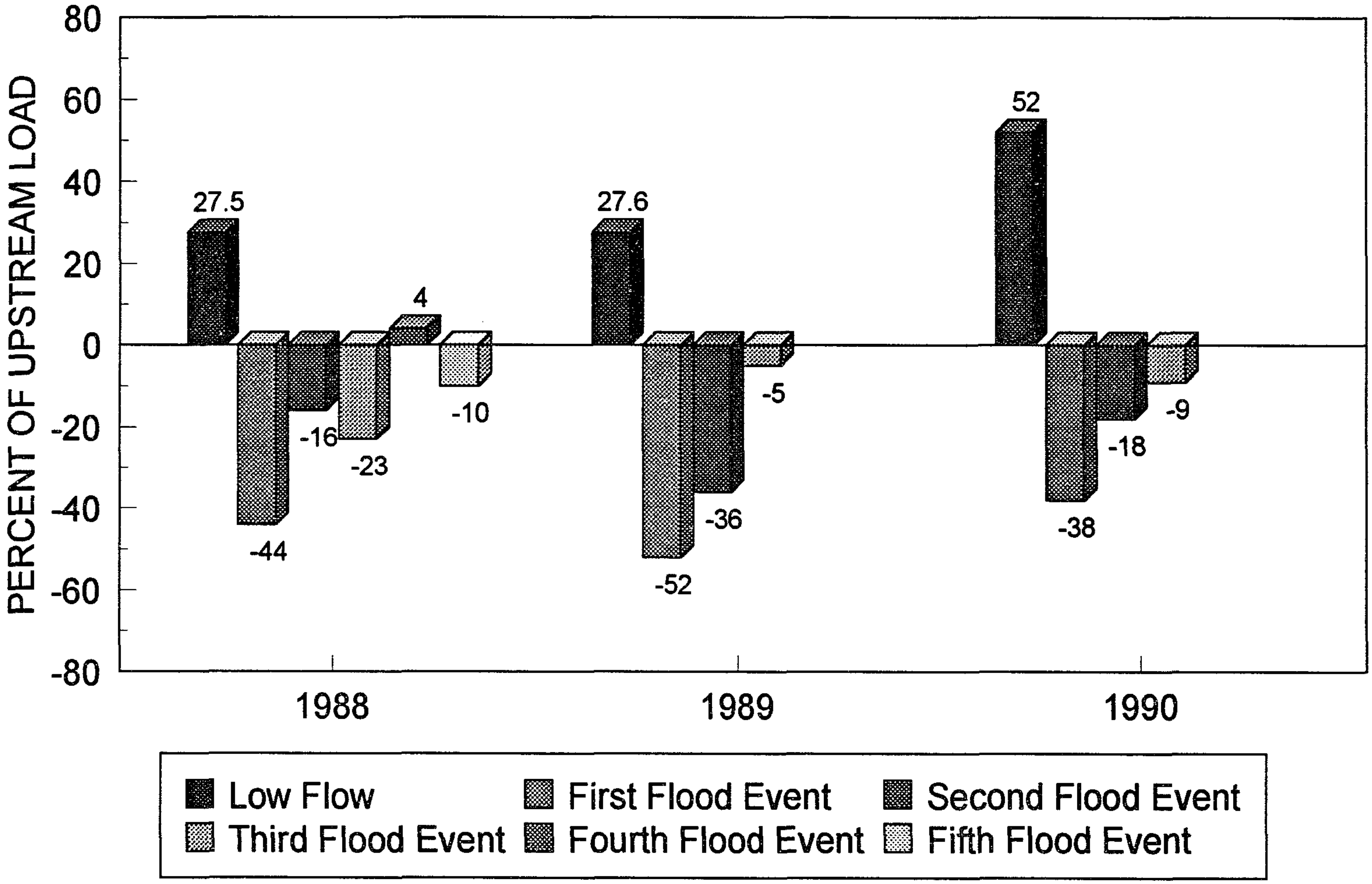

Figure 21. Suspended sediment load during individual hydrologic events (expressed as upstream load minus downstream load divided by upstream load).

the season, between 38 and 52% of the suspended sediments that entered the system at Patterson were retained by the system before the water left at Cotton Plant. During each successive flood event, the percentage of sediment retained generally decreased, so that only a small amount of sediment (between 5 and 10%) is retained by the system during the last flood event in the spring. One possible explanation is that during the first flood of the water year, the floodplain is well armored with leaf litter, some herbaceous growth, and roots, and the previous year's sediment deposits are compacted and consolidated. So, when new sediment is deposited on this surface, very little of the old sediment is resuspended. During later flood events, however, leaf litter has been buried or washed away, the herbaceous material has been submerged and senesced, and the surface sediments have had only days or weeks to consolidate. Therefore, a much greater proportion of the surface sediment deposited from the earlier floods is resuspended into the water column.

Floodplain Study

Sediment Accretion Rates

Mass accretion rates for the material on the sediment disks and vertical accretion rates for the other methods were measured annually during low water for each WY of the study.

Sedimentation disks. Mass accretion data for each of the 30 sites for each of the three years are presented in Tables 4 and 5. Average loss on ignition is also presented for each sample site. There is significant variability between results for the

Table 4. Sedimentation disk measurements of average annual and overall average mass accretion rates on Transects A and B.

SEDIMENT STATION	MEAN MASS ACCRETION RATE WY 1988 (g/m²)	MEAN LOSS ON IGNITION WY 1988 (%)	MEAN MASS ACCRETION RATE WY 1989 (g/m²)	MEAN LOSS ON IGNITION WY 1989 (%)	MEAN MASS ACCRETION RATE WY 1990 (g/m²)	MEAN LOSS ON IGNITION WY 1990 (%)	OVERALL MEAN ANNUAL MASS ACCRETION RATE (g/m²)	OVERALL LOSS ON IGNITION (%)
A1	13.89	31.46	337.14	20.01	826.32	18.14	459.12	23.20
A2	544.69	8.76	888.49	10.97	1744.92	12.34	973.67	10.48
A3	908.28	6.07	1366.00	6.78	801.47	5.71	1025.25	6.19
A4	55.83	53.82	413.89	50.04	390.14	25.21	286.62	43.02
A5	117.04	55.24	366.22	19.75	782.83	44.20	277.43	39.73
A6	82.05	37.53	585.39	22.68	343.72	24.10	337.05	28.10
A7	22.81	86.25	5.28	77.32	41.48	87.43	23.19	85.48
A8	46.49	86.86	27.76	83.54	63.59	83.76	45.95	84.72
B1	617.23	16.58	585.48	23.97	466.34	20.58	566.40	20.38
B2	78.30	57.66	148.74	62.16	61.22	56.81	96.09	59.47
B3	1137.26	14.60	1788.59	13.93	1031.16	14.31	1319.01	14.28
B4	1466.56	8.15	1460.59	10.34	440.20	8.17	1122.45	8.88
B5	395.16	18.60	1331.94	16.78	629.88	14.81	805.13	16.97
B6	77.37	63.67	86.98	55.88	27.04	87.61	63.80	69.05
B7	104.95	53.79	82.60	58.06	82.05	53.11	89.86	54.99
B8	82.61	66.93	191.32	46.76	128.46	40.47	134.13	51.39

Table 5. Sedimentation disk measurements of average annual and overall annual mass accretion rates on Transects C and D.

SEDIMENT STATION	MEAN MASS ACCRETION RATE WY 1988 (g/m^2)	MEAN LOSS ON IGNITION WY 1988 (%)	MEAN MASS ACCRETION RATE WY 1989 (g/m^2)	MEAN LOSS ON IGNITION WY 1989 (%)	MEAN MASS ACCRETION RATE WY 1990 (g/m^2)	MEAN LOSS ON IGNITION WY 1990 (%)	OVERALL MEAN ANNUAL MASS ACCRETION RATE (g/m^2)	OVERALL LOSS ON IGNITION (%)
C1	330.14	27.25	1635.55	19.39	1396.45	16.21	1056.36	21.14
C2	327.26	32.91	829.43	26.30	816.27	23.93	636.18	27.89
C3	714.96	20.47	1455.82	18.73	1508.10	16.49	1235.29	18.58
C4	1359.74	17.59	911.04	17.00	666.79	20.84	979.19	18.84
C5	1194.38	22.71	891.34	20.52	711.02	20.70	995.45	21.48
C6	7.99	75.50	12.17	43.23	52.63	31.57	21.94	51.47
C7	19.60	60.37	165.06	15.27	525.18	12.28	236.61	29.31
C8	12.49	44.88	490.15	18.82	727.46	9.71	410.03	24.47
D1	89.40	28.48	219.10	30.01	576.89	20.39	295.13	26.29
D2	2.92	83.83	10.96	88.79	29.42	66.37	14.44	79.14
D4	29.25	57.43	142.96	43.55	145.46	15.94	132.33	35.68
D5	120.07	19.97	323.99	33.94	370.95	15.80	271.67	23.23
D6	117.89	57.85	103.79	40.44	136.32	18.93	119.51	36.73
D7	50.05	83.44	39.10	70.05	77.57	58.52	53.22	70.58

three years. The trend which existed in the mass-balance data, where significantly more sediment was retained in WY 1990, is not apparent in these data. There was always less sediment deposited during WY 1988, but the highest rates of deposition occurred during WY 1989 on Transect B, during WY 1990 on Transects A and D, and 1989 and 1990 were virtually identical on Transect C. There was also not an upstream-downstream trend in these data. Transect C had the highest overall sediment accretion rate, followed by Transect B, Transect A and then Transect D. This trend is positively correlated with the elevation and flood duration of the transects, but does not support the idea that more materials are removed by the upstream sites, thus decreasing the sediment availability for downstream sites. These was a sharply greater amount of sediment deposition at the sites located in the cypress/tupelo swamp that were semi-permanently flooded versus the temporarily flooded sites higher in the forest.
There was also a sharp difference in the loss on ignition values between the semi-permanently flooded sites and the less flooded sites. The less flooded sites had a very high loss on ignition rates, in the range of 50 to 85%. This was not a measurement of the organic content of the soil. This indicates the large amount of undecomposed leaf litter which fell on the sediment disks in the higher elevation woods. Oftentimes, there was no mineral material present at all, and the leaf litter was the only material collected for these sites.

Feldspar clay measurements. Overall, there is less year to year variability between vertical accretion measurements using feldspar clay (Tables 6 and 7) than the

Table 6. Feldspar clay measurements of average annual and overall annual vertical accretion rates on transects A and B.

SEDIMENT STATION	MEAN VERTICAL ACCRETION RATE WY 1988 (cm/yr)	MEAN VERTICAL ACCRETION RATE WY 1989 (cm/yr)	MEAN VERTICAL ACCRETION RATE WY 1990 (cm/yr)	OVERALL MEAN ANNUAL VERTICAL ACCRETION RATE (cm/yr)
A1	0.5	0.20	0.72	0.50
A2	1.0	1.55	1.41	1.32
A3	0	1.25	1.33	0.86
A4	0	1.08	0.70	0.59
A5	0	0.63	0.61	0.41
A6	0	0.58	0.67	0.42
A7	0	0	0.07	0.02
A8	0	0.10	0.10	0.07
B1	1.5	2.00	1.03	1.51
B2	0.5	0.50	1.17	0.72
B3		3.50	2.13	1.88
B4	1.5	1.13	0.88	1.17
B5	1.0	2.50	1.33	1.61
B6	0.4	0.08	0.13	0.20
B7	0.1	0.05	0.44	0.20
B8	0.2	0.10	0.83	0.38

Table 7. Feldspar clay measurements of average annual and overall annual vertical accretion rates on Transects C and D.

SEDIMENT STATION	MEAN VERTICAL ACCRETION RATE WY 1988 (cm/yr)	MEAN VERTICAL ACCRETION RATE WY 1989 (cm/yr)	MEAN VERTICAL ACCRETION RATE WY 1990 (cm/yr)	OVERALL MEAN ANNUAL VERTICAL ACCRETION RATE (cm/yr)
C1	2.25	1.75	1.89	1.96
C2	0.2	0.68	0.71	0.53
C3	3.0	2.75	2.17	2.64
C4	4.0	2.00	1.89	2.63
C5	1.5	0.88	1.33	1.24
C6	0	0	0.23	0.08
C7	0	0.35	0.39	0.25
C8	1.0	0.88	1.50	1.13
D1	0.5	0.63	2.08	1.07
D2	0	0.05	0.27	0.11
D4	0	0.15	0.49	0.21
D5	1.5	0.75	1.00	0.58
D6	0.1	0.08	0.29	0.16
D7	0	0	0.21	0.07

mass accretion measurements. Again, there is a sharp difference between the semi-permanently flooded versus the temporarily flooded sites. The relative rates of sediment accretion per transect, and the lack of temporal trends between the WY sampled was the same as for the sediment disks.

^{137} Cesium measurements. ^{137}Cesium does not appear to be the most useful tool for measuring sediment accretion in this particular floodplain environment. While the other three methods showed a clear difference between the wetter and drier ends of the transects, the cesium numbers are fairly uniform across the transect (Table 8). The 1963 peak was not clearly evident on several of the samples. When it did occur, it was spread out over several centimeters of the core. It is possible that this was due to vertical migration of the cesium in the soil profile, but I think that it is more likely due to the depositional environment of the lower floodplain. The mass-balance part of the study suggested that there may be cycles of deposition followed by resuspension. If this is the case, sediments high in ^{137}cesium would be alternately deposited and washed from the floodplain. Also, the sediments deposited in the swamp most likely have been transported from agricultural fields in the upper part of the drainage basin. The time of transport for the ^{137}cesium laden sediments could be long and non-uniform. In other words, ^{137}cesium which was atmospherically deposited on an agricultural field in 1963, might not have made it downstream to the Cache River swamps until 1974, thus making the peak in the core indistinct and less useful.

Table 8. ^{137} Cesium activity in cores from selected sedimentation sites.

SEDIMENT STATION	DEPTH TO 1954 MINIMUM (cm)*	DEPTH TO 1963 PEAK (cm)*	VERTICAL ACCRETION BASED ON 1954 MINIMUM (cm/yr)	VERTICAL ACCRETION RATE BASED ON 1963 PEAK (cm/yr)	MEAN BULK DENSITY (g/cm^3)
A6	9.72	3.24	0.29	0.13	1.38
A7	8.48	2.65	0.25	0.11	1.20
A8	6.60	3.30	0.19	0.13	1.20
B1	13.02	8.37	0.38	0.33	1.27
B2	7.63	3.27	0.22	0.13	1.66
B3		10.32		0.41	0.62
B4		6.40		0.26	1.22
B5	7.32	1.22	0.22	0.05	1.18
B6	7.42	3.18	0.22	0.13	1.43
B7	5.76	0.96	0.17	0.04	
B8	5.85	2.60	0.17	0.10	1.50
C1	7.70	5.50	0.23	0.22	0.76
C2	12.3	6.15	0.36	0.25	0.97
C3	10.8	6.0	0.32	0.24	0.62
C4					0.77
C5					0.55
C8	9.28	5.80	0.27	0.23	1.40
D2	9.35	3.30	0.28	0.13	1.31
D5	7.12	4.45	0.21	0.18	1.37
D6	11.11	5.85	0.33	0.23	1.54
D7	6.66	2.78	0.20	0.11	1.51

* Depth corrected for expansion or contraction of core which occurred during core collection.

Dendrogeomorphic measurements. Although the actual numerical rates of deposition estimated using the dendrogeomorphic technique are more in line with the ^{137}cesium numbers, the trend toward high deposition in the swamps and low deposition in the oak/hickory areas is consistent with the data from sediment disks and feldspar clay pads (Table 9). This method provides a one-time look at sediment accretion. Historical trends can be postulated looking at trees of different ages, but repeating the measurements during several years is not meaningful.

Comparison of methods. In nearly every case, the greatest vertical accretion rate was measured with the feldspar clay technique, and most often the dendrogeomorphic approach yielded the lowest rate of vertical accretion. This was, at least in part, due to the time period covered by the method. The feldspar clay results were based on annual measurements, averaged over a three year period. The cesium measurement covered about a 25 year period. Dendrogeomorphic measurements depended upon the age of the trees sampled, which ranged from 15 to 80 years. Over a longer time span, sediments were subject to longer periods of compaction and consolidation, which would appear as lower rates of accumulation, and the samples from longer periods may be affected by changes in historical sedimentation rates. Figures 22 through 25 are bar graphs which show the rate of sediment accretion as measured by all four methods for all 30 sites.

Distribution of sediment on the floodplain. Despite some differences between methods, overall trends in sedimentation rates across the floodplain can be detected.

Table 9. Results of dendrogeomorphic sedimentation measurements.

SEDIMENT STATION	NUMBER OF TREES	MEAN RATE OF VERTICAL ACCRETION (cm/yr)	STANDARD DEVIATION
A1	3	0.14	0.05
A2	5	0.14	0.04
A3*		0.15	
A4	6	0.16	0.11
A5	4	0.18	0.05
A6	4	0.36	0.06
A7	5	0	0
A8	5	0.01	0.03
B1	10	0.32	0.21
B2	3	0	0
B3	7	0.25	0.12
B4	7	0.27	0.16
B5	3	0.04	0.03
B6	5	0.04	0.04
B7	5	0.04	0.04
B8	7	0.08	0.09
C1	2	0.36	0.05
C2	3	0.3	0.28
C3	4	0.6	0.06
C4	4	0.33	0.14
C5	5	0.2	0.14
C6	5	0.05	0.06
C7	5	0.02	0.03
C8	6	0.11	0.12
D1	5	0.4	0.19
D2	5	0.01	0.01
D4	5	0.42	0.44
D5	5	0.16	0.15
D6	5	0.06	0.07
D7	5	0.02	0.07

* A3 is an estimated value. Data from Hupp and Morris (1990).

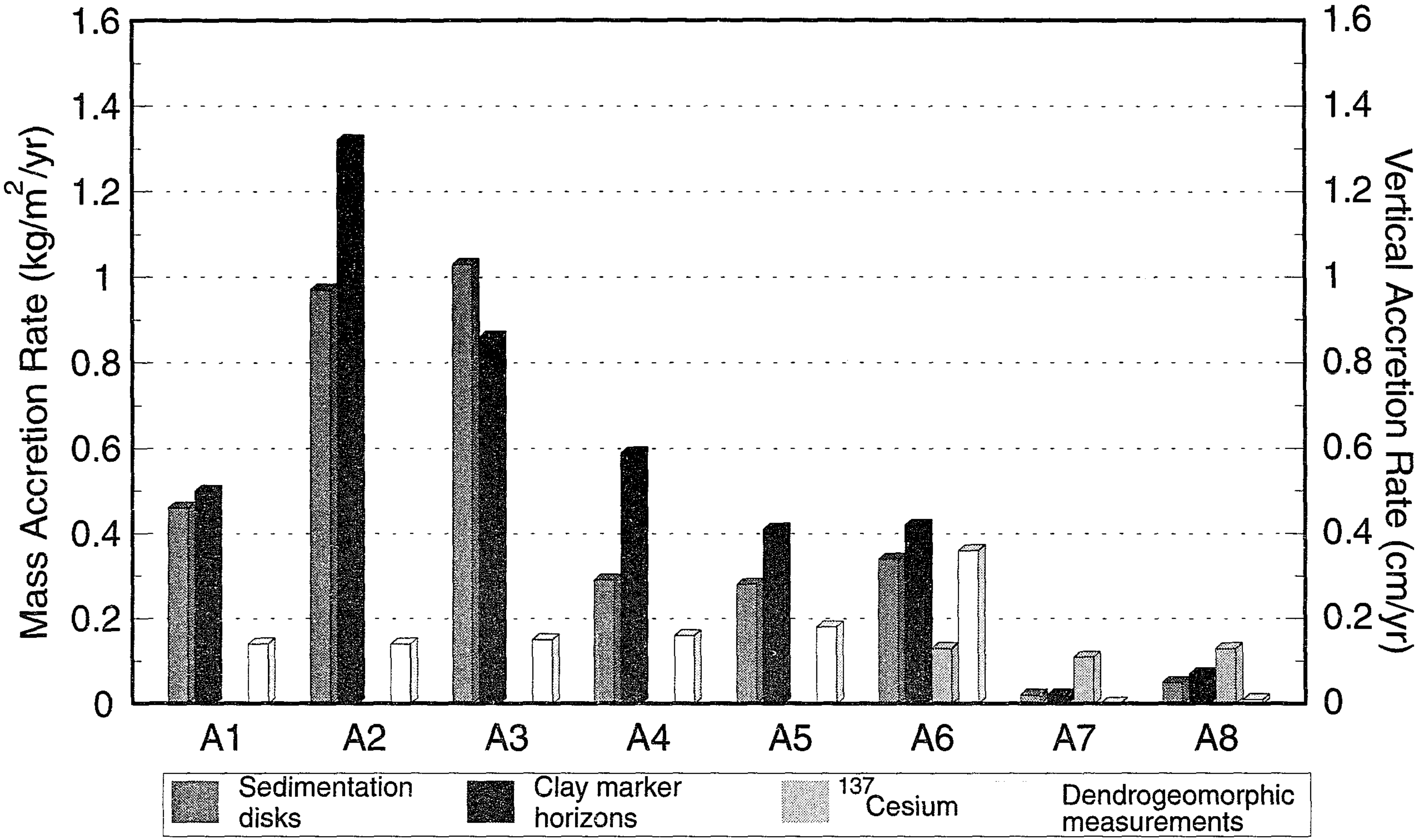

Figure 22. Sedimentation rates for Transect A. Site A1 is closest to the Cache River, A8 is farthest away. Rates for the sedimentation disks use the left axis labels and are given in (kg/m2/yr). The rest of the methods are described using the right axis.

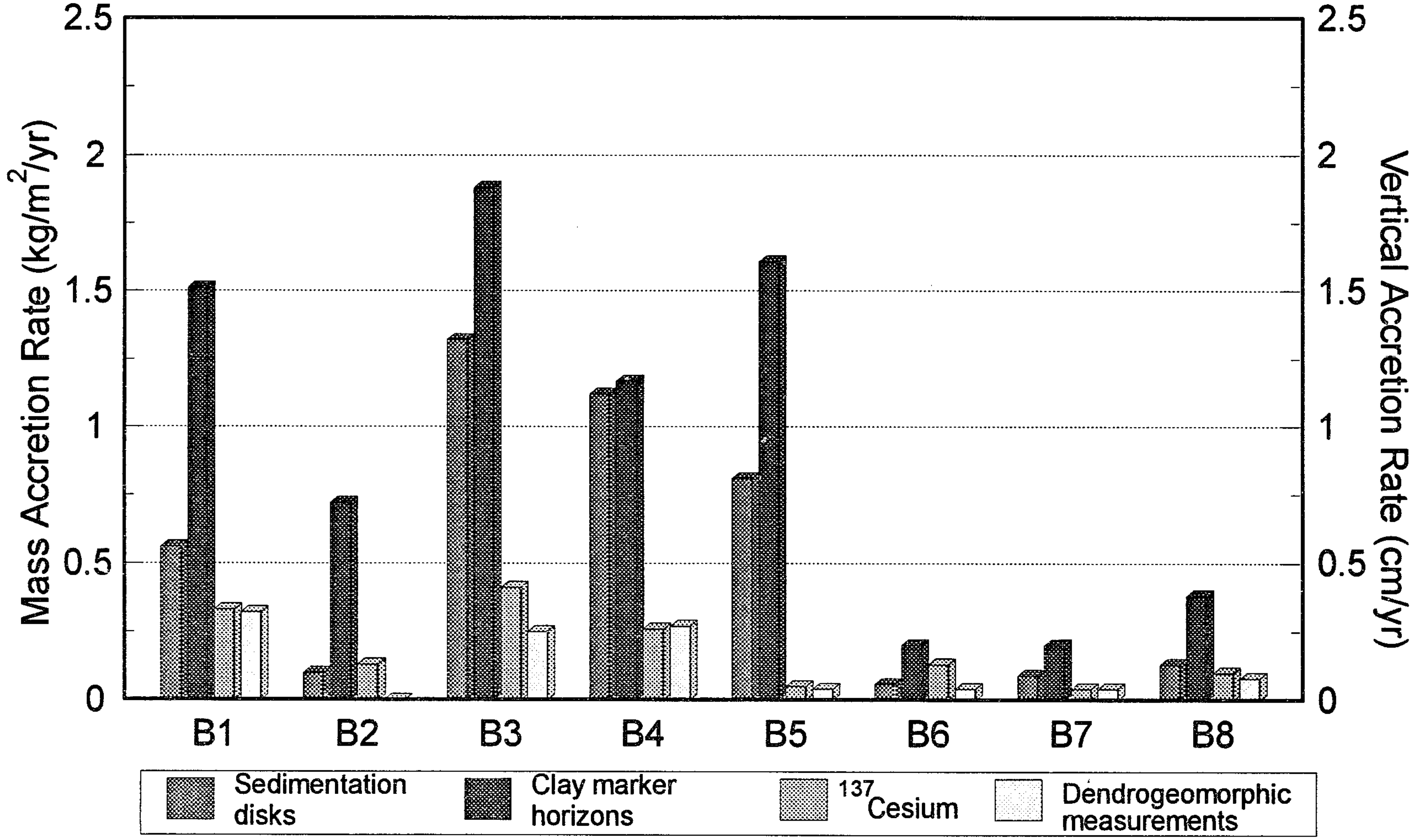

Figure 23. Sedimentation rates for Transect B. B1and B2 are located off the main transect. B1 and B3 are located close to the river, while B8 is farthest away

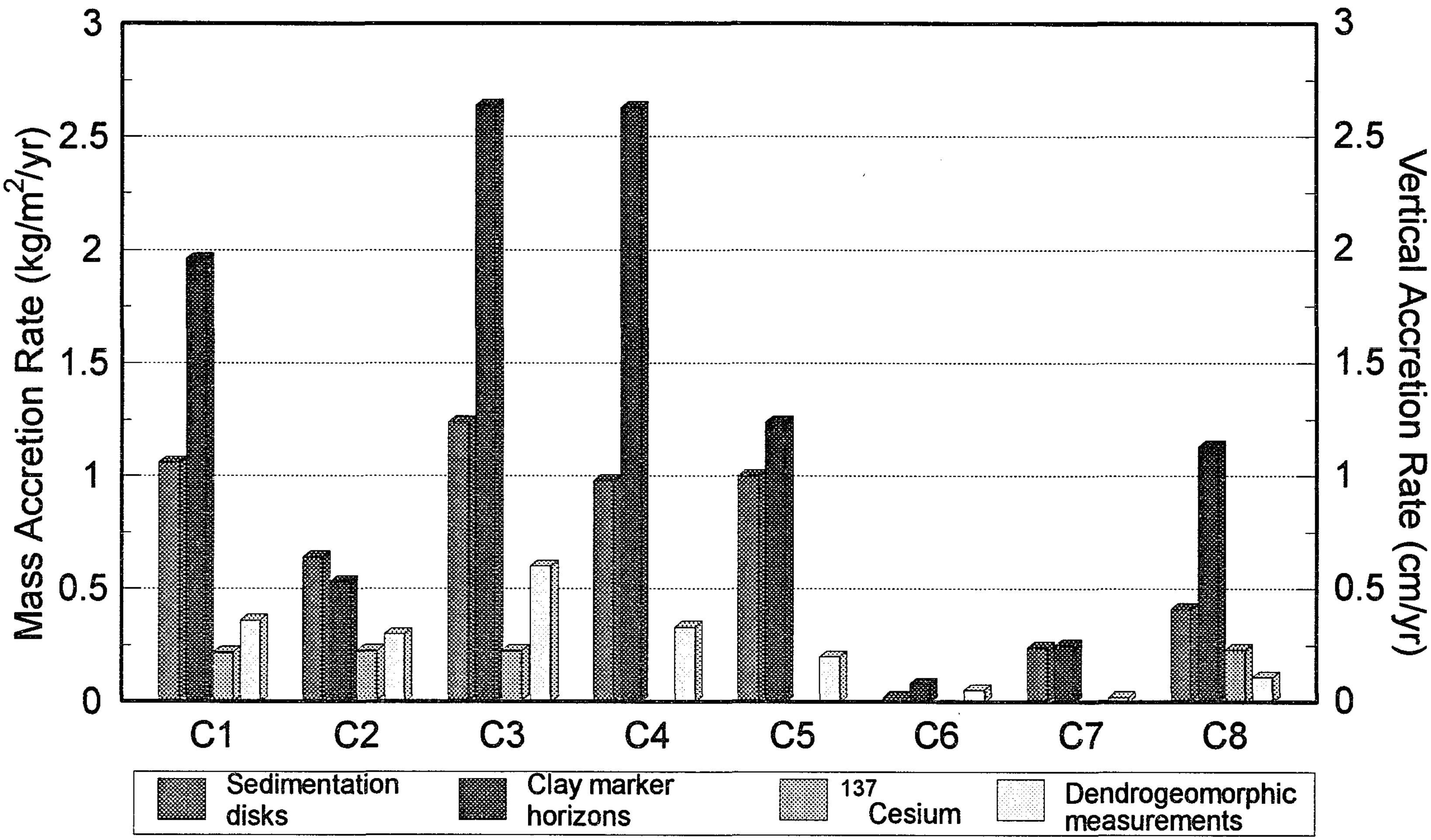

Figure 24. Sedimentation rates for Transect C. C1 and C2 are located off of the main transect. C1 and C3 are located nearest the Cache River.

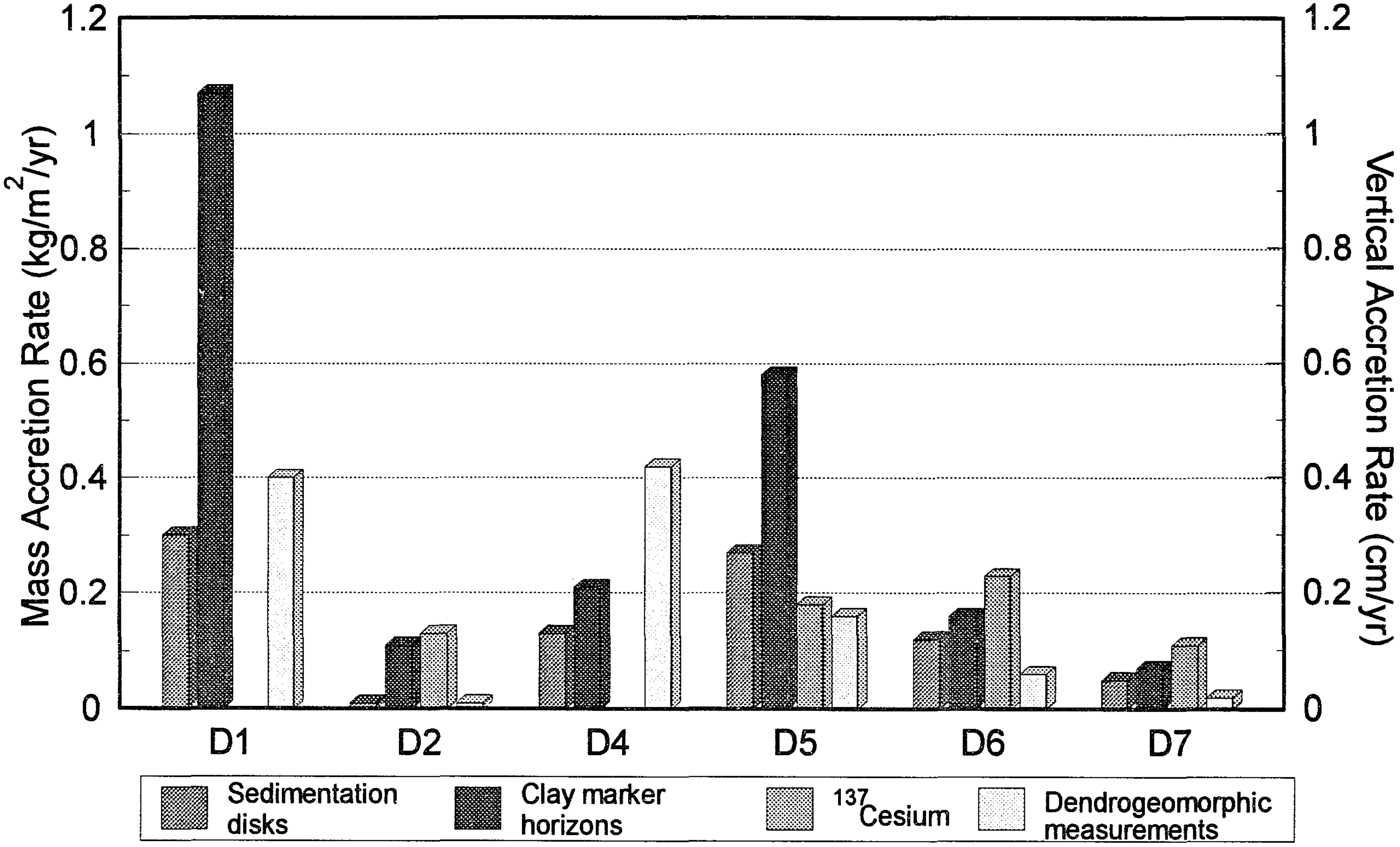

Figure 25. Sedimentation rates for Transect D. D1 is located in an abandoned oxbow. D4 is on the natural levee and D5 located in low area behind it.

Generally, the floodplain can be divided into four zones: the natural levee, the swamp, ridges and swales. As expected, high rates of sediment accretion occurred on the natural levees, as the floodwaters first left the river channel and entered the floodplain (Sites A1, B3, and D4). Less expected, however, was that the sites in the cypress/tupelo swamp (A2, A3, B1, B4, B5, C1, C3, C4, C5 and D5), had nearly equal or sometimes greater rates of sediment accretion than the levee sites. Rates dropped drastically for sites located on a ridge or slight terrace (A4, A5, A6, A7, B2, B6, B7, C2, C6, C7, D2, D6 and D7) and increased slightly in swales or depressional areas, far away from the river that are probably abandoned channels from the St Francis or Black Rivers (A8, B8, C8 and D1). This general trend is depicted in Figure 26, where, for Transect A, the height of the bars is proportional to the sediment mass accretion in each location within the floodplain.

Sediment Particle Size

The particle size of sediments suspended in the water column was measured at the surface, middle and bottom of the water column during flood stage at Patterson, Cotton Plant, and along the Transect B once during 1990 and once during 1991 (Table 10). An average of all samples showed that nearly 96% of the suspended material was less than 0.00195 mm. No distinction was found between samples at different depths, nor was there a higher proportion of large grained material in the main river than in the floodplain. Curiously, there was a slightly higher proportion of silts at the transect sites farthest away from the river during both years. It is possible that these silts may be a

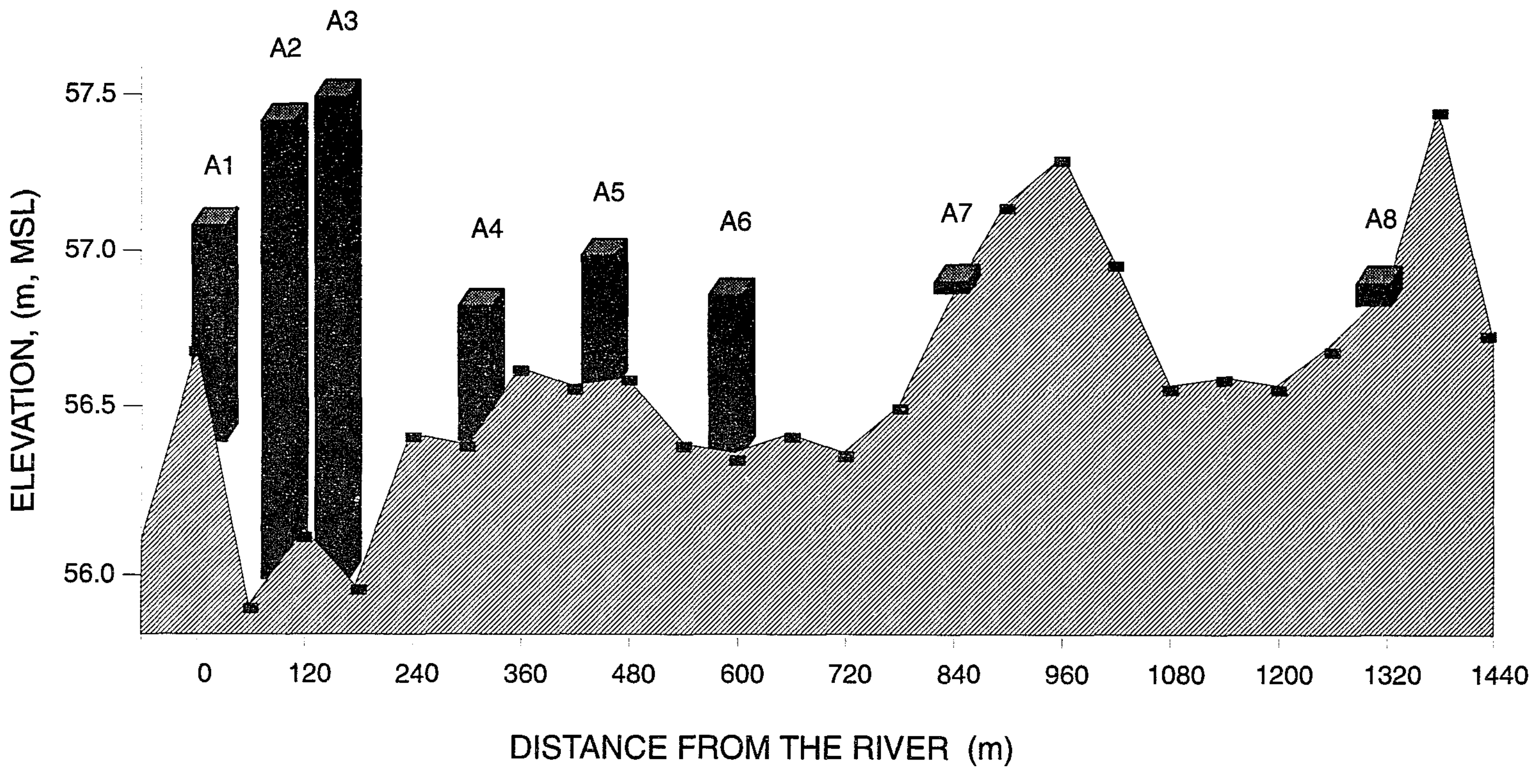

Figure 26. The distribution of sediment deposition across the floodplain at Transect A. The bars are proportional to the mass accretion (g/m2/yr) of sediment. The highest deposition occurred in the cypress/tupelo area at sites A2 and A3.

Table 10. Particle size of suspended sediments at Patterson, Cotton Plant and on Transect B.

	RIVER					B3			B4	B5	B6	B8
	PATTERSON	COTTON PLANT	TOP	MID-DEPTH	BOTTOM	TOP	MID-DEPTH	BOTTOM				
1990												
% > 0.062 mm	0.02	0.3				0.07	0.06	0.12	0.01	0.0	0.0	
% < 0.062 and > 0.00195 mm	~4	5.4				1.1	2.5	4.1	1.6	3.8	6.1	
% < 0.00195 mm	~96	94.3				98.8	97.4	95.7	98.4	96.2	93.9	
1991												
% > 0.062 mm	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0		0.0
% < 0.062 and > 0.00195 mm	4.2	4.0	3.5	4.7	2.7	4.3			1.5	3.3		10.9
% < 0.00195	95.8	96.0	96.5	95.3	97.3	95.7			98.5	96.7		89.1

remanent of the wind blown loess common to this area that appears only in the higher locations which have not been covered with alluvial clays. The unusually high proportion of clays suspended in the Cache River may be at least in part responsible for the pattern of sediment deposition seen. The clay particles can stay suspended in the water column beyond the natural levee, and require the long retention times in the more quiescent backwaters to fall out of suspension.

Water velocity measurements on Transect B for a flood which inundated the entire floodplain, but was not a flood of record, were only about 4 or 5 cm/sec in the main channel, dropped to 1 cm/sec about 100 m away from the river, and were not measurable farther away from the river than that. In developing a numerical model for predicting water chemistry for the Cache River, Dortch (in review) estimated that the mean flow velocity for the entire basin would be 7.6 cm/sec. Certainly, water velocity in the main thalweg would be considerably higher, allowing for many areas of virtually no flow on the floodplain.

Soil Descriptions

Broadly, the rates of sediment deposition across the floodplain are reflected in soil descriptions for the 30 sites. Sites where sediment was rapidly accreting in the cypress/tupelo swamps were most often described as Fluventic Haplaquepts and Typic Fluvaquents. Inceptisols, and especially Entisols, are new soils that have had little time to develop distinct horizons, which is consistent with a rapidly accreting environment. On the other hand, many of the sites with the lowest rates of sediment accretion in the oak/hickory areas were Albic Glossic Natraqualfs, which have a distinct argillic horizon with a high exchangeable sodium content about 35 cm from the surface. Birkeland (1984:224) stated that Alfisols with a natric or argillic horizon may require about 10,000 years to develop. The location of this horizon just 35 cm from the surface indicates that very little sediment has been deposited above it during the last several thousand years. Detailed soil descriptions for each site are given in Appendix A.

Environmental Parameters

The measures of various physical, chemical and biological samples taken at each of the 30 sedimentation sites are presented in Tables 11 and 12.

Elevation. To compare the elevation of all of the sites, the elevation was "adjusted" to account for the overall slope of the stream. This was done by adding an appropriate number of meters to the elevation of the sites on Transects B, C, and D to make them comparable to Transect A. The correction factor was computed from surveyed river channel cross-sections done at multiple locations along the stream channel. Generally, the elevation of the sites increased with increasing distance from the river. Also, as site elevation increased, sediment accretion decreased.

Flood events. Flood duration is dependent upon the elevation of the site, and addresses the amount of time suspended sediment particles have to settle out at each site, as well as the amount of time there is water on a site to make it possible for sediments to settle. Sediment accretion generally increased with increasing flood duration. Flood frequency addresses the theory that each new flood event carries with

Table 11. Summary statistics for floodplain sedimentation sites on Transects A and B.

SEDIMENT STATION	SEDIMENTATION RATE ($g/m^2/yr$)	ELEVATION (m MSL)	ADJUSTED ELEVATION (m MSL)	DISTANCE FROM THE RIVER (m)	FLOOD DURATION (days)	FLOOD FREQUENCY (events)	TREE DENSITY (stems/ha)	TREE BASAL AREA (m^2/ha)	UNDERSTORY DENSITY (stems/ha)	TOTAL SUSPENDED SEDIMENTS (mg/L)	TURBIDITY (NTU)	INDICATOR STATUS OF TREES
A1	459	56.54	56.54	60	90.0	5	888	46	122	44	150	1.7
A2	974	56.27	56.27	120	137.7	6	963	64	84	49	152	1.4
A3	1025	55.93	55.93	180	195.7	7	863	56	228	42	136	1.6
A4	287	56.33	56.33	240	129.0	5	850	26	303	30	152	2.0
A5	277	56.51	56.51	480	94.7	5	1013	10	723	33	126	2.2
A6	337	56.30	56.30	600	133.3	5	1188	16	278	31	96	2.2
A7	23	56.94	56.94	840	20.3	2	988	33	231	45	156	2.3
A8	46	57.15	57.15	1320	6.3	1	688	22	250			2.5
B1	556	55.02	55.82	60	141.7	5	1175	96		43	161	1.0
B2	96	55.81	56.61	1100	59.0	2	975	53		14	30	1.3
B3	1319	54.60	55.40	30	250.3	6	850	21	28	60	195	2.0
B4	1122	54.48	55.28	120	263.0	5	925	51	28	60	189	1.2
B5	805	54.72	55.52	300	231.0	7	613	26	313	60	177	1.1
B6	64	55.55	56.35	420	81.3	3	538	11	234	36	115	2.5
B7	90	55.53	56.33	540	81.3	3	488	14	622	29	108	2.2
B8	134	55.38	56.18	660	95.7	3	463	16	280	45	118	1.6

Table 12. Summary statistics for floodplain sedimentation sites on Transects C and D.

SEDIMENT STATION	SEDIMENTATION RATE ($g/m^2/yr$)	ELEVATION (m MSL)	ADJUSTED ELEVATION (m MSL)	DISTANCE FROM THE RIVER (m)	FLOOD DURATION (days)	FLOOD FREQUENCY (events)	TREE DENSITY (stems/ha)	TREE BASAL AREA (m^2/ha)	UNDERSTORY DENSITY (stems/ha)	TOTAL SUSPENDED SEDIMENTS (mg/L)	TURBIDITY (NTU)	INDICATOR STATUS OF TREES
C1	1056	54.14	55.24	30	221.0	6	1150	46		41	131	1.0
C2	636	54.62	55.72	800	140.7	4	1900	31		33	128	1.3
C3	1235	54.13	55.23	20	224.0	6	169	39	25	39	140	1.0
C4	979	54.19	55.29	60	217.0	6	300	22	41	37	128	1.0
C5	995	54.25	55.35	300	204.7	7	363	33	194	30	125	1.2
C6	22	55.23	56.33	540	95.0	2	763	11	256	31	115	2.8
C7	237	55.14	56.24	1020	98.7	2	763	47	538	29	113	2.2
C8	410	54.86	55.96	1440	115.7	3	638	41	264	25	107	1.5
D1	295	54.16	55.56	1300	140.0	2	1388	61	22	43	118	1.0
D2	14	55.20	56.60	1300	92.3	2	550	25	253	32	146	2.1
D4	132	54.15	55.55	60	140.7	2	625	37		40	132	1.2
D5	272	53.86	55.26	300	365.3	1	1375	70		39	114	1.1
D6	120	54.22	55.62	480	137.3	2	1825	42		34	119	1.7
D7	53	54.80	56.20	1080	106.7	2	575	24	156	26	111	1.7

it a new load of suspended materials which can be deposited. Increased sediment accretion correlated with increased flood frequency.

Vegetation. Tree and understory density on the floodplain is related, by definition, to the roughness coefficient. Theoretically, increased vegetation density should result in increased roughness, which should slow the water velocity and increase sediment accretion in those locations. In the Cache River floodplain, both tree density and understory density were so variable that they did not correlate with anything, nor were there any trends with distance from the river or along the moisture gradient. Tree basal area was consistently higher in the frequently flooded zone near the river, primarily because there were many, very large, very old *Nyssa aquatica* growing in this swamp. There appeared to be limited regeneration in this area due to the long duration flooding, so the numbers were dominated by the large trees. Accordingly, there is a slight correlation between tree basal area and sediment accretion, but it is not indicative of a cause and effect relationship. The indicator status of the trees at each site characterized the vegetation's response to the hydrologic regime. This is a "wet wetland" with the indicator status of the highest site surveyed only 2.8, which shows a prevalence of vegetation which is usually found in wetland situations. As would be expected, there is a relationship between indicator status and elevation and flood duration.

Suspended sediment availability. Measurements of the total suspended sediment concentration and turbidity of the floodwater over each site addressed the availability of material to be deposited. If all of the suspended materials settled out of the water column on the natural levee or the first bottom, there could conceivably be no material left to be deposited farther away from the river. Although there is a general decrease in both suspended sediments and turbidity with increased distance from the river, the difference between the highest numbers and the lowest are not significant. Additionally, there is still plenty of sediment in the water column that could settle out. The controlling factor appears to not be availability of sediment, but retention time. Although there were reasonable concentrations of suspended sediments in the water at the higher sites, the sediments were probably fine clays, which may have been unable to settle during the shorter retention times in the higher woods.

Environmental parameters by zones. Grouping sedimentation rate and environmental parameters by geomorphic zones (Natural Levee, Swamp, Ridge and Swale) generates some interesting comparisons (Table 13). The Swamp zone has the highest sedimentation rate, the lowest elevation, the greatest flood frequency and lowest indicator status. The Ridge sites have a much lower rate of sediment accretion and these sites lie on the opposite end of the spectrum for all of the environmental parameters listed above. Vegetation density seems to play very little role in sediment accretion in the Cache River floodplain. In fact, overall, vegetation density was highest for the Ridge sites which have the lowest sedimentation rates.

Table 13. Overall averages for mass accretion rates and environmental parameters grouped by floodplain location.

SEDIMENT STATION	SEDIMENTATION RATE ($g/m^2/yr$)	ADJUSTED ELEVATION (m MSL)	DISTANCE FROM THE RIVER (m)	FLOOD DURATION (days)	FLOOD FREQUENCY (events)	TREE DENSITY (stems/ha)	TREE BASAL AREA (m^2/ha)	UNDERSTORY DENSITY (stems/ha)	TOTAL SUSPENDED SEDIMENTS (mg/L)	TURBIDITY (NTU)	INDICATOR STATUS
NATURAL LEVEE (Sites A1, B3, D4)	636.8	55.3	50	160.3	4.3	787.7	34.7	75	48	159	1.6
SWAMP (Sites A2, A3, B1, B4, B5, C1, C3, C4, C5, D5)	799.5	54.7	149	220.1	5.6	789.6	50.3	130	44	145	1.2
RIDGE (Sites A4, A5, A6, A7, B2, B6, B7, C2, C6, C7, D2, D6, D7)	173.5	56.3	726	97.7	3.0	951.2	26.4	332	31	117	2.0
SWALE (Sites A8, B8, C8, D1)	221.3	56.2	1180	89.4	2.3	794.3	35.0	204	37	114	1.7

Regression Model

Using the mass accretion rate of sediment for each site as the dependent variable, the environmental parameters were considered in a stepwise multiple regression model. The model that best fit the data was:

$$\textbf{Sedimentation rate} = -187.23 + (4.576 * \textbf{Flood Duration}) - (0.308 * \textbf{Distance from the River}) + (6.768 * \textbf{Tree Basal Area})$$

The adjusted R^2 was 0.89. Most of the variation was explained by the first variable, flood duration, which accounts for the retention time on the floodplain. Increased flood duration allows the sediment a longer period of time to settle. The model was improved slightly with the addition of distance from the river and tree basal area.

Comparison of Mass-Balance and Floodplain Study Results

The mass-balance study showed a decrease of suspended sediment load between Patterson and Cotton Plant of 11,025, 11,738 and 34,735 metric tons, for WY 1988, 1989 and 1990, respectively, for an average of 19,166 metric tons for the three years. Theoretically, the mass accretion rates measured on the floodplain should generate a value similar to this. Multiplying the overall average mass accretion rate of 469 g/m^2 by the 7745 hectares of flooded forest, yielded an average annual mass accretion rate for the floodplain of 36,323 metric tons. Although this average floodplain mass accretion value is nearly double the average mass-balance value, it is still within range of the 1990 maximum value of 34,735 metric tons. This simple calculation does not take into consideration that all of the forest is not flooded, nor does it account for the different sedimentation rates in the different zones of the forest. About 77.5 km^2 of forest have been estimated by the National Wetland Inventory to be at least temporarily flooded. Lacking good spatial estimates of the area of each zone, natural levee, swamp, ridge or swale, I estimated the proportion of each of these zones from the average linear extent of the zone on each of the four surveyed transects. For example, I determined that approximately 1050 m of a total of 5640 m of transect was swamp. Using this proportion, I estimated that 14.4 km^2 of the 77.5 km^2 of flooded forest was swamp and multiplied this value by the mass accretion rate of 799.5 kg/m^2/yr for the zone from Table 13. Summing the values for the four zones yielded an average annual mass accretion rate of 24,465 m tons--certainly close enough to the 19,166 m tons average from the mass-balance data to claim that the data are comparable.

Implications of Accelerated Sedimentation Rates

There are several indications that the sediment accretion rates I measured are not those that have occurred in the geological history of the basin. Using sedimentation rates associated with trees of different ages, Hupp and Morris (1990) suggested a marked increase in sedimentation rates in the Cache River basin since 1945. This fits in with the land-clearing patterns of the area, which showed a significant conversion of forested land to row crops in the 1930's and 40's.

Site D1 is additional evidence for change in the system. The meander radius of the oxbow lake in which this site is located clearly places it as a meander of the St. Francis/Black River system. As these rivers changed course more than 12,000 years ago, this oxbow has been present on the landscape for at least that period of time. Current measurements show that sediments are filling the oxbow at an average rate of more than 1 cm/yr. This material is about 26% organic, so this might be a somewhat generous estimate of vertical accretion; but even at half the current rate, it is evident that this geomorphic feature has not been filling at this rate for the last 12,000 years.

Finally, although there is a large proportion of fine sediments in alluvial river systems such as the Cache, for the suspended material to be composed almost entirely of clay-sized particles seems unusual. Soils in the floodplain had more sand than the suspended materials would indicate. A possible explanation is that the increased agricultural development of the basin has resulted in high non-point source runoff of fine materials. This also provides an explanation for the anomalously high deposition rates in the cypress/tupelo swamp when compared with the natural levee. Geologically, the levee was formed in the classical way; it is the site where the coarser materials, though they may never have been great, fell out first as the river left its banks (Ritter 1978:260). However, the water that went beyond the levee into the swamp was quite likely clear. Currently, the same coarse materials are deposited on the levee, but the floodwaters that go beyond the natural levee into the floodplain are heavily laden with fine particles that settle out only after a greater retention time. This retention time is provided in the quiet waters of the cypress/tupelo swamp.

This accelerated sedimentation rate can only be a temporary phenomenon by geologic standards. Figure 27 is a prediction of the change in the shape of the floodplain of the Cache River at Transect A if the current rate of sedimentation continues for the next 100 years. Floodplain filling of this extent will ultimately cause changes in the vegetation community, reduce floodplain storage, and may result in channel migration.

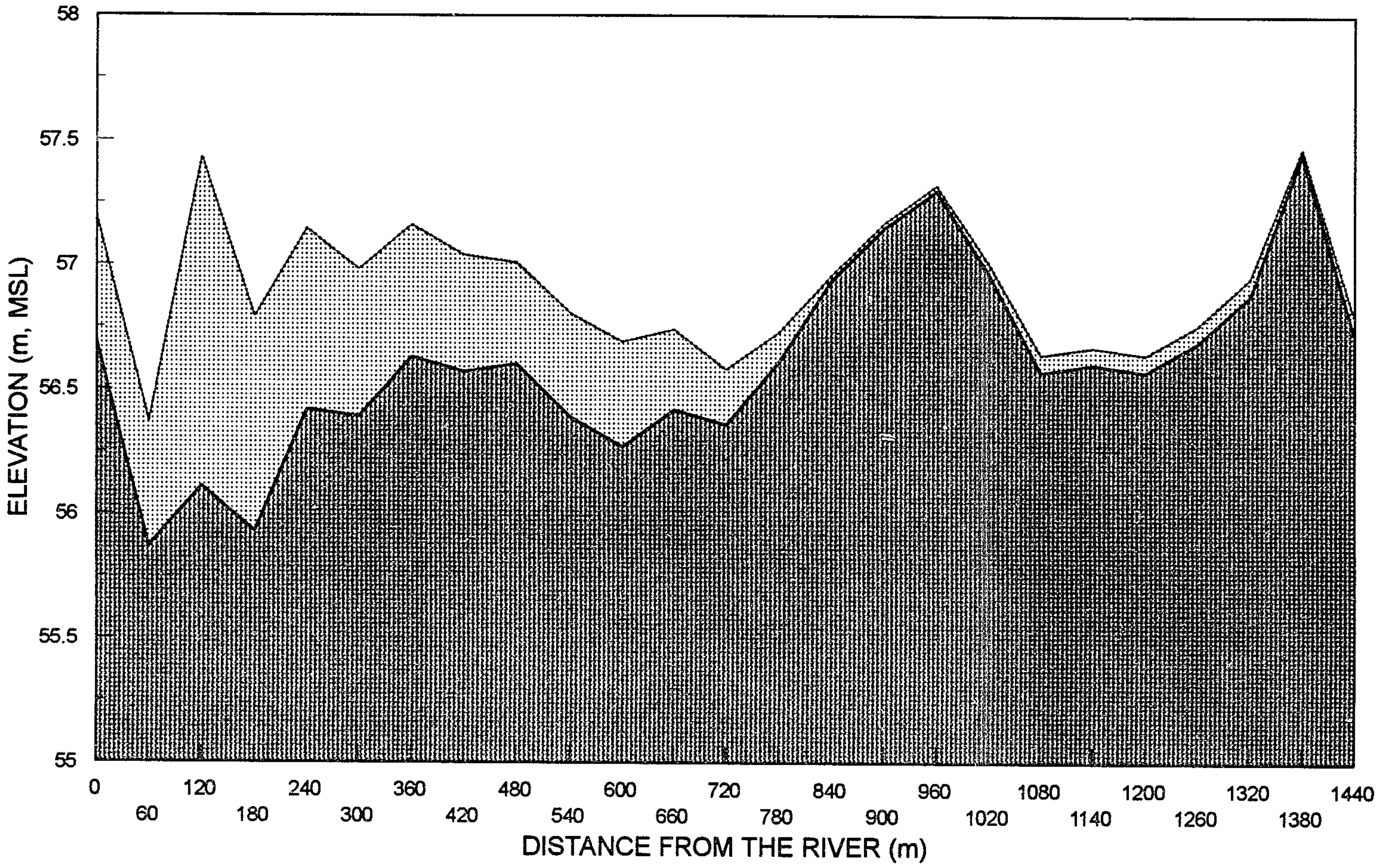

Figure 27. A prediction of the Cache River floodplain configuration in the year 2090, based on current rates of vertical accretion estimated by the clay pad method on Transect A. The light gray shading represents future deposition and the new ground surface, while the dark gray shading is the present cross section of the floodplain.

CONCLUSIONS

Over three water years, the bottomland hardwood wetlands along the Cache River retained an average of 14% of the suspended sediment load entering the system at the upstream end. This is particularly significant when it is noted that these forested wetlands represent only 3.2% of the area of the watershed upstream of the Patterson gage. This strongly implies that the suspended sediment load of the river would be much lower if the entire landscape was in its natural, forested condition. This rate of reduction is appropriate for other wetlands in the Mississippi Alluvial Valley, where there is a predominance of erodible, fine grain alluvium in the watersheds of the rivers, but may not be representative of sites where the rivers carry a lower sediment load.

The accretion of sediments in the wetland was also considerable, particularly in the cypress/tupelo zone (the vegetation in the zone where flood retention was the greatest) where rates averaged nearly 1 cm/yr. This finding may be both positive and negative--the suspended sediment load and turbidity of the Cache River are decreased during passage through the wetland, but indications are that the swamps in the Cache River system are filling at a rate that has accelerated since the time of the intensive agricultural development of the watershed. The fact that most of the sediment retention occurred in the cypress-tupelo zone near the river demonstrates that to perform a sediment trapping function, relatively narrow (200-300 m) strips of forest parallel to the river would be adequate.

Suspended sediments were retained by the wetland system during high flow periods, when the flood water was spread over the floodplain and retained for long periods of time. This suggests that construction projects that artificially confine a river to its channel or limit a river's incursion onto the floodplain will serve to limit the sediment retention function of the floodplain wetlands.

Flood events early in the season showed much higher rates of sediment retention than those late in the season. Accretion rates appear to be due to a combination of deposition and resuspension, and that antecedent conditions on the floodplain may play an important role in the net sediment deposition rate.

This study strongly supports efforts to reestablish forests in the floodplains of riverine systems. Additional forests would not only trap sediments and improve the water quality of the adjacent rivers, but will also reduce the sediment burden on existing bottomland hardwoods, thus preventing premature filling of these systems. This study indicated that retention time may be the most dominant factor associated with sediment trapping, with the roughness provided by vegetation playing secondary role. If this reasoning was followed, it might be suggested that the construction of artificial retention ponds or temporary flooding of cropland might be just as effective for sediment retention as forested wetlands. Although, some sediment would be trapped using other systems, in addition to sediment retention a bottomland hardwood wetland provides root structure and leaf litter to prevent erosion and resuspension into the aquatic system, provides quality habitat for wildlife while retaining sediments and the reestablishment of forested wetlands would serve to compensate for the millions of acres of this ecosystem which have been lost to land clearing over the last few decades.

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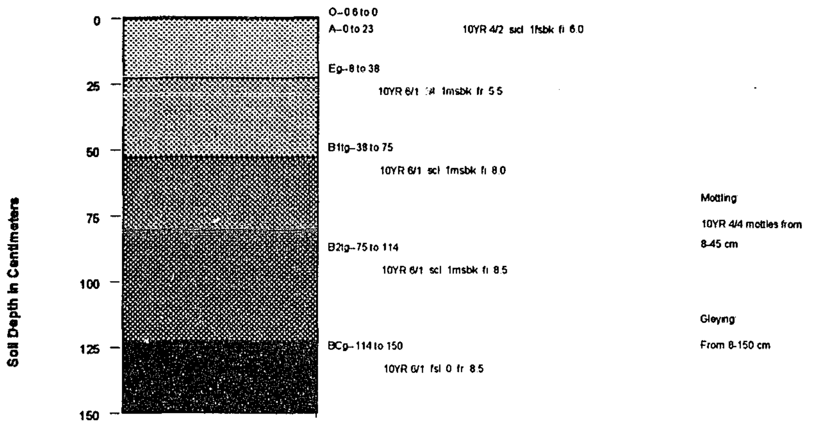
APPENDIX A

SOIL DESCRIPTIONS

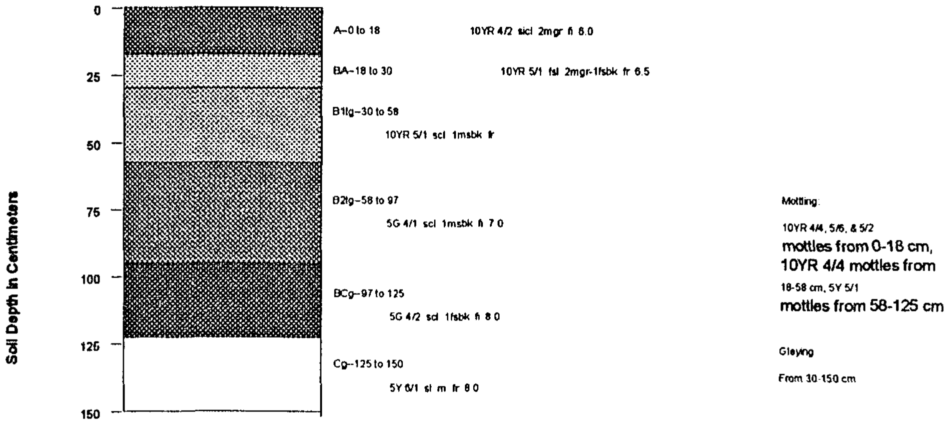
Site A1

Typic Ochraqualf--



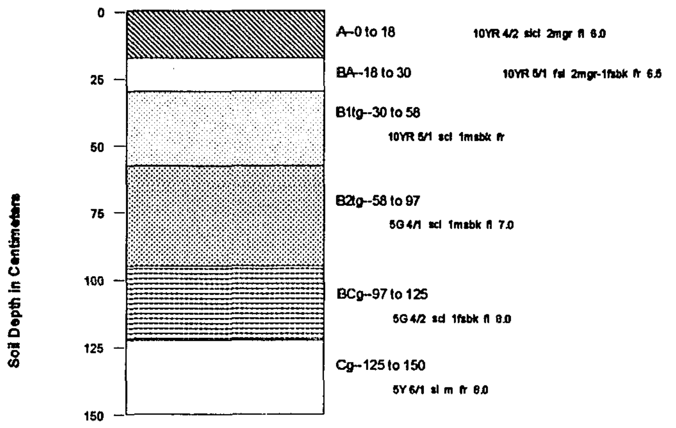
Site A2

Typic Ochraqualf--



Site A3

Typic Ochraqualf--



Mottling:

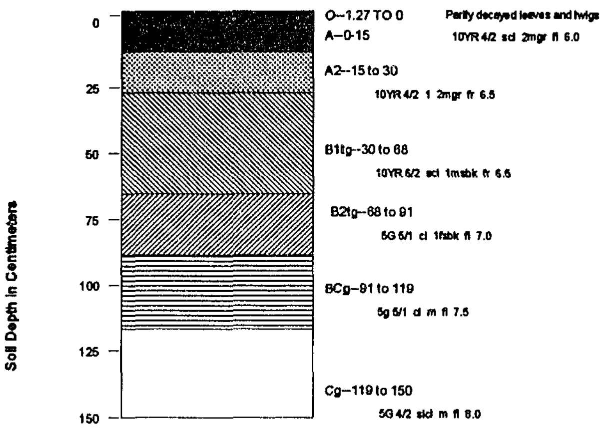
10YR 4/4, 5/6, & 5/2 mottles from 0-18 cm, 10YR 4/4 mottles from 18-58 cm, 5Y 5/1 mottles from 58-125 cm

Gleying:

From 30-150 cm

Site A4

Typic Ochraqualf-



Mottling:

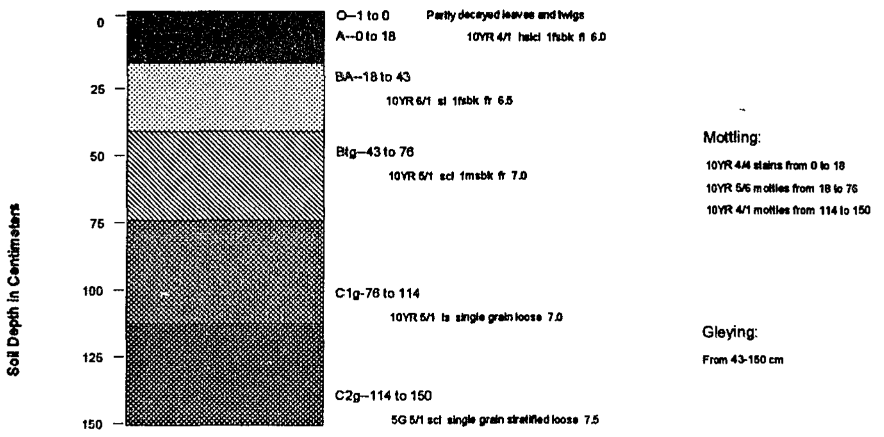
10YR 4/4 and 5/1 mottles from 0 to 15
10YR 4/4 and 6/2 mottles from 15 to 30
10YR 4/4 and 5/1 mottles from 30 to 68
10YR 4/4 and 10YR 5/6 stains around root channels mottles from 68 to 91
10YR 4/4 and many 10YR 5/6 stains mottles from 91 to 119

Gleying:

From 30-150 cm

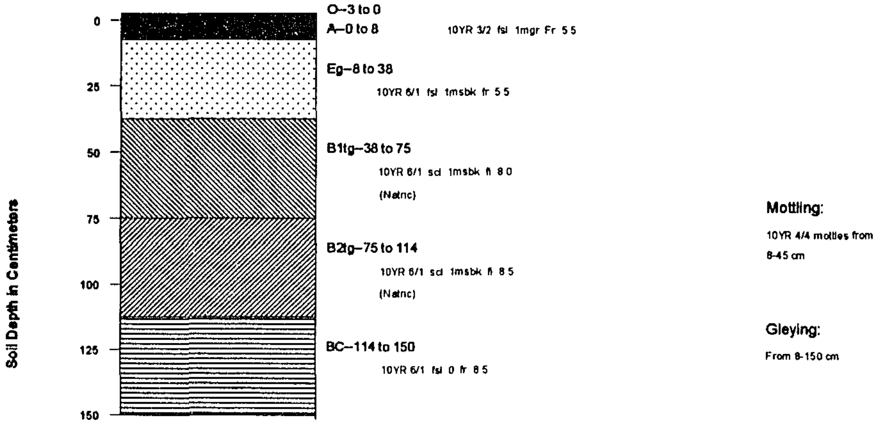
Site A5

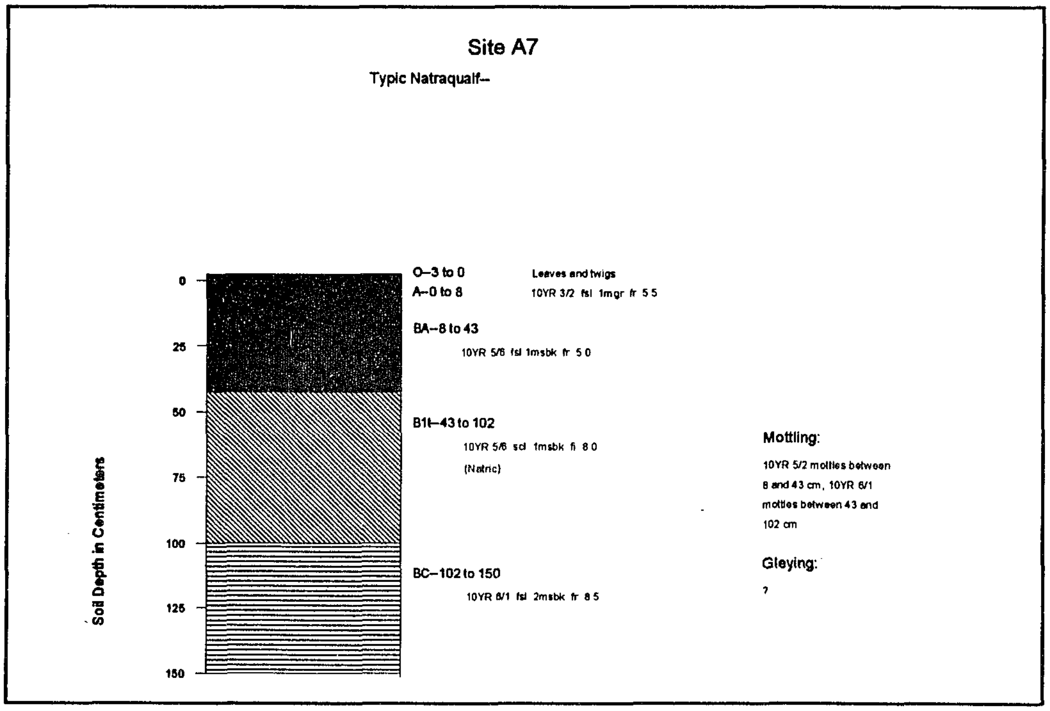
Typic Ochraqualf--

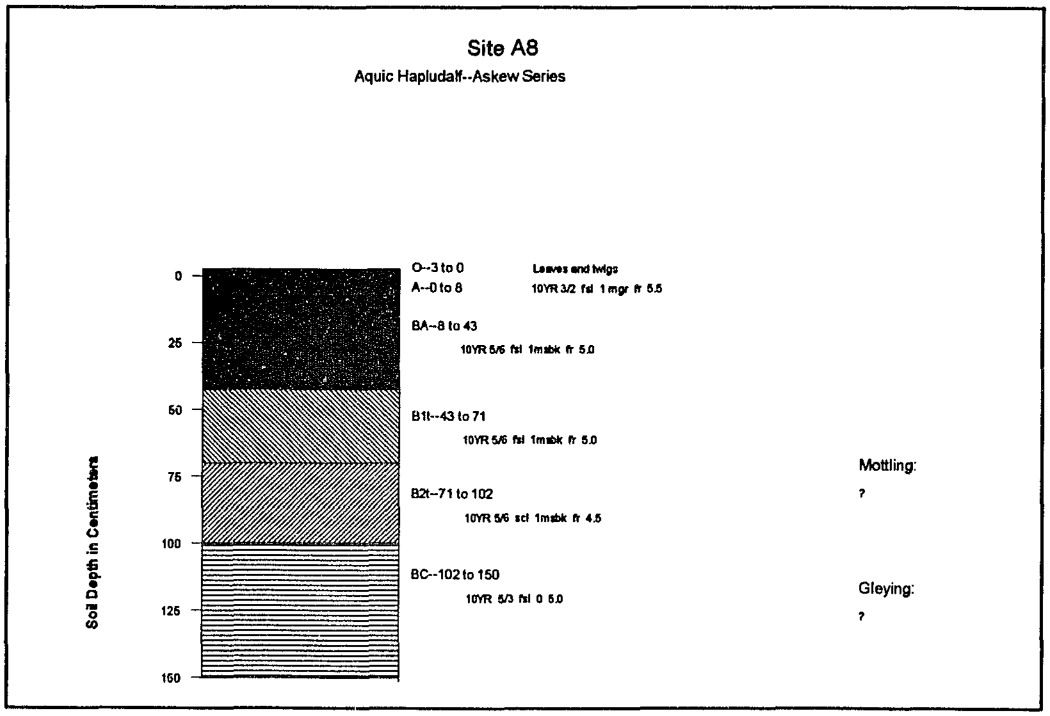


Site A6

Albic Glossic Natraqualf–McCrory Series

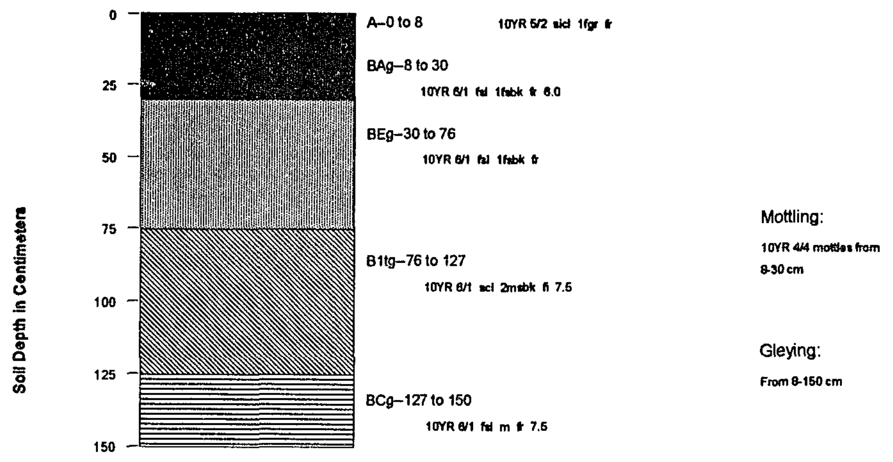



Site A7
Typic Natraqualf--
Soil Depth in Centimeters
0
25
50
75
100
125
150
O--3 to 0
Leaves and twigs
A--0 to 8
10YR 3/2 fsl 1mgr fr 5 5
BA--8 to 43
10YR 5/6 fsl 1msbk fr 5 0
B1t--43 to 102
10YR 5/6 scl 1msbk fi 8 0
(Natric)
BC--102 to 150
10YR 6/1 fsl 2msbk fr 8 5
Mottling:
10YR 5/2 mottles between 8 and 43 cm, 10YR 6/1 mottles between 43 and 102 cm
Gleying:
?


Site A8
Aquic Hapludalf--Askew Series
Soil Depth in Centimeters
0
25
50
75
100
125
150
O--3 to 0
Leaves and twigs
A--0 to 8
10YR 3/2 fsl 1 mgr fr 5.5
BA--8 to 43
10YR 5/6 fsl 1msbk fr 5.0
B1t--43 to 71
10YR 5/6 fsl 1msbk fr 5.0
B2t--71 to 102
10YR 5/6 scl 1msbk fr 4.5
BC--102 to 150
10YR 5/3 fsl 0 5.0
Mottling:
?
Gleying:
?

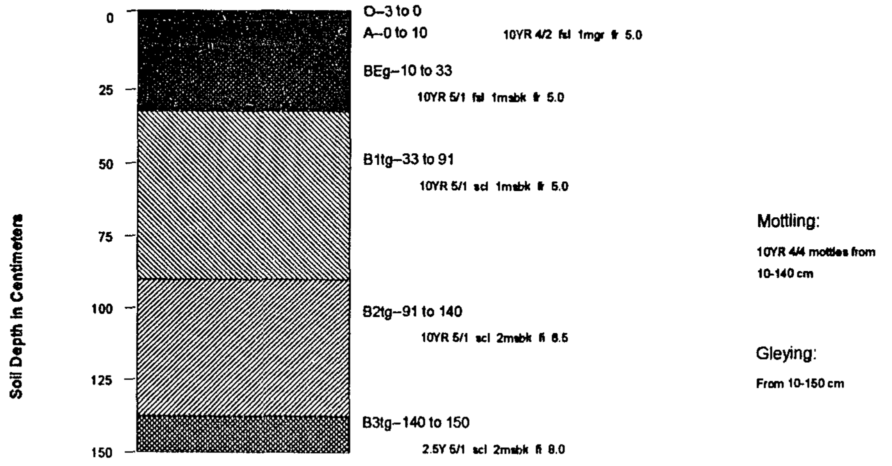
Site B1

Typic Ochraqualf--



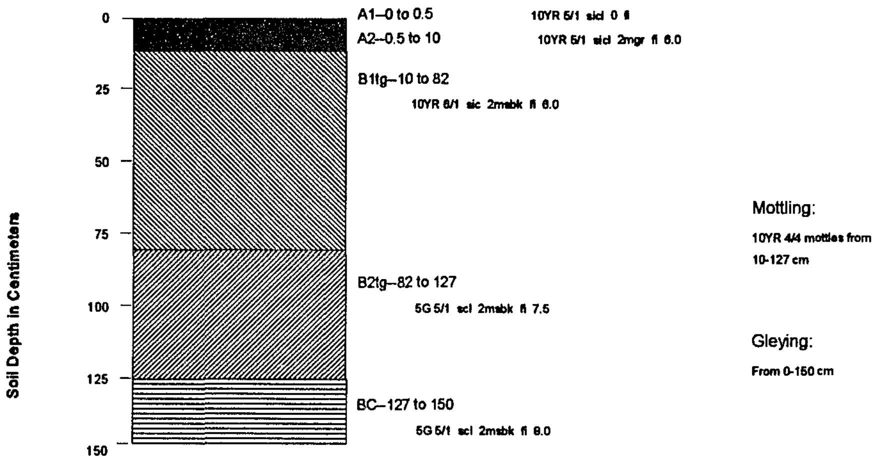
Site B2

Typic Ochraqualf--Tuckerman Series



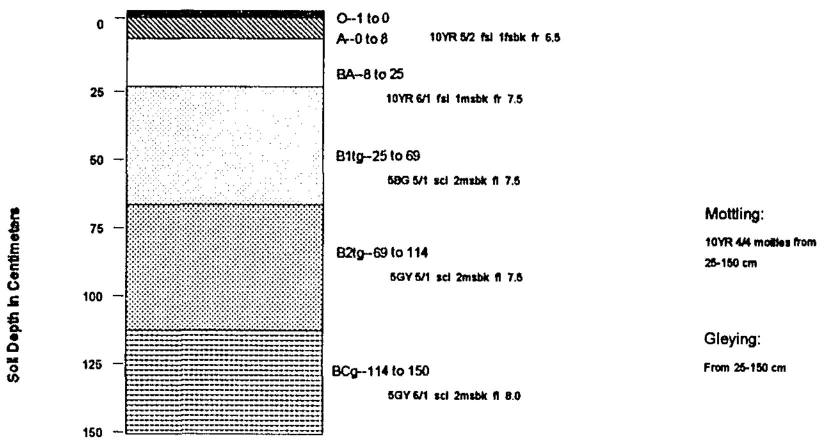
Site B3

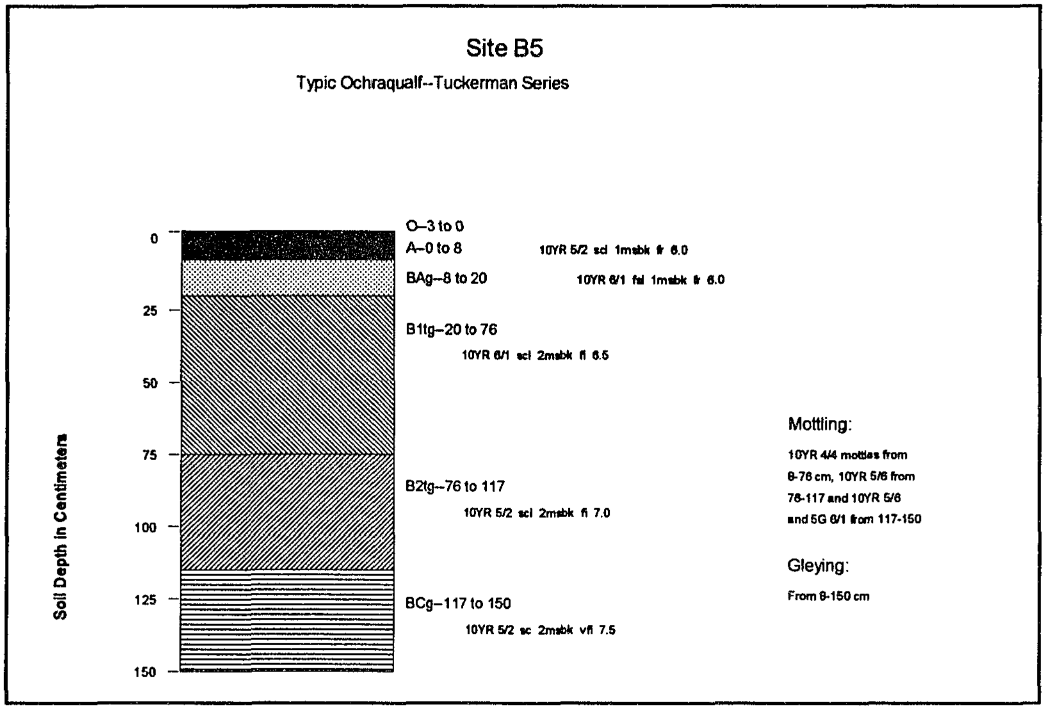
Fluventic Haplaquept--



Site B4

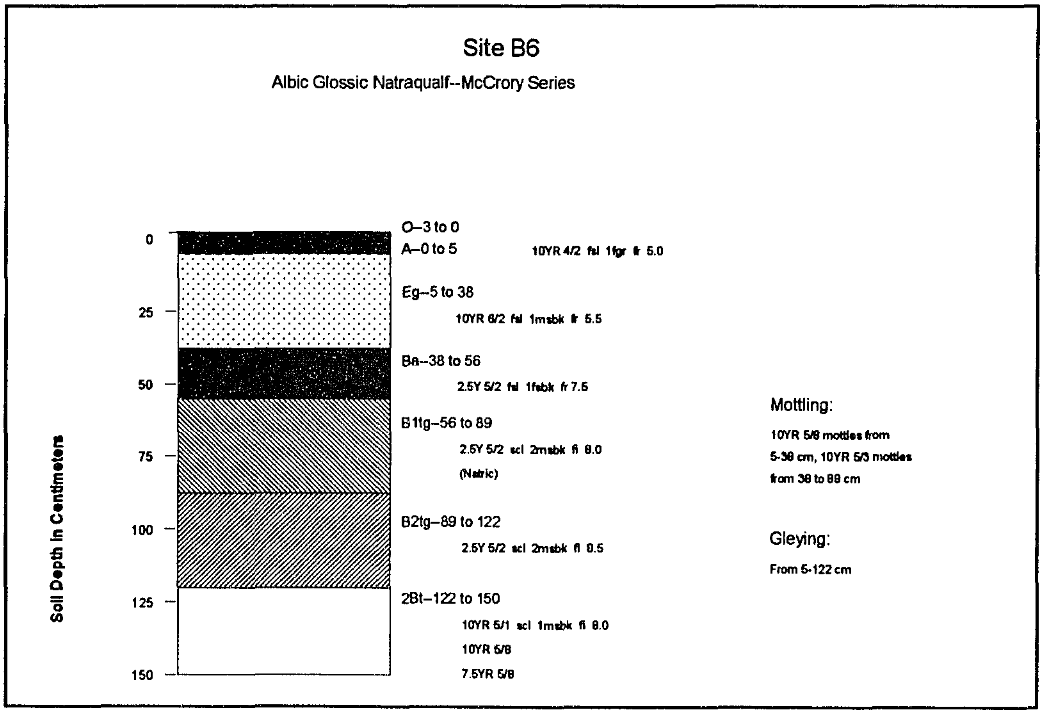
Typic Ochraqualf--





Site B5

Typic Ochraqualf--Tuckerman Series

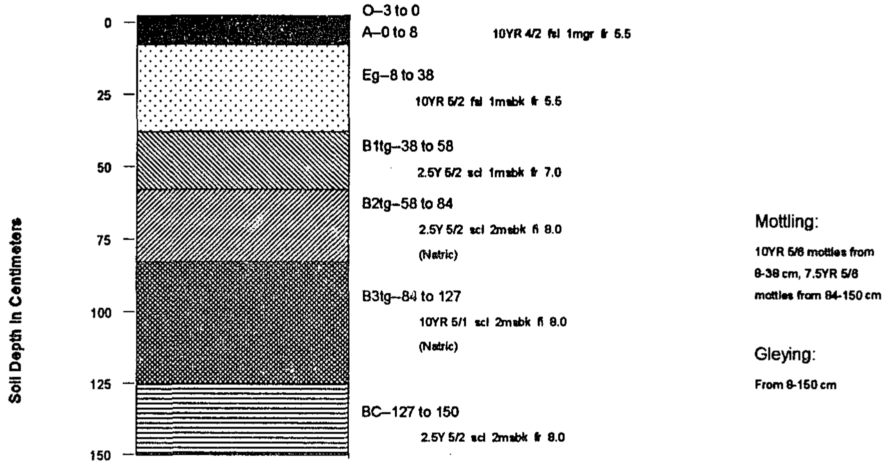


Site B6

Albic Glossic Natraqualf--McCrory Series

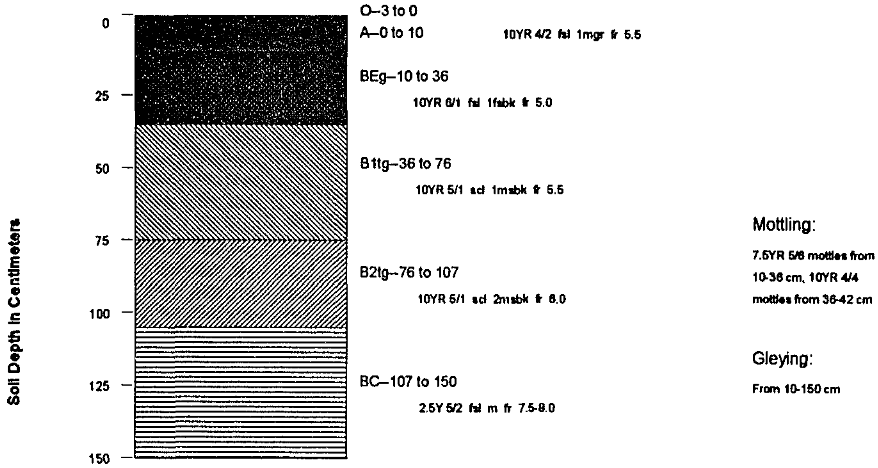
Site B7

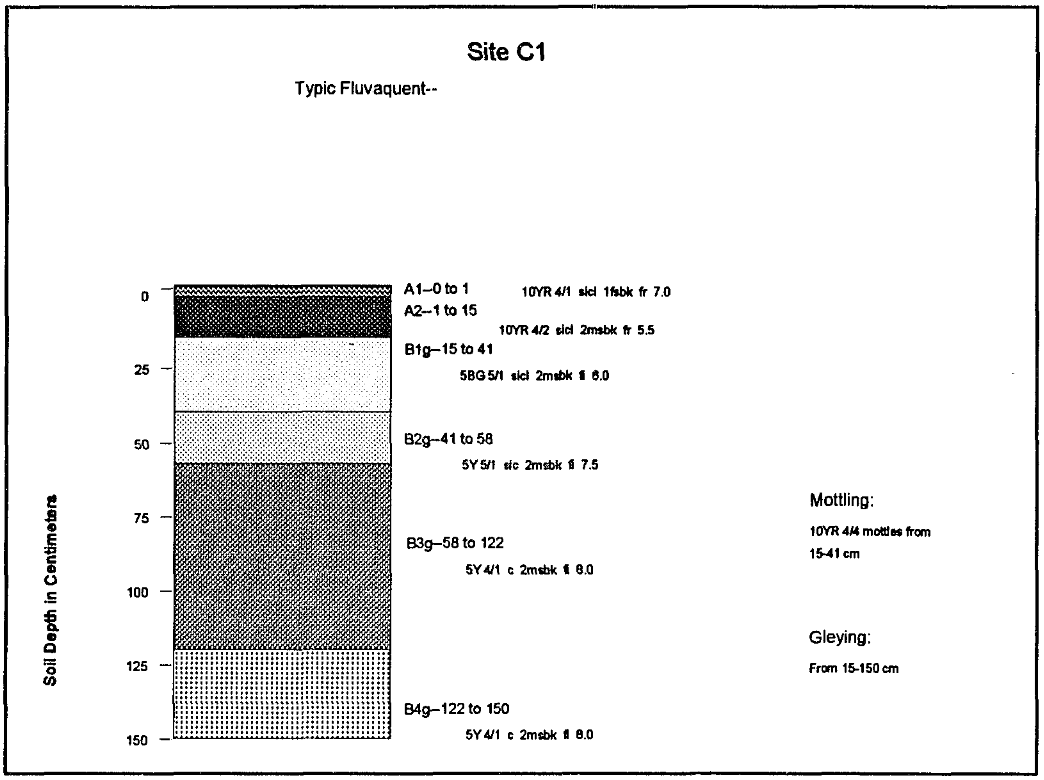
Albic Glossic Natraqualf--McCrory Series

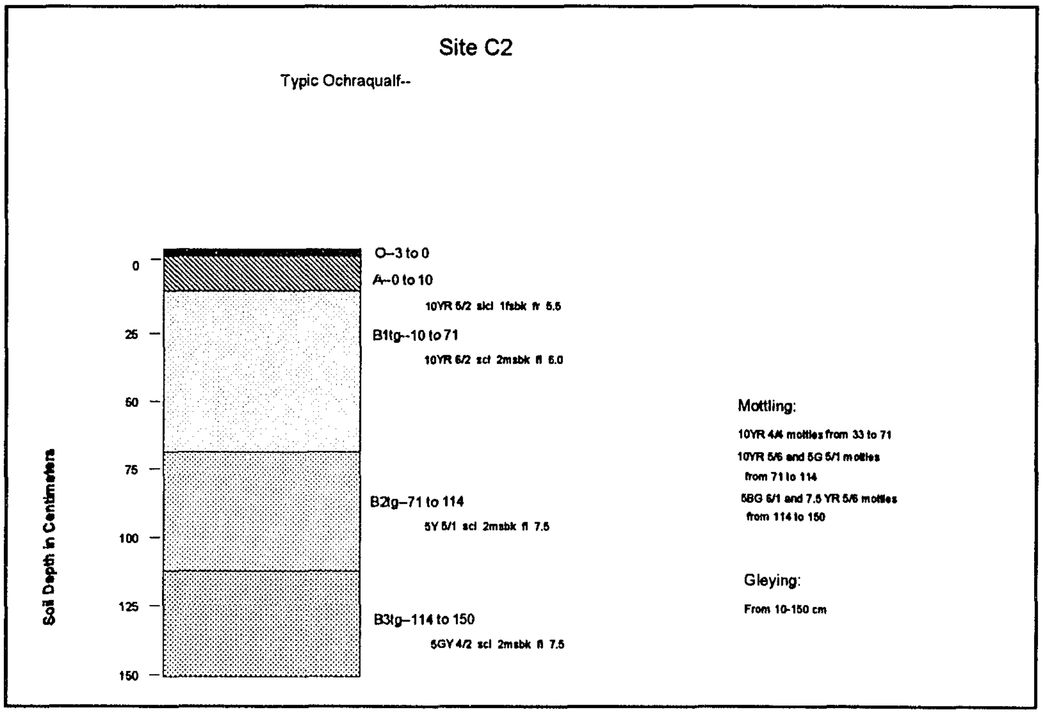


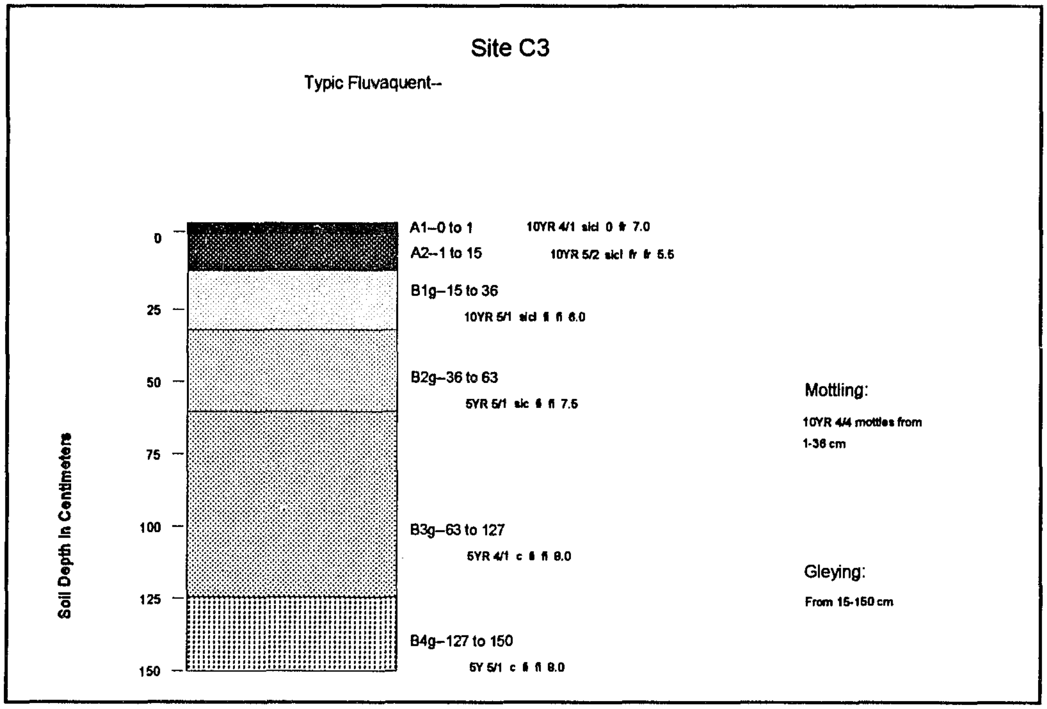
Site B8

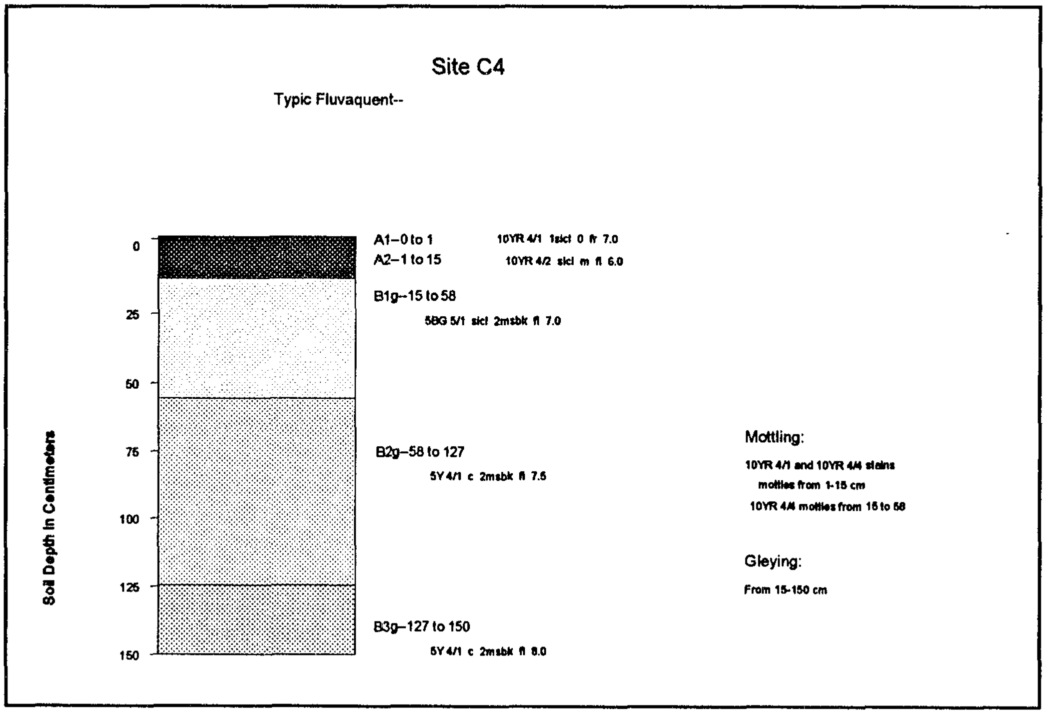
Fluventic Haplaquept--Tuckerman Series




Site C1
Typic Fluvaquent--
Soil Depth in Centimeters
0
25
50
75
100
125
150
A1--0 to 1
10YR 4/1 sicl 1fsbk fr 7.0
A2--1 to 15
10YR 4/2 sicl 2msbk fr 5.5
B1g--15 to 41
5BG 5/1 sicl 2msbk fi 6.0
B2g--41 to 58
5Y 5/1 sic 2msbk fi 7.5
B3g--58 to 122
5Y 4/1 c 2msbk fi 8.0
B4g--122 to 150
5Y 4/1 c 2msbk fi 8.0
Mottling:
10YR 4/4 mottles from 15-41 cm
Gleying:
From 15-150 cm

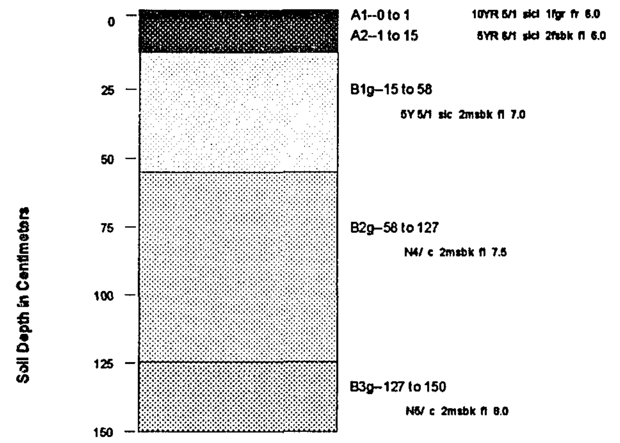

Site C2
Typic Ochraqualf--
Soil Depth in Centimeters
0
25
50
75
100
125
150
O--3 to 0
A--0 to 10
10YR 5/2 sicl 1fsbk fr 5.5
B1tg--10 to 71
10YR 6/2 scl 2msbk fi 6.0
B2tg--71 to 114
5Y 5/1 scl 2msbk fi 7.5
B3tg--114 to 150
5GY 4/2 scl 2msbk fi 7.5
Mottling:
10YR 4/4 mottles from 33 to 71
10YR 5/6 and 5G 5/1 mottles from 71 to 114
5BG 6/1 and 7.5 YR 5/6 mottles from 114 to 150
Gleying:
From 10-150 cm


Site C3
Typic Fluvaquent--
Soil Depth in Centimeters
0
25
50
75
100
125
150
A1--0 to 1 10YR 4/1 sicl 0 fr 7.0
A2--1 to 15 10YR 5/2 sicl fr fr 5.5
B1g–15 to 36
10YR 5/1 sicl f fl 6.0
B2g–36 to 63
5YR 5/1 sic f fl 7.5
B3g–63 to 127
5YR 4/1 c f fl 8.0
B4g–127 to 150
5Y 5/1 c f fl 8.0
Mottling:
10YR 4/4 mottles from
1-36 cm
Gleying:
From 15-150 cm


Site C4
Typic Fluvaquent--
Soil Depth in Centimeters
0
25
50
75
100
125
150
A1–0 to 1 10YR 4/1 1sicl 0 fr 7.0
A2–1 to 15 10YR 4/2 sicl m fl 6.0
B1g--15 to 58
5BG 5/1 sicl 2msbk fl 7.0
B2g–58 to 127
5Y 4/1 c 2msbk fl 7.5
B3g–127 to 150
5Y 4/1 c 2msbk fl 8.0
Mottling:
10YR 4/1 and 10YR 4/4 stains
mottles from 1-15 cm
10YR 4/4 mottles from 15 to 58
Gleying:
From 15-150 cm

Site C5

Typic Fluvaquent--



Mottling:

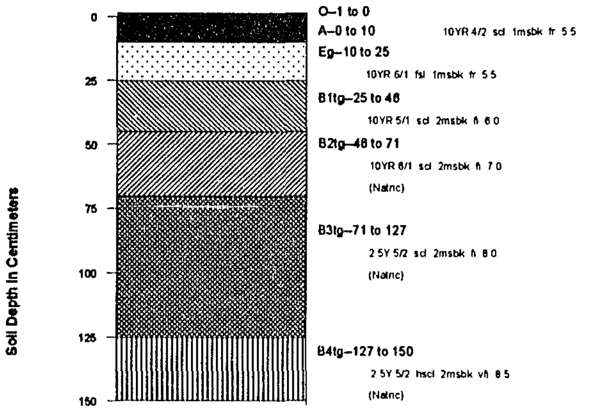
10YR 5/4 stains mottles from 1-15 cm

Gleying:

From 15-150 cm

Site C6

Albic Glossic Natraqualf--McCrory Series



Mottling:

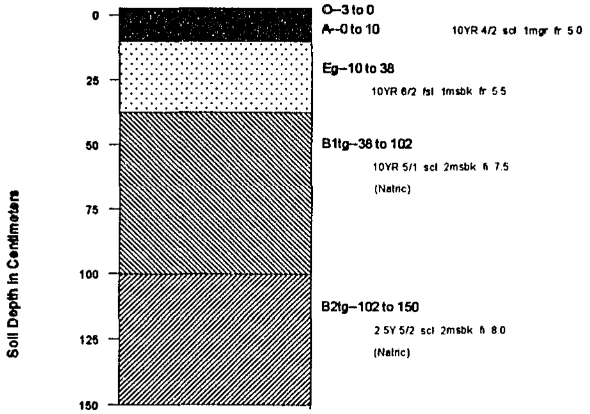
10YR 4/4 and 10YR 5/2 mottles from 10-25 cm, 10YR 5/3 from 25-46 cm, 10YR 5/4 from 46-127 cm, and 7 5YR 5/6 from 127-150 cm

Gleying:

From 10-150 cm

Site C7

Albic Glossic Natraqualf–McCrory Series



Mottling:

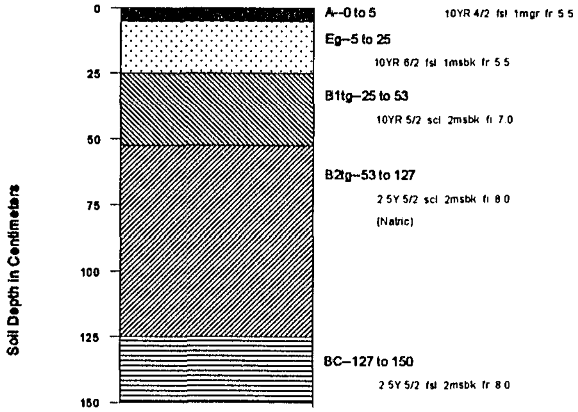
10YR 4/4 and 10YR 5/8 mottles from 10-38 cm, 10YR 5/4 from 38-150 cm

Gleying:

From 10-150 cm

Site C8

Albic Glossic Natraqualf–McCrory Series

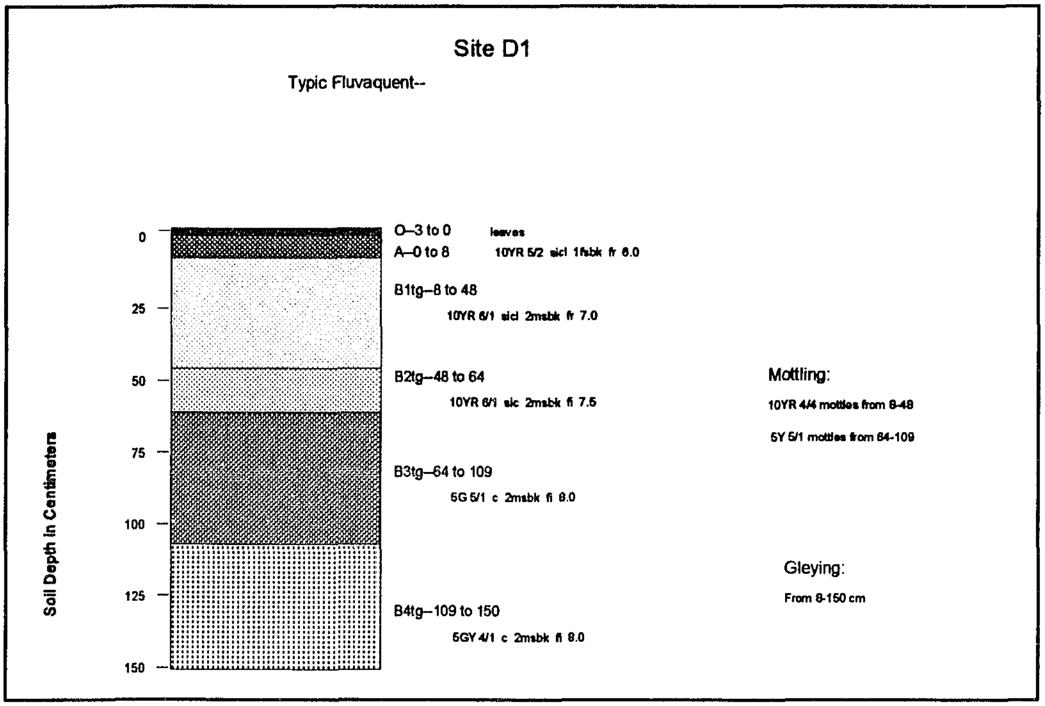


Mottling:

10YR 5/6 mottles from 5-25 cm, 10YR 4/4 from 25-53, 10YR 5/8 from 53-127 cm

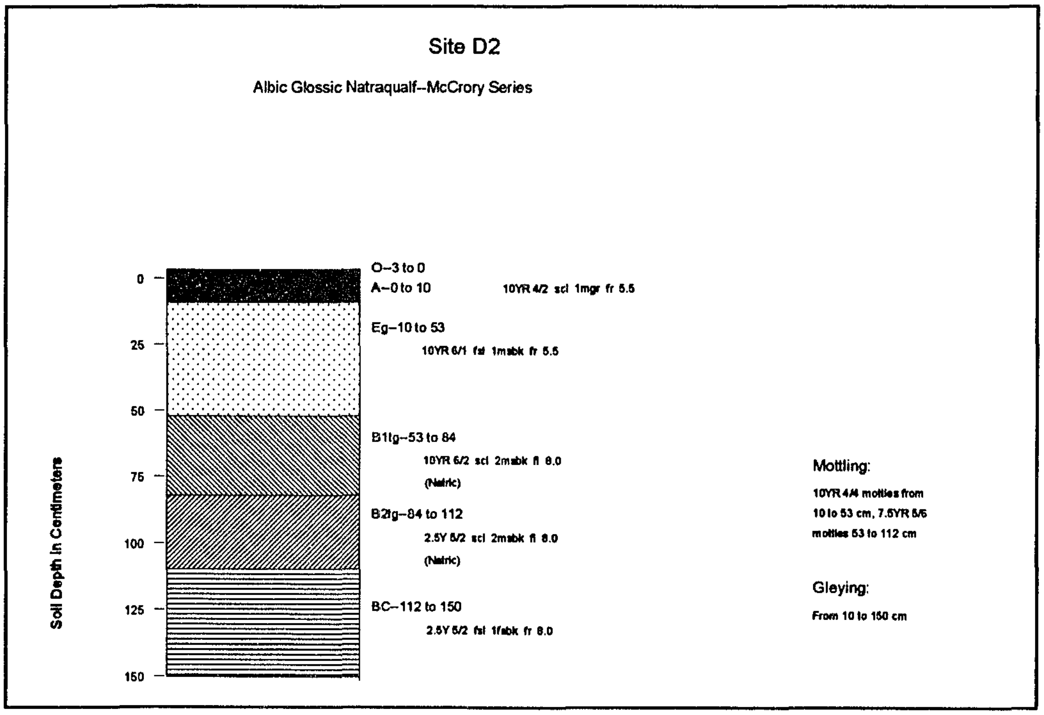
Gleying:

From 5-150 cm



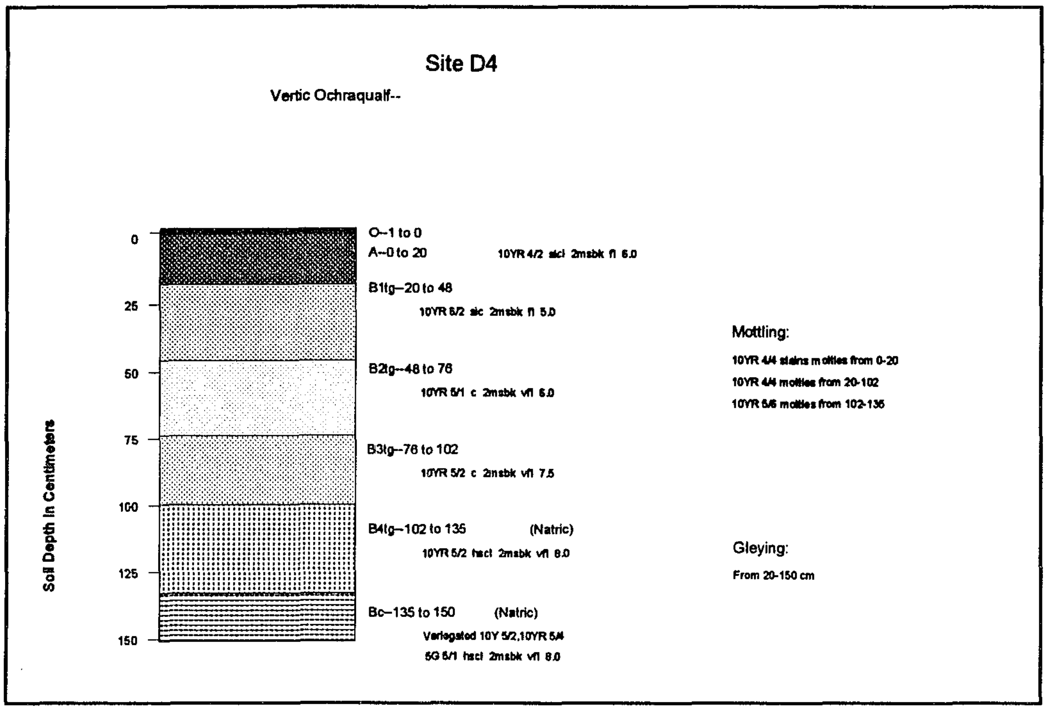
Site D1

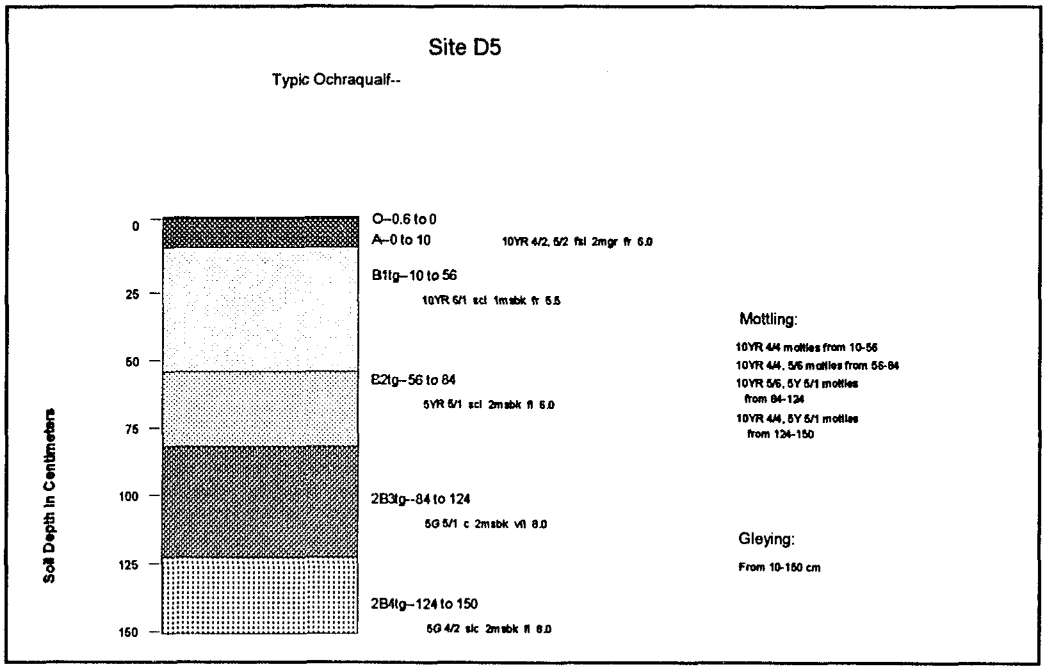
Typic Fluvaquent--

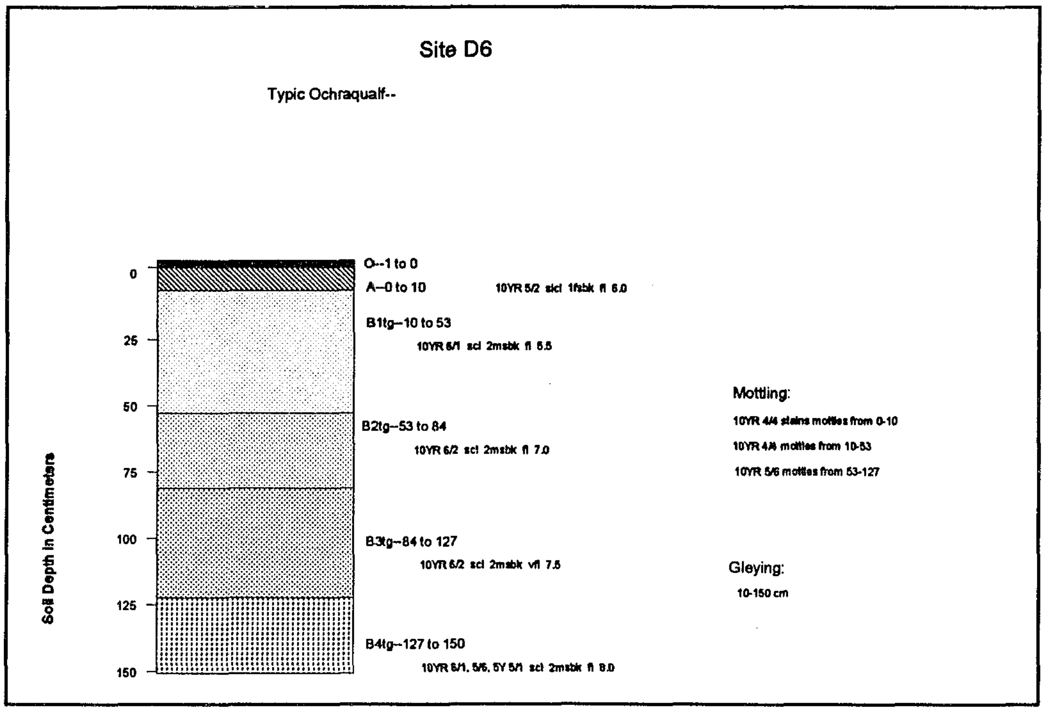


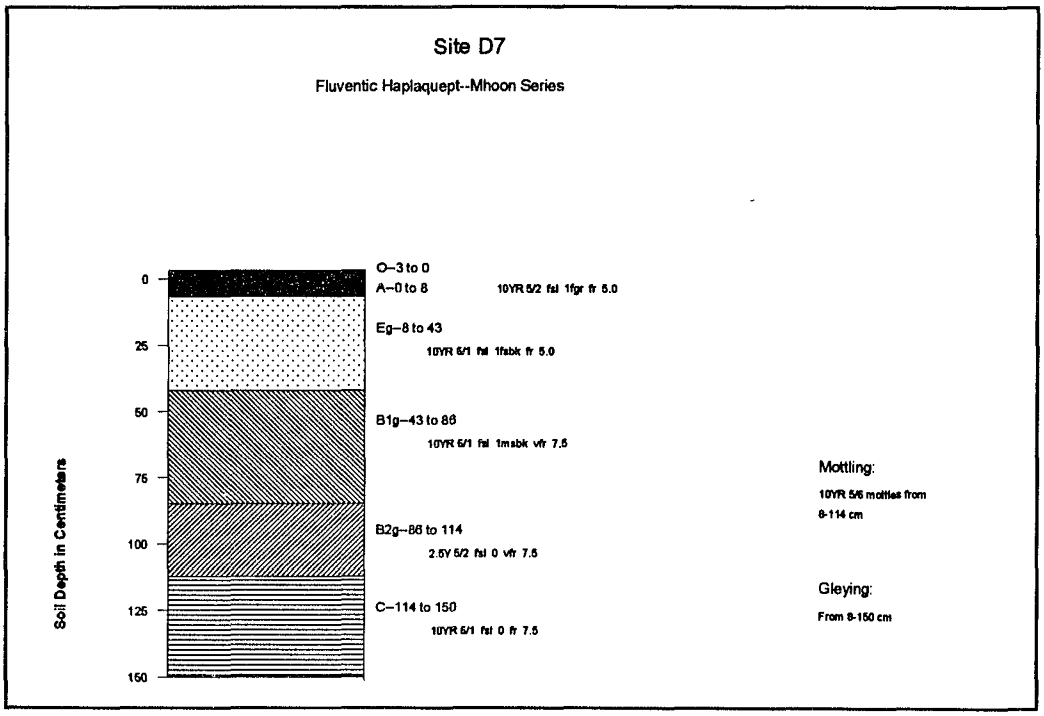
Site D2

Albic Glossic Natraqualf--McCrory Series


Site D4
Vertic Ochraqualf--
Soil Depth in Centimeters
0
25
50
75
100
125
150
O--1 to 0
A--0 to 20
10YR 4/2 sicl 2msbk fl 6.0
B1tg--20 to 48
10YR 6/2 sic 2msbk fl 5.0
B2tg--48 to 76
10YR 5/1 c 2msbk vfl 6.0
B3tg--76 to 102
10YR 5/2 c 2msbk vfl 7.5
B4tg--102 to 135 (Natric)
10YR 5/2 hscl 2msbk vfl 8.0
Bc--135 to 150 (Natric)
Variegated 10Y 5/2,10YR 5/4
5G 6/1 hscl 2msbk vfl 8.0
Mottling:
10YR 4/4 stains mottles from 0-20
10YR 4/4 mottles from 20-102
10YR 5/6 mottles from 102-135
Gleying:
From 20-150 cm


Site D5
Typic Ochraqualf--
Soil Depth in Centimeters
0
25
50
75
100
125
150
O--0.6 to 0
A--0 to 10
10YR 4/2, 6/2 fsl 2mgr fr 6.0
B1tg--10 to 56
10YR 6/1 scl 1msbk fr 5.5
B2tg--56 to 84
5YR 6/1 scl 2msbk fl 6.0
2B3tg--84 to 124
5G 5/1 c 2msbk vfl 8.0
2B4tg--124 to 150
5G 4/2 sic 2msbk fl 8.0
Mottling:
10YR 4/4 mottles from 10-56
10YR 4/4, 5/6 mottles from 56-84
10YR 5/6, 5Y 6/1 mottles
from 84-124
10YR 4/4, 5Y 6/1 mottles
from 124-150
Gleying:
From 10-150 cm


Site D6
Typic Ochraqualf--
Soil Depth in Centimeters
0
25
50
75
100
125
150
O--1 to 0
A--0 to 10
10YR 5/2 sicl 1fsbk fi 6.0
B1tg--10 to 53
10YR 6/1 scl 2msbk fi 6.5
B2tg--53 to 84
10YR 6/2 scl 2msbk fi 7.0
B3tg--84 to 127
10YR 6/2 scl 2msbk vfi 7.5
B4tg--127 to 150
10YR 6/1, 5/6, 5Y 5/1 scl 2msbk fi 8.0
Mottling:
10YR 4/4 stains mottles from 0-10
10YR 4/6 mottles from 10-53
10YR 5/6 mottles from 53-127
Gleying:
10-150 cm


Site D7
Fluventic Haplaquept--Mhoon Series
Soil Depth in Centimeters
0
25
50
75
100
125
150
O--3 to 0
A--0 to 8
10YR 5/2 fsl 1fgr fr 5.0
Eg--8 to 43
10YR 6/1 fsl 1fsbk fr 5.0
B1g--43 to 86
10YR 6/1 fsl 1msbk vfr 7.5
B2g--86 to 114
2.5Y 5/2 fsl 0 vfr 7.5
C--114 to 150
10YR 6/1 fsl 0 fr 7.5
Mottling:
10YR 5/6 mottles from
8-114 cm
Gleying:
From 8-150 cm

APPENDIX B

LETTER OF PERMISSION

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

DEPARTMENT OF THE ARMY
WATERWAYS EXPERIMENT STATION, CORPS OF ENGINEERS
3909 HALLS FERRY ROAD
VICKSBURG, MISSISSIPPI 39180-6199

REPLY TO
ATTENTION OF

CEWES-ER-W

January 27, 1993

RELEASE

Dr. Doug Wilcox
Editor-in-Chief, Wetlands,
U. S. Fish and Wildlife Service
National Fisheries Research Center-Great Lakes
1451 Green Road
Ann Arbor, Michigan 48105

Dear Sir:

This office is preparing manuscript material for a dissertation entitled: "Sediment Retention in an Eastern Arkansas Bottomland Hardwood Wetland".

Permission is requested to include in this publication the following material: figure 3, page 113, volume 10, no. 1, 1990, from the work entitled "A Dendrogeomorphic Approach to Measurement of Sedimentation in a Forested Wetland, Black Swamp, Arkansas", written by C.R. Hupp, E. G. Morris, which was published by your company.

Would you please indicate on one copy of this letter, in the space provided below, whether this material may be used in the publication this office is preparing and whether an appropriate credit line is desired. A self-addressed envelope is enclosed for your use.

Barbara A. Kleiss
Research Ecologist

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Wetlands, U. S. Fish and Wildlife Service
By
Douglas A. Wilcox,Ph.D.
Editor-in-Chief

Date 2/2/93

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* Line out response not applicable.

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GEOTECHNICAL LABORATORY
STRUCTURES LABORATORY
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COASTAL ENGINEERING RESEARCH CENTER
INFORMATION TECHNOLOGY LABORATORY

VITA

Barbara A. Kleiss was born on August 24, 1958 in Bloomington, Illinois, to John and Mary Kleiss. She grew up in northern Illinois, where she graduated from Cary-Grove High School, in Cary, Illinois. In 1979, she graduated from Spring Hill College in Mobile, Alabama with a Bachelor of Science in biology. Kleiss received her Master of Science in biology from the University of Southern Mississippi in 1983. She has been employed as an ecologist by the Mississippi Department of Environmental Quality, the U.S. Environmental Protection Agency, the U.S. Army Engineer Waterways Experiment Station, and the U.S. Geological Survey.

Kleiss is married to John S. Files, of Vicksburg, Mississippi. They reside in Clinton, Mississippi with their three children, Micki, Kim and Jake.

While employed at the Waterways Experiment Station (WES), she took course work from Louisiana State University through the WES Graduate Institute. Kleiss is currently enrolled in the Graduate School at Louisiana State University, Baton Rouge, Louisiana, and is a candidate for the degree of Doctor of Philosophy in the Department of Oceanography and Coastal Sciences.

DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: Barbara A. Kleiss

Major Field: Oceanography and Coastal Sciences

Title of Dissertation: Sediment Retention in a Bottomland Hardwood Wetland in Eastern Arkansas

Approved:

Major Professor and Chairman

Dean of the Graduate School

EXAMINING COMMITTEE:

Jim L. Chambers

Robert P. Gambrell

Date of Examination:

May 1, 1995