Heather E. Golden. SPATIAL AND TEMPORAL VARIABILITY OF HISTORIC ALLUVIAL SEDIMENTATION ON THE LOWER COASTAL PLAIN, NORTH CAROLINA. (Under the direction of Dr. Paul Gares) Department of Geography, December 1998.

The purpose of this thesis was to assess local scale spatial and temporal variations in historic, or post-European settlement, alluvial sedimentation rates and patterns in the backwater area of a historic gristmill dam on the lower coastal plain, North Carolina. A secondary goal was to investigate possible alluvial sediment sources.

Spatial variations in historic alluvial sedimentation were evident in both between-circle and within-circle historic alluvium depths and physical soil characteristics. In addition, Kruskall Wallis ANOVA tests and t-tests calculated significant variability between the 2 m^2 sampling areas.

Two periods of historic sediment accretion were recorded behind the milldam constructed in 1869: one during the late nineteenth/early twentieth century and one beginning about 40 years ago. Both periods correspond to advanced upland timber removal and agricultural land use. Sedimentation rates using dendrogeomorphology over approximately the past 60 years averaged .65 mm yr^{-1}. Rates calculated based on the average depth of historic alluvium and the age of the gristmill dam averaged 2.7 mm yr^{-1}. This suggests an apparent decline in historic sediment accretion over the past 60 years. However, factors such as colluvial storage and dendrogeomorphic methodology using cypress knees may account for this.

Possible sediment sources were derived by comparing physical soil characteristics in the floodplain to those of upland sediment sources, along with analyzing topography and land use activity within the drainage basin. It appears that sediment enters into the backwater area by stream channel delivery from the uplands during storm events; however, in higher magnitude rain and flood events, slope erosion from adjacent uplands influences sedimentation.

SPATIAL AND TEMPORAL VARIABILITY OF HISTORIC ALLUVIAL SEDIMENTATION ON THE LOWER COASTAL PLAIN, NORTH CAROLINA

A Thesis

Presented to

the Faculty of the Department of Geography

East Carolina University

In Partial Fulfillment

of the Requirements for the Degree

Masters of Arts in Geography

by

Heather E. Golden

December 1998

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ACKNOWLEDGMENTS

First, cheers to all my graduate comrades for the mutual support system and for sharing the enlightening experience of Greenville, North Carolina. Appreciative thanks to Dr. Jonathan Phillips and Dr. Mike Slattery who advised me in the initial stages of this project and continued to assist me throughout despite the cross-continent spatial hurdles. Thanks to Dr. Paul Gares for taking over the reigns near the end and becoming the crowned third advisor, and thanks to Dr. Jeff Colby and Dr. Deborah Dixon for the additional help. Appreciation goes out to Jim Watson in geology for allowing me access to the lab and equipment, to Doris Stevenson for her help with the gristmill dam information and the use of her land, and finally to the neighbors on the other side of the swamp.

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CHAPTER I

INTRODUCTION

Changing sediment yields associated with historic changes in land use practices is an undeniably widespread phenomenon. Sediment delivery often increases exponentially with land use alterations such as deforestation, agriculture, and construction (Trimble 1974). Knox (1977), for example, found thick sediment accumulations on alluvial floodplains in Wisconsin due to increased human-induced surface runoff. In the eastern United States, European expansion in the late seventeenth century and simultaneous deforestation and agricultural land use has measurably increased erosion (Gottschalk 1945; Trimble 1974; Knox 1977). Therefore, the conversion of previously undisturbed forested land has decreased sediment retention on the uplands resulting in increased sediment production within the drainage basin.

Increased historic sediment accretion rates on alluvial floodplains in the southeastern U.S. as a result of culturally-accelerated erosion have been well documented (Trimble 1970, 1974; Costa 1975; Knox 1977; Barnhardt 1988; Hupp and Morris 1990; Hupp and Bazemore 1993, Phillips 1993, 1997a,b). These sediments are often stored as colluvium or as alluvium on floodplains. As a result of the lack of well-developed soil structures on coastal plain floodplains, it is difficult to discern a time marker of initial post-European settlement accretion in the stratigraphy. However, buried historical features can be used as a record of changes in historic sedimentation by providing a time marker from which sediment can be dated. Trimble (1970, 1974) and Phillips (1997a,b), for example, used historic gristmill dams to record historic alluvial sediment accretion rates. As the sediment behind the dam is unequivocally historic, the depth of sediment in the backwaters of the dam divided by the age of the dam provided estimates of annual sedimentation rates.

Much of the work on erosion and sedimentation in the eastern U.S. has been focused on inland areas, such as the piedmont. The coastal plain of North Carolina, however, has often been neglected in geomorphic research and sedimentation studies because of its relatively low relief and lack of readily-visible evidence of geomorphic activity. Streams originating in the coastal plain have typically been classified as low gradient, blackwater, and clastic "sediment-starved" systems (Hupp and Osterkamp 1996). As a result of these broad generalizations, coastal plain streams with higher sediment loads have been neglected in research agendas (Simmons 1988). However, the toll of human agency on soil loss and increased sediment yields in the NC coastal plain and its river systems is comparable to that of areas of steeper topography (Phillips1997a,b). Some previous research has focused on measuring sediment accumulations as a result of human transformations of forested land to agricultural use on alluvial floodplains in the coastal plain of North Carolina (Phillips 1993, 1997a,b; Phillips et al. 1993).

As a whole, it is widely recognized that converting forested land to agricultural landscapes increases sediment yields, and buried historical features provide a record of this. As this widespread practice commenced in the late seventeenth century, increased colonial expansion, a burgeoning forest industry, and road and bridge construction also played a significant role in rapid land alterations (Merrens 1964). Many of these practices continued to flourish until the early 1920*s*. Recent studies have found that in the North Carolina coastal plain, sedimentation rates from historic (post-European settlement) land use may be greater than those arising from Holocene sea level rise (Phillips 1997b). Although soil conservation practices and a decrease in farming in some portions of the Atlantic Drainage system have reduced the amount of erosion in more recent years (Trimble 1974; Meade 1982), sedimentation from the eighteenth through early twentieth centuries "use and leave" land use activity is still an issue. Once sediment has been eroded from converted land and is entrained, it can quickly move out of the basin. However, as noted earlier, the majority of the sediment is temporarily deposited and stored in riparian floodplain areas (Malanson 1993) or stored as colluvium, creating variable patterns of sedimentation over an area. Measuring sediment accumulation and storage at buried historical features can provide a record of historic sedimentation.

Sedimentation Variability

Research analyzing stratigraphic records and sedimentation over broad scales most often relies on only a few core samples along cross-valley transects or a small number of local stratigraphic exposures to reconstruct the environment (Schumm 1967; Nanson and Young 1981). However, sedimentation is often spatially and temporally variable over local scales. Several studies have focused on the spatial variability of deposition relating to different physical factors such as geomorphic mechanisms, hydroperiods, topography, and land uses (Connor and Day 1988; Barnhardt 1988; Hupp and Morris 1990; Kleiss 1996) along with biological factors (Aust et al. 1991) such as the basal area of trees (Kleiss 1996) and vegetative abundance on the floodplain (Nanson and Beach 1996). All of these studies revealed spatial variability in sedimentation, albeit on a regional scale. Thus, in order to fully understand the broad picture of erosion and sedimentation, one needs to characterize the degree of local scale variability and influences on this variation. This will contribute to a better understanding of floodplain alluvial stratigraphy.

Deposition is also typically discontinuous throughout time and sediment can travel in episodic pulses (Schumm 1967; Campbell 1992). These episodes may be the result of seasonal flooding in the coastal plain (Hupp and Osterkamp 1996). Deposition can increase or decrease, however, from elevated sediment supplies from road, bridge, industry, and housing construction along with changes in agricultural and silvicultural land use patterns, hurricanes, rare floods, fires, and changes in sea level, climate, or tectonic activity.

Calculating annual sedimentation rates assists in determining spatial and temporal variations in sedimentation patterns. Datable historical features can provide ages and possible causes of pulses or gradual changes in sediment deposition. Buried historical features such as old gristmills (Phillips 1997a,b; Trimble, 1974), railroad ties (Phillips 1997a), fences (Happ 1975), bridges (Hupp and Morris 1990), and reservoirs (Julien 1995), along with dendrogeomorphic techniques (Hupp and Bazemore 1993; Hupp and Morris 1990; Phillips 1997b; Kleiss 1996) have been used to estimate annual sedimentation rates. These studies have focused primarily on regional scale interpretations of alluvial sedimentation rates. There is a clear need to characterize local sedimentation variability.

Purpose and Objectives

There are two objectives of this study. The primary objective is to measure and analyze the spatial and temporal variability of historic alluvial sedimentation rates on a local scale in the coastal plain of North Carolina. Mean annual sedimentation rates are calculated using dendrogeomorphology and alluvial accretions behind a historic gristmill dam. This research provides data on the local variability in sedimentation patterns, and hence, a basis for future alluvial stratigraphic research and land management practices. Also, as little quantitative data exists for sedimentation rates in freshwater wetlands (Boto and Patrick 1978), the purpose is to provide measurable and datable links to past geomorphic events (Hupp and Morris 1990). The secondary objective is to provide a history of local land use, geomorphic setting, and topographic setting to interpret the variations in and possible sources of local alluvial sedimentation. Through sediment and historical land use analysis, a general reconstruction of the sedimentary history on a local scale is designed at a historical gristmill dam site.

CHAPTER II

LITERATURE REVIEW

Historical Background

Colonial Land Use. The first permanent English settlement was established on the Atlantic seaboard in 1607, yet it was not until the end of the seventeenth century that European settlement proliferated. Native Americans, including the Tuscarora and other smaller tribes, inhabited the coastal plain prior to European settlement, living within the forests and utilizing only small plots of land for farming communities. At that time, around 1663, North Carolina was described as a nearly "unbroken forest" from the coast to the mountains (Lee 1963; Merrens 1964; Cathey 1974; Phillips 1994). Rapid forest denudation and environmental degradation resulted with the establishment and expansion of the colonies (Merrens 1964). Natural resources were initially transformed for subsistence farming but eventually became sources of income through commercial forestry and agricultural pursuits.

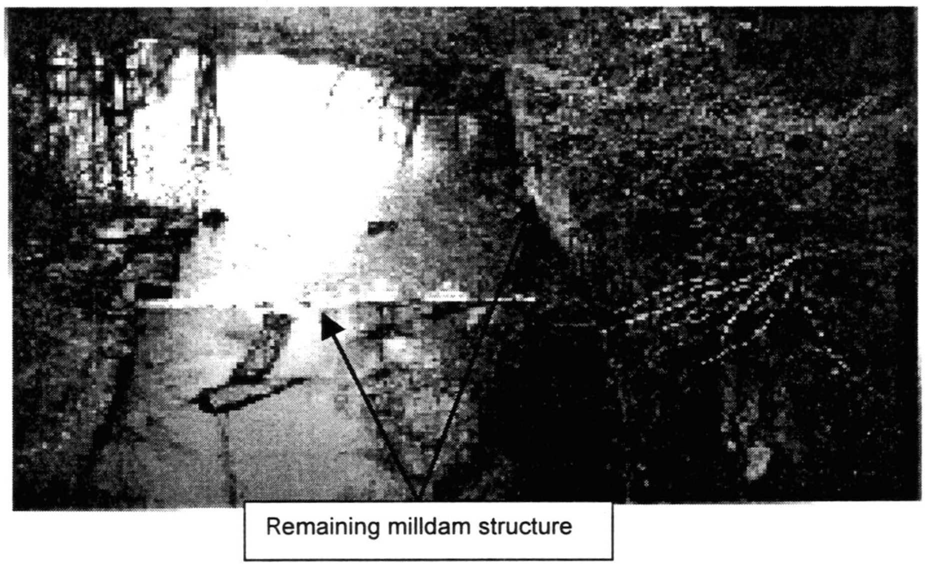
The history of settlement and land use in the coastal plain is quite complex. Early histories account for the purity and clarity of coastal plain streams. During this period, a minimal amount of sediment from erosion entered into the basins (Phillips 1995). Forest clearing for settlement, agriculture, and forestry then occurred at variable spatial and temporal scales (State Board of Agriculture 1896). The most densely populated and largest areas of forest denudation in colonial times lay north of the Albemarle Sound (Merrens 1964).

The lumber industry then flourished during the early to mid eighteenth century. The proliferous *Pinus palustris* (longleaf pine) became an important commodity for industry and export. In 1766, Governor Turon wrote to the Board of Trade stating that lumber was a "considerable staple" to the coastal plain region. Large amounts of wood products including tar, pitch, turpentine, shingles, sawn lumber, and staves were made in eastern North Carolina. By 1775, the forests of Eastern North Carolina were considerably altered and diminished, yet the succeeding generation curried enough raw material to continue commercial forestry (Merrens 1964). By 1897, most timber had been removed from the loblolly pine (*Pinus taedus*) forests in Eastern North Carolina for manufactured products (Pinchot and Ashe 1897).

Agriculture became the predominant form of land use in the coastal plain with corn, tobacco, and wheat becoming the most productive crops for the settlers. By 1753, a corn surplus occurred, resulting in the first recognized overuse of the land in eastern North Carolina (Merrens 1964). By the 1920s, 70 to 80 percent of the well-drained upland soils had been cultivated (Phillips 1994). Livestock, especially cattle and hogs, also became an important agricultural industry. By 1728, beef and pork were exported to Virginia. Open grazing became a popular practice (especially in the east in areas without salt marshes) along with the use of fire to open forests and maintain a landscape for grazing, tick eradication, and increased settlement. The geography of abounding agriculture shifted periodically after settlement. With this came rapid road and bridge construction for industry (Merrens 1964). Overall, the coastal plain became an open medium for land alterations for profit. These land use patterns continued through the early twentieth century.

Mill Operations. Many communities in the NC coastal plain constructed a grist- and/or flourmill to grind harvested corn and wheat into flour, grits, cornmeal, and other milled products. The gristmills were constructed along streams for water power (Fig. 1).

Figure 1. Gristmill dam at study site



Dams were built to provide increased water elevation for greater fall and to store water for mill operation (Hobbs 1985). Some dams in North Carolina were wood-constructed, but most were earthen (Hobbs 1985; Phillips 1997a). Old gristmills that have now decayed or have been destroyed can be recognized by human-constructed ridges perpendicular to the stream channel and scallop-shaped upland borrow areas near the millpond as a result of the removal of soil for the dam (Fig. 1).

Evidence from archival records indicates that many of the mills that operated in the colonial period of the eighteenth and nineteenth centuries through the 1920s can be dated back to their construction (Phillips 1997a,b; Swain et al. 1899). According to Phillips (1997a,b), buried historical features, such as gristmills, provide datable measurements of historical river sedimentation. After a dam is built along a stream channel, water velocity may be slowed enough to allow some suspended particles to settle. For example, Trimble (1974) found that a milldam constructed *circa* 1865 was made inoperable by sediment by 1906. Yet, even if the dam is not large enough to have a significant impact on trapping sediment, sediment deposited on the dam or in the backwaters created by it is unequivocally historic. Therefore, by knowing the time of dam construction and the total depth of sedimentation, mean annual sedimentation rates can be calculated.

Culturally-Accelerated Erosion

Recent studies have documented accelerated upland erosion on the NC coastal plain. For example, Slattery et al. (1997) reported soil loss of 3.4 t ha^{-1} on a NC coastal plain agricultural field, while Phillips et al (1993) estimated a time-averaged rate of upland soil loss in the NC coastal plain of 9.4 t ha^{-1} yr^{-1}. Only recently has the role of human agency in geomorphic change been addressed in the coastal plain (Sheridan et al. 1982; Lowrance et al. 1986; Phillips et al. 1993; Phillips1993, 1995, 1997a,b). Some studies have focused *primarily* on culturally-accelerated erosion and sedimentation (Phillips 1993,1997a,b).

Phillips (1997a) investigated the impacts of human agency on geomorphic changes in the Croatan area of the NC coastal plain. Estimates of historical sedimentation were calculated for a variety of soil types. Because the humid subtropical climate of the NC coastal plain demonstrates no distinct wet/dry seasons and little seasonal variation, and slopes, geological activity, and climate provide little impetus for accelerated soil loss (Daniels et al. 1971; Phillips 1997a), Phillips concluded that any rapid geomorphic change will more than likely be a result of environmental factors other than geology and/or climate. Land use, including rapid vegetation alterations after European settlement, increased the erosion and sediment rates in the coastal plain. An example of this is in the forest alterations created for farming and logging in the Croatan area after 1700. These transformations induced an increase in erosion and sediment transport to streams. Alluvial sedimentation rates varied from a minimum of 1.9 mm yr^{-1} to a maximum of 136.5 mm yr^{-1}. Table 1 summarizes a number of alluvial sedimentation rates of previous studies in the region.

Table 1. Average Alluvial Sedimentation Rates on Coastal Plain Floodplains

Study	Rates (mm/yr)	Location	Time Period
Phillips, 1997a	5.4 to 136.5 max.	Croatan Area, NC	~ 1760 – 1995
	1.9 to 52.4 min.	Croatan Area, NC	~1760 – 1995
Phillips, 1997b	6.8	Croatan Area, NC	~ 1700 – 1995
Kleiss *et al.* , 1996	0.1 to 26.4	Cache R. Wetland, AR	~ 1915 – 1995
Hupp & Bazemore,1993	2.4	Hatchie River, TN	1880 – 1988
Hupp & Bazemore,1993	2.8	Big Sand River, TN	1910-1988
Aust *et al.* , 1991	7.1	Mobile/Tensaw R., AL	1954-1989
Hupp and Morris, 1990	0.1 to 6.0	Black Swamp, AR	~ 1927 – 1989
Barnhardt, 1988	7.0 to 13.0	Beehive Gully, TN	~1900s – 1980s
	12.0 to 22.0	Beehive Gully, TN	~1930s – 1980s
Barnhardt, 1988	0.5	Wagon Wheel Gully, TN	2180 – 900 BP
	1.0	Wagon Wheel Gully, TN	900 - 100 BP
	7.0	Wagon Wheel Gully, TN	1880s –1980s
	10.0	Wagon Wheel Gully, TN	~ 1900 – 1980s
	18.0	Wagon Wheel Gully, TN	~ 1930s - 1980s
Simmons, 1988	4.3	Neuse River, NC	1970 – 1979
Cooper *et al.*, 1987	$\geq$ 2.5	CypressCr./PantherSw., NC	~1960s-1980s

There are many factors that influence the amount of erosion at specific locations such as grain size, energy, geomorphic and topographic setting, stress, resistance, precipitation, soil erodibility, vegetation type and density, soil hydrologic properties, and surface roughness. However, the amount of exposed soil is one of the most important factors in increasing erosion and soil loss. Vegetative cover decreases erosion by rainfall interception, rainfall retention, reduction of water velocity by root systems, and increased infiltration. Accelerated erosion and consequent sedimentation from intensive colonial agriculture and land clearing has therefore had a great impact on rivers draining the agricultural uplands (Costa 1975). Although the relatively flat relief in the coastal plain may appear to provide little geomorphic energy for carrying eroded material, seasonal flooding events can transport large amounts of sediment. Along with this, the poor drainage of many coastal plain surface soils significantly increases runoff.

The amount of soil loss and sedimentation that occurs within the coastal plain region is comparable to those areas, such as the southeastern piedmont, with more visible and recognized geomorphic fluctuations (Trimble 1974; Phillips 1990). In the first 150 years after colonial settlement, sedimentation increased from agriculture and the development of highways, bridges, mining, large-scale silviculture, and urban areas (Trimble 1974). The intersection of human impacts and other environmental factors creates a matrix of complex geomorphic events that produce transformations of the landscape.

Research in other locations has also investigated links between land use practices and increased sediment yields (Ursic 1963; Trimble 1970, 1974). In a study of the southeastern piedmont, Trimble (1974) addressed two primary issues: (1) Was soil erosion occurring prior to European settlement, and (2) What are the spatial and temporal patterns associated with erosive land use and consequent erosion? As part of a project to construct a predictive model of erosion and consequent sedimentation under agricultural land use practices, Trimble analyzed archival land use history and erosion in the Southern piedmont. Although sedimentation does not directly correlate with erosion due to colluvium storage (Trimble 1970, 1974; Renfro 1975; Meade 1982; Walling 1983; vanHooff and Jungerius 1984; Sutherland and Bryan 1991), Trimble (1974) found that soil loss over a short period was more significant than the same soil denudation over two centuries of less intense land use. However, because of the storage and remobilization of sediments, a considerable temporal lapse of increased sediment yields in the watershed area occurred. Barnhardt (1988) drew similar conclusions in studies of loessal soils in a West Tennessee park showing significant ranges in sedimentation rates between two gullies (Table 1). In addition, he found that most sediment eroded from agricultural fields travels in episodic pulses. These episodic events of sedimentation may be evident in soil profiles by sporadic occurrences of upland sediments.

These studies provide data indicating a direct relationship between erosive land use practices and increased sedimentation on floodplains and in sediment yields. However, research conducted in this area has often focused on broad, regional scales. Assumptions are often made regarding uniform depositional processes over time and space. It is therefore necessary to clarify characteristics in variable sediment patterns on a local scale.

Sedimentation Variability

A floodplain is a spatial “mosaic” of sediment (Sigafoos 1964). Sediments can exist in varying states of erosion, deposition, and/or reworking by numerous channel or overbank processes. Deposition is therefore spatially and temporally heterogeneous (Campbell 1992; Malanson 1993), and sediments are in temporary storage across space. Hupp and Simon (1989), for example, investigated temporal variations in sedimentation as a result of stream channelization. They found that sedimentation rates were highest after channelization, in the early stages of stream widening and aggradation.

Often, coastal plain stream channels are not confined within narrowly-spaced valley walls, which tends to result in broader floodplain development. This allows deposition to occur over a greater area and for a significant amount of channel migration to occur compared to areas with steeper and narrower valley walls (Schumm 1977). However, the expanse of deposition is dependent upon vegetation and microtopography near the stream channel (Pye 1994). Differences in vegetation patterns over a floodplain area can result in variable spatial sedimentation. For example, organic matter generally increases in alluvial sediment from the edge to the center of cypress domes related to the density of vegetation (Monk and Brown 1965). The bottomland areas of coastal plain streams in the Southeastern U.S. are extensive vegetated wetlands with seasonably variable flow regimes (Hupp and Osterkamp 1996). The variations in flow can result in temporally variable sedimentation patterns.

Sedimentation patterns can vary on broad and local scales relative to specific environmental conditions. Walling (1993) concluded that diverse topography, land use, and soil loss from specific sources causes local variations in sediment delivery response. Aust and others (1991) found that variations in sedimentation rates were a result of diverse harvesting methods in a clear cut swamp during a flood season in the Tensaw River Delta, Arkansas. A recent study analyzed the spatial and short-term temporal variations of sedimentation in wetlands along the Cache River, Arkansas (Kleiss 1996). The spatial variability of sedimentation rates was explained by distance from the river, flood durations, and basal area of trees. Hupp and Morris (1990) investigated the spatial and temporal variations of sedimentation in the Black Swamp, Arkansas in relation to topographic setting and hydroperiods. In this study, sedimentation rates (Table 1) and hydrologic periods had a negative exponential relation.

Overall, varying sedimentation can result from a myriad of factors such as different slopes, geomorphic mechanisms, land uses, and vegetative cover, among many other things (Barnhardt 1988; Hupp and Morris 1990; Aust et al. 1991). This fact can be easily recognized through contemporary research but has only been documented on a broad scale. Often, stratigraphic studies are necessarily confined to utilizing only a few core samples over a broad area to reconstruct sedimentary histories or to document depositional events. Schumm (1977), for example, reconstructed the suballuvial morphology of the James River Valley based upon three drill holes. Nanson and Young (1981) reconstructed floodplain alluvial stratigraphy utilizing five cores along a 5 km coastal stream floodplain in New South Wales. These studies raise questions as to whether a few cores or samples can actually be representative of broad areas. This research does not recognize nor emphasize any local spatial variability in sedimentation.

This leads to two major questions: (1) How extensive is local spatial variability in sedimentation, and (2) What are the possible causes and controls of this variation? This study attempts to address these issues.

Sediment Sources

Sediment may enter into a fluvial transport system by channel erosion, unconcentrated surface runoff, rills, gullies, or mass movements. For sediment to be transported, an ample supply of sediment must be available along with the necessary transport capacity. It is well established that removal of forests and vegetation from the land greatly increases the availability of soil to be eroded (Trimble 1974; Costa 1975; Knox 1977; Lowrance et al. 1988; Phillips 1993, 1997a,b). However, it is also well-established that a small proportion of sediment eroded from hillslopes actually makes it to the basin outlet (Meade 1982; Walling 1983). Sediment is most often deposited as colluvium and/or will remain in fields where erosion has occurred (Renfro 1975; Knox 1977). Thus, sediment redistribution may be the major mechanism within the basin system. The conventional view is that sediment carried by coastal plain streams is from a source elsewhere, especially the piedmont. However, Phillips (1993, 1995, 1997b) argued that the majority of historic sediment delivered to the lower reaches of the Neuse and other NC rivers is of coastal plain, rather than piedmont, origin. This suggests that piedmont sediment may be stored in the upper reaches of the streams, and/or the sediment is being diluted by increased coastal plain sediment (Phillips 1993, 1995, 1997a,b). By calculating slope-to-stream sediment delivery, Phillips (1995) found the amount of eroded coastal plain sediment great enough to account for the sediment supply to coastal plain rivers.

Floodplain deposition can occur in stratigraphically recognizable pulses relative to land use on uplands adjacent to or surrounding an area of fluvial transport. Rapid road, bridge, and housing construction along with land denudation and forest regrowth for periodic agricultural or silvicultural use can provide increased amounts of sediment in relatively short time spans. This can be recognized in the stratigraphic record by a surge or surges of upland sediment in the floodplain from the washload of the channel. Although other studies (Sheridan et al. 1982; Lowrance et al. 1988; Barnhardt 1988) have delineated sedimentation rates and/or delivery ratios from land use practices on a broad watershed or regional scale, little research has analyzed the implications and established a history of land use practices resulting in variability in sedimentation patterns on a local scale. This research links land use practices surrounding the upstream and adjacent river sources to the sediment delivered to the study site.

Although excessive rates of deposition have been linked to upstream sediment sources (Lowrance et al. 1988), accounting for variability of sediment rates on this regional scale is relatively complex. Relating geomorphic changes to sediment yield becomes even more difficult due to colluvial storage and spatially variable transport dynamics. Concentrating on local scale deposition greatly increases the possible delineations of depositional sources, yet distinguishing the source(s) of sediment remains a complex task (Pye 1994), largely due to reworking of floodplain deposits and storage complications. Broader scale studies have utilized Caesium-137 tracers (Lowrance et al. 1988; Walling and Bradley 1988; Walling 1990) and mineralogical indicators such as mica or muscovite flakes (Phillips1992a,b) to establish sediment sources. For this research, possible sediment sources are discerned by comparing standard soil physical properties of upland soils to that of the floodplain deposits.

CHAPTER III

STUDY AREA

General Setting

The study site is located in a forested backwater area of a historic gristmill dam site in Martin County, North Carolina (Fig 2). The millpond is situated 8 km west of Williamston, directly south of NC 125 in a bald cypress (*Taxodium distichum*) swamp. Information concerning purchases and transfers of mill ownership was obtained from the Martin County Office of Register of Deeds. These records date the mill back to 1869. Local residents suggest an earlier age of construction; however, deed records do not support this. Transition of mill ownership occurred four times from 1869 to 1933. The mill was operated by water until the 1930s when electric motors were installed. It is said to have burned in the 1950s, breaching the dam, with only the bottom structure remaining at present. At this time, the mill is referred to as Abbitt's Mill under the name of its owner from 1933 to the 1950s (Martin County deeds 1997).

The watershed of the millpond has an area of 4500 ha (Fig. 3). On the most recent U. S. Geological Survey quadrangle map and soil survey (SCS 1989) the creek is unnamed. The main stem flow to the millpond is from Beaverdam Creek flowing north towards NC 125 (Fig. 4). Along with Beaverdam Creek, several third and fourth order low gradient tributaries, most with 0 to 6 percent gradients, flow to the mill site that eventually empty into the Roanoke River with a final outlet into the Albemarle Sound. The tributaries adjacent to the millpond are at present slow-flowing wooded swamp areas.

Figure 2. North Carolina coastal plain with scarps and terraces. Study site is located in eastern Martin County on the Talbot terrace (north-central portion of map). Source: Wyrick, 1993.

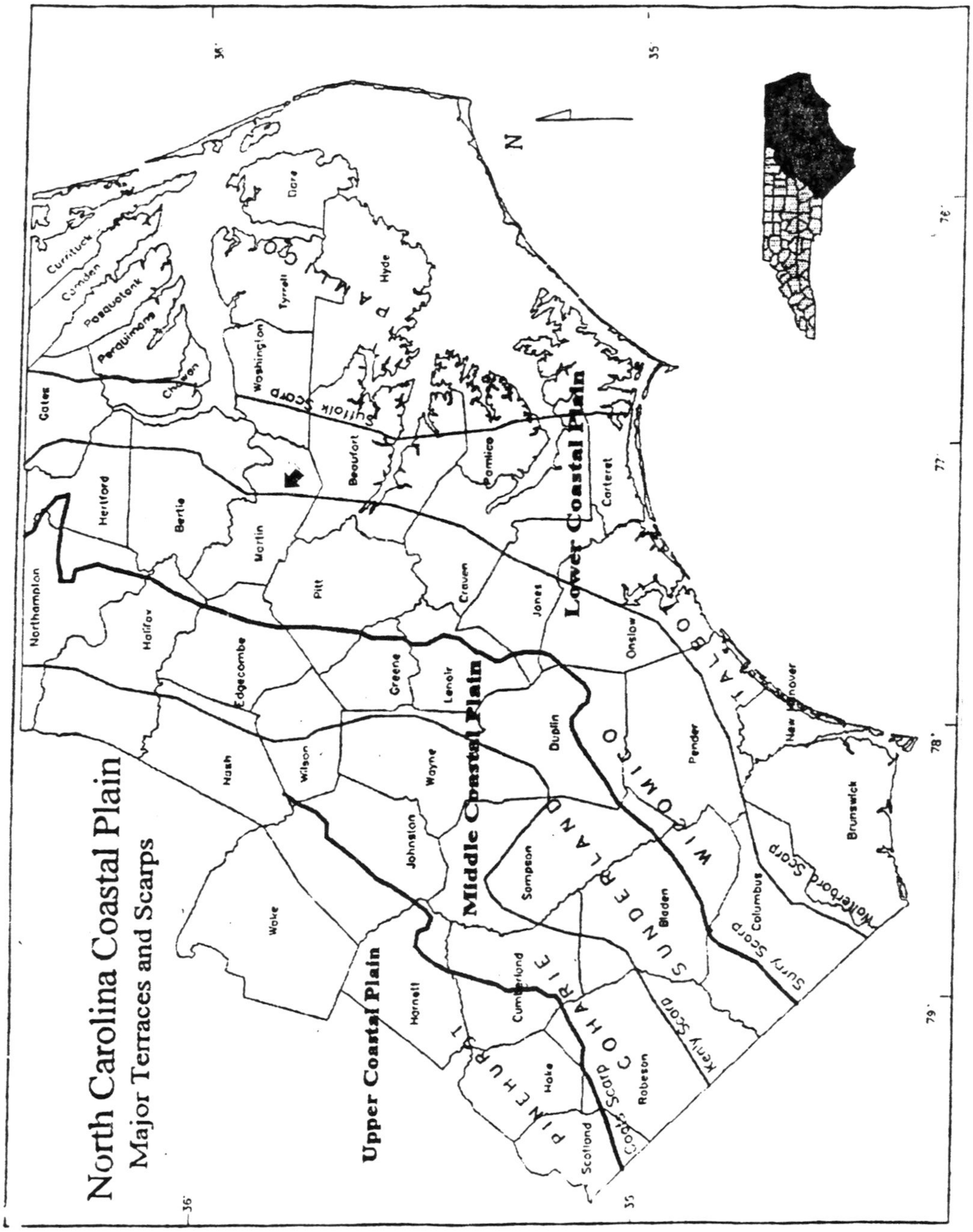


Figure 3. Topographic model of the gristmill watershed

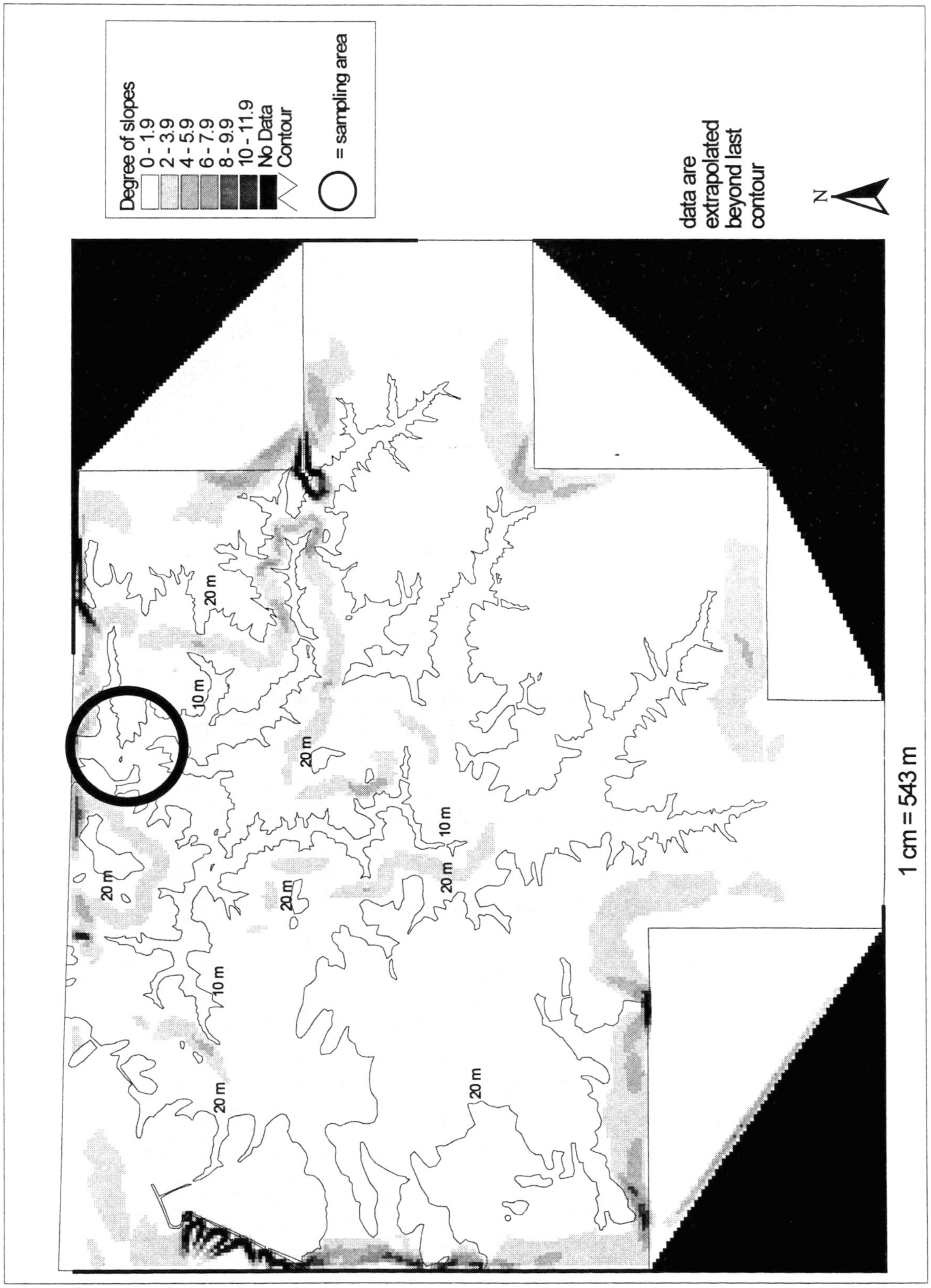
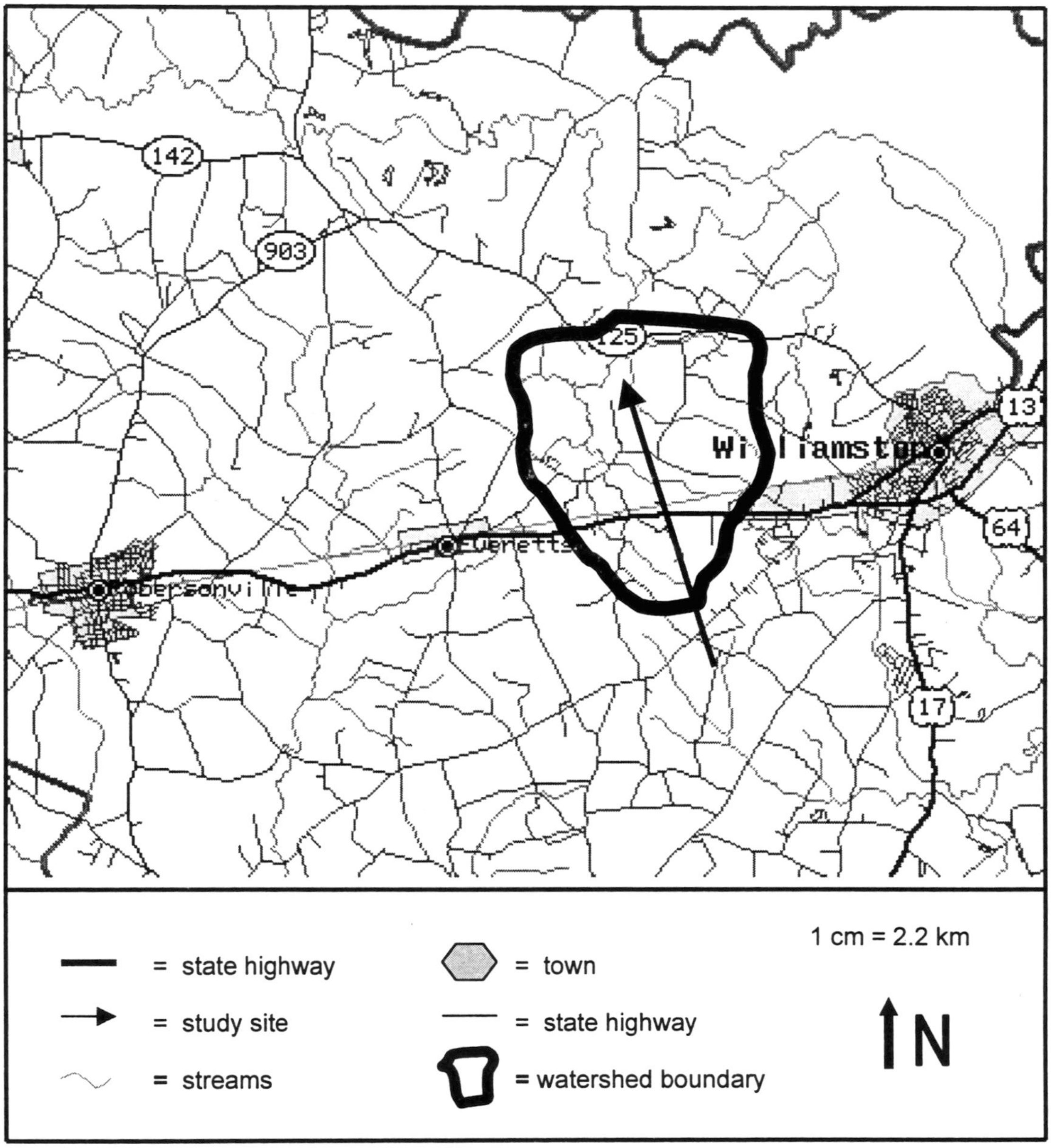


Figure 4. Map of Study Site and Surrounding Areas. Source: Tiger Map Service, 1997.



The vegetative composition of the swamp is typical of most southeastern coastal plains (Hupp and Morris 1990). Trees within the backwater area are mostly bald cypress (*Taxodium distichum)*, but also include tupelo gum (*Nyssa aquatica)* and some hydrophytic oaks (*Quercus sp.)*.

Geology and Geomorphology of the Lower Coastal Plain

The North Carolina lower coastal plain is a segment of the Atlantic coastal plain consisting of seaward sloping marine terraces and scarps lying nearly parallel to the coastline. In North Carolina, there are six recognized terraces and scarps (Fig. 2). The terrace and scarp system of the coastal plain evolved through cycles of sea level rise in interglacial periods and marine lows in glacial periods (Soller and Mills 1991). Sediments were deposited as sea level transgressed and regressed. Scarps represent paleoshorelines. As marine waters regressed, transgressive sediments were dissected and entrenched forming river systems and regressive sediments of shallow-marine, barrier, back-barrier, and fluvial origin were deposited (Soller and Mills 1991). The surfaces created are therefore underlain by Late Cretaceous to Holocene marine, fluvial, and estuarine sediments typically of sand, silt, clay, and shelly materials. The sediments generally thicken towards the coastline ranging from less than one meter thick at the Fall Zone, the boundary between the piedmont and the coastal plain, to more than 18 m thick at the coastline. The underlying mineral sediment of the terraces are primarily of Pleistocene age (Daniels et al. 1978). Elevations and ages of each surface generally decrease towards the modern shoreline (Markewich et al. 1990). Until recently, floodplain sediments of the coastal plain were assumed to be derived from either piedmont-transported sediment or alluvium or colluvium from adjacent tributaries, terraces, or valley sides (Markewich et al. 1990); however, Phillips (1995) suggests that most lower coastal plain floodplain sediments are derived primarily from coastal plain sources.

Daniels et al. (1978) identified three geologically stable physiographic segments of the NC coastal plain as the upper, middle, and lower divisions: the upper beginning at the Fall Zone and the lower ending at the coastline. Each division has its characteristic formations and scarps, although overlapping among some surfaces does occur. Because of the interfingering of sediments from sequential sea level rises and falls, an easily discernible Quaternary stratigraphy on the coastal plain is lacking.

This study focuses on the lower coastal plain region. This region extends east of the Surry Scarp including the Wicomico, Talbot, and Pamlico terraces. Two scarps, the Walterboro and Suffolk, separate these terraces (Fig. 2). From the Pamlico, the lowest lower coastal plain surface, to the Wicomico, elevations range from sea level to 30.5 m (Smith et al. 1976) with relief changes in some areas only of 1.5 m per 3 km (Daniels et al. 1984). The relief in this segment of the coastal plain is measurably less than that of the upper and middle coastal plain and has larger and wider areas of poorly to very poorly drained surfaces.

The climate of this coastal plain region is humid subtropical with a total annual precipitation of about 123 cm. Average monthly temperatures range from 5.7°C in January to 26°C in July. The average yearly temperature is 16.2°C (SCS 1989).

Soils

Pedogenesis in coastal plain soils generally initiates from siliceous parent material of marine, estuarine, and fluvial origins on upland soils. The coarse texture of the soils allows for leaching and eluviation. Soils are more developed and thicker, ranging from 5 to 10 m thick, towards the Fall Zone (Markewich et al. 1990). The lower coastal plain soils are generally greater than 1.5 m thick (Daniels et al. 1984) with poorly-developed or no B horizons (Phillips et al. 1993). Mineral floodplain soils have typical bulk densities of about 1.4 g cm^{-3}.

The Pamlico terrace consists primarily of 57 to 87 percent quartz with feldspars of secondary importance. Ninety-one to 99 percent of Talbot and Wicomico soils are quartz and siliceous (Smith et al. 1976). Soils may also contain abundant iron concentration (Markewich et al. 1990).

Ultisols, the most weathered soils in the mid-latitude region, are the predominant soil order. Histosols are common on floodplains in the lower coastal plain, in geologically recent swamps, marshes, and pocosins. The development of Histosols is governed more by the decomposition of organic material in anaerobic conditions than by the weathering of the mineralogical parent material. Mature soil profile development in Histosols is therefore inhibited (Wyrick 1993).

The Soil Conservation Service (SCS) (1989) suggests that the floodplain area of the millpond where sampling is conducted consists primarily of Bibb loam soils (Coarse loamy, siliceous, acid, thermic Typic Fluvaquents). However, field research in this study suggests significant disparities from the SCS soil property descriptions in this area. According to the Soil Conservation Service (1989), the soil is frequently flooded, poorly drained, is not agriculturally productive, and typically remains as wooded swamp area. These observations were confirmed in the field. However, Bibb soils are also described having dark grayish brown loam surface layers with gray-shaded mottles, an upper surface layer of light gray sandy loam with gray and yellow-shaded mottles, and a lower portion of gray loamy sand. The results section of this paper will explicate how these properties vary from this uniform description.

The Soil Survey of Martin County, North Carolina (1989) indicates that most of the slopes connecting the uplands to the sampling area, especially on the east side of the millpond, are Bonneau loamy sands with 6 to 12 percent slopes. Bonneau soils are well drained with rapid surface and subsurface permeability. The surface layer is very dark gray loamy sand, the subsurface layer extending to 70 cm deep is very pale brown loamy sand, and the upper layer of the subsoil is yellowish brown and brownish yellow sandy clay loam with red and brown-shaded mottles. Most Bonneau soils with 6 to 12 percent slopes are used as woodlands.

According to the Soil Survey of Martin County, North Carolina (1989), almost all of the upland areas adjacent to the sampling area consist of Norfolk loamy fine sands with 2 to 6 percent slopes (Table 2). These soils typically have a yellowish brown loamy fine sand surface layer with a subsoil extending up to 155 cm deep. The upper layer of the subsoil is yellowish brown sandy loam. Norfolk soils are well-drained, moderately permeable, and are commonly cultivated for crops. The detailed soil map of the SCS (1989) indicates that most of the upland soils within the watershed are either Norfolk loamy fine sands with 0 to 2 percent or 2 to 6 percent slopes, Goldsboro fine sandy loams, or Bonneau loamy sands (Table 2). Goldsboro soils are moderately well drained, have a moderately slow permeability, and are typically nearly level with 0 to 2 percent slopes. Most Goldsboro soils are used for croplands. The surface layer of Goldsboro soils is dark grayish brown fine sandy loam, and the upper layer of the subsoil if yellowish brown sandy clay loam with brown-shaded mottles. Bonneau soils (BoB) are well drained with rapid surface and subsurface permeability. Slopes can range from 0 to 6 percent. The surface layer of Bonneau soils is grayish brown loamy sand, the subsurface layer, extending about 65 cm deep, is light yellowish brown loamy sand, and the upper subsoil is brownish yellow and light yellowish brown sandy loam. Mostly, Bonneau soils are used for croplands, but are used in a few areas for woodlands and pasturelands.

Table 2. Upland soils of the watershed area. Source: SCS (1989)

Soil Name	Slope	Description	Typical Land Use
Bonneau	0 - 6%	Grayish brown loamy sand sfc. layer; well drained; Loamy, siliceous, thermic Arenic Paleudults	Croplands
Bonneau	0 – 12 %	Very dark gray loam sand sfc. layer; well drained; Loamy, siliceous, thermic Arenic Paleudults	Woodlands
Craven (very small amount)	1 – 4%	Brown fine sandy loam sfc. layer; moderately well drained; Clayey, mixed, thermic Aquic Hapludults	Croplands
Goldsboro	0 – 2%	Dark grayish brown fine sandy loam sfc. layer; moderately well drained; Fine-loamy, siliceous, thermic Aquic Paleudults	Croplands
Norfolk	0 – 2%	Light yellowish brown loamy fine sand sfc. layer, well drained; Fine-loamy, siliceous, thermic Typic Paleudults	Cultivated Crops
Norfolk (west adjacent slopes)	2 – 6%	Light yellowish brown loamy fine sand sfc. layer; well drained; Fine-loamy, siliceous, thermic Typic Paleudults	Cultivated Crops
Wickham (small amount)	0 – 6%	Yellowish brown sandy loam sfc. layer; well drained; Fine-loamy, siliceous, thermic Typic Hapludults	Croplands
Winton	8 – 15%	Dark grayish brown fine sandy loam sfc. Layer; moderately well drained; Fine-loamy, mixed, thermic Typic Hapludults	Woodlands
Woodington (at airport)	< 2%	Black fine sandy loam sfc. layer; poorly drained; Coarse-loamy, siliceous, thermic Typic Paleaquults	Woodlands

CHAPTER IV

METHODS

Historical Land Use

Historical records of land use provided information regarding land use activity on upland areas. Deed records were first examined to develop a precise age of the milldam. Any sediment behind the milldam is unequivocally historic. Therefore, the time of the dam construction provides a baseline date for alluvial aggradation in the backwaters of the millpond.

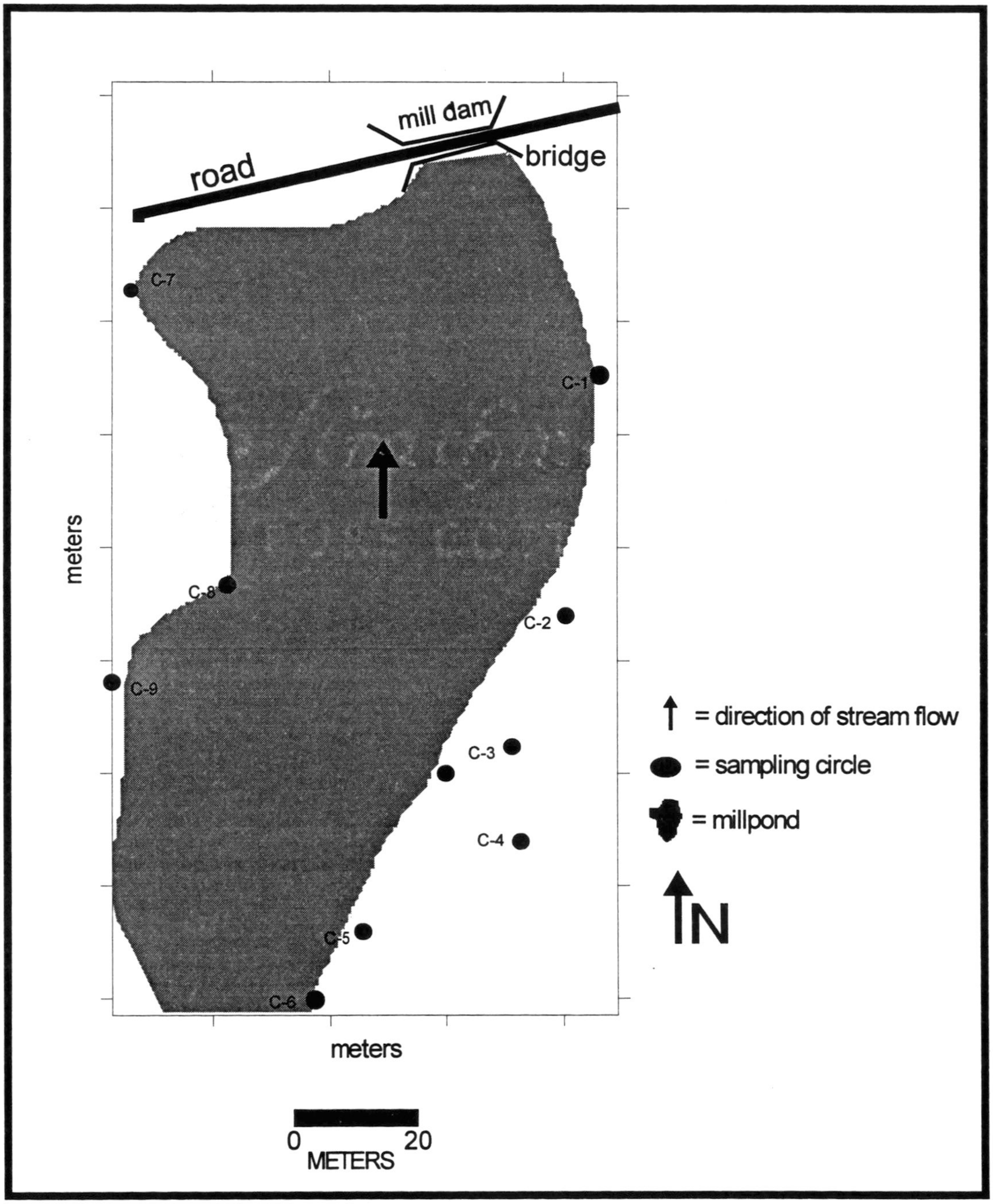
After the watershed area of the millpond was manually delineated on 1:24,000 topographic maps, historic land use data was collected for the upland areas within the watershed. Agricultural land use and deforestation trends were researched on three levels increasing in scale from general NC coastal plain land use, to Martin county, and local land use. As a whole, coastal plain, Martin county, and the gristmill watershed agricultural expansion and forest denudation follow the same general pattern. Cathey (1956,1974) traced the development of agriculture, including land use techniques, forest and soil use, and crop production, in Eastern North Carolina from the pre-civil war era to the late nineteenth century. Trends in the timber industry and forest cover on the NC coastal plain were found in historic documents such as Pinchot and Ashe (1897) and Ashe (1915), along with Phillips (1994). These sources provided information on historic forest denudation, successional growth, areas of most intensive forest excavation, and tree species most suitable in industry and most easily removed from upland areas. Land use data pertaining to Martin County and the drainage basin of the study area were derived from several sources. The State Board of Agriculture (1896) provided a detailed account of Martin County land use practices, including agricultural development, timber stand status, and corresponding soils in 1896.

Manning and Booker (1979) traced agricultural development in Martin County from the period of European settlement to contemporary times. Soil data was extracted from an early Martin County Soil Survey (Perkins and Bacon 1928) and the contemporary soil survey (SCS 1989). U.S. Census of Agriculture data from 1870 provided acres in woodland and cropland on the uplands around the time of dam construction. Several Martin County research documents, including Martin Agricultural Stabilization and Conservation County Committee (1959, 1970), Howell et al. (1967), and Martin County Planning Board (1968), provided accounts of forested lands and/or farms from 1959 to 1970. Contemporary forest, timber, and cropland data was derived from the U.S. Census of Agriculture (1992) and Shore (1993). In addition, to more accurately delineate possible sediment sources from episodic pulses of deposition, specific construction events within the watershed were identified. Manning (1979) provided a detailed account of the time and place human-constructed features such as roads, bridges, railroads, and gristmills were constructed within the county.

Field Methods

Prior to field data collection, a general sampling strategy was developed to randomly remove a stratigrahic core at ten sites around the perimeter of the millpond. Each core would then be the center of a 4 m diameter sampling circle. Ultimately, only nine cores were excavated from the backwater area: six on the east side and three on

Figure 5. Sampling points in the backwater area of the gristmill dam

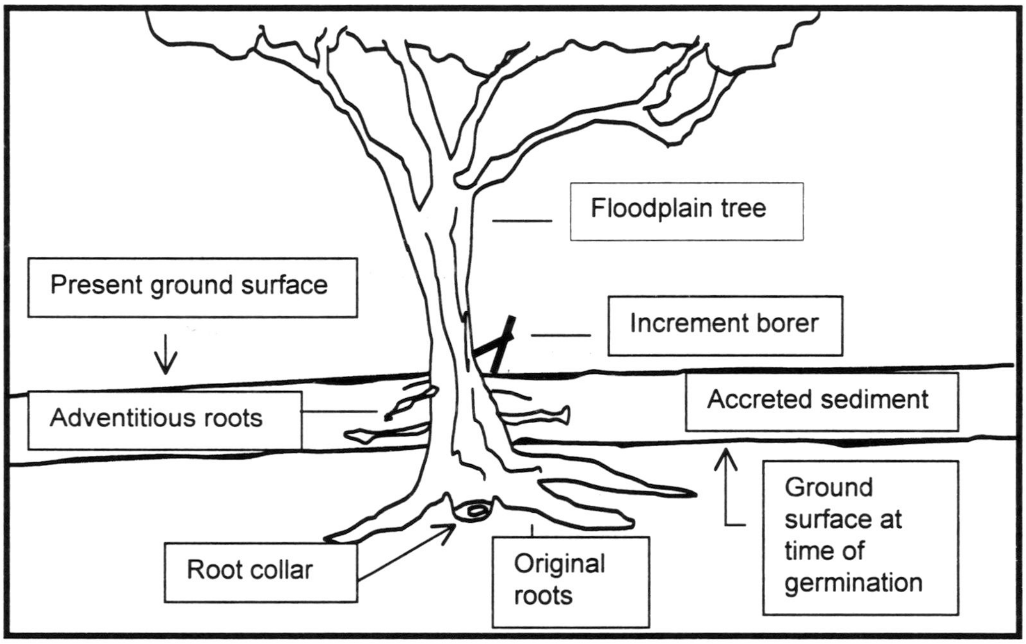


the west (Fig. 5). This final sampling strategy was constrained, ultimately, by accessibility to open areas within the densely-wooded backwater area, areas not inundated by water, areas where root growth would not inhibit core penetration, and areas where at least ten cypress knees could be sampled. Cores were removed in 150 x 7.56 cm aluminum pipes with aluminum clamp arms. The depth of each core hole was measured for calculations of percent compression. Sampling circles were then delineated with a 2 m radius from the core center to delineate spatial sampling for analysis of sediments, calculating sedimentation depth or scour, and finding the age of cypress knees. The cores were then taken back to the lab for stratigraphic and physical soil analysis.

Within each sampling circle, two random stratigraphic samples were removed with a Dutch-style auger for supplemental analysis. Along with this, any recognizable pulses of deposition from upland areas were examined as keys to possible sources and dates of sedimentation. Although individual soil properties such as color may not be suitable for distinguishing sediment sources (Peart 1993), a combination of properties and land use data may allow for a general distinction of sediment sources.

A dendrogeomorphic approach was used to measure depth of sediment or scour and age of the sediment for calculations of sedimentation rates. Dendrogeomorphic techniques have been employed and demonstrated useful in calculating sediment accretion rates (Sigafoos 1964; Hupp and Morris 1990; Hupp and Bazemore 1993; Kleiss 1996). Shroder (1990) provides a complete explanation of dendrogeomorphic uses and techniques. Dendrogeomorphology involves measuring the age of a tree root, or cypress knee, and the depth of sediment burying its roots to calculate sedimentation rates. The dating technique is performed by extracting increment cores from trees or cypress knees affected by some geomorphic process and counting the tree rings to estimate the age of the tree (Fig. 6).

Figure 6. Buried floodplain tree with deposition and measurements using Dendrogeomorphology. Source: Hupp and Morris, 1990.



Some floodplain trees bear a telephone pole-like appearance from burial of basal flares, root crowns, and associated adventitious roots (Hupp and Morris 1990; Hupp and Bazemore 1993). Adventitious roots are outward growths on the tree resulting from successive sedimentation burying the lower portions of the tree. Sediment depth is measured to the depth of the initial root zone or basal flare. Recognizing that trees initially begin to grow below the surface and proliferate from that initial germination point, buried roots and stems provide a logical method of estimating sedimentation (Hupp and Bazemore 1993). The root axis, located between the present ground surface and basal flare of the tree, provides an accurate estimate of the original ground surface of root development (La Marche 1968). Knees on cypress trees are "vertical outgrowths from lateral roots which develop into somewhat conical structures, varying from a few inches to several feet in height" (Kramer et al. 1952) and grow where the soil is alternately exposed and flooded. The height of the cypress knees provides a relatively accurate marker of the average high-water level of the habitat. The arch of a cypress knee can provide another general estimate of the original ground surface. Every cypress knee develops a convex arch at its center, separating it from the initial tree root from which it grows (Fig. 7). In this study, burial of the arch provides an estimate of alluvial aggradation, and exposure of the arch is recognized as scour (Fig. 7). Brown (1984) concluded that rings on cypress knees mark seasonal growth, and cypress trees have been successfully utilized in numerous dendrochronology studies (Stahle et al. 1988; Cleaveland and Stahle 1989). While the arch of the cypress knee may be only a general estimate of the original ground surface, standardizing this method throughout this study results in internally consistent and comparable estimates of sedimentation rates. Rates of sedimentation were calculated by obtaining a close estimate of cypress knee age, by counting annual rings on longitudinal cross-sections (Fig. 8), and dividing this by the depth of sediment or scour from the arch of each knee.

Within each of the nine sampling circles where the core and auger samples were extracted, ten cypress knees were randomly selected and distance measurements were made from each previously sampled knee. Each cypress knee was measured for the depth of sedimentation from the buried arch in the knee to the ground surface or extent of scour from the exposed arch of the knee to the ground surface. A longitudinal cross-section was then removed from each knee and taken back to the lab for ring counts. In addition, the elevation and location of the center of each circle was surveyed with a Topcon total station. Slope surveys adjacent to the millpond were inhibited by tree density and seasonal high water levels.

Figure 7. Cypress knee deposition and scour

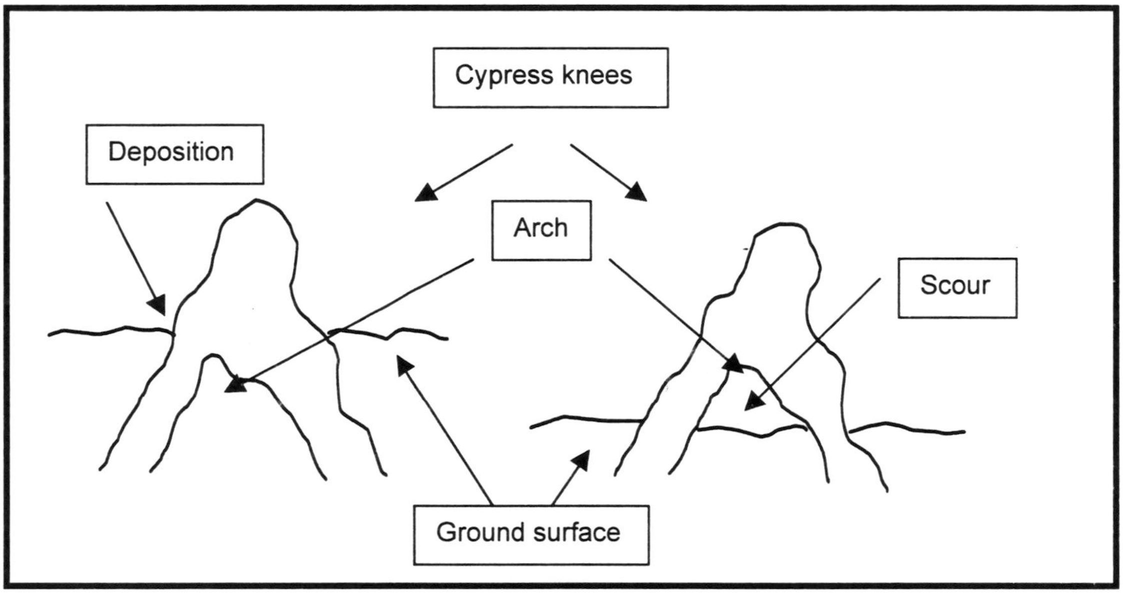
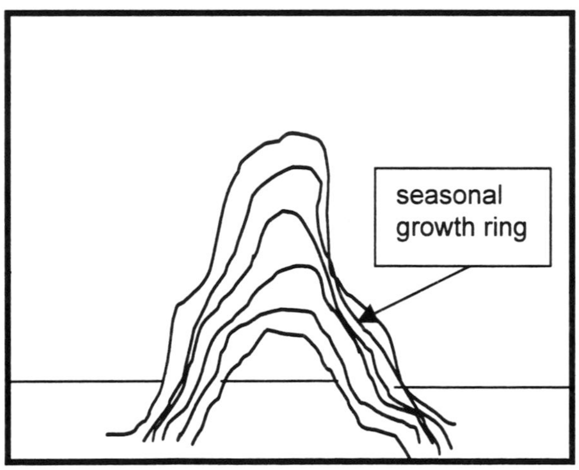


Figure 8. Longitudinal cross-section of a cypress knee



Laboratory Methods

Each core was dissected longitudinally with a circular table saw and core faces were cleaned with a fine wire and spatula. Cores were logged for physical soil characteristics, horizonation, and recognizable pulses of sediment. The physical properties of alluvium from the cores and auger samples around the millpond were compared to those of surface horizon of upland soils so that possible sediment sources could be deduced. Samples were extracted from the cores for dry bulk density and were oven-dried at 20°C for 1.5 days.

Cypress knees were each sanded using a palm-sander with 60 grain coarse sandpaper to highlight seasonal growth. As ring counts were made on each knee, water was applied along with additional sanding if needed to enhance the rings. Each sample was counted until the number of rings was matched twice, plus or minus two years. Of the few knees where consistent annual rings were not prevalent, only estimates could be made. If certain grain characters of a knee appeared as a ring, it was counted as an annual ring. This way, sedimentation rates would be under- rather than over-estimated.

A basic database of the drainage area was created in ARC/INFO to use in subsequent studies. Ten and twenty meter contours were digitized in vector format, transformed into a lattice structure, and imported into ARCView. Slopes were calculated in ARCView from the imported lattice grid coverage. The contour map was then overlain on the gridded slope map for visual and quantitative slope interpretations (Fig. 3).

Data Analysis

Sedimentation rates, using depth of sediment or scour divided by the annual ring count, were calculated for each of the 10 knees within each of the 9 circles. Basic means, standard deviations, ranges, and correlations of rates were conducted within and between each sampling circle. *A priori* plans were to use a one-factor analysis of variance (ANOVA) to statistically test for variability; however, the degrees of freedom, or number of samples, were too low for useful calculations. A Kruskal-Wallis non-parametric ANOVA was then calculated in SPSS to determine whether between-circle variations in sedimentation rates and depths exist. This would reveal whether spatial variations in sedimentation are statistically significant within the alluvial floodplain of the gristmill dam. Independent t-tests were also performed, but only to compare singular differences in means between two pairs of circles.

Additional sedimentation rates were calculated using two auger measurements per circle of the depth of historic alluvium overlying a buried swamp muck divided by the age of the gristmill dam. As noted earlier, the assumption here is that if the majority of sediment is organic, there has been virtually no inorganic sediment input. Therefore, if a swamp muck is buried by mineral sediment, an influx of upland- or upstream-derived material has most likely occurred. As mineral sediment was evident behind the milldam, it can be presumed that this accretion has occurred after milldam construction in 1869. These assumptions are necessary as a result of the lack of dating techniques and visual delineations for alluvium unrelated to the dam. Therefore, these results are presumed to give maximum apparent annual accretion rates because the age of the dam, 129 years, is the minimum possible age. Apparent rates of annual historic sedimentation were also calculated using the age since the last dam breaching in 1950; however, these rates were considered unreliable because no field evidence indicates that pre-breaching sediments were evacuated from the backwater area.

To statistically test for temporal variations in sedimentation depths and rates between circles, cypress knees were clustered, similar to the technique used by Hupp and Morris (1990), into five age groups: a 10-29 year group, a 30-39 year group, a 40-49 age group, a 50-59 age group, and a 60 and over age group. Means, ranges, and standard deviations were calculated for each age group. A Kruskal-Wallis ANOVA was performed to test for temporal variations of sedimentation depths and rates between age groups. Independent t-tests were used to compare independent differences between two different age groups.

CHAPTER V

RESULTS

Historical Land Use in Watershed

Agriculture and Timber. Post-settlement land use within this Martin County drainage basin generally corresponds with that of the NC coastal plain as a whole. European settlers arriving in the coastal plain in the late seventeenth and early eighteenth century encountered a massive expanse of longleaf pine (*Pinus palustris*) and hardwood forests. Although the original settlers, various Native American groups, kept patches of land open by fire and clearing, the large majority of the land was still covered in forests (Phillips 1994). The 1870 agricultural census found 178, 443 acres (61 percent) of Martin County covered in woodland area. However, by the mid- to late-1700s, the majority of the land within Martin County had been converted for agricultural use (Cathey 1956). The common practice at this time was to reap the benefits of the land, take no action to replenish the soils or forests, leave the land infertile, and allow sediment to wash away and the land to grow back as pines and sedges (Cathey 1974). Although this practice may appear comparable to contemporary clear-cutting, modern practices typically are designed with management plans usually taking into account and planning for erosive activity and habitat alterations. After the pine forests regrew, however, most were once again stripped for manufactured products and continued agricultural pursuits (Pinchot and Ashe 1897; State Bd. of Agr. 1896; Cathey 1974; Phillips 1994). In fact, by 1897, Pinchot and Ashe noted that "The forests of Beaufort, Washington, and *Martin* counties have, however, been exhausted" (163, emphasis mine).

By 1898, the population of Martin County was 15,221 with a booming timber industry along the cypress swamps of the Roanoke. With the primary focus on the timber industry at this time, agriculture was less advanced than in adjacent counties (State Board of Agriculture 1896). Most of the upland soils in the watershed between 1898 and 1928 were classified as sandy loams (State Board of Agriculture 1895; Perkins and Bacon 1928). The higher ridges near the rivers, however, were "a lighter and more sandy soil" (State Board of Agriculture 1896, 365). Almost all of the uplands developed for agriculture were classified as Norfolk fine sandy loams with a gray surface layer lacking organics underlain by a pale-yellow to grayish yellow layer (Perkins and Bacon 1928). The contemporary soil survey shows the majority of upland soils to be Norfolk loamy fine sands, Goldsboro fine sandy loams, or Bonneau loamy sands (SCS 1989).

By 1968, areas along the creeks and tributaries in the watershed were described as not suited for agriculture and urban development, and the uplands were utilized for a mixture of timber harvesting and agriculture. Large commercial timber companies were purchasing farmlands and converting them to tree farms at this time (Martin County Planning Board 1968). An airphoto from 1974 overlain by the 1989 Martin County Soil Survey shows that almost all upland forests on Norfolk soils have been cleared. Remaining forested areas exist only along streams and tributaries as Bonneau, Bibb, and some dispersed Winton soils (SCS 1989). Much of the forested land exists as pine plantations. Forest regrowth occurred from the early 1900s to the 1940s and subsequently declined from 1949 (127,700 acres) to 1992 (36,769 acres). Much of the drainage area had been timbered in the years from 1960 to 1990, with the heaviest harvests in poorly-drained non-riverine pocosins and swamps, not on the upland areas. By 1990, most of the upland areas of Martin County were cleared for crops (Frost et al.

1990). Croplands cover 31 percent (91,627 acres) of the land, woodlands cover 12 percent (36,769 acres), and 3 percent (10,205 acres) of Martin County is used for pasture (U.S. Census of Agriculture 1992). At present, the upland areas remain primarily as agricultural croplands. As of 1993, 62 percent (183,300 acres) of Martin County was covered in forested land (Shore 1993), the majority of which is located along the perimeter of rivers, not the uplands (SCS 1989). No major areas of industrialization or incorporated towns exist in the drainage basin. Therefore, upland sediment supply is most likely from deforestation, agriculture, and possibly construction events. Table 3 summarizes upland land use practices after milldam construction.

These data suggest three major periods of increased soil exposure and sediment entrainment: one directly after European settlement when the forests were denuded, one in the mid-1800s until the early 1900s when deforestation reached its peak and scientific soil conservation programs increased in popularity (Cathey 1974), and one beginning about the early 1960s through the 1990s. Sediment behind the milldam, however, records only the latter two pulses after dam construction in 1869.

Table 3. Summary of upland land use after milldam construction (1869)

Time period	General land use
1869 to early 1900s	Upland forest clearing for crops/timber; nearly "exhausted" forests by 1897 (Pinchot and Ashe 1897)
Early 1900s to ~1940s	Period of forest regrowth throughout upland areas
Early 1950s to 1990s	Successive decline in woodland areas; most wooded areas only along stream channels
Present	Uplands mostly croplands

Construction. Road, bridge, and railroad construction within the watershed after European settlement constituted increased land clearing and alterations elevating the amount of exposed sediment for entrainment. In about 1735, the road crossing over the milldam, now highway 125, was developed as a post road, and was reconstructed with mule-drawn scoops as a main road with sandy upland soils in the early 1900s. At this time, the demands for roads increased, and the majority of roads were created, albeit rutty and with abundant sand. By 1921, many roads were added and improved, including NC 64 extending east-west in the southern part of the watershed. All road building generally halted by early 1927; however, NC 125 was still not hard surfaced by 1931 (Manning 1979).

Between the mid- to late-1800s, the Seaboard Coast Line railroad was built crossing east-west along the southern part of the drainage basin. By 1901, wooden bridges over creeks were replaced with iron or steel bridges. In 1940, a major flood wiped out many bridges along the Roanoke and its tributaries (Manning 1979). The bridge directly over the milldam was reconstructed in 1954. Along with this, a house was constructed in the early 1990s on the uplands directly adjacent to the west side sampling circles. At present, the majority of the watershed includes predominately rural upland areas used mostly for croplands and some timberland.

Sedimentation Rates Within Milldam

Sedimentation rates were also calculated using the depth of historic alluvial sediment from two auger samples per circle divided by the age of milldam (129 years) are shown in Table 4. As core samples were imperative to describe alluvial stratigraphy, they were not used to calculate sedimentation rates as a result of a mean compression rate amongst the cores of 42 percent. Compression rates in the cores ranged from15 to

67 percent. The mass calculations for sedimentation rates were calculated using the average depth of historic sediment for the sampling area, the average dry bulk density, and the areas of both the sampling area and the watershed.

Table 4. Mean annual sedimentation rates per circle using age of milldam

Circle number	Mean depth (cm)	Sedimentation rate (mm yr^{-1})
Circle 1	34.5	2.5
Circle 2	Muck	Muck
Circle 3	37.5	2.9
Circle 4	35.0	2.7
Circle 5	21.5	1.6
Circle 6	25.5	2.0
Circle 7	48.0	3.7
Circle 8	29.5	2.3
Circle 9	50.0	3.9

Rates range, on average, from 1.6 mm yr^{-1} in circle 5 to 3.9 mm yr^{-1} in circle 9. The average overall annual sedimentation rate of the study area using this method is 2.7 mm yr^{-1} (Fig. 9). This indicates a significant amount of historic alluvial sedimentation has occurred in this backwater area. The average mass rate of sedimentation for the watershed area is 0.024 t ha^{-1}. This rate may appear low; however, it is not directly comparable to other studies as a result of varied methodologies. This rate does suggest upstream colluvial storage typical of coastal plain areas.

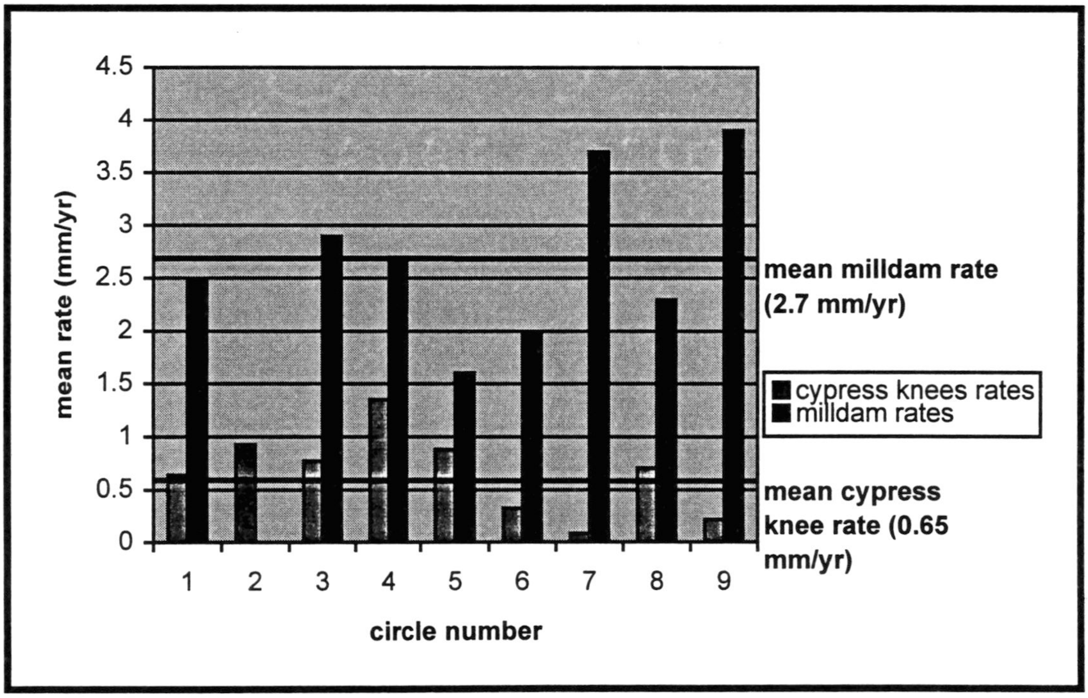
Sedimentation Rates With Cypress Knees

Sedimentation rates computed within the sampling circles using the cypress knee method, or dendrogeomorphology, are shown in Table 5 and Figure 9. Individual deposition depths, ages of knees, and sedimentation rates for the ten knees within each of the nine sampling circles are referenced in Appendix A. The overall average sedimentation rate per year, including rates of scour, is 0.65 mm yr^{1}, with a standard deviation of 0.96.

Table 5. Annual sedimentation rates per sample circle using cypress knees. Negative numbers = scour

Circle number	Mean (mm yr^{-1})	Standard dev.	Range (mm yr^{-1})
Circle 1	0.64	0.95	-.95 – 1.71
Circle 2	0.93	0.17	.00 – 2.00
Circle 3	0.77	0.46	.00 – 1.76
Circle 4	1.35	0.95	-.25 – 2.68
Circle 5	0.88	1.00	-.44 – 3.27
Circle 6	0.33	1.52	-2.80 – 1.67
Circle 7	0.08	0.69	-.67 – 1.33
Circle 8	0.71	1.00	-.89 – 2.83
Circle 9	0.22	0.84	-.83 – 2.05
Total	0.65	0.96	-2.80 – 3.27

Figure 9. Comparison of cypress knee sedimentation rates per circle to milldam rates per circle



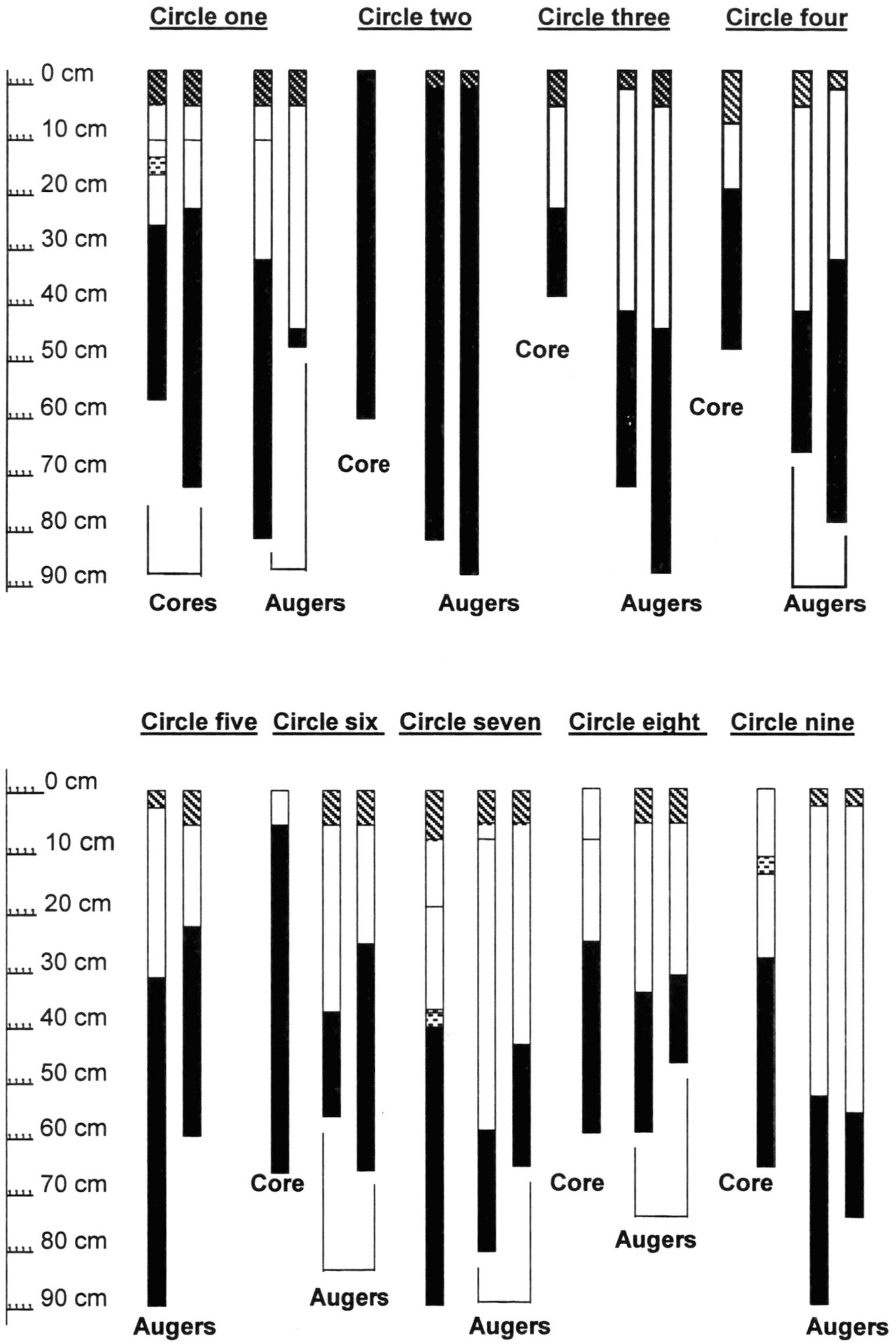
Mean annual rates per sampling circle range from 0.08 mm yr^{-1} in circle 7 on the east side of the millpond to 1.35 mm yr^{-1} in circle 4, a sampling circle located near intermittent tributaries and inundated for short, frequent periods on the west side of the millpond. Standard deviations are high within each circle indicating variable sedimentation rates within each circle. This variability is also evident with the wide range of rates within each circle. For example, the highest individual rate of scour is 2.8 mm yr^{-1} (circle 6), and the highest individual rate of deposition is 3.27 mm.

Spatial Variability

A considerable amount of measured and visual variation was evident in the field. Core and auger samples reveal variability in the alluvial stratigraphy and the depth of historic alluvium. Complete descriptions of core and auger samples from each circle are referenced in Appendix B. Circle locations can be referenced in Figure 5, and Figure 10 shows the general physical composition of core and auger samples from each circle. A brief summary of each circle is given below.

East Side of Millpond. *Circle one*. Circle 1 is positioned closest to the milldam, directly south of the bridge on the east side of the millpond (Fig. 5). This area is one of the first sample circles to be inundated during high water stands. Auger samples revealed 0 to 5 cm organic debris over 26 to 40 cm of historic alluvium burying a massive swamp muck; however, two compressed core samples showed only 17 or 19 cm of alluvium. Two distinctly different layers of alluvium were present in all samples generally ranging from a top layer of very dark gray sandy or silt loam to a grayish brown silty clay layer. A sandy lens is located from 15 to 16 cm in one core sample indicating a pulsed erosional/ depositional event. The average bulk density of the

Figure 10. Physical composition of core and auger samples.
▧ = organic matter; ☐ = historic alluvium; ■ = swamp muck; ⊞ = sand lens



alluvium is .64 g cm^{-3}; however, the layer of silty clay alluvium has a higher bulk density of 1.06 g cm^{-3}.

Circle two. Circle 2 is located about 40m south of circle 1. Circle 2 shows no signs of historic sediment accretion. The core sample, with 49 percent compression, has 58 cm of swamp muck. Seventy-nine to 83 cm of swamp muck was found with auger samples. Forty-eight cm of the core sample has a bulk density $< .48$ g cm^{-3}. Although 10 cm of the core sample has a bulk density of $>.48$ g cm^{-3}, the lack of mottling or visible mineral material and the presence of abundant organics ruled this segment out as being historic upland sediment.

Circle three. This circle is located 25 m directly south-southwest of circle 2 (Fig. 5). Two auger samples 2 m apart revealed 36 to 37 cm of historic alluvial sediment overlying a buried swamp muck. Only 17 cm of alluvium was found in the core sample; however, the sample was compressed 67 percent. Alluvium ranged from very dark gray sandy clay with a bulk density of .53 g cm^{-3} to a very dark brown sandy loam. These sediments were heavily mottled and more waterlogged than other circles.

Circle four. Circle 4 is situated on the perimeter of a shallow intermittent tributary flowing from the adjacent uplands into the millpond. Using the cypress knee calculations, this circle has the highest average rate of sedimentation of 1.35 mm yr^{-1}, at least over the past 55 years (Table 5). Historic alluvium depths are comparable to other circles; however, with 31 to 38 cm from auger samples 1.7 m apart and only 10 cm from the core sample (51 percent compressed). Sediments were either a very dark grayish brown clay or silt loam with a bulk density of .42 g cm^{-3}.

Circle five. Circle 5 is located about 15m southwest of circle 4. Although the core sample collapsed from an abundant root system and a distorted core pipe, 16 to 27 cm of historic alluvium burying swamp muck was found with auger sampling. The alluvium from the two auger samples 3.25 m apart is a very dark gray to very dark grayish brown clay loam.

Circle six. Circle 6 is located directly between intermittent shallow stream flow and the millpond during mean water level. Within this circle, historic alluvium depths are variable ranging from 6 cm in the core sample (31 percent compression), 17 cm in one auger sample, and 34 cm in the other auger sample 0.8 m away. All historic sediments bury a massive swamp muck and range from very dark grayish brown sandy clay to clay loam with an average bulk density of .43 g cm^{-3}.

West Side of Millpond. *Circle seven*. Circle 7 is situated on the west site of the millpond closest to the bridge and the dam (Fig. 5). Both the core and one auger sample reveal two distinct layers of historic alluvium with considerable variability. Thirty-one cm of historic alluvium was found in the core sample of very dark grayish brown sandy clay overlying grayish brown sandy clay with 2 cm of a coarse yellow brown sandy lens on the bottom. The two auger samples, 2 m apart, also show considerable variability. One sample consists of two historic alluvial layers equal to 57 cm of black sandy clay overlying a grayish brown silty clay loam. The average bulk density is .83 g cm^{-3} with the highest bulk density of 1.13 g cm^{-3} in the lower alluvial layer of the core sample. All samples were heavily mottled. This circle, along with circle nine, has one of the highest sedimentation rates of 3.7 mm yr^{-1}, using the milldam date method (Table 4). However, this circle has the lowest sedimentation rate in about the 60 years (0.08 mm yr^{-1}), using the cypress knee method (Table 5).

Circle eight. Circle 8 is located at a small footslope about 48 m south-southeast of circle 7. Core and auger samples show 24 to 31 cm of historic alluvium burying a massive swamp muck. Only one grayish brown sandy loam layer of historic sediment is present in the auger sample 1.25 m apart. Two layers are recognizable in the core sample: a very dark grayish brown silty clay overlying very dark grayish brown silty clay. The average bulk density of the sediment is .52 g cm^{-3}.

Circle nine. Circle 9 is situated at the footslope of a hill upon which a house was constructed in the early 1990s. Considerable variability exists among the core and auger samples in circle 9. One layer of historic alluvium was found in the two auger samples, 1.3 m apart, ranging from 48 cm of very dark grayish brown sandy loam to 52 cm of a very dark grayish brown silty clay loam. The core sample showed two layers equal to 29 cm of historic alluvium: 18 cm of very dark grayish brown sandy clay interspersed with a coarse yellowish brown sandy lens from 15-17 cm and 11 cm of black clay loam. Average bulk density of the sediments is .54 g cm^{-3}. This circle has the highest sedimentation rate, 3.9 mm yr^{-1}, using the milldam date method (Table 4).

The Kruskall-Wallis non-parametric ANOVA calculated a chi-square of 15.4 and a significance of .05, suggesting statistically significant between-circle variability (Table 6).

Table 6. Kruskall-Wallis ANOVA results

Circle	N	Mean Rank
1	10	46.6
2	10	53.6
3	10	47.7
4	10	64.3
5	9	46.7
6	10	45.8
7	10	26.4
8	10	44.0
9	10	30.2
Total	89	
Chi-square = 15.4		
Deg. of freedom = 8		
Significance = 0.05		

In addition, individual t-tests were calculated to test for statistical variability in sedimentation rates between circles. Although the assumptions involved in t-tests inhibit the statistical analysis of variations within the sampling area as a whole, this method did reveal some individual between-circle variability. Using a significance level of .05 and N of 10 for each circle (except circle 5 with 9 samples), circle 2 and circle 4, with mean sedimentation rates of .93 mm yr^{-1} and 1.34 mm yr^{-1}, respectively, both vary significantly with circle 7 and circle 9, with rates of 0.08 mm yr^{-1} and 0.27 mm yr^{-1}, respectively (Table 7). Circle 2 and 4, however, are located on the east side of the millpond while circle 7 and 9 lie on the west side. This suggests that where statistical variability does exist, sampling circles on the same side of the backwater area do not vary significantly with each other. It also appears that the mean rate, at least in the past 60 years, is higher on the east side of the millpond (0.82 versus 0.34 mm yr^{-1}).

Table 7. Significant variations between circles using t-tests. "X" indicates which circles differ.

Circle	1	2	3	4	5	6	7	8	9
1									
2							X		X
3									
4							X		X
5									
6									
7		X		X					
8									
9		X		X					

Temporal Variations

Field Variability. Field evidence suggests that varying episodes of historic sedimentation have occurred since gristmill dam construction. First, historic accretion rates using the depth of sediment divided by the age of cypress knees were low compared to the rates utilizing the depth of alluvium divided by the milldam age and compared to other coastal plain studies in general. The majority of cypress knees were younger than 60 years old, and sedimentation rates were low in comparison to other studies, suggesting that at least in the past 60 years, alluvial sediment has not been accumulating as quickly as in the past. Also, most of the recent alluvium in the study area is organic. This suggests that contemporary alluvium does not have a significant source from exposed mineral upland soils. Third, thin sandy lenses were evident in three cores: Circle 1, circle 7, and circle 9. The sand lenses were qualitatively much coarser in comparison to other sediments within the core samples. Therefore, the lenses most likely indicate pulsed depositional events because the origin of the sediment is of a different source than the rest of the core, and/or the sediment is from a singular source during a high runoff event. Finally, the presence of two distinct layers of historic alluvium in some cores suggests at least two episodes of vertical sediment accretion. Although not all samples have two alluvial layers, variations such as microtopography, vegetation, spatial positioning within the backwater, and other geomorphic dynamics may account for the spatial variability. Temporal variations are therefore clearly visible within the sampling area.

Statistical Variability. To statistically test for temporal variations in sedimentation rates and depths, cypress knees were clustered into age groups similar to the technique used by Hupp and Morris (1990). Table 8 shows the mean and standard deviations of sedimentation rates per year for each age group.

Table 8. Annual sedimentation rates for each age group

Cypress knee age group	Number of cypress knees	Mean (mm yr^{-1})	Standard Deviation	Range
10-29 year group	11	.07	1.54	-2.80 – 2.00
30-39 year group	18	.94	1.15	-.64 – 3.27
40-49 year group	31	.80	.78	-.83 – 2.32
50-59 year group	13	.55	.68	-.67 – 1.34
60 & over group	16	.54	.62	-.89 – 1.76
Total	89	.65	.96	-2.80 – 3.27

A salient point in relation to these data is that standard deviations are relatively high, indicating high within group variability. The lowest average sedimentation rate is 0.07 mm yr^{-1} in the 10-29 year age group, and the highest is 0.94 mm yr^{-1} in the 30-39 year age group. The modal age group is the 40-49 year group, comprising 31 of the 89 cypress knee measurements and a mean rate of 0.80 mm yr^{-1}. Figure 11 shows these differences in the means of cypress knee age groups graphically.

Figure 11. Average sedimentation rates per age group

The Kruskall-Wallis ANOVA indicates no significant temporal variability, using a significance level of 0.05. However, assuming no relationships between all groups, individual t-tests indicate significant variability in deposition depth only between the 10-29 year age group and the 30-39 year age group.

CHAPTER VI

DISCUSSION

Sedimentation Rates

The two methods used to calculate annual historic alluvial sedimentation rates, the depth of deposition or scour divided by the age of cypress knees (dendrogeomorphology) or the depth of alluvium divided by the age of the milldam, produced quite different results. Because the dendrogeomorphologic techniques using cypress knees is innovative in estimating sedimentation rates and has yet to be fully tested, differences in sedimentation rates between the two methods will be described as apparent, rather than real. However, this does not discount the possibility of real discrepancies in annual rates of sedimentation between methods. Both, however, are significant in terms of historic coastal plain alluvial sedimentation. Average cypress knee deposition rates per circle ranged from 0.08 to 1.35 mm yr^{-1}, with an overall mean rate of sedimentation of 0.65 mm yr^{-1} of historic sediment accretion over the past sixty years or less, presuming the majority of cypress knees are under 60 years old.

Although 0.65 mm yr^{-1} is a significant amount of sedimentation, there are several possible reasons as to why recent rates may be lower than longer-term rates in this study (Table 4) and generally lower than rates found in previous NC coastal plain studies (Table 1). First, it might be argued that low cypress knee sedimentation rates in comparison to other studies reflect the inefficiency of small coastal plain drainage basins. It is well-known that a time-lag exists between on-site soil loss and sediment yields at the basin outlet. For example, Simmons (1988) measured suspended sediment yields from coastal plain uplands to be 0.3 t ha^{-1} yr^{-1} and Kim (1990) estimated two-year sediment delivery to the Neuse River estuary to be about 0.03 to 0.06 t ha^{-1} yr^{-1}, measurably low compared to the time-averaged historic soil loss on coastal plain uplands of about 9.4 t ha^{-1} yr^{-1} (Phillips 1993 et al.). Along with this, Slattery (personal communication) found the sediment delivery ratio for a NC coastal plain agricultural field drainage basin to be only 1.7 percent, about average when compared to other coastal plain basins. Floodplains within coastal plain drainage basins are typically areas of significant sediment storage. Stream efficiency may not be great enough to supply the energy for upland sediments to reach the basin outlet in many coastal plain streams, but it is able to transport and subsequently deposit sediments on floodplains positioned randomly within the drainage basin. This is documented in this study with the longer-term milldam data and in Phillips (1997a) with historic NC coastal plain accretion rates behind milldams as high as 135.6 mm yr^{-1}, or 70 t ha^{-1} yr^{-1}. In addition, sediments may be transported to the sampling area by sheet or rill erosion from adjacent uplands rather than further upstream, increasing the chances of sediment transport to the milldam. These arguments most likely rule out the idea of relatively lower sediment accretion rates as a result of the inefficiency of streams.

Second, rates of historic soil loss on the NC coastal plain uplands are time-averaged, and may well record one or more major episodes with limited erosion otherwise (Phillips et al. 1993). Cypress knee rates results suggest at least two things: (1) possibly, the most significant sediment accumulations occurred prior to 1938 (subtracting 60 years from present for the majority of cypress knees) or, (2) consequent sedimentation rates are not reflective of upland soil loss as a result of colluvial storage. It is possible that less sediment was available and/or transported during the most recent period of timber removal in the 1960s to 1990s. Considering that two layers of historic alluvium were present in some core samples and that sediment behind the milldam must have been deposited after dam construction (1869), it can be assumed that only the two most recent episodes of forest denudation have been recorded in the stratigraphy. If cypress knee rates estimate only the past 60 years of sedimentation, this may suggest that consequent sedimentation from the 1960 to 1990 removal was not as great as that of past episodes. In addition, the upper layer of historic sediment in cores is typically not as thick. This may reflect upland colluvial storage, and consequently, not all sediment has been transported from the most recent timber removal.

Finally, when cypress knee ages were estimated, *all* rings were counted, even if they possibly reflected inter-annual seasonal growth. The premise for this method is the lack of conclusive research concerning the physiology of cypress knee annual ring growth. No known research explicates how to distinguish between annual and inter-annual growth rings. This method, therefore, accounts for the maximum age of the cypress knees so that annual sedimentation rates would not be overestimated. Therefore, using the cypress knee method, or dendrogeomorphology, minimum historic annual sediment accretion rates were calculated (minimum sediment accumulation or scour divided by the maximum age of the knee). The overestimate of age may then partially account for low cypress knee sedimentation rates.

Overall, then, there are at least two possible factors that may affect cypress knee sedimentation rates. First, if this drainage basin reflects the general NC coastal plain pattern of historic sedimentation, then the majority of sediment most likely accumulated in the backwater area from increased soil erosion up through a peak in timber removal in the late-nineteenth/early-twentieth century. However, contemporary soil loss and sedimentation should be comparable because of recent timber clearing from the 1960s to 1990s in Martin County. It is possible that sediment storage in fields, field edges, riparian areas, slope bases, and floodplains lower recent sedimentation rates and that contemporary soil loss from timber removal has not yet been completely transported out of storage. Second, overestimates of cypress knee ages may have underestimated some of the sedimentation rates.

Sedimentation rates with the depth of alluvium divided by the age of the milldam were considerably higher than those using cypress knees and were more comparable to other coastal plain historic alluvial sedimentation rates during similar time periods (Table 1). Initially, sedimentation rates were also calculated using the date of the most recent dam breaching in the early 1950s. These apparent rates would account for the rate of sediment accumulation from the uplands after sediments were evacuated by the release of the dam. Two factors ruled out this possibility. First, upslope of the sampling circles, alluvial sediments remain intact. If sediment evacuation had occurred with the breaching of the dam, no sediment would be left in the mean water-level area when the dam was intact. Along with this, if the historic sediment had been flushed out of the backwater area, trees on the floodplain downstream would most likely bear a telephone pole-like appearance as a result of sediments burying the roots and basal flares. Only a few trees downstream demonstrated this phenomenon. This leads to the conclusion that when the dam was breached, the majority of historic alluvial sediment from the backwater area was not evacuated. Therefore, rates using the age of the milldam were deemed more useful as apparent estimates of historic sediment accretion. Historic accretion rates are apparent because they account for deposition minus the soil loss and erosion. These rates, however, are maximum rates because the age of the gristmill dam (129 years) is the minimum age from historic records.

The average historic accretion rates per circle range from 1.6 to 3.9 mm yr^{-1}, with an average for the sampling area of 2.3 mm yr^{-1}, using this method. These results are within the range of most other floodplain sedimentation studies (Table 1). Phillips (1997b) estimated that the majority of historic sedimentation rates on floodplains in the southeast range from 2.4 to 26 mm yr^{-1}, discounting anomalously high rates. The rates within this study, therefore, fall mostly into the lower end of other coastal plain estimates of sedimentation. This suggests a comparable and considerable amount of consequent sedimentation from post-European settlement land use practices has taken place in the backwater of this gristmill dam.

The mass rate of historical sediment accretion is 0.024 t ha^{-1} yr^{-1} for the watershed area using the average depth of historic sediment in the backwater, the average bulk density, the area of sampling, and the area of the drainage basin. Although this rate is not comparable to other studies as a result of methodological discrepancies, several studies have documented low sediment delivery in coastal plain streams. The apparently low mass rate for this study may reflect storage within the drainage basin in riparian areas, slope bases, and field/forest borders.

Spatial Variability

Spatial variability in sedimentation is a critical issue if discerning whether a few cores or samples can be representative of broader alluvial sediment reconstructions. If local spatial variability is high, yet generally discounted in broader-scale studies, questions arise as to whether descriptions of alluvial stratigraphy and management practices actually account for what is happening in a specific location. The results of this study investigating local scale historic alluvial sedimentation suggest local scale variability.

The individual t-tests, although comparing only two circles at a time and not placing rates within the context of the whole sampling area, show some specific between-circle variability in sedimentation rates. These variations occur on opposite sides of the millpond, i.e., circle 2 and 4 on the east side (0.93 and 1.34 mm yr^{-1}, respectively) vary significantly with circle 7 and 9 on the west side (0.08 and 0.27 mm yr^{-1}, respectively). These variations would be expected, as different stream flow and slope dynamics affect deposition on each side of the backwater area differently. However, the basis for this variability can become quite complex because circle 7 and circle 9 have the highest overall historic sedimentation rate, but the lowest rates in the past 60 years. Both circles are positioned at the foot of relatively steep slopes (Fig. 3 and 5), and sediment has been seen flowing into circle 9 during a recent storm runoff event. This suggests that these areas are possible sinks for upland erosion from the adjacent slopes. Both have two distinct layers of historic alluvium, suggesting either two different periods of sedimentation and/or a change in sediment sources. However, because of the lack of data concerning flow regimes, flood events, cypress knee physiology, and detailed sediment samples throughout the entire watershed, reasons for this discrepancy can only be speculative and need to be further researched.

More striking evidence of variability involves the field sampling of historic alluvial sedimentation. First, historic alluvium depths, even within the 2 m radius of sampling circles, can vary greatly. For example, in circle 6, 6 cm of historic alluvium was found in the core sample (with 31 percent compression), 17 cm of historic alluvium was uncovered in one auger sample, and 34 cm was found in another, 0.8 m away. Along with these within-circle discrepancies, circle 2 showed no signs at all of historic alluvial accretion. This demonstrates significant variability in the amount of alluvial accretion even within a very small area. Second, the amount of historic sediment between circles can be variable. Circle 6, for example, has as little as 17 cm of historic alluvium while circle 7 has as much as 57 cm, both measured by auger sampling. These two circles, however, did not demonstrate any significant statistical variability using dendrogeomorphology. This is difficult to reconcile, especially because strong field evidence indicates variability. One suggestion may be that contemporary sedimentation rates explain depositional activity at either site better than the time-averaged rates, or vice versa. Third, differences in physical soil properties within circles and between circles were evident. For example, core results in circle 1 distinguish two layers of alluvium: a surface silt loam and a lower sandy clay (the colors of the two sandy clays also vary from light olive brown to a very dark gray). The auger results, however, indicate only one layer of historic alluvium of silt clay or silty clay loam. Other circles that vary in physical soil properties between the core and auger samples within the same circle include 4, 6, and 8 (Appendix B). Some samples within one circle are so variable that neither the auger nor the core samples are alike. Circle 7, for example, shows two layers of historic alluvium in the core sample and in one auger sample, yet only a single layer in another. Both samples with two layers have an upper layer of sandy clay (although variable in color); however, the lower layer of sediment varies from a silty clay in the core sample to a silty clay loam in the auger sample. Circle 9 demonstrates this similar phenomenon of variability. Only circle 5 suggests a uniform pattern of sediment distribution; however, even this still varies in the depth of historic sediment between the two auger samples (16 cm vs. 27 cm) (Appendix B).

Why, then, are patterns of historic alluvial sediment so variable in a localized area? Previous studies have pointed to varying reasons including microtopography, vegetative patterns, flow regimes and hydroperiods, distance from the channel or tributaries, and topographic setting (Hupp and Morris 1990; Hupp and Bazemore 1993;

Pye 1994; Kleiss 1996). A few of these factors, and some others, appear to qualitatively explain some of the variable patterns of sediment within the backwater area.

First, topographic setting and spatial positioning to upland areas appears to exert a significant control on the depth of alluvium, abundance of mottles, and the presence of a sandy lens in circle 9. Sediments from the adjacent upland area tend to accumulate at this location. For example, in a recent period of intense rainfall and flooding, a recognizable rill system of sandy sediments flowing from the adjacent upland area was evident where a house was recently constructed. It appears that circle 9 has a high rate of sedimentation (3.9 mm yr^{-1}), using the milldam method, and varying patterns of mottling, along with a 2 cm sandy lens in the stratigraphy, as a result of its spatial positioning at the foot of a hillslope.

Second, spatial positioning relative to the tributaries and milldam may explain circle 4's deep deposition in at least the past 60 years, using dendrogeomorphological techniques. Although some scour was measured in this circle, deposition depths ranged from 51 to 102 mm, relatively deep compared to other circles, such as circle 6 (Appendix B). Circle 4 is located on the perimeter of a small slow-flowing intermittent tributary to the millpond from the upland area. Along with this, the area appears to be inundated only for short, yet frequent, periods of time. It is possible, then, that fine sediments accumulate at this location as a settling out point where flow velocity decreases entering the millpond, and that periodic inundation provides a greater supply of pulsed sediment to this location (Hupp and Morris 1990).

Third, the positioning of trees or cypress knees account for some deep sediment accumulations with the cypress knee deposition measurements. For example, in circle 3, 120 mm of sediment accumulated over the past 68 years within a cluster of five cypress knees. This is a relatively thick accumulation, compared to other measurements within the same circle with deposition depths over the past 65 years ranging from 0 to 50 mm. These measurements were conducted, however, where cypress knees stood singularly, not clustered with other knees.

Finally, positioning relative to a construction area seems to describe a sandy pulse of sediment in circle 1. Circle 1 is near the footslope of a road and a bridge reconstructed in 1953. The texture and color of sand within the stratigraphy matches that of the base of the bridge, and the lens is found only 15 cm deep. Along with this, the slopes at this northeast area of the watershed (Fig. 4) provide enough energy for a sandy pulse of sediment to be transported to circle 1 during a high runoff event.

Temporal Variability

Statistical analysis, using a Kruskall-Wallis ANOVA, suggest no significant variability in temporal variations between cypress knee age groups, possibly as a result of the small number of samples within each group. However, statistical analysis was only performed on dendrogeomorphological measurements and incremental clustering of cypress knees. Therefore, only about the past 60 years were analyzed quantitatively in 10- to 20-year groups. Some temporal variations may therefore have been excluded statistically.

Field data suggest episodic pulsed or ramped depositional activity has occurred in the study area. First, as previously mentioned, cypress knee, or dendrogeomorphology, results show that over about the past 60 years or less, sedimentation rates have been comparatively low. This is apparent by the discrepancy in the average rate using dendrogeomorphology (0.65 mm yr^{-1}) compared to the time-averaged rate of 2.7 mm yr^{-1} in the backwater area. These results suggest that since about 1938, alluvial accretion has apparently declined from previous stages in the sedimentary history at the study area. This is supported by the fact that the most recent surface alluvium throughout the study area is organic and does not suggest contemporary accelerated sedimentation. However, although lower, some recent sedimentation has occurred in the backwater from timber clearing from about the 1960s through the 1990s. This is evident by the rise in sediment accretion 30-39 years ago (Fig. 11) and by the presence of a second layer of historic sediment accretion in some cores.

Next, two distinct layers of historic alluvium are evident within several of the sampling circles. Circle 1, on the northeast part of the sampling area, and circles 7, 8, and 9, on the west side, all demonstrate this phenomenon. Although the physical properties of the alluvium are not the same in all four circles (most likely explained by the spatial positioning, discussed in the previous section, relative to different critical settling velocities of the sediments), two layers of alluvial sediment accretion suggest two major episodes of alluvial sedimentation. Through at least two periods after European settlement, a large amount of sediment was most likely available for transport within the drainage area and subsequently deposited behind the milldam. Along with this, three of the four circles (1, 7, and 8) have thicker sediment accumulations from the first episode of deposition, because the bottom layer of historic sediment is thicker (Appendix B). Therefore, assuming that all or most of the culturally-accelerated sediment eroded from the uplands has accumulated on the floodplain, the first major episode of deposition from post-settlement deforestation may have supplied a greater amount of sediment than the second event. Although the presence of two historic alluvial layers is evident in only four out of nine circles, three of these appear to best represent the sedimentological record at the site because both circle 7 and 9 have the highest time-averaged sedimentation rates (3.7 and 3.9 mm yr^{-1}, respectively), the best core and auger records, and circles 1,7, and 9 have a sandy lens of sediment somewhere in the stratigraphy (Appendix B).

Third, the sandy lens of sediment in circles 1,7, and 9 core samples suggest a pulsed episode of deposition from both of the two major episodes of increased historic sedimentation discussed above. The sandy lens in circles 1 and 9 is in the upper layer of alluvium, suggesting a pulse of sediment during the most recent major depositional event. And, the sand lens is in the *bottom* layer in circle 7, suggesting a pulse of sediment during the first period of post-settlement deposition. These pulsed periods of erosion were most likely from a different upland source than that of the more gradually accumulating finer sediment. Sandy sediments settled at these locations, possibly as a result of a runoff event as seen recently in circle 9. The fact that all three circles are positioned at the foot or close to the foot of adjacent slopes with steeper slope inclination than some of the surrounding areas further supports this argument (Fig. 4).

From the above evidence of temporal variations and from known history of post-European settlement land use in the watershed area, a few qualitative conclusions can be derived about how temporal variability has occurred. First, as with the majority of the coastal plain, the uplands in this drainage basin have undergone at least three major phases of nearly complete forest denudation since European settlement: one immediately after settlement, from about the mid- to late-1700s, one after the civil war until about the late-nineteenth/early-twentieth century, after subsequent forest regrowth from the first clearing, and one from about the 1960s to 1990s (Perkins and Bacon 1920; Cathey 1974; Phillips 1994; Phillips 1997a). However, only the two most recent episodes were recorded behind the milldam built in 1869. Many of the upland areas within the drainage basin were depleted of forests and fertility by the mid-1800s, and were subsequently abandoned and left to grow back into forested land (Manning and Booker 1979). By 1894, the second growth forests in Martin County, primarily composed of loblolly pine, were two-thirds removed (Ashe 1894). By 1897, the forests in Martin County were once again exhausted (Pinchot and Ashe 1897). Ninety-percent of the upland loblolly pine forests in 1940 that had been partially cut or were planned to be cut were 25 to 55 years old (Cruikshank 1940). By 1949, the area in agricultural woodlands peaked at 127,700 acres (U.S. Census of Agriculture 1949), but continued to decline, along with the area in farms, to the 1992 figure of 36,769 acres (U.S. Census of Agriculture 1992). In addition, more than 50 percent of the greater than 3 percent decrease in commercial forest land from 1963 to 1974 was converted to agricultural lands (Welch and Knight 1974). This suggests that much of the forested area in Martin County was succeeding through a regrowth during the early twentieth century subsequent to the second major denudation, and thence began to be removed again after the middle part of the century.

It can be assumed that any extreme increase in deforestation will result in increased sediment entrainment and consequent floodplain aggradation. This parallels Phillips (1997a), along with the evidence of two historical depositional episodes in circles 1,7,and 9 in this study, and records of decreased cypress knee sedimentation rates after about 1938. Also, the sandy lens of sediment about 1 to 2 cm thick found in some of the samples indicates that some sort of pulsed depositional event from a different upland source interspersed the more gradually accumulating sediment. As small rills of sediment were seen flowing from the adjacent uplands into circle 9 in the most recent intense rainfall and flood events, it can be presumed that sporadic flood event(s) at some point transported these sandy sediments from an adjacent slope to the sampling area, rather than from suspended load in the streamflow. However, it is difficult to correlate the sandy sediments with a major change in land use or a specific flood event. Assuming the compression within each of the cores is equally distributed, an apparent depth of the sand lenses within cores 1, 7, and 9 could be calculated. Using the mean rate of sedimentation over the past 130 years (2.7 mm yr^{-1}), the date the sand lenses were deposited in cores 1, 7, and 9 were approximated to be 1934, 1823, and 1919, respectively. Obviously, these dates do not correspond well with each other to determine one major event that contributed to the runoff of sand from adjacent slopes into these locations. In addition, it could be assumed that, although the cores only had one lens of sandy sediment, more than one high runoff event has occurred in the past 130 years. However, circle 1's lens may roughly correlate to the bridge construction on the uplands in the early 1950s, and the lens in circle 9 may approximate a high runoff event during the most recent peak in deforestation in the late-nineteenth/early-twentieth century. However, these cases are only speculative. Additional sediment samples and hydrologic data throughout the entire drainage area could contribute to future research.

Sediment Sources

Sediment has obviously been accumulating since European settlement in the backwater area of the gristmill dam. It is difficult to distinguish the exact sources of upland sediment without some combination of pedological, mineralogical, and chemical evidence of upland sediment sources. However, no mineralogical or chemical tracers were used in this study to determine the source of this sediment. Only a combination of physical soil properties (Appendix B) in comparison to upland soils (Table 2) were used.

Along with this, sediment samples in the backwater area of the gristmill dam are often in varying states of saturation and aeration, i.e., spatial variations in reduction and oxidation conditions exist. This setting accounts for a significant alteration of sediments supplied from the upland areas as a result of redox reactions and periodic remobilization of sediments. Also, upland land use has been rather spatiallly uniform over time. Most land has been cleared and is either used for croplands on upland areas or timber harvesting on some uplands, but mostly along rivers. Therefore, only general estimates of sediment sources could be derived at this time. These are outlined below.

First, it can be presumed that mineral sediment accumulating on the floodplains behind the gristmill dam is from areas within the watershed that have been cleared and altered for agriculture, timber harvesting, and possible construction events, i.e., bridge, road, and housing construction. However, it is difficult to detect any direct correlation of floodplain sediments to upland soils. For example, the upland soils are used predominately for croplands. Those covering the widest extent in the watershed are the Bonneau, Norfolk, and Goldsboro. These soils have either a loamy sand, loamy fine sand, or fine sandy loam surface layer of grayish brown, light yellowish brown, or dark grayish brown, respectively (Table 2). Although all of these sediment properties exist in at least some of the historic alluvium at the study site, sediments can be altered through cycles of saturation, aeration, and reworking. In addition, spatial variability of sedimentation in the backwater area of the milldam inhibits any specific correlations to upland soils.

Second, stratigraphic evidence suggests that historic sedimentation at sampling circles positioned at the foot of slopes is significantly influenced by surface runoff. This is evident in circle 7 and 9 with the appearance of sandy lenses in the stratigraphy, most likely as a result of overland flow during intense rainfall and flooding from the adjacent uplands. This is further supported by the correlation of the fine sandy lenses to loamy fine sands on the uplands connected to the sampling circles. In addition, stratigraphic evidence at circle 1 (as indicated by the sandy lens in the core), located on the northernmost part of the sampling area (Fig.5), suggests that sediment from the base of the bridge on the adjacent upland can to flow into this area during high runoff events. Therefore, sediment may be transported from most upland areas by the channel during storm events, but in higher magnitude flood events, these sediments are interspersed with coarser sedimnts from the adjacent hillslope. This could lead to future research investigating the storage of coarse material throughout the drainage basin. For example, it is known that a significant amount of sediment is lost from coastal plain uplands during high storm events (Slattery et al. 1997). If the coarser sediment in the core samples in this study are only prevalent in pulses from adjacent slopes as a result of high magnitude runoff events, and the majority of sediment behind the milldam is fine mineral sediment, questions arise concerning exactly where the coarser sediments eroded from the uplands are stored within the drainage basin. Future studies correlating on-site soil loss and slope-to-stream measurements throughout the drainage area could possibly begin to explain this issue.

Only these general conclusions of sediment sources can be drawn at this point. Appropriate mineralogical and chemical tracing techniques would further enhance any estimates of where the sediment behind the milldam originated. Distinguishing sources of sediment is a topic in need of further, more refined, investigation.

Cypress Knee Methodology

The utilization of cypress knees provided an innovative approach for estimating historic alluvial sedimentation rates. This study appears to be the first using this method. Although thorough research has not been conducted concerning the accuracy of cypress knee use in dendrogeomorphology, standardizing this method throughout this study provided for internally consistent sedimentation rates in the past 60 years and a basis for a new methodological approach to alluvial sedimentation research. These rates were lower, but relatively comparable, in relation to other floodplain sedimentation studies (Table 1, Table 2).

There are, however, a few potential problems with this method that could be further researched. First, ring counts needed to be estimated in some cases as a result of root rot within the knees, closely-spaced rings, and/or ring distortion. Where the presence of a ring was questionable, the ring was still counted. This may have resulted in an over-estimate of age in some cases causing an underestimate in sedimentation rates. Second, it is possible that the cypress knee arches migrate upward throughout the life of the knee. An upward-migrating arch would result in lower deposition measurements and/or higher measurements of scour. This, again, may underestimate sedimentation rates. These issues could be resolved with further research concerning the physiology of cypress knee growth and development, and the use of cypress knees in dendrogeomorphology.

CHAPTER VII

SUMMARY AND CONCLUSIONS

Summary

The primary goal of this study was to measure and analyze local-scale temporal and spatial variability of historic sedimentation on the lower coastal plain of North Carolina. Sedimentation rates were calculated using two methods: (1) dividing the depth of deposition or scour by the age of ten cypress knees within nine sampling circles (dendrogeomorphology) and (2) measuring the depth of historic alluvium within the nine sampling circles divided by the age of a historic gristmill dam. Cypress knee sedimentation rates account for only about the past 60 years of deposition (the oldest age of most cypress knees), but the milldam rates cover the past 130 years (the minimum age of the gristmill dam).

The Kruskall-Wallis ANOVA test had statistically significant results, and t-tests indicated variability between individual circles. In addition, all other data suggest local scale spatial and temporal variability in sedimentation patterns in the backwater of the gristmill dam.

Considerable differences in physical soil properties and depths of historic alluvium, ranging from 17 to 57 cm, were prevalent throughout the sampling area, suggesting local scale spatial variations in sediment patterns. These variations appear to be attributable to topographic setting and spatial positioning to slopes, upland areas, tributaries, trees and cypress knees, and areas of past construction.

Temporal variations were also evident. Average sediment rates in at least the past 60 years (0.65 mm yr^{-1}) were considerably lower than those time-averaged over 130 years (2.7 mm yr^{-1}). Although recent rates are lower, both sets of rates are comparable to the time-averaged rate of historic soil loss on the lower coastal plain of North Carolina, indicating that a significant amount of soil loss and subsequent deposition is still occurring. Recent sedimentation may be the result of the continuous decrease in wooded upland areas since 1949 (127,700 acres in 1949 vs. 36,769 acres in 1992) and the prolonged effect of historic sediment storage and remobilization. Along with this, two layers of historic alluvium were present in some samples, suggesting at least two major episodes of deposition that have been recorded behind the milldam. These episodes most likely correspond to two major forest clearings after European settlement: one after the civil war up through the late-nineteenth/early-twentieth century and one from about the 1960s to the 1990s. Finally, sandy lenses of sediment interspersed with slower-accumulating sediment were present in some samples, indicating a pulsed depositional event. Recent evidence during intense rainfall and flooding suggests that these lenses were deposited from sediment flowing from adjacent uplands during high runoff events.

The second objective, to interpret variations in and possible sources of sediment through historic land use data, geomorphic, and topographic setting was inhibited by a number of factors. First, a combination of physical soil properties in the sampling area was used to compare to surface layers of upland soils to derive possible sources of sediment. However, because the soils around the millpond go through cycles of reduction, oxidation, and reworking, sediments are greatly altered in physical properties. Also, the diversity of upland land use is low. The land is generally cleared for either croplands or timber harvesting, and the majority of soils are of only three types. Therefore, it was possible to derive only very general sediment sources. First, historic mineral alluvium can be assumed to be from the erosion of upland sediments within the drainage basin. Second, sandy lenses of sediment were found in circles 1, 7, and 9, and it was concluded that these sediments were deposited from adjacent upland surface flow during high runoff events. Overall, it appears that during storm events, sediments deposited behind the milldam are derived from throughout the drainage basin. However, during higher magnitude rainfall and flooding events, coarser sediments can flow into the sampling area from adjacent slopes interspersing more slowly accumulating sediments.

<u>Conclusion</u>

The conclusions concerning the spatial and temporal variability of historic alluvial sedimentation on a local scale are as follows:

- Kruskall-Wallis statistics and individual t-test indicate variability of local scale annual historic alluvial sedimentation, at least in the past sixty years.
- There is evidence of local scale spatial and temporal variability in sedimentation since the earliest date of gristmill construction in 1869. This includes:
  - Differences in physical soil properties and depths of historic alluvium within and between sampling circles.
  - Lower recent sedimentation rates, the presence of two historic alluvial layers, and sandy lenses in the stratigraphy.
- Although dendrogeomorphological sedimentation rates suggest a decrease in historic sediment accretion in at least the past sixty years, both sets of rates indicate that a substantial amount of historic sedimentation has occurred in this drainage basin.
- Sedimentation sources were difficult to discern as a result of sediment alteration and the uniformity of upland land use. However, it can be presumed that mineral floodplain sediment is a result of accelerated upland erosion within the watershed during storm events. In addition, some sediment has most likely been transported to the backwater area during higher magnitude rainfall and flooding events from upland areas adjacent to the millpond.

Implications and Future Studies

The evidence of spatial variability of sedimentation within the sampling area suggests that broad scale alluvial reconstructions based upon a few cores or samples may be discounting a more descriptive picture of what has happened or is happening with deposition in a floodplain area. This may lead to unfitting interpretations and management practices for alluvial floodplains. Overall, the future implications of this study concerning spatial variability depend upon the researcher's theoretical basis for modeling alluvial stratigraphy. Recognizing local scale variability and accounting for this necessarily adds complexity to a model.

In addition, temporal variations show that intense land use practices increase erosion and sediment supplies. This study re-emphasizes that even in low relief coastal plain environments, land use practices greatly effect erosion and sedimentation. This justifies the need for land management practices to control erosive activity on the coastal plain uplands.

Many future studies could create a clearer picture of historical alluvial accretion on a local scale. First, as future research increases into the nature of the physiology of cypress knees and the growth of their rings, possibly even better estimates of sedimentation rates could be calculated. However, this study has contributed to the innovative use of these features as estimates of sedimentation. Second, a complete history of flow regimes, hydroperiods, and flood events within the drainage basin would contribute to a better understanding of temporal variations in sediment transport and patterns. Third, the introduction of mineralogical and chemical tracers of sediment and corresponding historic changes in land use may establish more precise sources of sediment and assist in interpretations of the sedimentary history at the gristmill pond.

Finally, the addition of coverages, including soil maps, land use, and flow patterns, into the GIS (ARC/INFO) database created for the project would establish a visual and statistical model of possible causes and controls over variations in alluvial sedimentation.

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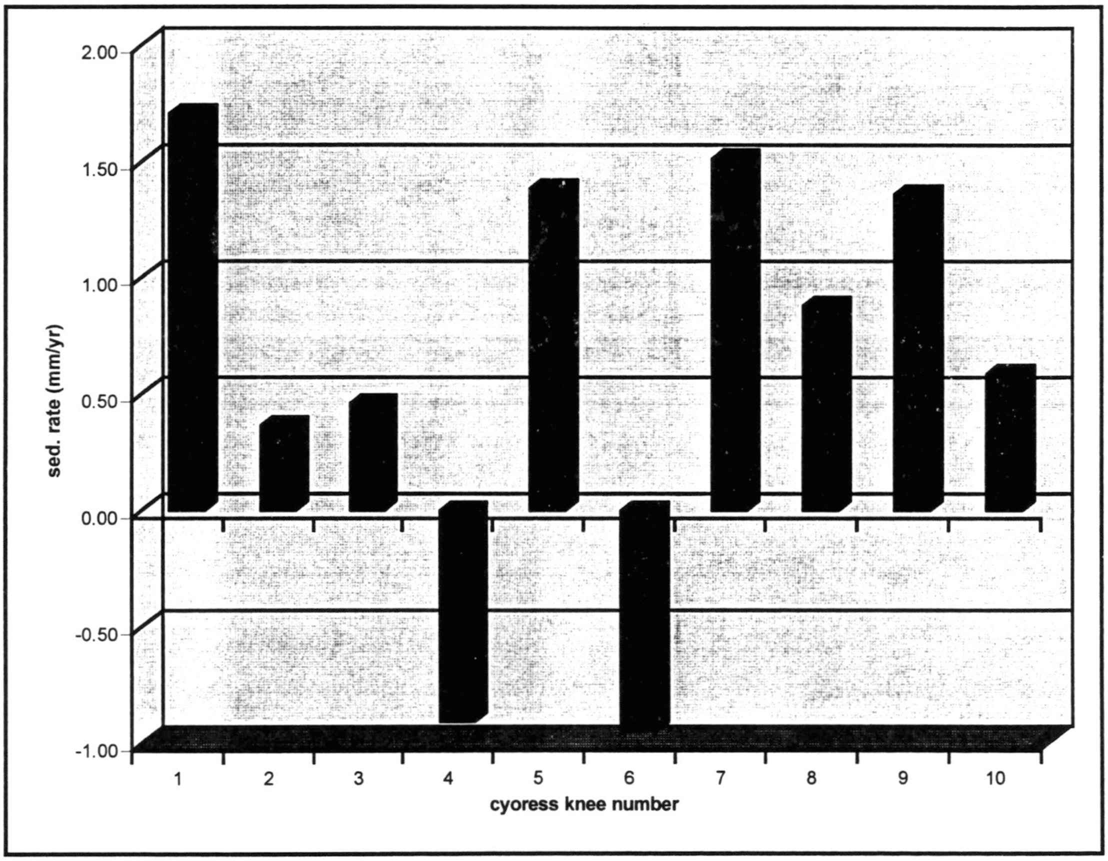
APPENDIX A

SEDIMENTATION RATES USING DENDROGEOMORPHOLOGY

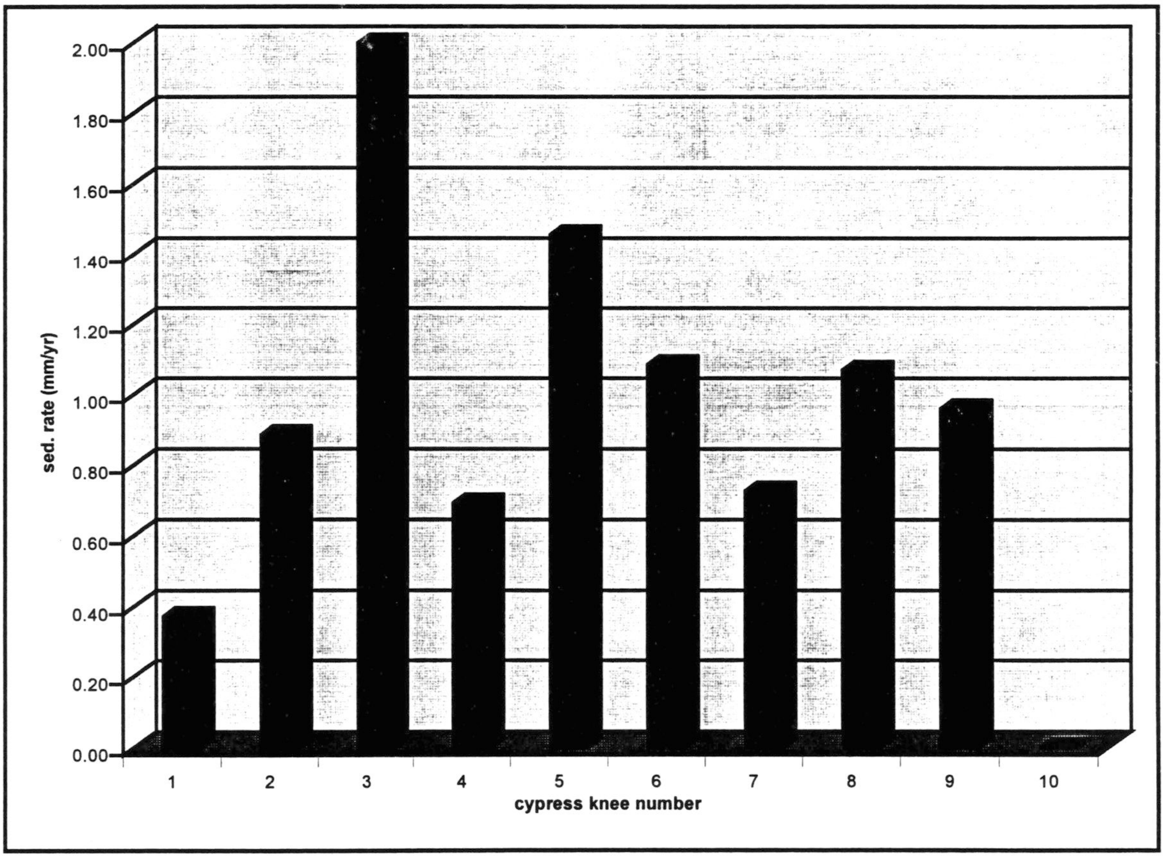
Circle one

Knee Number	Deposition (mm)	Age	Sed. Rate (mm/yr)
1	70	41	1.71
2	30	82	0.37
3	30	65	0.46
4	-10	11	-0.91
5	50	36	1.39
6	-20	21	-0.95
7	50	33	1.52
8	65	74	0.88
9	60	44	1.36
10	20	34	0.59



Circle two

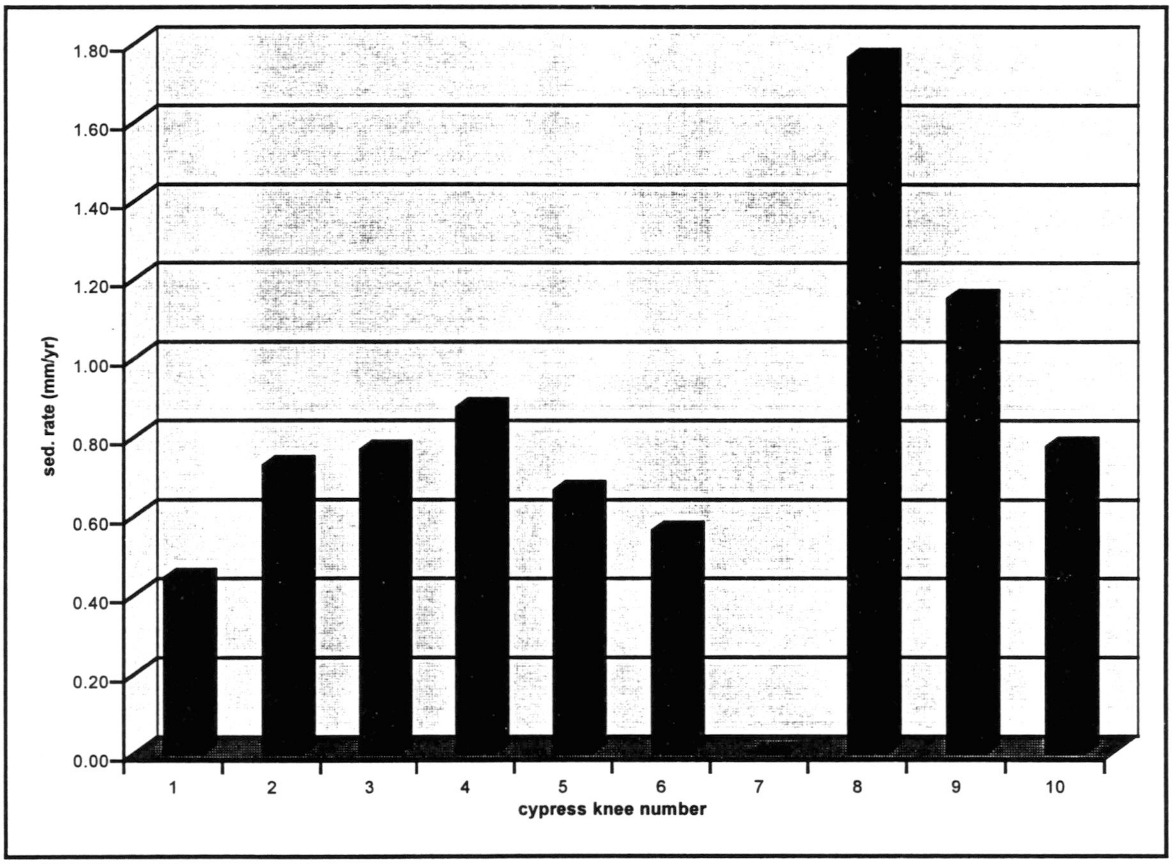
Knee Number	Deposition	Age	Sed. Rate (mm/yr)
1	15	40	0.38
2	40	45	0.89
3	50	25	2.00
4	50	72	0.69
5	70	48	1.46
6	50	46*	1.09
7	35	48	0.73
8	30	28	1.07
9	25	26	0.96
10	0	33	0.00



* = best estimated age

Circle three

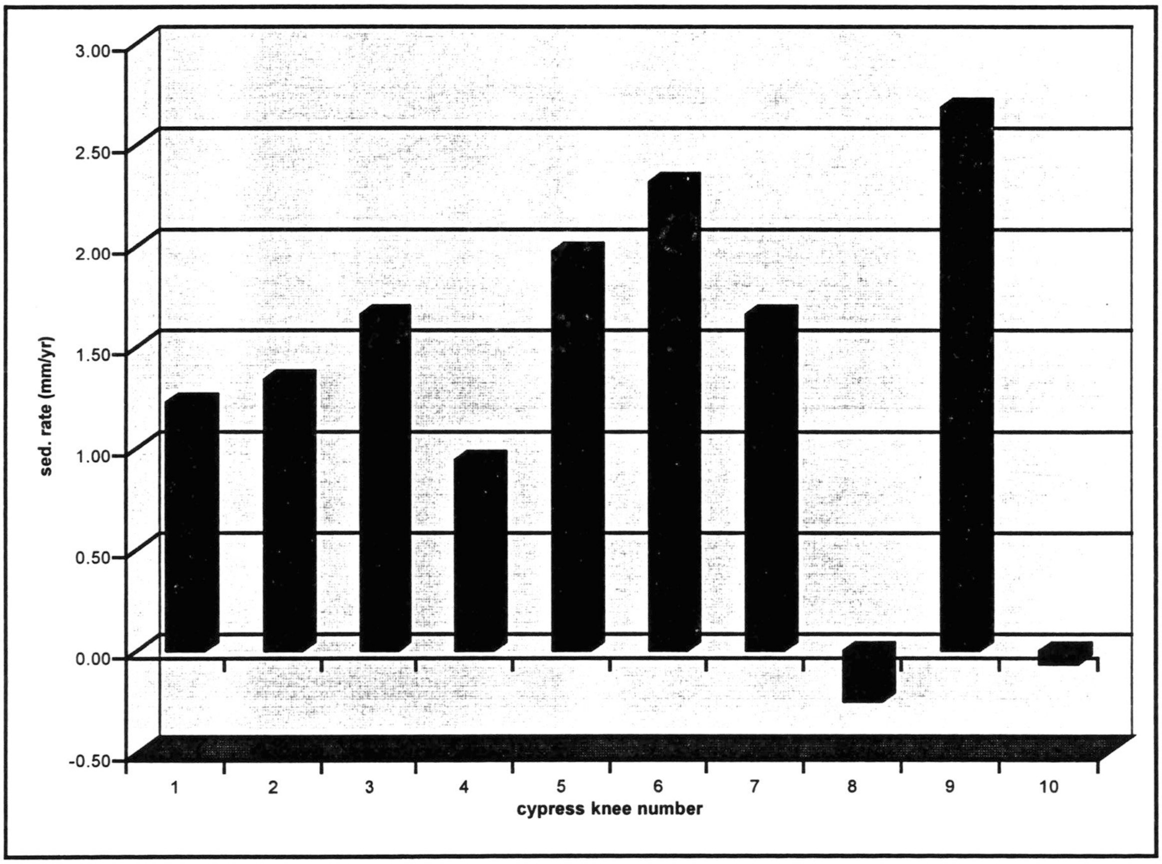
Knee Number	Deposition	Age	Sed. Rate (mm/yr)
1	20	45	0.44
2	35	48	0.73
3	50	65	0.77
4	50	57	0.88
5	38	57	0.67
6	22	39	0.56
7	0	47	0.00
8	120	68	1.76
9	38	33	1.15
10	35	45*	0.78



* = best estimated age

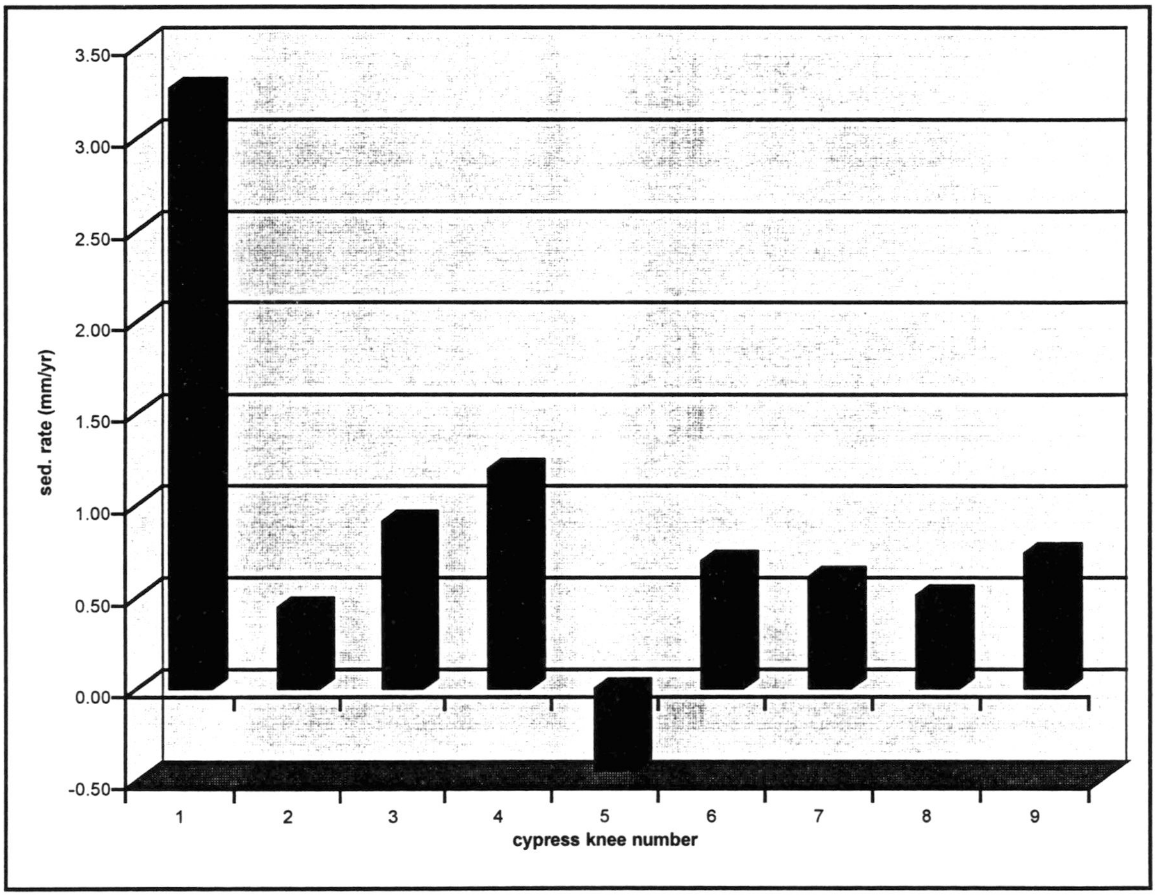
Circle four

Knee Number	Deposition	Age	Sed. Rate (mm/yr)
1	65	53	1.23
2	75	56	1.34
3	78	47	1.66
4	51	54	0.94
5	71	36	1.97
6	102	44	2.32
7	78	47	1.66
8	-10	40	-0.25
9	102	38	2.68
10	-2	30	-0.07



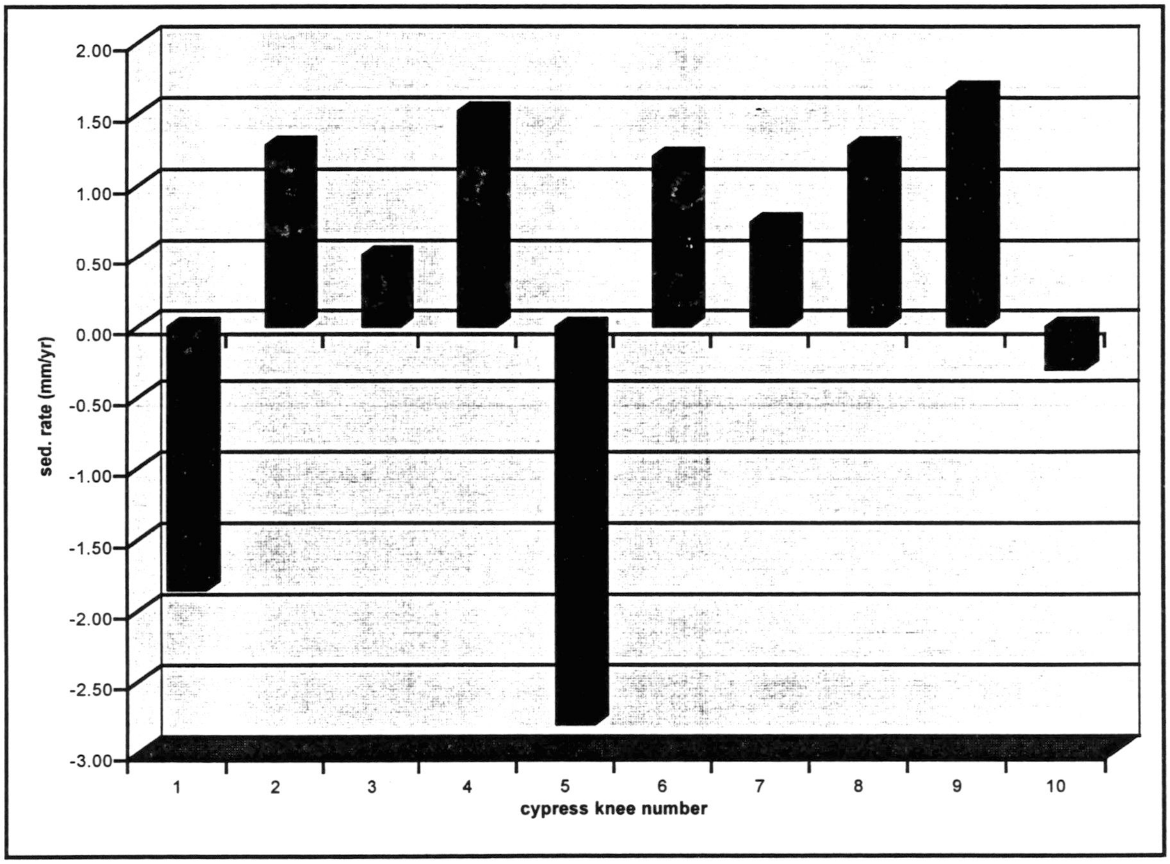
Circle five

Knee Number	Deposition (mm)	Age	Sed. Rate (mm/yr)
1	108	33	3.27
2	30	68	0.44
3	31	34	0.91
4	55	46	1.20
5	-28	63	-0.44
6	50	72	0.69
7	28	46	0.61
8	30	59	0.51
9	48	65	0.74



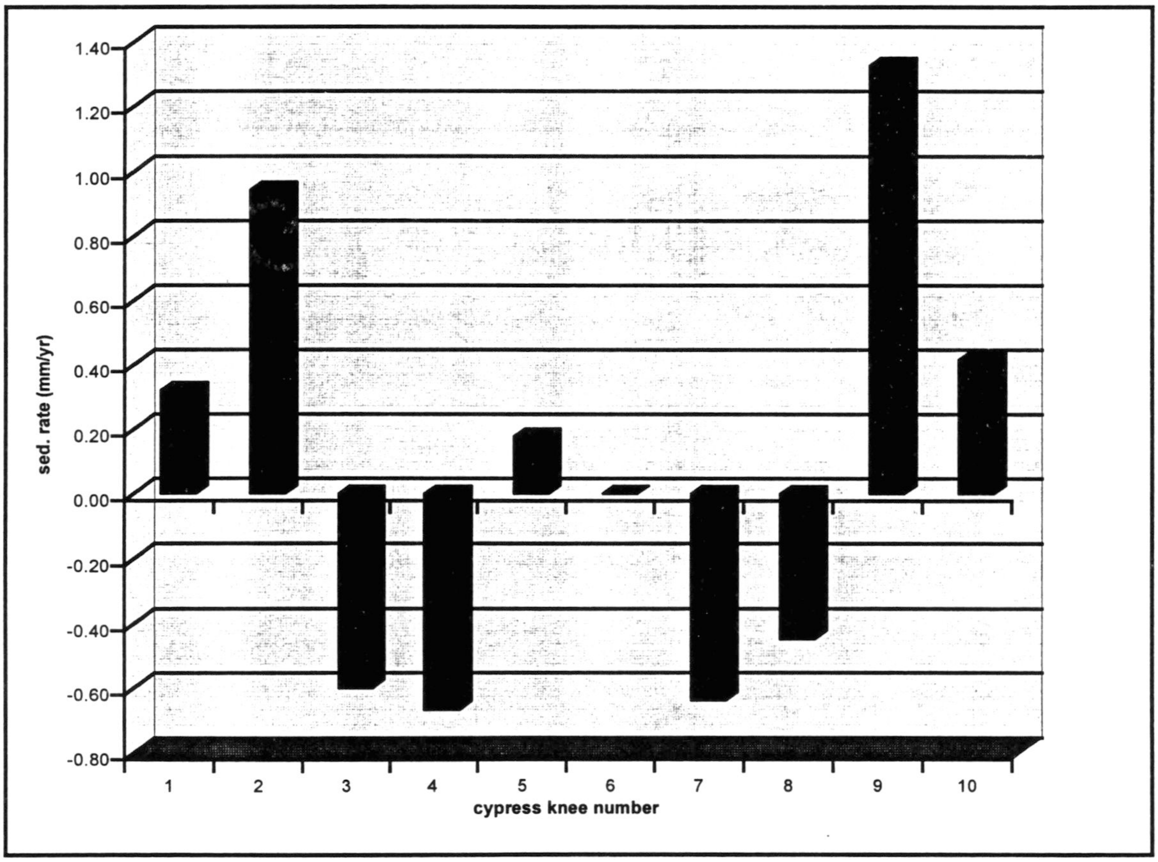
Circle six

Knee Number	Deposition (mm)	Age	Sed. Rate (mm/yr)
1	-50	27	-1.85
2	59	46	1.28
3	20	39	0.51
4	38	25	1.52
5	-70	25	-2.80
6	53	44	1.20
7	32	43	0.74
8	120	68	1.28
9	38	33	1.67
10	35	45	-0.30



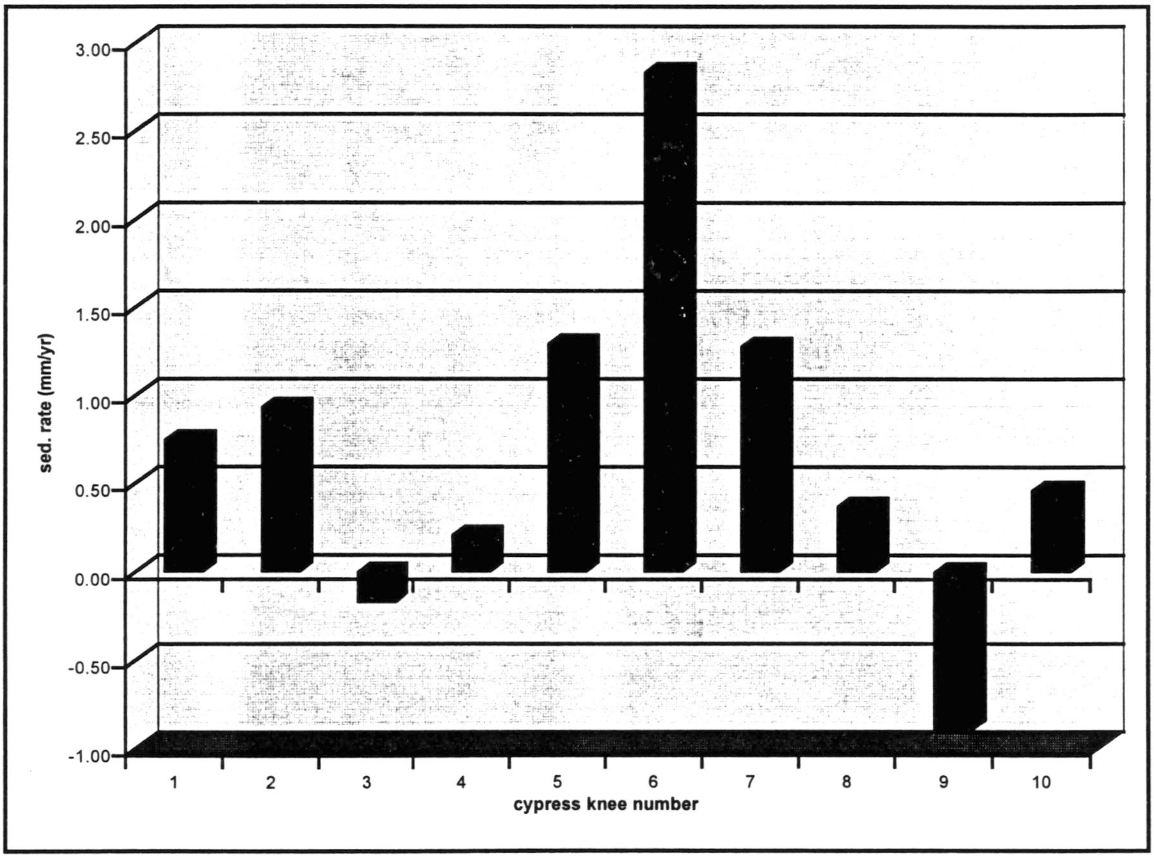
Circle seven

Knee Number	Deposition (mm)	Age	Sed. Rate (mm/yr)
1	25	78	0.32
2	50	53	0.94
3	-33	55	-0.60
4	-36	54	-0.67
5	10	56	0.18
6	0	42	0.00
7	-23	36	-0.64
8	-21	47	-0.45
9	65	49	1.33
10	20	48	0.42



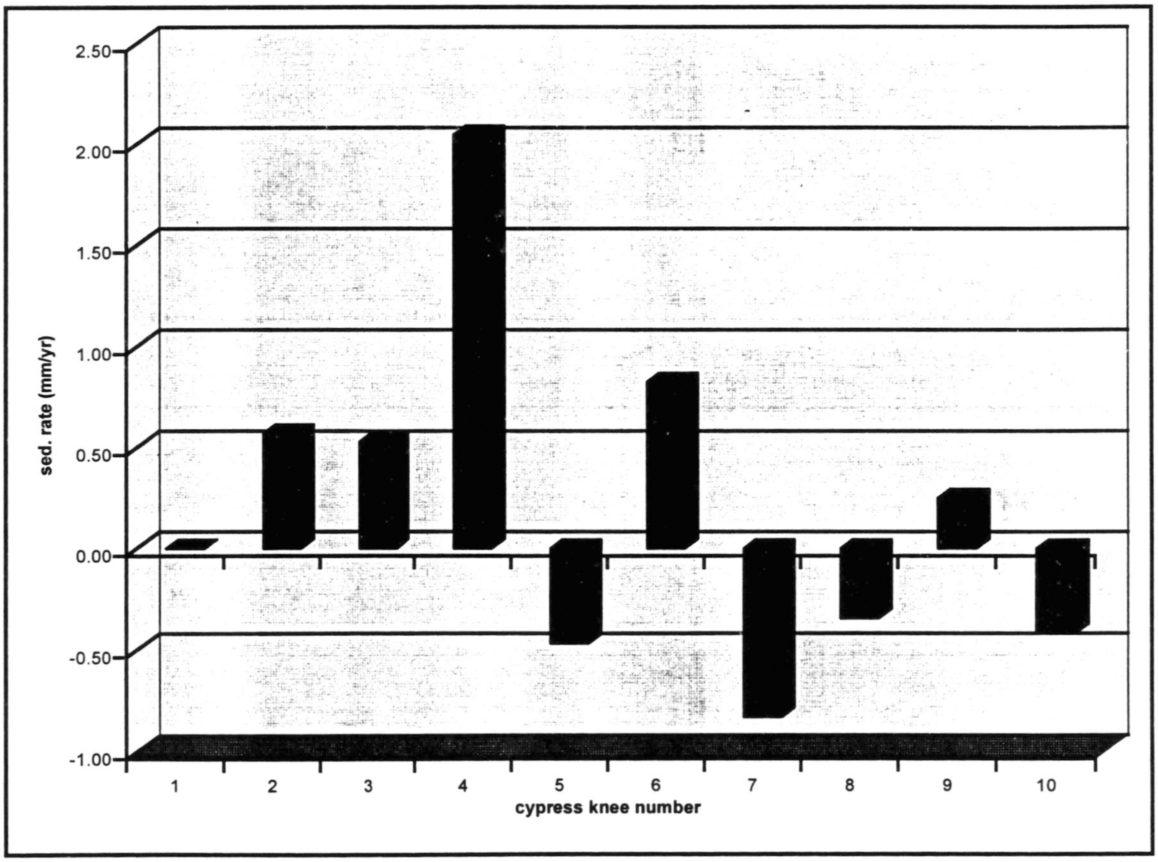
Circle eight

Knee Number	Deposition (mm)	Age	Sed. Rate (mm/yr)
1	18	24	0.75
2	58	62	0.94
3	-10	58	-0.17
4	20	95	0.21
5	35	27	1.30
6	102	36	2.83
7	78	61	1.28
8	30	81	0.37
9	-68	76	-0.89
10	18	39	0.46



Circle nine

Knee Number	Deposition (mm)	Age	Sed. Rate (mm/yr)
1	0	44	0.00
2	32	56	0.57
3	18	34	0.53
4	86	42	2.05
5	-15	32	-0.47
6	38	46	0.83
7	-39	47	-0.83
8	-10	29	--0.34
9	10	40	0.25
10	-18	43	-0.42



APPENDIX B

CORE RESULTS

H1 - Circle 1: Length attempted: 69 cm Length retrieved: 58 cm

0-5 cm; organic debris.
5-10 cm; dark gray (10YR 4/1) silt loam; common coarse prominent yellowish brown (10YR 5/6) mottles; dark gray (10YR 4/1) clay films covering ped faces; wet; non-sticky, plastic; few fine roots.
10-24 cm; light olive brown (2.5Y 5/4) sandy clay; common fine faint strong brown (7.5YR 5/8) mottles; common fine prominent black (10YR 2/1) mottles; lens of medium granular sand from 15 to 16 cm; well developed medium subangular blocky structure; wet; slightly sticky, plastic; few very fine roots.
24-58 cm; black (10YR 2/1) massive hemic swamp muck.

H2 - Circle 1: Length attempted: 132 cm Length recovered: 73 cm

0-5 cm; loose organic debris; common living root sprouts.
5-9 cm; black (10YR 2/1) silt loam; few fine faint yellowish brown (10YR 4/4) mottles; wet; slightly sticky, slightly plastic; common fine roots; few fine living root sprouts; abundant organics.
9-22 cm; very dark gray (10YR 3/1) sandy clay; abundant fine distinct yellowish brown (10YR 5/6) and dark yellowish brown (10YR 4/6) mottles; moderately developed fine subangular blocky structure; wet; sticky, plastic; few fine roots.
22-73 cm; black (5YR 2.5/1) folic swamp muck.

H4 - Circle 2: Length attempted: 115 cm Length recovered: 58 cm

0-58 cm; black (10YR 2/1) massive swamp muck.

H5 - Circle 3: Length attempted: 110 cm Length recovered: 36 cm

0-5 cm; very dark brown (10YR 2/2) silt loam; common fine prominent dark yellowish brown (10Y/R 3/6) mottles; wet; sticky, slightly plastic; common fine roots.
5-22 cm; very dark grayish brown (10YR 3/2) sandy clay; common fine prominent dark yellowish brown (10YR 3/6) and dark brown (10YR 2/2) mottles; moderately developed fine subangular blocky structure; wet; sticky, plastic; few fine roots.
22-36 cm; black (10YR 2/1) massive hemic swamp muck.

H6 - Circle 4: Length attempted: 97 cm Length recovered: 48 cm

0-7 cm; black (5Y 2.5/1) sandy loam; many coarse prominent dark brown (7.5YR 3 /4) mottles; wet; non-sticky, slightly plastic; common fine roots.
7-17 cm; very dark grayish brown (10YR 3/2) silt loam; many coarse faint dark brown (7.5YR 3/3) mottles; well developed medium subangular blocky structure; wet; slightly sticky; slightly plastic; common fine and medium roots.
17-48 cm; black (2.5Y 2.5/1) hemic swamp muck; few fine faint brown (7.5YR 4/3) mottles.

H7 - Circle 5: Collapsed from root abundance and core distortion

H8 - Circle 6: Length attempted: 91 cm Length recovered: 62 cm

0-6 cm; very dark grayish brown (10YR 3/2) sandy clay; few coarse faint dark brown (10YR 2/2) mottles; wet; sticky; plastic; very few fine roots.
6-13 cm; very dark grayish brown (10YR 3/2) swamp muck; black (2.5Y 2.5/1) organics covering some grain faces.
13-63 cm; black (2.5 Y 2.5/1) organic hemic swamp muck.

H9 - Circle 7: Length attempted: 120 cm Length recovered: 91 cm

0-9 cm; loose organic debris; many fine roots.
9-19 cm; very dark grayish brown (2.5Y 3/2) sandy clay; common coarse faint (5YR 4/6) mottles; many fine prominent yellowish brown (10YR 5/8) mottles; moderately developed medium subangular blocky structure; wet; sticky, plastic; many fine roots; few medium roots.
19-38 cm; grayish brown (10YR 5/2) sandy clay; many coarse distinct strong brown (7.5YR 4/6) and yellowish brown (10YR 5/6) mottles; moderately developed fine subangular blocky structure; wet; sticky, plastic; common fine roots.
38-40 cm; coarse yellow brown (10YR 4/6) sandy lens.
40-49 cm; very dark gray (10YR 3/1) swamp muck; few fine prominent strong brown (7.5 YR 4/6) and yellowish brown (10YR 5/6) mottles.
49-91 cm; black (10YR 2/1) massive hemic swamp muck.

H10 - Circle 8: Length attempted: 120 cm Length recovered: 61 cm

0-7 cm; very dark grayish brown (10YR 3/2) silty clay loam; common fine faint dark yellowish brown (10YR 4/4) mottles; wet; slightly sticky, slightly plastic; common fine roots.
7-24 cm; very dark grayish brown (10YR 3/2) silty clay; moderately developed medium subangular blocky structure; wet; slightly sticky, very plastic; few fine roots.
24-61cm; black (5Y 2.5/1) massive hemic swamp muck.

H11 - Circle 9: Length attempted: 117 cm Length recovered: 64 cm

0-18 cm; very dark grayish brown (2.5Y 3/2) sandy clay; many fine faint dark yellowish brown (10YR 4/6) mottles; coarse sandy lens from 15-17 cm; wet; slightly sticky, slightly plastic; common fine roots.

18-29 cm; black (2.5/1) clay loam; few fine faint dark yellowish brown (10YR 4/6) mottles; moderately developed fine subangular blocky structure; wet; sticky, plastic; few fine roots.

29-64 cm; massive sapric swamp muck.

APPENDIX C

AUGER RESULTS

<u>Circle 1</u>:
Auger 1:

0-5 cm; organic debris
5-11cm; very dark gray (2.5Y 3/1) sandy loam; wet; slightly sticky, non-plastic; many fine live fibrous roots.
11-31 cm; grayish brown (2.5Y 5/2) silty clay; many coarse distinct strong brown (7.5YR 5/8) mottles; moderately developed medium subangular blocky structure; wet; sticky, very plastic; few very fine roots.
31-83 cm (poor recovery after); black (5Y 2.5/1) massive folic swamp muck.

Auger 2:

0-4 cm; organic debris
4-44 cm; very dark gray (2.5Y 3/1) silty clay loam; few fine prominent yellowish brown (10YR 5/8) mottles: moderately developed medium subangular blocky structure; wet; slightly sticky, plastic; common fine and medium roots; few coarse roots.
44-48 cm (poor recovery and root inhibition after); very dark brown (10YR 2/2) massive hemic swamp muck.

<u>Circle 2</u>:
Auger 1:

0-2 cm; organic debris
2-54 cm; very dark grayish brown (2.5Y 3/2) massive clay loam; wet; slightly sticky, very plastic; common fine and medium roots.
54-81 cm (root inhibition after); very dark brown (10YR 2/2) massive hemic swamp muck.

Auger 2:

0 -2 cm; organic debris.
2 -85 cm; black (7.5YR 2.5/1) massive hemic swamp muck.

<u>Circle 3</u>: samples (random) 2 m apart
Auger 1:

0-2 cm; organic debris.
2-40 cm; very dark brown (10YR 2/2) sandy loam; many prominent coarse yellowish red (5YR 4/6) mottles and abundant organics covering ped facies; moderately developed coarse subangular blocky structure; wet to waterlogged; slightly sticky, slightly plastic; many fine and medium roots.
40-71 cm; black (5YR 2.5/1) massive hemic swamp muck.

Auger 2:

0-5 cm; organic debris and folic swamp muck.
5-42 cm; very dark grayish brown (2.5Y 3/2) sandy clay; many prominent coarse yellowish red (5YR 4/6) mottles; well developed coarse subangular blocky structure; wet; sticky, plastic; few fine roots.
42-84 cm; black (5YR 2.5/1) massive hemic swamp muck.

Circle 4: samples (random) 1.7 m apart

Auger 1:

0-4 cm; organic debris.

4-42 cm; very dark grayish brown (10YR 3/2) clay loam; many coarse prominent brown(7.5YR 4/4) mottles; clay loam; well developed medium subangular blocky structure; wet; sticky, plastic; few fine roots.

42-65 cm; black (10YR 2/1) massive hemic swamp muck.

Auger 2:

0-3 cm: organic debris.

3-34 cm: very dark grayish brown (2.5Y 3/2) clay loam; common medium faint brown (7.5YR 4/4) mottles; well developed coarse subangular blocky structure; wet; sticky, plastic; common fine and medium roots.

34-78 cm; black (10YR) massive hemic swamp muck.

Circle 5: samples (random) 3.25 m apart

Auger 1:

0-3 cm; organic debris.

3-30 cm; very dark grayish brown (10YR 3/2) clay loam; many medium prominent dark yellowish brown (10YR 4/4) mottles; well developed medium subangular blocky structure; wet; sticky, plastic; very few fine roots.

30-96 cm; black (10YR 2/1) massive hemic swamp muck.

Auger 2:

0-6 cm; organic debris and swamp muck.

6-22 cm; very dark gray (5Y 3/3) clay loam; many medium prominent dark yellowish brown (10YR 4/6) mottles; well developed fine blocky structure; wet; slightly sticky, slightly plastic; few very fine roots.

22-60 cm; very dark brown (10YR 2/2) massive hemic swamp muck.

Circle 6: samples (random) 0.8 m apart

Auger 1:

0-5 cm; organic debris and folic swamp muck.

5-39 cm; very dark grayish brown (10YR 3/2) clay loam; few fine faint brown (7.5YR 4/4) mottles; wet; slightly sticky, slightly plastic; few fine roots.

39-56 cm (poor recovery after); black (10YR 2/1) massive hemic swamp muck.

Auger 2:

0-7 cm; organic debris and muck

7-24 cm; very dark grayish brown (10YR 3/2) clay loam; many fine faint dark yellowish brown (10YR 3/6) mottles; wet; sticky, plastic; common fine roots.

24-66 cm; black (10YR 2/1) massive hemic swamp muck.

Circle 7: samples (random) 2 m apart

Auger 1:

0-3 cm; organic debris.

3-10 cm; black (2.5Y 4/2) folic sandy clay; few coarse prominent dark reddish brown (5YR 3 /4) mottles; dark grayish brown (2.5Y 4/2) clay films on ped facies; moderately developed coarse subangular blocky structure; wet; slightly sticky, very plastic; abundant very fine, fine, and medium roots; abundant organics.

10-60 cm; grayish brown (2.5Y 5/2) silty clay loam; abundant coarse prominent reddish brown (5YR 4/4) mottles; gray (7.5YR 5/1) clay films on grain and bridges; well developed medium subangular blocky structure; wet; sticky, very plastic;common fine and medium roots.

60-80 cm; black (10YR 2/1) massive hemic swamp muck; grayish brown (2.5Y 5/2) clay films on grain faces.

Auger 2:

0-3 cm; organic debris.

3-42 cm; grayish brown (2.5Y 5/2) silty clay loam; abundant coarse distinct dark yellowish brown (10YR 4/6) mottles; well developed medium subangular blocky structure; wet; sticky, plastic; many fine and medium roots.

42-68 cm; black (10YR 2/1) massive hemic swamp muck; grayish brown (2.5Y 5/2) clay films covering grain faces.

Circle 8: samples (random) 1.25 m apart

Auger 1:

0-3 cm; organic debris.

3-34 cm; grayish brown (2.5Y 4/2) sandy loam; moderately developed medium subangular blocky structure; wet; slightly sticky, slightly plastic; common fine roots.

34-6 cm; black (5Y 2.5/1) massive hemic swamp muck.

Auger 2:

0-4 cm; organic debris.

4-32 cm; grayish brown (2.5YR 4/2) sandy loam; few fine prominent reddish brown (2.5YR 4/4) mottles; moderately developed medium subangular blocky structure; wet; slightly sticky, slightly plastic; common fine roots.

32-47cm; black (5Y 2.5/1) massive hemic swamp muck.

Circle 9, H11: samples (random) 1.3 m apart

Auger 1:

0-3 cm; organic debris.

3-51 cm; very dark grayish brown (2.5Y 3/2) sandy loam; common fine faint dark yellowish brown (10YR 4/6) mottles; moderately developed fine subangular blocky structure; wet; slightly sticky, slightly plastic; common fine and medium roots.

51-92 cm; black (10YR 2/1) massive hemic swamp muck.

Auger 2:

0-2 cm; organic debris.

2-54 cm; very dark grayish brown (2.5Y 3/2) silty clay loam; few coarse faint light olive brown (2.5Y 5/3) mottles; common coarse faint dark yellowish brown (10YR 3/6) mottles; few medium prominent brown (7.5YR 4/4) mottles; well developed medium subangular blocky structure; wet; slightly sticky, plastic; few fine roots.

54-76 cm; very dark brown (10YR 2/2) massive hemic swamp muck.