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Sedimentation in the Upper Reaches of Lake Ouachita

J. A. Patton
Arkansas Tech University, jpatton@atu.edu

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J.A. Patton

Department of Physical Sciences, Arkansas Tech University, Russellville, AR 72801

Correspondence: jpatton@atu.edu

Running Title: Sedimentation in the Upper Reaches of Lake Ouachita

Abstract

Lake Ouachita in west-central Arkansas is the largest man-made reservoir in the state. The lake was created by the U.S. Army Corps of Engineers (USACE) in 1953 for the purposes of hydropower, flood control, and recreation. Although Lake Ouachita is widely known for its high water clarity near Blakely Dam, little is known about the volume and ultimate fate of sediments that enter the lake from two primary tributaries: the North and South Forks of the Ouachita River. This project utilized a dual-frequency echo sounding system in combination with geographic information system and statistical analysis to calculate an average post-impoundment sediment thickness of approximately 0.78 m present throughout the study area, with a maximum sediment thickness of 2.93 meters. The total volume of post-impoundment sediment in place was calculated as 2,750,000 m^3 and the average linear sediment accumulation rate was determined to be 1.3 cm y^{-1}. Variations within the project area show widespread sediment focusing with statistically significant variations in sediment thickness between littoral and deeper zones, as well as between the lotic-transitional and lacustrine zones.

Introduction

Lake Ouachita was created as an impoundment on the Ouachita River in 1953 for the purposes of hydropower, flood control, and recreation. At over 16,000 hectares, it is the largest lake completely contained within the state. Known throughout the south as a popular scuba diving destination because of the high water clarity (low total suspended solids) near Blakely Dam, little is known about sediments entering the lake through the two primary tributaries: the North and South Forks of the Ouachita River. Located more than 40 kilometers from the dam, these tributaries potentially transport significant quantities of sediment that is deposited in the western reaches of the lake.

Reservoir sedimentation is commonly investigated using hydroacoustic mapping of post-impoundment sediment to calculate total sediment volumes (Dunbar et al. 1999, Odhiambo and Boss 2004, USBR 2006, Elci et al. 2009, Anderson et al. 2013). The process uses a dual-frequency echo sounding (DFES) system to simultaneously measure both modern-day bathymetry and the pre-impoundment surface. The 200 kHz pulse bounces off the modern-day bottom, providing real-time bathymetric depths, while the 20 kHz pulse penetrates the fine-grained, low density lacustrine sediments and bounces off the high-density pre-impoundment surface. Depth differences between the two signals indicate the total amount of sediment accumulated since impoundment (Clark et al. 2015). Collected along a series of transects perpendicular to the thalweg, the DFES data is manipulated using a geographic information system (GIS), gridded to interpolate values between transects, then analyzed to compute sediment thickness (max, mean, accumulation rate) and volumetric statistics.

Even though hydroacoustic mapping has been an important development in being able to accurately determine the amount (Clark et al. 2015, Anderson et al. 2013) and even the type (Elliott et al. 2006) of sediment present in reservoirs, none of these studies has attempted to determine the ultimate fate of the sediments by quantifying the effects of sediment focusing. Sediment focusing involves a variety of processes that all work to redistribute sediments into the deeper zones of a lake. In an attempt to create a conceptual framework for which processes dominate in different lakes, Hilton (1985) provided an overview of many of these processes, including peripheral wave action (PWA) as a dominant force in certain settings. PWA can remove sediment from the shore zone by creating turbulence that resuspends and redistributes the sediment into deeper water (Zakonnov et al. 1999), especially in lakes with significant water level fluctuations (Dirnberger et al. 2005). A review of the water level in Lake Ouachita since impoundment (Figure 1) shows frequent fluctuations of approximately 3 meters, with occasional greater fluctuations.

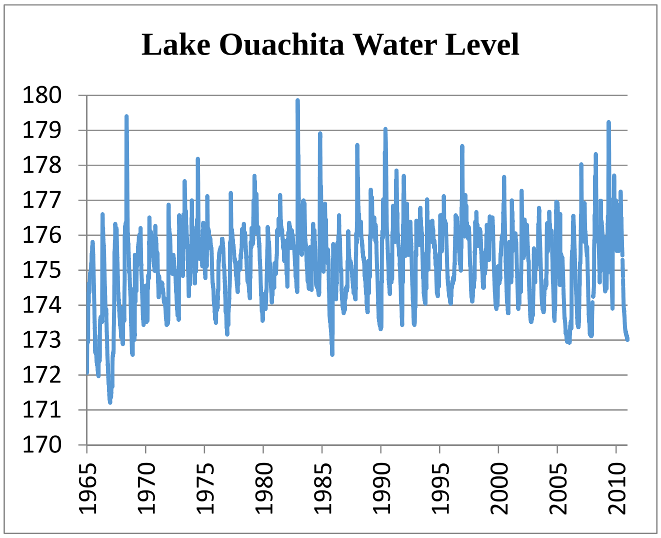

Figure 1. Chart showing water level changes in Lake Ouachita from 1965 to 2011. Elevation data are in meters. Note the conservation pool level is 176.2 m.

This study analyzed the sedimentation patterns where the South Fork of the Ouachita River enters Lake Ouachita (Figure 2). The total sediment volume, linear accumulation rate, and effects of sediment focusing were investigated to better understand the sediment dynamics in this region of the lake where the moving waters of the lotic zone transition into the lacustrine zone of the lake.

Methods

Hydroacoustic mapping using a dual-frequency (24kHz and 200 kHz) echo sounder was utilized to map sediment volumes in June, 2011. The echo sounder (manufactured by Specialty Devices, Inc.) with integrated GPS was mounted to a jon boat and maneuvered along transects perpendicular to the thalweg (pre-impoundment channel) spaced approximately 50 m apart. The boat was driven at a constant speed of 2 m s^{-1} to collect data at approximately 1 meter between locations. Post-processing of the data was performed to interpret pre-impoundment and modern-day bathymetric surfaces using Depthpic v. 4.84 (Specialty Devices, Inc.).

All recorded depths were normalized to elevations using daily lake level data provided by USACE (2016). The resulting X, Y locations and corresponding Z values (bathymetry and sediment thickness) were exported from Depthpic as ascii text files and imported into ArcGIS (ESRI) v. 10.1 for raster interpolation and manipulation.

Calculation of sediment volume and modern-day bathymetry was performed in ArcGIS by using an IDW interpolation technique on the sediment data exported from Depthpic. A series of additional points with a net thickness of 0.0 meters were added to the DFES derived thickness dataset along the lake boundary to minimize edge effects present in most interpolation algorithms (Patton 2008). An output cell size of 10 m was chosen for both the bathymetry and

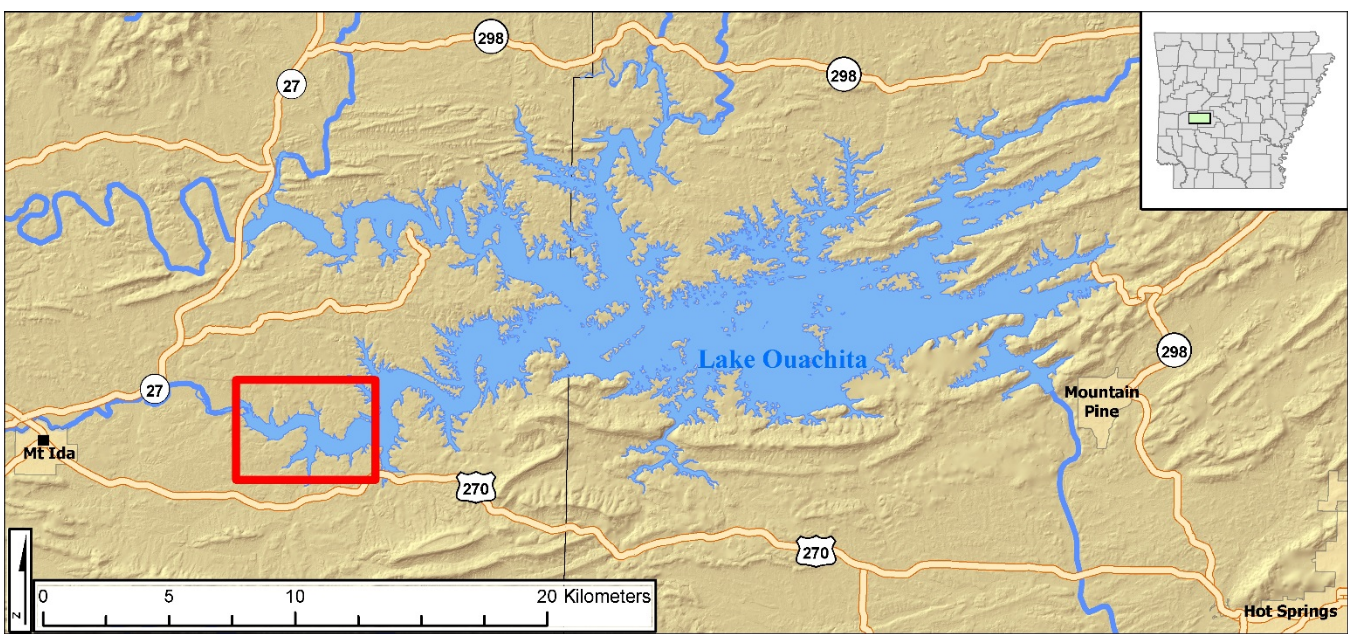

Figure 2. Map showing study area outlined in red. Inset map shows location of Lake Ouachita.

sediment thickness grid. The resulting grids were then clipped using the lake boundary to eliminate from future calculations any grid cells that were interpolated outside of the lake boundary. Simple statistics (max and mean thickness) were extracted from the grid statistics, while the average linear accumulation rate was calculated by dividing the mean thickness by the number of years since impoundment at the time of the study (58 years).

Investigation of the effects of sediment focusing required additional data manipulation techniques. To investigate differences in sediment thickness downslope along the thalweg, the entire study area was divided into three regions (Figure 3). The boundary between the regions was placed at the point where the lake reached a width of approximately 400 meters perpendicular to the thalweg. Regions 1 and 2 are lotic-transitional, while Region 3 is lacustrine. The primary input for Region 1 is the South Fork of the Ouachita River, while Region 2 receives input from the smaller tributaries Shady Creek and Twin Creek. Each of these regions was then further divided into three sub-regions based on water depth. The thickness and bathymetry grids were merged to allow for the zonation of thickness by water depth. Peripheral wave action was assumed to be the primary sediment focusing phenomenon in the study area, therefore the sediment thickness values were divided into three groups based on water depth relative to the conservation pool (176.2 m): <3m; 3-6m; >6m. This division was made based on the observation of frequent water level fluctuations of approximately 3 m below the conservation pool (Figure 1), which would expose that zone to peripheral wave action.

The data from the combined grid was exported from ArcGIS for further processing in Excel (Microsoft), where a simple one-way ANOVA was performed to compare the sediment thickness means of each sub-group.

Results

The average post-impoundment sediment thickness was calculated to be 0.78 m throughout the study area (Figure 3). The maximum sediment thickness was found in Region 3 at 2.93 meters. The total volume of post-impoundment sediment in place was calculated at approximately 2,750,000 m^3 and the average linear sediment accumulation rate was determined to be 1.3 cm y^{-1}. Mean sediment thickness in Regions 1 and 2 were both 0.64 m, while the mean thickness in Region 3 was 0.89 m (Table 1).

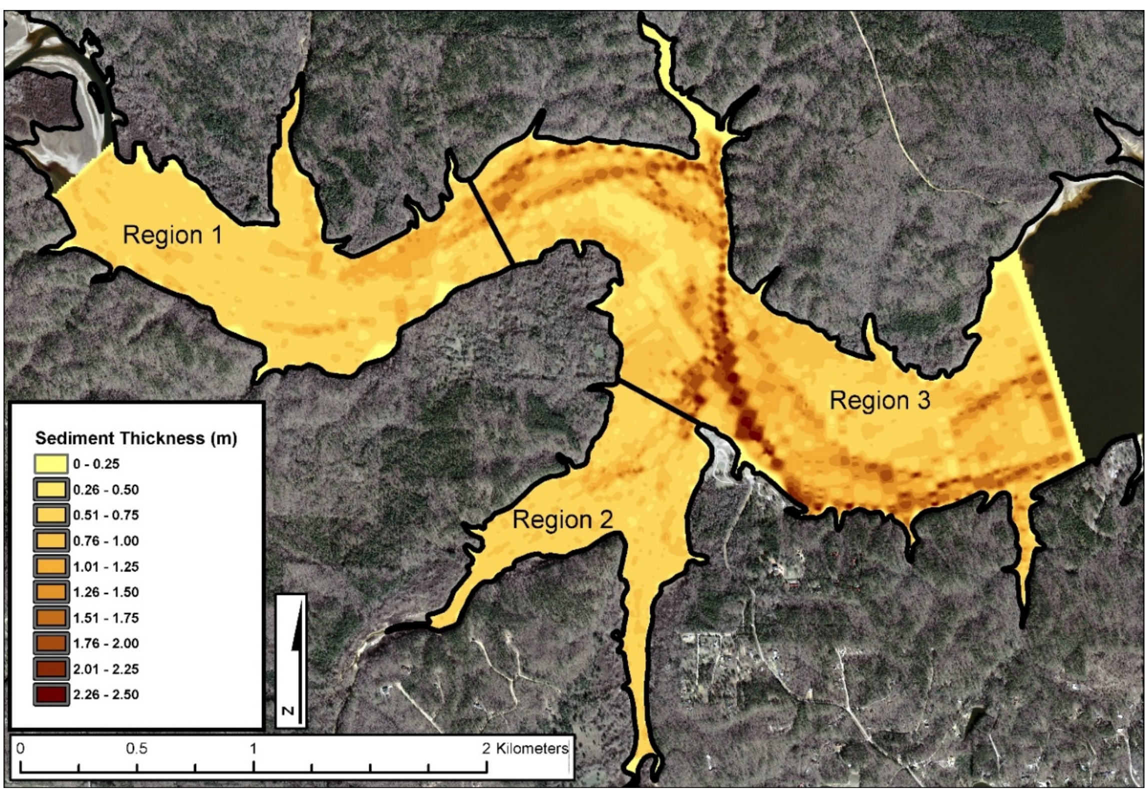

Figure 3. Map showing sediment thickness in three regions.

Table 1. General statistics by region.

	Region 1	Region 2	Region 3
Mean Sediment Thickness (m)	0.6	0.6	0.90
Max Sediment Thickness (m)	1.6	1.9	2.3
Mean Water Depth (m)	2.9	3.3	5.9
Max Water Depth (m)	6.8	8.5	11.8
Total Sediment Volume (m^3)	607,665	373,512	1,772,768
Linear Sedimentation Rate (cm y^{-1})	1.1	1.1	1.5

Further statistical analysis of each region by depth shows some important differences. A simple one-way ANOVA test was conducted to compare the effect of depth on mean sediment thickness in water depths of <3, 3-6, and > 6m. There was a significant effect of depth on sediment thickness at the $p<0.05$ level for the three conditions (see Table 2).

Table 2. Mean sediment thickness in meters in each region by depth. Variance for each mean shown in parentheses. p-Value shown for each region at the bottom of the table.

		Region 1	Region 2	Region 3
Depth	**< 3 m**	0.52 (0.05)	0.53 (0.07)	0.27 (0.12)
	3-6 m	0.75 (0.04)	0.71 (0.02)	0.75 (0.07)
	> 6 m	1.1 (0.04)	0.92 (0.10)	1.14 (0.18)
		p=0.00	*p=0.00*	*p=0.00*

Discussion

Hydroacoustic mapping of bottom sediments in the study area shows an overall sedimentation rate similar to that found in other Arkansas lakes (Table 3), which span a wide range of geologic settings, land use, and reservoir age. Although the linear sedimentation rate in this study (1.2 cm y^{-1}) was on the high end of the range of these studies, it is still low when compared to other regional values.

Analyzing sediment thickness variations by creating regions found some important features. In the two regions that are lotic-transitional (Regions 1 & 2) there was no difference found in the mean thicknesses, which is attributed to the similar depth profile and position. The mean depth of Region 1 was 2.9 m, while the mean depth of Region 2 was 3.3 m. If sediment focusing is continually moving sediment from shallower to deeper parts of the lake, portions of the lake with a similar depth profiles should have similar sediment volumes. Comparing either of these regions with the deeper, more lacustrine Region 3 (mean depth = 5.9 m), shows a dramatic difference in mean thickness and total sediment volume, as would be expected if focusing were occurring.

Statistically significant variations within each region also confirm the presence of sediment focusing. Each region showed the general trend of increasing sediment thickness with increasing water depth. Inspection of the sediment thickness map (Figure 3) shows the thickest sediment accumulations are located in the thalweg, which are by function the deepest parts of the reservoir. Regions 1 and 2 had similar means in each depth range, while Region 3 had a lower mean in the shallow water range. This lower mean in the shallow depths of Region 3 may be related to the steeper topography of the lake bed in that region and the corresponding overall small area of Region 3 in that depth range.

Conclusions

Understanding sediment dynamics in local waterbodies is important for planning and quantifying impacts to the aquatic environment. Hydroacoustic mapping and the zoning by regions can be an effective tool to discover and understand the ultimate fate of sediment. Future research on sedimentation rates in deeper zones of the lake and overall sediment quality (e.g. concentration of trace metals, organic compounds, etc), will allow a better understanding of the full impact of sedimentation to Lake Ouachita.

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Literature Cited

Anderson M, J Conkle, P Pacheco and **J Gan**. 2013. Use of hydroacoustic measurements to characterize bottom sediments and guide sampling and remediation of organic contaminants in lake sediments. Science of the Total Environment 458-460: 117-124.

Table 3. Linear sedimentation rate results from other studies in Arkansas. Studies with asterisk (*) did not directly report linear sedimentation rate. Value calculated by dividing reported average thickness by reservoir age.

	Linear Sedimentation Rate (cm y^{-1})
Lee Creek Reservoir (Odhiambo and Boss, 2004)*	1.5
Lake Shepherd Springs (Odhiambo and Boss, 2004)*	0.4
Lake Wedington (Polly, 2001)	0.2
Lake Wedington Repeat (Barnes, 2006)	0.2
Lake Fort Smith (Brown, 2000)	0.3
Prairie Creek Tributary of Beaver Lake (Hansen, 1999)*	1.0
Multiple Tributaries of Beaver Lake (Patton, 2008)	0.5 - 0.7

Barnes A. 2006. A repeat survey of bathymetry, sedimentation, and aquatic vegetation of Lake Wedington, Washington County, Arkansas [MS thesis]. Fayetteville (AR): University of Arkansas. 52 p. Available via Interlibrary Loan.

Brown B. 2000. Bathymetry and sedimentation patterns of Lake Fort Smith, Arkansas utilizing dual frequency sonar [MS thesis]. Fayetteville (AR): University of Arkansas. 68 p. Available via Interlibrary Loan.

Clark E, B Odhiambo, S Yoon and **L Pilati**. 2015. Hydroacoustic and spatial analysis of sediment fluxes and accumulation rates in two Virginia reservoirs, USA. Environmental Science and Pollution Research 22:8659-8671.

Dirnberger J, and **J Weinberger**. 2005. Influences of Lake Level Changes on Reservoir Water Clarity in Allatoona Lake, Georgia. Lake and Reservoir Management 21(1):24-29.

Dunbar J, P Allen and **P Higley**. 1999. Multifrequency acoustic profiling for water reservoir sedimentation studies. Journal of Sedimentary Research 69:521-527.

Elci S, A Bor and **A Caliskan**. 2009. Using numerical models and acoustic methods to predict reservoir sedimentation. Lake and Reservoir Management 25:297-306.

Elliott C, R Jacobson and **K Chojnacki**. 2006. Hydroacoustic mapping to define sedimentation rates and characterize lentic habitats in DeSoto Lake, DeSoto National Wildlife Refuge. U.S. Geological Survey Open-File Report 2006-1254, 24 p.

Hansen J. 1999. Bathymetry and empirical modeling of sedimentation in the Prairie Creek sub-basin of Beaver Lake, Northwest Arkansas [MS thesis]. Fayetteville (AR): University of Arkansas. 59 p. Available via Interlibrary Loan.

Hilton J. 1985. A conceptual framework for predicting the occurrence of sediment focusing and sediment redistribution in small lakes. Limnology and Oceanography 30(6):1131-1143.

Patton J. 2008. Comparative sedimentation and geochemistry of three coves, Beaver Reservoir, Northwest Arkansas [Dissertation]. Fayetteville (AR): University of Arkansas. 158 p. Available via Proquest.

Polly A. 2002. Bathymetry, sedimentation, and water chemistry of Lake Wedington, Washington County, Arkansas [MS thesis]. Fayetteville (AR): University of Arkansas. 75 p. Available via Interlibrary loan.

Odhiambo B and **S Boss**. 2004. Integrated echo sounder, GPS, and GIS for reservoir sedimentation studies: Examples from two Arkansas lakes. Journal of the American Water Resources Association 40:981-997.

U.S. Army Corps of Engineers (USACE). 2016. Water Control Center, Vicksburg District. <http://rivergages.mvr.usace.army.mil/WaterControl/stationinfo2.cfm?sid=CE418B32> Accessed on 3/15/2016.

U.S. Bureau of Reclamation (USBR). 2006. Erosion and sedimentation manual: U.S. Department of the Interior, Bureau of Reclamation, Technical Service Center, Sedimentation and River Hydraulics Group, Denver, CO, 587 p.

Zakannov V, L Ikonnikov and **A Zakonnova**. 1999. Shore Erosion and Sedimentation in the Cheboksary Reservoir. Water Resources 26(4):368-376.