WATER QUALITY AND TROPHIC STATE

OF LAKE BLACKSHEAR

Lake Blackshear Watershed Association
P.O. Box 1218, Cordele, Georgia 31010

November 2002

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By:

Martin E. Lebo
Weyerhaeuser Company
New Bern, North Carolina

William L. Tietjen
H.E. Cofer
Yonnie Williams
Georgia Southwestern State University
Americus, Georgia

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Executive Summary

Lake Blackshear on the Flint River system is a nutrient-rich reservoir that provides important recreational opportunities in central Georgia. Due to concerns about shoreline development and potential pollutant loading from watershed sources, a study of the ecological condition of the reservoir was conducted during 1992-93 as part of the Georgia Clean Lakes program. Regular monitoring of water quality in the lake is also conducted by staff of the Weyerhaeuser Pulp Mill near Oglethorpe, as well as an annual survey of bottom-dwelling macroinvertebrates. Water quality data indicate Lake Blackshear exhibits seasonal stratification during summer months when river flow is often low and solar radiation is high. For surveys conducted during May through September, a temperature gradient of 2-4°C between surface and bottom waters was observed for most survey dates. Dissolved oxygen (DO) concentrations for this stratified period of the year showed a surface photic layer that was saturated with oxygen during late afternoon and intermittent depletion of bottom water DO. However, bottom water DO concentrations for shallow off-channel regions were typically 1.5 to 2.0 mg/L higher than in the deeper portions of the main river channel indicating refugia were present in the lake at all times. Water movement into and through Lake Blackshear throughout the year is governed largely by the discharge of the Flint River.

Throughout the past three decades, Lake Blackshear has been characterized as eutrophic due to high nutrients and low light penetration (i.e. Secchi depth). Algal growth potential (AGP) tests conducted in 1992-93 confirmed a high potential for algal growth in the lake. However, algal biomass (measured as chlorophyll *a*, Chl*a*) in the lake indicates a trophic status from oligotrophic to mesotrophic/eutrophic depending on location. A lower level of actual production is supported by limited data on the algal assemblage in Lake Blackshear during 1992 and 1993 (43 samples on three dates); total number of species present and diversity metrics were similar among three dates at 22.1 to 23.6 and 3.35 to 3.66, respectively. The blue-green cyanobacterium *Lyngbya wollei*, which can bloom into high densities and adversely affect water quality, was found in several embayments but rarely in the main body of the lake. Bottom-dwelling macroinvertebrates in Lake Blackshear have been surveyed annually since the mid-1980s and exhibited a relatively consistent distribution among major taxonomic groups over time, with individual species that exhibit a broad sensitivity to pollution. Several species, including the predominant chironomid (*Coleotanypus*), *Chaoborus,* and oligochaete worms have high tolerance for pollution while other common taxa are considered sensitive to pollution. *Hexagenia*, commonly known as a mayfly, comprises a large fraction of total biomass and is generally considered indicative of a healthy aquatic environment.

Future management efforts for portions of the Flint River Basin draining to Lake Blackshear should consider how the overall productivity of the lake may be affected. Reduction of nutrient loading to the lake would decrease the potential for development of excess algal production but benefits may be more localized in particular embayments due to non-nutrient limitation of algal growth in the main body of the lake. In embayments plagued by *L. wollei* or emergent vascular vegetation, nutrient controls may help improve ecological condition. Reduction of sediment loading to the lake resulting in increased Secchi depth is one factor that could change algal utilization of available nutrients. The evaluation of whether higher productivity would be beneficial depends on a balance between enhanced fish production and potential increased depletion of DO in bottom waters. Another important unknown is how future changes

in inflow to Lake Blackshear due to increasing regional water usage may affect sediment and nutrient delivery to the lake, water clarity, and water retention time, all of which may affect lake productivity and ecological health. How future changes affect the current good ecological health of Lake Blackshear needs to be part of ongoing management programs for the Flint River basin.

Introduction

Lake Blackshear, a hydroelectric reservoir created in 1929 on the Flint River in central Georgia, serves area needs for fishing and other recreational activities, and in recent decades, has undergone extensive shoreline development. While some water quality problems may have been noted in its earlier years, no significant water quality studies were undertaken until 1973, when as part of the National Eutrophication Survey, Lake Blackshear was classified as eutrophic based primarily on high nutrient values (EPA, 1975). Of the other 14 lakes surveyed in Georgia, none had lower chlorophyll *a* values (range 0.8 – 4.0 µg/L) and all had greater Secchi disc transparencies. The low chlorophyll *a* values were attributed to algal growth being inhibited by turbidity present at all sampling stations at all times. In 1981, Georgia Environmental Protection Division (GA EPD) initiated surveys of lake quality and showed water quality in Lake Blackshear to be similar to the original work done by EPA (GA EPD, 1981).

The survey program by GA EPD included calculation of a composite or total trophic state index (TTSI) based on the sums of the indices of Carlson (1977) for chlorophyll *a* (Chl*a*), Secchi depth, and total phosphorus (TP). Included in the statewide assessment were 132 lakes throughout Georgia. Based on TTSI values for samples collected during the May-October growing season between 1980 and 1993, Lake Blackshear ranked in the top three for eight of the twelve years sampled; in three of the years, Lake Blackshear had the highest TTSI value (most eutrophic) of all lakes sampled (GA EPD, 1992*a*, 1994). However, component TSI values for TP and Secchi depth were consistently much higher than for values derived from Chl*a* concentrations, indicating the three parameters used are not equally estimating the algal state of the lake. While a general correspondence in TSI derived from the three parameters has been demonstrated for many water bodies, non-nutrient limiting factors to algal biomass have been recognized since trophic classifications were introduced in the 1930’s. More recently algal growth control by factors other than nutrients has been suggested as potential causes for discrepancies among trophic states/classifications (Kimmel *et al.*, 1990; Carlson, 1991; Jones and Knowlton, 1993; Kennedy, 2001).

Foth and Van Dyke (1985) evaluated nutrient loading to Lake Blackshear based primarily on the data collected by the EPA in 1973. Loading rates for total nitrogen (TN) and phosphorus (TP) were estimated for the Flint River, tributaries to the lake, and other local sources. When nutrient loadings to the lake were compared with guidelines provided by Vollenweider (1976) as a model for the system, loads for TN and TP exceeded thresholds considered to be “dangerous” for lake eutrophication. Foth and Van Dyke attributed lack of elevated Chl*a* levels to maintenance of “aerobic” conditions in the lake and to rapid flushing due to the short hydraulic retention time. EPA, in cooperation with GA EPD, sponsored a Clean Lakes study in 1992-93 to address general concerns about water quality, especially nutrient levels. The study evaluated patterns in dissolved oxygen (DO), temperature, pH, conductivity, Secchi depth, Chl*a*, and nutrients throughout Lake Blackshear and its embayments (LBWA and GSSU, 2000).

An extensive ecological study of the Flint River / Lake Blackshear ecosystem was conducted in 1983 by the Academy of Natural Sciences of Philadelphia (ANSP, 1984) in response to concerns at that time about degradation of water quality following the startup of a pulp mill in 1981 upstream of the reservoir. Results from this study indicated diverse populations for all functional trophic groups in the lake from bacteria to algae to fish, with communities indicative of natural, healthy riverine and lake ecosystems.

However, the cyanobacterium, *Lyngbya wollei*, was found in several embayments and was noted to have been present for at least 20 years. An important recommendation from the ANSP study was to initiate regular monitoring of the density/biomass of mayflies (*Hexagenia spp.)* to provide data suitable to determine future change in the ecological integrity of the system.

This paper utilizes water quality and macroinvertebrate data that have been collected over the past decade to evaluate the overall ecological condition of Lake Blackshear. The assessment is complicated by a series of disturbances to the lake following Hurricane Alberto in July 1994. Within a 14-month period following the hurricane, Lake Blackshear experienced record flooding, extensive dewatering of the reservoir to repair damage to the earthen dam impounding the river, and widespread bottom water anoxia in July-August 1995 as the reservoir was refilled. Because regular DO monitoring and annual surveys of bottom-dwelling macroinvertebrates were implemented in the mid-1980s, the effects of the disturbances can be removed from this evaluation of the general condition of the lake. During April-August 2001, additional monitoring of Chl*a* levels was done to compare algal biomass in Lake Blackshear post-disturbance with data collected during the Clean Lakes study in 1992-93. The condition of the lake is evaluated in the context of general water quality, ecological health, and the capability of the reservoir to support recreational activities important to the region.

Methods and Study Design

Site Description

Lake Blackshear is a run-of-the-river impound, formed by a concrete and earthen dam and hydroelectric power station on the Flint River at Warwick, Worth County, Georgia, and is owned and operated by the Crisp County Power Commission. There are approximately 1800 residences located around the lake. Recreational lake use was estimated by the Crisp County Power Commission in 1992 to be 750,000 person-days per year.

Lake elevation is normally maintained at full pool, with lake elevation normally fluctuating no more than one foot in a day. Power generation utilizes the available river flow based on river discharge measured at the Montezuma gage 22 mi (37 km) upstream from the lake. A minimum release of 760 ft^3/sec per day and a minimum of 600 ft^3/sec for any hour period is mandated. Lake elevation may be adjusted in anticipation of excessively high river flow, but there is no proscribed flood control function. Discharges up to about 10,000 ft^3/sec can pass through the turbines to produce electricity. Flow in excess of this amount is released through floodgates. This pattern of operation results in a measurable downstream movement of the water mass within the lake, which is particularly evident in the old river channel.

Lake Blackshear is the first impoundment below the river's source near the Atlanta airport, about 200 mi (345 km) upstream. The lake has a surface area of approximately 8,442 acres (3,429 hectares) with a length of 15.6 mi (25 km). Based on information gained during the Clean Lakes Study and following the lake draw down, lake volume, mean lake depth, and theoretical retention time have been revised from previous estimates. Mean lake depth is 10.5 ft (3.2 m) with a maximum depth in the old river channel at the dam forebay of 44.2 ft (13.5 m). Lake Blackshear's storage at full pool is estimated to be 88,641 acre-feet (a lake volume of 3.86 billion cubic feet) and its theoretical retention time is estimated to be 10.7 days (revised from prior estimate of 16 days). Several embayments resulting from the filling of major tributary stream valleys are associated with the main lake body. During periods of lower flow (<2,500 ft^3/sec or 71 m^3/sec), water interchange between the reservoir and the tributary embayments is limited to local rain events and the generation of thermal currents. As river discharge increases to 3,000 ft^3/sec (85 m^3/sec) or greater, exchange commonly occurs. During periods of rapidly rising water level in Lake Blackshear (e.g. inflow in excess of 10,000 ft^3/sec or 205 m^3/sec), water from the main body of Lake Blackshear moves into drowned tributary valleys and frequently well into their lotic zones, resulting in extended periods of outflow as the river recedes (LBWA and GSSU, 2000).

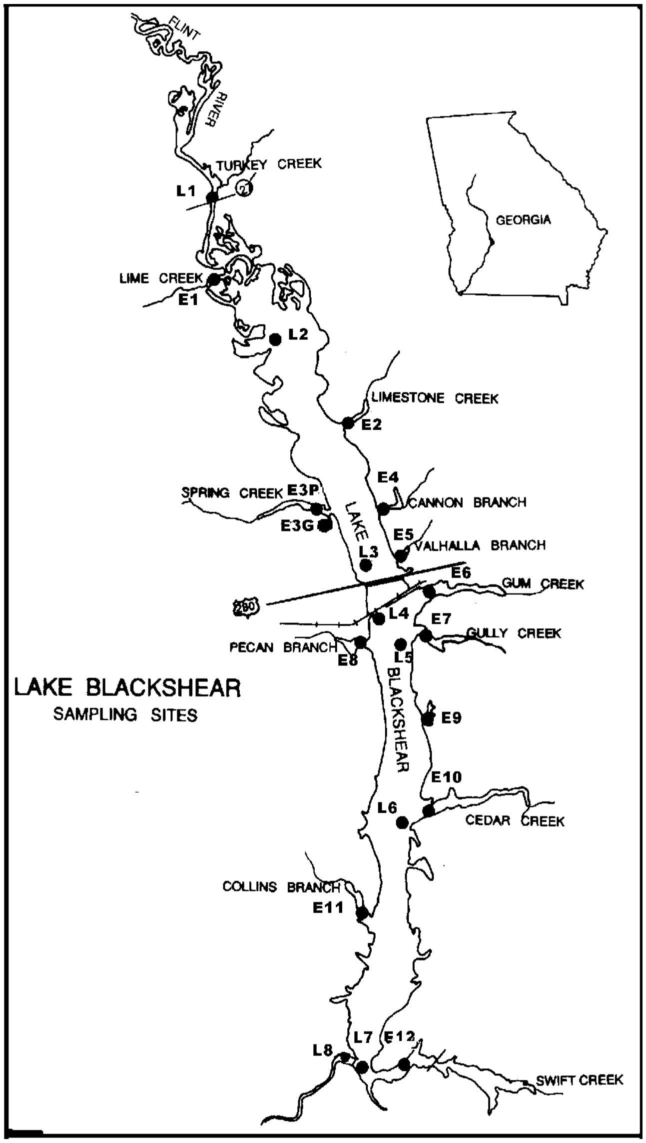
Based on work of the Clean Lakes 1992-1993 study, it was determined that the Flint River supplied 88.8% of the inflow to the lake. Lake tributaries contributed 6.9%, local runoff, intermittent streams and direct precipitation (less evaporation) added 0.9%. The remaining 3.8% was derived from groundwater. Much of the latter was from three large springs with measured or estimated discharges of about 35 ft^3/sec. The upper drainage of the Flint River, comprising 55% of the Flint watershed above Lake Blackshear, is located in the Piedmont and Fall Line transition regions. The remaining watershed above Lake Blackshear is located in the Upper Coastal Plain. In general, during flows into the lake in excess of

10,000 ft^3/sec a disproportional percentage of that water originates in the Piedmont due to the presence of steeper slopes and thinner, lower porosity soils than those of the Coastal Plain. Only 25% of the Piedmont, compared to 55% of the Coastal Plain is classed as open land (harvested forest, exposed/cultivated, pasture, and urban). Further, urban development in the upper basin is much greater than that of the Coastal Plain portion; forty-three permitted discharges, including ten industrial sources, are identified in the Piedmont Province (GAEPD, 1992b). Twenty-two permitted discharges, including four industrial facilities, are identified in the Coastal Plain Province. Of the local urban area, 2,000 acres (809 hectares) are in the immediate vicinity of the lake and are served by individual septic systems. The vast majority of the remaining local urban 1,443 acres (584 hectares) are served by the city of Cordele sewage system from which treated effluent is discharged into Gum Creek, a tributary to Lake Blackshear.

Study Design

A Clean Lakes Phase I Diagnostic/Feasibility Study of Lake Blackshear was conducted during April 1992 to March 1993 to assess water quality in the lake and embayments associated with tributary inflows to the reservoir. Water quality surveys were done biweekly during the months of May to October and monthly during other months. For the surveys, measurements were done and water samples collected at seven lake stations along the flooded river channel, 13 tributary embayments, and in the Flint River downstream from Warwick Dam (Fig. 1). Embayment stations were located at embayment mouths over flooded tributary channels. Water sampling was done as a photic zone composite at each station, and water samples were analyzed for ammonia (NH_3-N), nitrate (NO_3-N), nitrite (NO_2-N), total N (TN), phosphate (PO_4-P), total P (TP), chlorophyll *a* (Chl*a*), and suspended solids (TSS). Nutrient analyses were completed by the Institute of Ecology of the University of Georgia in Athens, Georgia. Following the same schedule, profiles of dissolved oxygen (DO), pH, conductivity and temperature were taken using a Hydrolab Surveyor 3 at one meter depth intervals from surface to bottom. In addition to the lake and embayment stations, water samples and measurements of water quality were made in the free-flowing portion of each of the major tributaries. Sampling and analytical procedures used in the study followed Greenberg *et al.* (1992).

The Clean Lakes study from 1992-93 also conducted a number of special sampling efforts to examine a diverse number of water quality issues. On a weekly basis during mid-June to mid-September, measurements of DO and temperature profiles at two meter depth intervals were done every four hours for a 24-h period along a transect across the lake near Highway 280. In cooperation with U.S. EPA Region IV (Athens, Georgia), sediment oxygen demand (SOD) measurements were made in June 1992 at three lake (L2, L3, and L6) and two embayment stations (Limestone and Gum). Algal growth potential (AGP) tests also were conducted by US EPA Region IV with samples collected from the Flint River (L1), two lake stations (L3 and L6), and four embayments (Limestone, Spring, Gum, and Swift creeks) on July 6, 1992, September 13, 1992, and January 9, 1993. Special samplings also provide limited information on the phytoplankton community from samples collected in July/August 1992, September 1992, and June 1993. Algal species enumeration and trophic state index values were determined by Aquatic Analysis Services in Wilsonville, Oregon. Additional data collection was done to characterize sediment nutrients and contaminants, fecal coliforms, macrophyte abundance, and water column metal concentrations. LBWA and GSSU (2000) provide a full description of all samplings done during the study including additional details on the subset utilized in this paper.



Mainstem Lake Stations:

L1 = GA Hwy 27
L2 = Joe's Island
L3 = U.S. Highway 280 Bridge
L4 = Gum Lake
L5 = Gully Lake
L6 = Cedar Lake
L7 = Swift Lake

Embayment Stations:

E1 = Lime Creek Embayment
E2 = Limestone Creek Embayment
E3P = Spring Creek Embayment
E3G = Warren Slough
E4 = Cannon Branch Embayment
E5 = Valhalla Embayment
E6 = Gum Creek Embayment
E7 = Gully Creek Embayment
E8 = Pecan Slough
E9 = Lincoln Pinch
E10 = Cedar Creek Embayment
E11 = Wheatley Slough
E12 = Swift Creek Embayment

Downstream Flint River:

L8 = Below Warwick Dam

Figure 1. Map showing sampling stations in Lake Blackshear and tributaries for Clean Lakes study.

Weyerhaeuser Mill staff have conducted regular monitoring of DO and temperature at several locations in the upper portion of Lake Blackshear as well as sponsoring annual surveys of bottom-dwelling macroinvertebrates since the mid-1980s. Station locations and survey frequency for water quality monitoring have varied among years and were enhanced in 1995 to characterize better the spatial and temporal patterns in DO concentration following the disturbances associated with Hurricane Alberto. Figure 2 identifies sampling stations utilized for a portion or all of 1995-2001. In terms of the long-term record, stations 5, 6-3, 7-2, Hwy 280, and 9-4 have been consistently sampled throughout 1985-2001. Typically, DO and temperature measurements at survey stations include depth profiles from near the surface (0.5 ft, 0.2 m) to near the bottom. Determination of bottom water DO concentrations were standardized in 1995 to include measurements at 0.5 ft (0.2 m) and 1.6 ft (0.5 m) from the sediment surface, while distance from the sediment surface is unknown for prior years. The standardization of bottom water measurements was done to better integrate information from water quality surveys with the annual survey of bottom-dwelling macroinvertebrates done along four transects (stations 6, 7, 8, and 9) in the upper portion of Lake Blackshear. For 1986-2000, a total of 20 sediment samples were collected along each transect with a petite ponar grab sampler and preserved in the field. Samples were sorted in the laboratory and identified to species or family, depending on the taxonomic group. The number of samples collected in Lake Blackshear was reduced to 10 per transect in May 2001 to allow samples to be collected in the Flint River upstream and downstream of the mill outfall (see SWRC, 2001).

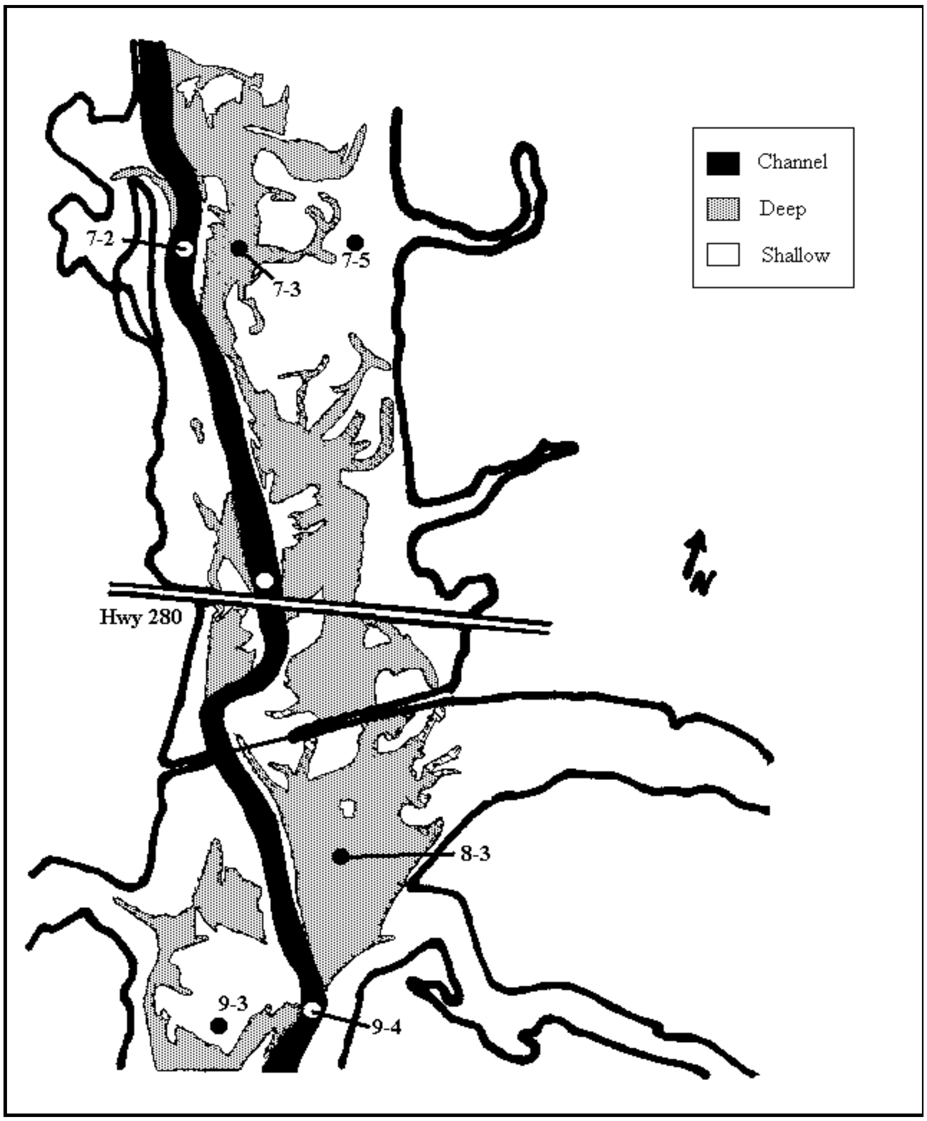


Figure 2. Lake Blackshear habitat types and DO monitoring locations for Weyerhaeuser Mill for Spring Creek to State Park. Upstream channel stations are: GA 27 (st.5), Joe's Island (st. 6-3 or L2), and Sawdust Pt (6A-2 or midway between L2 and L3).

The occurrence of Hurricane Alberto in July 1994 potentially altered water quality and productivity in the Lake Blackshear ecosystem due to dewatered and anoxic bottom water conditions during 1994-95. Additional sampling of lake stations for general water quality (temperature and DO profiles), collection of a water sample at a depth of 3.3 ft (1.0 m), and measurement of Secchi depth were done semi-monthly from mid-April through mid-August 2001 to characterize post-disturbance spatial patterns in some key parameters. The water sample collected was used to analyze Chl*a* concentration at each lake station according to methods utilized in the Clean Lakes study. Surveys in April-August 2001 included six lake stations (L1, L2, L3, L5, L6, and L7) from the Clean Lakes study and sampling near Sawdust Point (Weyerhaeuser station 6A-3) and near Lincoln Pinch to better delineate the lake.

Results

General Hydrology

Water movement into and through Lake Blackshear is governed largely by the discharge of the Flint River. For example, the operation of hydroelectric generation at Warwick Dam is based on stage in the Flint River at the Montezuma gaging station 22 mi (37 km) upstream of Lake Blackshear (USGS, Gage 02349500). Except during periods of high local rainfall, the Flint River at Montezuma accounts for about 89% of water flow through Warwick Dam (LBWA and GSSU, 2000). Inflow to Lake Blackshear has a strong seasonal pattern, with generally higher flows during January through April of most years (Table 1). A comparison of flow records for the Flint River at Montezuma for water years 1904-2000 with data from the past 20 years (1981-2000), shows a marked shift in average flow throughout much of the year. In all but three months, minimum monthly average flow for the entire period of record occurred in the past 20 years, especially for spring through fall months (i.e. April to September). The highest monthly average flow occurred in July 1994 following excessive rainfall associated with a stalled tropical depression (Alberto). During the 1981-2000 period, discharge at the Montezuma gage exceeded 3000 ft^3/sec (85 m^3/sec) on 2288 days but only 12.9% of those occurred during the months of May through September.

Table 1. Summary statistics for the Flint River at Montezuma (U.S. Geol. Survey Gage 022349500). Values are based on monthly averages for individual years from the periods indicated.

	Water Years 1981--2000			Water Years 1904--2000		
Month	Minimum	Mean	Maximum	Minimum	Mean	Maximum
January	1557	4245	7443	1443	4851	12350
February	1962	6067	10960	1962	5963	11380
March	2426	6070	12810	1953	6743	14890
April	1736	4346	9697	1736	5512	15030
May	840	2462	4888	840	3256	9758
June	509	1751	2921	509	2340	6122
July	477	2703	23990	477	2582	23990
August	506	1604	4710	506	2066	4854
September	672	1186	3986	672	1550	4105
October	700	1496	4116	639	1705	6339
November	947	2226	7272	838	2115	7272
December	1474	3554	8702	1306	3577	11490

The run-of-the-river nature of Lake Blackshear creates a measurable down-lake movement of water that tends to follow the old river channel and its adjacent flood plain. Previous hydrodynamic studies using dye releases (Tsivoglou, 1977,1979) and an Endeco current meter (LBWA and GSSU, 2000) indicate that the time of travel between L1 (Hwy 27) and the Hwy 280 bridge near L3 is approximately 5.5 days at a river flow of 2000-2500 ft^3/sec (56.6-71 m^3/sec). In terms of exchange between the main body of Lake Blackshear and the many embayments, movement of water from the lake into embayments has been shown to increase at high river flows (LBWA and GSSU, 2000). Current meters were deployed near the mouths of Gum and Spring creeks during winter months in 1990-91 as preliminary work to the Clean Lakes study. River water was shown to move into the embayments as flow increased while deeper waters in the embayment continued to flow downstream into the lake.

Water Quality Patterns

Lake Blackshear, as is typical for southern reservoirs, exhibits seasonal stratification during summer months when river flow is often low and solar radiation is high. Data from 1992-93 showed that from late September 1992 though the end of the study in March 1993 the lake was well-mixed, with relatively constant temperature though out the water column (Fig. 3). For surveys conducted during May through September, a temperature gradient of 2-4°C between surface and bottom waters was typically observed at lake stations, with the largest differences during the months of May and June. However, the survey conducted on July 16, 1992 illustrates how local weather conditions at Lake Blackshear associated with a storm system can cause intermittent mixing of the water column. Figure 4 shows vertical profiles of temperature and DO for April 27 and June 20, 1992 as examples of well-mixed and stratified conditions. For measurements on April 27, temperature and DO were nearly uniform throughout the water column at Hwy 280 compared with decreasing values for both parameters at the same location for the June 30 survey. These seasonal patterns in temperature and DO concentration in Lake Blackshear are typical for most years based on regular monitoring at lake stations since 1985 (data not shown).

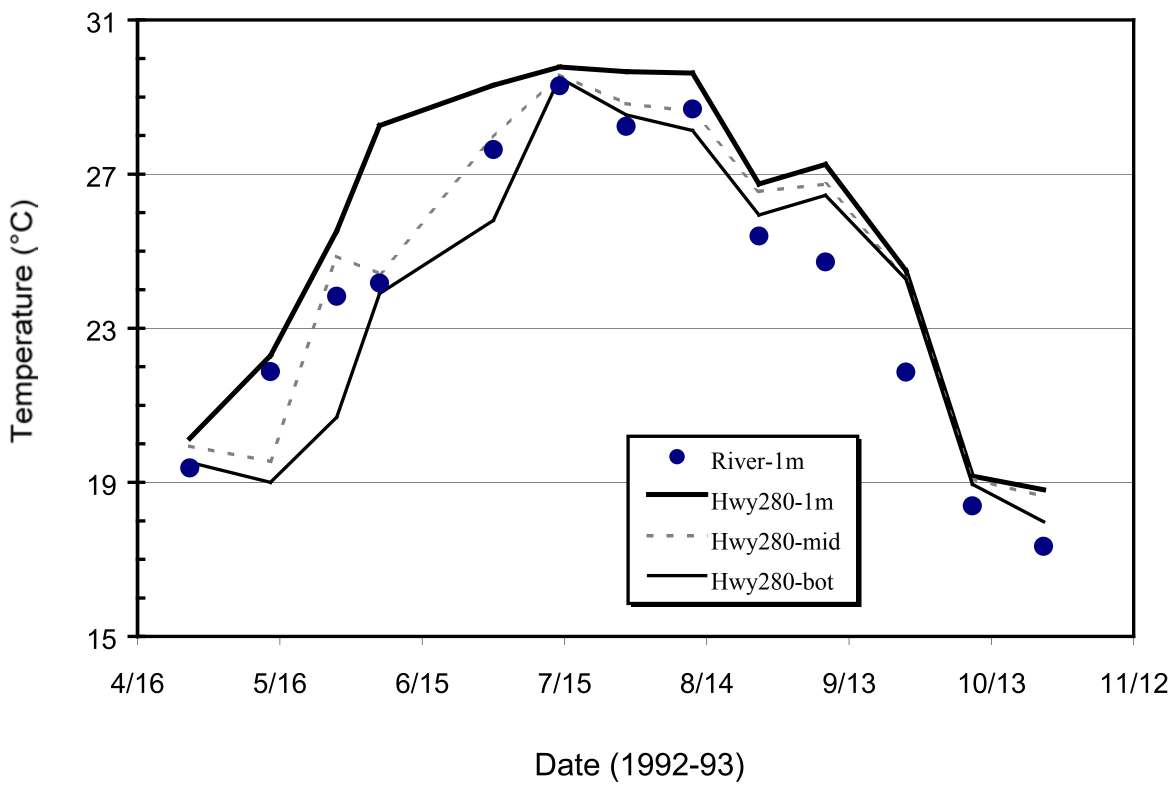


Figure 3. Temperature at Hwy 280 by depth and date for April to October 1992. The plot also shows the temperature at 1 m for the Flint River as it enters Lake Blackshear at GA 27.

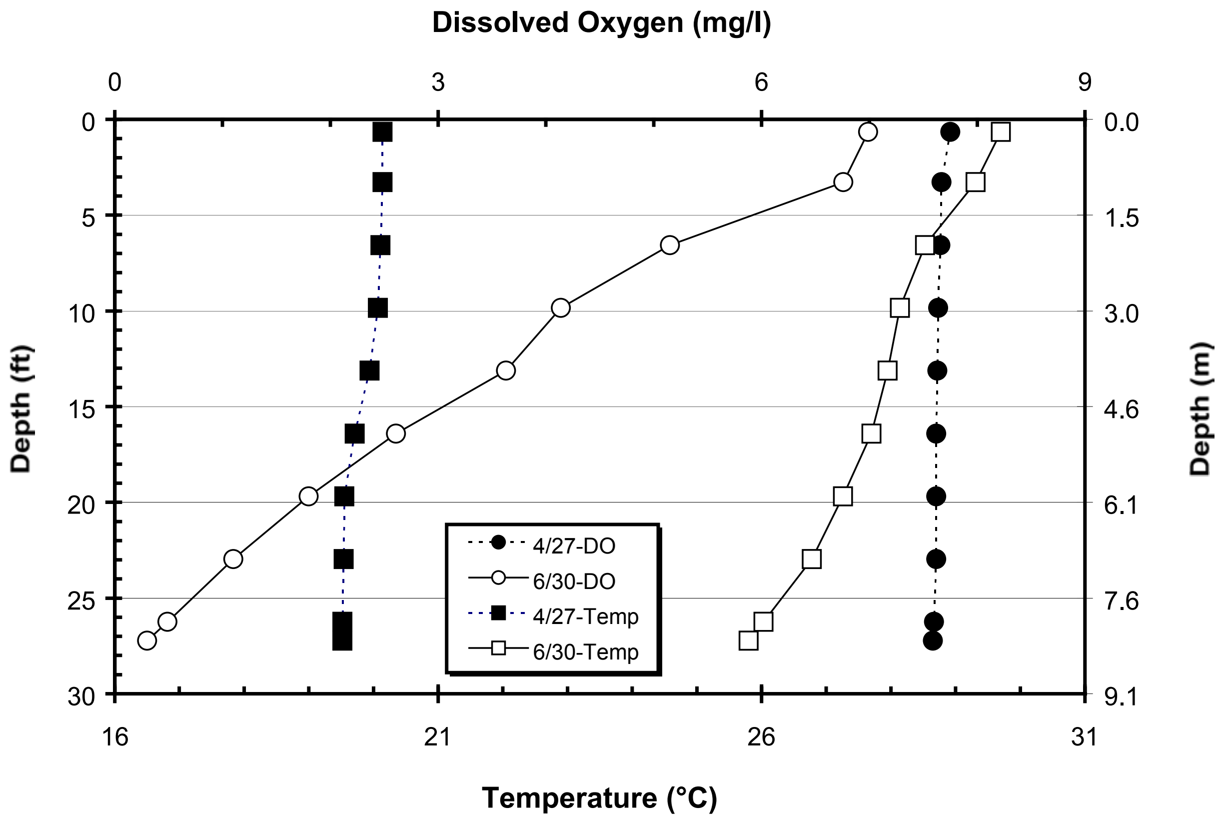


Figure 4. Profiles of temperature and DO in Lake Blackshear at Hwy 280 on April 27 and June 30, 1992.

Weekly monitoring of temperature and DO concentration near Hwy 280 over a 24-h period during May-October 1992 revealed that the surface photic layer may become saturated with oxygen during late afternoon. Certainly, upper waters were always well-oxygenated (80% or better), but decreased oxygen concentrations in bottom waters were often observed during periods with stable thermal stratification (see Fig. 4). LBWA and GSSU (2000) present data from the weekly measurements of DO and temperature over a 24-h period. In terms of spatial variation in DO, the monitoring of DO concentration along the lake transect every four hours showed that bottom water depletion of DO during periods of thermal stratification occurred across the lake, with the lowest values measured in deeper regions such as the main channel or old river meanders. The overall spatial pattern for bottom water DO concentration in Lake Blackshear can be evaluated by the regular monitoring by Weyerhaeuser Mill staff conducted at stations along the old river channel and along several transects across the lake. Monitoring from 1997 to 2001 showed that deep off-channel sites demonstrated the same temporal pattern of DO depletion in bottom waters as stations along the channel, as observed in 1992. This consistent spatial pattern indicates intermittent periods of low bottom water DO associated with the physical setting of different regions of the lake. However, the regular monitoring also showed bottom DO concentrations for shallow off-channel regions of the lake were typically 1.5 to 2.0 mg/L higher than in the deeper portions of the main river channel (Fig. 5), indicating maintenance of adequate habitat for bottom-dwelling invertebrates despite periods of low DO concentration in deeper regions of the lake. By early fall (September to

October), the disparity between channel and off-channel stations had diminished as stratification weakened in the lake (see Fig. 3).

Temperature data for Lake Blackshear indicate a seasonal change in the depth at which water from the Flint River enters the lake. Figure 3 includes the temperature of the Flint River as it enters Lake Blackshear in addition to the observed temperature profile at the Hwy 280 station. During the summer season, the headwater was always cooler than the upper layer in the main body of the lake, and consequently, river water during summer months should remain in the lower portion of the water column. Supporting the concept of river flow continuing below the lake surface are the results of a series of current measurements made with an Endeco Flowmeter from July through October, 1992 (LBWA and GSSU, 2000). Measurements made in the river above GA Hwy 27 showed that maximum velocity occurred in the upper portion of the water column, with velocity approximately two-fold lower near the bottom. In contrast, maximum velocities in the main body of the lake were usually at mid-depth or deeper and continued almost to the bottom. Azimuth readings indicated these flows were down-channel. In cases where peak velocity was measured in surface waters, the direction of flow was not in a downstream orientation, indicating a wind-driven surface current. Higher mid-depth to bottom velocities for the study persisted all the way to the dam forebay. For data from April and May 1992, measured river temperature profiles were similar to downstream stations in Lake Blackshear, indicating the Flint River would have entered the lake at all depths.

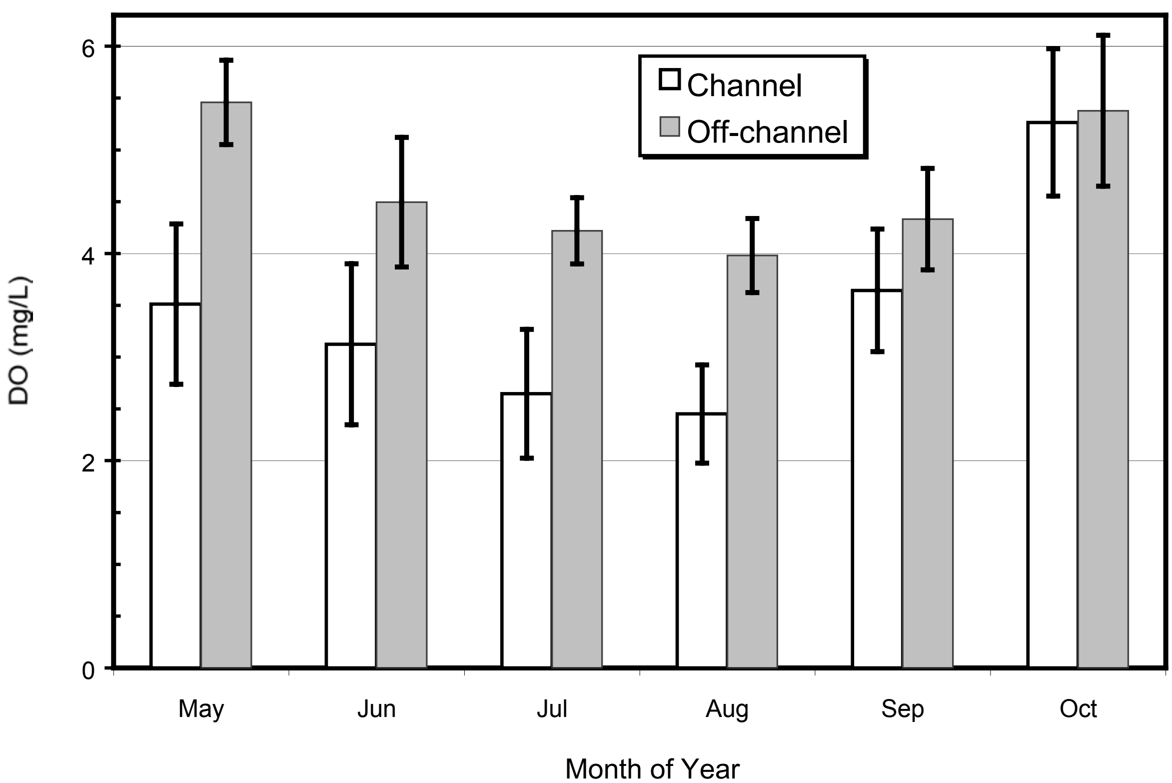


Figure 5. Comparison of monthly mean near-bottom DO concentration at channel and shallow off-channel sampling sites in Lake Blackshear from 1997 to 2001. Data were collected by Weyerhaeuser Mill staff.

Nutrients

Lake Blackshear has been characterized as eutrophic since the 1970s when it was assessed as part of the National Eutrophication Survey. Table 2 lists average NO_3-N and TP concentrations by station and study period; reported values of TN and NH_3-N are omitted due to unknown analytical problems in those analyses. For each of the three periods shown, average NO_3-N and TP concentrations were relatively constant among lake transect sampling stations but highly variable among tributary streams. In the 1983 study, sample collection was limited to summer months and available data indicate a reduction in concentration may occur as water moves through Lake Blackshear during summer months (ANSP, 1984). This retention of NO_3-N and TP within the lake was also apparent in the 1992-93 study for individual summer sampling dates but not overall station averages. For the tributary sampling sites, higher NO_3-N and TP concentrations were found in Lime, Limestone, and Cedar Creeks, consistent with agricultural activities within those watersheds (see LBWA and GSSU, 2000). The lower mean TP concentration in Gum Creek for 1992-93, compared with previous studies, perhaps reflects the reduction in use of phosphate detergents in Georgia during the late 1980s. Elevated loading of TP to Gum Creek in the past is also reflected in the phosphorus content of sediments in Gum Creek embayment (LBWA and GSSU, 2000).

Table 2. Nutrient concentrations in Lake Blackshear during 1992-93 and prior studies.

	Nitrate (mg/l)			Total Phosphorus (mg/l)		
Station	1972[1]	1983[2]	1992-93	1972[1]	1983[2]	1992-93
Lake Stations						
L1	0.20	0.24	0.27	0.07	0.05	0.05
L2		0.20	0.21		0.05	0.05
Hwy 280	0.20	0.19	0.23	0.05	0.03	0.07
L4		0.28	0.27		0.04	0.07
L5		0.21	0.21		0.03	0.04
L6		0.19	0.37		0.04	0.05
L7		0.16	0.23		0.03	0.04
Tributaries						
Lime Creek	0.13	0.26	0.33	0.03	0.03	0.06
Limestone Creek	0.72		1.08	0.05		0.06
Spring Creek		0.68	0.31		0.06	0.06
Gum Creek	1.57	1.47	1.35	0.49	0.16	0.11
Gully Creek	1.38		1.02	0.12		0.06
Cedar Creek	0.30	0.78	0.25	0.03	0.06	0.08
Collins Branch			0.17			0.05
Swift Creek	0.95		1.57	0.03		0.08
Below Dam	0.18		0.19	0.05		0.06

Notes: (1) data from US EPA, 1975; (2) data from ANSP, 1984.

Algal growth potential (AGP) tests with *Selenastrum capricornutum* were conducted on three dates (7/6/92, 9/13/92, 1/9/93) to evaluate the potential for nutrient limitation of algal growth in the Flint River (L1), two lake stations (L3 and L6), and four embayments (Limestone, Spring, Gum, and Swift Creeks). A general conclusion of the tests is that N and P concentrations in Lake Blackshear are typically (18 of 21 tests) above levels that may cause nuisance algal blooms (dry weight >5 mg/l). For July, samples from L1, and Spring and Gum Creek embayments indicated potential N limitation compared with L3 for which addition of P stimulated additional growth. Potential N limitation was predicted for L1 and three of the embayments in September while algal growth for L6 was stimulated by P addition. In contrast to the July and September sampling dates, four of seven tests from January showed potential enhancement by P addition, although growth in all control tests was >10 mg/l indicating ample nutrients at all sites. Calculation of the growing season average trophic state (TSI) for TP by lake and embayment stations confirms the general P-rich state of Lake Blackshear; mean TSI values for May-October 1992 were >56 (eutrophic range) for all stations (Fig. 6).

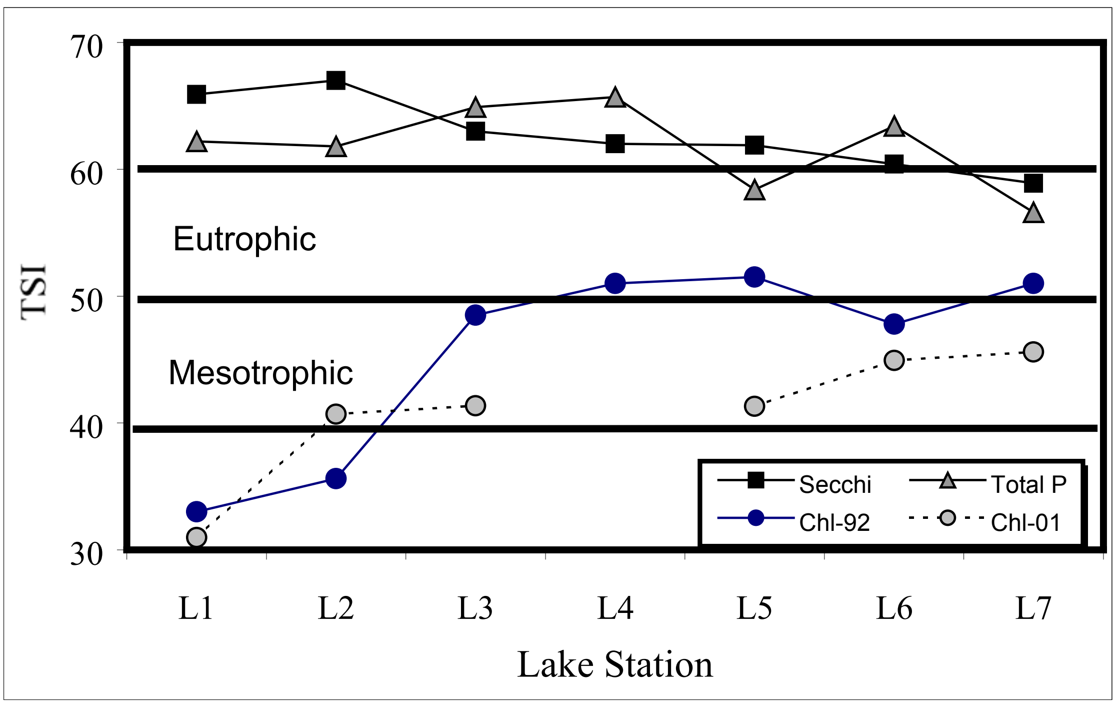


Figure 6. Trophic state index values according to Carlson (1977) calculated by parameter based on average values from May-October in 1992. Chlorophyll values are also included for data collected in 2001.

Algal Community

Algal biomass in Lake Blackshear was regularly assessed during the 1992-93 Clean Lakes study as Chl*a* with species identifications done on three occasions. Along the main axis of the reservoir, Chl*a* concentrations were highest during June and July and increased from a growing season median value of approximately 1 µg/l at L1 to 5.8-8.3 µg/l for stations L3-L7 (Fig. 7). The highest Chl*a* concentrations measured during the 1992-93 study were in Gum embayment on October 23-24 (114 and 152 µg/l), reflecting the local input of TP. Additional Chl*a* measurements were done in April-September 2001 to evaluate how the overall productivity of Lake Blackshear may have been affected by the disturbances associated with Hurricane Alberto (1994-95). Data collected in 2001 showed a similar range of values for the upper portion of the reservoir (L1 to L3) but much lower values for stations L5 to L7. Lower overall productivity in the lower reservoir in 2001 may be associated with lower river flows (and hence nutrient loading) during regional drought conditions in the southeastern U.S. during summer 2001. In terms of overall trophic state, the growing season average Chl*a* values range from oligotrophic to mesotrophic/eutrophic (Fig. 6) compared with hypereutrophic conditions indicated by the Secchi TSI. For the more recent data, the Chl*a* TSI values were generally in the mesotrophic range.

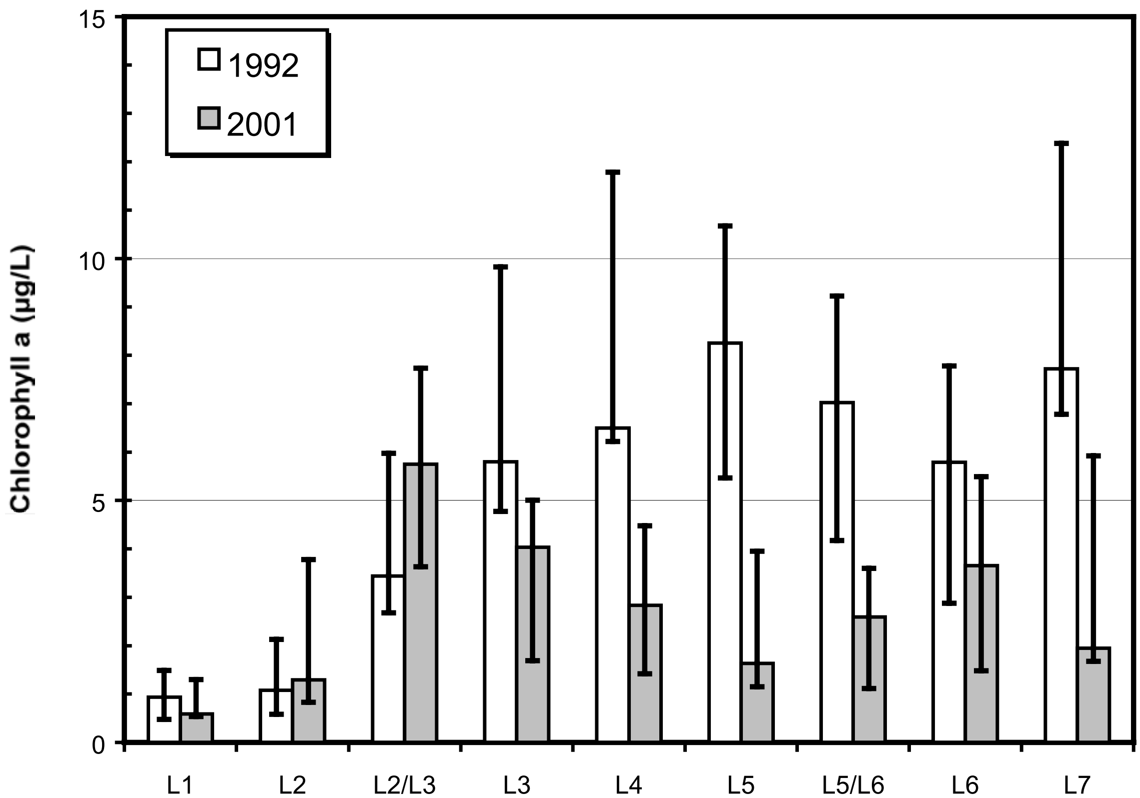


Figure 7. Median chlorophyll *a* concentrations for samples collected during the growing season of 1992 and 2001 by station. Error bars denote the interquartile (25^{th} to 75^{th} percentile) range for measurements. Stations L2/L3 and L5/L6 are for Sawdust Point and Lincoln Pinch, respectively.

The algal community in Lake Blackshear was surveyed at 12-14 stations on three dates in 1992-93 as part of the Clean Lakes Study. A total of 98 species was found in the 43 samples collected, with 15 species accounting for ≥9% of total abundance in at least one sample. Species that were dominant in a number of samples collected generally were present at most other sites and dates. The most common dominant species was the Cryptophyte *Cryptomonas erosa,* which accounted for >9% of total abundance in 34 of the samples enumerated. Five other species (*Chlamydomonas sp., Anomoeoneis serians, Chrysococcus rufescens, Rhodomonas minuta, and Gymnodinium sp*.) were dominant in 7-13 of the samples collected. Table 3 provides summary statistics on the algal community in Lake Blackshear for the three survey periods evaluated. Total number of species present and the diversity of the algal assemblage are commonly used as indicators of ecological health, and both metrics decrease in stressful conditions. The average number of species present and average diversity were similar among the three dates surveyed ranging 22.1 to 23.6 and 3.35 to 3.66, respectively. Total abundance varied from 1210 in September 1992 to 1928 in June 1993. The stations with the lowest number of species and diversity were Lime (12-19 and 2.6-3.0) and Limestone (17-18 and 2.7-3.0) embayments while the greatest abundance for algae occurred in Gum (4500) and Swift (4241) embayments. In terms of trophic state, the estimated biovolume of the algal assemblage for the three dates was in the mesotrophic range at 40.5 in September 1992 up to 50.2 in June 1993 (LBWA and GSSU, 2000)

Table 3. Summary statistics for algal community in Lake Blackshear. Values are the mean (± stdev) of 12-14 samples collected in the main body of the lake and the major embayments. The Shannon-Weaver diversity index was used to evaluate the average diversity in individual samples. Total abundance is in number per milliliter while the TSI listed is based on algal biovolume.

Dates	Species No.	Diversity Index	Total Abundance	TSI
7/28/92 and 8/4/92	22.1 ± 5.0	3.35 ± 0.47	1622 ± 1587	46.7 ± 6.1
9/25-26/92	23.6 ± 6.7	3.66 ± 0.51	1210 ± 1573	40.5 ± 6.5
6/6/93	23.4 ± 4.4	3.42 ± 0.48	1928 ± 1332	50.2 ± 4.3

In addition to the planktonic algal community in the Lake Blackshear ecosystem, the blue-green cyanobacterium *L. wollei* was found in several embayments but rarely in the main body of the lake. Embayments in which filamentous mats were regularly found include Limestone (E2), Warren Slough (E3G), Cannon (E4), Gum (E6), Gully (E7), Pecan (E8), and Lincoln Pinch (E10). There have been occasional reports of *L. wollei* present in other embayments but not on a regular basis. Dr. Larry Dyck (pers. comm.) characterized conditions favoring *L. wollei* growth as protection from excessive wave action, adequate nutrient supply, and waters rich in dissolved calcium. In embayments of Lake Blackshear, masses of *L. wollei* began rising to the water surface from benthic mats after several weeks of active growth and eventually broke free from the mat. Floating portions of *L. wollei* have been observed in the main body of Lake Blackshear and are redistributed to other locations by wave action.

Macroinvertebrates

The bottom-dwelling macroinvertebrate community of Lake Blackshear has exhibited, exclusive of the disturbance years in the mid-1990's, a relatively consistent distribution among major taxonomic groups and a stable level of total biomass. In routine sampling from 1992 to 1994 and 1998 to 2001, dipterans of the chironomidae family were usually the most represented component of the macroinvertebrate community; constituting between 30 and 60% of the relative organism abundance (Fig. 8). Dipterans of the *Chaoborus* genus were usually much rarer except in 1994 when they represented 40% of the community by number. The sediment-burrowing oligochaetes and the ephemeropteran *Hexagenia* each usually comprised between 10 and 30 % of the community by number, both before and after the disturbances. Furthermore, these groups represented the bulk of the biomass for the macroinvertebrate community, particularly *Hexagenia*, and an important component of the trophic resources in the lake (Fig. 9). The exception to a stable biomass of bottom-dwelling macroinvertebrates was in 1998 as the lake was in the process of recovery from the post-hurricane disturbance events; biomass had recovered by the following spring (May 1999) to a level comparable to 1992-94.

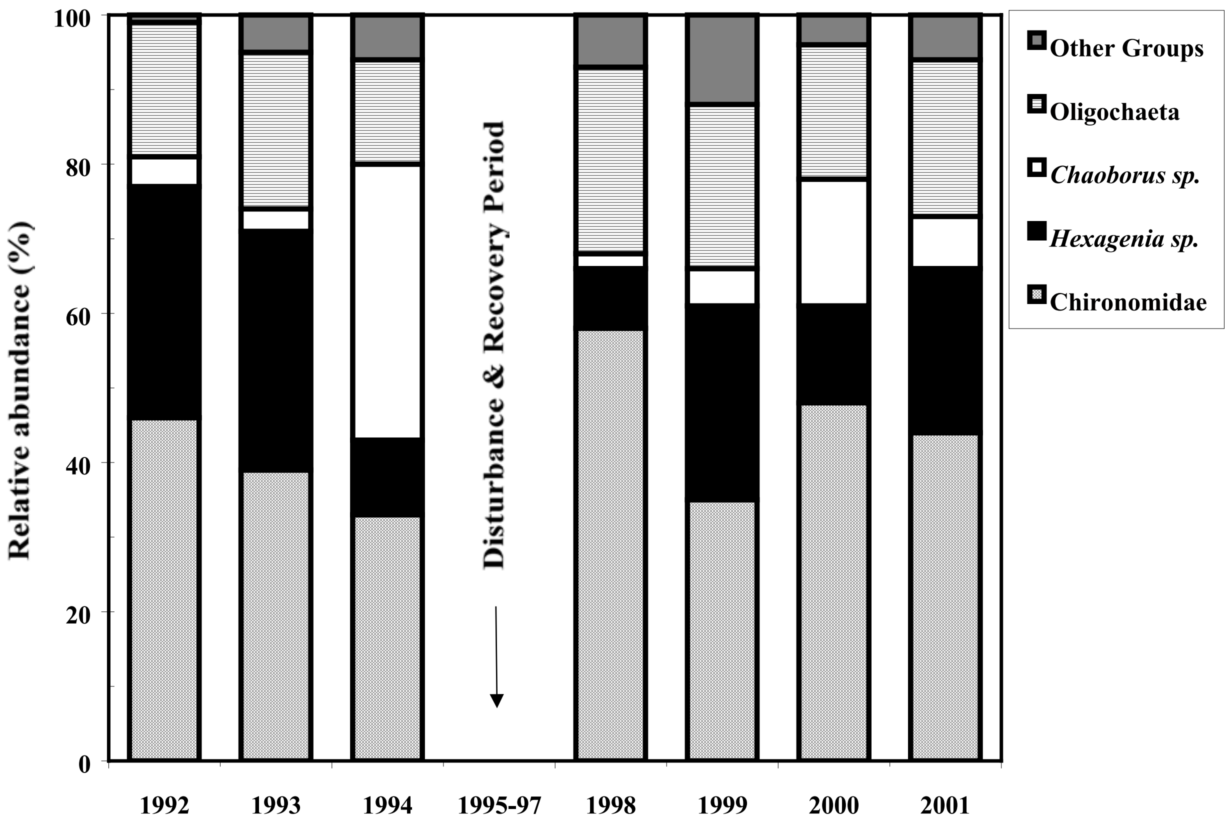


Figure 8. Relative abundance of major bottom-dwelling macroinvertebrate groups in Lake Blackshear by year.

The bottom-dwelling macroinvertebrate community in Lake Blackshear can be used to characterize the pollution status of the lake by examining the pollution sensitivity of the species present. Tolerance values that rate the general pollution sensitivity of macroinvertebrate taxa, many of which are found in Lake Blackshear, have been developed for North Carolina waters (0-10 scale with 0 indicating species most sensitive to pollution)(NCDENR, 2001). The species present in Lake Blackshear exhibit a broad sensitivity to pollution (Table 4). Several species, including the predominant chironomid (*Coleotanypus*), *Chaoborus,* and oligochaete worms, have high tolerance values and are generally considered indicative of organic enrichment. However, other common taxa are considered sensitive to pollution. Included are the chironomids *Cryptochironomus*, *Pseudochironomus*, and *Tanytarsus* with intermediate tolerance values of 5.4 to 6.8 and *Cladopelma* and *Cladotanytarsus* with low tolerance values of 3.5 and 4.1. Further, the tolerance value of *Hexagenia*, which represents a large fraction of total biomass and abundance for bottom-dwelling macroinvertebrates, is 4.9, and the abundance of *Hexagenia* is often used as an indicator of good habitat condition (Edmunds et al, 1976; Rasmussen, 1988; Fremling and Johnson, 1990; Fremling, 1991). Therefore, although a portion of the macroinvertebrate community in

Lake Blackshear is represented by pollution tolerant species, the community as a whole indicates habitat conditions in the lake promote a diverse assemblage of macroinvertebrates.

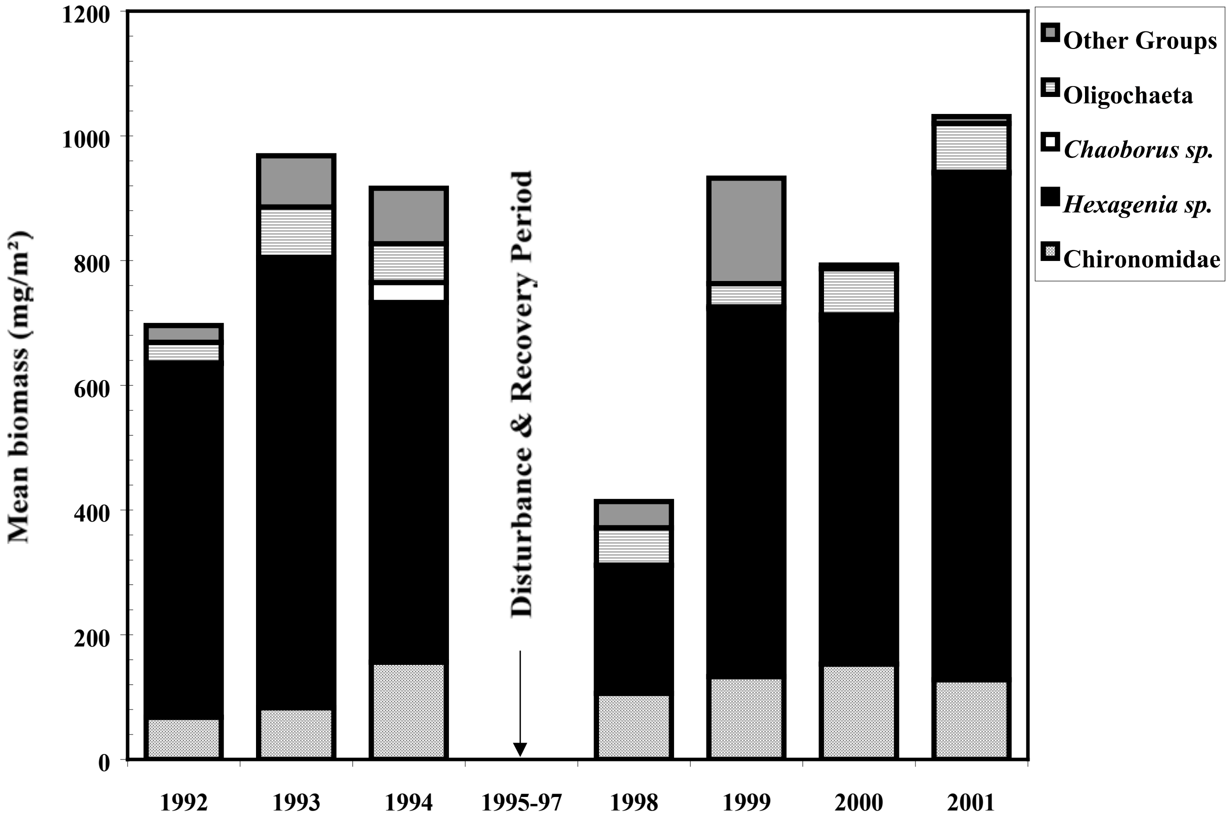


Figure 9. Biomass of major bottom-dwelling macroinvertebrate groups in Lake Blackshear by year.

Table 4. Pollution tolerance value for dominant species comprising Lake Blackshear bottom-dwelling macroinvertebrate community (from NCDENR, 2001).

Genus/Species	Family/Order	Tolerance Value	Relative Abundance
Hexagenia	Ephemeroptera	4.90	Abundant
Coelotanypus	Chironomidae	8.00	Abundant
Chironomus	Chironomidae	9.63	Abundant
Tanytarsus	Chironomidae	6.76	Abundant
Ablabesmyia	Chironomidae	7.20	Abundant
Cryptochironomus	Chironomidae	6.40	Abundant
Harnischia	Chironomidae	9.07	Abundant
Cladopelma	Chironomidae	3.49	Regularly Present
Cryptotendipes	Chironomidae	6.19	Regularly Present
Dicrotendipes	Chironomidae	8.10	Regularly Present
Glyptotendipes	Chironomidae	9.47	Regularly Present
Pseudochironomus	Chironomidae	5.36	Regularly Present
Chaoborus	Diptera	8.50	Regularly Present

Discussion

The ecological integrity of the Lake Blackshear ecosystem, as a productive southern reservoir, is influenced by both its physical environment and water quality conditions. During the winter-spring months, flow in the Flint River is typically high, which limits algal growth in the system due to short residence time and a well-mixed water column. As Flint River inflow to the lake decreases in the late spring, algal abundance increases, with peaks in Chl*a* >20 µg/l (LBWA and GSSU, 2000). Longer residence time and regular thermal stratification of the water column during summer months are likely key factors in this seasonal algal cycle. The correspondence in Lake Blackshear between peak algal production and warm, stratified conditions has been observed in many lakes and reservoirs (e.g. Wetzel, 1975) and can lead to depleted bottom water DO. Monitoring data for the lake over the past several years confirm the occurrence of low DO concentrations in bottom waters, primarily in drowned river and tributary channels. The duration of hypoxic conditions appears to be controlled by irregular mixing events associated with local and regional storms.

The series of disturbance events affecting Lake Blackshear in 1994-95 illustrate the sensitivity of the ecosystem to large-scale changes. Following the physical stress of high velocity conditions during post-hurricane flooding in July 1994, water level was lowered 13-15 ft below full pool to repair Warwick Dam from damage sustained during the flood (ANSP, 1996); lake bed area exposed during dam repair ranged from 60% in the middle portion of the lake to >90% near Joe's Island (L2). Lake level remained low until June 1995 when the lake was refilled. Within a few weeks of lowering, seed germination led to the extensive growth of sedges and forbs over much of the exposed bottom with cypress and willow seedlings in historical near-shore areas. Terrestrial vegetative growth continued until drowned by the refilling of the lake in summer of 1995. Another effect of the dewatering of the lake to repair Warwick Dam was the exposure of lake sediments to the atmosphere. SWRC (2001) reported that the physical characteristics of lake sediments in spring 2001 remained different from pre-flood conditions six years after rewetting. Field observations of exposed lake sediments revealed numerous *Hexagenia* burrows and shell remains of several species of native river mussels and Asiatic clams (*Corbicula*). However, monitoring of macroinvertebrate and fish communities in 1994-95 indicated a healthy remnant survived the flood (C. Couch, U.S. Geol. Survey, Atlanta, pers. comm.; ANSP, 1996), including large numbers of large mouth bass (*Micropterus salmoides*) caught by recreational fisherman in deeper pools in embayments. The greatest effect of the flood on the biology of Lake Blackshear was in summer 1995 when the lake was refilled and extensive regions of low bottom water DO concentrations were observed for several weeks. In contrast to the limited effects of lake dewatering on the composition of the macroinvertebrate assemblage, the prolonged anoxic conditions across the lake bottom in July-August 1995 greatly reduced the abundance of sensitive species (e.g. *Hexagenia*) while increasing several species of chironomids and oligochaete worms (SWRC, 2001). Annual monitoring of the bottom-dwelling macroinvertebrate population during subsequent years indicated the general characteristics of the population had recovered by May 1999.

Lake Blackshear has been classified primarily through the use of trophic state indices as introduced by Carlson (1977). Inherent in the use of this system is the assumption that each index value is a true equivalent of the others. For each index, an increase of ten units represents a doubling of algal biomass.

Carlson (1977) strongly cautioned against using Secchi depth or TP TSIs as predictors for algal biomass in water bodies where there are discrepancies among index values for the different parameters, but rather, he encouraged investigation into the causes behind the divergences. Data from the Clean Lakes study in 1992-93 and from Georgia EPD over the prior decade have consistently shown Lake Blackshear to be a eutrophic lake based on TP, Secchi depth, and Chl*a*. However, a consistent contradiction has been shown in the trophic condition indicated by the different parameters (e.g. Fig. 6). A classification based on Secchi depth or TP clearly shows the lake to be highly eutrophic, while one based on the algal biomass would show the lake to be mesotrophic/eutrophic. Algal growth potential test data for Lake Blackshear provide support that more than adequate phosphorous is present, although not efficiently utilized by algae to support bloom development. As pointed out by Lebo, et al. (2000) for Lake Blackshear and noted by Kennedy (2001) and Knowlton and Jones (2000) more generally, algal growth often fails to reach its potential in reservoirs due to short hydraulic retention times and non-algal turbidity limiting light penetration. Note however, that values for the different indices become less disparate as the dam forebay is approached and conditions are more like those on which the original trophic state calculations were derived i.e. turbidity is determined by algal biomass and algal biomass is generally limited by phosphorous availability.

A gap in our current understanding of the trophic condition in Lake Blackshear is why available nutrients are not effectively utilized. Light availability is certainly a constraining factor on algal growth, but nutrients are not effectively depleted even in surface waters during periods of thermal stratification. However, a high potential to support algal growth was determined in the laboratory with the algal growth potential tests that were done during the Clean Lakes study. An important deficiency in our characterization of nutrient concentrations in Lake Blackshear is the partitioning of TN and TP among the various inorganic and organic forms. Better understanding the availability of nutrients in the lake and the factors limiting the overall productivity of the algal community are essential to understand potential future changes in lake ecology in response to management actions in watersheds draining to the lake.

The ecological condition of Lake Blackshear needs to be evaluated in the context of maintenance of diverse invertebrate and fish communities while achieving the recreational uses which are an important public benefit from the project. Sparse monitoring of the nutrient condition of the lake done over the past three decades indicates nutrient loading to Lake Blackshear is sufficient to support a eutrophic classification, while corresponding Chl*a* data indicate a much lower level of productivity. Further, lake transparency, as measured by Secchi depth, is low and inconsistent with Chl*a* data. The lack of correspondence between Secchi depth and Chl*a* likely reflects high turbidity associated with inorganic particles. Thus, the ecological integrity of Lake Blackshear may be affected by high nutrient and sediment loading and resulting changes in the benthic environment in the lake. Examination of the algal and benthic macroinvertebrate communities, however, indicates the potential eutrophic level of lake productivity supported by measured nutrient concentrations is not achieved. In fact, recent measurements of Chl*a* and algal species enumeration done in 1992-93 indicate a moderate level of total production that may be a limiting factor for sport fishery production in the lake. At the same time, there are problems with the cyanobacterium *L. wollei* and emergent vascular plants in some embayments and lake margin areas. Periods of low bottom water DO have also been observed in the lake, but the absence of reported fish kills and the presence of a healthy benthic macroinvertebrate fauna suggest that oxygen depletion does not result in severe harm to the lake.

Future management efforts for portions of the Flint River Basin draining to Lake Blackshear should consider how the overall productivity of the lake may be affected. Reduction of nutrient loading to the lake would decrease the potential for development of eutrophic conditions. However, the effect of decreased nutrient loading may be more localized in particular embayments rather than in the main body of the lake where algal growth appears to be constrained by other factors. In embayments plagued by *L. wollei* or emergent vascular vegetation, nutrient controls may help improve ecological condition. Reduction of sediment loading to the lake resulting in increased Secchi depth is one factor that could change algal utilization of available nutrients. Increased algal production in Lake Blackshear may increase the rate of DO depletion in bottom waters, which would increase stress on bottom-dwelling macroinvertebrates. As the same time that potential negative effects of increased algal production are evaluated, it is important to consider that algal production provides the primary food base for most of the sport fish species in the lake. Clayton and Maceina (2002) demonstrated a correlation between lake trophic state and gizzard shad production in two Alabama reservoirs. For Lake Blackshear, lake fishermen and fisheries biologists for Georgia DNR have expressed concern that sport fish populations are declining, with speculation that decreased shad production may be a contributing factor (Russell Ober, pers. comm.). Another important threat to lake health is a reduction in overall inflow to Lake Blackshear due to increased water demands throughout the Flint River Basin. It is unknown how reduced inflow to Lake Blackshear may affect sediment and nutrient delivery to the lake, water clarity, and water retention time, all of which may affect lake productivity and ecological health.

Conclusions

Lake Blackshear represents an important ecological and recreational resource for central Georgia. Evaluation of the condition of the lake requires integration of knowledge on water quality and on overall primary production to support a thriving sport fishery. Clearly, typical nutrient levels are sufficient to support much higher algal production in the lake than indicated by measured summertime Chl*a* concentrations. At the same time, there are problems with the cyanobacterium *L. wollei* and emergent vascular plants in some embayments and lake margin areas and periods of low bottom water DO in deeper relict channels. In contrast, the presence of a healthy benthic macroinvertebrate fauna and a lack of reported fish kills suggest that oxygen depletion does not result in severe harm to the lake. Concerns have been expressed by state fishery biologists that overall production of sport fish species may actually be declining in the lake due to lower than desired algal levels. As future management actions or new pollutant sources are evaluated in watershed draining to Lake Blackshear, consideration should be given to how overall productivity and water quality may be affected so that both ecological and recreational needs for the system are taken into account.

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Literature Cited

Academy of Natural Sciences of Philadelphia. 1984. Ecosystem Studies of the Flint River and Lake Blackshear - 1983. Div. Environ. Res., Acad.Nat. Sci. Phil., Philadelphia, PA.

ANSP. 1996. Environmental Monitoring Studies on the Flint River at Lake Blackshear: Population Dynamics of Hexagenia and Other Macroinvertebrates. Div. Environ. Res., Acad. Nat. Sci. Phil., Philadelphia, PA.

Carlson, R.E. 1977. A trophic state index for lakes. Limnology and Oceanography. 22:361-369.

Carlson, R.E. 1991. Expanding the trophic state concept to identify non-nutrient limited lakes and reservoirs. P. 59 -71 *In*: Proceedings of a National Conference on Enhancing the States' Lake Management Programs: Monitoring and Lake Impact Assessment – U.S. Environmental Protection Agency.

Clayton, D.L. and M.J. Maceina. 2002. Trophic state differences in population characteristics of Gizzard Shad in two Tennessee River impoundments. Lake and Reservoir Management 18(2): 109-117.

Edmunds, G.F., S.L. Jensen, and L. Berner. 1976. The Mayflies of North and Central America. University of Minnesota Press, Minneapolis.

Foth and Van Dyke. 1985. Lake Blackshear Nutrient Study. A report developed for the Crisp County Power Commission.

Fremling, C.R. 1991. *Hexagenia* mayflies (Ephemeroptera:Ephemeridae): Biological monitors of water quality in the upper Mississippi River. Pages 118-128 *in*: L.G. Sanders (ed.), Techniques for Evaluating Aquatic Habitats in Rivers, Streams, and Reservoirs; Proceedings of a Workshop. Miscellaneous Paper W-91-2, US Army Corps of Engineers Waterway Experiment Station, Vicksburg, MS.

Fremling, C.R. and D.K. Johnson. 1990. Recurrence of *Hexagenia* mayflies demonstrates improved water quality in Pool 2 and Lake Pepin, upper Mississippi River. Pages 243:248 *in*: I.C. Campbell (ed.), Mayflies and Stoneflies: Life Histories and Biology. Kluwer Academic, Dordrecht.

GA EPD. 1981. Georgia Department of Natural Resources, Environmental Protection Division. 1981. Flint River – Upper Lake Blackshear Study. Georgia DNR/EPD, Atlanta, GA.

GA EPD 1992a. Georgia Department of Natural Resources. 1992. Water Quality in Georgia, 1990-1991: Atlanta, GA Georgia Department of Natural Resources, Environmental Protection Division. 69p.

GA EPD 1992b. Flint River Basin Point Source Inventory. Atlanta, GA Georgia Department of Natural Resources, Environmental Protection Division.

GA EPD 1994. Georgia Department of Natural Resources. 1994. Water Quality in Georgia, 1992-1993: Atlanta, GA Georgia Department of Natural Resources, Environmental Protection Division. 99p.

Greenberg, A. E., L. S. Glesceri, and A. D. Eaton, editors 1992. Standard Methods for the Examination of Water and Wastewater. 18th edition. Published by the American Public Health Association, American Water Works Association, and Water Environment Federation.

Jones, J.R. and M. F. Knowlton. 1993. Limnology of Missouri Reservoirs: An Analysis of Regional Patterns. Lake and Reservoir Management. 8(1): 17-30.

Kennedy, R.H. 2001. Considerations for establishing nutrient criteria for reservoirs. Lake and Reservoir Management. 17(3):175-187.

Kimmel, B.L., O.T. Lind and L.J. Paulson. 1990. Reservoir Primary Production. P133-193 *In*: Reservoir Limnology: Ecological Perspectives. 1990. Thornton, K.W., B. L. Kimmel and F.E. Payne, eds. John Wiley and Sons. 246p.

Knowlton, M.F. and J.R. Jones. 2000. Non-algal seston, light, nutrients and chlorophyll in Missouri reservoirs. Lake and Reservoir Management. 16(4): 322-332.

LBWA and GSSU 2000. Water Quality Conditions in Lake Blackshear, Georgia Prior to the Flood of 1994: The Results of a 1992 Study. Lake Blackshear Watershed Association and Georgia Southwestern State University.

Lebo, M. E., H. E. Cofer, P. Y. Williams, and W. L. Tietjen. 2000. Evaluating the Trophic State of Lake Blackshear (Georgia). Abstract in Protecting Lakes and Watersheds: Innovative Solutions to Point and Non-point Source Pollution. NALMS 9th Annual Southeastern Lakes Management Conference.

North Carolina Department of Environment and Natural Resources (NCDENR). 2001. Standard Operating Procedures for Benthic Macroinvertebrates. NCDENR, Division of Water Quality, Water Quality Section, Environmental Sciences Branch, Biological Assessment Unit. Raleigh, NC.

Rasmussen, J.B. 1988. Habitat requirements of burrowing mayflies (Ephemeridae: *Hexagenia*) in lakes, with special reference to the effects of eutrophication. Journal of the North American Benthological Scociety. 7:51-64.

Stroud Water Research Center. 2001. Environmental Monitoring Studies on the Flint River at Lake Blackshear: Population Dynamics of Hexagenia and Other Macroinvertebrates. Stroud Water Research Center, Avondale, PA.

Tsivoglou, E. C. 1977. Waste Assimilative Capacity of the Flint River Below Oglethorpe, Ga.: Main Report. Volumes 1 and 2.

Tsivoglou, E. C. 1979. Waste Assimilative Capacity of the Flint River Below Oglethorpe, Ga.: Supplemental Report. Volumes 1 and 2.

U.S. EPA. 1975. Report on Lake Blackshear, Georgia. EPA Region IV, Working Paper No. 283.

Vollenweider, R. A. 1978. Input-Output Models, with Special Reference to the Phosphorus Loading Concept in Limnology. Schweiz A. Hydro. Vol. 37, pp 53 – 84.

Wetzel, R.G. 1975. Limnology. Saunders College Publishing, Philadelphia.