Sediment Properties and Deposition in Lake Atoka, Oklahoma

R.G. Menzel, F.R. Schiebe, and J.R. McHenry
USDA-ARS Water Quality and Watershed Research Laboratory, Durant, OK 74702

Properties of Lake Atoka sediment were studied in relation to the persistent turbidity of Lake Atoka water. The rate of sediment deposition was measured from the depth distribution of ^{137}Cs in the sediments. The deposition rate varied from less than 1 cm/year in deep areas of the lake to about 2 cm/year in some of the shallow areas. Surface sediment samples from shallow areas contained from 31 to 46% clay, much of the clay is particles < 0.5 μm in diameter. Resuspension of clays by wind action in shallow areas of the lake appears to contribute most of the clay in suspension. The fineness of the clay, together with wave action and low dissolved solids content of the water, account for the persistent turbidity of Lake Atoka.

INTRODUCTION

Lake Atoka is located about 170 km southeast of Oklahoma City on North Boggy Creek at the western edge of the Ouachita Mountain uplift. The lake was completed in 1959, and now provides almost half of the water supply for Oklahoma City. Suspended sediment in the water causes persistent turbidity of the lake, which greatly limits its aesthetic and recreational values. Practical possibilities for reducing the turbidity have been sought by the Oklahoma Water Resources Board (OWRB).

This study was made in 1981 and 1982 in cooperation with the OWRB to help determine the causes of turbidity in Lake Atoka. The amount and particle size distribution of deposited sediments were determined at several points in the lake. Probable relationships between these sediments and lake turbidity were considered.

The watershed of Lake Atoka covers 39,900 ha in hilly terrain. The hills trend northeast to southwest and rise 90 to 150 meters above the creek beds. Bedrock material is mainly fine-grained sandstone of mid to late Pennsylvania age (1). The soils generally have a loamy or sandy loam surface with clayey subsoil. They are very susceptible to erosion when cropped (2), but little of the watershed is presently cropped. Land use in 1982 was 52% forestland and 40% pasture or range (3).

The major inflows to the lake are at the north end through North Boggy, Buck, Beck, and Limestone Creeks. Together these creeks drain 2/3 of the lake watershed, and contributed about 2/3 of the inflow during the study. It was estimated that 72% of the soil loss occurred in the watersheds of these creeks (3).

EXPERIMENTAL METHODS

Sediment deposits were sampled on 6 ranges across Lake Atoka (Fig. 1). The shallow water sediments were sampled by excavating pits into the dry lake bed when the water level was about 4.3 m below normal. The deep water sediments were sampled by using simple tube coring devices operated by hand from a boat. The east, north, and south ranges (Fig. 1) were sampled by the excavation method during February, 1981. Pits were dug 1 m deep and samples were taken in 5 - cm increments to a depth of 30 cm, and then in 10 - cm increments to a depth of 80-90 cm. Ranges 2,4, and 8 (Fig. 1) were sampled by the coring method during January, 1982. Cores were either 5 or 10 cm in diameter. It was possible to obtain sediment cores ranging from 9 to 28 cm in depth at different sites. Locations of all sampling sites are shown in Fig. 1.

The age of the shallow sediments was determined from the distribution of ^{137}Cs according to the technique of McHenry *et al.* (4). This technique utilizes the fact that concentrations of ^{137}Cs in deposited sediments are correlated with radioactive fallout deposition on the land surface. The peak concentration is associated with the maximum rate of fallout deposition in the northern hemisphere in 1963. The sediment samples were dried and thoroughly mixed. A 1 - kg subsample was taken for determining the concentration of ^{137}Cs by counting its 0.662 MeV gamma radiation, with a lithium-drifted germanium crystal and a 4096-channel analyzer.

Particle-size distributions in the sediment samples were determined with a Micromeritics Sedigraph† (5). Samples were treated with hydrogen peroxide and dispersed with sodium hexametaphosphate before analysis.

Measurements of conductivity, filterable residue (dissolved solids), settleable matter, and turbidity were made on surface water samples using standard methods (6). The samples were collected at monthly intervals from April, 1981 to March, 1982. They were refrigerated from the time of collection until analyses were completed in the laboratory within 24 hr after samples were taken. The concentrations of $CaCl_2$ and NaCl required to flocculate the suspended clay were determined on a sample of surface water taken in April, 1985.

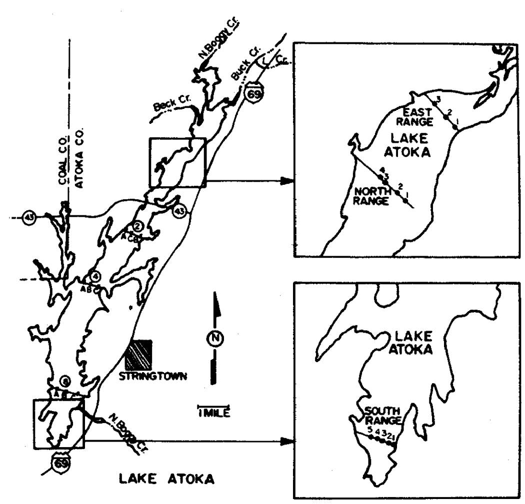

Figure 1. Sediment deposit sampling sites on Lake Atoka.

RESULTS

The turbidity of Lake Atoka surface water ranged from 69 to 310 nephelometric turbidity units (NTU), and was generally about 140 NTU (3). The concentration of suspended clay in mg/L corresponds roughly to the NTU value. Even at the highest turbidities, there was no measurable settleable matter (< 1 mL/L). The total dissolved solids ranged from 30 to 62 mg/L, and conductivities were correspondingly low, 43 - 112 μmhos/cm.

The suspended clay flocculated within 24 hours in 0.002 M $CaCl_2$, but not in 0.001 M (111 mg/L). Flocculation was incomplete in 0.1 M NaCl, the highest concentration used (5855 mg/L). The concentrations of dissolved solids required for flocculation are several times as high as those found in Lake Atoka.

The particle size and ^{137}Cs distributions in a typical sediment profile are shown in Fig. 2. The maximum ^{137}Cs concentration, indicating sediment deposited in 1963, occurs at a depth of 20-25 cm in this profile. Thus, the sedimentation rate from 1963 through 1980 averages about 1.5 cm/year at this location.

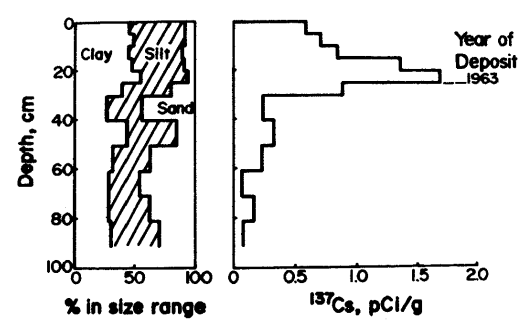

Figure 2. Particle size and ^{137}Cs distribution in a typical sediment.

The sediments deposited since 1963 contain more silt and clay than the deeper materials. This probably is the result of deposition from waters impounded since Lake Atoka was completed in 1959. The sandy layer from 30 to 40 cm appears to be the original surface soil. The texture of this layer is intermediate between loam and silt loam according to USDA classification (7). In all sediment profiles having a ^{137}Cs peak, a similar layer with a loam or silt loam texture was found immediately below the peak. The dominant flood plain soils along

†Mention of commercial products is for identification only, and does not constitute endorsement by USDA over products of similar nature not mentioned.

North Boggy Creek are Boggy fine sandy loam, Guyton silt loam, and Rexor loam (2). Thus, the surface textures of these soils agree well with those of the 30 - 40 cm depth in North #4 profile. The subsoils of these soils contain more silt and clay than the surface soil, which also agrees with the particle size distribution of North #4 profile (Fig. 2) and other profiles not shown. Thus, it seems reasonably certain that the sediment profile below 30 cm is the original soil profile, and that 30 cm of sediment has been deposited at this location since the lake was formed. The ^{137}Cs distribution below 30 cm agrees with this interpretation.

Maximum ^{137}Cs concentrations and the depths at which they occurred are shown in Table 1. Since the maximum ^{137}Cs concentration indicates sediment deposited in 1963, there has been from 15 to 30 cm of sediment deposited in 18 years at most of the sampled points. Two profiles (East #1 and South #4) have little or no sediment deposition. The East #1 profile is on a natural levee near the main channel entering the lake. Currents at this location could have greatly reduced sediment deposition. This location, as well as South #4, South #5, and North #3, had visibly less sediment deposition at the time of sampling.

We were unable to date the sediment deposits in deep water because of small sample size. However, these deposits would not be expected to be as thick as those in the upper end of the lake near the main inflows. The fact that the coring devices could not be pushed further than 28 cm into the sediments also indicated a shallow deposit. Thus it appears that the overall sedimentation rate in Lake Atoka is less than 1.5 cm/year.

The clay, silt, and sand compositions of the upper 10 cm of sediments are shown in Table 2. In general, the deep basin sediments contained more clay than the shallow water sediments. The three samples with high sand content (2C, 4C, and 8C) were obtained near the original stream channel where currents would be strong. Several samples from the deep basin contained more than 60% clay particles. These samples also had a large fraction (40 - 50%) of fine clay < 0.5 μm in equivalent diameter.

TABLE 1. Normal water depth, and depth to maximum ^{137}Cs concentration, in sediment profile samples from Lake Atoka, 1981.

Profile identification	Depth of sediment surface below normal lake level (cm)	Depth to maximum ^{137}Cs concentration (cm)	Maximum ^{137}Cs concentration (pCi/g)
East #1	100	5-10	0.13
East #2	115	25-30	1.05
East #3	145	25-30	1.15
North #1	205	15-20	0.85
North #3	205	10-15	1.22
North #4	245	20-25	1.71
North #5	265	30-41	1.41
South #1	370	25-30	2.21
South #2	375	25-30	1.63
South #3	395	10-15	0.64
South #4	360	10-15	.14
South #5	335	10-15	.80

TABLE 2. Particle size distribution in surface sediments (0-10 cm) from Lake Atoka, 1981.

Sample	Percent in size range Clay <2 μm	Silt 2-20 μm	Sand >20 μm
	Shallow water sediments		
East #1	31	31	38
East #3	33	45	22
North #1	40	40	20
North #4	46	45	9
	Deep basin sediments		
2A	38	33	29
2B	50	31	19
2C	26	20	54
4A	68*	29	3
4B	64	30	6
4C	19	16	63
8A-2	76*	20	4
8B-1	75*	22	3
8C	14	8	78

*From 40 to 50% of upper 10 cm of sediment in these samples was < 0.5 μm.

DISCUSSION AND CONCLUSIONS

The rate of sediment deposition at the sampled sites ranges from less than 1 to about 2 cm/year. The water depth at these sites ranges from 1 to 4 m so that it will require several hundred years for most of the shallow portion of Lake Atoka to fill with sediment if present rates of sedimentation continue. The deeper portion of the lake is filling at a lower rate, and has a much longer expected lifetime.

The amount of clay suspended in the water column is relatively insignificant. If the content of clay is usual (140 mg/L), and the mean lake depth 5.8 m (3), the amount of clay in suspension is about 81mg/cm^2. As the normal density of settled clay is about 1.3 g/cm^3, this represents a deposit of only 0.6 mm. The hydraulic residence time of Lake Atoka is 1 to 2 years (3). Therefore, the amount of suspended clay moving through the lake is a small fraction of the amount of sediment that is deposited.

Wind action can contribute significantly to resuspension of sediments in shallow lakes (8). Lake Atoka is frequently drawn down by withdrawals of water for Oklahoma City, causing large areas of the former flood plain at the north end of the lake to become very shallow. The prevailing southwesterly winds, and the long southwest-to-northeast axis of the lake, increase the probability of significant wave action. A positive correlation was found between lake turbidity and amount of drawdown (3). The turbidity of tributary water was usually less than that of the lake, indicating that the dominant sources of turbidity are within the lake (3).

Apparently, the bulk of sediment deposited in Lake Atoka is carried during infrequent flood flows, and is deposited rather quickly. Since the amount of clay in suspension is so small, the resuspension of clay would affect the distribution of deposited sediments very little. The abundance of fine clay in the sediments makes them easy to resuspend through wave action. This, combined with the low dissolved solids content of the water, accounts for the persistent turbidity of Lake Atoka.

ACKNOWLEDGMENTS

We thank Mr. Don Schreiber and Miss Lynda Sinclair of the Oklahoma Water Resources Board for obtaining the sediment samples from the deeper parts of Lake Atoka, and for providing the analyses of the surface water.

REFERENCES

1. Oklahoma Geological Survey, *Geology and Earth Resources of Oklahoma*, Educational Publication 1, Norman, OK, 1972.

2. U.S. Department of Agriculture, *Soil Survey of Atoka County, Oklahoma*, USDA Soil Conservation Service, Washington, DC, 1979.

3. Oklahoma Water Resources Board, *Lake Atoka Clean Lakes Project, Phase I, Final Report*, Oklahoma City, OK, 1983.

4. J.R. McHenry, J.C. Ritchie, and A.C. Gill, Water Resources Res. 9:676 - 686 (1973).

5. N.H. Welch, P.B. Allen, and D.J. Galindo, J. Environ. Qual. 8:543 - 546 (1979).

6. American Public Health Association, *Standard Methods for the Examination of Water and Wastewater, 14th ed.*, APHA, Washington DC, 1975.

7. U.S. Department of Agriculture, *Soil Classification. A Comprehensive System, 7th Approximation*, USDA Soil Conservation Service, Washington, DC, 1960.

8. G.C. Carper and R.W. Bachman, Can. J. Fish. Aquat. Sci. 41:1763 - 1767 (1984).