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Effects of suspended sediment reduction on chlorophyll and water quality in a large natural lake

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Introduction

Lake Chicot, Arkansas, is a riverine lake which lies in alluvial deposits adjacent to the Mississippi River in the south central United States. Since permanent settlement began in the 1830's, the percentage of Lake Chicot's watershed covered in natural vegetation has steadily declined. A major flood in 1927 enlarged the drainage area flowing into the lake and scoured the inflow and outflow of Lake Chicot, lowering normal water level. The northern fourth of the lake was isolated by a dam in 1948. The enlarged watershed size was coupled with a steadily increasing percentage of the watershed used for intensive agriculture. This resulted in several decades of lake water quality deterioration from agricultural runoff. Channelization of the main drainage network facilitated movement of sediment-laden runoff into the main basin of Lake Chicot, causing differences to develop between the isolated northern basin and the southern basin. In 1985, a diversion system was completed to prevent storm flow suspended sediments from entering Lake Chicot (U.S. Army Corps of Engineers 1986). Water quality, biological productivity, and suspended sediments were monitored before and after diversion. The purpose of this paper is to evaluate effects of suspended sediment reduction by the storm flow di-

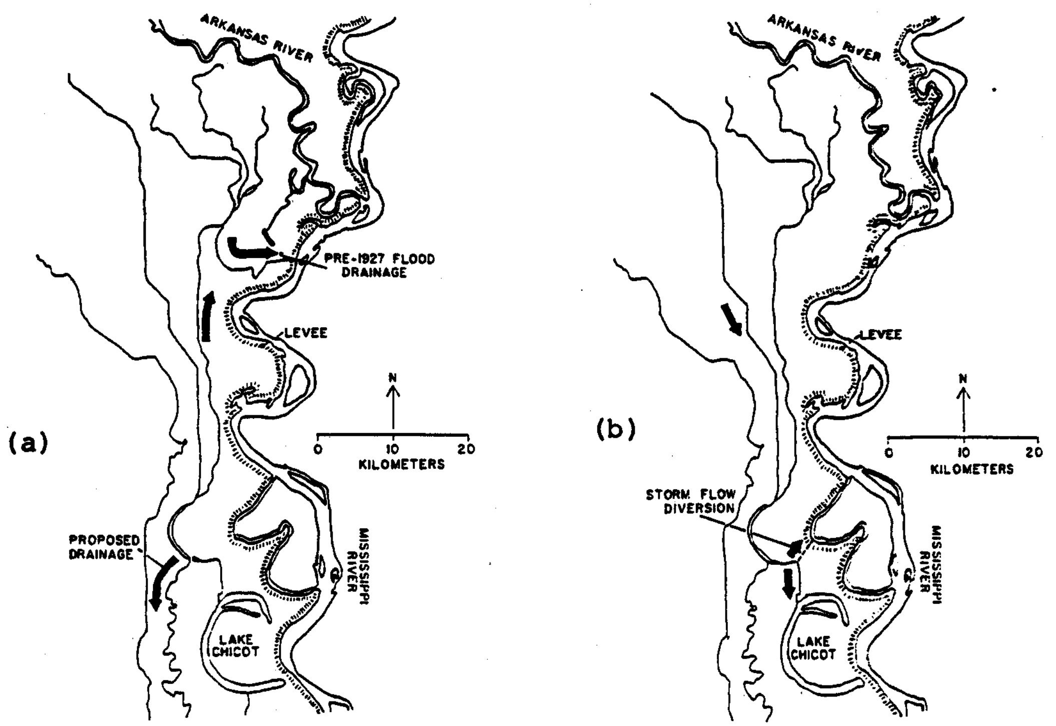

Fig. 1. Lake Chicot and surrounding drainage (a) before 1927 flood and (b) after 1985 diversion.

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version on chlorophyll and water quality in lake Chicot.

Materials and methods

Lake Chicot (19.3 km²) is a large natural oxbow of the Mississippi River located in the southeastern corner of Arkansas, USA (Fig. 1 a). It is 27 km in length and an average 0.7 km in width. The primary land use in the lake's catchment area is intensive agriculture (75%) with the principal crops being cotton (*Gossypium hirsutum*), rice (*Oryza sativa*), and soybeans (*Glycine max*). Until a flood in 1927, Lake Chicot was an undivided oxbow with a small watershed and limited inflow from Connerly Bayou and outflow via Ditch Bayou (Fig. 1 a). Water quality, fisheries, and recreational opportunities were excellent. In the 1920's, the Mississippi River levee bordering Lake Chicot was completed. Water which had previously drained into the Mississippi River was routed south, parallel to Lake Chicot (Fig. 1 a) in a newly constructed drainage system. The drainage system, scheduled to be enlarged later, was inadequate for large runoff events so the 1927 flood followed land contours and scoured a new drainage through Lake Chicot. The flood deepened Connerly and Ditch Bayous and lowered the normal lake level. By capturing the channelized canal system, the flood also increased the drainage area of the lake from 100 km² to 930 km² (U.S. Army Corps of Engineers 1986). A sand spit was formed across Lake Chicot north of the mouth of Connerly Bayou by large quantities of deposited material during the flood. In 1948, additional fill materials were added to the sand spit to form a permanent dam that divided the lake into two sections: an isolated northern basin (3.9 km²) with only ephemeral runoff from a predominantly agricultural watershed of < 100 km² and a larger (15.4 km²) southern basin with greatly increased inflow from a 930 km² watershed with channelized drainage. At normal pool level, the north basin had maximum and mean depths of 5.5 m and 3.4 m respectively, while the south basin had maximum and mean depths of 9.2 m and 4.2 m.

In 1985, installation of a pumping plant was completed on the west levee of the Mississippi River north of Lake Chicot. This pumping plant contains ten 17 $m^3 \cdot s^{-1}$ (cubic meters per second) and two 7 cms pumps plus a gravity outlet structure ($\leq 280\ m^3 \cdot s^{-1}$) to divert sediment-laden floodwaters from Lake Chicot into the Mississippi River. The outlet channel from the pumping station flows into a cut-off channel on the Mississippi River (Fig. 1 b). A gated weir was constructed on Connerly Bayou near its confluence with Macon Lake to regulate inflow into Lake Chicot. Additionally, another gated weir was built on Ditch Bayou to regulate downstream discharge and lake elevation.

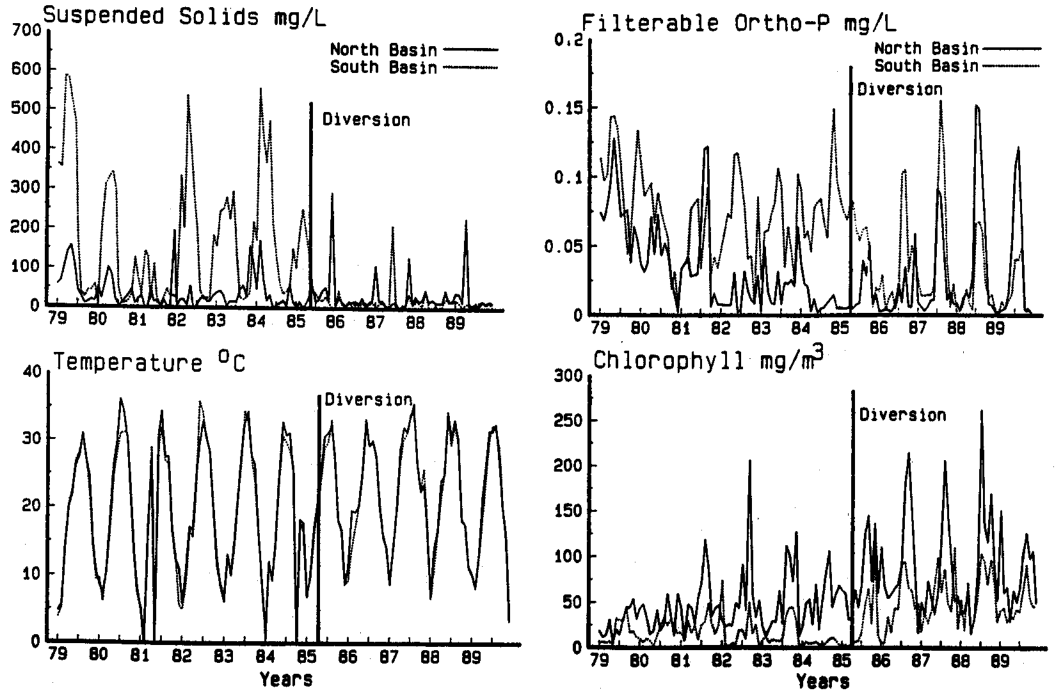

Fig. 2. Selected surface water quality parameters for the North and South basins of Lake Chicot, Arkansas, before and after diversion.

Nine water quality sites were initially chosen to include watershed channels, inflow, lake water, and outflow. Of these, six stations were picked to be continuously sampled throughout the project. Sampling was conducted bi-weekly during the initial intensive phase of the study (1976–1979) and monthly beginning in 1980. Electronic water quality meters were used to measure temperature, dissolved oxygen, conductivity, and pH in situ. Chlorophyll, coliforms, nutrients, and total, dissolved, and suspended sediments were collected, preserved when necessary, and analyzed according to standard methods (APHA 1975, USEPA 1974).

The data set used for statistical analysis for this paper compared five years of data immediately before diversion (1980–1984) and five years of post-diversion data (1985–1989). Statistical Analysis Systems (SAS 1985) was used to obtain analysis of variance with least squares means procedures to test for significant differences between means. All differences reported as significant were statistically significant at 0.01 probability.

Results

Pre-diversion differences between the isolated north basin and the flow-through south basin due to watershed sizes and drainage characteristics were seen in significant yearly or seasonal effects in physical, chemical, and biological parameters. Highly significant differences were found in suspended sediment concentrations (Fig. 2). The mean suspended sediment concentration for the south basin from 1980 to 1985 was 208 mg $\cdot$ l^{-1}, while the mean for the north basin was only 47 mg $\cdot$ l^{-1}. Late winter/early spring storm events caused peaks of suspended sediments in the water column, with the highest concentrations measured in March/April (Fig. 2). While both basins showed this pattern, it was more pronounced in the south basin where suspended sediments values averaged 385 mg $\cdot$ l^{-1} each April compared with 69 mg $\cdot$ l^{-1} in the north basin. Conductivity was also significantly higher in the south basin than the north basin. pH and chlorophyll values, indicative of primary algal productivity, were significantly lower in the turbid south basin (Fig. 2). Chlorophyll peaks were prominent in the north basin during August, September, and October. The south basin experienced a single peak in September. Filterable orthophosphorus (Fig. 2) was significantly higher in the productive north basin, but there were no significant differences in nitrogen between the two basins. Annual temperature cycles for the basins were similar (Fig. 2). Minimum water temperatures ranged from 4 to 10 °C, and occasionally approached 0 °C. Maximum summer surface temperatures exceeded 35 °C. Periods of thermal stratification were brief in both basins, and after fall turnover in September, both basins were usually homothermic until April.

Diversion of storm flows from the south basin began in March, 1985. Mean suspended sediments for the south basin declined from 251 mg $\cdot$ l^{-1} in March to 193 mg $\cdot$ l^{-1} in April. Comparison of the five year periods before and after diversion showed that the mean annual suspended sediment concentration for the south basin dropped from the pre-diversion level of 208 to 39 mg $\cdot$ l^{-1}, while the north basin concentrations were 47 and 30 mg $\cdot$ l^{-1} respectively. For the five year period when storm flows were diverted, suspended sediment concentrations in the south basin were not significantly different from north basin values. Conductivity and pH values were no longer significantly different between the basins. Because of lower nutrient input from the watershed and greater nutrient uptake by phytoplankton, phosphorus concentrations in the south basin declined significantly from their pre-diversion levels. Chlorophyll values steadily increased each spring until they reached summer maxima. Following diversion, total chlorophyll concentrations in the south basin were significantly higher than before storm flow diversion but were not significantly different from the pre-diversion chlorophyll values of the north basin. Increased phytoplankton biomass also occurred in the north basin.

Discussion

The water quality recovery and resulting increases in chlorophyll in the south basin after the construction of the pumping station is apparent when the two basins are compared before and after the diversion. Before diversion, suspended material inflow and resulting suspended sediment concentrations represented the most noticeable difference between the two basins. Phytoplankton production, as indicated by chlorophyll, was limited seasonally in the south basin by suspended sediments in spite of excessive phosphorus. When suspended sediments in the south basin were reduced by diversion of storm runoff, significant differences in phosphorus between the basins disappeared as light penetration increased (Stefan et al. 1983) and phytoplankton populations became greater. Within months significant differences in chlorophyll between the two basins were minimized.

A comparison of two storms emphasizes the results of the diversion. In a pre-diversion storm (Dec. 83), suspended sediments in the south basin increased from 39 to 219 mg · l^{-1} while total chlorophyll declined from 30 to 2 mg · m^{-3}. In the north basin, suspended sediments increased from 29 to 159 mg · l^{-1}. Unlike the south basin, phytoplankton growth was stimulated and total chlorophyll increased from 72 to 127 mg · m^{-3}. In another storm when high flows were diverted from the south basin (April, 89), suspended sediments in that basin only increased from 4 to 13 mg · l^{-1} and chlorophyll increased from 28 to 36 mg · m^{-3}. Suspended sediments in the isolated north basin increased from 16 to 229 mg/l and chlorophyll temporarily decreased from 67 to 29 mg · m^{-3}.

Sediment-laden runoff from intensive agriculture caused long-term water quality and aquatic productivity deterioration in Lake Chicot. When storm flow was diverted by an active/passive bypass system, suspended sediments were eliminated as a limiting factor. Thus, water quality, flood control, water supply, and aquatic productivity, as indicated by chlorophyll, benefitted.

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