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Sedimentation in three small erosion control reservoirs in northern Mississippi

D.G. Wren, R.R. Wells, C.G. Wilson, C.M. Cooper, and S. Smith Jr.

Abstract: The water storage capacity and dam integrity of thousands of flood control reservoirs built since 1950 may be compromised by excessive stored sediments. The fate of these structures depends on the amount and characteristics of accumulated material. To aid in understanding the scope of impairment of small reservoirs in the hill lands of northern Mississippi, physical sediment characteristics and reservoir storage capacity were evaluated in three small reservoirs (<8 ha [<20 acres]) built in the early 1960s as part of the Yazoo-Little Tallahatchie erosion control project. A vibrating corer was used to collect continuous cores of deposited sediment and preimpoundment soil. Bulk density, grain size, and activity of ^{137}Cs were used to identify the boundary between preimpoundment soil and postimpoundment sediment. Mean local sediment accumulation rates ranged from 5.6 to 7.9 mm yr^{-1} (0.22 to 0.31 in yr^{-1}) with reductions in storage capacity of 7% to 18% since construction. Selected cores were tested for pre-1972 residual pesticides and more recently used pesticides. Results suggest that some currently used pesticides are being transported by prevailing winds from the heavily farmed Mississippi Delta area.

Key words: core sampling—pesticide—reservoir sedimentation—watershed

About 75,000 dams of various sizes exisft in the United States (Graf 1999). Approximately 11,000 reservoirs in the United States have been constructed since the 1940s by the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) (Caldwell 1999). Many of the structures that were implemented by the USDA NRCS are reaching their original design lifespan of 50 years and are in need of evaluation so that informed decisions on rehabilitation or decommissioning can be made. The study of these structures also gives an opportunity to obtain data on erosion in watersheds, including the effects of management practices and changing land uses. Continued study of reservoir sedimentation processes is necessary as worldwide reservoir storage declines at an estimated rate of up to 1% per year (Mahmood 1987).

Exploitive agricultural methods applied since the 1830s in areas of west Tennessee and north-central Mississippi resulted in excessive erosion. Many of these upland areas have become unproductive due to loss of topsoil and gullying. During the years 1948 to 1976, the Yazoo-Little Tallahatchie Project (YLTP) was implemented by the USDA National Forest Service to control upland erosion. The YLTP is credited with planting over 690,000,000 pine trees on 42,897 ha (106,000 ac) of highly eroded land (Ursic 1963). Numerous small erosion control dams were also built as part of the project.

In this study, three small erosion control reservoirs that were installed in north Mississippi's Holly Springs National Forest as part of the YLTP were chosen for investigation. These reservoirs were selected because of the forested nature of the watersheds and their role as sediment catchments. The

Daniel G. Wren is a hydraulic engineer and **Robert R. Wells** is a hydrologist at the National Sedimentation Laboratory, United States Department of Agriculture (USDA) Agricultural Research Service (ARS), in Oxford, Mississippi. **Christopher G. Wilson** is a postdoctoral research associate at the University of Iowa C. Maxwell Stanley Hydraulics Laboratory in Iowa City, Iowa. **Charles M. Cooper** is an ecologist and **Sammie Smith Jr.** is a research chemist at the National Sedimentation Laboratory, USDA ARS, in Oxford, Mississippi.

watersheds are primarily composed of soil of the Maben-Smithdale-Tippah association. These soils range from brown sandy loams to dark brown silt loams. The average annual rainfall at the University of Mississippi rain gauge in Oxford, Mississippi (15 miles from the watersheds), is approximately 1,422 mm yr^{-1} (56 in yr^{-1}) for a 114 year period of record. The slopes in the watersheds are generally low, although there are isolated steep slopes resulting from the remnants of gullies.

The main objective of the study was to determine the accumulation rate and characteristics of sediments stored in the reservoirs. Other objectives of the study included the comparison of different methods for identifying postimpoundment sediment depths and assessing contamination of the sediments by agricultural pesticides.

Materials and Methods

A commercially available vibrating corer was used to collect a total of 20 sediment cores from the three lakes (figure 1, table 1). The core locations (figures 2 to 4) were chosen with the goal of characterizing sedimentation rates throughout the lakes. Primary inflow and outlet locations are noted. The outlet in each reservoir is a standard NRCS vertical drop constructed of concrete for the intake section with a metal pipe through the dam. Water depth at the core locations is in table 2. Emphasis was placed on collecting samples that were distributed between the inflow and outflow areas so that changes in sedimentation rate due to proximity to sediment sources would be measured.

The vibrating core system was suspended from an aluminum tripod with flotation provided by plastic drums connected to wooden platforms. The cores were collected in 76 mm (2.99 in) diameter aluminum irrigation pipe that had a wall thickness of 1.5 mm (0.06 in). The vibrating core method has been shown to collect relatively undisturbed samples of bottom sediments due to liquefaction of the sediment at the vibrating interface between the sample pipe and sediment (Lanesky et al. 1979; Smith 1984). Minimal core compaction was verified by observing the depth of penetration of the core pipe and the resulting core length from selected cores. All cores were capped immediately after extraction and secured with duct tape. Care was taken to ensure that no air voids were present at the top of the cores. All cores were stored at 4°C (39°F) for approximately four months prior to processing.

Figure 1
Location of study sites.

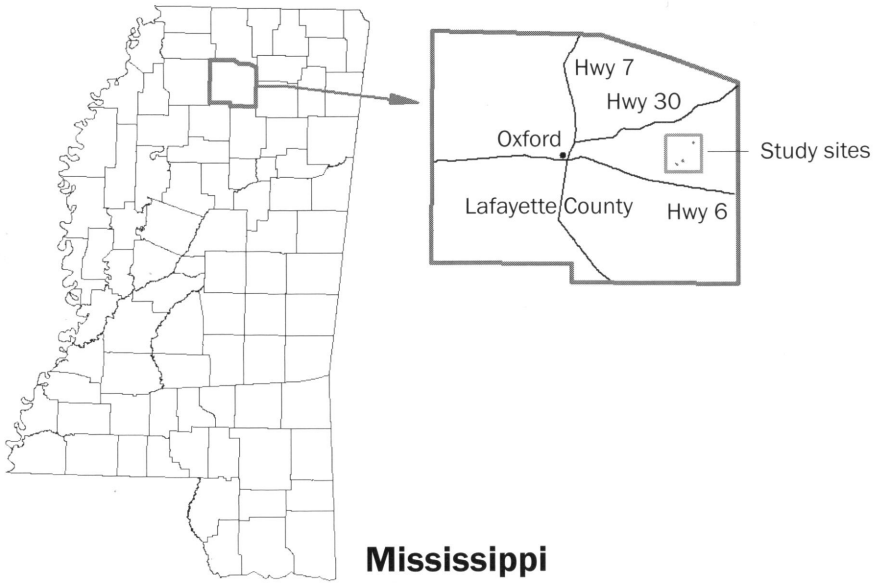


Table 1
Lake characteristics.

Lake	Year built	Drainage area (ha)	Surface area (ha)	Reduction in storage	Sediment yield (kg ha^{-1} yr^{-1})	Mean local accumulation (mm^{-1})
Lt 14A-4	1962	280	3	18%	585	7.9
Drewery	1965	171	7	7%	636	4.1
Denmark	1965	284	4	7%	668	5.6

Figure 2
Denmark Lake with core numbers and depth of sedimentation indicated.

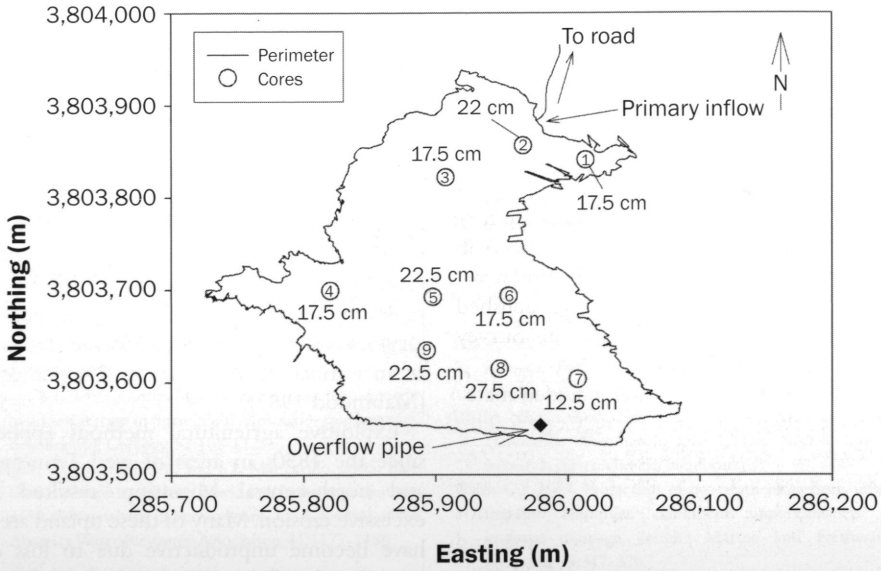
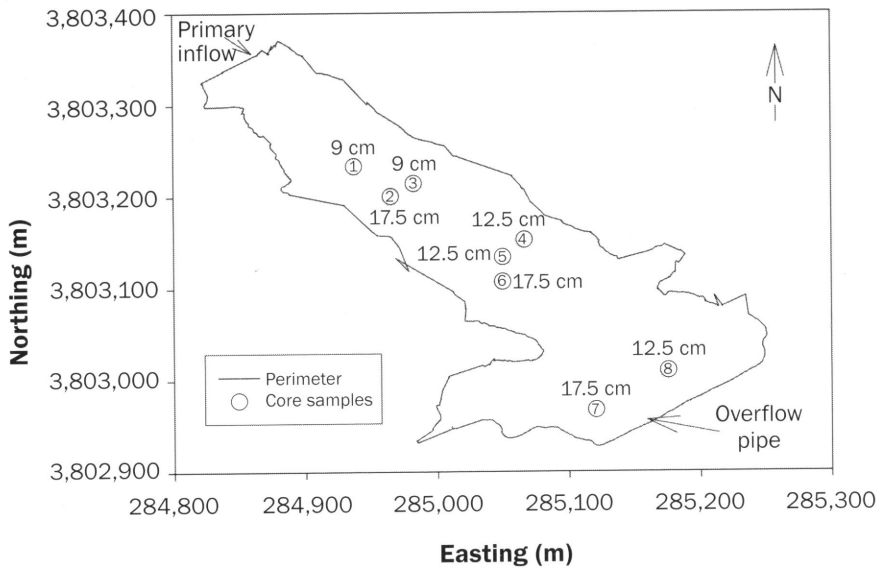


Table 2
Water depth at core locations.

Core	Water depth (m)
Denmark 1	0.5
Denmark 2	1.0
Denmark 3	0.5
Denmark 4	1.4
Denmark 5	2.2
Denmark 6	4.1
Denmark 7	3.0
Denmark 8	3.9
Denmark 9	2.0
Drewery 1	1.4
Drewery 2	1.5
Drewery 3	1.6
Drewery 4	2.0
Drewery 5	2.0
Drewery 6	2.3
Drewery 7	2.6
Drewery 8	3.1
Lt14A-4 1	0.9
Lt14A-4 5	1.5
Lt14A-4 7	2.1

Figure 3
Drewery Lake with core numbers and depth of sedimentation indicated.



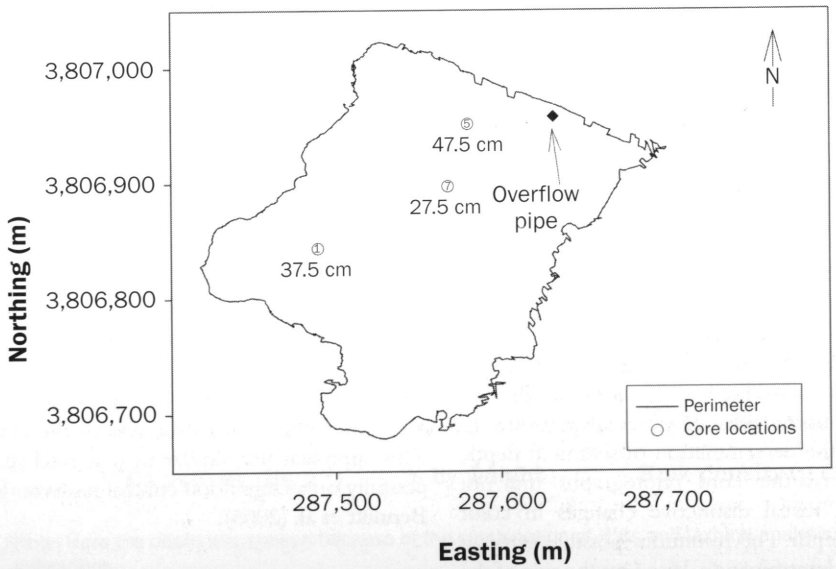
The cores were photographed after splitting the aluminum pipe longitudinally. Cores were sectioned for analysis in 2 cm (0.79 in) intervals for the first 10 cm (3.94 in), then 5 cm (1.97 in) for the remainder of the cores. The sampling intervals were chosen with the goals of high resolution and a reasonable number of samples to process and were finer than those used in many similar studies (Bennett et al. 2005, 2002; Cooper and McHenry 1989; McHenry et al. 1980). Samples were initially weighed wet, dried at 60°C (140°F) for 48 hours and weighed again. Bulk densities for each depth interval were found as follows:

Dry bulk density = dry mass/total volume ,

where total volume $= V_{voids} + V_{particles}$; V_{voids} = (wet mass – dry mass)/1 g cm^{-3} (62.43 lb ft^{-3}); $V_{particles}$ = dry mass/2.65 g cm^{-3} (165.43 lb ft^{-3}). Particle size fractions in each core increment were determined using an established pipette method (Method 3A1; Soil Survey Staff 1992).

Sediment from a slice that included material along the length of the top 20 cm (7.9 in) of the cores was tested for selected pre-1972 residual pesticides and more recently used pesticides. Preimpoundment soils were not tested. Aldrin, dieldrin, methoxychlor and p,p'-DDT (metabolites p,p'-DDE and p,p'-DDD) are relatively persistent, chlorinated hydrocarbon insecticides with some history of past use throughout the area. The other compounds are generally less persistent herbicides and insecticides that are in current use. Analysis of samples was similar to the method of Smith et al. (1994), with modifications by Bennett et al. (2000). Sediment samples were allowed to come to room temperature (about 25°C [77°F]), and the volume was measured and recorded. The entire sample was extracted by sonification with 1 g reagent-grade KCl and 100 mL pesticide-grade EtOAc, partitioning in a separatory funnel with the water phase discarded. The EtOAc phase was dried over anhydrous Na_2SO_4 and concentrated by rotary evaporation to near dryness. The extract was taken up in about 5 mL pesticide-grade hexane, subjected to cleanup by silica gel column

Figure 4
LT 14A-4 with core numbers and depth of sediment indicated.



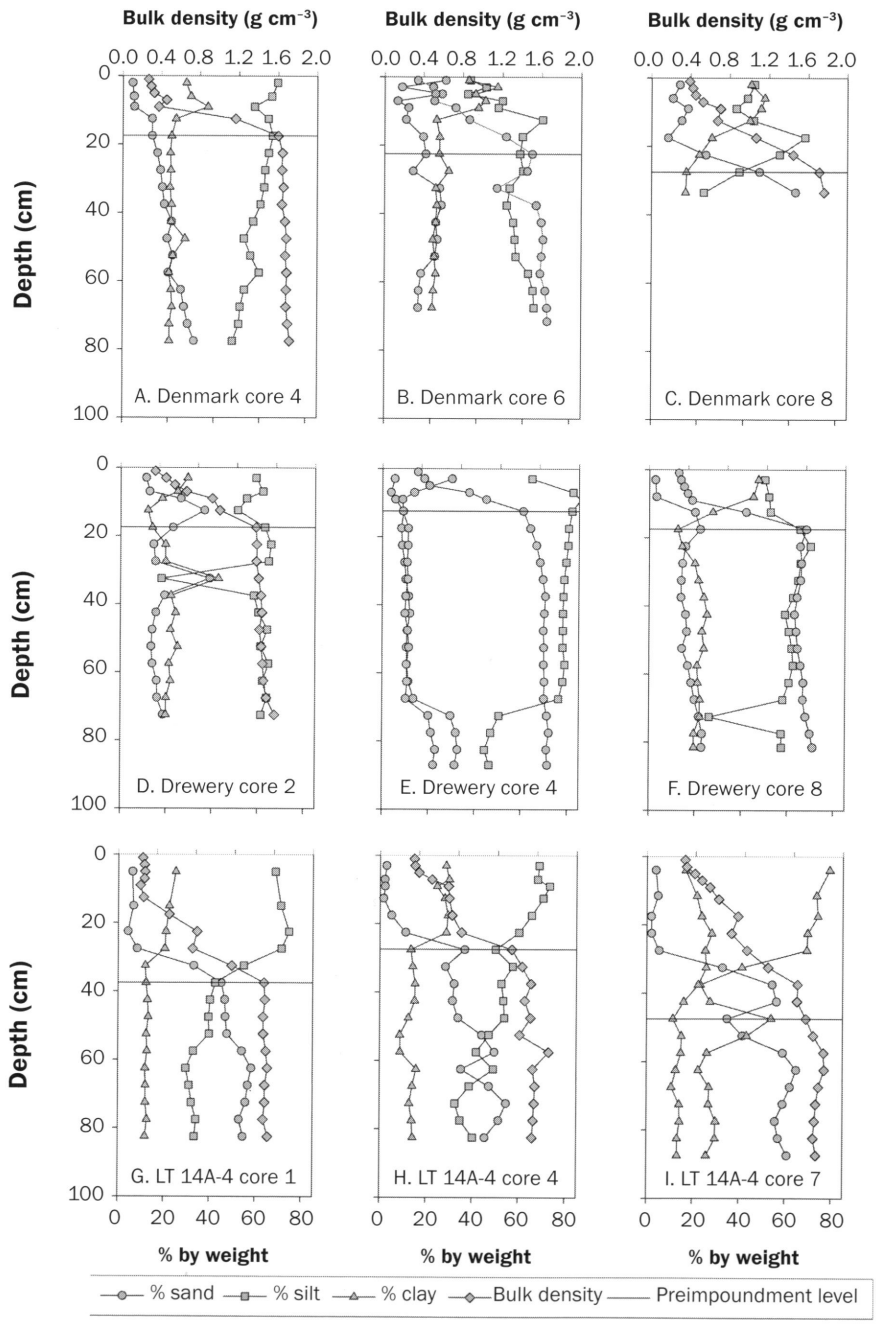
chromatography, and concentrated to 1 mL for gas chromatograph analysis. Mean extraction efficiencies, based on fortified samples, were greater than 87% for all pesticides.

A multilevel calibration procedure was used with standards and samples injected in triplicate. Calibration curves were updated every tenth sample. Two Hewlett Packard model 6890* gas chromatographs each equipped with dual HP 7683 ALS autoinjectors, dual split-splitless inlets, dual capillary columns, and a HP Kayak XA chemstation were used for analysis. One HP 6890 was fitted with two HP μECDs and the other 6890 with one HP μECD, one HP nitrogen phosphorus detector, and a HP 5973 mass selective detector (MSD).

For one core per reservoir, gamma spectroscopy was used to determine the activity of ^{137}Cs in the cores. Samples were counted in standardized geometries for at least 82,800 seconds on a High Purity Germanium (HPGe) gamma detector. Counting efficiencies for ^{137}Cs were established using two mixed radionuclide solutions (Bonniwell 2001; Wilson 2003).

The amount of sediment was determined primarily by observing changes in bulk density associated with the transition from preimpoundment soil to postimpoundment sediment. A sharp change in bulk density relative to deeper layers was assumed to coincide with the transition from more dense preimpoundment soil to postimpoundment deposits. Textural analysis was used to compare to the work of Bennett et al. (2005), where increased clay content and decreased silt content caused by preferential transport of clay particles into the reservoir was used to identify the depth of sediment. The third method used for determining deposition depth used gamma spectroscopy to measure radionuclide activities in stored sediments. The 1964 ± 2 year peak in ^{137}Cs caused by atmospheric nuclear testing was assumed to coincide with the preimpoundment layer since the reservoirs were all constructed near this time period. If both ^{137}Cs and textural analysis were in agreement on a sediment depth, this depth was chosen even if the bulk density data disagreed. Limited comparison with photographs of cores also served to verify the determination of sediment depth. However, the core photographs did not usually reveal distinctive changes in color with depth. The minimum possible error in depth determination, based on the size of the core increments used in both textural analysis and gamma spectroscopy, ranges from ±1 cm (±0.39 in) in the first 10 cm (3.94 in) to ±2.5 cm (±0.98 in) in the rest of the core. This approach was similar to that used successfully on a large flood control reservoir by Bennett et al. (2005).

Figure 5
Selected particle size and bulk density data.



Results and Discussion

Bulk density, particle size, and preimpoundment levels for selected cores from each site are shown in figure 5. Values are plotted in the center (average depth) of each sample interval. Figures 5A and 5F show consistency between changes in bulk density and clay enrichment in determining the depth of sediment for Denmark Lake. Figure 5 also

shows, for most cores, the abrupt changes in bulk density that were used to identify the preimpoundment level. Similar agreement was obtained in some cases from Drewery Lake and LT14A-4 (figures 5D and 5G). Of the 20 cores that were analyzed, three did not show a discernable trend in clay percentage. In the other 17 cores, the clay content shift underpredicted the sediment depth by approximately 20% relative to the depth determined using a downward shift in bulk density. Although difficult to prove with the available data, this lag in clay content shift could be related to the history of the watersheds. A broader range of particle sizes were likely transported through the watershed while high erosion and sedimentation rates prevailed during the early years of the reservoirs' life spans. In later years, when erosion rates dropped, the preferential transport of clays may have become more prevalent. See table 3 for a comparison of sediment depths obtained with the three methods. One anomaly should be pointed out in both figure 2 and table 3. It is unknown why core 5 from Denmark Lake has a sediment depth of only 5 cm. It seems unlikely that bioturbation would cause such a large difference from other cores from the area. The most likely explanations are mishandling of the sample or some effect of local bed topography.

The association between bulk density gradient and clay enrichment in this study differs somewhat from the findings of Bennett et al. (2005) for Grenada Lake, Mississippi, where a weaker relationship was found. The discrepancy may be due to the large difference in scale and watershed characteristics between Grenada Lake and the small reservoirs in the current study. The deposition of coarser materials in the more extensive channel network of the much larger Grenada Lake watershed likely played a role. This difference is important because it addresses the generality of the textural shift method for determining the depth of sediment. The method may not be generally applicable in all reservoirs and should therefore be checked against other techniques before being used to determine sediment depth.

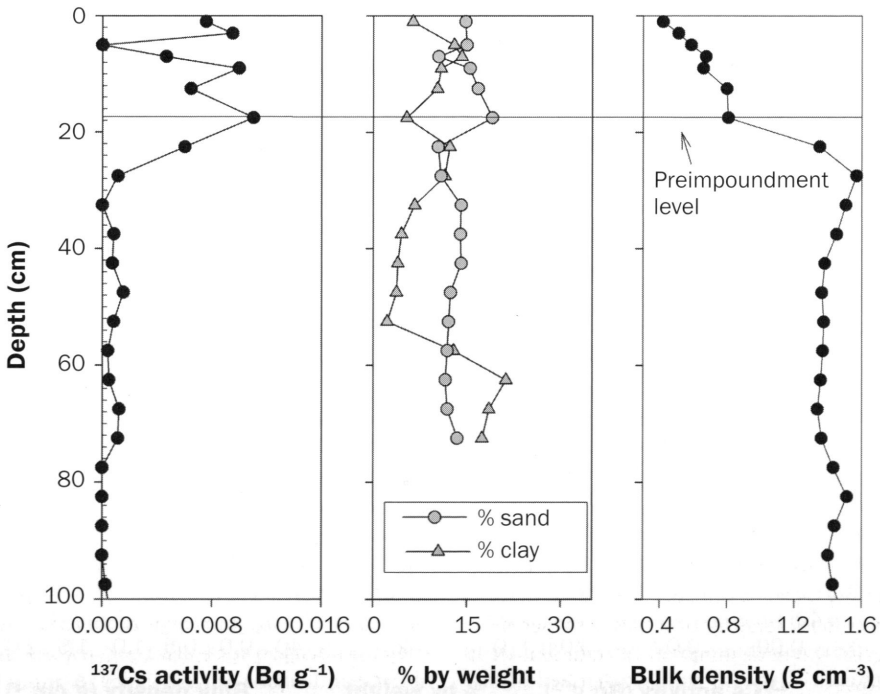
^{137}Cs data were used to verify the preimpoundment level in Denmark Lake core 1 (figure 6), Lt 14A-4 core 1 (figure 7), and Drewery Lake core 1 (figure 8). Since these lakes were constructed near the peak time of

Table 3
Comparison of sedimentation depths (cm) determined by three different methods.

Core	Textural analysis	Bulk density	Gamma spectroscopy
Denmark 1	N/A	28	18
Denmark 2	N/A	28	N/A
Denmark 3	13	28	N/A
Denmark 4	18	28	N/A
Denmark 5	4	5	N/A
Denmark 6	13	23	N/A
Denmark 7	18	18	N/A
Denmark 8	28	28	N/A
Denmark 9	23	23	N/A
Drewery 1	9	13	7
Drewery 2	13	18	N/A
Drewery 3	9	27	N/A
Drewery 4	9	13	N/A
Drewery 5	13	13	N/A
Drewery 6	13	18	N/A
Drewery 7	9	9	N/A
Drewery 8	18	18	N/A
Lt14A-4 1	32	38	28
Lt14A-4 5	28	28	N/A
Lt14A-4 7	N/A	38	N/A

Note: N/A = not applicable.

Figure 6
Activities of ^{137}Cs, % sand, % clay, and bulk density data from Denmark core 1.



Note: Here the depth was chosen because of the combination of ^{137}Cs and textural analysis indications.

Figure 7

Activities of ^{137}Cs, % sand, % clay, and bulk density data from Lt 14A-4 core 1. Here, the strong bulk density shift was used to identify the sedimentation depth.

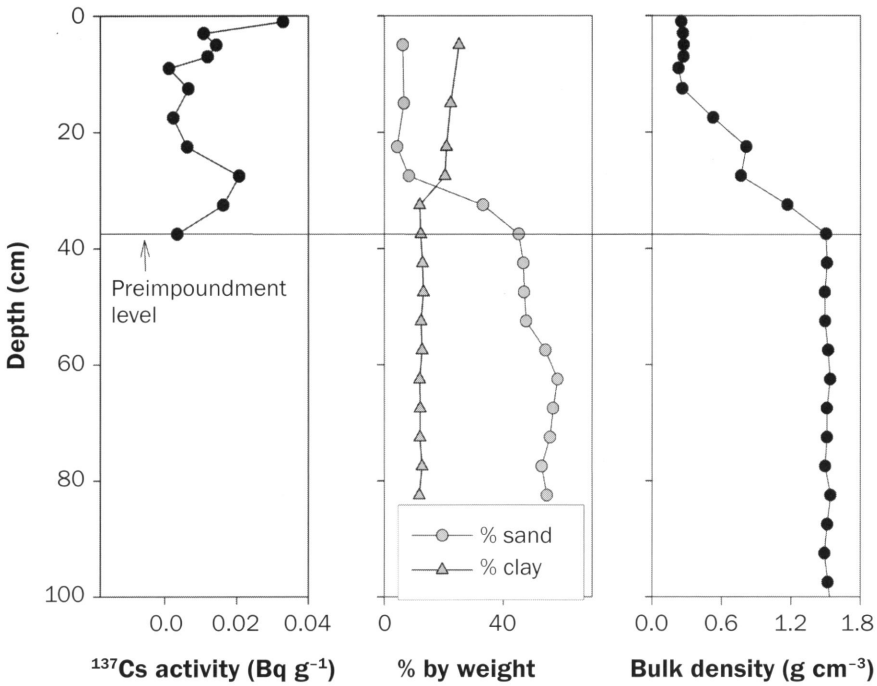
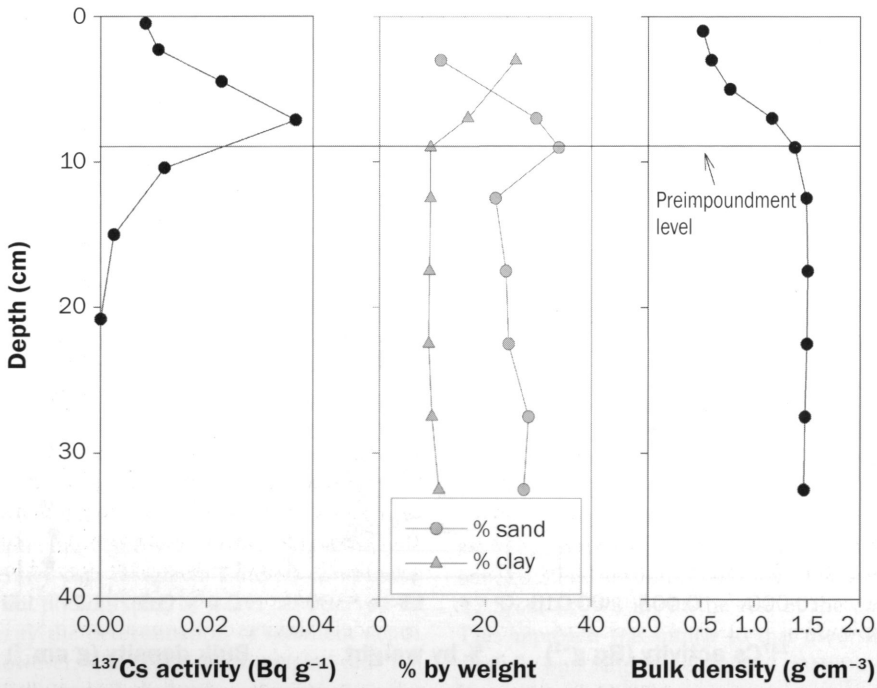


Figure 8

Activities of ^{137}Cs, % sand, % clay, and bulk density data from Drewery core 1.



Note: Here the bulk density shift and clay shift are in good agreement and the ^{137}Cs peak is at a slightly higher level.

atmospheric nuclear testing (1964 ± 2), the peak activity of ^{137}Cs was used to indicate the preimpoundment layer. Figure 6 shows good agreement of the peak activity of ^{137}Cs with clay enrichment and differs by two sample intervals with decreasing bulk density. Silt content was not plotted because it showed no discernable trend and because the silt content plot obscured trends in the clay content. In figure 7, the ^{137}Cs differs from the bulk density and clay enrichment derived bottom depth by 10 cm. Figure 7 also shows a significant decrease in sand content near the preimpoundment level indicated by changes in bulk density and clay content. Figure 8 shows consistent trends in bulk density, clay enrichment, and ^{137}Cs data. In the three cores where both ^{137}Cs and bulk density data were available, the bulk density shift yielded sediment depths approximately 13% deeper than those determined by the ^{137}Cs peak. The shift between the ^{137}Cs peak and bulk density data in LT14A-4 may be in part due to the fact that the lake was completed in 1962, before the highest peak in atmospheric nuclear testing. This may have allowed for some sediment deposition prior to the testing peak, resulting in deeper bulk density shift. For Drewery Lake, both indicators are within one sample interval, and so are indistinguishable with the current sample spacing. The reasons for the difference between bulk density and Cs^{137} positions in Denmark Lake, however, are not clear.

The mean at-a-point sedimentation rates shown in table 1 are quite low compared to other reservoirs in the region, likely due to the overall low sedimentation rates that would have prevailed after the watersheds were stabilized. The calculated loss in storage shows little impairment of these structures. Lt 14A-4 shows the greatest loss in storage (18%). This is not surprising since it is the smallest of the three lakes and has the largest ratio of watershed area to reservoir surface area. Accumulation rates were significantly less than those found by Bennett et al. (2005) in Grenada Lake. Based on data from a nationwide study of about 800 lakes with drainage areas over 2.59 km^2 (1 mi^2) in surface area in the United States, Dendy and Bolton (1976) identified an inverse relationship between watershed area and sedimentation rate. The three lakes surveyed in the current study had sediment yields that averaged only 13% of the rates observed in impoundments with similar watershed areas that were surveyed by

Table 4
Pesticide concentrations in sediments of small impoundments in forested watersheds in northern Mississippi.

Pesticide Concentration (ppb)																	
Core	Trifluralin	Atrazine	Methyl parathion	Alachlor	Metolachlor	Cyanazine	Chlorpyrifos	Pendimethalin	Fipronil	Dieldrin	pp'-DDE	Fipronil sulfone	Chlorfenapyr	pp'-DDD	-DDT	Bifenthrin	λ-Cyhalothrin
14A 1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	6.5	0.0	0.0
14A 5	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0	8.7	0.0	0.0
14A 7	0.0	0.0	0.0	0.0	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.5	0.0	0.0
Denmark 1	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.4	0.0	0.0
Denmark 2	4.9	0.0	0.0	0.0	33	0.0	0.4	0.0	0.0	0.1	0.0	1.3	0.0	0.0	7.6	0.0	0.0
Denmark 3	0.0	4.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.9	0.0	0.0
Denmark 4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Denmark 5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.2	0.0	0.0	0.0	0.0
Denmark 6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.2	0.0	0.0
Denmark 7	1.8	116	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Denmark 8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Denmark 9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Drewery 1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Drewery 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Drewery 3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Drewery 4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Drewery 5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.1	0.0	0.0
Drewery 6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Drewery 7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Drewery 8	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Dendy and Bolton (1976). The current lakes were closer in sediment yield to lakes with much larger watersheds, showing the effectiveness of the erosion control efforts of the YLT project.

Comparison to other relatively small reservoirs also shows that the depth of sediment within the three study lakes is low. Sugar Creek No. 12, located near Hinton, Oklahoma (Bennett and Dunbar 2003), has a watershed area of 817 ha (2019 ac). Sediment accumulations of 1 to 2 m (39.4 to 78.7 in) were observed. The average accumulation rate of sediments in Sergeant Major No. 4, near Cheyenne, Oklahoma, was found to be approximately 25 mm yr^{-1} (0.98 in yr^{-1}) from 1964 to 2002 by Bennett et al. (2002). Sergeant Major No. 4 has a surface area of 14 ha (34.59 ac) and a watershed area of 1513 ha (3739 ac) that is composed mainly of rangeland, grassland, and pastureland. As a third comparison point, Hubbard-Murphree Dam Y-17-73, near Charleston, Mississippi, has an 822 ha (2031 ac) watershed area with about 4 ha (10 ac) of surface area and is 78% forested. Bennett (2001) found the sedimentation rate to be approximately 35 mm yr^{-1} (1.38 in yr^{-1}) from 1960 to 2001. Hubbard-Murphree Dam Y-17-73 is the closest analog to the watersheds in the present study, again illustrating the low rates of sedimentation found here.

Measurement of the reservoir trapping efficiency in these small reservoirs was beyond the scope of this study. However, the work of Dendy (1974) shows that small reservoirs typically have trapping efficiencies ranging from 81% to 98% for silt and clay particles. Given the lack of data on inflow and outflow from the study sites, it is assumed that the trapping efficiency of the structures was high enough that the majority of eroded soil that entered the reservoirs was retained. The assumption of high trapping efficiency is also supported by the use of overflow pipes that are likely to allow only fine particles to exit the lake.

Accumulated sediments in lakes and reservoirs can provide a record of recent and historical contamination by pesticides. This study provided an excellent opportunity to examine the sediment record for pesticide history and occurrence, especially since the time of impoundment and current watershed use (silvaculture with minimum disturbance) are known. See table 4 for pesticide concentrations. As expected, the residual insecticide DDT was found at all three reservoirs, where it was the most prevalent compound at different vertical increments. DDT's aquatic breakdown isomer p,p'-DDE was detected in a limited number of samples from reservoirs LT 14A-4 and Denmark. Alachlor was not detected, and Dieldrin was detected in concentrations less than or equal to 0.6 ppb at both Denmark and Lt 14A-4.

All currently used insecticides except Fipronil were detected in at least one of the reservoirs. However, Fipronil sulfone, the major breakdown product was found in reservoirs LT14A-4 and Denmark. The herbicide Cyanazine was not detected. It has a very low volatility in soil and has now been replaced by atrazine for most uses.

Since the watersheds of all three reservoirs have supported Loblolly pine (*Pinus taeda*) forest for decades, it is concluded that most of the current-use pesticides detected were from aerial deposition. This theory is supported by the fact that all pesticides detected are sprayed in the intensively cultivated Mississippi Delta, which is located upwind in the prevailing wind flow pattern. The study area has little row crop agriculture, and local crops would not be treated with the mixture of widely varying compounds detected. The wind-blown deposition theory is indirectly substantiated by runoff-related information. Denmark Lake has an unpaved road that crosses the watershed where the main

inflow of the lake enters the uppermost part of the lake. Air deposited pesticides wash off the road surface, road ditches, and adjoining watershed directly into the reservoir with no filtering from forest litter. Denmark Lake also had the greatest number of detections of currently used pesticides, and they were clustered in lake sediments most directly within the flow path of incoming water. Concentrations of all indicator pesticides were low (<1.0 ppb) or nondetectable.

Summary and Conclusions

Sedimentation rates and loss in storage for three small sediment/water detention structures in the Holly Springs National Forest east of Oxford, Mississippi, were found to be lower than other similarly sized water bodies in the region. These results show the effectiveness of forest cover for controlling erosion in previously gullied land. Sedimentation rates were also much lower than those of other recently surveyed small reservoirs, including Sergeant Major No. 4, whose watershed is made up of mostly rangeland. Use of the textural shift method for determining the depth of deposition was generally successful, although results from the present study indicate that both watershed size and characteristics may have affected the results. An interesting divergence from other studies was the indication of sedimentation depth by clear shifts of bulk density. Residual and currently used pesticides were found in all three reservoirs, generally at low concentrations. Evidence, including the variety of pesticides detected, their distribution, and the nearest source indicate that their presence was linked to air transported material.

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