RESERVOIR HYDRODYNAMICS, NUTRIENTS AND PRIMARY PRODUCTIVITY IN LAKE BLACKSHEAR

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Abstract. Nutrient load in the main lake is similar to that found in tributary embayments. Chlorophyll a productivity is generally lower in the main lake than in the embayments, and this is thought to result from the short hydraulic retention time of the main lake. Main lake productivity does increase down stream as the reservoir becomes lacustrine.

INTRODUCTION

Past Studies Showing Eutrophication

Lake Blackshear, a hydroelectric impoundment on the Flint River, has had recurring nuisance algae problems over the last twenty to thirty years. The benthic bluegreen algae, *Lyngbya wollei* has been especially prolific in certain of the tributary embayments of the reservoir. A review of these problems was included in a paper presented at the Georgia Water Resources Conference in 1993 (Cofer, *et al.*, 1993).

A 1973 study by the U. S. Environmental Protection Agency determined that Lake Blackshear was eutrophic based on nutrient levels (USEPA, 1975). A study directed by the Academy of Natural Sciences involving sampling in April, August, and October of 1983 demonstrated that nutrient loading was sufficient in the spring and summer to classify the lake as eutrophic (ANSP, 1984). A study funded by the Crisp County Power Commission applying the 1973 USEPA data to the Vollenweider model (Vollenweider, 1978), concluded that eutrophic problems would be expected to be greatest in the tributary embayments (Foth and Van Dyke, 1985). A subsequent study (Cofer, *et al.*, 1991) of Gum Creek, a major lake tributary supported the conclusion that embayments have the greatest eutrophic problems.

Lake Description

Lake Blackshear is a 25 km long shallow water impoundment formed when Warwick Dam was constructed in 1929-30 and is owned by the Crisp County Power Commission. It is located primarily between Crisp and Sumter Counties, but also borders Dooly, Lee, and Worth. The 1975 USEPA report described Blackshear as having a surface area of 34.5 km^2 and a mean depth of 5.3 m with a mean retention time of 16 days. The Foth and Van Dyke study (1985) estimated that 88.7% of the annual mean flow into Blackshear came from upstream sources. This study also estimated that 1.6% of the mean annual flow into the lake came from Gum Creek. The Gum Creek study (Cofer *et al.*, 1991) estimated that 4.8% of the nitrogen and 5.5% of the phosphorus entering the lake came from Gum Creek, the drainage basin of which includes the city of Cordele.

Current Study

A Clean Lakes Phase I Diagnostic Feasibility Study of Lake Blackshear was begun in April, 1992, and field sampling concluded in March, 1993. Preliminary aspects of the study were reported at the third Biannual Georgia Water Resources Conference in Athens (Cofer, *et al.*, 1993). The present report examines the inter-relationship between reservoir dynamics, nutrients and primary productivity in this lake.

LAKE HYDRODYNAMICS

Lake Morphometry

Lake morphometry was determined for subsegments of the main lake and for each of the tributary embayments. A total lake surface of 34.2^2 was determined. The mean depth was calculated to be 3.2 m with a maximum depth in the river channel at the dam pool of 13.5 m. Total volume of the lake is calculated to be 109.35 x 10^6 m^3.

No basic topographic maps existed when Warwick dam was constructed. Land acquisition maps dated 1927-1930 show ownership and predicted full-pool levels and approximate margins of the river channel (not to scale). In 1973, there was an 11-foot drawdown of the lake to improve recreational areas by removing stumps and debris. A topographic map at a scale of 1:6000 and 2-foot contour interval was made of the lakeshore and exposed lake floor.

During the Clean Lakes Study (1992-93), forty transects using a recording sonar (Lowrance X-16) were made of lake and shallow water over-bank areas of the riverine portion of the lake and plotted on the 1973 base map. Lake transect information and exposed embayment floors, and twelve additional transects were used to calculate surface area, mean depth, and volume.

The mean elevation of the lake surface at full pool is 72.2 m (237 ft) MSL. The topography of the lake floor is characterized by a moderately narrow flood plain with a mean elevation of 69.5 m MSL in the upper lake and 67 m MSL in the lower lake. A prominent river terrace with a mean elevation of about 70.8 m

MSL occupies a significant portion of the valley floor and corresponds in elevation to the irregular embayed areas in the valley walls and the floor of many embayed tributaries. The tributaries with significant flow have cut narrow channels through the terrace to the river base-level. The terrace remnants may nearly isolate the embayments from the principle flow path of the river itself. Exchange of water between the embayment and river is restricted.

Discharge

Discharge was determined using USGS gauging stations 111 km above and 22 km below Warwick Dam and the calculated discharges of intervening tributaries, local drainage areas, rainfall and evaporation. Discharge for tributaries was based on instantaneous measurements normalized for basinal rainfall and 30-day average discharge. These discharge values are in reasonable agreement with those calculated using Carter's (1983) mean annual run-off data for the region normalized for rainfall during the study period.

Hydraulic Retention Time

The theoretical retention time is the time required for run-off from the drainage basin and rainfall compensated for evaporation to replace the volume of water in the reservoir. A volume of 109.35 x 10^6 m^3 and a mean discharge at Warwick based on Oakfield mean discharge (1930-1993) of 118.5 m^3 results in a 10.7 day theoretical retention time. Since the exchange of water between embayments is restricted by topography of the lake floor, the net effect is that the mean retention time of the main part of the lake is less than 10.7 days and that for the embayed areas is probably much greater. Studies of velocity and direction of current flow in the lake proper and tributaries confirm this water movement pattern. These studies were made using fixed digital current meters (General Oceanics), remote reading current meter (Endeco) and additional data from dye studies (Tsivoglou, 1978).

WATER QUALITY

Methods

Sampling was carried out at two-week intervals during the growing season from April through October, 1992, and at monthly intervals from November through March, 1993, at seven main lake stations (located over old river channel) and at thirteen tributary embayment stations. Measurements of temperature, dissolved oxygen, pH, and conductivity were made at the surface and one-meter intervals using a Hydrolab. Secchi depth was determined.

Photic depth was determined using a Licore photometer. A composite water sample was made from this layer and sub-samples taken for chlorophyll a determination and nutrient analysis. Additional samples were taken for alkalinity measurement, total suspended solids and metal analysis. Samples were placed on ice. Nutrient samples were acidified with sulfuric acid. Samples were filtered upon return to lab for chlorophyll and for suspended solids. Samples for nutrient analysis were frozen.

Chlorophyll analysis was made following procedure given in pages 10-17, Standard Methods (1992), using a Beckman DBG Spectrophotometer.

Nutrient analysis was done by the Soils Laboratory of the Ecology Institute of the University of Georgia. Nutrients samples were transported to this lab in a frozen state.

Means of total nitrogen, total phosphorus and chlorophyll a were calculated for each main lake station and each tributary embayment station for the growing season, April through mid-September. These are given in Table 1. Table 1 also gives station means for Secchi depth, and total suspended solids for this same time period. Main lake stations and tributary stations are arranged in Table 1 in order from lake headwater (Ga. 27) to dam forebay (Swift Lake).

Lake Stations

Parameter values for the lake stations in Table 1 show trends typical for reservoirs. The decline in suspended solids from the riverine headwaters to the more lacustrine region reflects sedimentation of transported river materials. The increasing Secchi depth supports this conclusion. Increasing chlorophyll a reflects the improved habitat for phytoplankton provided by the more lacustrine environment.

Nutrient load changes are not related to the development of lacustrine conditions. The increase in both phosphorus and nitrogen in the upper mid-lake probably results from nutrient loading from tributary streams such as Spring Creek and Limestone Creek. Both of these tributaries have extensive agricultural activities in their drainage basins.

Embayment Stations

The higher suspended solid load of both Valhalla and Gum Creek may be explained by the fact that both of these are shallow and have extensive boat traffic (boats frequently run at higher speed in Gum, which also is a main access ramp). Wheatley has less boat traffic and, because of extensive stumps, boat speed is generally slow here. Swift is a deeper embayment, thus less bottom agitation probably occurs.

Nutrient values in the embayments reflect nutrient sources in the drainage basins of the tributaries. Lime, Limestone, Spring, and Wheatley embayments are fed by tributaries draining extensive row crop and livestock operations. Gum Creek drainage includes the city of Cordele, with its sewage treatment plant, and agricultural activities. Warren Slough develops off of Spring Creek Embayment, probably receiving nutrients from Spring Creek. Both Warren Slough and Spring Creek embayments have extensive long-term residential development, a likely source of nutrient enrichment. A similar condition exists at Pecan Slough. The higher nitrogen of Swift may reflect residential development or may result from influx from the lower lake (dam forebay). The values of both nitrogen and phosphorus are a little lower in the Swift embayment than those found in the Swift lake station. Swift embayment angles off of the old river channel in such a way as to allow influx of lake water into the embayment. This is likely the point of greatest exchange between lake and embayment in the entire system.

The one clear exception to this relationship is Lime. Lime embayment is the least lacustrine of the embayments, frequently

Table 1. Photic Zone Water Parameters
Means of Late April to Mid-September 1992 Samples

Station	Chlorophyll a (µg/l)	Total Phosphorus (µg/l)	Total Nitrogen (mg/l)	Secchi Depth (meters)	Total Suspended Solids (mg/l)
(main lake)					
Ga. 27	1.4	56	6.48	0.73	12.6
Joe's Is.	1.9	56	7.24	0.40	8.4
US 280	7.4	73	10.40	0.83	6.2
Gum Lk.	8.8	70	6.71	0.86	5.4
Gully Lk.	8.8	39	6.03	0.90	5.7
Cedar Lk.	6.3	57	6.91	0.98	5.6
Swift Lk.	8.3	45	9.49	1.13	5.4
(embayments)					
Lime Cr.	4.3	61	11.94	0.74	6.9
Limestone	15.1	57	6.91	0.79	7.2
Spring C.	15.0	78	7.14	0.80	8.1
Warren S.	13.9	88	11.37	0.92	7.4
Cannon B.	6.0	45	6.79	1.02	7.4
Valhalla	8.0	47	6.81	0.77	13.2
Gum Cr.	20.6	74	12.42	0.76	10.0
Gully Cr.	10.1	46	6.01	0.88	7.3
Pecan Sl.	10.0	50	6.36	0.87	6.7
Lincoln	10.4	37	5.86	1.06	6.6
Cedar Cr.	6.8	40	6.00	1.01	5.7
Wheatley	6.1	54	9.50	1.06	5.2
Swift Cr.	15.0	40	8.96	1.13	5.0

having a noticeable current. This short retention time appears to prevent the development of phytoplankton populations that could be supported by available nutrients. On the other hand, Swift embayment appears to have a chlorophyll a value that is high relative to the mean total phosphorus.

Primary Productivity and Reservoir Hydrodynamics

Chlorophyll a values are generally lower in the main lake than in the embayments. This is especially obvious between the Swift lake station and the Swift embayment station where nutrient values are higher in the lake but chlorophyll value is greater in the embayment. Nutrient values of Gully, Pecan, and Lincoln embayments are generally lower than the lake stations, but chlorophyll is higher in these embayments. The short retention time of the lake prevents establishment of phytoplankton populations resulting in these differences in productivity. At the same time the longer retention times of the embayments allow more extensive populations to develop. The embayments export algae into the main lake. However, since almost 90% of the discharge at the dam enters the upper end of the reservoir (Ga. 27) this dilution effect reduces build-up of exported chlorophyll a.

Measurements in the main lake of the vertical profile of temperature and dissolved oxygen showed times of lake stratification followed by mixing, followed by re-stratification, etc. Polymixis in the main lake supports the concept of a short retention time in a shallow lake system where phytoplankton populations would have difficulty becoming established.

MANAGEMENT IMPLICATIONS

The morphometric description and related hydrodynamics developed through this study provide a better understanding of the dynamics of Lake Blackshear. This has implications in predicting assimilative function and in a clearer understanding of the relationship of river flow and lake mixing and lake level changes.

The relative dynamics of primary production between the main lake and the embayments supports the earlier predictions of the Foth and Van Dyke modeling that the embayments would have the greater problems of eutrophication. The implications of this conclusion include the importance of nutrient management in embayment watersheds if eutrophication is to be minimized

The obvious recommendations would include reduction of nutrient loading in the tributary watersheds as a way of decreasing eutrophic development in the embayments and as a way of decreasing down-river nutrient loading. Reduction of nutrient loading throughout all of the Flint River watershed is important in improving water quality both in Blackshear and down stream. Improved residential sewage treatment, including local treatment plants; reduced agricultural loading through stream buffer zones, riparian wetlands, and livestock lagoons; and improved urban nutrient control are nutrient management options.

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