INTEGRATING TWO SEDIMENTATION RATE METHODS TO DETERMINE PAST CHANNEL ADJUSTMENT RATES

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Abstract: Channel adjustment and sedimentation rates are needed when determining stream management activities to reduce erosion and sedimentation. Channel adjustment rates are typically determined using historical channel geometry, channel profiles, and air photos, or dendrogeomorphic techniques. When this information is not available, sediment deposition rates of a downstream waterbody may be used as a surrogate for long-term channel adjustment rates in the watershed. Methods of determining sediment deposition rates include developing sediment budgets and/or radiometric (^{137}Cs) analysis. Using these two methods, short-term and long-term depositional rates within the Lower Cache River-Cypress Creek Wetland in southern Illinois were computed and compared. Results provide insights into the historical rate of upstream channel adjustments in the watershed. Specifically, based on sediment core data collected in 2000, the radiometric (^{137}Cs) analysis determined that the wetland has a long-term sediment deposition rate of 0.86 cm/yr (1963-2000). The sediment budget method, based upon sediment monitoring data collected between 1986 and 2002, computed a nearly identical short-term sediment deposition rate of 0.79 cm/yr. Since the depositional rates determined by the two methods are very similar, it is reasonable to assume that the sediment deposition in the wetland, as well as the channel adjustment rates in Big Creek, have been steady since at least 1963.

INTRODUCTION

Identifying the prevailing channel response processes to disturbances is needed for predicting the rates and magnitudes of channel adjustments. Conceptual models of channel evolution (i.e. Schumm et al., 1984; Simon, 1989) are used to identify these processes and focused geomorphic assessments utilize historical analyses and field measurements to quantitatively predict the channel response rates (Simon et al., 2005). Channel adjustment rates are typically determined by measuring changes in channel geometry over time using channel gradient profiles and cross-section surveys (Trimble, 1998). Maps and aerial photography integrated with GIS technology has improved the ability to inspect changes in channel planform and measure channel meander rates (Urban and Rhoads, 2003). Dendrogeomorphic indicators have also been used to establish stages of channel evolution, rates of channel widening, and floodplain accretion (Hupp and Bornette, 2003). In the absence of these types of data, depositional (sedimentation) rates in lakes or wetlands can be used as a reflection of erosion responses, one of which is channel adjustment, in a watershed. Generating a sediment budget based on annual yields measured at the inflows and outflows of a reservoir is a common technique to determine sedimentation rates. Other techniques include sedimentation surveys or radiometric analysis using cesium-137 (^{137}Cs). Sedimentation rates based on radiometric ^{137}Cs analysis has been reviewed by Crickmore et al., 1990) Ritchie and McHenry (1990), and Santschi and Honeyman, 1989). Brown et al. (1981), Lance et al. (1986), and McHenry et al. (1973) have demonstrated the application of ^{137}Cs to measure accumulation patterns in small watersheds and Kadlec and Robbins (1984) in a wetland area. Cesium-137 measurements were used to determine in-channel, wetland, and reservoir sediment storage for erosion response studies in small catchments (Zhang et al., 1997; Walling et al., 2002).

The ^{137}Cs measurement technique has been successfully used in Illinois to study sedimentation processes in backwater lakes associated with the Illinois and Mississippi Rivers (Cahill and Autrey, 1987). Demissie et al. (1992) determined sedimentation rates for the Lower Cache River-Cypress Creek Wetland in southern Illinois by comparing two methods: ^{137}Cs analysis in the wetland and a sediment budget generated from measured sediment yield data for the watershed. The objective of their study was to determine the sedimentation rates for various depositional environments of the Lower Cache River-Cypress Creek Wetland. The two sedimentation rate methods were used because each had some limitations for achieving that objective. The sediment budget method provided the sedimentation rate over the entire area and identified high sediment yield sub-watersheds but was not capable of providing the spatial distribution of sediment deposition within the wetland. The radiometric method provided the site-specific data of the sedimentation rates for various depositional environments. The combination of these two methods provided a more complete picture of the sedimentation pattern in the wetland.

Demissie and others (1990b) identified Big Creek as the tributary that contributes a significant portion (nearly 70%) of the suspended sediment load to the Lower Cache River-Cypress Creek Wetland. Subsequently, several investigations have been conducted in the Big Creek watershed to determine the magnitude of the sedimentation and the erosion processes responsible for the high sediment loads (Allgire, 1991; Demissie and Xia, 1991; Demissie et al., 1992; Allgire and Cahill, 2001; Demissie et al., 2001). A geomorphic assessment was recently conducted in the Big Creek watershed to determine and quantify the prevailing erosion processes. The study found that there was significant channel straightening in the lower reaches of Big Creek, bedrock controls in the upper reaches, and historical land use changes throughout the watershed. This resulted in two styles of channel adjustment responses distributed between upper and lower regions of the Big Creek watershed. Data typically used to directly measure channel adjustments rates was unavailable for the Big Creek watershed which made it difficult to estimate potential channel adjustment rates. Therefore, sedimentation rates in the wetland were examined as a surrogate to determine an average channel adjustment rate in Big Creek. This paper presents the results of an investigation that determined the rates of sediment deposition in the wetland using the two methods as described by Demissie et al. (1992). This investigation utilized the sedimentation rates for the Lower Cache River-Cypress Creek Wetland as reported by Allgire and Cahill (2001). They determined the rates from 1963 to 2000 based on ^{137}Cs measurements of cores collected for a sedimentation survey conducted in 2000. Based on eight years of monitoring data in the Lower Cache River watershed collected by the Illinois State Water Survey, annual sediment budgets were generated by this investigation to determine the average wetland sedimentation rate between 1986 and 2002. The 1986-2002 sedimentation rate determined by the sediment budget method will be contrasted with the 1963-2000 rate reported by Allgire and Cahill (2001) to identify the adjustment rate leading up to the current character of the Big Creek watershed.

BACKGROUND

Study Watershed Description: The Cache River Basin is located in extreme southern Illinois near the confluence of the Ohio and Mississippi Rivers (figure 1). During the first half of the 1900s, intensive drainage, flooding, and water-level control projects here implemented to facilitate “reclamation” of the land for agricultural use that resulted in the division of the Cache River into two distinct drainage basins (Hutchison, 1984). The Upper Cache River watershed (953 km^2 drainage area) drains directly into the Ohio River, but farther upstream from the original outlet, and the Lower Cache River watershed (927 km^2) drains westward into the Mississippi River through a diversion channel. During high flows the Lower Cache River can also drain eastward to the Upper Cache River-Post Creek Cutoff through one-way culverts in a levee. The Lower Cache River-Cypress Creek Wetland is recognized by state, national, and international organizations as a “biologically significant” natural area and a RAMSAR “wetland of importance”. The wetlands are known for being the northern most extent of cypress-tupelo gum tree stands of the Coastal Plains Province, some more than 1,000 years old. The wetland has two major tributaries: Big Creek and Cypress. Each of these tributaries drains a high-relief headwater area and flows into the nearly flat valley bottom of the Lower Cache River. Logging, conversion of forest to agriculture, and many drainage alterations projects have led to substantial changes in runoff and sediment supply, which set into motion adjustment processes that have caused erosion of the uplands and channel perimeter and delivery of high suspended-sediment loads to the Lower Cache River-Cypress Creek Wetland (Demissie et al., 1990). The position of the wetland and changes to the river’s hydraulic characteristics due to drainage alterations causes the wetland to act much like a sedimentation basin. This has produced deposition and high levels of turbidity in the wetland, endangering the sensitive components of the ecosystem.

Geomorphic Assessment: The geomorphic assessment established the temporal and spatial context of the stream channel character through a combination of historical analysis and multi-scale field reconnaissance for the entire watershed. The study identified the major disturbances and two responding channel adjustment processes in the lower and upper regions of Big Creek. The major disturbance in Big Creek was the 58% reduction in channel length due to channel straightening in the 1930s and 1940s. Inspection of maps and air photos show no significant lateral channel movement outside of the straightened reaches. The other was a major shift from virtually all forest to agricultural production by the 1930s. Currently, 18% of the land cover is in forest. Watershed area in agricultural use has increased slightly from 1925 (26%) to present (34%) due to increase in row crops. Pasture and

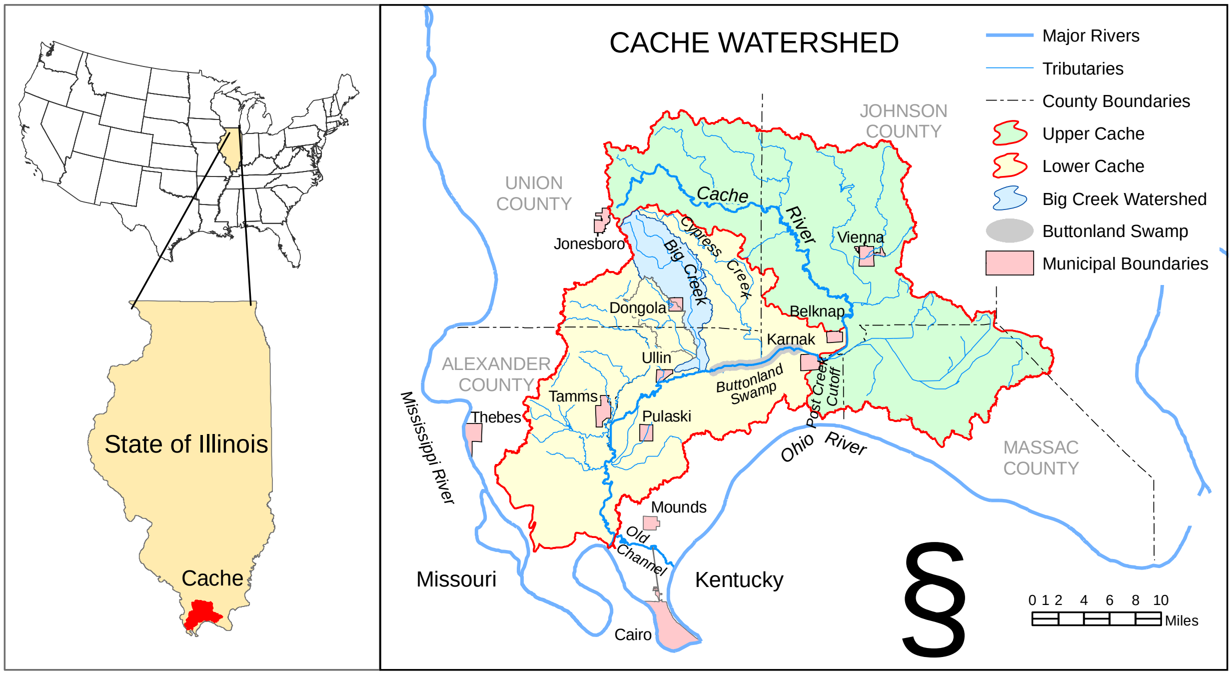

Figure 1 Location of study area in the Cache River Basin, Illinois.

open lands comprise the remaining area for agricultural use. The channel straightening projects included six major flow control structures to compensate for the increased slope (figure 2). However, field reconnaissance has identified incision and widening throughout the channel in the lower region which currently exhibits Stages IV (threshold) and V (aggradation) of channel evolution (Simon, 1989). Historical channel geometry confirms that incision and widening occurred within straightened reaches (figure 3). Although it is the reaches further upstream

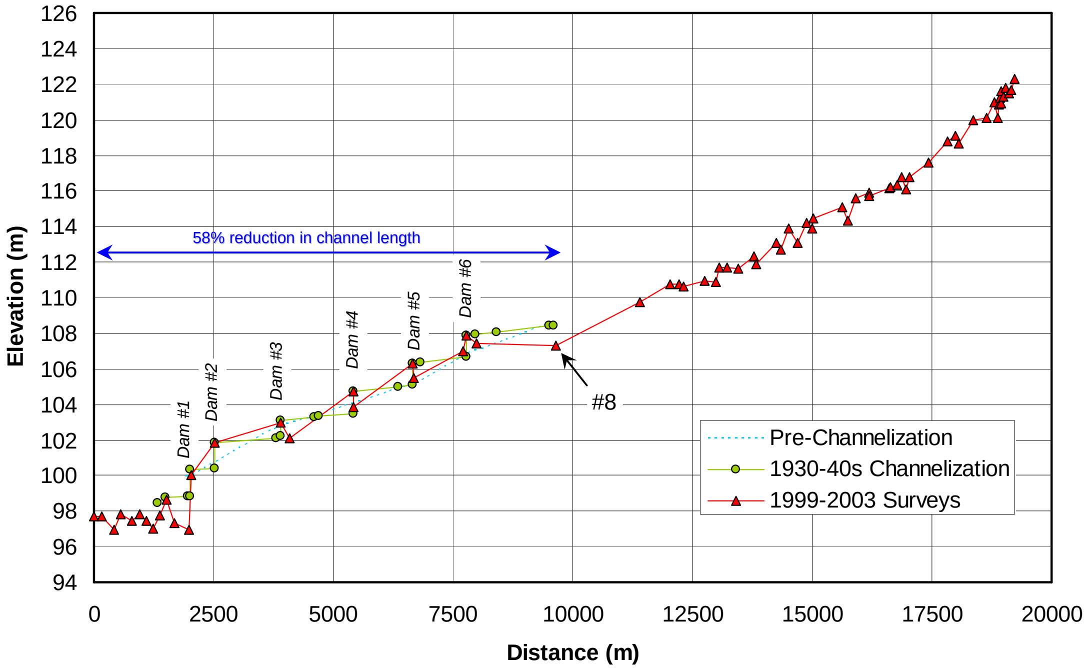

Figure 2 Channel profiles for 1944-2003

that have significant bank instabilities (rotational slips, toe erosion, and major large woody debris) indicative of active channel widening. Hydraulic modeling shows the absence of energy for further significant channel incision which infers that the channel may be entering Stage V (aggradation) of evolution. The channel in the upper region is underlain by Mississippian limestone bedrock and Quaternary gravel lake deposits which has interrupted any incision processes. Gravel is the major bed material and forms mid-channel bars that tend to deflect flow into the channel banks. The entire watershed is covered by 1-2 meters of Peoria loess which is exposed at all channel banks. Particle size analyses show that the sediment deposited in the wetlands is the same as the material found in the banks.

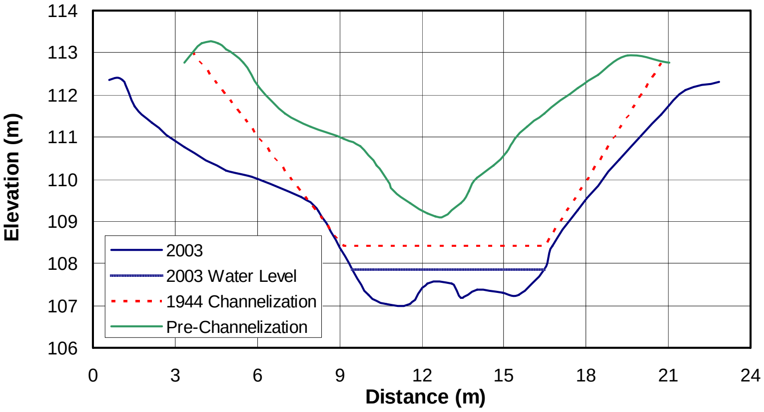

Figure 3 Change in channel geometry from at Site #8 1944-2003

METHOD

This investigation uses a combination of two sedimentation rate methods as described by Demissie et al., (1992). The first is a sediment budget generated from sediment yields measured at streamgaging stations monitoring the inflow and outflow of the wetland. The volume of sediment deposited in the wetland is determined from the sediment budget by dividing the sediment weight by the sediment density. The rate of vertical deposition is then calculated by dividing the sediment volume by the area of sediment deposition. The second method determines sedimentation rate by ^{137}Cs measurement of sediment cores collected from various locations within the wetland. The ^{137}Cs method and results of the Lower Cache River-Cypress Creek Wetland 2000 sedimentation survey as reported by Allgire and Cahill (2001) are presented below. The method for determining sedimentation rate by sediment budget and results will follow.

Sedimentation Rates Based on Radiometric Dating: Allgire and Cahill (2001) performed a sedimentation survey of the Lower Cache River-Cypress Creek Wetland in 2000. Sediment cores were collected along 10 transects through the river channel, sloughs, and floodplain deposits as well as areas not disturbed by dredging or tillage operations. A piston-type and Wildco gravity core samplers were used to sample submerged sediments in the wetlands while a stainless steel soil probe was used to collect sediment cores in aerated sediments. The piston-type core sampler was used to collect submerged sediment cores for unit weight, particle size, and chemistry analyses. Several representative 5-centimeter (cm) sub-samples were sectioned from the core for laboratory analyses.

The Wildco gravity core sampler, with lexan core tubes, was used to collect submerged sediment cores for analysis by the Cesium-137 (^{137}Cs) dating technique. Sediment cores collected using the soil probe were sub-sampled in the field, prepared and packaged, and transported to the analytical laboratory for unit weight, particle size, and radiometric analysis. Sediment cores for radiometric analysis were extruded, cut into detailed 5 cm intervals, and sub-sampled for ^{137}Cs analysis. Sediments were weighed and then air-dried in a Class 100 laminar-flow clean bench. Sediment sub-samples were ground using a ceramic mortar and pestle and sieved to pass a 1.0-mm stainless steel sieve. Ten grams (g) of sediment were weighed into polystyrene petri dishes, which were then sealed.

The long radioactive half-life (30.174 years) and the distinct pattern of ^{137}Cs in the environment make it a very useful tracer of recent hydrologic and sedimentologic processes. The atmospheric testing of nuclear weapons that produced ^{137}Cs began to be deposited worldwide in significant quantities in 1952. About 90 percent of the total flux of ^{137}Cs in the Northern Hemisphere was deposited between 1954 and 1963, prior to the signing of the Limited Nuclear Test Ban Treaty of 1963. Despite sporadic inputs in recent years, the amount of ^{137}Cs in the atmosphere has decreased since 1966 to near zero (Ritchie and McHenry, 1990).

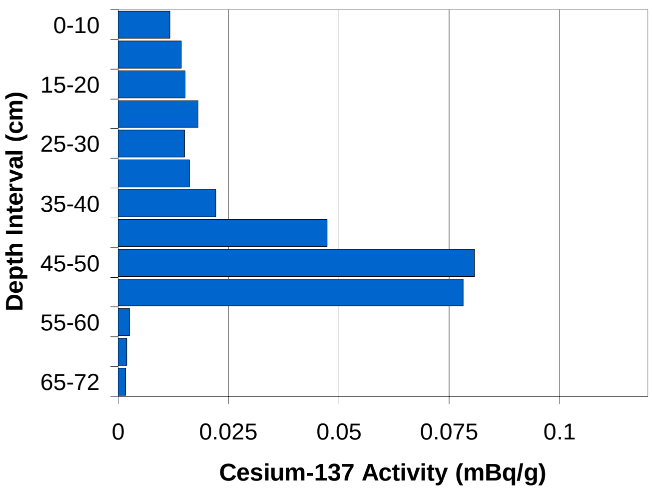

Figure 4 Example 137Cesium core results from transect 9-10 in the Cache River wetland.

Gamma activity of sediment samples was measured using high-purity germanium and lithium-drifted germanium [Ge (Li)] crystals. Sediment samples were counted for an average of 45 hours. Peak analysis software was use to calculate net peak area. The sample activity relative to NIST 4350B was then calculated in milli-becquerel per gram (mBq/g). The lowest specific activity that could be detected in a 10-g sample was approximately 0.003 mBq/g. Figure 4 illustrates the ^{137}Cs activity versus depth plotted for each core to select the position in the sedimentation record when fallout from testing of nuclear weapons (1954) in the atmosphere began or the peak time of fallout from nuclear testing (1963). Sedimentation rates then were calculated with these dates as a marker. All sedimentation rates obtained by this technique are based on the assumption of a constant rate of sedimentation over the time interval of interest (37 or 46 years). However, computing a sedimentation rate between the depths of 1954 and 1963 can be highly suspect unless there is good evidence of no significant shifting or scouring of bottom sediments.

Allgire and Cahill (2001) reported that the wetland sedimentation rates for the 1963-2000 period averaged 0.86 cm/yr and ranged from 0.2 to >2 cm/yr. In general, the side channels had the highest rate of sedimentation followed by backwater sloughs, ponds, and wetland meadows. The samples collected from the floodplain showed the lowest rate of sedimentation, and the sites directly connected to the main channel in the wetland had the highest sedimentation rates.

Sedimentation Rates Based on Sediment Budget: A sediment budget was generated from suspended sediment data collected from stream gaging stations during water years 1986-1990 and 2000-2002 by the Illinois State Water Survey. Sediment load was computed for three stations in the Lower Cache River-Cypress Creek Wetland area. The wetland has two major tributaries, Big and Cypress Creeks, and each has a station that monitored sediment inflow. The third station, Lower Cache River at Ullin, monitored the sediment outflow from the wetland. Using the sediment yields at Big and Cypress Creek to estimate yields for non-monitored watersheds, a sediment budget was generated using the total sediment inflow into the wetland area and sediment outflow at Ullin. Sediment yield from the entire area draining into the wetland was determined by dividing the area into nine sub-watersheds (figure 5). Sub-watersheds 1 and 8 are the Big Creek and Cypress Creek monitored watersheds, respectively. The sediment yields at the Cypress Creek gage was used to determined yields for sub-watersheds 3-7 and 9. Big Creek's sediment yield rate was used for sub-watershed 2 due to similarity of physical characteristics with Big Creek. Once the yields were determined, the sediment budget for the Lower Cache River wetland area was calculated by using an equation similar to one used by Parker (1988):

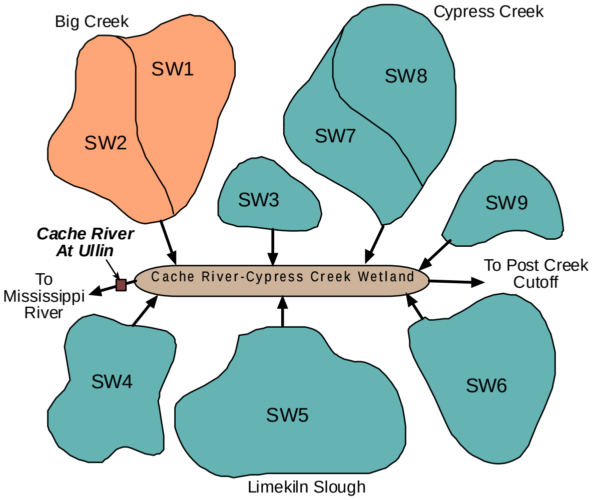

Figure 5 Sub-watersheds draining into the Cache River-Cypress Creek Wetland

$$\Delta Qs = \sum_{i=1}^{n} Qs_{Ti} - Qs_{o} \quad (1)$$

where ΔQs = sediment trapped/scoured from the study area; Qs_o = sediment outflow from the study area; Qs_{Ti} = sediment inflow from tributary stream; and n = number of tributary streams.

Table 1 Sediment Budget of the Cache River-Cypress Creek Wetland

		Sediment Yields (tons x 10^3)							
Subwatersheds	*Hectares ($x10^3$)*	*1986*	*1987*	*1988*	*1989*	*1990*	*2000*	*2001*	*2002*
SW1 (Big)	8.1	8.1	74.6	14.3	16.1	46.6	36.4	18.9	4.5
SW2	4.8	4.8	44.0	8.5	9.5	27.5	21.5	11.1	2.7
SW3	3.3	3.3	3.8	1.9	2.8	5.2	5.8	2.7	0.7
SW4	1.6	1.6	1.9	0.9	1.4	2.5	2.8	1.3	0.3
SW5	5.7	5.7	6.8	3.3	4.9	9.1	10.2	4.8	1.2
SW6	3.0	3.0	3.6	1.7	2.6	4.8	5.4	2.5	0.6
SW7	5.7	5.7	6.7	3.3	4.9	9.1	10.2	4.8	1.1
SW8 (Cypress)	6.3	6.3	7.4	3.6	5.4	10.1	11.2	5.3	1.3
SW9	1.7	1.7	2.0	1.0	1.5	2.8	3.1	1.5	0.3
Total Sediment Inflow:	40.2	150.8	38.5	49.1	117.8	106.6	52.9	12.7	246.5
Cache R. @ Ullin		23.3	7.9	14.0	41.2	32.2	8.7	2.4	25.4
Total Sediment Outflow:*		25.6	8.7	15.4	45.3	35.4	9.6	2.6	27.9
Total Sediment Deposited		**125.2**	**29.8**	**33.8**	**72.5**	**71.2**	**43.3**	**10.1**	**218.6**

*Adjusted sediment yield at Cache River at Ullin x 1.10

The total sediment yield into the wetland was calculated by summing the yields for all nine sub-watersheds. However, the total sediment discharge from the wetland area was calculated by increasing the measured sediment load at Ullin by 10 percent to account for some outflow of sediment through the levee culverts to Post Creek Cutoff (Demissie et al., 1992). Using this approach, the sediment yield rates for the sub-watersheds, presented in table 1, are considered conservative and would tend to underestimate the sediment yield from the entire area but should provide a reasonable estimate.

With the total sediment deposited in the wetland for each year determined, the annual vertical rate of sediment deposition was calculated using the equation used by Demissie, et al. (1992):

$$\Delta Z = \frac{S_{wt}}{S_d \bullet A_s} \tag{2}$$

where ΔZ = vertical sedimentation rate; S_{wt} = weight of sediment deposited; S_d = density of the deposited sediment; and A_s = area of sediment deposition.

An average sediment density of 800 kilograms per cubic meter (kg/m^3) for the entire area was estimated from densities determined in the laboratory of several submerged (641 kg/m^3) and exposed (1,442-1,602 kg/m^3) samples (Demissie et al., 1992). To determine the area of deposition, Demissie et al. (1992) generated stage exceedence curves using water level records in the wetland. Based on these curves, and knowledge of the river valley, they determined an area that included all stream channels, backwaters, sloughs, and the wetlands along the streambanks. These areas are generally flooded every year and took into account natural variability of flood water-levels from year to year. The area was estimated by using an elevation-surface area curve also developed by Demissie et al. (1992).

Results: The results of the sedimentation rate calculations based on the sediment budget method are summarized in table 2. The annual sedimentation based on sediment budget ranges from 0.3 to 2.3 inch with an overall average rate of 0.79 inch for the eight years. The average sedimentation rate for water years 1986-1990 is 0.69 and 2000-2002 is 0.95 cm/yr. However, it should be noted that water years 1987, 1988, 2000, and 2001 were dryer years, while water years 1986, 1989, and 1990 varied near normal and 2002 was extremely wet. The variation of wet and dry years is not evenly distributed and consequently cannot be used to infer a change in sedimentation rate between these two periods. Therefore, the 0.79 average sedimentation rate will be assumed to be the representative rate for the entire 17-year period (1986-2002).

Table 2 Sedimentation Rates Based on Sediment Budget

Water Year	*Sediment Accumulation (tons x 10^3)*	*Volume of Sediment (m^3 x 10^3)*	*Area of Wetland Sedimentation (ha x 10^3)*	*Wetland Sedimentation Rates (cm)*
1986	125.2	156.5	1.2	1.30
1987	29.8	37.3	1.2	0.31
1988	33.8	42.2	1.2	0.35
1989	72.5	90.6	1.2	0.76
1990	71.2	89.0	1.2	0.74
2000	43.3	54.1	1.2	0.45
2001	10.1	12.6	1.2	0.11
2002	218.6	273.2	1.2	2.28

DISCUSSION

The sedimentation rate as determined by sediment budget for the more recent 17-year period (WY1986-2002) is on average 0.79 cm/yr and ranges from 0.3 to 2.3 cm/yr, depending in the year. The radiometric analysis determined the rate in the wetland for the 38-year period of 1963-2000 to be 0.86 cm/yr with a range of 0.2 to >2 cm/yr, depending on the depositional environment. Based on the sediment budget and radiometric analysis, the average sedimentation rate for the wetland, as well as the range of rates, is very similar. Therefore, it is reasonable to assume that since the rate from the recent period is nearly the same as the longer 40-year period, sedimentation in the wetland has been steady since at least 1963. The sedimentation rates for the wetland are lower than nearby lakes such as Horseshoe Lake, a natural oxbow lake in the Mississippi River valley, and the Vienna Correctional Center Lake, which had sedimentation of 1.3 cm/yr during the 1951-84 (Horseshoe Lake) and 1965-96 (Vienna Lake) periods (Bogner et al., 1985; Bogner et al., 1997). However, the wetland rates are higher than those for wetlands in other Coastal Plain rivers, which range from 0.15-0.54 cm/yr (1.5-5.4 mm/yr) (Hupp, 2000).

Since Big Creek was identified as contributing 70% of sediment to the wetland (Demissie et al., 1990), the wetland sedimentation rate was assumed to be representative of sediment delivery from Big Creek. Based on the similar rates between the two time periods, this implies that Big Creek has been steadily adjusting for the last 40 years. Although, sedimentation rates between the 1940s and 1963 are unknown, the influence of the six flow control structures installed during the channel straightening is assumed to have slowed upstream adjustments during this period similar to the effect constructed pool/riffle sequences would have on improving channel stability. Without these structures, the 58% reduction in stream length, doubling of slope, would have resulted in much higher initial sediment transport rates. Field reconnaissance and modeling information has established that Big Creek is currently transitioning out of a Stage IV of channel evolution (incision and widening process). This is 60 years from the initial disturbance (Stage II), which implies that the channel may take many years to evolve through the Stage V phase of widening to restabilization (Stage VI). The integration of disturbance history, identification of the active channel response processes (CEM), and determination of sedimentation rates as a surrogate for channel adjustment rates allows for reasonable determination of future channel response. Combining sedimentation rates as determined by sediment budget and radiometric analysis methods is an alternative for estimating average channel adjustment rates when typical data and information are not available.

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