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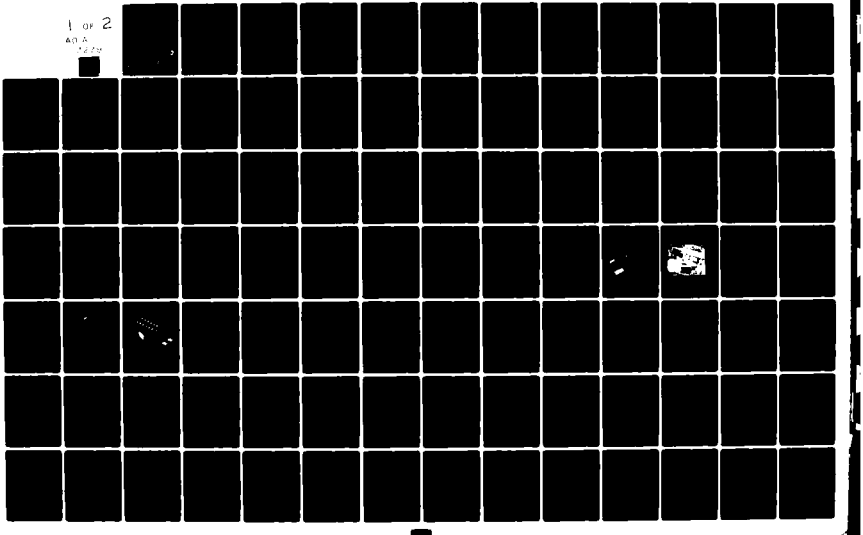

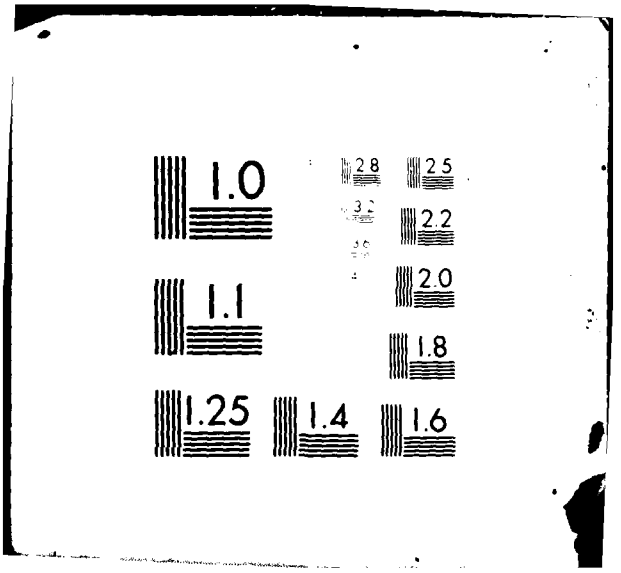
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FINAL REPORT
FOR
A BIOASSAY EXPERIMENT TO DETERMINE WATER QUALITY IMPACTS RELATED TO TROUT MORTALITY AT A HATCHERY DOWNSTREAM OF LAKE SIDNEY LANIER, GEORGIA

Presented to:

U.S. Army Corps of Engineers, Mobile District
P.O. Box 2288
Mobile, Alabama 36628

Contract No. DACW01-80-C-0368

Presented by:

Jones, Edmunds & Associates, Inc.
730 North Waldo Road
Gainesville, Florida 32601

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A major trout kill occurred at Buford Trout Hatchery in northern Georgia during its first year of operation in autumn 1976. Several studies linked toxicity to anoxic conditions in the hypolimnion of Lake Sidney Lanier (the reservoir formed by Buford Dam, 1 1/2 miles up the Chattahoochee River from the hatchery). No consensus as to the toxic agent(s) was reached as a result of the initial studies. An Interagency Task Force recommended bioassays to identify the toxic agent(s), and the

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

U.S. Army Corps of Engineers, Mobile District, retained Jones, Edmunds & Associates, Inc. (JEA), to design and conduct bioassay tests on site during the fall and winter of 1980. After approval of its Plan of Study, JEA established a compound on top of Buford Dam and drew test water directly from Lake Sidney Lanier. Waters from different depths in the reservoir were tested for toxicity to rainbow trout swim-up fry, and each water was extensively analyzed chemically. Bottom water was most toxic and had the highest levels of manganese (Mn) and iron (Fe). No other metals were detectable, no humics or pesticides could be measured, and no hydrogen sulfide was found. In a second set of experiments, bottom water was treated in various ways to remove potential toxicants. An anion exchange resin to remove organics had no effect on toxicity of the water. Na_4 EDTA increased toxicity, but Ca_2 EDTA gave full protection. Removing Mn and Fe removed toxicity if the hardness (12 ppm in lake) also removed by the cation exchange resin was added back. Increasing hardness by $\geq$25 ppm without other treatment also prevented trout fry mortality. Prolonged aeration decreased dissolved Fe, but not Mn, and increased toxicity. Activated carbon removed almost all Fe, but no Mn, and increased toxicity.

In static bioassays, Mn^{++} or Fe^{++} added to non-toxic epilimnetic water was acutely toxic to trout fry at the concentrations measured in the Chattahoochee River below Buford Dam.

Rainbow trout fry held at 6 stations in the Chattahoochee River up to 23 km below Buford Dam suffered heavy mortalities while the lake was still stratified (November), with only slight improvement at the farthest station. Yearling trout showed the same pattern but with lower mortality rates. Bluegill sunfish, which occur naturally in the river, survived 4-day exposures at all stations.

Comparisons of liver contents of 24 metals between Buford Trout Hatchery and Walhalla National Trout Hatchery were difficult to interpret. Of the eight detectable metals, six showed significant differences between hatcheries, all higher in Buford trout even though some of the six are known to be in higher concentrations in water at Walhalla.

The study concluded that Mn and Fe explained all toxicity observed at the hatchery and demonstrated in the river, with no evidence for involvement of any other metal nor of any organic compound. Recommendations were made with respect to possible solutions to seasonal toxicity problems at Buford Trout Hatchery and to further understanding of the impacts of Mn and Fe toxicity on biota of the Chattahoochee River below Lake Sidney Lanier.

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SECTION 1.0. INTRODUCTION

1.0 INTRODUCTION

1.1 PROBLEM STATEMENT

Lake Sidney Lanier, a multi-purpose reservoir in northeast Georgia operated by the U.S. Army Corps of Engineers, Mobile District, was formed by the construction of Buford Dam on the Chattahoochee River in the middle 1950's (Figure 1.1). The lake elevation is normally between 1,060 feet (323 m) mean sea level (msl) and 1,070 feet (325 m) msl, at which level the lake covers 38,000 acres (15,378 hectares). Buford Trout Hatchery was built in 1976 approximately 1.5 miles (2.5 kilometers) downstream from Buford Dam, by the Game and Fish Division of the Georgia Department of Natural Resources. The hatchery location was chosen because bottom waters released from Lake Sidney Lanier are cold enough to allow trout culturing during periods when water temperatures so far south are generally too warm for trout.

During the fall of 1976, massive rainbow trout kills occurred at the hatchery, which had been placed in operation six months earlier. Approximately 435,000 fish (60 percent of operational loadings) were lost. Initial studies by the Environmental Protection Division of the Georgia Department of Natural Resrouces postulated both manganese and organic material (some form of humic acid) as toxicants. The toxicants were related to the seasonal stratification of Lake Sidney Lanier and to the release of hypolimnetic water into the Chattahoochee River, from which the hatchery draws its water.

In May 1977, Georgia Governor Busbee wrote General McIntyre of the U.S. Army Corps of Engineers South Atlantic Division in Atlanta, bringing to his attention the serious problem at the Buford Trout Hatchery. Subsequent coordination resulted in the formation of a task force comprised of Georgia Department of Natural Resources Game and Fish, and Environmental Protection Divisions; the U.S. Army Corps of Engineers, South Atlantic Division, Mobile District, and Savannah District; and the U.S. Environmental Protection Agency (EPA). The primary objectives of the task force were to better define water quality below Buford Dam and to investigate alternative solutions to toxicity problems at the hatchery.

1.2 EVENTS LEADING TO THIS STUDY

Task Force members performed several investigations in the fall of 1977 directed at understanding and solving the water quality problems in the hatchery and at determining if similar impacts existed in the river. Georgia Department of Natural Resources monitored water quality and fish health in the hatchery and initiated a temporary treatment system for organic material. EPA, at the request of the State of Georgia, performed an independent investigation of hatchery conditions. In addition to the hatchery studies, the U.S. Army Corps of Engineers funded several studies pertaining to conditions in the river. Water quality data were collected by the U.S. Geological Survey (USGS), Georgia District Office. Fish movement studies were conducted by the University of Georgia, and fish health studies were conducted by Auburn University. The

U.S. Army Corps of Engineers also funded a limited assessment of mutagenic activity by Morehouse College (Atlanta University) at the request of the State of Georgia.

The 1977 studies provided better definitions of water quality conditions in the Chattahoochee River below Buford Dam and in the hatchery; however, the acute mortality problems in 1976 were not experienced in 1977. No evidence of fish mortality was detected in the river. Fish health was impacted somewhat, but causes were undefined. The significance of any adverse water quality impact on the downstream fishery resource or on other uses of the Chattahoochee River, either alone or in conjunction with other related environmental factors, such as short-term flow variations, remained unknown.

Disagreement resulted over interpretation of data gathered during the 1977 studies (U.S. Army Corps of Engineers, Mobile District, 1980a.). The U.S. Army Engineer Waterways Experiment Station, Vicksburg, at the request of the U.S. Army Corps of Engineers, Mobile District, reviewed the technical aspects of the fish kill studies. Waterways Experiment Station commented that a definitive conclusion for the 1976 kill could not be made based on available data. These comments were rebutted by Georgia Department of Natural Resources, whose hypothesis of trout mortality due to humic substances was restated following the 1977 work. EPA, as a result of its investigations in 1977, postulated that copper toxicity was the cause of trout mortality (Mount et al., 1978).

Studies similar to those initiated in 1977 were continued throughout 1978. The U.S. Army Corps of Engineers funded continuation of fish health and electron microscopy studies of fish gills by Auburn University. The U.S. Army Corps of Engineers also funded periodic water quality sampling in Lake Sidney Lanier and in an 8.5-mile (13.7 km) reach of the Chattahoochee River downstream of Buford Dam. EPA performed a limnological study directed at selected heavy metals and conducted some tissue analyses of hatchery fish. Georgia Department of Natural Resources continued testing and monitoring water quality in the lake and river. Fish movement studies were continued by the University of Georgia. The 1978 studies generally supported 1977 data concerning water quality below Buford Dam, but the basic question of the primary cause for the hatchery mortality remained unresolved. Hatchery conditions in 1978 appeared worse than in 1977, but not as severe as in 1976.

Studies as extensive as those conducted in 1977 and 1978 were not carried over into 1979 because the task force felt that little additional information would be gained (U.S. Army Corps of Engineers, Mobile District, 1980a). The U.S. Army Corps of Engineers continued the baseline water quality study of the lake and river, and Georgia Department of Natural Resources continued its hatchery, lake, and river monitoring program. Evaluation of 1979 monitoring data indicated water quality conditions similar to previous years. The hatchery was able to avoid serious trout mortality problems in 1979 by a 50 percent reduction in loadings and by recirculating water within the hatchery during periods of low flow in the Chattahoochee River since low flow periods exhibited

worse water quality. Hatchery water could only be recirculated a limited number of times, so special flow releases from Buford Dam were granted by the U.S. Army Corps of Engineers to augment critical low flow periods.

Study efforts from 1976 to 1979 contributed significantly to the definition of water quality conditions within the lake, river, and hatchery, but no consensus was reached as to the cause of the toxicity nor as to whether the river biota was adversely affected by the autumnal water quality deterioration. However, hatchery personnel were able to predict the onset of toxicity by following the decrease of oxygen in the hypolimnion of Lake Lanier and by monitoring the subsequent increase of dissolved metals in the river.

Don Mount of EPA (Duluth) proposed the basic concept for a bioassay experiment after his studies in 1977. In 1978, a technical committee from the U.S. Army Corps of Engineers, EPA, and Georgia Department of Natural Resources was formed to develop a conceptual scope of work for the experiment. The Task Force decided in mid 1979 that the experiment designed by the technical committee was the best next-step towards determining the cause of the toxicity. Time did not allow initiation of the bioassay experiment in the fall of 1979, so the task force recommended that the U.S. Army Corps of Engineers, Mobile District, perform the studies in 1980.

In May 1980, Jones, Edmunds & Associates, Inc. (JEA) was selected by U.S. Army Corps of Engineers, Mobile District, to prepare a detailed study design for a bioassay experiment to investigate the cause of trout mortality at the Buford Hatchery. The detailed study design proposal was approved in August 1980 by an Interagency Technical Review Committee (ITRC) composed of the U.S. Army Corps of Engineers, Georgia Department of Natural Resources, U.S. Fish and Wildlife Service, and EPA. JEA was notified by the U.S. Army Corps of Engineers, Mobile District, in September 1980 to proceed with the plan of study and to conduct the bioassay experiment.

1.3 THIS STUDY

Three contract documents generated during this project contained versions of the plan of study for the Lake Lanier bioassay experiment. JEA submitted a draft plan of study (DPOS) to the Interagency Task Review Committee on August 6, 1980. The DPOS proposed three sets of bioassays at the lake, one set at the hatchery, and benthic experiments and in situ bioassays in the river. The DPOS document was reviewed and discussed at a meeting of the ITRC and JEA in Atlanta on August 19, 1980. The ITRC generally concurred with the DPOS with some revisions. Benthic experiments in the river were eliminated because too extensive a study would have been required to produce useful results. Time and budget constraints eliminated Set 3 of the lake bioassays, and the hatchery set of bioassays were held in contingency. The Set 2 lake bioassays were expanded from 96-hr to 14-day tests.

The second contract document, the Final Plan of Study (POS) (U.S. Army Corps of Engineers, Mobile District, 1980b.), outlined the contracted workscope. The POS included two sets of bioassays at Lake Lanier and in situ bioassays in the Chattahoochee River. The hatchery bioassays were contingent based on completion of lake bioassays with sufficient time remaining before lake destratification to move to the hatchery.

The third document, this Final Report, describes the actual experimentation, including two major differences between the work accomplished and the work proposed. The contingency bioassays at the hatchery were not accomplished. The most significant difference is that in addition to the scheduled bioassays in the POS, five sets of static bioassays were completed which contributed further information in achieving the study objectives.

Objectives of this study were to:

1. Define the toxic constituents which have caused trout mortality at the Buford Trout Hatchery.

2. Define water quality impacts (related to the toxic constituents) on the aquatic environment of the Chattahoochee River downstream of the dam and evaluate their significance, and

3. Recommend future courses of action for evaluating potential solutions to the problems defined in Items 1 and 2.

The successful completion of all phases of this study was the result of the collective efforts of several participants. JEA developed the detailed experimental approach and plan of study and conducted the scientific experimentation. The U.S. Army Corps of Engineers, Mobile District, initiated the project, had major funding responsibility, and coordinated the collective efforts of all participants. The Georgia Department of Natural Resources (GDNR), the U.S. Fish and Wildlife Service (FWS), and EPA all served as members of the ITRC. The ITRC provided review, comment, and assistance with study design and experimental execution. In addition, the Game and Fish Division of GDNR and the FWS provided test organisms; the Environmental Protection Division of GDNR provided the majority of the required chemical analyses; and EPA provided selected tissue and metals analyses. Representatives of these agencies and JEA comprised the Project Team as follows:

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Fred Ramsey, Water Resource Engineer; Assistant Manager, Sciences Division.

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Richard Jones, Water Treatment

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Randy Schulze, Aquatic Ecology
Mary Leslie, Limnology and Aquatic Chemistry
Willy Eriksson, Chemistry
Jim Rosenbauer, Biology

Project Technicians

Ray Lewis, Aquaculture
Chris Newman, Biological Technician
Lisa Grant, Biological Technician

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Statistical Design & Analysis	Dr. James McClave	Info Tech, Inc. Gainesville, Florida
Histopathology	Dr. Norman Blake	Dept. of Marine Sci. Univ. of South Florida St. Petersburg, Florida

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Administration

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Willis Ruland, Contracting Officer's Representative
Gerry Penland, Negotiator

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Diane Findley, Project Manager

U.S. ARMY CORPS OF ENGINEERS, SOUTH ATLANTIC DIVISION

John Rushing, Chief, Environment and Resources Branch
Mary Cooper
Jim Bradley

U.S. ENVIRONMENTAL PROTECTION AGENCY

Bill Peltier, Athens, Georgia
Ron Weldon, Athens, Georgia

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Environmental Protection Division

Roy Herwig, Atlanta, Georgia
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Kerry Wilkes, Atlanta, Georgia

Game and Fish Division

Wayne McCord, Buford Hatchery
George Engel, Buford Hatchery
Russell England, Gainesville, Georgia
Rich Fatora, Lake Burton Hatchery

U.S. FISH AND WILDLIFE SERVICE

Frank Richardson, Atlanta, Georgia
Gene Braschler, Atlanta, Georgia
Don Toney, Buford Hatchery
Jim Clugston, Clemson, South Carolina

1.4 ACKNOWLEDGEMENTS

This report is based on studies sponsored by the U.S. Army Corps of Engineers, Mobile District. Mr. Emery Baya, the Project Officer through March 1981, provided valuable historical and background information, in addition to serving the vital role of coordinator of the Project Team through contracting, study design, and field studies. Dr. Diane Findley

served an important technical advisory role to Mr. Baya, and has effectively served as the Project Officer during final analyses and report writing. Mr. Gerry Penland, the project negotiator, was instrumental in accomplishing the necessary contractual details within a compressed schedule so that adequate time remained to conduct critical field studies.

Mr. Cecil B. Patterson (U.S. Army Corps of Engineers), Lake Lanier Resource Manager, and his staff provided timely and valuable logistical support that was key to the success of field operations.

Mr. Don Toney and Mr. George Engle, Buford Trout Hatchery, provided information and use of hatchery lab facilities which were important to field operations.

Mr. Sherman Stairs (U.S. Fish and Wildlife Service) sent shipments of rainbow trout swimup fry from Max Meadows Fish Hatchery (Virginia) as needed for the bioassays, and Mr. Jack Trask (U.S. Fish and Wildlife Service) provided yearling trout from Walhalla National Fish Hatchery for liver analyses.

Site visits and technical advice by Mr. Russ England, Georgia Department of Natural Resources Game and Fish Division, Gainesville, and Mr. Bill Peltier, EPA Athens, were beneficial to the project. Their advice in discussions of contingency experiments during the Set 2 bioassays is reflected in types of treatments used and in static bioassays performed.

Several people reviewed a preliminary report of this study. Their comments were appreciated:

Dr. Diane Findley	U.S. Army Corps of Engineers, Mobile District
Mr. Emery Baya	U.S. Army Corps of Engineers, Mobile District
Mr. Larry Aggus	U.S. Fish and Wildlife Service
Dr. John Grizzle	Auburn University
Dr. Raymond K. Hart	Pasat Research Assoc., Inc.
Mr. Russ England	Georgia Department of Natural Resources
Mr. Bill Peltier	EPA-Athens
Dr. Ron Raschke	EPA-Athens
Mr. Paul Frey	EPA-Athens
Dr. James P. Clugston	U.S. Fish and Wildlife Service
Mr. Don Toney	Buford Hatchery, Georgia
Dr. Joseph Norton	U.S. Army Corps of Engineers, Waterways Experiment Station (Vicksburg)
Mr. Herb De Rigo	U.S. Army Corps of Engineers, Savannah District
Mr. Dan M. Mauldin	U.S. Army Corps of Engineers, South Atlantic Division (Atlanta)

Mr. Jim Bradley and his wife Jan, Lake Lanier residents, befriended JEA project staff and provided gracious hospitality, especially during the holiday season.

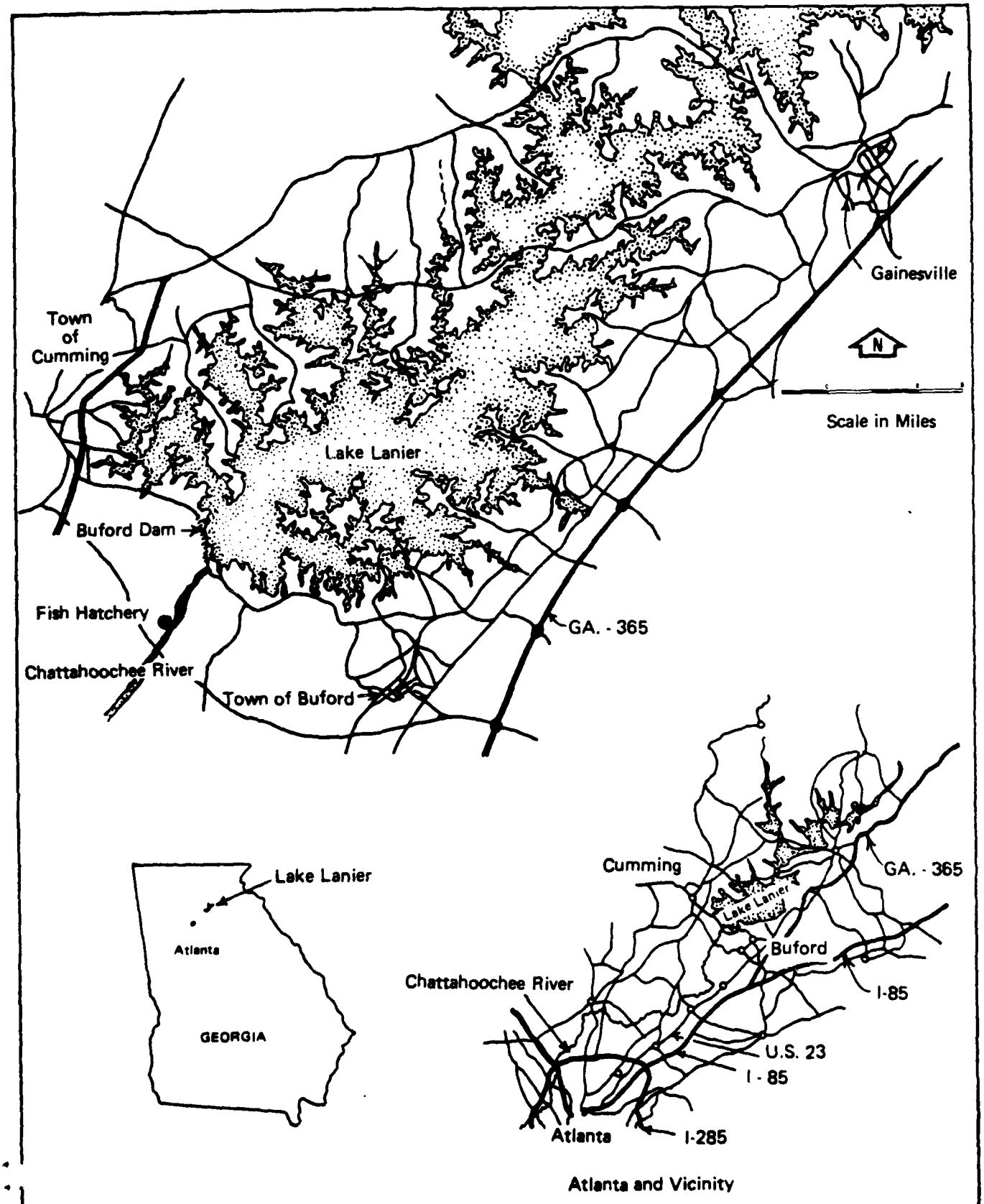


Figure 1.1. Location of Lake Sidney Lanier, Buford Dam, and Buford Trout Hatchery, Georgia

SECTION 2.0. LAKE, RIVER, AND HATCHERY SETTING

2.0 LAKE, RIVER, AND HATCHERY SETTING

Lake Sidney Lanier was formed in 1957 by the impoundment of the Chattahoochee River by Buford Dam, located 35 miles (56 km) northeast of Atlanta, Georgia. Minimum lake elevation for power generation is 1,035 feet (315 m) above sea level, and maximum flood level is 1,085 feet (331 m). Lake elevation is normally between 1,060 feet (323 m) and 1,070 feet (326 m), at which level the lake covers 38,000 acres (15,378 hectares).

Penstocks for power generation draw from 919 feet (280 m) elevation, at the bottom of the lake. Usually, only a small generator (6,000-kW) is in operation, and water released through the dam is approximately 550 cfs; this is the low flow period in the river. Two larger generators (40,000-kW) are peaking units delivering power to Georgia Power Company. Usually, these generators operate for about two hours on weekday afternoons, but occasionally the peaking units are needed during weekend afternoons or weekday mornings. During peaking, up to 9,000 cfs may flow through the dam; this is the high flow period in the river.

Buford Trout Hatchery was built in 1976 approximately 1.5 miles (2.5 km) downstream from Buford Dam. This location was chosen because, in late summer and autumn, bottom waters released from Lake Sidney Lanier are cold enough to allow trout culture when water temperatures so far south are generally too warm for trout. Unfortunately, these bottom waters are also the source of the problem at the hatchery because, in autumn, the hypolimnetic water becomes toxic to trout unless substantially diluted by epilimnetic waters.

After lake destratification (December) and until the lake once again stratifies beginning about late July, few or no chemical differences exist between high and low flow waters each day. However, in late summer and fall, as the chemical characteristics of the hypolimnion and epilimnion differ more and more, so too do low and high flow waters in the Chattahoochee River. During low flow, the deep intake for the dam draws only hypolimnetic water. During high flow, however, the volume drawn through is so great that lake stratification immediately behind the dam is temporarily disrupted (Mount et al., 1978), and Chattahoochee River water is a mix of hypolimnetic and epilimnetic waters.

Thus, in autumn, the Chattahoochee River shows not only brief, large increases in flow rate but also associated increases in temperature and dissolved oxygen (Figure 2.1). During periods of high flow, total iron (Fe_t) and manganese (Mn_t) concentrations decrease dramatically from low flow levels (Figure 2.2); lesser changes occur in other constituents.

Approximately 4,200 gpm (gallons per minute) of water is continuously drawn from the Chattahoochee River and returned to the river after flowing through the hatchery only once. In autumn, the hatchery sometimes draws water in only during high flow and recirculates it, thus avoiding intake of toxic bottom waters during low flow. However, warming of the water limits the duration of recirculation; furthermore, loading of fish in the hatchery must be less for recirculation than for once-through circulation. Recirculation is neither an adequate nor reliable solution to the hatchery problems.

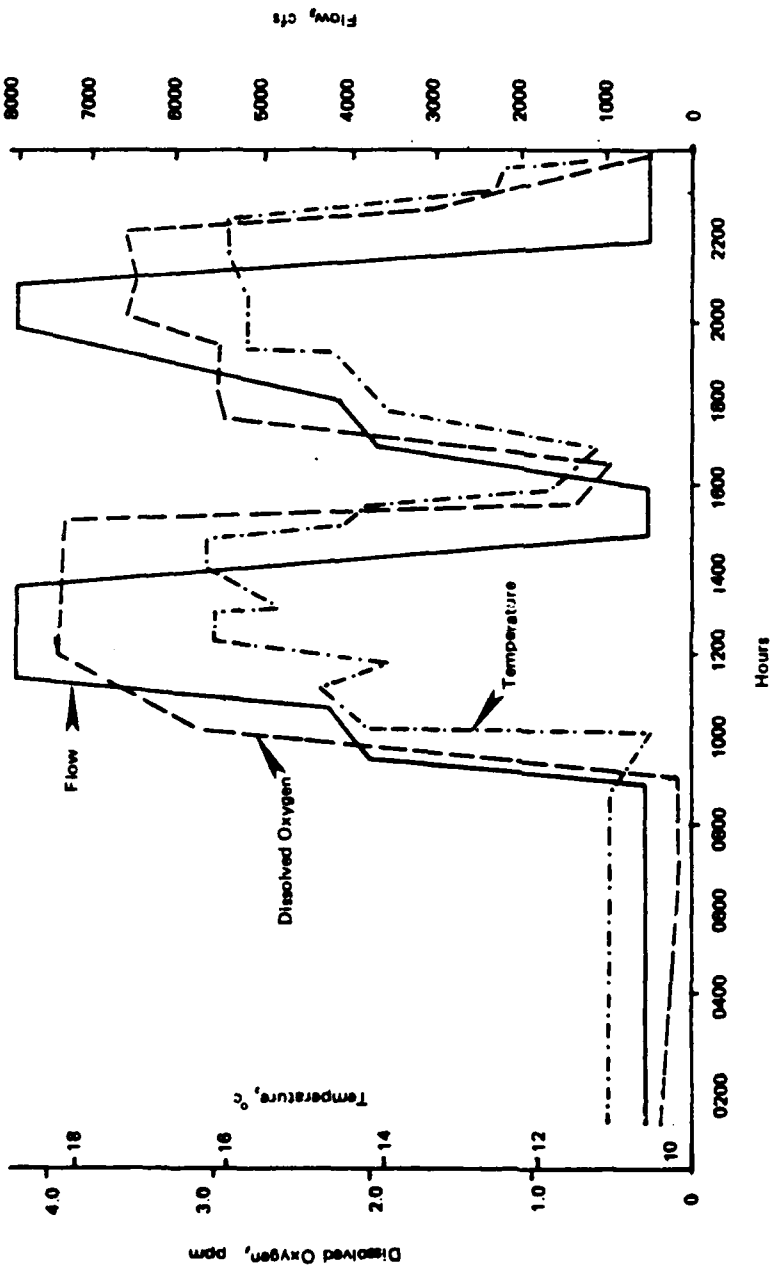


Figure 2.1. Daily Fluctuations in Flow, Dissolved Oxygen, and Temperature in the Tailrace of Buford Dam on October 29, 1972, During Stratification of Lake Lanier, Georgia
Source: Modified From Strain, 1980

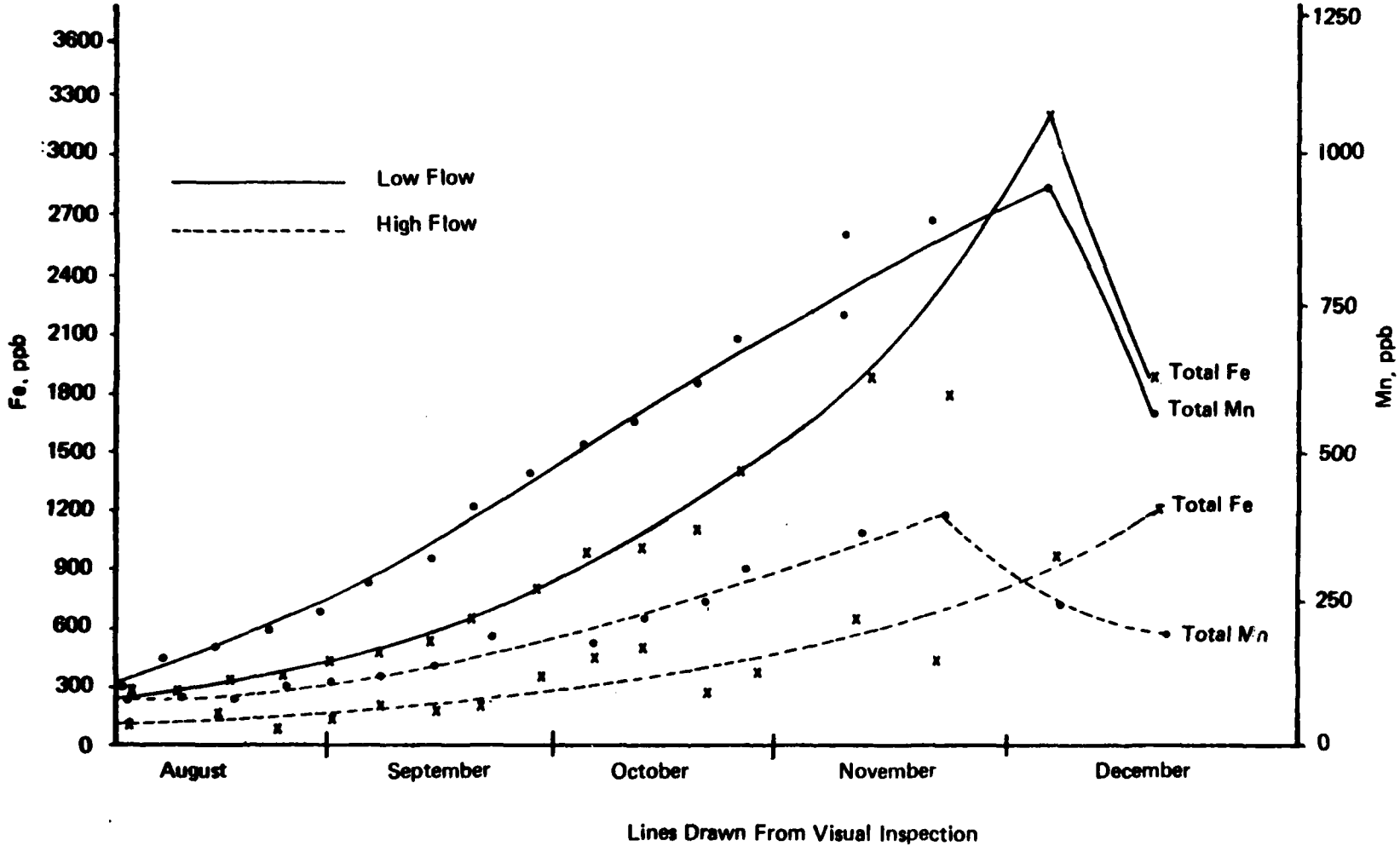


Figure 2.2. Comparison of Total Iron and Manganese Concentrations During High Flow Versus Low Flow at Tailrace of Buford Dam, Georgia, from August 3, 1977, to December 21, 1977. Lines Drawn Through Data Points Were Visually Fit To Show Trends.
Source: Data from Metrics, Inc., 1978

SECTION 3.0. HISTORY OF THE PROBLEM AT THE HATCHERY

3.0 HISTORY OF THE PROBLEM AT THE HATCHERY

In the autumn of 1976, its first year of operation, the Buford Trout Hatchery lost approximately 435,000 trout of a total of 700,000 brook, brown, and rainbow trout. Ninety percent of the fish lost were rainbow trout, which are most sensitive to metal toxicity (Affleck, 1952; Nehring and Goettl, 1974; Chapman, 1978). Fish were excitable, swam in circles before death, and showed "gill deterioration" (Noell and Oglesby, 1977). The cause of death is disputed. Declining water quality appeared to be the triggering factor, but disease and overstocking of fish may have contributed to the severity of the problem. Considerable iron floc was found in the hatchery raceways, and physical clogging of gills was believed responsible for many deaths. Mortality problems began September 12; when first measured on September 18, total Fe was 0.9 ppm and Mn 0.5 ppm in the hatchery. All surviving fish were either moved to another hatchery or stocked into streams (Noell and Oglesby, 1977).

In late October 1976, a team from the Georgia Department of Natural Resources, with the EPA, Auburn University, and the Army National Guard, used the entire fish hatchery in a large-scale experiment in which different raceways received different chemical additions to determine the effects on rainbow trout delivered from Walhalla National Fish Hatchery (Noell and Olglesby, 1977). Results (Table 3.1) showed that increasing hardness to 70 ppm mostly eliminated mortality but that a similar alkalinity increase (and some iron decrease) had a marginal effect. Tetrasodium EDTA at approximately 100 ppm also markedly decreased mortality during the 2 1/2-day experiment; fish appeared in poor condition (England, personal communication) and showed no histopathological differences from toxic controls. Most likely, mortality was somewhat delayed but would have occurred if tests had continued longer. The other treatments did not affect water chemistry measurements or fish mortality. This study also included histological examination of fish, blood hematocrits, and blood iron and manganese level determinations. The conclusion was reached that blood iron did not rise significantly in any of the series but that mortality did correspond to variations of total manganese in the blood (Oglesby et al., 1978). However, only single or duplicate determinations of blood Mn were recorded and, for some treatments, live fish were bled, while for others (those with higher Mn) dead fish were taken for bleeding. Histopathological differences in gills, livers, and trunk kidneys were found between treatments and between fish before versus after the treatments. Few fish were examined, and the exposure time was too short to expect any clear effects.

In 1977, daily mortalities went as high a 1.4 percent in November. Weekly chemical monitoring by USGS (data reported by Metrics, Inc., 1978) showed total iron (Fe_t) at the hatchery intake reached 1,700 ppb and total manganese (Mn_t), 870 ppb in November (Figure 3.1). Erratic swimming, convulsions, loss of equilibrium, tremors, rapid ventilation, and often darkened coloration were the same symptoms observed during other years (1976-1980).

In 1977 several studies related to possible water quality problems below Buford Dam were funded by U.S. Army Corps of Engineers, Mobile District. These studies included those of Gilbert and Reinert, Hess, Grizzle, Hart, and England.

Gilbert and Reinert (1979) stocked over 2,000 tagged trout into the river and followed their movement, growth, and survival by biweekly electrofishing. Larger, untagged fish collected from the river were tagged and released. Stations were approximately 0.1, 1.9, 5.2, and 11 miles (0.2, 3.1, 8.4, and 18 km, respectively) below the dam.

Ninety-two percent of recaptured fish were recaptured from the station where they had been tagged. Although results varied between stations, generally a continual decrease in catch-per-unit-effort from August through December (1977) seemed to occur. The majority of recaptured rainbow and brook trout had lost weight, but most brown trout and all yellow perch had gained weight.

During 5 months of electrofishing, a total of 27 species of fish were collected from 4 stations. This was considered a depauperate fauna. Yellow perch were most abundant, and the three species of stocked trout ranked second, third, and fourth in abundance. Centrarchids (sunfish) were most diverse with 11 species and hybrids.

Artificial substrates were placed at the same 4 river stations to assess abundance of prey items for fish. The lack of replicates and the lack of any clear trend downstream make it difficult to draw any conclusions based on these samples. Total numbers ranged from 6,386 benthic macroinvertebrates (39 taxa) at the station furthest from the dam (11 miles) to 185 (15 taxa) at the next station upstream (5.2 miles from the dam).

Concurrent with the above study by Gilbert and Reinert (1979), Hess (1978) electrofished 390 fish representing 21 species approximately 6 miles (10 km) downstream from Gilbert and Reinert's furthest downstream station but found no evidence of tagged fish moving downstream.

Grizzle (1981) histopathologically examined fish from the Chattahoochee River immediately below the dam. In 1977, he noted increases in the numbers of lesions soon after an increase in iron and manganese levels and, in 1978, a continual increase in lesions throughout the study period (August through December). No consistent differences were noted between fish taken immediately below the dam and near the hatchery (1.5 miles below the dam), but immediately below the dam, rainbow trout were more affected than brook trout or yellow perch. Edema and aneurysms in the gill lamellae, fatty change in the liver, congestion of the spleen, and vacuolization of the kidney- tubule epithelium were similarly common in yellow perch and the trout species, while the gill lamellar hypertrophy common in trout was observed only once in yellow perch in 1978. Such lesions could be due to low dissolved oxygen; however, they also occurred at a station where dissolved oxygen was near or over 5 ppm.

Hart (1979) used energy dispersive x-ray analysis to examine gills of fish collected immediately below the dam and 1.5 miles (2.5 km)

further downstream. He found that the iron content of lamellae increased with iron content of the water for rainbow trout, but not for yellow perch.

Grizzle (1981) also performed metals analyses on the livers of fish taken from the Chattahoochee River shortly below Buford Dam in 1978. Average levels found in ppm dry weight were:

	Cd	Cu	Fe	Mn	Zn
Rainbow Trout	1.1	416	821	30	137
Brown Trout	3.4	610	580	27	96
Brook Trout	1.7	162	585	15	177
Yellow Perch	2.5	8.7	1,405	23	96

Because manganese toxicity had been suggested as the problem at Buford Trout Hatchery, England (1978) performed manganese ($MnCl_2.4H_2O$) bioassays at Lake Burton Trout Hatchery where pH (6.2) and hardness (2 ppm) are comparably low but where no toxicity problems have occurred. The 96-hour LC_{50} for yearling rainbow trout was 24.7 ppm manganese and was estimated for brook and brown trout as considerably higher, thus suggesting that the far lower Mn levels (up to 1 ppm) at the Buford Hatchery should not be a problem.

Also during the fall of 1977, EPA (Mount et al., 1978) studied the toxicity problem at the hatchery. Hatchery rainbow trout exposed several weeks to low flow waters showed no consistent pattern of necrosis in the kidney, liver, or gill. The most consistent finding was dilation of the terminal vessels of the lamellae, with clavate-glovate lamellae congested with hemorrhagic exudate, blood, and/or inflammatory cells. Some hepatic necrosis, and decrease in liver glycogen and in pancreatic zymogen granules also were observed in some distressed rainbow trout, but kidney tissue appeared normal.

Gas chromatographic-mass spectrometric (GC-MS) analyses of river water found no organics detectable at one ppb; even when organics were concentrated 550 X by an extraction process, no consistent effect on Daphnia could be demonstrated. Examination of all information aroused no suspicion of any toxicant from municipal or industrial discharges nor from any non-point source. No abnormal levels of chlorinated hydrocarbons were found in kidneys or livers nor did rigorous GC-MS analysis of 100 grams of muscle tissue detect hydrocarbon contamination (Mount et al., 1978).

Single water samples at Gwinnet County and City of Atlanta water works and in Lake Sidney Lanier, but not at the hatchery, showed potentially toxic levels of copper. Livers of rainbow trout from the hatchery and from the adjacent Chattahoochee River contained 230-510 ppm copper (dry weight). These copper levels were considered to be high and to indicate exposure of the trout to toxic levels of copper; however, no comparative data for copper levels in known unexposed rainbow trout were presented to justify this conclusion of Mount et al. (1978). Further analyses were performed in 1978 with similar results but still without any controls (U.S. Environmental Protection Agency, 1979).

In 1978 the hatchery used recirculation, supplemental aeration, and hydrogen peroxide in efforts to limit mortalities. Mortality rates (Figure 3.2) were lower than in the two previous years until late November when they reached 0.6 percent per day. Few measurements of Fe and Mn are available for 1978, but levels were apparently lower than for 1976 and 1977, with Fe_t reaching only about 1,200 ppb and Mn_t about 700 ppb.

In 1978, Grizzle continued histopathological examination of fish from the Chattahoochee River. This study, initiated in 1977, is discussed earlier in this section. U.S. Army Corps of Engineers, Mobile District, also contracted for chemical and biological studies of Lake Sidney Lanier; this work included occasional chemical sampling at four stations in the Chattahoochee River between Buford Dam and McGinnis Bridge (Environmental Science and Engineering, Inc., 1981; data presented in Figure 3.2).

In 1979, the hatchery was able to limit mortalities effectively by recirculating water drawn in only during high flow. This was possible because U.S. Army Corps of Engineers made special releases from Buford Dam for this purpose on weekends. Mortalities and iron and manganese levels are graphed in Figure 3.3. The only high mortality began two days after low flow water (2,300 ppb Fe_t) was drawn on November 21. Unfortunately, manganese measurements had been discontinued, but a few days prior to low flow intake levels in the river at low flow had been approximately 600 ppb Mn_t and 2,400 ppb Fe_t.

In 1980, trout losses were limited by recirculation of high flow water and by stocking mostly brook trout, which are more resistant to metals than rainbow trout. In spite of these measures and metals concentrations lower than in 1979 (Figure 3.4), some losses were sustained, and trout showed such excitability that feeding had to be discontinued for several days. A mortality increase predicted from elevated iron levels did not occur, possibly because manganese did not show the usual concommitant rise. Later, when manganese concentration did increase, mortalities also increased (Don Toney and George Engle, personal communications).

Note:

Table 3.1 and Figure 3.4 present data for ferrous iron (Fe^{++}). Figure 3.4 also refers to Fe^{++} as dissolved iron. It may not be completely accurate to assume all dissolved iron measured is ferrous iron, or conversely, that all ferrous iron is dissolved. However, in general, most of the ferrous iron will be measured in the dissolved fraction. Throughout this report, for discussion purposes, ferrous iron (Fe^{++}) and dissolved iron (Fe_d) are used interchangeably. Where iron additions were made to test waters in this study, additions were made as ferrous iron and are reported as Fe^{++}. Where test waters were analyzed for iron content, concentrations are reported as dissolved iron (Fe_d) and/or total iron (Fe_t).

Table 3.1. Summary of Data from the 1976 Buford Trout Hatchery Experiments Reported by Noell and Oglesby, 1977

Treatment	Mean Mortality RBT	Fe^{++} (ppm)	Fe_t (ppm)	pH	Alk (ppm)	Hardness (ppm)
Control	50.17 %	2.28	2.88	6.71	18.30	11.50
$CaSO_4$ & $MgSO_4$	1.43%**	2.22	2.81	6.81	18.54	70.00
Na_4 EDTA 100ppm	2.96%**	0.16	2.96	7.10	27.56	5.00
$NaHCO_3$ & Na_2CO_3	38.29%*	0.76	2.95	7.48	86.27	11.59
$Ca(OH)_2$	48.09%n.s.	1.97	2.89	6.79	18.73	12.89
O_3	53.76%n.s.	2.30	2.92	6.70	17.50	11.50

Notes:

* Significantly different from control ($p = 0.05$) one-tail test.
** Significantly different from control ($p = 0.01$).
n.s. = Not significantly different from control, two-tail test ($p = 0.05$).
RBT = Rainbow trout.
Alk = Alkalinity
Fe^{++} = Ferrous Iron
Fe_t = Total Iron

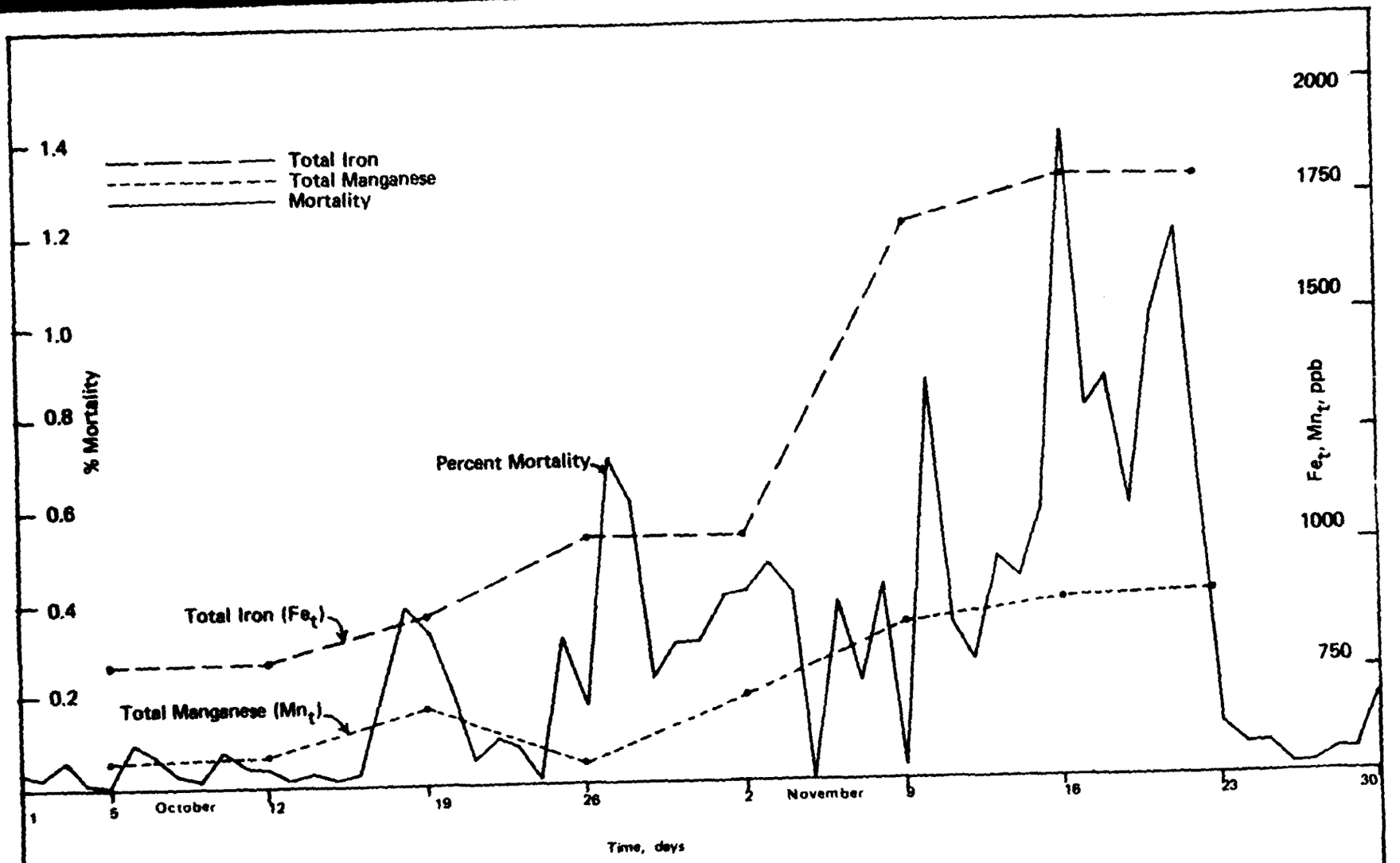


Figure 3.1. Rainbow Trout Mortality, Total Manganese and Total Iron Levels for Buford Trout Hatchery, Georgia in October and November 1977

Metal Data for Wet Well at Hatchery from Metrics, Inc., 1978; Mortality Data from Unpublished Handout at Meeting of the Task Force on Water Quality Problems Below Buford Dam, December 13, 1978

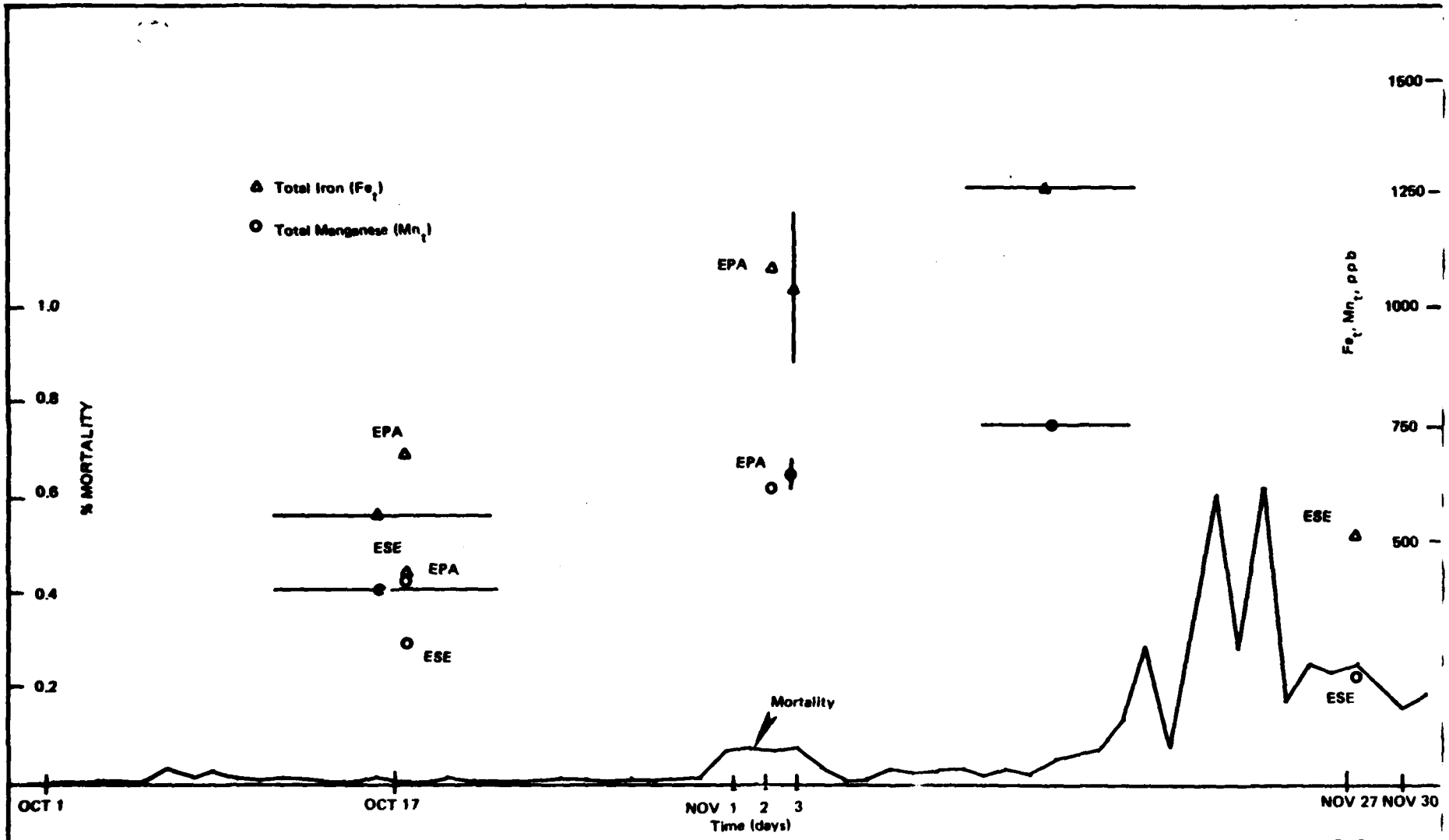


Figure 3.2. Rainbow Trout Mortality, Total Iron and Total Manganese at Buford Trout Hatchery, Georgia, October and November 1978

Fe and Mn Data Sources: ESE 1981 October 17 and November 27 Only,for Chattahoochee River; EPA, 1979, October 17 and November 2 for Chattahoochee River and November 3 Ranges (Vertical Bars) for Hatchery Raceways; Grizzle, 1981, Single Undated Values for Each Month (Horizontal Bars); Mortality Data from Unpublished Handout at Meeting of the Task Force on Water Quality Problems Below Buford Dam, December 13, 1978.

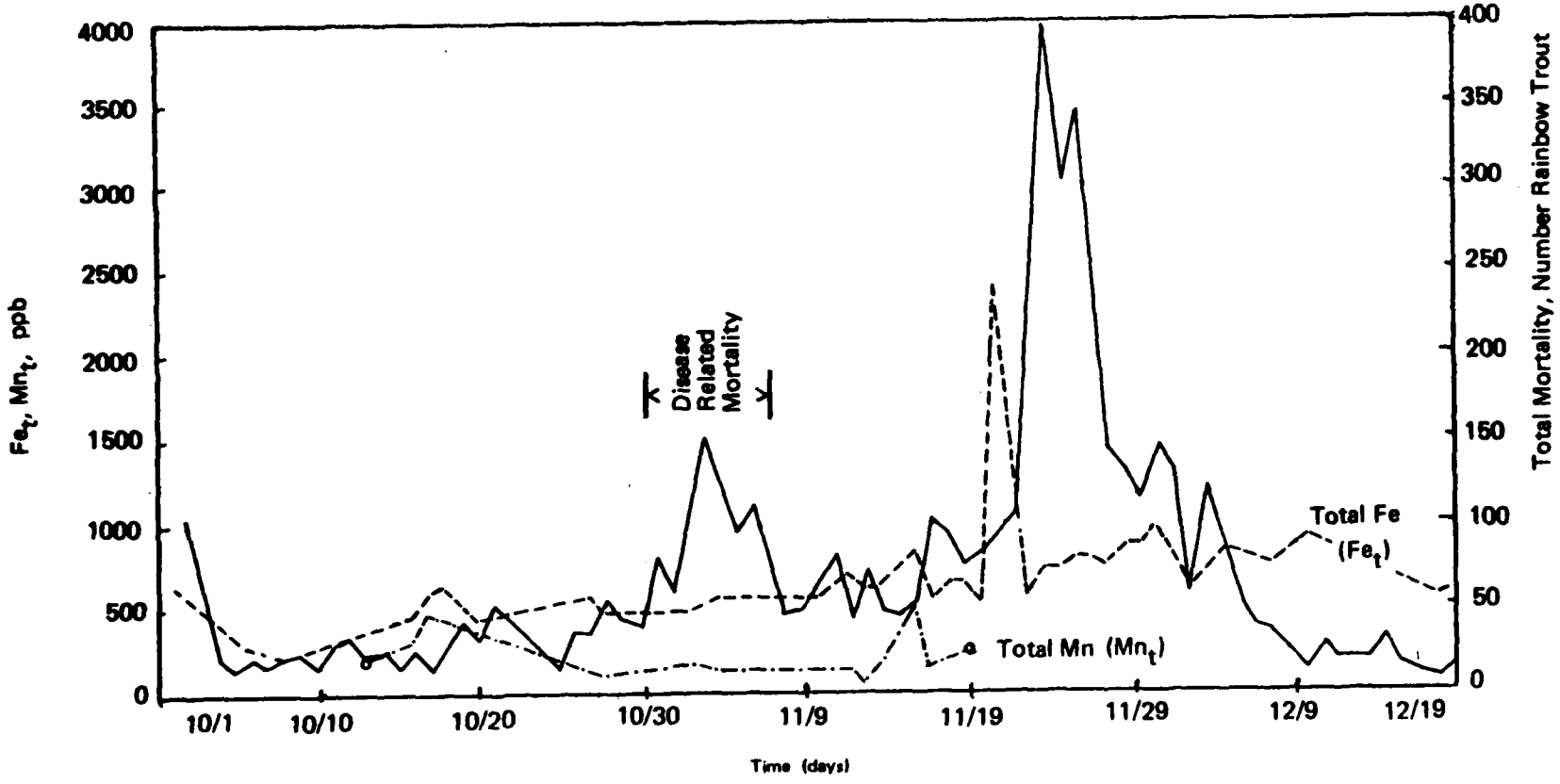
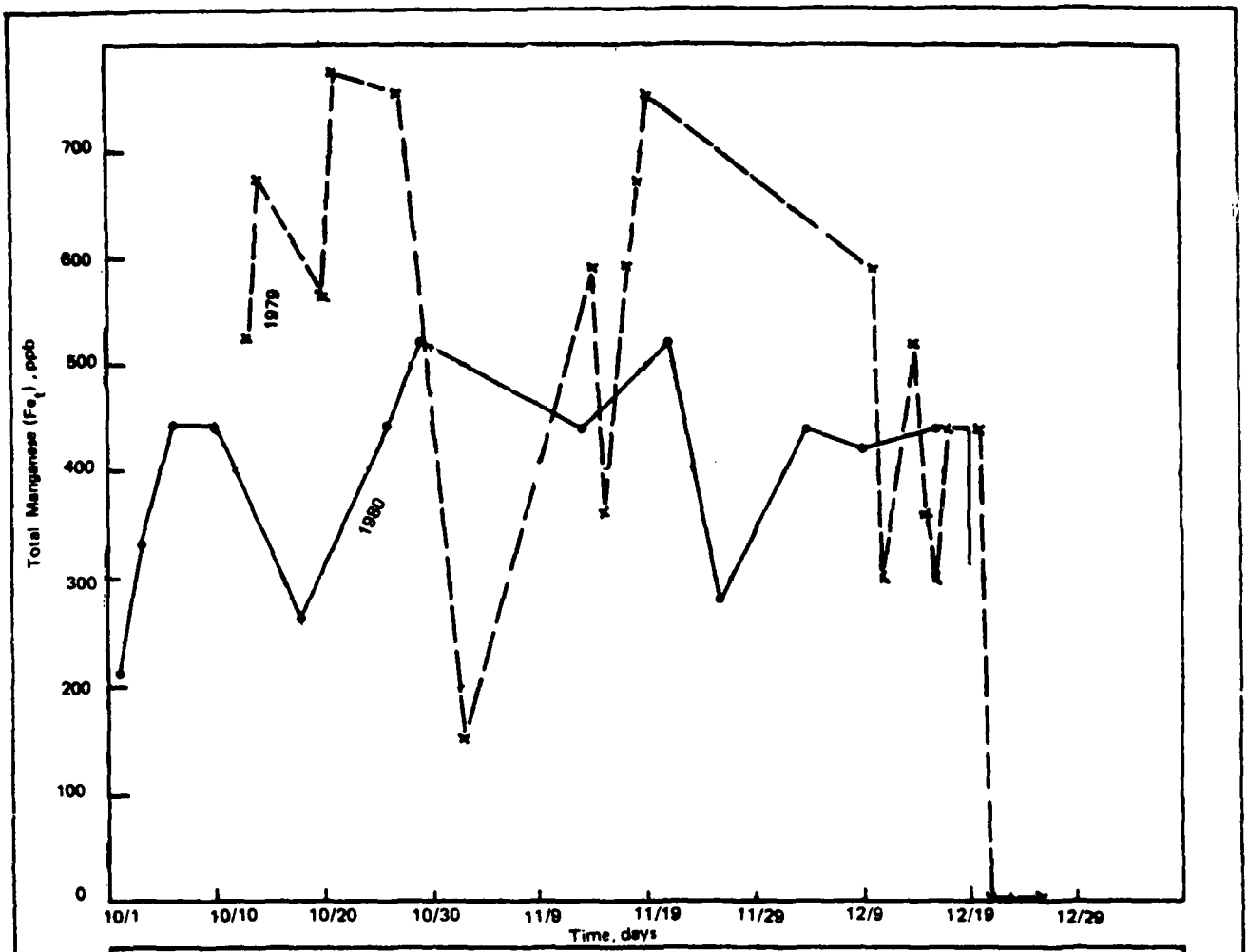


Figure 3.3. Daily Manganese, Iron and Mortality Levels for Buford Trout Hatchery, Georgia, from October 20, 1979 to November 21, 1979

Water Drawn In Only During High Flow and Recirculated During Low Flow



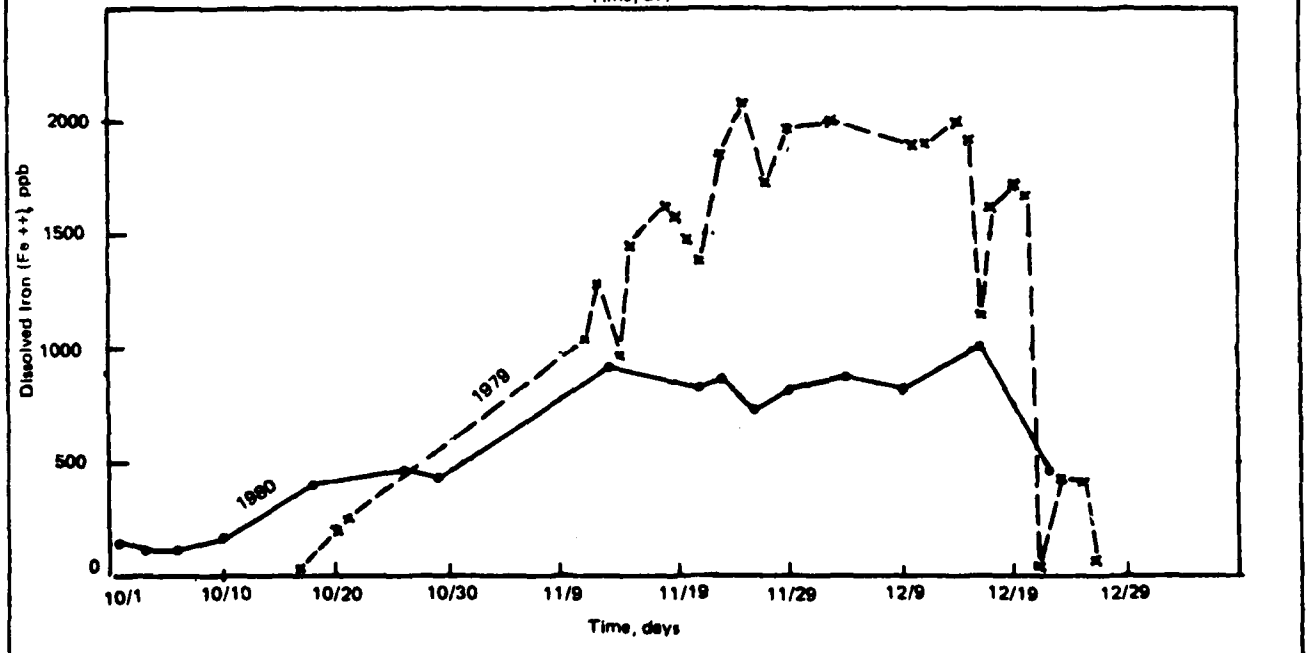


Figure 3.4. Total Manganese and Dissolved Iron (Fe++) in the Chattahoochee River, Georgia, at Buford Hatchery Intake, Fall 1979 and 1980
(Data Courtesy of Don Toney)

SECTION 4.0. MATERIALS AND METHODS

4.0 MATERIALS AND METHODS

4.1 INTRODUCTION

The Interagency Task Force recommended use of several bioassay treatments for the current study, each removing a different potentially toxic agent from water of demonstrated toxicity. Where toxicity was reduced, the removed substance would be identified as toxic.

To avoid the complications of frequent toxicity fluctuations in river water at the hatchery and to provide test water of relatively constant composition and toxicity during individual experiments, water was drawn from Lake Sidney Lanier immediately behind Buford Dam (Figure 4.1).

A fenced bioassay compound (Figure 4.2) was established directly on top of Buford Dam. The compound was staffed by JEA personnel 24 hours a day for the duration of the project. The compound consisted of a mobile bioassay laboratory, water and fish holding facilities, a utility shed, and a small Winnebago trailer which provided office space and accommodations for personnel on duty.

The mobile bioassay laboratory was modified and equipped for this project. The lab was divided into two operational sections. The rear section served as the bioassay laboratory, requiring additional insulation, temperature control equipment, and aquarium racks with fluorescent lighting. The front section served as a support laboratory for handling chemical samples and monitoring equipment.

As an experimental expedient, rainbow trout swim-up fry were used rather than the larger fingerling trout normally received into the hatchery. Fry were chosen both because of their smaller size and consequently lesser space requirements and because of their greater sensitivity to metals (U.S. EPA, 1980), the class of toxic agents most strongly implicated by previous evidence from the hatchery. Two sets of experiments were conducted, each with more than one run. Set I determined the toxicity of untreated waters from four different depths 20, 76, 95, and 115 feet (6, 23, 29, and 35 meters) in the reservoir 600 feet (180 m) behind Buford Dam. The objectives were to choose the most toxic water for use in Set II bioassays and to attempt to correlate toxicity with chemical composition of the waters. In Set II, which was run four times with variations, water from the reservoir depth found most toxic in Set I was treated in various ways to attempt to remove the toxic factor. Designs for Set I and Set II experiments are compared in Table 4.1.

Initially, a third set was to be conducted at the hatchery to verify conclusions based on Sets I and II. However, due to the limited time between project initiation and the cessation of toxicity when the reservoir destratified, this set was not performed.

4.2 WATER MOVEMENT AND FLOWS

To facilitate retrieval of hypolimnetic lake water, the U.S. Army Corps of Engineers anchored a buoy 600 feet (180 meters) off-shore upstream of the dam (Figure 4.3). JEA personnel attached a submersible pump (STA-RITE 10-cm, 60-hertz, 2-horsepower, 2.5 liters per second) to the buoy in a manner that allowed raising or lowering the pump to any desired depth. An identical pump was suspended over the side of the dam 20 feet (6 meters) below the water surface to provide a continuous supply of non-toxic epilimnetic water for controls and for holding and acclimating fish prior to testing. Water from both sources was conveyed through 2-inch (5-cm) diameter linear polyethylene pipe (Driscopipe 8600).

Warmer, epilimnetic water was cooled by passage through a kam carbon steel heat exchanger (6 inches x 7 feet), using hypolimnetic water as a coolant.

Water sufficient for Set I bioassays was pumped from four depths prior to the bioassay and stored in separate 250-gallon (950-liter) linear polyethylene (LPE) tanks. To prevent temperature fluctuations, these tanks were held in two aboveground swimming pools, measuring 12 feet (3.5 meters) in diameter, through which cool hypolimnetic water was continuously circulated. Eighty-gallon (300-liter) LPE fish holding tanks were also kept in these swimming pool water baths.

To prevent aeration during storage of the hypolimnetic water composited for the Set I bioassays, a special system was designed to maintain a nitrogen atmosphere within the void space of the tanks during storage and pump-out.

The water source for the Set I experiments and all epilimnetic controls was the 250-gallon (950-liter) tanks outside the bioassay trailer. For the first three runs of Set II experiments, hypolimnetic water was pumped directly from the bottom of the lake into a 30-gallon (110-liter) header tank inside the trailer. Because turnover of the reservoir appeared imminent, all water for Set II Run 4 was drawn prior to the experiment and stored under nitrogen atmosphere in a 3,000-gallon (11,500-liter) iron tank.

For both Set I and Set II experiments, water movements into the experiments were controlled by timers on a 10-minute cycle (Figure 4.4). A separate pump filled a volume setting chamber for each treatment. After the first pump was off long enough for all excess water to overflow and for water to be aerated, a second pump transferred water to a specially designed plexiglass splitter which divided the single inflow into 8 equal outflows to 8 replicate aquaria (see Figure 4.4). Average flow to each aquarium was 230 milliliters/10 minutes, which provided one replacement of the 4-liter standing volume approximately every three hours. Each volume setter was equipped with an air stone which provided the only aeration for most treatments. Timers activated the air pumps for approximately 4 minutes during each 10-minute cycle. This aeration also provided mixing for hardness or EDTA additions.

4.3 TREATMENTS AND TREATMENT MATERIALS

The various treatments provided in the Set II flow-through bioassays are summarized in Table 4.2. Essentially, these treatments were accomplished by adding resin columns, granular activated carbon columns, or prolonged aeration before the volume setters; by adding chemicals (EDTA, hardness) via Dias Model BX55 peristaltic pumps to water in the volume setters; by adding filtration (Teel filter holders and 5-μm cellulose cartridges) either before or immediately following the volume setters; or by combinations of the above (see Figure 4.5).

Anion exchange resin (Dowex 11), cation exchange resin (Dowex HCR-S), and activated carbon were individually packed in well-leached 1-meter (3.3-foot) lengths of 15-centimeter (6-inch) diameter PVC pipe with tightly fitting PVC caps; all tubing used in bioassay equipment and treatment apparati was Silastic® silicon tubing.

4.4 FISH USED IN BIOASSAYS

All fish tested in the static and flow-through bioassays were rainbow trout swim-up fry from the U.S. National Fish Hatchery at Max Meadow, Virginia, provided to JEA by the U.S. Fish and Wildlife Service upon request. Fry were approximately 2 to 3 centimeters (approximately one inch) in length and varied from 0.117 to 0.44 grams average weight.

Fry were packed with ice in Styrofoam® coolers and shipped by bus (14-hour trip). When received, the unopened plastic bag was placed in a holding tank with cooled, flowing, epilimnetic water to allow gradual warming over 4 to 6 hours. Fry were then released into the holding tanks and fed. Mortalities during shipping and holding were extremely few when fry shipments were received promptly. Fry were held at least two days before being used in bioassays. During holding and acclimation, fry were fed trout chow provided by Buford Hatchery 4 times during daylight hours. During the bioassays, fry were fed sparingly twice daily. No disease treatment was needed; handling was minimized.

4.5 RIVERINE BIOASSAYS

The object of the riverine bioassays was to document fish mortality in the river and to determine the extent of toxic effects downstream. Two species of fish were used, rainbow trout (Salmo gairdneri) and bluegill (Lepomis macrochirus), both of which are found in the river. The in situ bioassays were run concurrently with Set II laboratory bioassays, thus facilitating a comparison between the riverine and laboratory bioassays.

Swim-up fry and 15-centimeter (6-inch) rainbow trout were used in the riverine bioassay. Swim-up fry were also intended for use in histological examinations, but they were not examined because histological effects were not observed in the laboratory bioassays.

The in situ bioassays were conducted simultaneously at six sites in the Chattahoochee River (Figure 4.6). The six sites were the tailrace of the dam (300 meters downstream of Buford Dam), the sluice channel at the dam (immediately below Buford Dam), in the river near the water

intake to the trout hatchery (2.5 km downstream of Buford Dam), Settle's Bridge (7.5 km downstream of Buford Dam), McGinnis Bridge (also known as Little's Ferry Bridge) (13.6 km downstream of Buford Dam), and Abbotts Bridge (22 km downstream of Buford Dam). In addition, cages were placed in the first raceway at the trout hatchery, and a control was held in cooled epilimnetic water at the bioassay facility at the dam (Figure 4.6).

The first set of 96-hour bioassays was conducted November 22 through 26, 1980, and the second set on February 5 through 9, 1981, after the lake had destratified.

At each of the eight sites, fish were placed in a 15-chamber holding cage (Figure 4.7) and the 96-hour tests run. The test chambers were tethered to a stable post in the river and weighted by an attached cement bag. After securing the cages in the river, a 2-day leaching period was allowed before fish were introduced. Each cage contained three chambers with ten large trout each, eight replicates of ten swim-up fry each, and three chambers with ten bluegills each.

Dissolved oxygen, temperature, pH, and conductivity were measured in the field on a daily basis during the 96-hour in situ bioassays. Total and dissolved iron and manganese were determined on one mid-low flow and one mid-high flow sample for three consecutive days at the hatchery intake and at McGinnis Bridge. Samples for dissolved metal analyses were filtered immediately in the field using a 0.1-micron Nucleopore membrane filter and then acidified. All metals samples were stored in polyethylene bottles.

4.6 METHODS FOR ROUTINE CHEMICAL MONITORING

Samples for chemical analyses were all composites of six equal aliquots taken 4 hours apart. Samples were taken during the beginning, middle, and final 24-hour periods for Set I runs and daily for Set II runs. Volumes for the separate samples in each set were 900 milliliters for total metals and hardness (pH < 2 by HNO_3 addition), 120 milliliters for dissolved metals (0.1 µm filter, pH < 2), 1,800 milliliters for chlorinated hydrocarbons (Set I only), 240 milliliters for ammonia and total organic carbon (pH < 2 with H_2SO_4), and 1,800 milliliters for alkalinity, color, and total dissolved and suspended solids. Samples for chlorinated hydrocarbons were stored in glass containers; all other samples were stored in LPE bottles.

Water samples were taken either from the volume setters or from the splitters by siphoning water into graduated cylinders. For filtered samples, water was drawn into a 50-milliliter plastic syringe and then forced through an 0.1-µm Nucleopore polycarbonate filter (47-millimeter diameter) held in a syringe filter holder. To prevent cross-contamination between treatments, a separate siphon, graduated cylinder, syringe, and filter holder were used for each treatment.

Samples were analyzed according to methods referenced in Table 4.3.

4.7 METHODS FOR OTHER MONITORING

Routine measurements of dissolved oxygen (DO), pH, conductivity, and temperature were taken in three replicate aquaria for each treatment every four hours for the duration of each experiment, up to 120 hours (see Appendix B). DO measurements were made with Yellow Springs Instrument Company, Model 57 portable DO meters and conductivity with a YSI Model 33 SCT meter. For pH measurements, VWR mini pH meters with digital readout were used; consistent problems with drift during readings occurred, with poor repeatability of readings. pH probes were later found to have a short life and to give erratic and low readings (up to 0.5 pH units) as they failed. Because the meters continued to calibrate, not giving a clear beginning for gradual failure, no corrections were made for any pH values. Weston Model 2284 Mirroband stainless steel dial thermometers accurate to $\pm$ 0.5°C were used for temperature measurements.

DO meters were air calibrated before each set of readings, and calibration was checked at least once during and at the end of a series of readings. At the same intervals, the pH meter was calibrated using pH 7.0 and 4.0 buffers.

Fish counts and removal of mortalities were performed every 8 hours. Early in the tests, mortalities were removed more frequently, but this often caused great distress to the commonly excitable survivors and was discontinued.

4.8 SPECIAL CHEMICAL SAMPLES

Supplemental to the routine chemical monitoring of the bioassay treatments, several kinds of special samples were taken once or a few times each. Hydrogen sulfide samples from the 250-gallon (950-liter) LPE tanks (Set I), from the header tank in the laboratory (Set II) and from a Kemmerer grab sample from the bottom of the lake were carefully siphoned into the bottom of one-liter glass jars. Approximatley one quart (one full volume) was allowed to overflow. Four millliliters of 2N zinc acetate were immediately added, followed by addition of 6N NaOH and the completely filled bottle was carefully sealed so as to trap a minimum of air.

Samples for volatile organic carbon (VOC) analyses were taken from the volume setters (Set I only) before aeration. Solvent-rinsed, thoroughly dried (300°C), septum top, glass vials supplied by Georgia EPD were filled and sealed underwater so that no air bubbles were trapped in the vials.

During Set II, samples were taken simultaneously from the header tank in the laboratory and by Kemmerer grab from the bottom of the lake adjacent to the pump which filled the header tank. Samples were analyzed for total and dissolved iron and manganese, sulfides, TOC, and alkalinity.

Two 2-quart glass jars of hypolimnetic water taken from the 3,000-gallon (11,500-liter) storage tank, and placed in cold, dark storage,

were subsequently analyzed for humic substances by high pressure liquid chromatography (HPLC).

4.9 TISSUE ANALYSIS

Identical rainbow trout liver samples were taken at Buford Trout Hatchery and at Walhalla National Fish Hatchery, where trout of the same age and strain and originating from the same hatchery were available. At each hatchery, livers were taken from thirty 20-centimeter rainbow trout and pooled into 10 separately analyzed samples of 3 livers each. Samples were frozen and delivered to EPA Athens laboratory where they were analyzed.

4.10 HISTOPATHOLOGY

At the end of each bioassay run, two fry from each replicate (total 16 fish per treatment) were fixed in Dietrich's solution and sent to Dr. Norman Blake (University of South Florida Marine Science, St. Petersburg, Florida) for histopathological examination.

In Dr. Blake's laboratory, trout were cut longitudinally so as to expose most of the internal organs. Each half was placed in a casette and washed overnight in flowing tap water. The fish were then processed on an Autotechnicon through a series of S-29, UC-670, and Paraplast. Each fish was embedded in Paraplast in such a way that sections could be made through the internal organs as well as through the eye, epithelial tissues, and musculature. The tissue blocks were cut at 6 µm and the resulting sections were routinely stained with Harris- hematoxylin. Slides were examined and interpreted by Dr. Blake and selected slides sent to Dr. Paul Yevitch (EPA Narragansett) for confirmation of interpretations.

4.11 STATISTICAL HANDLING OF DATA

In the statistical analyses of bioassay results, each time period was analyzed separately rather than together because for each replicate survival at one time is highly dependent upon survival at preceding times. The arc sine square root transform of proportion survival was used to obtain more stable variability than untransformed proportion survival (Mendenhall, 1968).

Analyses of variance (ANOVA) were conducted to compare stations (riverine) or treatments (laboratory) for each 24 hours. When ANOVA showed differences between stations or treatments, a Duncan's multiple comparison was employed to compare and rank the individual station or treatment means. Eight replicates made the experiments so sensitive that even seemingly small differences may be statistically significant. In riverine experiments, the station-age interaction in ANOVA was significant; therefore, fry and yearling tests were analyzed separately. For laboratory experiments, the run-treatment interactions were significant usually for Set I and always for Set II, so treatment comparisons were made only within runs.

For each set of experiments, mean survival (transformed) for all treatments was regressed against dissolved iron (Fe_d), total iron (Fe_t), and total manganese (Mn_t), and hardness measured in the treatments. Experiments were not designed specifically for this type of treatment, and regressions can provide no more than suggestions of potential causality.

Comparisons of metal contents of trout livers simply used a student's t-test.

4.12 ANALYTICAL QUALITY CONTROL

The bulk of the samples was analyzed by the Georgia Environmental Protection Division laboratory, Atlanta; additional QA/QC samples were analyzed by JEA's laboratory, Micro Methods, in Pascagoula, Mississippi.

Quality assurance and quality control (QA/QC) duplicates, spikes, and blanks were included with each set of chemical samples. For one treatment chosen randomly, two additional sets of samples were taken to send Georgia EPD triplicates for all but total metal samples. For total metals, duplicates were sent and the third sample was spiked at known levels of some or all of the metals to be analyzed. For a second treatment, also randomly chosen, two additional sets of samples were taken for analysis by JEA's laboratory; one of these total metals samples was spiked. A dissolved metals blank, prepared by filtering an aliquot of doubly de-ionized water each time one of the six aliquots was taken, was included with each set of samples for Georgia EPD.

Spiked samples were prepared using certified standards from Fisher Scientific and from Environmental Research Associates; the latter was provided by the U.S. EPA, Athens, Georgia.

To assure that spike values would fall within acceptable limits, 500 ug/l Fe or Mn was added. Total metals samples were spiked with 50 ml of 10-ug/l stock solution and brought to one liter total volume. For dissolved metals, 5 ml of stock solution spiked 100 ml total final volume.

All glassware used to prepare spiked samples and all sample containers were washed with soap (Alconox), thoroughly rinsed with de-ionized water, and, if appropriate, finally rinsed in a 10 percent nitric acid (reagent grade) solution.

Table 4.1. Summary Comparison of Set I and Set II Flow-Through Bioassay Experiments Performed at Lake Sidney Lanier, Georgia, Fall 1980

	Set I	Set II
Date of runs	1. Oct. 28 - Nov. 2 2. Nov. 7 - Nov. 10	1. Nov. 21 - Nov. 23 2. Nov. 23 - Nov. 24 3. Dec. 4 - Dec. 8 4. Dec. 19 - Dec. 23
Types of water treatments	none, water type varied with reservoir depth	several, to remove specific potential poisons or to add EDTA or hardness (see Table 4.2)
Hypolimnetic depths drawn from	23 m (76 ft), 29 m (95 ft), 35 m (115 ft)	35 m (115 ft)
Non-toxic control	cooled epilimnetic water from 6-m (20 ft) depth	same as Set I
Schedule for drawing water	drawn prior to bioassay and stored under N_2	drawn continuously from reservoir
Treatments each run	4	5 to 8
Replicates per treatment	8	8
Rainbow trout fry per replicate	20	20
Frequency of physical monitoring	every 4 hours	every 4 hours
Chemical parameter monitoring	intensive, including several metals, H_2S, organics, pesticides, PCB's (see Appendix A)	narrowed by elimination of numerous substances not detected in Set I
Times of chemical sampling	24 hr., 60 hr., 96 hr.	24 hr., 48 hr., 72 hr., 96 hr.
Method of chemical sampling	each sample sum of aliquots every 4 hr. for previous 24 hr.	same as Set I

Table 4.2. Summary of Treatments for Flow-Through Bioassay Experiments Performed at Lake Sidney Lanier, Georgia, Fall 1980

Set I Run 1, October 28 through November 2
and Set I Run 2, November 7 through 10

A Epilimnetic water from 6-meter (20-foot) water depth, pump suspended from Buford Dam

B Hypolimnetic water from 23-meter (75-foot) water depth, 180 meters (600 feet) behind Buford Dam

C Hypolimnetic water from 29-meter (95 foot) water depth, 180 meters (600 feet) behind Buford Dam

D Hypolimnetic water from 35-meter (115-foot) water depth, 180 meters (600 feet) behind Buford Dam

A, B, C, and D - all water for the run was drawn just before the experiment and stored in 950-liter (250-gallon) LPE tanks.

Set II

General: All epilimnetic water was drawn by a pump suspended at 6-meter (20-foot) water depth off Buford Dam. Water was stored briefly in a 950-liter (250-gallon) LPE tank before use in experiments.

All hypolimnetic water was drawn by a pump suspended at 35-meter (115-foot) water depth about 180 meters (600 feet) behind Buford Dam. For Runs 1, 2, and 3, water flowed continuously into a 110-liter (30-gallon) header tank in the laboratory. For Run 4, all water was drawn before the experiment and stored under nitrogen atmosphere in a 11,500-liter (3,000-gallon) iron tank.

For every treatment, water was aerated for about 4 minutes while in the volume setter.

See Figure 4.5 for diagram of Run 1 set up.

Run 1, November 21 through 23

A TOXIC CONTROL - untreated hypolimnetic water.

B NON-TOXIC CONTROL - epilimnetic water.

C EDTA - hypolimnetic water with 10 ppm Na_4 EDTA added.

D AERATION - hypolimnetic water continuously aerated during passage through ten 16-liter LPE buckets, giving an aeration time of 12 to 15 hours before flow into the volume setter. The objective was to oxidize soluable Fe^{++} to insoluble Fe^{+++} compounds.

(Continued)

Table 4.2. Summary of Treatments for Flow-Through Bioassay Experiments Performed at Lake Sidney Lanier, Fall 1980

E ORGANICS REMOVED - hypolimnetic water run through a 5-µm cellulose filter then through a column of Dowex 11 resin which exchanges Cl^- for other anions (which include organics).

F METALS REMOVED - hypolimnetic water run through a 5-µm filter then Dowex HCR-S resin which exchanges Na^+ for other cations.

G ORGANICS AND METALS REMOVED - hypolimnetic water, 5-µm filter, activated carbon, 5-µm filter (to remove carbon particles), Dowex 11, Dowex HCR-S resins.

H FILTER CONTROL - otherwise untreated hypolimnetic water run through a 5-µm cellulose filter.

Run 2, November 23 and 24

A TOXIC CONTROL - untreated hypolimnetic water.

B NON-TOXIC CONTROL - epilimnetic water.

C EDTA - hypolimnetic water with 50 ppm Na_4 EDTA added (vs. 10 ppm Run 1)

F METALS REMOVED FROM EPILIMNETIC WATER - run through 5-µm filter and Dowex HCR-S resin. Objective was to see if removing hardness, as happened along with metals removal in SII 1F and G, would adversely affect the trout fry. For unknown reasons, however, the resin did not remove hardness from the epilimnetic water.

G CHANGED ORDER OF RESIN AND CARBON COLUMNS - hypolimnetic water through 5-µm filter, Dowex HCR-S, Dowex 11, activated carbon, 5-µm filter. Objective was to test possibility that an organic leached from Dowex HCR-S resin was toxic; Dowex 11 and activated carbon should remove any such organic.

Run 3, December 4 through 8

A TOXIC CONTROL - untreated hypolimnetic water.

B NON-TOXIC CONTROL - epilimnetic water.

C AERATION + FILTRATION + HARDNESS - hypolimnetic water aerated 12 hours as in Run 1, D, then allowed to settle for 2 hours, then run through a 5-µm filter to remove iron floc, then 50 ppm hardness added as $CaCl_2$ (but expressed as $CaCO_3$).

D AERATION + FILTRATION - exactly as C but without hardness addition. Flows C and D were split after 2 hour settling and before the filters.

(Continued)

Table 4.2. Summary of Treatments for Flow-Through Bioassay Experiments Performed at Lake Sidney Lanier, Fall 1980

E METALS REMOVED THEN HARDNESS REPLACED - hypolimnetic water run through 5-µm filter, activated charcoal, 5-µm filter, HCR-S cation exchange resin, then 10 ppm hardness added (as $CaCl_2$ but expressed as $CaCO_3$) to replace hardness removed by the resin.

F METALS REMOVED - exactly as E but without hardness addition. Filters and columns were completely separate for E and F.

G ACTIVATED CHARCOAL + HARDNESS - hypolimnetic water, 5-µm filter, activated charcoal column, 5-µm filter, the 10 ppm hardness added to replace what the charcoal was expected to remove.

H ACTIVATED CHARCOAL - exactly as G but without hardness addition. Flows for G and H were completely separate.

Run 4, December 19 through 23

A TOXIC CONTROL - untreated hypolimnetic water. All bottom water for Run 4 was stored in a 3,000-gallon (11,500-liter) iron tank.

B NON-TOXIC CONTROL - epilimnetic water.

C METALS PRECIPITATION - performed as a static. Hypolimnetic water, pH raised to 11 with NaOH, aerated 1 hour, settled for 1 hour, floc removed by 5-µm filter, adjusted to pH 6 with HCl. The acid pH adjustment step to pH 6 could not be performed readily for a flow-through.

D METALS PRECIPITATION + HARDNESS - exactly as C with final addition of $CaCl_2$ to increase hardness by 10 ppm.

E AERATION - hypolimnetic water aerated for about 6 hours in a setup similar to that in SIIID.

F AERATION + 10 PPM HARDNESS - otherwise untreated hypolimnetic water with 10 ppm hardness added as $CaCl_2$ (but expressed as $CaCO_3$).

G AERATION + 25 PPM HARDNESS - similar to F.

H AERATION + 50 PPM HARDNESS - similar to F.

Table 4.3. Methods Used for Chemical Analysis of Water Samples, Lake Sidney Lanier, Georgia, Fall 1980

Parameter	Method	Reference
Temperature	Thermometer	APHA p. 125
Dissolved Oxygen	Membrane electrode	APHA p. 450
pH	Hydrogen ion electrode	EPA p. 239
Conductivity (@ 25 C)	Condictivity bridge	APHA p. 71
Total Suspended Solids	Gravimetric	EPA p. 268
Total Dissolved Solids	Gravimetric, lab filtered	EPA p. 266
Ammonia	Ammonia Electrode or	APHA p. 412
	Distillation, Nesslerization	EPA p. 165
Alkalinity	Titrimetric method	EPA p. 3
Color Apparent	Visual comparison method	APHA p. 64
Total Organic Carbon	Beckman TOC analyzer	EPA p. 236
Aluminum, Total	AAS	EPA p. 92
Arsenic, Total	AAS	APHA p. 159
Cadmium, Total	AAS	EPA p. 101
Chromium, Total	AAS	EPA p. 105
Copper, Total	AAS	EPA p. 108
Iron, Total	AAS	EPA p. 110
Iron, Dissolved	Field filtration (0.1 µm), AAS	EPA p. 110
Lead, Total	AAS	EPA p. 112
Manganese, Total	AAS	EPA p. 116
Manganese, Dissolved	Field Filtration (0.10 µm), AAS	EPA p. 116
Mercury, Total	AAS (Flameless-AA)	APHA p. 156
Nickel, Total	AAS	EPA p. 141
Zinc, Total	AAS	EPA p. 155
Sulfide, Total	Methylene blue	APHA p. 503
Hardness	EDTA titration	APHA p. 202
Calcium, Total	AAS	EPA p. 103
Magnesium, Total	AAS	EPA p. 114
PCB's - Arochlor series	GC-EC	PAM, APHA
Organophosphorus Pesticides -	Parathion, malathion methyl parathion, Guthion	PAM, APHA
Organochlorine Pesticides -	DDE, DDD, DDT Toxaphene Chlorodane, Heptachlor, Dieldrin, methoxychlor	PAM, APHA

Abbreviations:

AAS = Atomic Absorption Spectrophotometry, all total metals are digested by the EPA, 1974 method on p. 83, Section 4.1.4.

GC-EC = Gas Chromatography using an election capture detector.

APHA = American Public Health Association. 1975. Standard Methods for the Examination of Water and Wastewater, 14th ed. AWWA, WPCP, APAA, Washington, D.C.

EPA = U.S. Environmental Protection Agency. 1974. Environmental Monitoring and Support Laboratory. Cincinnati, Ohio. Methods for Chemical Analysis of Water and Wastes.

PAM = Pesticide Analytical Manual, 1977. U.S. Department of Health, Education and Welfare. Vol. I. Methods which Detect Multiple Residues. Washington D.C.

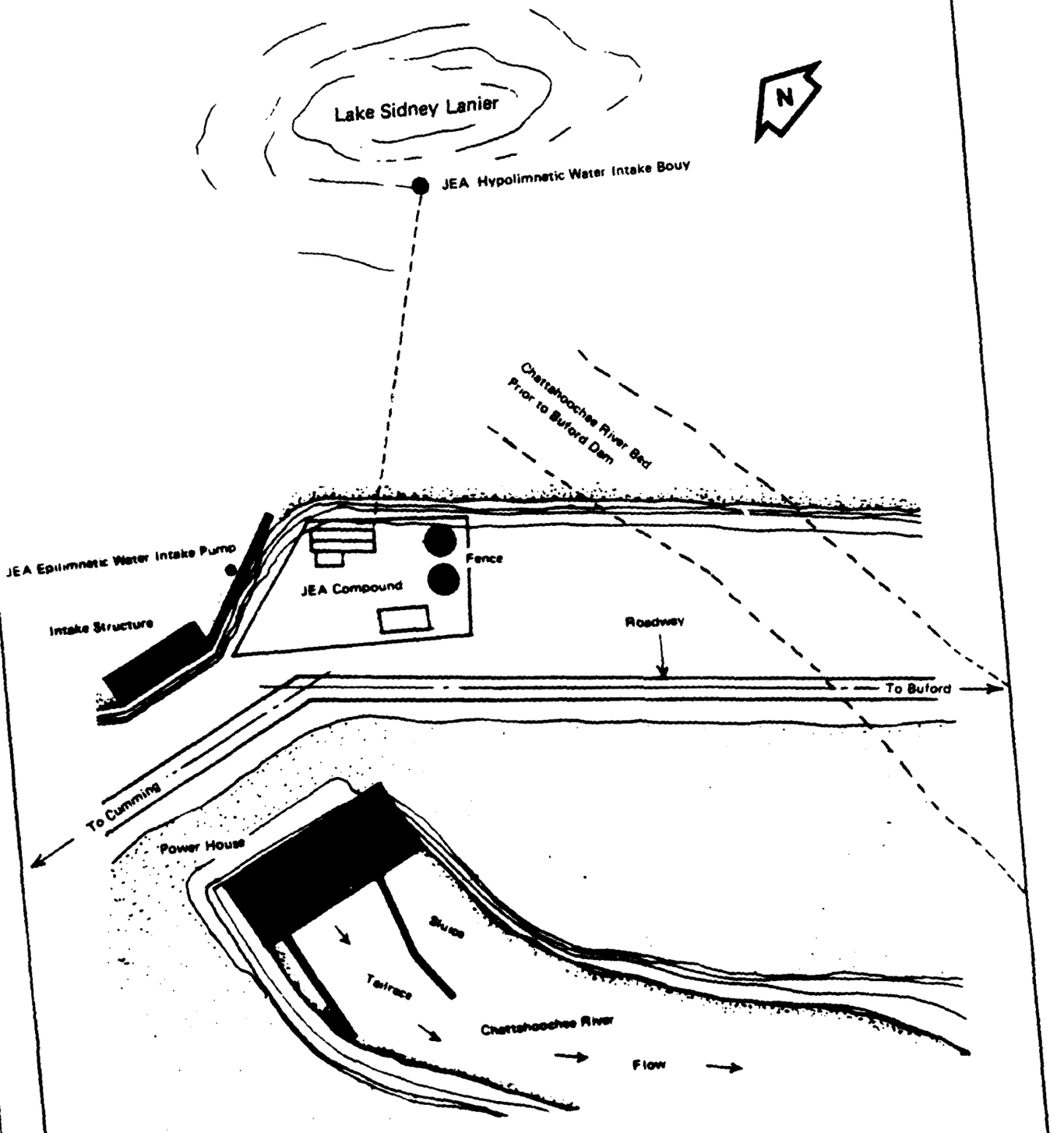


Figure 4.1. JEA Buoy Location with Hypolimnetic Pump Approximately 200 Meters Upstream of Buford Dam, Lake Sidney Lanier, Georgia

Figure 4.2. JEA Experimental Bioassay Compound on Top of Buford Dam, Georgia

KEY

A. Bioassay mobile laboratory with special cooling unit on left end.

B. Twelve-foot diameter swimming pool used as a water bath for four 250-gallon linear polyethylene (LPE) water storage tanks and for two fish holding tanks.

C. Heat exchange for cooling epilimnetic water.

D. Nitrogen tanks for maintaining N_2 atmosphere in 250-gallon (LPE) tanks.

E. Field office.

F. Storage shed.

G. Two inch line from hypolimnion.

H. Outflow line to lake.

I. Two inch line from epilimnion (pump is suspended from the dam just off the upper left of the photo).

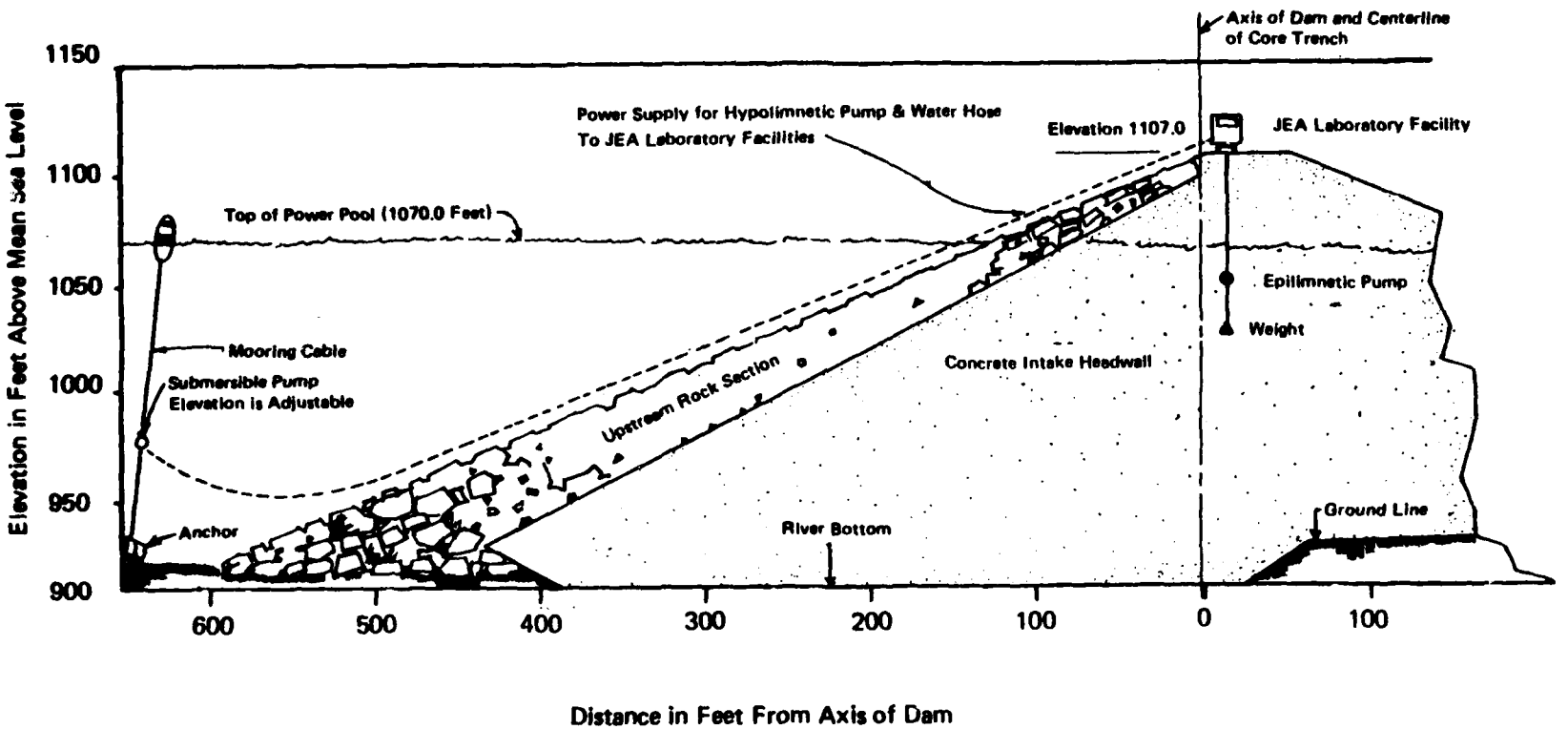
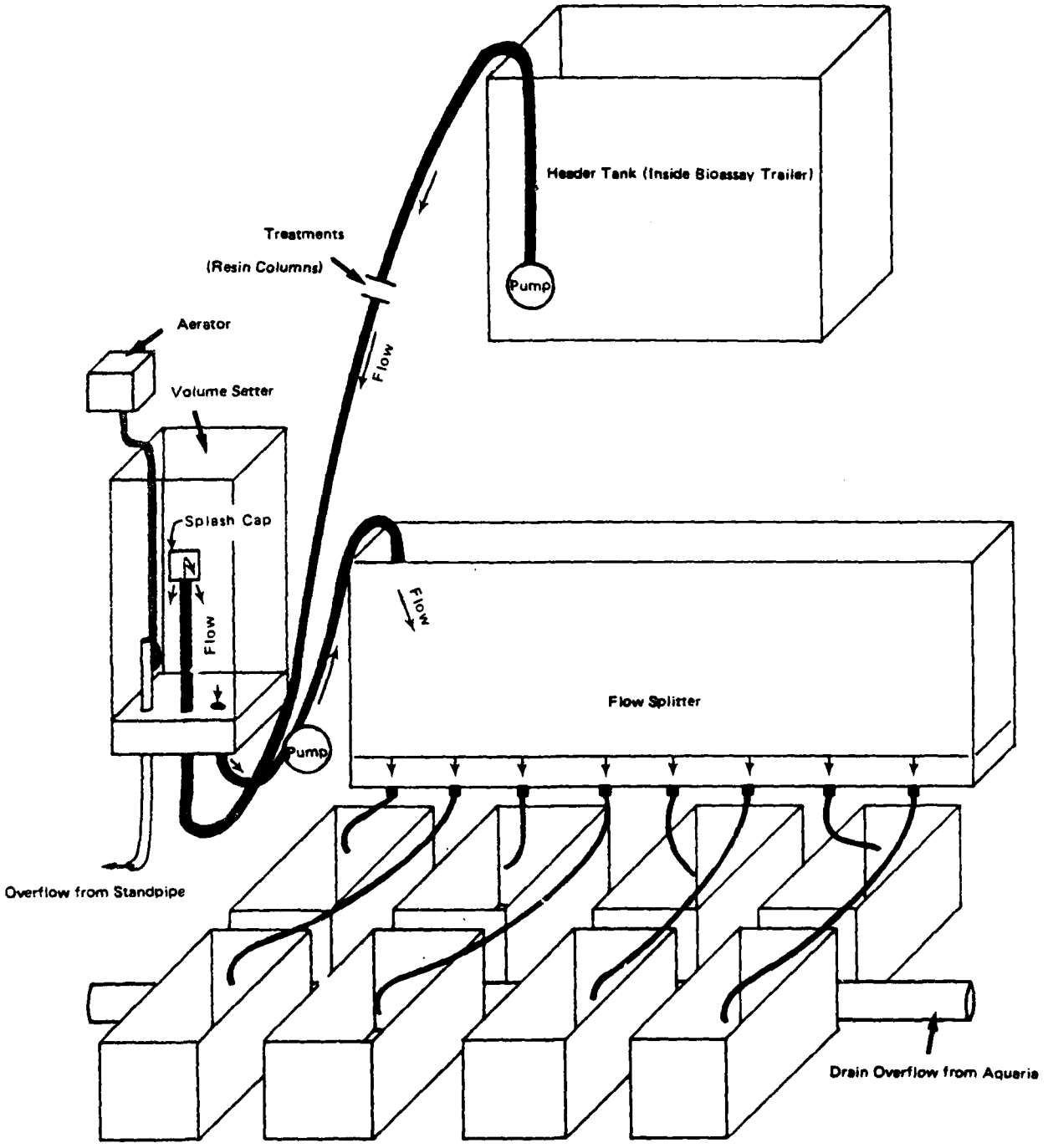


Figure 4.3. JEA Laboratory Test Water Intake Assembly for Bioassay Experiments at Lake Sidney Lanier, Georgia



Hypolimnetic Water Continuously Flowed Into and Overflowed Out of the Header Tank. Flows for Set I and for Set II Run 4 Were Identical Except That the Water Source Was an Outdoor Storage Tank Rather Than a Continuous Flow Header Tank.

Figure 4.4. Diagram of Water Flows for One Treatment of Set II Bioassays at Buford Dam, Georgia, Fall 1979

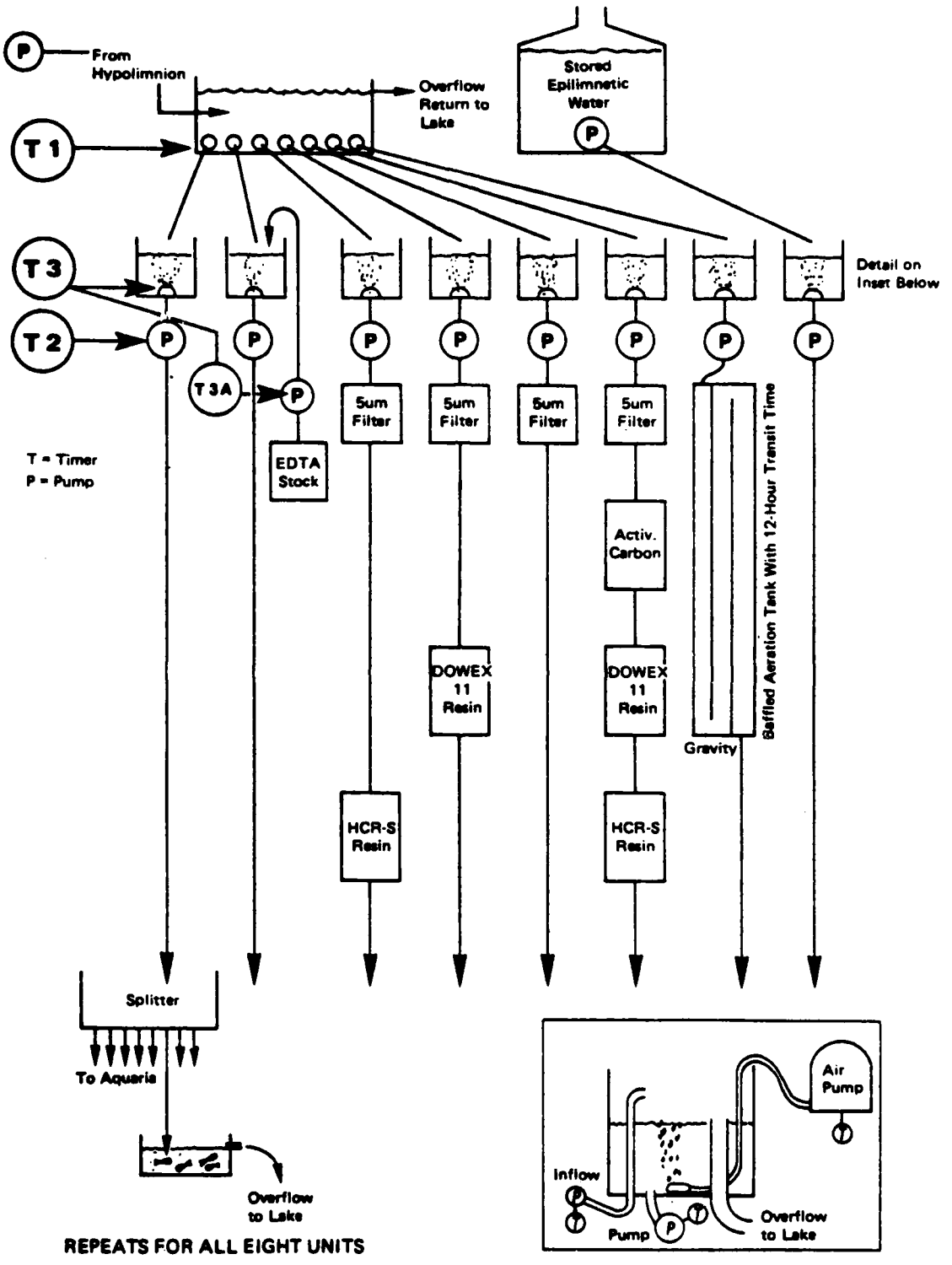


Figure 4.5. Diagram of the Flows for Individual Water Treatments in Set II Run 1 Bioassays Performed at Buford Dam, Fall 1980

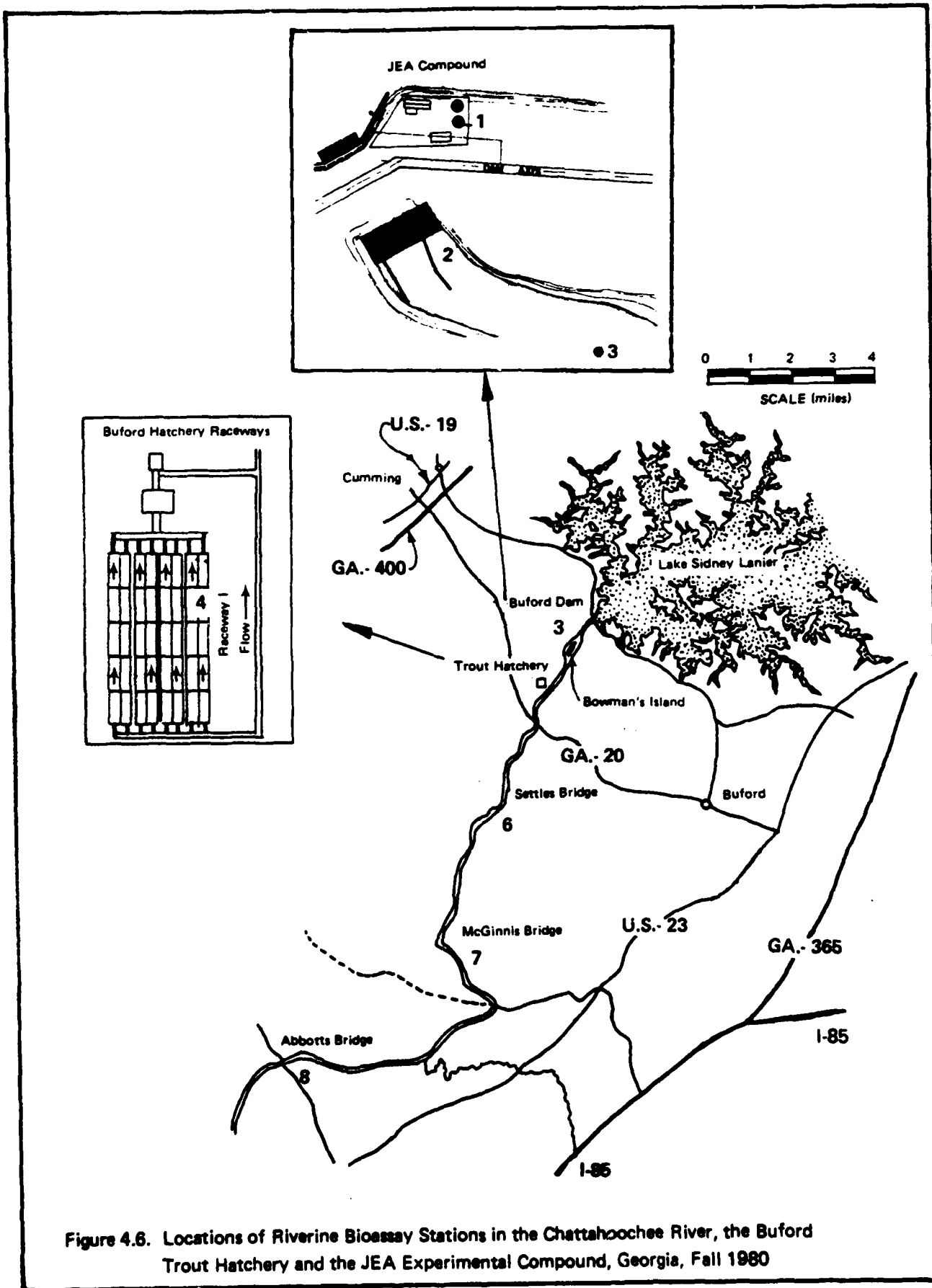
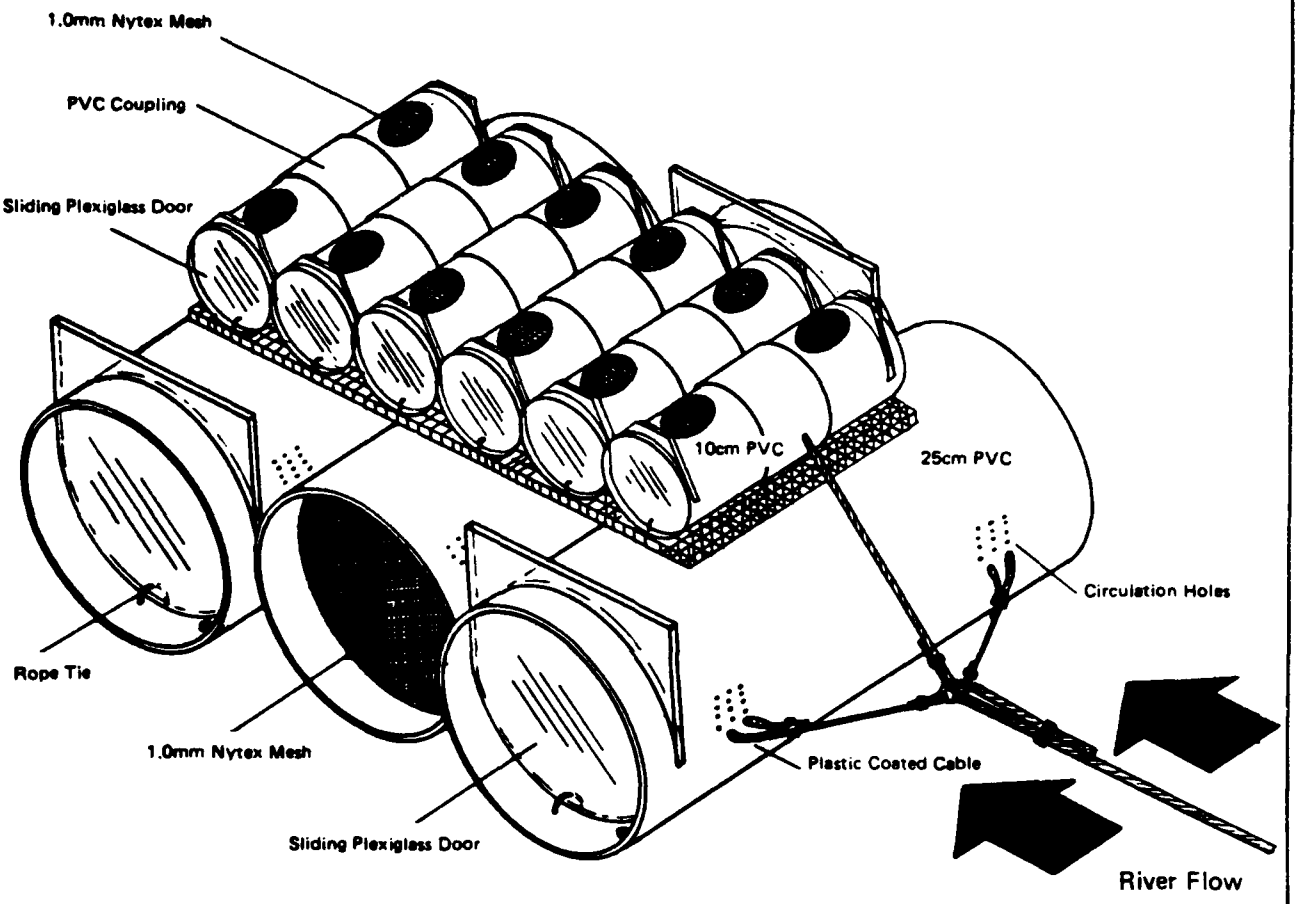


Figure 4.6. Locations of Riverine Bioassay Stations in the Chattahoochee River, the Buford Trout Hatchery and the JEA Experimental Compound, Georgia, Fall 1980



Each holding cage consisted of 3 large chambers made of 60-cm lengths of 25-cm ϕ PVC pipe and 12 smaller chambers made of 12-cm lengths of 10-cm ϕ PVC pipe. The 12 smaller chambers were connected in pairs using PVC couplings. The chambers were held together with plastic coated cable. The cages were secured in the river by tethering to a post and attaching a weight to the front of the unit.

Figure 4.7. Cages Used to Hold Fish for Bioassays Performed in the Chattahoochee River Below Buford Dam, Georgia, November 1980 and February 1981

SECTION 5.0. RESULTS

5.0 RESULTS

5.1 TABULAR RESULTS FOR EACH BIOASSAY

Tables 5.1 through 5.12 summarize mortality and chemical data for each of the bioassays: Set I (SI) and Set II (SII) flow-through bioassays and five groups of static bioassays (Stat 1-Stat 5). Set I bioassays were run twice (SI1 and SI2), and four different groups of experiments were included in Set II (SII1 to SII4). Individual treatments for each experiment are lettered (e.g., SII1A through SII1H). Graphic presentations of mortality data and of selected regressions of mortality against metals or hardness are presented in Figures 5.1 through 5.3.

Each experimental run included treatments testing several different hypotheses. Because of this presentation of results is much clearer when organized by the ideas explored rather than by the temporal sequence of experiments.

5.2 EPILIMNETIC CONTROLS

Fry kept in epilimnetic water as non-toxic controls throughout the experiments showed excellent survival rates, thus demonstrating that fry were not seriously stressed by handling or by the experimental procedures. Of a total of 800 fry used in flow-through experiments (SI and SII) only one died, and only two of 250 fry died in the static epilimnetic controls.

5.3 TOXICITY VARIATIONS WITH WATER DEPTH

As anticipated, Set I experiments showed that both iron and manganese content and toxicity increased with water depth. Therefore, bottom water was drawn for Set II experiments, because bottom water was most toxic.

Toxicity was clear or suggested in those waters with dissolved manganese (Mn_d) over 500 ppb and dissolved iron (Fe_d) over 200 ppb. Regression analysis showed that measured differences in Fe_d between treatments in Set I could explain 98 percent of the mortality differences (Figure 5.1). No copper, arsenic, lead, cadmium, chromium, or mercury was detectable in any of the 36 routine chemical samples (Tables A.1 and A.2). EPA's scan for 27 metals detected only aluminum (390 ppb), barium (20 ppb), manganese (1,150 ppb), strontium (20 ppb), titanium (10 ppb), calcium, magnesium, iron, and sodium (Table 5.13). Dissolved aluminum was always below detection, but total aluminum reached 250 to 390 ppb in bottom water. Although mostly below detection, zinc was inconsistently found at levels up to 32 ppb, but only in one of three sets of samples from a single source of stored water from Set I. No organochlorine compounds were detected in any of the samples.

5.4 VARIATIONS IN UNTREATED BOTTOM WATER

During the experiments, the dissolved metals levels of bottom water varied approximately 50 percent for Mn and 500 percent for Fe, and mortality rate also varied in a pattern not clear at the time. The loading

rate (water flow per gram of fish) differences now help explain the sometimes large toxicity variations between runs. However, loading rates were the same for all treatments within a single run, and the results and conclusions of this study are in no way compromised by between-runs differences in loading rates (see Table 5.14).

With the exception of SII4, the 48-hour survival rate decreases as the flow per gram decreases both as Fe_d increases from 1,133 ppb to 3,288 ppb and as Fe_d decreases back to 1,940 ppb. The exceptional low survival rate for a light loading rate in SII4 was associated with high manganese but relatively low iron. Why lowered Fe levels should make Mn more toxic is not understood; some completely unrelated variable may be of importance. However, in aeration treatments which lowered Fe_d without changing Mn_d, toxicity was increased; and when a column of activated carbon removed all Fe_d but no Mn_d, toxicity was increased.

5.5 ORGANICS REMOVAL WITHOUT EFFECT

Removal of organics by Dowex 11 anion exchange resin (SII1E) yielded exactly the same survival rate as no treatment (SII1A). Dowex 11 and HCR-S resins together with carbon (SII1G) produced exactly the same survival rates as HCR-S resin alone.

Since these experiments demonstrated that organics did not influence toxicity and no organics were detected chemically (Tables A.1 and A.13), no further experiments were performed with Dowex 11 resin.

5.6 FORM OF EDTA CRITICAL

Addition of 10 ppm Na_4 EDTA (SII1C) left fewer fish alive than in toxic controls (59 percent versus 73 percent at 24 hours). Increasing Na_4 EDTA to 50 ppm (SII2C) caused an even larger decrease in survival rate (24 percent versus 50 percent). Neither addition caused any change in any chemical measurement except for a slight increase in alkalinity. A preliminary static test showed that 100 ppm Na_4 EDTA also greatly increased mortality.

Although Na_4 EDTA at 10 ppm or 50 ppm caused mortality increases, Ca_2 EDTA at 100 ppm and 10 ppm (Stat 5 C and D) was completely effective in preventing mortality during the 2-day test.

5.7 PROLONGED AERATION INCREASES TOXICITY

Aeration was attempted three times in Set II experiments without improving survival. In Run 1, 12-hour aeration decreased dissolved iron by 67 percent, yet survival rates were significantly less than in untreated water (2 percent versus 14 percent at 48 hours).

In Run 3, settling and 5-μm filtration was added after 12 hours aeration, resulting in an 80 percent decrease in dissolved iron; however, after slightly improving 24-hour survival, fewer fish remained alive at 48-96 hours than in untreated bottom water (16 percent versus 37 percent at 96 hours). A parallel treatment differed only in that

hardness was increased to 50 ppm. This added hardness substantially improved survival over that in untreated water.

In Run 4, 6-hour aeration did not decrease dissolved iron levels, and survival rates were statistically identical to toxic controls.

5.8 METALS REMOVAL AN EFFECTIVE TREATMENT

Interpretation of the effects of metals removal by Dowex HCR-S cation exchange resin was complicated by the fact that the resin removed not only Fe and Mn but also hardness (Ca and Mg). Removing hardness also increased toxicity, but removing Fe and Mn and leaving or adding back hardness resulted in almost complete survival.

In Run 1, the HCR-S resin alone (SII1F) removed 79 percent of Fe_d and 69 percent of Mn_d, but also 64 percent of hardness, and survival was significantly lower than in untreated hypolimnetic water (SII1A) (46 percent versus 73 percent at 24 hours).

HCR-S, Dowex 11, and activiated carbon columns together (SII1G) removed 97 percent of Fe_d, 93 percent of Mn_d, but 82 percent of hardness, and survival rates were statistically identical to those for HCR-S alone. In Run 2 (SII2G), these three treatment columns were combined in a different order with Dowex 11 last so that any organic leached from the other columns would be removed by Dowex 11, but the new arrangement of columns yielded the same result as the first arrangement.

In Run 3, HCR-S and activated carbon together (SII3F) reduced Fe_d and Mn_d below detection but also lowered hardness from 14.5 ppm to 4.5 ppm. All fish died within 48 hours compared to 54 percent survival in untreated water. A parallel treatment (SII3E) differed only in that $CaCl_2$ was added to increase hardness back to 12 ppm. In this treatment, 94 percent of the fish survived the 96-hour test (versus 37 percent in untreated water).

In Run 4, Fe_d and Mn_d were precipitated out by raising the pH to 11 (NaOH), aerating, filtering, and adjusting back to pH 6 (HCl). None of the fish died in this treatment (SII4C), showing that removing Fe_d and Mn_d removed all toxicity.

Activated carbon alone (SII3H) removed all dissolved Fe but did not decrease Mn_d or hardness. Surprisingly, this selective removal of Fe substantially decreased survival (16 percent versus 54 percent in untreated water at 48 hours). In a parallel treatment (SII3G) differing only in that hardness was increased to 19 ppm (versus 13 ppm SII3H), survival was the same as in untreated water.

5.9 HARDNESS ADDITION PROTECTS FISH

In all cases, increasing hardness was effective in increasing survival of the fry. In Run 4, increasing hardness to 28 ppm (versus 12 ppm without treatment) by adding $CaCl_2$ increased survival rate to 84 percent after 96 hours (versus 24 percent). With hardness increased to 38 ppm (SII4G) or 63 ppm (SII4H), 100 percent of the fry survived the 96-hour tests.

In the static test also, adding 20 ppm or 100 ppm hardness was completely effective in preventing mortality (Stat 1 J, K, and L).

An increase to 50 ppm hardness was less effective following 12-hour aeration (SII3C), but the improvement in survival rate still was substantial (77 percent versus 37 percent without treatment at 96 hours).

The detrimental effects of removing only iron with activated carbon (SII3G and H) were ameliorated by increasing hardness from 13 ppm (H) to 19 ppm (G) (7 percent versus 31 percent survival at 96 hours).

Adding hardness increased the survival rate associated with any given level of Mn or Fe addition to epilimnetic water. Adding 10 ppm, 20 ppm, or 50 ppm hardness to 1,000 ppb Mn^{++} completely eliminated the 90 percent mortality (48 hours) of 1,000 ppb Mn^{++} alone (Stat 2 B, H, I, J). In Stat 4, the 64-hour survival rate of 4 percent when 1,000 ppb Mn^{++} was added was increased to 94 percent if 10 ppm hardness was added. Survival in 3,000 ppb Mn^{++} plus 10 ppm hardness was equivalent to 1,000 ppb Mn^{++} without added hardness (Stat 4 F and D).

Adding 10 ppm hardness also markedly increased the survival rates associated with 2,000 ppb or 4,000 ppb Fe^{++} or 1,000 ppb Mn^{++} + 2,000 ppb Fe^{++} (Stat 4 I, J, K, L, N, P).

5.10 EFFECTS OF DILUTING BOTTOM WATER

In Stat 1, 90 percent and 70 percent hypolimnetic water (diluted with epilimnetic water) were just as toxic as undiluted water, and 50 percent dilution increased survival only to 26 percent (versus 8 percent at 42 hours). A repeat of the test with 50 percent dilution in Stat 2 yielded an improved survival rate of 40 percent versus 5 percent in straight hypolimnetic water at 48 hours.

5.11 MANGANESE ADDITIONS TOXIC

In several static tests, manganese was added to epilimnetic water. Where chemically measured, concentrations agreed with calculated values, and manganese toxicities were the same for $Mn(NO_3)_2$ as for $MnCl_2$. In every case of eight tried, 1,000 ppb was acutely toxic, leaving 10 percent or fewer survivors after 48 hours, while 250-320 ppb show little or no effect. From plotting these and intermediate values (Figure 5.4) and roughly sketching a line, the estimated 48-hour LC_{50} is approximately 650 ppb Mn^{++}, which is considerably lower than previously reported (Lewis, 1976; England, 1978; Lewis *et al.*, 1979).

5.12 IRON ADDITIONS TOXIC

Ferric iron added to epilimnetic water had no effect either alone or in combination with manganese (Stat 1 and 2). Ferrous iron, in contrast, was toxic at relatively low levels; however, poor correlation between calculated and the few measured values makes the exact levels uncertain. A calculated value of 1,000 ppb Fe (measured 220-240 ppb) left only 22 to 28 percent of fish alive at 48 hours (Stat 4H and 5I). A calculated level of 2,000 ppb (measured 260-290 ppb) produced 30 to 35

percent survival at 48 hours (Stat 4I and 5J). Calculated 500 ppb Fe^{++} and measured 130 ppb Fe_d gave 62 percent survival at 48 hours (Stat 5H).

From these few data, straight line interpolation produces a 48-hour LC_{50} of 660 ppb iron (Fe^{++}) based on calculated values or 160 ppb iron (Fe_d) based on values measured at the end of the exposure periods. These values compare with the 480 ppb Fe 96-hour LC_{50} reported for yearling brook trout at pH 6.0 (Decker and Menendez, 1974). The 480 ppb Fe was an average of daily measurements in a flow-through system, and this value represents actual exposure level over 96 hours. On the other hand, in the 48-hour static tests reported herein, concentration probably started at the calculated value and decreased at an unknown rate to the concentration measured only at the end of the 48-hour test. Given the differences in duration of test, basis for nominal concentrations, trout species and age, results are similar.

The poor correlation between calculated iron levels and those measured at the end of the bioassay most likely is due to adsorption of Fe to aquarium walls or possibly to uptake by fish. Such losses of test substances are common in bioassays and are a major reason that flow-throughs are preferred over statics. While this discrepancy gives a wide range for LC_{50} values based on statics, it does not affect any conclusions based on the flow-throughs because Fe_d was measured daily with consistent results and because constant replacement would prevent iron adsorption to aquarium walls from causing a decrease in Fe concentration.

5.13 MANGANESE AND IRON TOXICITIES ADDITIVE

At moderate concentrations, Fe and Mn toxicities appear to be simply additive. Using calculated concentrations, 500 ppb Mn^{++} in 24 hours produced 34 percent mortality (Stat 5F), 1,000 ppb Fe^{++} 44 percent mortality (Stat 5I), and the two combined caused 70 percent mortality (Stat 5L), in agreement with predicted 78 percent mortality for additive effects. In Stat 4, 500 ppb Mn^{++} produced 13 percent mortality (interpolated between B and C) in 18 hours; 1,000 ppb Fe^{++} 26 percent (H); for a projected combined mortality of 39 percent compared to an observed 36 percent (M). In Stat 5, 250 ppb Mn^{++} caused no mortality (24 hours, 5E) and 500 ppb Fe^{++} 18 percent (5H), but the two together killed 36 percent of the fry (5K), in this case suggesting more-than-additive effects for low concentrations.

At high Fe concentrations results were inconsistent, with calculated 4,000 ppb Fe^{++} not much different from 1,000 or 2,000 ppb (Station 4 H, I, J), and calculated 1,000 ppb and 2,000 ppb Fe^{++} measured similarly at 220 ppb and 260 ppb, respectively. Because the results did not give a consistent pattern, conclusions about interaction of Mn and Fe at higher concentrations cannot be drawn.

5.14 SUBLETHAL EFFECTS

Behavioral changes and sublethal effects were similar for all toxic treatments, and the severity could be qualitatively correlated to the degree of toxicity.

Frequently, fish were disoriented and poorly coordinated, swimming slowly on the side or back with occasional bursts of rapid swimming. Under observation, fish became nervous and excitable, often swimming quickly and in a frenzied manner around the aquaria.

In the more toxic treatments, dip netting out the dead fish or putting DO or conductivity probes in the aquaria made the fish nervous and caused some to go into shock and immediately die.

Numerous fish showed trailing feces and some had mucus strands trailing from the gills; darkened color was common. In several treatments, the fish fed poorly. Dead fish often were curved in a C-shape.

5.15 ROUTINE PHYSICAL MONITORING

Conductivity was usually 30 to 35 µmhos for bottom water and 20 to 25 µmhos for surface water. Hardness additions were apparent in the conductivity records.

Dissolved oxygen levels were always above 6 ppm except for brief aeration problems during SI1.

Temperature was held near 12 to 13°C for SII1, SII2, and SII3, but a daily temperature range of 5C°, sometimes more, could not be avoided during SI1, SI2, and SII4 because of heat gain or loss in the water lines running into the laboratory from outside water storage tanks.

pH mostly remained between 6.0 and 6.5, but pH as low as 5.1 was recorded. The low readings are likely erroneously low, since pH probes were later found to have a short life and to give erratic and low readings as they failed, even though they continued to calibrate against standards. Because the meters continued to calibrate, not giving clear sign as to when gradual failure commenced, no corrections were made for any of the pH values in Appendix B.

Daily temperature, DO, pH, and conductivity ranges for each treatment are presented in Appendix B.

5.16 CHEMISTRY AND QUALITY CONTROL

Throughout the study period, the levels of manganese and especially iron increased steadily (Figure 5.5). Initially, in early October, almost all iron was particulate iron, but the percentage of dissolved iron rose to 65 in late November and to 88 in early December. Measurements after that were from water stored in the 11,500-liter tank, and oxidation and precipation during storage may explain why total and dissolved iron decreased while manganese did not. Nearly all manganese was in dissolved form throughout the study.

Comparison with the few data reported for fall 1979 by ESE (1981) suggests that iron was five times as high in 1980 and manganese three times as high as in 1979 (Table 5.15), with dissolved to total ratios similar for both metals. However, hatchery records, which are more

frequent for both years, show that manganese and dissolved iron (Fe^{++}) in the river were higher in 1979 than in 1980 (Figure 3.4).

Chemical monitoring results for all runs of both sets of flow-through bioassays are presented in Appendix A. Interlaboratory comparisons of quality control samples (also in Appendix A) shows that agreement between the two laboratories was usually closer than the maximum acceptable difference of $\pm$ 25 percent (Dr. J.T. McClave, personal communication). Of the numerous spiked metals samples, the only recoveries outside $\pm$ 10 percent were some low copper recoveries (22 to 77 percent), one high zinc (138 percent), and one high dissolved manganese (120 percent).

5.17 METALS IN TROUT LIVERS

Of the 24 metals measured in livers of rainbow trout from Buford Hatchery (Table 5.16) and from Walhalla National Fish Hatchery (Table 5.17), 16 were below detection in all samples. Of the 8 detectable metals, Al, Ca, Cu, Mg, Mn, and Zn all were significantly higher in Buford trout than in Walhalla trout (Table 5.18). Na averaged 42 percent higher at Buford, but variance was so high that this difference was not significant. Fe contents were the same in both sets of liver samples.

Not all of these results can be explained based on known water chemistry for Buford Hatchery (Appendix A) and the following analyses of water flowing into Walhalla National Fish Hatchery on November 1, 1977 (the most recent analyses):

Ca	21 ppm	Fe	0.33 ppm
Mg	10 ppm	Mn	<0.01 ppm
Hardness	62 ppm	Al	0.8 ppm
Alkalinity	47 ppm	pH	6.9

Ca, Mg, and Al appear to be in substantially higher concentration in water at Walhalla than at Buford, yet trout from Walhalla show lower liver Ca, Mg, and Al levels than do rainbow trout from Buford. Fe at 0.33 ppm is relatively high at Walhalla and possibly comparable to Fe concentrations averaged from summer lows through November highs at Buford, so that equal liver Fe contents for the two hatcheries perhaps requires no special explanation.

Mn content is significantly higher in livers from Buford trout, in accordance with probable water chemistry differences. However, concerning higher Cu and Zn in Buford trout, the fact that Ca, Mg, and Al are higher in water at Walhalla yet lower in livers from Walhalla trout makes accepting high Cu and Zn in Buford trout livers as evidence of exposure to high levels of Cu or Zn difficult. Other factors may explain the differences in Cu and Zn levels between the two hatcheries as discussed below.

The relationship between environmental levels of individual metals and tissue levels of those metals has been insufficiently studied; the relationship is a complex one which can be influenced by factors such as

age and reproductive stage of the animals, foods, and environmental levels of other elements and compounds. Age, strain, source, reproductive stage of trout, and food were controlled variables in choosing the source of trout to compare with Buford trout, but controlling all environmental variables was impossible. Increased hardness is known to decrease toxicity of metals (Chakoumakos et al., 1979; Pagenkopf et al., 1974; Lloyd, 1960); perhaps hardness decreased availability of the metals at Walhalla and therefore decreased the tissue uptake of metals.

Alternatively, other types of research suggest that the known high Mn levels at Buford might explain the elevated tissue Cu levels. Lambs fed high levels of supplemental Mn showed significantly higher levels of Cu in livers than did controls (Watson et al., 1973). Similarly, rats given manganese supplemented drinking water showed increased copper levels in brain tissue (Singh et al., 1979). While these data are for mammals rather than for fish, they do show that higher tissue concentrations of Cu (or other metal) need not indicate higher environmental or dietary levels of Cu (or other metal).

In view of the probable influence of known high Mn at Buford Hatchery on tissue metal levels and of consistent failure to detect Cu or Zn in river and reservoir water of demonstrated high toxicity, the fact that Cu and Zn are more concentrated in livers of Buford trout than in livers of Walhalla trout cannot be accepted as evidence of Cu or Zn toxicity at Buford hatchery.

5.18 FEW HISTOPATHOLOGICAL EFFECTS

Fish used in SI1 (5 days exposure), SI2 (4 days), and SII1 (7 days) were examined. None of the 90 fish examined showed any abnormality in the gills, liver, kidney, gut, central nervous system, or skin. Pathology was limited to proliferation of the pigmented layers of the eye, some separation of the retina, and somatic myodegeneration (Figure 5.6).

The lack of effects, particularly in the gills, is unexpected because previous examinations of rainbow trout from the hatchery and from the river have reported gill, liver, and kidney pathology, with the suggestion that gill damage was the primary toxic action with the other pathology a possible secondary result of poor oxygen exchange across the gills (Noell and Oglesby, 1977; Grizzle, 1981).

In SI1, one fish exposed to water from 35 meters, 2 fish from 28 meters, 3 from 23 meters, and none from 6 meters (10 examined from each treatment) showed a proliferation and thickening of cells in the pigmented layers of the eye and showed small foci of degenerating muscle bundles. In SI2, the same symptoms were evident in one fish from 35 meters of water, 3 from 28 meters, none from 23 meters, and one from 6 meters.

For SII1, only 10 fish were examined, 5 exposed to untreated bottom water (A) and 5 kept in epilimnetic water (B). One fish from B showed the same early indications of pathology seen in SI. In A, three fish showed only beginning myodegeneration, but the other two showed extensive muscle degeneration with replacement by connective tissue.

The muscular degeneration first would suggest inadequate diet. However, the first histological effects of inadequate diet should be seen in erosion of the intestinal columnar epithelium, yet the gut appeared normal even in those fish exhibiting the most advanced myodegeneration.

Myodegeneration with no suggestion of pathology in liver, kidney, or gut is unexpected because the internal organs usually are the first to show histopathological effects. Neither Dr. Blake nor Dr. Yevitch (EPA Narragansett) could recall seeing this phenomenon before nor could they explain it.

A similar muscular dystrophy without other obvious histopathology has been reported for Atlantic salmon fed a diet deficient in Vitamin E and selenium (Poston et al., 1976), but such a dietary deficiency is unlikely in trout fed regular hatchery food.

5.19 RIVERINE BIOASSAYS

River water was acutely toxic to rainbow trout in November but was non-toxic in February after Lake Sidney Lanier reservoir had destratified. No rainbow trout died in February riverine bioassays. Bluegills survived both fall and winter bioassays except for asphyxiation in tailwaters (Station 3) from the dam in the fall.

Trout fry showed 24 percent survival at the last station, 13.5 miles (22 km) below the dam, but significantly lower (0 to 6 percent) survival at other stations (Table 5.19, Figure 5.7). Yearling trout asphyxiated within an hour immediately below the dam (Station 3) but showed 73 to 97 percent survival at other river locations except the sluice at the dam, where only 17 percent survived.

The increase in survival at Station 8, 13.5 miles (22 km) below Buford Dam in November, is statistically significant for fry but not clearly significant for yearlings (Table 5.19). Yearlings showed high survival rates. Given freedom of movement to seek most favorable conditions, stocked yearlings might live through the fall. Survival is evidenced also by the facts that live trout were seen in the river during the work in fall and that fishermen catch rainbow trout between the dam and the hatchery.

Fry mortality was still substantial 13.5 miles (22 km) below the dam, and it is unlikely that fry could survive in this section of the river. Fe and Mn in the Chattahoochee River were measured at the hatchery (2.5 km below the dam) and at McGinnis Bridge (13.6 km below the dam), 5 miles (8 km) upstream from the last riverine station. Mean low flow Fe_d was 1,222 ppb and Mn_d 752 ppb at the hatchery. At McGinnis Bridge, the mean low flow Fe_d was 267 ppb and Mn_d 595 ppb, values near the 48-hour LC_{50} estimated from laboratory static bioassays. Projecting the maximum rate of decrease between the hatchery and McGinnis Bridge a further 8 km to Abbotts Bridge (22 km below the dam), estimated levels for Fe_d would approach zero; estimated levels for Mn_d would fall below the highest 48-hour laboratory "no effect" 320 ppb levels for Mn_d.

As expected, iron and manganese levels were low at both high and low flow periods after lake turnover, and no trout died at any of the stations during the February riverine bioassay (Table C.5).

5.20 LAKE PROFILE DATA

By the time JEA arrived on site in early October, Lake Sidney Lanier had already been stratified long enough for the hypolimnion to have become anoxic (Figure 5.8). In 1978 and 1979 (Figure 5.9), the reservoir showed some thermal stratification in April, and oxygen in the hypolimnion began declining in July and became depleted about early October.

The oxygen profile of December 11, 1980 (Figure 5.8), showed mixing of waters above the slight thermocline at 30-m depth, and by December 21 the reservoir was isothermic.

5.21 HYDRAULIC CALCULATIONS

Hydrodynamic aspects of water quality were considered in addressing overall experimental considerations of this work. Hydraulic calculations were necessary to determine placement of the water intake pumps for the experiments. Some indications of potential hydraulic effect on water quality were also determined by calculations of residence times of water in Lake Lanier. Other hydraulic calculations provided information on the shape of the isotherms in Lake Lanier during low and high flows, and the immediate zone upstream of Buford Dam influenced by withdrawal.

Residence time is defined by the volume of the reservoir divided by the inflow rate (Fischer et al., 1979). In large, deep reservoirs, residence time is often several years, whereas in some run-of-the-river reservoirs formed by small dams, the residence time may be only a week. A short residence would suggest that water quality may be primarily determined by inflow to the reservoir; a long residence time would allow time for significant effects on water quality from surface or bottom inputs or from biological activity. Calculations of residence time were made for three cases based on the following:

1. Volume at normal pool elevation = 2,368 x 10^6 m^3 (1.92 x 10^6 acre-ft) (Noell and Oglesby, 1977)

2. Minimum and maximum flows: minimum flow = 550 cfs; maximum flow; = 9,000 cfs (Personal Communication, U.S. Army Corps of Engineers, Mobile District, 1982).

3. Average annual flow = 2,064 cfs (25-year average, including water year 1981) (Personal Communication, U.S. Army Corps of Engineers, Mobile District, 1982).

Residence time at minimum flow

$$\text{Residence Time} = \frac{\text{volume of reservoir}}{\text{minimum flow rate}} = 4.8 \text{ years}$$

Residence time at maximum flow

$$\text{Residence Time} = \frac{\text{volume of reservior}}{\text{maximum flow rate}} = 0.3 \text{ years}$$

Residence time at average annual flow

$$\text{Residence Time} = \frac{\text{volume of reservoir}}{\text{average annual flow rate}} = 1.3 \text{ years}$$

The residence time calculations suggest that Lake Sidney Lanier is influenced, but not dominated, by the run of the river, and the potential for effects on water quality from surface or bottom inputs is high.

Estimates of withdrawal layer thickness were made using appropriate equations from Fischer et al., 1979 and Brooks and Koh, 1969, for outflow dynamics. The efforts to estimate withdrawal layer thickness were limited and should not be considered as a full treatment of selective withdrawal in an elongated reservoir. The results represent a preliminary look at withdrawal during low and high flow situations with respect to approximate location of isotherms during October 1979 stratification. Results of the calculations were as follows:

1. Estimated withdrawal layer thickness at high flow (9,000 cfs) is approximately 75 meters using Fischer, et al., 1979, equations, or approximately 44 meters using Brooks and Koh, 1969, equations.

2. Withdrawal layer thickness at low flow (550 cfs) is approximately 24 meters using Fischer et al. equations, or is approximately 11 meters using Brooks and Koh, 1969, equations.

U.S. EPA (1979) data show the October isotherms were located between 15-20 meters from the surface. Similar data were obtained during 1980 (see Figure 5.8). The estimated thicknesses of withdrawal layers indicate that certainly under high flow conditions, withdrawal would occur from both the epilimnetic and the hypolimnetic layers. The calculations indicate the potential for withdrawal from both layers under low flow conditions as well. These calculations also indicated that over a day, average volume withdrawal will occur up to 914 meters (3,000 feet) upstream from the dam outlet, and up to 20 meters above the outlet center line. The influence of withdrawal on the isotherms would increase from October to destratification in December of January, as the thermocline descended. A more rigorous analysis would be necessary to define the specific behavoir of the isotherms under varying flow regimes; however, these calculations presented evidence that the isotherms will definitely tilt during high flow, but will tilt only slightly during low flow.

The final hydraulic consideration focused on the isotherm tilt under high flow situations and the necessity for locating the water intake pumps upstream of the zone where this would occur.

A rough drawdown zone (where the discharge would be strong enough to overcome buoyancy forces both in the hypolimnion and at the thermocline) was determined to exist up to 152 meters (500 feet) from the dam. This estimate was compared to U.S. EPA (1979) isotherms, which generally confirmed this calculation. Subsequently, the water intake assembly for the experiments was located between 150-180 meters from the dam.

Table 5.1. Summary of Set I Run 1 Bioassay Results, October 28 through November 2, 1980, Testing Untreated Water Drawn from Four Different Depths in Lake Sidney Lanier, Georgia

Depth of Testing Water (treatment)	Fish alive out of 160					Fe_t (ppb)	Fe_d (ppb)	Mn_d (ppb)	Hardness (ppm)	Alk (ppm)
	24 hours	48 hours	72 hours	96 hours	120 hours					
6m (A)	160	160	160	160	160	183	<50	97	nd	nd
23m (B)	160	160	160	160	160	528	100	286	nd	nd
28m (C)	160	159	159	157	157	810	137	506	nd	nd
35m (D)	159	154	149	138	128	1,800	613	833	14	nd

Notes:

1. Mn dissolved and total were always within measurement error of being equal. (Complete chemical monitoring data in Appendix A)
2. Statistical groupings of treatments (underlining groups together those treatments not significantly different from each other): 24 hr: A B C D

   48 hr to 120 hr: A B C D

   Statistical groupings did not change between 48 and 120 hr.

3. Treatment A = epilimnetic water from 20 ft. (6-m) depth.
   Treatment B = hypolimnetic water from 76-ft. (23-m) depth.
   Treatment C = hypolimnetic water from 95-ft. (29-m) depth.
   Treatment D = hypolimnetic water from 115-ft. (35-m) depth.

4. Fe_t = total iron; Fe_d = dissolved iron; Mn_d = dissolved manganese; Alk = alkalinity.

5. m = meters; ft = feet.

6. nd = no data (see Table 5.2 for approximate values).

Table 5.2. Summary of Set I Run 2 Bioassay Results, November 7 through November 10, 1980, Testing Untreated Water Drawn from Four Different Depths in Lake Sidney Lanier, Georgia

Depth of Testing Water (treatment)	Fish alive out of 160				Fe_t (ppb)	Fe_d (ppb)	Mn_d (ppb)	Hardness (ppm)	Alk (ppm)
	24 hours	48 hours	72 hours	96 hours					
6m (A)	160	160	160	160	50	<50	<5	13	10
23m (B)	160	160	160	160	513	80	337	11	11
28m (C)	160	156	145	137	647	217	553	11	13
35m (D)	158	130	84	70	2,800	1,133	1,010	12	15

Notes:

1. Mn dissolved and total were always within measurement error of being equal (complete chemical monitoring data are presented in Appendix A.
2. Statistical groupings of treatments (underlining groups together those treatments not significantly different from each other): 24 hr: A B C D

   48 hr to 96 hr: A B C D

   Statistical groupings did not change between 48 and 120 hr.

3. Treatment A = epilimnetic water from 20-ft. (6-m) depth.
   Treatment B = hypolimnetic water from 76-ft. (23-m) depth.
   Treatment C = hypolimnetic water from 95-ft. (29-m) depth.
   Treatment D = hypolimnetic water from 115-ft. (35-m) depth.

4. Fe_t = total iron; Fe_d = dissolved iron; Mn_d = dissolved manganese; Alk = alkalinity

5. m = meters, ft. = feet

Table 5.3. Summary of Results of Set II Run 1 Bioassays, November 19 through November 23, 1980, Testing the Effectiveness of Various Treatments in Removing Toxicity from Bottom Water (35-Meter Depth), Lake Sidney Lanier, Georgia

	Number of Survivors out of 160		Fe_t (ppb)	Fe_d (ppb)	Mn_d (ppb)	Hardness (ppm)	Alk (ppm)
	24 hours	48 hours					
A	117	23	3,695	2,690	1,090	11	16
B	160	160	57	50	5	8	10
C	94	9	3,487	2,683	1,053	10	18
D	106	3	3,123	877	1,073	11	16
E	118	22	2,560	1,898	1,053	11	8
F	73	3	627	561	343	4	17
G	65	5	303	85	75	2	9
H	113	10	2,367	2,103	1,070	10	16

Note:

1. Treatments:
   - A Hypolimnetic water (35 m water depth), briefly aerated
   - B Epilimnetic water (6 m water depth), briefly aerated
   - C A + 10 ppm Na_4 EDTA
   - D A aerated for 12 hours
   - E A + 5-µm filter + Dowex 11 resin (anion exchange-organics removed)
   - F A + 5-µm filter + Dowex HCR-S resin (cation exchange-metals removed)
   - G A + 5-µm filter + activated carbon + 5-µm filter + Dowex 11 resin + Dowex HCR-S resin
   - H A + 5-µm filter
2. Mn dissolved and total were always within measurement error of being equal (complete chemical monitoring data in Appendix A)
3. Statistical groupings of treatments listed in order from highest to lowest mean survival (underlining groups together those treatments not statistically different from each other):
   24 hr B A E H D C F G

   48 hr B E A H C G D F
4. Fe_t = total iron, Fe_d = dissolved iron; Mn_d = dissolved manganese; Alk = alkalinity

Table 5.4. Summary of Results of Set II Run 2 Bioassays, November 23 through November 24, 1980, Verifying Some Results of Set II Run 1, Lake Sidney Lanier, Georgia

Treatment	No. Survivors 24 hours	Fe_t (ppb)	Fe_d (ppb)	Mn_d (ppb)	Hardness (ppm)	Alk (ppm)
A	80	3,200	1,940	1,000	13	15
B	144	50	<50	<5	9	9
C	38	3,200	2,040	1,025	11	24
F	159	<50	<50	<5	13	8
G	42	400	100	110	5	8

Notes:

1. Treatments:
   - A Hypolimnetic water
   - B Epilimnetic water
   - C A + 50 ppm Na_4 EDTA
   - F B + 5-µm filter + HCR-S resin
   - G A + 5-µm filter + HCR-S + Dowex 11 + 5-µm filter
2. Mn dissolved and total were always within measurement error of being equal (complete chemical monitoring data in Appendix A)
3. Statistical grouping of treatments listed in order from highest to lowest mean survival (underlining groups together those treatments not statistically different from each other): 24 hr <u>B F A G C</u>
4. Fe_t = total iron; Fe_d = dissolved iron; Mn_d = dissolved manganese; Alk = alkalinity
5. Treatment B started with 144 fish; treatments A, C, F, and G with 160 fish.

Table 5.3. Summary of Results of Set II Run 1 Bioassays, November 19 through November 23, 1980, Testing the Effectiveness of Various Treatments in Removing Toxicity from Bottom Water (35-Meter Depth), Lake Sidney Lanier, Georgia

	Number of Survivors out of 160		Fe_t (ppb)	Fe_d (ppb)	Mn_d (ppb)	Hardness (ppm)	Alk (ppm)
	24 hours	48 hours					
A	117	23	3,695	2,690	1,090	11	16
B	160	160	57	50	5	8	10
C	94	9	3,487	2,683	1,053	10	18
D	106	3	3,123	877	1,073	11	16
E	118	22	2,560	1,898	1,053	11	8
F	73	3	627	561	343	4	17
G	65	5	303	85	75	2	9
H	113	10	2,367	2,103	1,070	10	16

Note:

1. Treatments:
   - A Hypolimnetic water (35 m water depth), briefly aerated
   - B Epilimnetic water (6 m water depth), briefly aerated
   - C A + 10 ppm Na_4 EDTA
   - D A aerated for 12 hours
   - E A + 5-µm filter + Dowex 11 resin (anion exchange-organics removed)
   - F A + 5-µm filter + Dowex HCR-S resin (cation exchange-metals removed)
   - G A + 5-µm filter + activated carbon + 5-µm filter + Dowex 11 resin + Dowex HCR-S resin
   - H A + 5-µm filter
2. Mn dissolved and total were always within measurement error of being equal (complete chemical monitoring data in Appendix A)
3. Statistical groupings of treatments listed in order from highest to lowest mean survival (underlining groups together those treatments not statistically different from each other):
   24 hr B A E H D C F G

   48 hr B E A H C G D F
4. Fe_t = total iron, Fe_d = dissolved iron; Mn_d = dissolved manganese; Alk = alkalinity

Table 5.4. Summary of Results of Set II Run 2 Bioassays, November 23 through November 24, 1980, Verifying Some Results of Set II Run 1, Lake Sidney Lanier, Georgia

Treatment	No. Survivors 24 hours	Fe_t (ppb)	Fe_d (ppb)	Mn_d (ppb)	Hardness (ppm)	Alk (ppm)
A	80	3,200	1,940	1,000	13	15
B	144	50	<50	<5	9	9
C	38	3,200	2,040	1,025	11	24
F	159	<50	<50	<5	13	8
G	42	400	100	110	5	8

Notes:

1. Treatments:
   - A Hypolimnetic water
   - B Epilimnetic water
   - C A + 50 ppm Na_4 EDTA
   - F B + 5-µm filter + HCR-S resin
   - G A + 5-µm filter + HCR-S + Dowex 11 + 5-µm filter
2. Mn dissolved and total were always within measurement error of being equal (complete chemical monitoring data in Appendix A)
3. Statistical grouping of treatments listed in order from highest to lowest mean survival (underlining groups together those treatments not statistically different from each other): 24 hr B F A G C
4. Fe_t = total iron; Fe_d = dissolved iron; Mn_d = dissolved manganese; Alk = alkalinity
5. Treatment B started with 144 fish; treatments A, C, F, and G with 160 fish.

Table 5.5. Summary of Results of Set II Run 3 Bioassays, December 4 through December 8, 1980, Further Testing the Effectiveness of Various Treatments in Removing Toxicity from Bottom Water (35-Meter Depth) Lake Sidney Lanier, Georgia

	Number of Survivors out of 160				Fe_t	Fe_d	Mn_t	Hardness	Alk
	24 hours	48 hours	72 hours	96 hours	(ppb)	(ppb)	(ppb)	(ppm)	(ppm)
A	130	86	67	59	4,214	3,288	1,178	14.5	16
B	159	159	159	159	107	<50	5	11	11
C	149	128	128	124	1,530	228	1,180	50	15
D	146	53	27	25	2,540	665	1,168	16	16
E	153	152	151	150	285	<50	31	12	20
F	30	0			155	<50	<5	4.5	20
G	148	87	58	50	205	<50	1,202	19	18
H	113	25	16	11	182	<50	1,192	13	19

Notes:

1. 24-hour and 48-hour survival interpolated from times 4-5 hours before or after.
2. Treatments:
   - A Hypolimnetic water briefly aerated
   - B Epilimnetic water briefly aerated
   - C A + 12-hour aeration + sedimentation + 5-µm filter + 50 ppm hardness ($CaCl_2$ expressed as $CaCO_3$)
   - D C without hardness addition
   - E A + 5-µm filter + carbon + 5-µm filter + HCR-S resin + 10 ppm hardness ($CaCl_2$ expressed as $CaCO_3$)
   - F E without hardness addition
   - G A + 5-µm filter + carbon + 5-µm filter + 10 ppm hardness
   - H C without hardness addition
3. Mn dissolved and total were always within measurement error of being equal (complete chemical monitoring data in Appendix A)
4. Statistical grouping of treatments listed in order from highest to lowest mean survival (underlining groups together those treatments not significantly different from each other): 24 hr: B E C G D A H F

   48 hr: B E C G A D H

   72 and 96 hr: B E C A G D H

Treatment F was discontinued after 48 hours due to total mortality.
Fe_t = total iron, Fe_d = dissolved iron, Mn_d = dissolved manganese, Alk = Alkalinity

Table 5.6. Summary of Results of Set II Run 4 Bioassays, December 19 through December 23, 1980, Lake Sidney Lanier, Georgia

	Number of Survivors out of 160				Fe_t	Fe_d	Mn_d	Hardness	Alk
	24 hours	48 hours	72 hours	96 hours	(ppb)	(ppb)	(ppb)	(ppm)	(ppm)
A	152	89	64	38	3,425	535	1,310	12	18
B	160	160	160	160	135	50	55	7	10
E	148	67	55	42	3,925	620	1,280	12	18
F	160	157	145	135	3,475	605	1,290	28	18
G	160	160	160	160	3,387	788	1,270	38	18
H	160	160	160	160	3,362	728	1,290	63	18
Statics: 5 reps, 10 fish/rep									
C	50	50	50	50	50	<50	<50	nd	nd
D	50	50	50	50	80	<50	65	nd	nd

Note:

1. Treatments:
   - A Hypolimnetic water, briefly aerated
   - B Epilimnetic water, briefly aerated
   - C A + NaOH to pH 11, aerated 1 hour, settled 1 hour, filter 5-µm, + HCl to pH 6
   - D C + 10 ppm hardness ($CaCl_2$ expressed as $CaCO_3$)
   - E A aerated for 6 hours
   - F A + 10 ppm hardness ($CaCl_2$ expressed as $CaCO_3$)
   - G A + 25 ppm hardness ($CaCl_2$ expressed as $CaCO_3$)
   - H A + 50 ppm hardness ($CaCl_2$ expressed as $CaCO_3$)
2. Mn dissolved and total were always within measurement error of being equal (complete chemical monitoring data in Appendix A)
3. Statistical groupings of treatments listed in order from highest to lowest mean survival (underlining groups together those treatments not significantly different from each other):

   24 hr: B H G F A E

   48 hr: B H G F A E

   72 hr: B H G F A E

   and 96 hr:
4. Fe_t = total iron, Fe_d = dissolved iron, Mn_d = dissolved manganese.
5. nd = no data; reps = repetitions

Table 5.7. Summary of Results for Static Bioassay 1, December 12 through December 16, 1980, Lake Sidney Lanier, Georgia

Treatment	Number Surviving Out of 50		
	18 hours	42 hours	96 hours
A Hypolimnetic control	50	4	*
B Epilimnetic control	50	50	49
C 90 percent A + 10 percent B	50	1	*
D 70 percent A + 30 percent B	50	4	*
E 50 percent A + 50 percent B	50	13	*
F B + 1,000 ppb Mn^{++}+500 ppb Fe^{+++}	49	3	*
G B + 1,000 ppb Mn^{++}+1,000 ppb Fe^{+++}	48	8	*
H B + 1,000 ppb Mn^{++}+2,000 ppb Fe^{+++}	49	2	*
I B + 2,000 ppb Fe^{+++}	50	50	50
J A + 20 ppm Hdn	50	50	50
K A + 100 ppm Hdn	50	50	49
L A + 70 ppm Hdn + 30 ppm Mg Hdn	50	50	50
M A + $Ca(OH)_2$ at 50 ppm Hdn, aerate 1 hour, filter 5-μ, + H_2SO_4 to pH 6	50	50	50
N A + NaOH to pH 8	50	1	*

Notes:

1. Hdn = hardness added as $CaCl_2$ (or $MgCl_2$) but expressed as ppm $CaCO_3$.
2. Mn^{++} added as $Mn(NO_3)_2$.
3. Fe^{++} added as $FeCl_3$, which formed a floc.
4. * = treatment discontinued because of complete or almost complete mortality.

Table 5.8. Summary of Results of Static Bioassay 2, December 14 through December 16, 1980, Lake Sidney Lanier, Georgia

Treatment	Number surviving out of 10 per replicate					
	24 hours			48 hours		
	1	2	3	1	2	3
A 2,000 ppb Mn^{++}	9	5	1	0	0	0
B 1,000 ppb Mn^{++}	7	6	6	0	2	1
C B + 500 ppb Fe^{+++}	8	7	7	1	1	0
D 500 ppb Mn^{++}	10	10	9	8	6	8
E D + 500 ppb Fe^{+++}	10	9	10	7	7	6
F D + 1,000 ppb Fe^{+++}	10	9	10	8	7	9
G D + 2,000 ppb Fe^{+++}	8	10	10	3	3	7
H B + 10 ppm Hdn	10	10	10	10	10	10
I B + 20 ppm Hdn	10	10	10	10	10	10
J B + 50 ppm Hdn	10	10	10	10	10	10
K Hypolimnetic control	9	9	8	1	0	0
L Hypolimnetic control	9	9	8	2	0	0
M 50 percent Hypolimnetic + 50 percent Epilimnetic	9	10	10	1	4	6
N 50 percent Hypolimnetic + 50 percent Epilimnetic	10	9	10	5	5	3

Note:

1. All metal additions were to epilimnetic water. Mn^{++} added as $Mn(NO_3)_2$, Fe^{+++} as $FeCl_3$. Run was concurrent with Static 1 control (no mortalities). All levels are calculated; none was measured. Extensive floc formed on bottoms of aquaria where Fe^{+++} was added.

2. Hdn = hardness added as $CaCl_2$ but expressed as $CaCO_3$.

Table 5.9. Summary of Results of Static Bioassay 3, December 19 through December 22, 1980, Lake Sidney Lanier, Georgia

Treatment*	Number Surviving Out of 50		
	24 hours	48 hours	72 hours
Static 3a December 18-19, 1980			
A Epilimnetic Control	50		
B A + 750 ppb Mn^{++}		(3a was run 37 for 24 hr only)	
C B + 1,000 ppb Fe^{++}	17		
D B + 3,000 ppb Fe^{++}	10		
Static 3b December 19-22, 1980			
A Epilimnetic control	50	50	50
B A + 1,000 ppb Mn^{++}	40	5	2
C A + 500 ppb Mn^{++} ppb Fe^{++}	44	21	14
D A + 1,000 ppb Fe^{++}	47	37	35

*Notes:

1. Mn^{++} added as $MnCl_2$.
2. Fe^{++} added as $FeCl_2$, no floc formed.
3. Mn^{++} Fe^{++} values all calculated only. When measured (Tables 5.10 and 5.11) Mn_t levels were near the calculated values of Mn^{++} addition, but Fe_d levels were substantially lower than calculated values for Fe^{++} addition.
4. Fe_d = dissolved iron; Mn_t = total manganese

Table 5.10. Summary of Results of Static Bioassay 4, December 23 through December 26, 1980, Lake Sidney Lanier, Georgia

Treatment	Measured Values		Survivors out of 50		
	Mn_d (ppb)	Fe_d (ppb)	18 hours	33 hours	64 hours
A Epilimnetic water	55	50	50	50	50
B A + 250 ppb Mn^{++}			47	44	44
C A + 750 ppb Mn^{++}	770		40	21	8
D A + 1,000 ppb Mn^{++}	990		32	5	2
E A + 1,000 ppb Mn^{++} + 10 ppm Hdn	1,000		49	48	47
F A + 3,000 ppb Mn^{++} + 10 ppm Hdn			27	4	1
G A + 500 ppb Fe^{++}			47	42	42
H A + 1,000 ppb Fe^{++}		220	37	14	14
I A + 2,000 ppb Fe^{++}		260	46	21	14
J A + 4,000 ppb Fe^{++}			44	16	6
K A + 2,000 ppb Fe^{++} + 10 ppm Hdn		90	49	47	47
L A + 4,000 ppb Fe^{++} + 10 ppm Hdn			47	27	26
M A + 500 ppb Mn^{++} + 1,000 ppb Fe^{++}			32	1	0
N A + 1,000 ppb Mn^{++} + 2,000 ppb Fe^{++}	1,040	260	19	0	0
O A + 1,000 ppb Mn^{++} + 4,000 ppb Fe^{++}			29	2	0
P A + 1,000 ppb Mn^{++} + 2,000 ppb Fe^{++} + 10 ppm Hdn	1,060	200	40	16	12

Notes:
1. Water samples for chemical analyses were taken at the end of the experiments and were filtered (0.4-µm).
2. Mn^{++} added as $MnCl_2$, Fe^{++} added as $FeCl_2$.
3. Hardness added as $CaCl_2 \cdot 2H_2O$, expressed as $CaCO_3$.
4. Mn_t and Fe_d for epilimnetic water from Set II, Run 4, December 19-23, 1980.
5. Mn_d = total manganese; Fe_d = dissolved iron.
6. Fe, when added was added as Fe^{++}, when measured was measured as Fe_d.

Table 5.11. Summary of Results of Static Bioassay 5, December 27 through December 29, 1980, Lake Sidney Lanier, Georgia

Treatment	Measured Conc.	Number Surviving Out of 50	
		24 hours	48 hours
A Hypolimnetic Water	-	37	7
B Epilimnetic Water	-	50	49
C A + 100 ppm Ca EDTA	-	50	50
D A + 10 ppm Ca EDTA	-	50	50
E B + 250 ppb Mn^{++}	320 ppb Mn_d	50	49
F B + 500 ppb Mn^{++}	660 ppb Mn_d	33	3
G B + 1,000 ppb Mn^{++}	1,020 ppb Mn_d	24	1
H B + 500 ppb Fe^{++}	130 ppb Fe_d	41	31
I B + 1,000 ppb Fe^{++}	240 ppb Fe_d	28	11
J B + 2,000 ppb Fe^{++}	290 ppb Fe_d	33	15
K E + H	360 Mn_d + 140 Fe_d	32	11
L F + I	580 Mn_d + 240 Fe_d	15	2

Notes:

1. All measurements on water from end of test, filtered 0.4-µm.
2. Mn^{++} added as $MnCl_2$, Fe^{++} as $FeCl_2$.
3. Mn_d = dissolved manganese; Fe_d = dissolved iron.
4. Fe, when added was added as Fe^{++}, when measured was measured as Fe_d.

Table 5.12. Summary of Results of Manganese Additions in Static Bioassays, Lake Sidney Lanier, Georgia

Test and Treatment	Mn Concentration (ppb)		Percent Survival					
	Calculated	Measured	18 hrs	24 hrs	33 hrs	42 hrs	48 hrs	64 hrs
5E (250 ppb Mn++)	250	320		100			98	
4B (250 ppb Mn++)	250		94		88			88
2D (500 ppb Mn++)	500			97			73	
2E (2D + 500 ppb Fe+++)	500			97			67	
5F (500 ppb Mn++)	500	660		66			6	
4C (750 ppb Mn++)	750	770	80	(65)	42		(29)	16
3aB (150 ppb Mn++)	750			74				
1F (1,000 ppb Mn++ + 500 ppb Fe+++)	1,000		98	(75)		6	(5)	
1G (1,000 ppb Mn++ + 1,000 ppb Fe+++)	1,000		96	(76)		16	(14)	
1H (1,000 ppb Mn++ + 2,000 ppb Fe+++)	1,000		98	(76)		4	(4)	
2B (1,000 ppb Mn++)	1,000			65			10	
3bB (1,000 ppb Mn++)	1,000			80			10	
4D (1,000 ppb Mn++)	1,000	990	64	(42)	10		(7)	4
5G (1,000 ppb Mn++)	1,000	1,020		48			2	
2A (2,000 ppb Mn++)	2,000			50			0	

Notes:

1. Statics 1 and 2: Mn^{++} added as $Mn(NO_3)_2$
   Statics 3, 4, and 5: Mn^{++} added as $MnCl_2$
2. () = interpolated value assuming straight line mortality
3. Mn concentration calculated (added) = Mn^{++}.
   Mn concentration measured = Mn_d = dissolved manganese.
4. All additions were to epilimnetic water.

Table 5.13. Results of Metals Scan of Water from 23-Meter and 35-Meter Reservoir Depths Used in Set I Run 2 Bioassays, November 7-10, 1980, Lake Sidney Lanier. Analyses by EPA, Athens, Georgia

Element		Concentration	
		35 m	23 m
Silver	Ag	<10 ppb	<10 ppb
Aluminum	Al	390	<100
Arsenic	As	<45	<45
Barium	Ba	20	<20
Beryllium	Be	<10	<10
Cadmium	Cd	<10 ppb	<10 ppb
Cobalt	Co	<20	<20
Chromium	Cr	<10	<10
Copper	Cu	<10	<10
Manganese	Mn	1,150	160
Molybdenum	Mo	<20 ppb	<20 ppb
Nickle	Ni	<35	<35
Lead	Pb	<40	<40
Antimony	Sb	<25	<25
Selenium	Se	<40	<40
Tin	Sn	<60 ppb	<60 ppb
Strontium	Sr	20	16
Tellurium	Te	<40	<40
Titanium	Ti	10	<10
Thallium	Tl	<100	<100
Vanadium	V	<10 ppb	<10 ppb
Yttrium	Y	<10	<10
Zinc	Zn	<10	<10
Calcium	Ca	2.7 ppm	2.2 ppm
Magnesium	Mg	1.1	0.9
Iron	Fe	3.3	0.2
Sodium	Na	1.4	1.4

Table 5.14. Loading Rate (Water Flow Per Gram Fish) Differences Related to Toxicity Variations in Untreated Hypolimnetic Water (35-Meter Depth) from Lake Sidney Lanier, Georgia, Fall 1980

Run	liter/ hour/gram	gram/ fish	48-hour Percent Survival	Fe_d(ppb)	Mn_d(ppb)	Mn_d/Fe_d
SII4	0.618	0.117	56	535	1,310	2.4
SI1	0.439	0.157	96	613	833	1.4
SI2	0.307	0.225	81	1,133	1,010	0.9
SII3	0.203	0.342	54	3,288	1,178	0.4
SII1	0.157	0.440	14	2,690	1,090	0.4
SII2	<0.157	>0.440	projected 0	1,940	1,000	0.5

SII4 = Set II flow-through bioassay, Run 4
SI1 = Set I flow-through bioassay, Run 1
Fe_d = dissolved iron
Mn_d = dissolved manganese

Table 5.15. Comparison of Hypolimnetic Iron and Manganese Levels in Lake Sidney Lanier, Georgia, for Fall 1979 (ESE, 1981) and Fall 1980

	Total Fe	Diss. Fe	Total Mn	Diss. Mn		Total Fe	Diss. Fe	Total Mn	Diss. Mn
August 1980	-	-	-	-	August 1979 (8/29/79)	304	29	288	186
Sept. 1980	-	-	-	-	Sept. 1979	-	-	-	-
October 1980 (10/28/80)	2,000	230	850	820	October 1979 (10/16/79)	570	6	456	382
November 1980					November 1979				
11/10/80	3,000	1,800	1,050	1,050	11/27/79	2,770	2,770	1,180	1,180
11/22/80	3,920	3,110	1,140	1,100					
11/23/80- at hatchery low flow	2,020	1,200	740	735	11/27/79- at the hatchery low flow	430	320	291	291
December 1980					December 1979				
12/4/80	4,150	3,260	1,200	1,160					
12/8/80	4,400	3,900	1,280	1,280					
12/23/80	3,125	320	1,400	1,320					
January 1981	-	-	-	-	January 1980	348	80	58	19
February 1981 at hatchery low flow	100	<50	15	15	February 1980	-	-	-	-

Note:
All values in ppb.
Total Fe = Fe_t, Dissolved Fe = Fe_d, Total Mn = Mn_t, Dissolved Mn = Mn_d.

Table 5.16. Analyses of Livers of One-Year Old Wytheville Strain Rainbow Trout Taken from Buford Trout Hatchery, Georgia, November 11, 1980

Element	Replicate No. 1B	2B	3B	4B	5B	6B	7B	8B	9B	10B
Silver (Ag)	<.5	<.5	<1.8	<.4						
Arsenic (As)	<1.1	<1.2	<4.5	<1						
Barium (Ba)	<1.1	<1.2	<4.5	<1		see Note 4				
Beryllium (Be)	<.5	<.5	<1.8	<.4						
Cadmium (Cd)	<.5	<.5	<1.8	<.4						
Cobalt (Co)	<1.1	<1.2	<4.5	<1						
Chromium (Cr)	<.5	<.5	<1.8	<.5						
Copper (Cu)	84	108	174	65	57	73	65	59	116	85
Molybdenum (Mo)	<1.1	<1.2	<4.5	<1						
Nickel (Ni)	<1.1	<1.2	<4.5	<1						
Lead (Pb)	<1.1	<1.2	<4.5	<1						
Antimony (Sb)	<1.1	<1.2	<4.5	<1						
Selenium (Se)	<1.8	<2	<7.1	<1.7		see Note 4				
Strontium (Sr)	<.5	<.5	<1.8	<.4						
Thallium (Tl)	<.5	<.5	<18	<4						
Vanadium (V)	<.5	<.5	<1.8	<.4						
Yttrium (Y)	<.5	<.5	<1.8	<.4						
Zinc (Zn)	27	29	37.6	20	22	21	13	16	30	23
Calcium (Ca)	54	60	-	48	90	-	34	39	50	54
Magnesium (Mg)	194	225	250	131	182	140	88	119	214	174
Aluminum (Al)	14	14	-	8.7	9	-	4.5	7.8	8.4	12
Iron (Fe)	27	30	-	35	36	-	19	23	42	31
Manganese (Mn)	2.2	3.1	-	2.4	2.7	-	1.3	2	3	2.6
Sodium (Na)	811	950	-	419	436	-	316	390	924	814

Note:

1. All values ppm (ug/g) wet weight.
2. Each analysis was performed on a pooled sample of three trout livers.
3. - = no analysis
4. Blank = EPA reported as below detection, giving only the first four columns to show approximate detection limits.
5. Replicate code, e.g., replicate no. 18 = pooled sample number one from Buford Trout Hatchery.

Table 5.17. Analyses of Livers of One-Year Old Wytheville Strain Rainbow Trout Taken from Walhalla National Fish Hatchery on November 20, 1980

Metal	Replicate No. 1W	2W	3W	4W	5W	6W	7W	8W	9W	10W
Silver (Ag)	<.2									
Arsenic (As)	<.6									
Barium (Ba)	<.6				see Note 4					
Beryllium (Be)	<.2									
Cadmium (Cd)	<.2									
Cobalt (Co)	<.6									
Chromium (Cr)	<2.3									
Copper (Cu)	15	23	30	20	20	25	15	21	14	20
Molybdenum (Mo)	<.6									
Nickel (Ni)	<.6									
Lead (Pb)	<.6					2				
Antimony (Sb)	<.6									
Selenium (Se)	<.9									
Strontium (Sr)	<.2				see Note 4					
Thallium (Tl)	<2.3									
Vanadium (V)	<.2									
Yttrium (Y)	<.2									
Zinc (Zn)	12	11	12	9.5	16	12	8.6	7.4	11	12
Calcium (Ca)	49	27	35	36	-	49	28	44	43	36
Magnesium (Mg)	107	91	98	84	100	98	75	58	95	105
Aluminum (Al)	3.6	7.4	6.3	2.1	13	5.5	<4	<5.5	7.7	6.0
Iron (Fe)	30	44	41	30	29	47	20	33	22	46
Manganese (Mn)	<1.2	<1.2	<1.6	<1	-	<1.1	<1	<1.4	<1.3	<1
Sodium (Na)	512	420	442	400	494	558	344	275	461	545

Notes:

1. All values ppm (ug/g) wet weight.
2. Each analysis was performed on a pooled sample of three trout livers.
3. - = no analysis
4. Blank = EPA reported as below detection, giving only the first four columns to show approximate detection limits.
5. Replicate code, e.g., replicate 1W = pooled sample number one from Walhalla National Fish Hatchery.

Table 5.18. Comparisons of Liver Metals Contents for Yearling Rainbow Trout from Buford Trout Hatchery (B), Georgia, Versus Walhalla National Fish Hatchery (W) for Metals above Detection Limits, November 1980

Element	Means ($\bar{x}$) ppm wet weight		Variances (s^2)				Student's t	
			$\bar{x}$		$\ln \bar{x}$			
	B	W	B	W	B	W	$\bar{x}$	$\ln \bar{x}$
Aluminum (Al)	9.8	6.1	10.9	8.8			2.50*	
Calcium (Ca)	53.6	38.6			0.09	0.05		2.48*
Copper (Cu)	88.6	20.3			0.13	0.06		10.62***
Iron (Fe)	30.4	34.2	54.8	95.5			0.94 n.s.	
Magnesium (Mg)	171.7	91.1			0.11	0.04		5.07***
Manganese (Mn)	2.4	1.2			0.04	0.01		6.01***
Sodium (Na)	632.5	445.1			0.20	0.05		1.70 n.s.
Zinc (Zn)	23.9	11.15			0.10	0.05		6.18***

Notes:

1. For Mn in livers from Walhalla, the detection limit was used as the value (all levels were below detection).
2. Ten analyses for each hatchery, each analysis on a pooled sample of 3 livers.
3. n.s. = not significant
4. * = significant $p < 0.05$ = significantly higher concentrations in trout from Buford Hatchery for this particular element.
5. *** = very highly significant $p < 0.001$ = significantly higher concentrations of these particular elements in trout from Buford Hatchery; the t-value is significant beyond the 0.01 level, but less than the 0.001.

Table 5.19. Results of Riverine Bioassays. Summary of Fish Survival, Physical Parameters, and Metals Concentrations in the Chattahoochee River Below Buford Dam, Georgia, November 23 to November 26, 1980

Station	Hours Into Bioassay 24 hour	48 hour	72 hour	96 hour
	Number Alive Rainbow Trout Swim-Up Fry (began with 80)			
1	80	80	80	80
2	60	34	6	1
3	0	0	0	0
4	61	14	8	5
5	58	4	1	0
6	65	4	1	0
7	69	8	5	4
8	76	22	20	19
	Number Alive Rainbow Trout Yearlings (began with 30)			
1	30	30	30	30
2	24	17	9	5
3	0	0	0	0
4	30	30	29	20
5	28	27	26	22
6	28	28	28	25
7	30	30	30	29
8	26	26	26	26

(Continued)

Table 5.19. Results of Riverine Bioassays. Summary of Fish Survival, Physical Parameters, and Metals Concentrations in the Chattahoochee River Below Buford Dam, Georgia, November 23 to November 26, 1980

Statistical Groupings of Stations

	24 hr.	48 hr.	72 hr.	96 hr.
RBT Fry	1 8 7 6 2 4 5	1 8 2 4 7 5 6	1 8 2 4 7 5 6	1 8 2 4 7 5 6
RBT Yearlings	1 4 7 6 5 8 2	1 4 7 6 8 5 2	1 7 4 6 8 5 2	1 7 8 6 5 4 2

Physical and Chemical Parameters

Station No. 5	24 hr. high flow	24 hr. low flow	48 hr. high flow	48 hr. low flow	72 hr. high flow	72 hr. low flow
Fe_t, ppb	-	2,020	600	1,980	760	2,200
Fe_d, ppb	-	1,020	165	1,125	280	1,340
Mn_t, ppb	-	740	185	730	300	810
Mn_d, ppb	-	735	160	730	270	790
Temp, °C	-	10.5	-	11.5	-	12.2
DO, ppm	-	5.4	-	5.1	-	5.4
pH	-	5.3	-	6.4	-	6.3
Station No. 7						
Fe_t, ppb	-	1,515	2,700	1,160	1,225	1,060
Fe_d, ppb	-	375	670	185	100	240
Mn_t, ppb	-	800	570	560	315	490
Mn_d, ppb	-	775	550	535	280	475
Temp, °C	-	10.0	-	11.5	-	11.0
DO, ppm, mg/l	-	7.3	-	6.5	-	7.7
pH	-	6.4	-	6.3	-	7.(

(Continued)

Table 5.19. Results of Riverine Bioassays. Summary of Fish Survival, Physical Parameters, and Metals Concentrations in the Chattahoochee River Below Buford Dam, Georgia, November 23 to November 26, 1980

Station Locations:

1. Control (at JEA Bioassay Facility on top of Buford Dam)
2. Sluice at Dam (immediately below Buford Dam)
3. River Station (300 meters downstream of Buford Dam)
4. Hatchery Raceway (Raceway 1 at Buford Hatchery, 2.5 km downstream of Buford Dam)
5. River Station at Buford Hatchery (2.5 km downstream of Buford Dam)
6. River Station at Settle's Bridge (7.5 km downstream of Buford Dam)
7. River Station at McGinnis Bridge (13.6 km downstream of Buford Dam)
8. River Station at Abbott's Bridge (22 km downstream of Buford Dam)

Notes:

1. Only six bluegills died in the November riverine bioassay with no statistical difference between stations.
2. No fish died in the February riverine bioassays (water quality data given in Appendix C).
3. RBT = rainbow trout; fry = swim-up fry.
4. Fe_t = total iron, Fe_d = dissolved iron, Mn_t = total manganese, Mn_d = dissolved iron, Temp. = temperature, DO = dissolved oxygen.
5. high flow = period of high flow in Chattahoochee River when peaking-power unit at Buford Dam is generating electricity. High flow periods are often for only a few hours duration and have variable occurrence based on electrical demand. High flow at full generating capacity is approximately 8,000 cfs.
6. low flow = period of low flow in Chattahoochee River when only maintenance unit at Buford Dam is generating electricity. Low flow periods are generally of much greater duration than high flow, and the low flow conditions predominate.
7. Dates of bioassay: 0 hour = November 22, 1980 (start of bioassay)
   24 hour = November 23, 1980
   48 hour = November 24, 1980
   72 hour = November 25, 1980
   96 hour = November 26, 1980
8. Statistical Groupings: horizontal lines beneath station numbers represent those stations not significantly different from each other at different times during the experiment.
9. All trout died due to low dissolved oxygen within 24 hours at Station 3. Therefore, no data exist for this station.

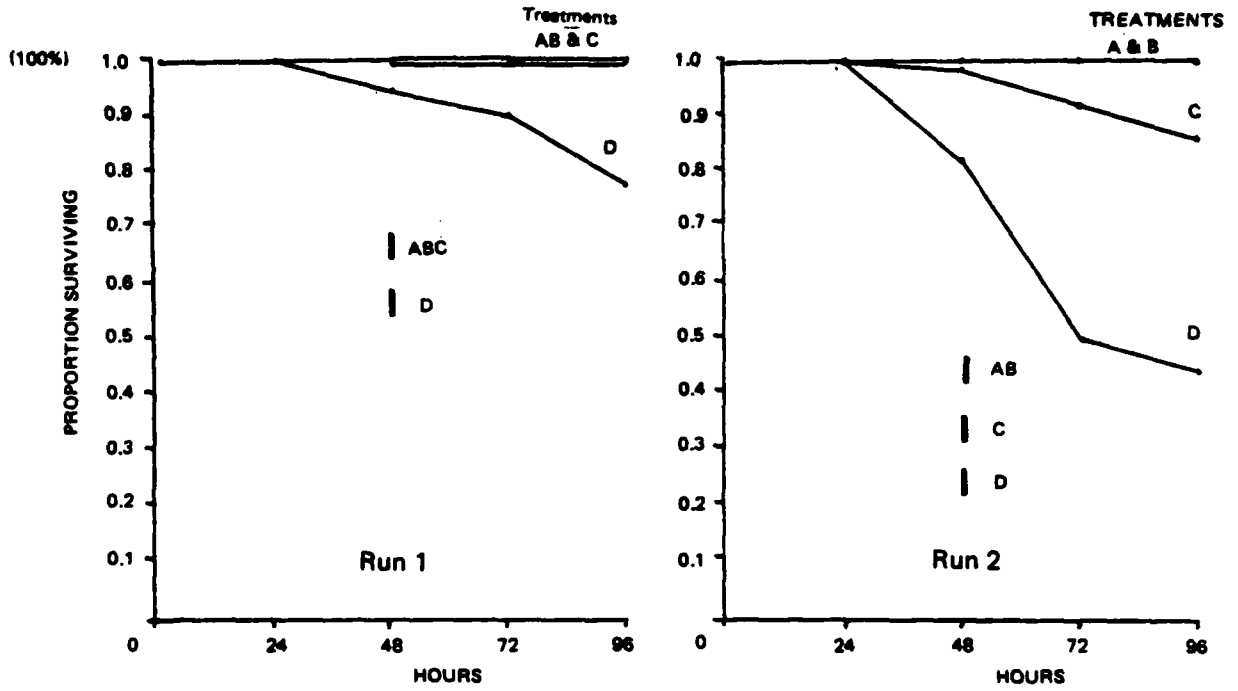


Figure 5.1a. Graphic Presentation of Survival Versus Time for Set I, Runs 1 and 2 Lake Sidney Lanier, Georgia, Fall 1980

48-Hr. Proportions Surviving are Listed Vertically in Same Order as Graph Lines Representing the Treatments. Vertical Lines to the Left of Letters Join Together Those Treatments Not Significantly Different From Each Other

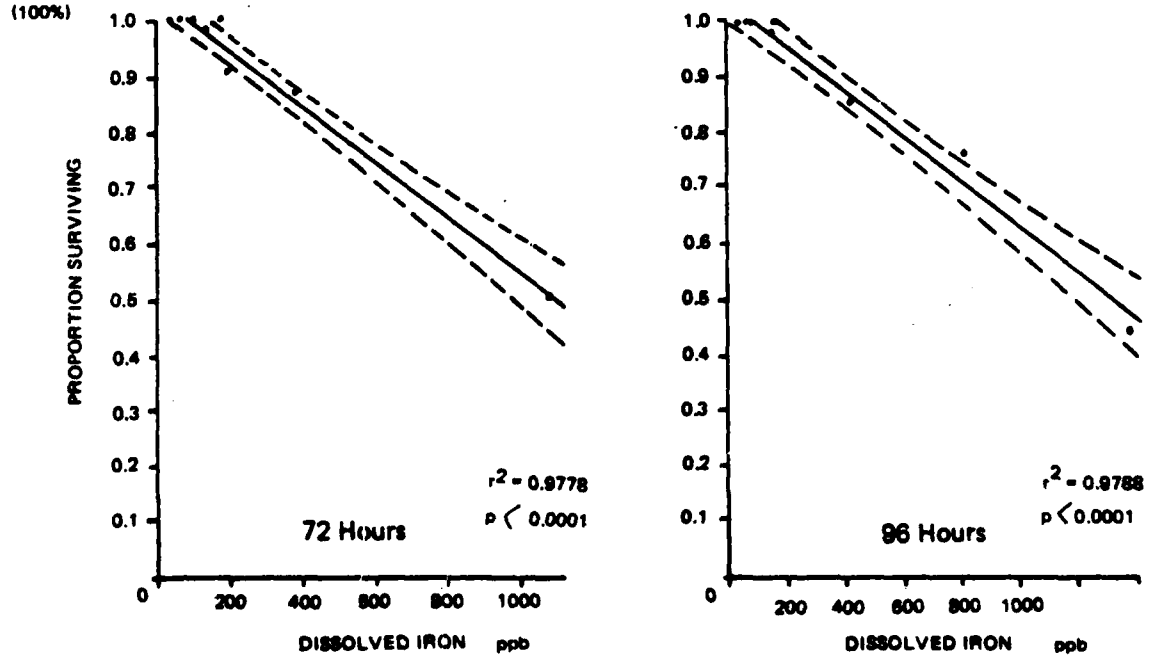


Figure 5.1b. Regressions of Survival Against Dissolved Iron Using Combined Run 1 and Run 2 Results at 72 Hours and 96 Hours into Bioassay, Lake Sidney Lanier, Georgia, Fall 1980

At Both 72 Hour and 96 Hour Dissolved Iron Concentration Explains 98 Percent of the Variability in Survival Rates With Narrow Confidence Limits (Dashed Lines) and High Probability ($p < 0.0001$)

Descriptions of Each Lettered Treatment are Given in Tables 5.7. and 5.2.

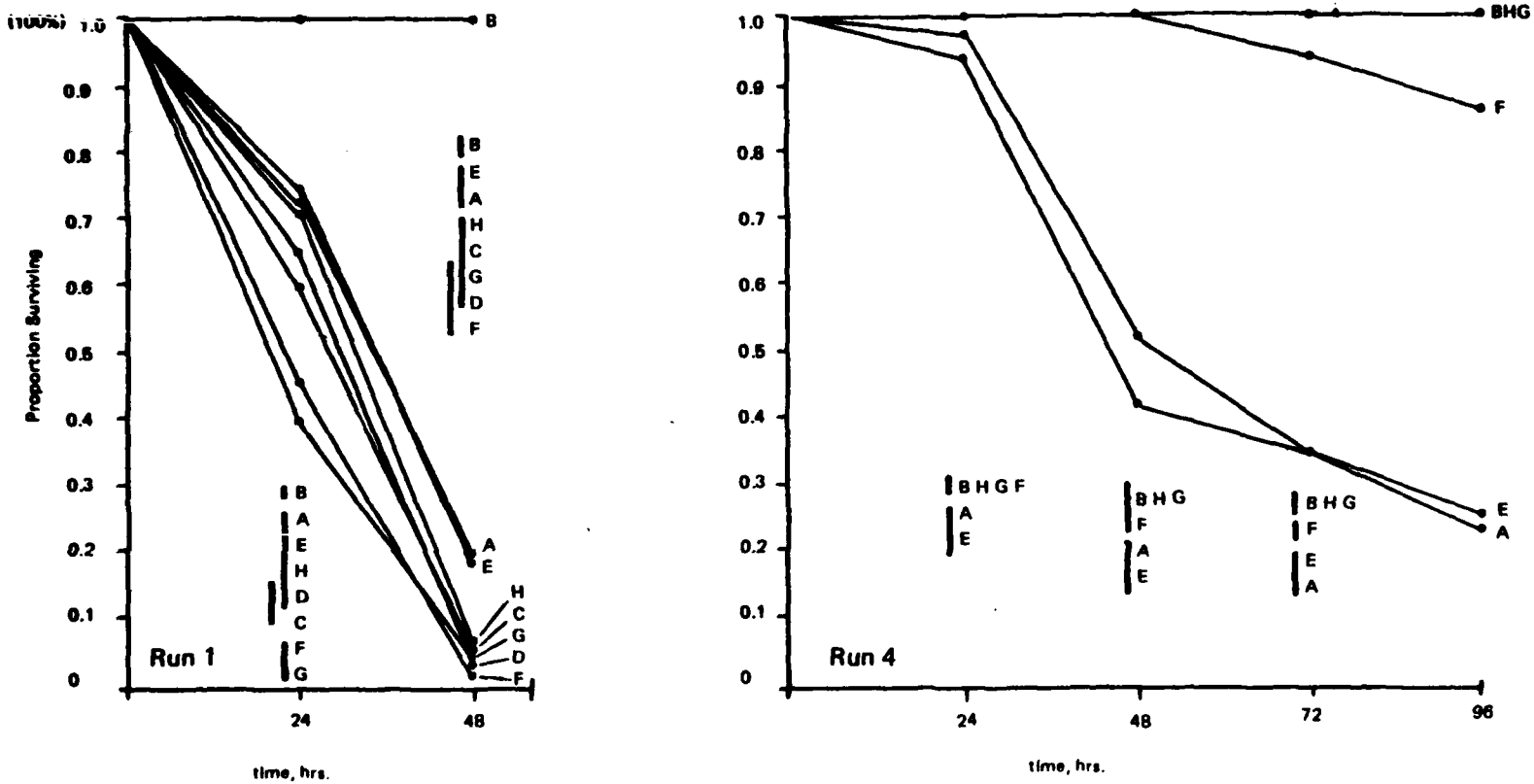


Figure 5.2a. Graphic Presentation of Survival Versus Time for Set II, Runs 1 and 4, Bioassay Results, Lake Sidney Lanier, Georgia, Fall 1980

Treatment letters are Listed Vertically in Same Order as the Graph Lines Representing the Treatments.
Vertical Lines at Left of Letter Columns Join Together Those Treatments Not Significantly Different From Each Other at Different Times During the experiment.
Treatments are Defined in Tables 4.2 and 5.3 - 5.6

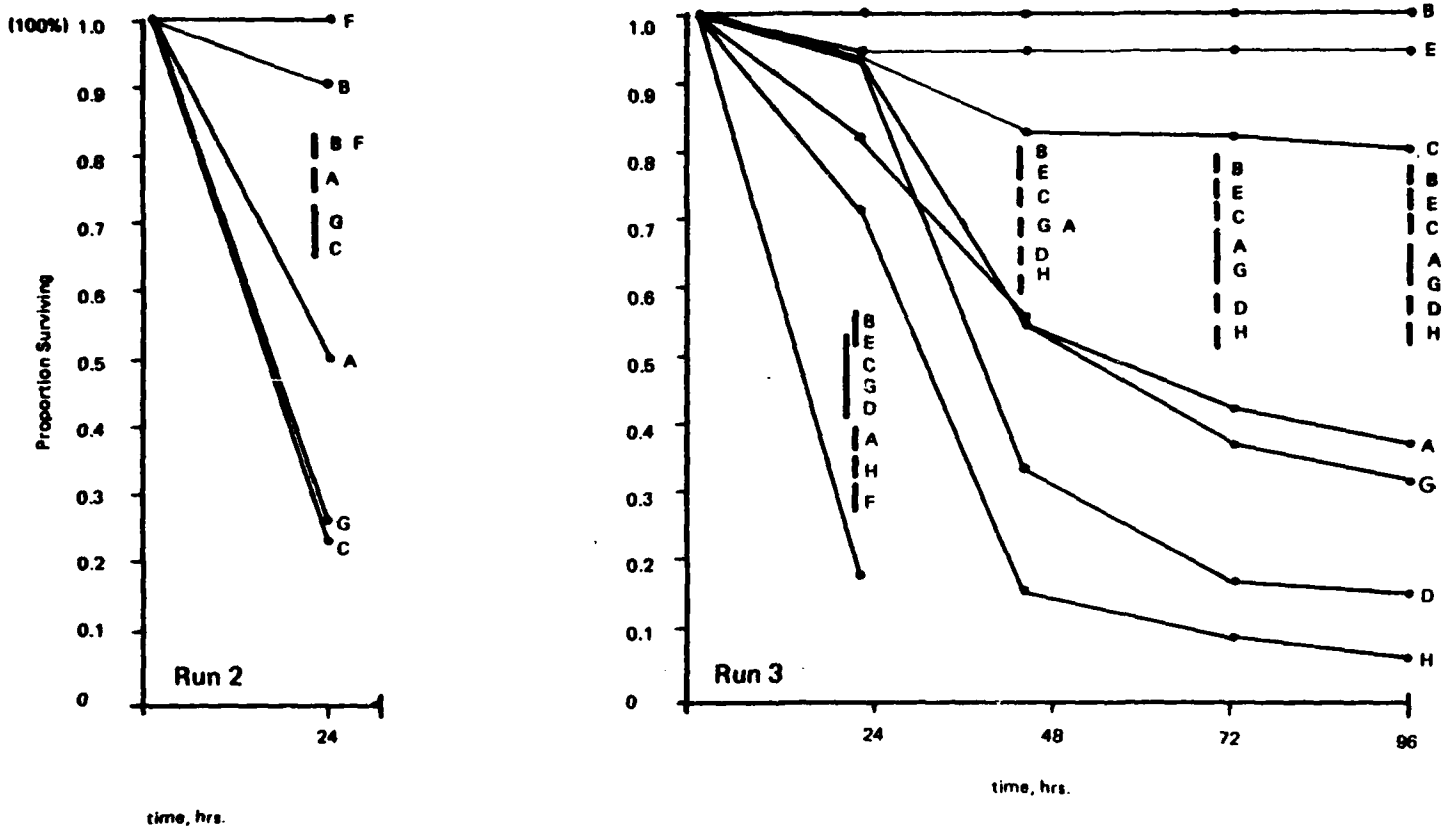


Figure 5.2b. Graphic Presentation of Survival Versus Time for Set II, Runs 2 and 3, Bioassay Results, Lake Sidney Lanier, Georgia, Fall1980

Treatment Letters are Listed Vertically in Same Order as the Graph Lines Representing the Treatments. Vertical Lines at Left of Letter Columns Join Together Those Treatments Not Significantly Different From Each Other at Different Times During the Experiment. Treatments are Defined in Tables 4.2. and 5.3. - 5.6.

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A BIOASSAY EXPERIMENT TO DETERMINE WATER QUALITY IMPACTS RELATE--ETC(U)
MAR 82 M E LEHMAN, M R CREZEE, R H JONES DACW01-80-C-0368

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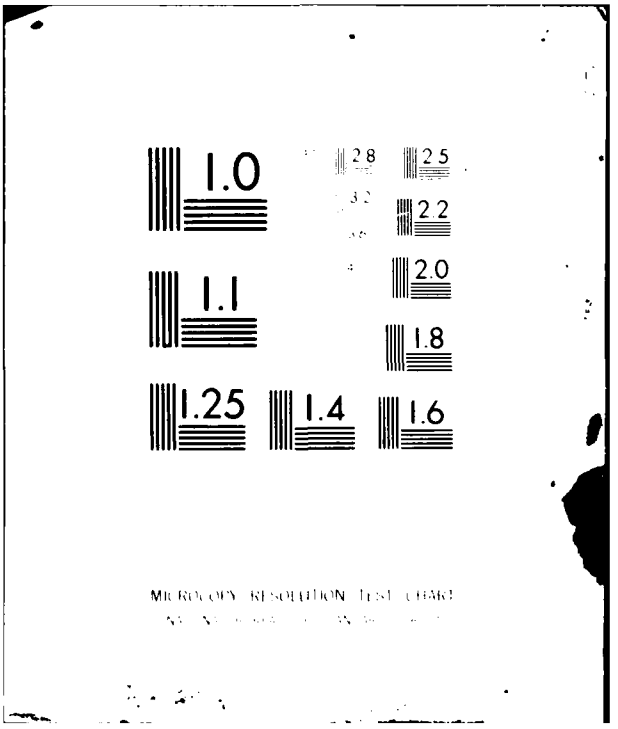
1.0
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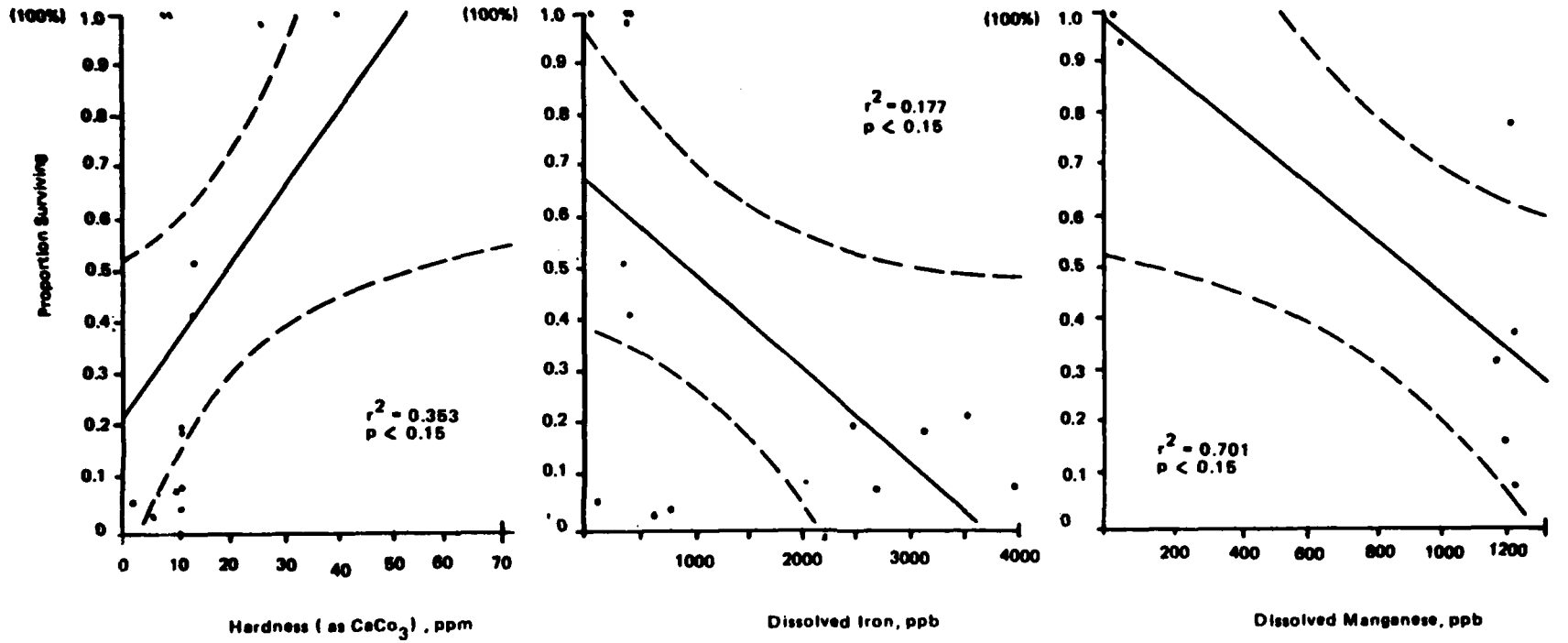
MICROCOPY RESOLUTION TEST CHART



a. 48-hrs. Into Bioassay, Hardness Explains 35.3% of Mortality

b. 48-hrs. Into Bioassay, Dissolved Iron Explains 17.7% of Mortality

c. 96-hrs. Into Bioassay, Dissolved Manganese Explains 70.1% of Mortality

95% Confidence Limits are Shown by Dashed Lines, Variability in Survival Between all Treatments in all Runs of Set II Bioassays; For Example: Combining all Data at 48 hrs. for all Runs of Set II, 35.3% of the Mortality Differences Between Treatments is Explained by Hardness Differences, 17.7% by Differences in Dissolved Iron, and None by Dissolved Manganese.

	24 Hour	48 Hour	72 Hour	96 Hour
Hardness	24.7%	35.3%	24.1%	22.0%
Fe_d	19.6%	17.7%	---	5.1%
Mn_d	---	---	66.8%	70.1%

Figure 5.3. Some Examples of Regressions of Survival Versus Hardness, Dissolved Iron and Dissolved Manganese Combining Data for All Four Runs of Set II Bioassays, Lake Sidney Lanier, Georgia, Fall 1980

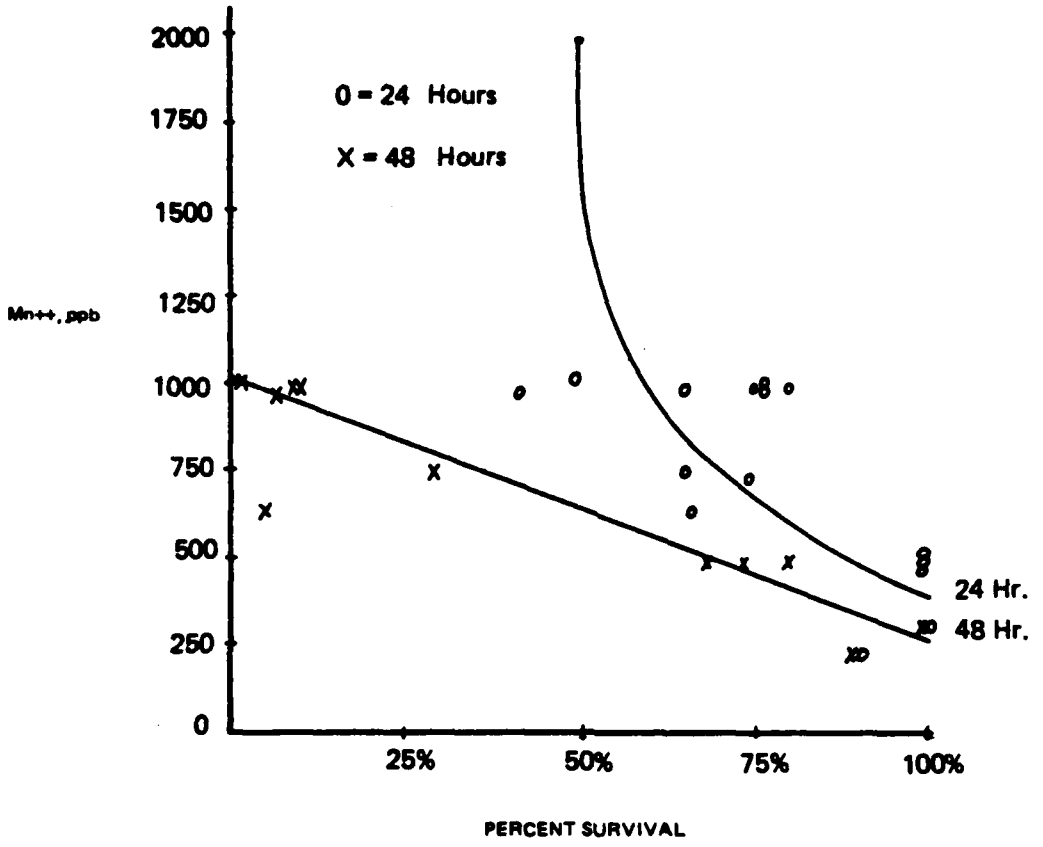


Figure 5.4. Graph of Percent Survival Versus Manganese Concentration in Static Bioassays, Lake Sidney Lanier, Georgia, Fall 1980

Lines are Hand Drawn From Visual Examinations
Manganese Was Added to Epilimnetic Water From Lake Lanier

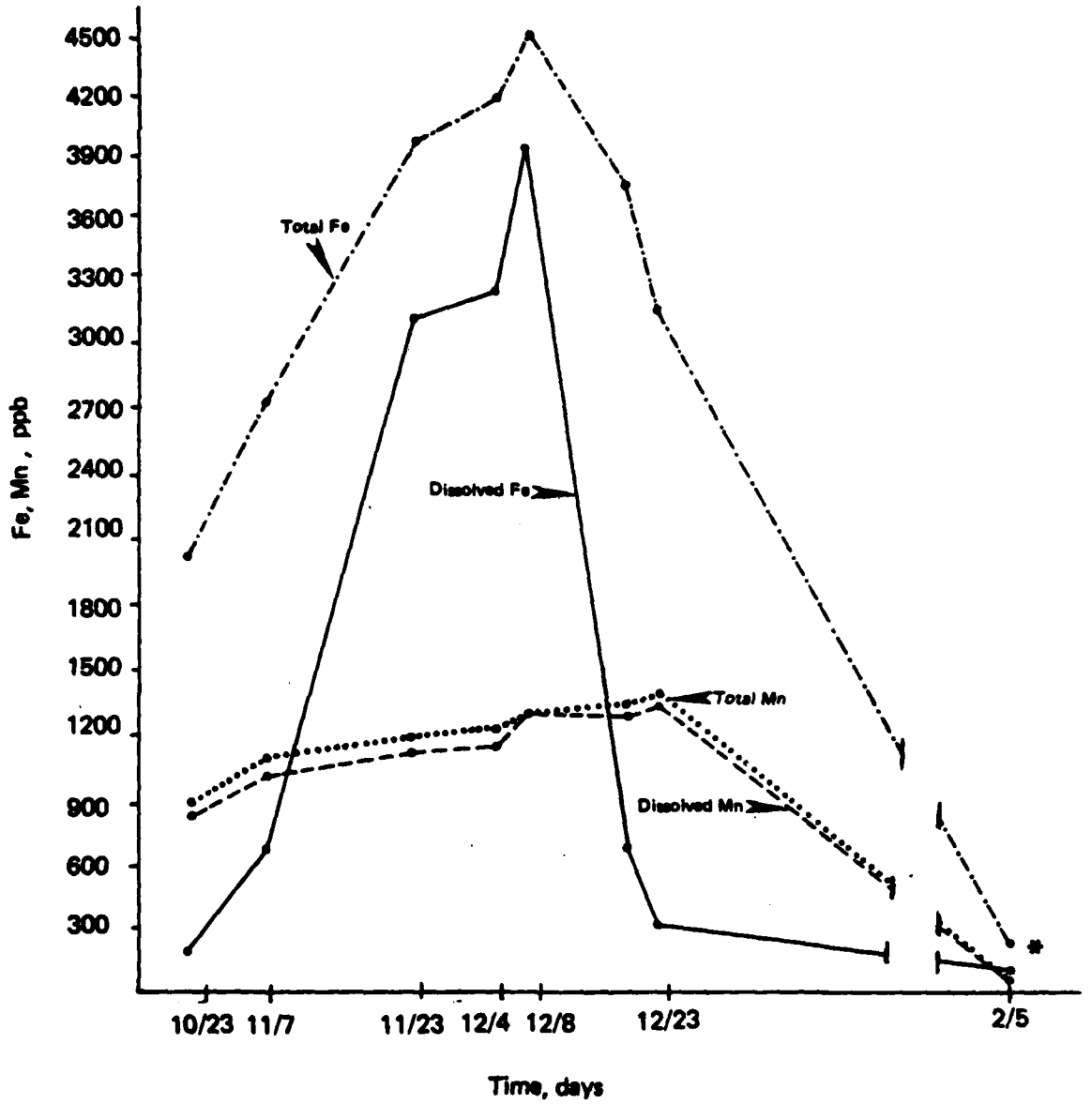


Figure 5.5. Iron and Manganese Concentrations in the Hypolimnion of Lake Sidney Lanier (35-Meter Water Depth) About 600 Feet (180 m) Behind Buford Dam, as Measured in Water Pumped Continuously into Bioassay Compound on Top of Buford Dam, Georgia, Fall 1980

Note:

1. Data for February Were Extrapolated From Measurements at the Hatchery (Low Flow) During Riverine Bioassay.

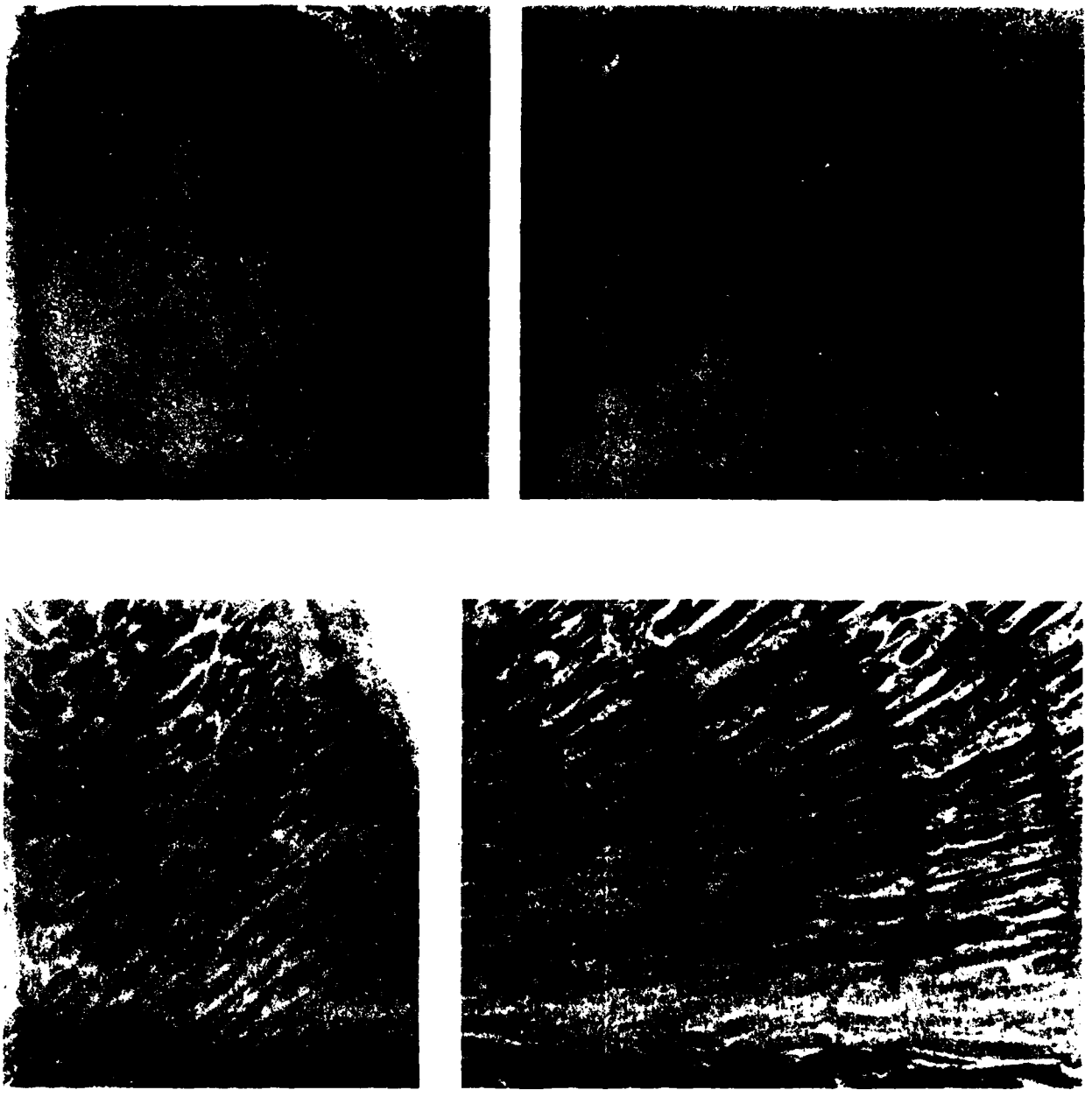


Figure 5.6. Photomicrographs of Eye and Muscle of Fry Taken From Set II Bioassays Performed at Buford Dam, Autumn 1980

KEY

A. Section Through Normal Eye.

B. Section Through Eye of Trout Fry from SII 1 A (Toxic Control) Showing Proliferation of Pigmented Layers (Arrow).

C. Muscle Bundles of Normal Trout.

D. Degenerating Muscle Bundles (Arrow) of Trout Fry from SII 1 A.

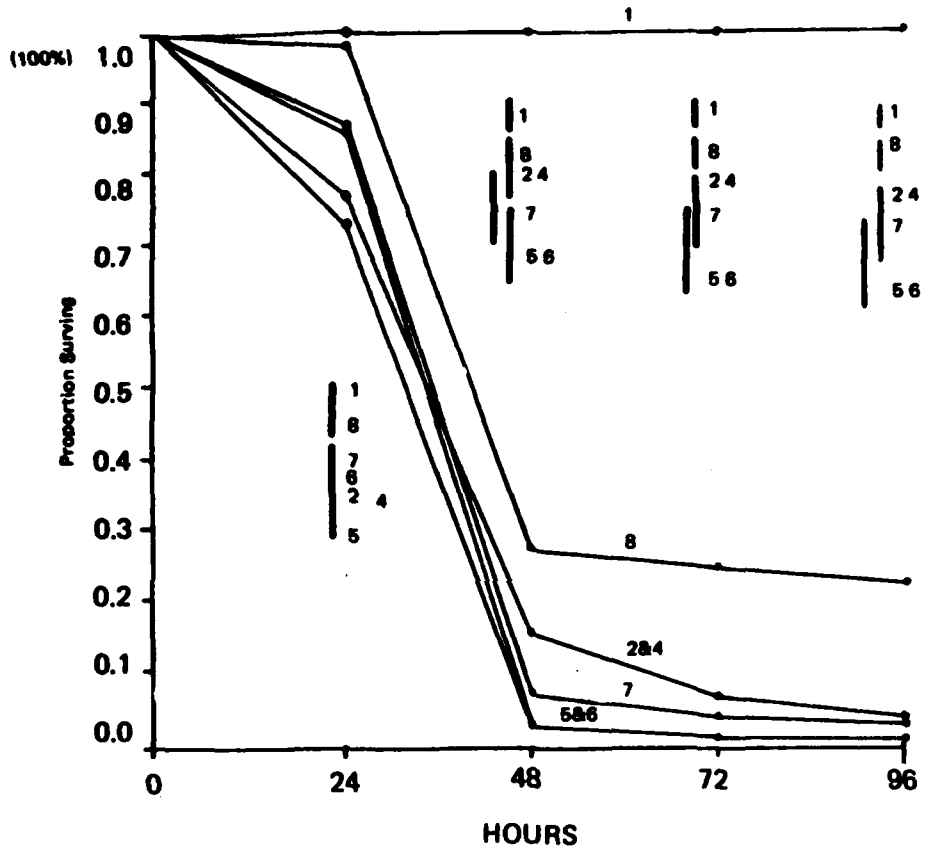


Figure 5.7a. Survival of Rainbow Trout Fry in the November 1980 Riverine Bioassays, Chattahoochee River, Georgia

1. The Station Numbers are Listed in Columns in the Same Order as Plot Lines for Each Time
2. When Plot Lines are Superimposed, Station Numbers are Listed on Same Line
3. Vertical Bars Group Together Stations not Statistically Different from Each Other
4. All Trout Died due to Low Dissolved Oxygen, Within 24 Hours at Station 3; Station 3 Values Were not Plotted for this Reason
5. Tabular Presentation of These Data in Table 5.19
6. Station 1 = Control; Station 2 = Sluice at Dam; Station 3 = 300m Downstream of Dam; Station 4 = Hatchery Raceway; Station 5 = 2.5km Downstream; Station 6 = 7.5km Downstream; Station 7 = 13.6km Downstream; Station 8 = 22km Downstream

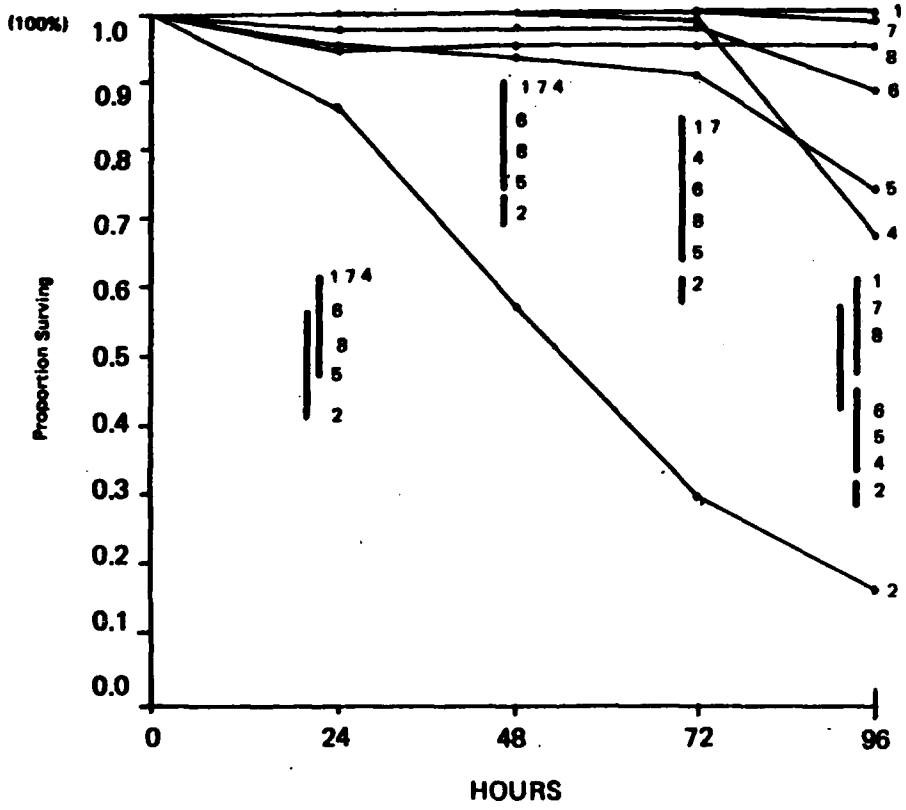


Figure 5.7b. Survival of Rainbow Trout Yearlings (15-cm Length) in the November 1980 Riverine Bioassays, Chattahoochee River, Georgia

1. The Station Numbers are Listed in Columns in the Same Order as Plot Lines for Each Time
2. When Plot Lines are Superimposed, Station Numbers are Listed on Same Line
3. Vertical Bars Group Together Stations not Statistically Different from Each Other
4. All Trout Died due to Low Dissolved Oxygen, Within 24 Hours at Station 3; Station 3 Values Were not Plotted for this Reason
5. Tabular Presentation of These Data in Table 5.19
6. Station 1 = Control; Station 2 = Sluice at Dam; Station 3 = 300m Downstream of Dam; Station 4 = Hatchery Raceway; Station 5 = 2.5km Downstream; Station 6 = 7.5km Downstream; Station 7 = 13.6km Downstream; Station 8 = 22km Downstream

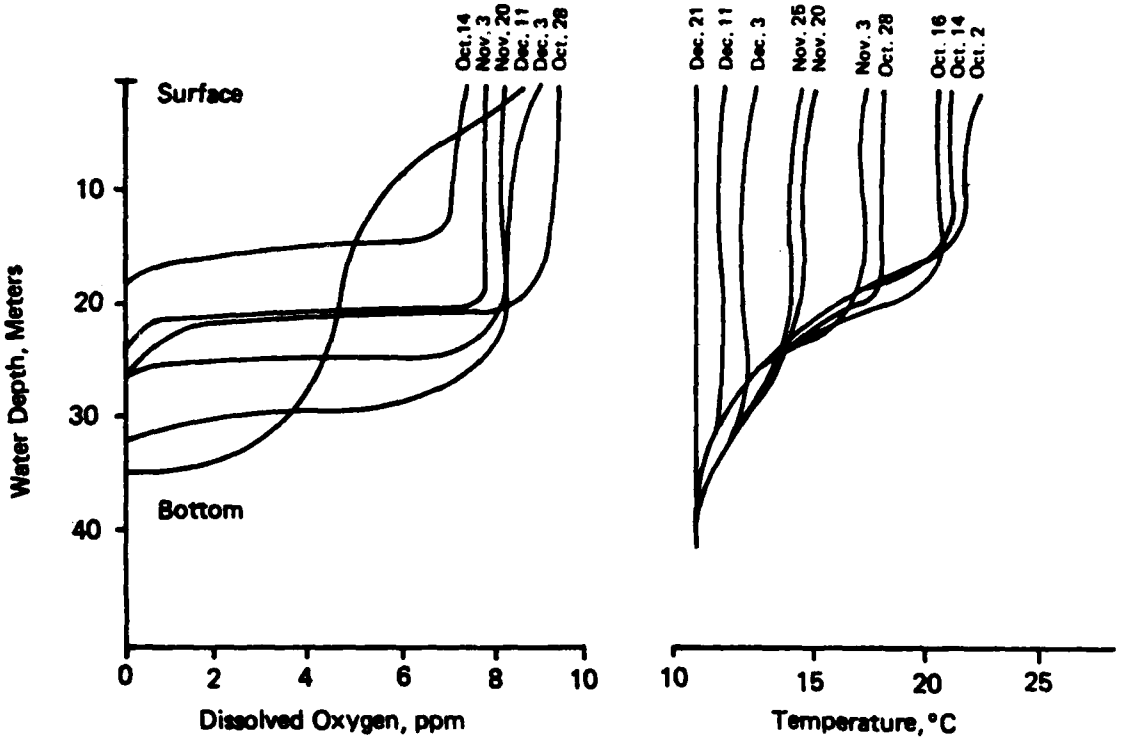


Figure 5.8. Temperature and Dissolved Oxygen Profiles from Lake Sidney Lanier, Sampled at JEA Laboratory Intake Buoy About 600 Feet (180 Meters) Behind Buford Dam, Georgia, Fall 1980

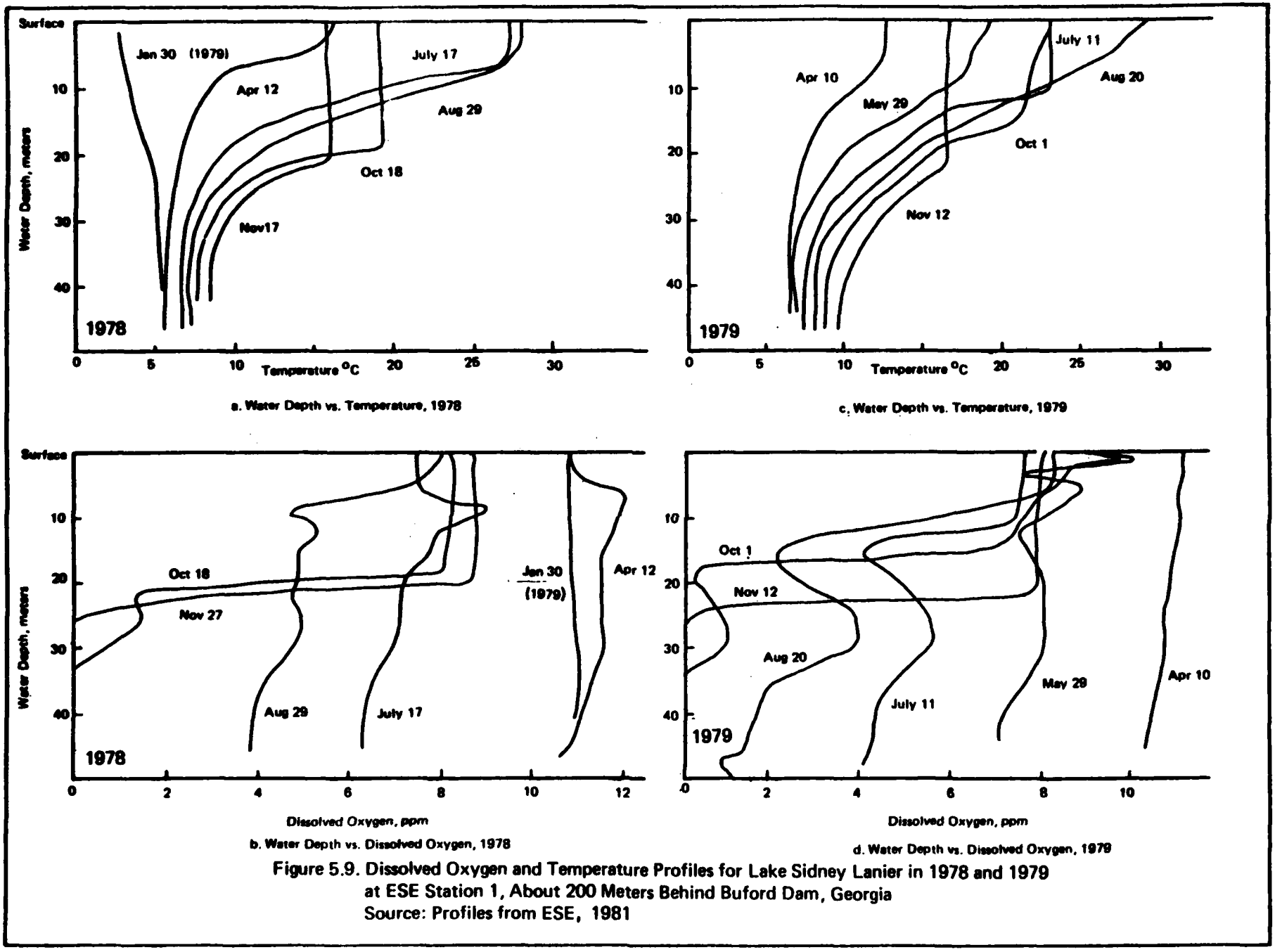


Figure 5.9. Dissolved Oxygen and Temperature Profiles for Lake Sidney Lanier in 1978 and 1979 at ESE Station 1, About 200 Meters Behind Buford Dam, Georgia
Source: Profiles from ESE, 1981

SECTION 6.0. DISCUSSION

6.0 DISCUSSION

6.1 MANGANESE AND IRON ARE TOXICANTS

Evidence that Mn and Fe are responsible for trout mortality at the hatchery is compelling. Only Fe and Mn have been found in high concentrations every autumn when mortality increases at the hatchery. Hatchery personnel have been able to predict the time of first mortalities by projecting date-concentration curves forward to Fe concentrations of 750 ppb or Mn concentrations of 500 ppb (Don Toney, p.c.). Approximately these same levels of Fe and Mn were found toxic in the laboratory bioassays.

Further, when Fe and Mn were removed by a resin column and hardness returned to its normal level, bottom water was no longer toxic to rainbow trout fry. Also, precipitating Fe and Mn by aeration at pH 11 and then filtering them out and returning to pH 6 removed all toxicity.

Finally, completely non-toxic epilimnetic water from Lake Lanier could be made acutely toxic by adding $MnCl_2$ or $FeCl_2$ to give the concentrations found in low flow river water in autumn. For epilimnetic water, the complicating possibility of some unknown toxicant or synergist produced by anoxic conditions or released from bottom sediments does not exist, yet Mn and Fe still are at least as toxic as in the river.

6.2 NO OTHER METALS ARE INVOLVED

Copper, zinc, and aluminum have at various times been reported at high concentrations in the lake, river, and/or hatchery. Mount *et al.* (1978) concluded that copper was the poison, because rainbow trout livers contained 400 to 500 ppm copper. U.S. EPA (1979) reported high levels of zinc (430-733 ppb) at the hatchery, and aluminum was once reported at 6 ppm at the city water intake, Atlanta (Mount *et al.*, 1978).

However, no metals other than Fe and Mn were above detection limits in the current study, yet the water was always toxic to rainbow trout fry. The water was frequently analyzed; stored water analyzed several times during storage was toxic, yet contained no metals except Fe and Mn at detectable levels. In this case, no occasional toxic pulses of Cu, Zn, or Al could have been missed.

Cu was always below detection. Zn was sporadically only slightly above detection, and the fact that all dissolved Zn values were higher than total Zn suggests that even these low levels may be due to an unidentified source of Zn contamination in the sampling procedure. Total Al never exceeded 250 ppb, and dissolved Al was seldom above the 25 ppb detection limit. Arsenic (As), lead (Pb), cadmium (Cd), chromium (Cr), and mercury (Hg)were not detected in any of the water samples.

Since these several metals were never detectable in water of demonstrated acute toxicity, the toxicity cannot be attributed to Al, As, Cd, Cr, Cu, Hg, Pb, or Zn, either singly or in combination.

6.3 NO ORGANICS INVOLVED

Since the 1976 hatchery experiments reported by Noell and Oglesby (1977) and Oglesby et al. (1978), toxicity has often been attributed to some organic interacting with manganese. After discussing results, Oglesby et al. (1978, p. 290) concluded that "in order to account adequately for these observations, it is necessary to postulate presence of an additional active material with the manganese... We postulate that this additional active substance is some form of humic material." However, postulating the presence of a humic material was not necessary. Their results (see Table 3.1) showed that increasing hardness to 70 ppm protected fish, that decreasing Fe^{++} by 67 percent and increasing alkalinity to 86 ppm protected fish, and that complexing metals with Na_4 EDTA gave at least temporary protection to fish. No humic material is necessary to explain these results.

Furthermore, explaining toxicity as manganese interacting with a humic from sediments or from decomposing organic material on the lake bottom is inconsistent with the demonstration in the static bioassays that Mn added to surface water is at least as toxic as an equivalent level of Mn in bottom water.

A conceptual problem with the humics hypothesis is that total organic carbon levels in Lake Sidney Lanier are low and that analyses have been unable to identify any humics. Analyses of the most toxic waters in Set I for volatile organic carbons, breakdown products of humic acid, found none. Examination of SII4 water by high pressure liquid chromatography, the appropriate technique for identifying humics, found no trace of humic substances.

Even if some humics were present, only a low level of complexes would be formed. In Lake Sidney Lanier, total organic carbon usually does not exceed 3 ppm. After experimenting with 3 ppm humic substances, Wilson (1978) concluded that "total metal concentrations... are comprised primarily of inorganic species. Humic complexes are present, but not in appreciable amounts". In Lake Erie sediments with approximately 2 percent humics less than 10 percent of total Mn may be bound to the humics (Nriagu and Coker, 1980). Thus, research suggests that even if all organics in Lake Lanier were humics, few metal-humic complexes would be present and that Mn-humic complexes would be few even at higher humic concentrations.

Furthermore, comparison of total and dissolved (0.1 µm filtered) Mn values shows no evidence of Mn-humic complexes. When Poldoski (1979) added cadmium and humic acids to Lake Superior water, he found a sharp drop in the amount of Cd passing a 0.1-µm filter as opposed to a 0.45-µm filter, showing that metal-humic complexes do not pass an 0.1-µm filter. In the current study, all samples for dissolved metals were filtered through a 0.1-µm filter, yet dissolved and total Mn almost always were within measurement error of being identical. When 0.1-µm and 0.4-µm filters were compared, both filters gave similar Fe_d and Mn_d concentrations (Table A-14), showing that there were no humic-metal complexes.

Finally, if humics were present and if Mn-humic complexes were formed, the result would be to decrease rather than to increase Mn toxicity. The results of Oglesby et al. (1978) showed that metals complexing by EDTA decreased toxicity. Even though copper is highly toxic, "it is now fairly well established that the organocupric complexes... are relatively nontoxic to fish and algae" (Wagemann and Barica, 1979, p. 519). For cadmium, five of six complexing agents decreased Cd uptake by Daphnia (Poldoski, 1979). The exception formed a hydrophobic complex retained by a 0.1-um filter (see above paragraph). In general, "the more strongly a metal is complexed, the lower the toxic effect" (Sposito, 1981, p. 396).

In summary, postulating the presence of a humic to explain results was not necessary. Few or no humics are found in Lake Sidney Lanier. At low levels of humics, only a small proportion of metals would be bound. The humics postulate is inconsistent with the facts that Mn added to surface water (no humics) is as toxic as Mn in bottom water (suggested humics) and that all Mn passes a 0.1-μm filter while Mn-humic complexes are retained on an 0.1-um filter. Finally, Mn-humic complexes would almost certainly be less toxic than free Mn^{++}, not more toxic, as postulated.

6.4 RESULTS APPLICABLE TO HATCHERY

The large differences in Mn toxicities between Lake Sidney Lanier waters and waters at Lake Burton Trout Hatchery (England, 1978) prove the necessity for having performed experiments on-site and using the same source of water used by the hatchery. However, several parallel observations at the hatchery and laboratory demonstrate that the short distance between Buford Dam and Buford Trout Hatchery is not important and that results of the bioassay studies on water from Lake Sidney Lanier are still directly applicable after the water flows 2.5 kilometers from the lake to the hatchery.

In the laboratory experiments where Mn levels varied, the acutely toxic level was found to be close to the 500 ppb Mn which hatchery personnel have found correlated with the onset of hatchery mortalities. (In round-robin tests, results are considered good if the highest LC_{50} is not more than twice the lowest LC_{50}, (Schimel, 1982).)

Low flow water in the river is drawn from several depths in the hypolimnion so that metals are more dilute than in full strength bottom water used in laboratory bioassays. However, even with this dilution, the river water is approximately as toxic as bottom water. The fact that toxicity does not decrease in proportion to dilution was also demonstrated in static bioassays in the laboratory, and the mortality rate in the river is roughly as would be predicted from the static bioassays.

In the laboratory, oxidation by prolonged aeration was found to cause an increase in toxicity. At the same time, oxidation by adding hydrogen peroxide to hatchery water caused an increase in mortality there.

In the laboratory, adding hardness was found to prevent mortalities. Noell and Oglesby (1977) reported the same results for the hatchery experiments in 1976.

The similarities between laboratory, hatchery, and river in metals levels found toxic, in dilution effects, in oxidation effect, and in effects of hardness additions can leave no doubt that the laboratory results are fully valid for both river and hatchery.

6.5 NEW QUESTIONS

In the course of answering the questions for which it was designed, any investigation finds new questions to pose. The primary new enigmas arising from the current study relate to why Mn and Fe are so toxic, why removing iron increases toxicity, why hardness removal so strongly affected the fish, and why experimental fish placed in the hatchery quickly died while hatchery fish did not.

The estimated 48-hour LC_{50} of 650 ppb Mn is far lower than the 24.7 ppm 96-hour LC_{50} for yearling rainbow trout (England, 1978) at Lake Burton Trout Hatchery (Georgia) where hardness was only 2 ppm or the 3.25 ppm Mn which over 72 hours had no effect on rainbow fry (Lewis, 1976) in distilled water. On the other hand, toxicity problems at Greer's Ferry National Fish Hatchery, Arkansas, were attributed to Mn concentrations of 1-2 ppm (Figure 6.1) at hardness of 12 to 35 ppm. Nix and Ingols (1981) reported no other metals in elevated concentrations, but few were measured. Toxicity problems at Greer's Ferry were never thoroughly investigated, and some toxic agent other than Mn remains a possibility. However, results of the current bioassays add credence to suggestions than Mn alone killed trout. Nix and Ingols (1981) suggested that differences in reported Mn toxicities could be explained if Mn were more toxic as it became more highly oxidized. However, it does not seem likely that Mn recently released from the anoxic hypolimnion of Lake Sidney Lanier would be more oxidized than Mn added in laboratory bioassays by Lewis (1976) and England (1978), nor does it seem likely that oxidation states would differ substantially between the current laboratory experiments and those of Lewis and of England. Since differences in the oxidation state of Mn seem unable consistently to explain the large differences in Mn toxicities, the differences must for now remain unresolved, for no other explanation is apparent.

In treatment SII4H, an activated carbon column removed all Fe from hypolimnetic water but left hardness and Mn levels unchanged. This Fe removal increased toxicity and the toxicity of the Mn alone was near that predicted from the static experiments. Prolonged aeration decreased Fe_d concentrations in two cases out of three and in those same two cases also caused an increase in toxicity (SII1D and SII3D versus SII4E). Static experiments indicated that at moderate levels, Mn and Fe toxicities were additive. This finding makes a protective effect of high Fe against high Mn seem improbable, but such a protective effect is the only readily apparent explanation for toxicity increase associated with Fe removal. Such a protective effect also was suggested by the comparison of different untreated waters (Table 5.6) because survival was anomalously low in SII4 where Fe but not Mn also was low.

When resin columns decreased hardness from 12 ppm down to 2-4.5 ppm, fish died quickly even though all Fe and Mn also were removed. The excellent survival rate obtained by adding back the hardness (SII3E) shows that the low hardness does explain the high mortalities. However, Lake Burton hatchery, where England (1978) found the 96-hour LC_{50} to be 24.7 ppm Mn, raises rainbow trout at a hardness of 2 ppm, and Lewis (1976) found no effects transferring rainbow trout fry from 5 ppm hardness into 3.25 ppm Mn in distilled water. An obvious explanation would be that it was not 4 ppm hardness that was lethal but rather the abrupt change from 12 ppm to 4 ppm. The reservations in accepting this explanation are that the absolute change is small and that, while the relative change is large, it seems no greater than in Lewis' transfer of fish from 5 ppm to distilled water.

It may seem inconsistent that experimental rainbow trout held in the hatchery died quickly at a time when the hatchery recirculated water and lost few fish. However, the hatchery was raising mostly brook trout, which are considerable less sensitive to metals than rainbow trout (Chapman, 1978), and the fewer rainbow trout at the hatchery were larger and therefore less susceptable to metals than were even the yearling experimental trout.

Metals levels at the hatchery could have been near those in the river because the previous high-flow period, during which water had been drawn from the Chattahoochee River, was one of little flow increase and would have given less than usual dilution of hypolimnetic water. Also, the hatchery was not on complete recirculation; low flow water was drawn continuously at 10 percent of the normal intake rate.

6.6 RIVERINE DISCUSSION

The intent of the riverine bioassay was primarily to document fish mortalities in the river and secondarily to determine the extent of the effects downstream. The results of the in situ bioassays conducted in late November showed that the conditions in the Chattahoochee River produced trout mortalities in an area from Buford Dam downriver to Abbotts Bridge. Seventy-five percent of the swim-up fry and 13 percent of the larger trout died at Abbotts Bridge, the bioassay station located furthest downriver from the dam (13.5 miles). As expected, no mortalities were observed during Run 2 (February) after Lake Lanier had completely destratified resulting in a sharp decrease in the concentration of Fe and Mn in the river.

In the riverine bioassays, the swim-up fry were considerably more sensitive to toxicity than were the larger trout (Figure 5.7). Similar results were obtained in a study by Howarth and Sprague (1978) in which smaller fish were found to be more sensitive to metal toxicity than were larger members of the same species.

Introduced trout and native yellow perch both show histopathology probably attributable to metals (Grizzle, 1981). However, all yellow perch and some trout tagged and recaptured from the first 18 km below Buford Dam showed weight gains, although many trout, especially rainbows, lost weight (Gilbert and Reinert, 1979). The 28 species of fish

taken by electrofishing in fall 1977 were considered to represent a depauperate fauna (Gilbert and Reinert, 1979). Ten times as many invertebrates settled on artificial substrates 18 km below the dam as at any of the 3 stations nearer the dam (Gilbert and Reinert, 1979), but diversities were the same at all four stations. All four stations were upstream of the point where a toxicity decrease was found in the in situ bioassay experiments reported herein, and no comparisons were made with other streams.

Available evidence suggests that fauna in the Chattahoochee River is a depauperate and species-poor fauna with animals in sub-optimal health for an undetermined but significant distance below Buford Dam. However, the severity of the impact is not established, and how much impact is due to toxicity, how much to low DO, and how much to other factors is not known. Other aspects of hypolimnetic releases shown to impact fauna include large and rapid changes in flow (Fisher and LaVoy, 1972; Kroger, 1973; Minshall and Winger, 1968), alteration of annual temperature regime (Lehmkuhl, 1972; Ward, 1974, 1976; Gore, 1977), and decreases in the amount and variety of suspended matter (Ward, 1976).

6.7 WATER QUALITY IMPACTS ON THE RIVERINE SYSTEM

Since completion of Buford Dam and creation of Lake Sidney Lanier in 1957, the Chattahoochee River for 50 miles below Buford Dam has been stocked with trout and has become a popular "put and take" trout stream. No water quality impacts were obvious until a commercial trout fish-out operation and later Buford Trout Hatchery commenced operations 1.5 to 2 miles below the dam and suffered heavy losses of trout in the fall of the year.

Riverine bioassays showed that in autumn the Chattahoochee River water is acutely toxic to trout, which are stocked into the river, but that bluegills, which occur naturally in the river, were much more resistant and survived the 96-hour riverine bioassays. Similarly, Gilbert and Reinert (1979) found that many tagged trout, especially rainbow trout, lost weight between recaptures below Buford Dam but that all of the native yellow perch gained weight.

Gilbert and Reinert (1979) also examined invertebrates colonizing artificial substrates collected monthly September through December after one month in the Chattahoochee River either 100 m, 3.1 km, 8.6 km, or 18 km below Buford Dam. Ten times as many invertebrates colonized the 18-km station as colonized the other three stations, but diversities were the same at all stations. All stations were upstream of the point where toxicity decrease was detected in the riverine bioassays.

The sparseness of the fauna below Buford Dam and the results of the riverine bioassays strongly suggest impact of the hypolimnetic releases on the Chattahoochee River. However, without comparisons with data from similar rivers (where impacts are not suspected), and considering the limited amount of comparative literature applicable to this case, firm conclusions cannot be made.

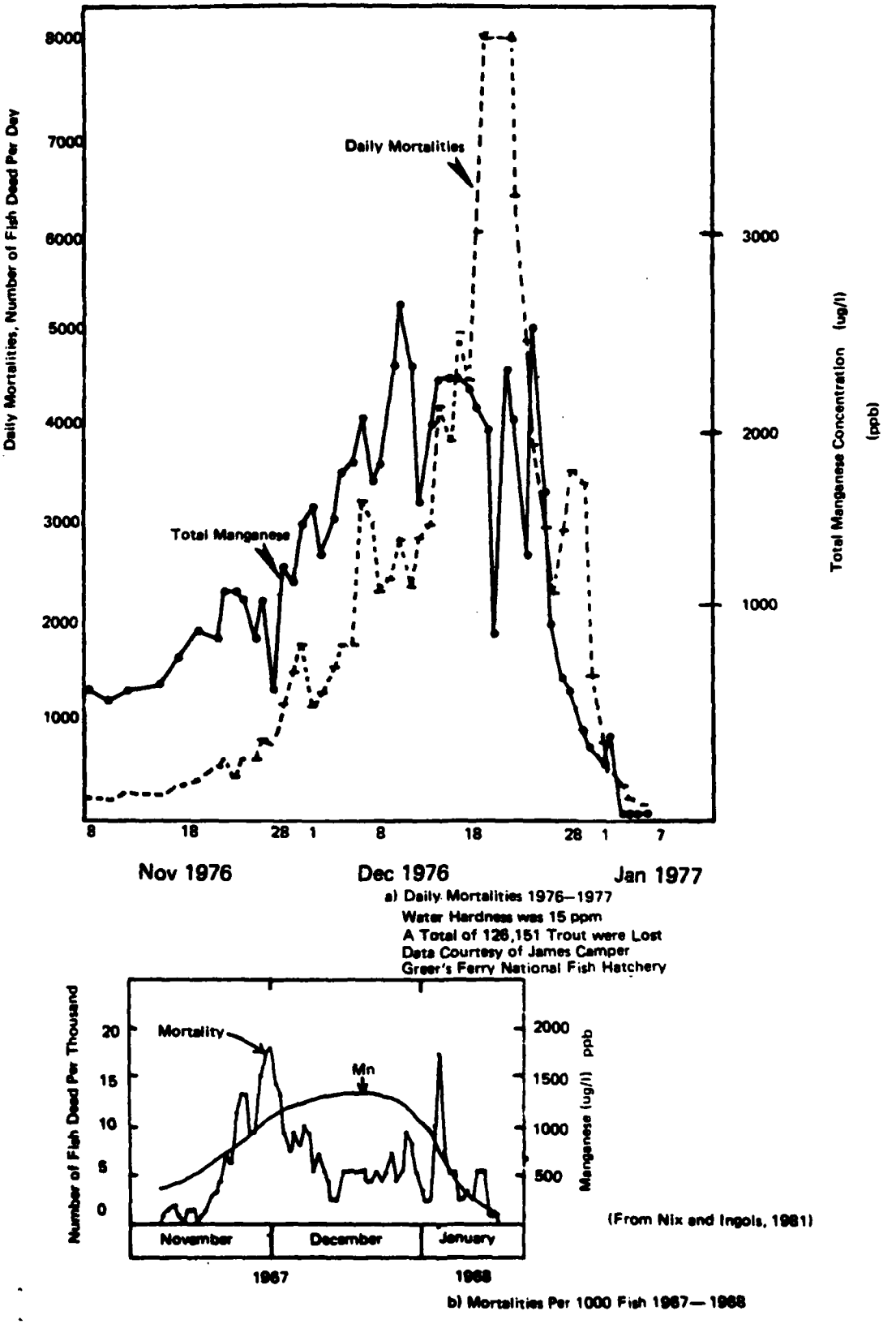


Figure 6.1. Manganese Concentrations and Total Mortalities at Greer's Ferry National Fish Hatchery, Arkansas, a) November 8, 1976, to January 5, 1977, and b) November 1967 to January 1968

SECTION 7.0. CONCLUSIONS

7.0 CONCLUSIONS

1. In numerous chemical analyses of toxic waters from Lake Sidney Lanier, iron and manganese were the only potential toxicants found, and they were consistently present in high concentrations in toxic waters.

2. Experiments adding iron and/or manganese to epilimnetic water demonstrated that the levels of iron and manganese in Lake Sidney Lanier and in the Chattahoochee River can explain all observed toxicity.

3. Removing metals from toxic water rendered it non-toxic if hardness was not also decreased, but removing organics had no effect.

4. Adding 25 ppm hardness to bottom water was completely effective in preventing trout mortality for at least 96-hours.

5. At low-flow in autumn Chattahoochee River water is acutely toxic to rainbow trout especially yearlings and fry but not to bluegill sunfish. The toxicity is moderately reduced 23 km downstream from the dam.

6. Of the eight detectable metals out of the 24 for which trout livers were analyzed, two (Na, Fe) did not differ between hatcheries while six were significantly higher at Buford. Results were considered inconclusive and perhaps explainable on the basis of high Mn at Buford Trout Hatchery.

SECTION 8.0. RECOMMENDATIONS

8.0 RECOMMENDATIONS

The results of this investigation have led to several potential alternatives to solving the toxicity problems at the Buford Trout Hatchery. Some of these alternatives have already been implemented at Buford Trout Hatchery or at other dams around the country.

Potential alternatives include management changes at the hatchery, treatment of hatchery intake water, use of an alternate source of water, treating water at the dam or reservoir, or creating non-toxic mixes of hypolimnetic and epilimnetic water.

8.1 MANAGEMENT CHANGES

Past modifications to management practices at Buford Trout Hatchery have been partially satisfactory. By drawing in water during high flow conditions and recirculating during low flow, the hatchery has been able to limit losses of fish. The U.S. Army Corps of Engineers have cooperated in the past with special high flow releases even when power was not needed. Recirculation requires reduced loading rates, so the hatchery must operate below capacity.

In 1980, the hatchery stocked mostly brook trout rather than rainbow trout because brook trout showed less sensitivity to low flow waters. Brook trout mortalities in 1980 were above normal; at times the trout became so excitable feeding had to be discontinued for several days.

Changes in management practices have provided interim, temporary, and partial reduction in trout mortality problems at Buford Trout Hatchery. Recirculation during high flow, special releases (when feasible), raising brook trout rather than rainbow trout, and operating at reduced loading should be continued on an interim basis until feasibility studies can be completed for a permanent alternative. Management changes alone do not provide a totally satisfactory cost-effective, long-term solution to the toxicity problem.

8.2 TREATMENT OF HATCHERY INTAKE WATER

The removal of Fe and Mn from water entering the hatchery is an alternative. Fe and Mn may be removed by oxidation followed by either sedimentation or filtration of the oxidized metals. The rate of oxidation is pH dependent, especially for Mn; pH adjustment, adequate detention time and filtration facilities would have to be constructed. Preliminary engineering design and cost estimates would be necessary to determine the cost-effectiveness of this alternative.

The addition of hardness to the water entering the hatchery can prevent toxicity. Because the problem is a seasonal one, the addition of hardness (in this case, calcium) could possibly have the lowest initial cost as well as operating cost. Potential chemicals include, but are

not limited to, $CaCO_3$, $CaCl_2$, and $CaSO_4$. Engineering design and cost estimates would have to be performed for this alternative.

8.3 ALTERNATIVE SOURCES OF WATER

A new source of water for the hatchery could be created by installating a multi-level intake structure on Buford Dam so that all water released would be a mix of epilimnetic and hypolimnetic water (similar to mix of water currently released at high flow).

Another source that should be considered includes a pipeline to carry a non-toxic mix of cool water from the reservoir to the hatchery. The pipeline could possibly be constructed to siphon water from the reservoir to the hatchery.

Temperature studies and engineering conceptual design and cost studies would have to be performed for the multi-level intake and pipeline alternatives.

Installing a well is another feasible alternative if a suitable groundwater source is available. Water quality and quantity studies of the local aquifiers would have to be conducted in conjunction with engineering design and cost studies for this alternative.

8.4 TREATMENT OF WATER AT DAM OR RESERVOIR

Aerating river water at the dam or in proximity to the penstocks would add oxygen to the water and reduce the problem of low dissolved oxygen in the river immediately downstream; however, this aeration may exacerbate toxicity problems at the hatchery, as evidenced by the toxicity increases associated with prolonged aeration without sufficient sedimentation or filtration. If sedimentation and filtration systems were constructed at the hatchery, then aeration at the dam could be considered feasible. Possibilities for aeration include but are not limited to: pulsed injections of oxygen close to penstocks, turbine modifications to draw in air, and rip-rap in the tailrace to create turbulence. Each alternative would have to be evaluated through conceptual engineering design and cost studies in conjunction with similar studies for sedimentation and filtration of hatchery intake water.

Seasonal aeration of a portion of Lake Sidney Lanier to prevent or to disrupt oxygen stratification and avoid creation of an anoxic hypolimnion could prevent reduction and solubilization of Mn and Fe. This alternative could reduce or eliminate problems in both river and hatchery. Air or pure oxygen can be introduced into the hypolimnion such that no temperature destratifying turbulence is created. Air is less expensive than oxygen, but hypolimnetic aeration produces nitrogen supersaturation which can be toxic to fish. Studies would have to be conducted to compare feasible approaches to this alternative, such as oxygen injection into a hypolimnetic diffuser system compared with surface aerators. Some studies of this type have been conducted by the

U.S. Army Corps of Engineers, Savannah, in Clark Hill Lake. Conceptual engineering design and cost studies will also be necessary.

8.5 RIVERINE CONSIDERATIONS

Additional studies are necessary for the Chattahoochee River system to determine specific measures to mitigate riverine impacts due to Fe and Mn. The extent, nature, and cause(s) of impacts must be identified and clarified. The available evidence suggests that fauna in the Chattahochee River is a depauperate and species-poor fauna, with animals in sub-optimal health for an undetermined distance below Buford Dam.

Additional studies will be needed to address the severity of impact; how much of the impact is due to metals toxicity, how much is due to low dissolved oxygen, and how much to other factors is not known. The first of such studies should be a continuation of *in situ* riverine bioassay experiments similar to those conducted previously. The experiments should also include other faunal organisms and sufficient water quality and histopathological data to provide data for cause-effect determinations.

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APPENDIX A. CHEMISTRY DATA

Table A.1. Lake Lanier, Georgia, Bioassay Set I Run 1 (October 28 - November 2, 1980)

Date (month/day)	Code	Alkalinity (mg/l)	TDS (mg/l)	TSS (mg/l)	TOC (mg/l)	NH_3 (mg N/l)	Color (CPU)	Hardness (mg/l)	Fe_t (µg/l)	Fe_d (µg/l)	Mn_t (µg/l)	Mn_d (µg/l)	Al_t (µg/l)	Al_d (µg/l)	Copper (µg/l)	Zinc (µg/l)	Arsenic (µg/l)	Lead (µg/l)	Cadmium (µg/l)	Chromium (µg/l)	Mercury (µg/l)
10/28-29	A1	-	-	-	3	-	-	9	1,900	230	850	820	130	<25	<5	<5	<10	<10	<1	<10	<0.5
	AK1	-	-	-	-	-	-	-	4,000	-	-	-	-	-	-	-	-	-	-	1	-
	AJ1	-	-	-	6	-	-	9	2,000	230	850	820	125	<25	<5	<5	<10	<10	<1	<10	<0.5
	B1	-	-	-	3	-	-	8	870	90	570	530	60	<25	<5	<5	<10	<10	<1	<10	<0.5
	C1	-	-	-	-	-	-	8	590	80	310	340	30	<25	<5	<5	<10	<10	<1	<10	<0.5
	CL1							6.4	450	30	320	300	10	-	4	<10	< 1	< 5	0.3	2	<0.1
	D1	-	-	-	-	-	-	-	70	<50	42	90	45	<25	<5	<5	<10	<10	<1	<10	<0.5
10/30-31	A2	-	32	<1	1	0.19	10	16	1,700	70	840	840	120	<25	<2	<5	<5	<10	<1	<10	<0.5
	AJ2	-	36	<1	1.5	0.16	10	19	1,700	240	820	840	190	30	<2	9	<5	<10	<1	<10	<0.5
	AK2	-	30	4	<1	0.10	10	16	S	350	S	780	105	30	<2	11	<5	<10	<1	<10	<0.5
	B2	-	30	2	<1	0.04	10	16	810	180	490	490	60	25	<2	<5	<5	<10	<1	<10	<0.5
	BL2	12	52	5	2	0.1	20	6.2	650	50	500	420	60	-	4	<10	<1	< 5	<0.2	4	<0.1
	BM2	-	-	-	4	<0.1	-	5.4	1630	50	490	410	60	-	3	230	1	< 5	0.5	< 2	<0.1
	C2	-	47	3	<1	0.04	5	17	515	170	290	270	35	85	<2	6	<5	<10	<1	<10	<0.5
	D2	-	14	2	<1	0.02	5	19	60	50	28	42	35	<25	<2	<5	<5	<10	<1	<10	<0.5
10/31-11/1	A3	-	21	7	<1	0.09	10	16	1,800	1,540	860	840	100	-	<2	32	<5	<10	<1	<10	<0.5
	AJ3	-	26	6	1.5	0.23	10	16	1,800	60	860	820	100	<25	<2	30	<5	<10	<1	<10	<0.5
	AK3	-	22	6	1.5	0.08	10	17	S	<50	860	850	90	<25	<2	17	<5	<10	<1	<10	<0.5
	B3	-	16	4	1.5	0.05	5	16	750	140	480	490	85	<25	<2	5	<5	<10	<1	<10	<0.5
	C3	-	14	4	1.0	0.02	5	12	480	290	290	250	40	<25	<2	8	<5	<10	<1	<10	<0.5
	CL3	9.5	51	1	3	0.1	10	6.8	420	<10	290	270	30	-	9	200	2	<5	0.2	2	<0.1
	CM3	-	-	-	2	0.46	-	6.3	900	90	540	240	10	-	92	10	2	<5	0.3	3	<0.1
	D3	-	19	5	1.0	0.04	5	15	420	50	150	160	90	<25	<2	8	<5	<10	<1	<10	<0.5

The Following Organo-Chlorine Pesticides and PCB's Were Below Detection Limits in Treatments A, B, C, and D. (µg/l)	
B-BHC	<0.01
Aldrin	<0.01
Chlordane	<0.05
DDD	<0.02
DDE	<0.01
DDT	<0.02
Dieldrin	<0.01
Endrin	<0.02
Toxaphene	<0.30
Heptachlor	<0.01
Methoxychlor	<0.10
Malathion	<0.20
Parathion	<0.03
Diazinon	<0.01
Methyl Parathion	<0.03
Lindane	<0.01
PCB's	<0.30

Code:
First Letter = treatment
Second Letter:
J = Duplicate sample (EPD)
K = Spiked sample (EPD)
L = Duplicate sample (Micro Methods)
M = Spiked sample (Micro Methods)
No second letter = regular sample to EPD.
Number = sample set, e.g., 3 means composite samples for 3rd 24-hour period sampled.

Notes: Sulfide concentrations were below detection (<0.02 ppm in all treatments.
EPD = Environmental Protection Division, Georgia Department of Natural Resources.
Fe_t = total iron, Fe_d = dissolved iron; same designation for other metals.

Table A.2. Lake Lanier, Georgia, Bioassay Set I Run 2 (November 7-10, 1980)

Date (month/day)	Code	Alkalinity (mg/l)	TDS (mg/l)	TSS (mg/l)	TOC (mg/l)	NH_3 (mg N/l)	Color (CPU)	Hardness (mg/l)	Fe_t (µg/l)	Fe_d (µg/l)	Mn_t (µg/l)	Mn_d (µg/l)	Al_t (µg/l)	Al_d (µg/l)	Copper (µg/l)	Zinc (µg/l)	Arsenic (µg/l)	Lead (µg/l)	Cadmium (µg/l)	Chromium (µg/l)	Mercury (µg/l)
11/6-7	A1	16	38	<1	2.5	0.18	20	13	2,800	680	1,050	980	215	<25	<5	<5	<5	<10	<1	<10	<0.5
	AJ1	15	40	<1	1.0	0.19	10	14	2,600	670	1,000	1,000	250	<25	<5	<5	<5	<10	<1	<10	<0.5
	AK1	16	36	4	1.0	0.20	10	14	3,600	670	1,250	980	185	<25	<5	8	<5	<10	<1	<10	<0.5
	B1	15	29	1	1.5	0.05	5	13	700	160	610	570	100	<25	<5	<5	<5	<10	<1	<10	<0.5
	C1	12	30	<1	<1	0.02	5	10	510	50	350	300	45	<25	<5	<5	<5	<10	<1	<10	<0.5
	D1	10	24	<1	<1	0.02	5	13	60	<50	27.5	<5	45	<25	<5	<5	<5	<10	<1	<10	<0.5
	DL1	14	18	2	5	0.1	-	8.6	10	24	50	30	30	-	4	10	<1	3	<0.2	<2	<0.1
	DM1	11	16	15	-	0.1	-	8.5	930	20	50	20	20	-	3	10	<1	<2	<0.2	<2	<0.1
11/7-8	A2	15	23	11	<1	0.11	10	11	2,600	920	1,000	1,000	130	<25	5	16	<5	<10	<1	<10	<0.5
	B2	12	18	4	<1	<0.02	5	9	650	80	590	560	90	<25	<5	<5	<5	<10	<1	<10	<0.5
	BJ2	11	12	8	<1	0.05	5	15	640	60	600	550	100	<25	<5	<5	<5	<10	<1	<10	<0.5
	BK2	11	11	7	<1	0.03	5	10	620	50	980	550	75	<25	<20	<5	<5	<10	<1	<10	<0.5
	C2	10	15	5	<1	<0.02	5	12	470	130	340	230	40	<25	<5	19	<5	<10	<1	<10	<0.5
	CL2	16	26	8	6	0.3	-	8.9	400	80	270	220	20	-	4	10	<1	<2	<0.2	<2	<0.1
	CM2	12	29	1	4	<0.1	-	8.9	400	330	650	130	20	-	10	10	<1	5	<0.2	<2	<0.1
	D2	10	13	3	<1	<0.02	5	11	<50	<50	24	6	35	<25	<5	10	<5	<10	<1	<10	<0.5
11/9-10	A3	15	22	10	1	0.14	5	12	3,000	1,800	1,050	1,050	155	<25	<5	8	<5	<10	<1	<10	<0.5
	AL3	15	26	15	9	<0.1	-	8.4	2,960	93	1,000	540	40	-	3	10	<1	<2	<0.2	4	<0.1
	AM3	16	26	13	10	0.30	-	8.2	3,200	1,630	1,200	1,020	30	-	5	55	<1	4	<0.2	4	<0.5
	B3	11	23	5	<1	<0.02	5	11	590	410	560	530	80	<25	<5	32	<5	<10	<1	<10	<0.5
	C3	10	20	6	<1	0.03	5	12	460	60	320	280	45	<25	<5	5	<5	<10	<1	<10	<0.5
	D3	10	11	5	1	0.03	5	14	<50	<50	21.5	<5	35	<25	6	8	<5	<10	<1	<10	<0.5
	DJ3	11	10	6	1	0.02	5	10	<50	<50	20.5	<5	35	<25	5	7	<5	<10	<1	<10	<0.5
	DK3	10	9	5	<1	0.04	5	11	290	<50	230	<5	25	<25	24	42	<5	<10	<1	<10	<0.5

Code:
First Letter = treatment
Second Letter:
J = Duplicate sample (EPD)
K = Spiked sample (EPD)
L = Duplicate sample (Micro Methods)
M = Spiked sample (Micro Methods)

No second letter = regular sample to EPD.
Number = sample set, e.g., 3 means composite samples for 3rd 24-hour period sampled.

Notes: Sulfide concentrations were below detection (<0.02 ppm in all treatments.
EPD = Environmental Protection Division, Georgia Department Of Natural Resources
Fe_t = total iron, Fe_d = dissolved iron; same designations for other metals.

Table A.3. Lake Lanier, Georgia, Bioassay Set II Run 1 (November 19-23, 1980)

Code	Alkalinity (mg/l)	TDS (mg/l)	TSS (mg/l)	TOC (mg/l)	NH_3 (mgN/l)	Color (CPU)	Hardness (mg/l)	Fe Total (ug/l)	Fe Diss. (ug/l)	Mn Total (ug/l)	Mn Diss. (ug/l)
A1	16	20	22	3	0.26	15	12	3,470	2,270	1,120	1,080
B1	10	26	10	1.5	<.02	<5	8	<50	<50	32	5
C1	18	32	16	5	0.28	20	11	3,470	2,270	1,100	1,100
CL1	26	37	13	20	0.25	-	10.2	3,600	2,300	1,000	970
CM1	20	33	9	7	0.35	-	10.1	3,800		1,390	
D1	16	27	19	2.0	0.26	15	11	2,910	500	1,120	1,080
DJ1	16	28	20	2	0.28	25	11	2,910	310	1,100	1,020
DK1	16	30	20	2	0.25	25	11	3,070	1,110	1,480	1,430
E1	9	29	11	<1	0.30	10	12	2,550	1,975	1,100	1,020
F1	17	40	6	1.5	0.05	<5	3	830	775	250	405
G1	5	27	7	<1	0.09	<5	2	285	110	85	75
H1	16	30	8	1.0	0.29	25	11	2,550	2,200	1,100	1,080
A2	16	27	9	1.0	0.19	35	10	3,920	3,110	1,140	1,100
AL2	16	23	10	15	0.25	-	12	4,060	2,900	1,000	970
AM2	16	24	8	14	0.16	-	10	4,210		1,400	
B2	10	16	<1	<1	<.02	<5	8	55	<50	30	<5
C2	19	36	8	4.7	0.17	30	10	3,960	3,950	1,140	1,000
D2	16	28	6	1.0	0.16	30	10	3,110	780	1,120	1,040
E2	8	21	5	3.5	0.30	10	10	3,150	2,450	1,140	1,050
F2	19	38	2	1.0	0.06	20	6	1,050	655	330	290
FJ2	19	27	2	1.0	0.06	20	4	1,050	615	320	280
FK2	18	29	5	1.0	0.07	10	4	1,475	1,135	885	950
G2	15	7	5	<1	<.02	10	1	325	95	85	75
H2	16	18	4	1.0	0.35	20	9	3,070	2,670	1,140	1,080
A3	16	28	14	-	-	10	12	-	-	-	-
B3	10	16	<1	1.0	<.02	10	7	65	-	33	-
C3	18	32	12	2.0	0.26	10	10	3,030	1,830	1,080	1,060
D3	16	17	9	1.0	0.32	50	11	3,350	1,350	1,120	1,100
E3	7	15	7	1.0	0.17	10	10	1,980	1,240	1,020	1,060
F3	16	23	7	<1	0.06	10	4	685	255	350	335
G3	6	12	2	<1	<.02	10	3	300	<50	85	75
H3	16	19	5	<1	0.31	10	11	1,780	1,440	1,060	1,050

Code:
First Letter = treatment
Second letter:
J = Duplicate sample (EPD)
K = Spiked sample (EPD)
L = Duplicate sample (Micro Methods)
M = Spiked Sample (Micro Methods)

No second letter = regular sample to EPD.
Number = sample set, e.g., 3 means composite samples for 3rd 24-hour period sampled.

Notes: EPD = Environmental Protection Division, Georgia Department of Natural Resources.

Table. A.4. Lake Lanier, Georgia, Bioassay Set II Run 1 Additional Metals Analyses on Selected Samples (November 19-24, 1980)

Code	Cu Total (µg/l)	Cu Diss. (µg/l)	Zn Total (µg/l)	Zn Diss. (µg/l)	Al Total (µg/l)	Al Diss. (µg/l)
A1	<5	<5	<5	27.5*	160	<25
DJ1	<5	-	<5	-	250	<50
DK1	<5	-	<5	-	190	75
FJ2	<5	-	<5	-	-	-
FK2	<5	-	5	-	-	

Notes:
*Unknown source of contamination.
Chemical analyses performed by Environmental Protection Division (EPD), Georgia Department of Natural Resources.

Code:
First letter = treatment
Second letter:
J = Duplicate Sample (EPD)
K = Spiked Sample (EPD)
No second letter = regular sample to EPD
Number = Sample set, e.g., 2 means composite samples for 2nd 24-hour period sampled.

Table A.5. Lake Lanier, Georgia, Bioassay Set II Run 2 (November 23-24, 1980)

Code	Alkalinity (mg/l)	TDS (mg/l)	TSS (mg/l)	TOC (mg/l)	NH_3 (mgN/l)	Color (mg/l)	Hardness (mg/l)	Fe Total (ug/l)	Fe Diss. (ug/l)	Mn Total (ug/l)	Mn Diss. (ug/l)
A1	15	47	5	2	.26	5	13	3,200	1,940	1,040	1,000
B1	9	28	<1	<1	.02	5	9	50	<50	35	<5
C1	24	91	1	13	.30	5	11	3,200	2,040	1,040	1,025
F1	8	24	<1	<1	.02	5	13	<50	<50	5	<5
G1	8	40	4	<1	.02	5	5	400	100	125	110

Notes:
There were no Treatments D, E, or H.
There were no duplicates, splits, or spikes for this brief Run 2.
Chemical analyses performed by Environmental Protection Division (EPD), Georgia Department of Natural Resources

Code:
First letter = treatment
Number = sample set, e.g., 1 means composite samples for 1st 24-hour period sampled.

Table A.6. Lake Lanier, Georgia, Bioassay Set II Run 3 (December 4-11, 1980)

Code	Alkalinity (mg/l)	TDS (mg/l)	TSS (mg/l)	TOC (mg/l)	NH_3 (mgN/l)	Color (CPU)	Hardness (mg/l)	Fe Total (µg/l)	Fe Diss. (µg/l)	Mn Total (µg/l)	Mn Diss. (µg/l)
A2	16	10	8	5	0.38	50	18	4,150	3,260	1,200	1,160
B2	10	25	1	3	0.04	5	13	120	<50	50	<50
BJ2	10	20	<1	2	0.04	<5	8	110	<50	50	<5
BK2	7	22	<1	4	0.04	<5	10	580	290	550	400
C2	17	18	2	7	0.36	30	55	1,680	230	1,200	1,160
D2	16	35	1	5	0.34	60	16	2,690	950	1,200	1,150
E2	20	49	3	4	<.02	5	15	240	<50	30	30
F2	20	44	<1	3	<.02	5	2	160	<50	<5	<5
G2	18	42	<1	4	0.36	5	20	180	<50	1,230	1,180
H2	20	31	1	5	0.38	5	15	150	<50	1,210	1,160
A3	16	30	10	2	0.34	45	16	4,110	3,260	1,230	1,200
B3	10	16	4	3	0.04	5	14	110	<50	50	5
C3	16	105	3	4	0.34	25	55	147	160	1,210	1,200
CJ3	16	135	1	4	0.36	35	52	1,478	190	1,200	1,180
CK3	16	121	3	3	0.36	25	54	1,780	170	1,460	1,200
D3	16	32	4	3	0.34	60	18	2,490	450	1,200	1,180
E3	20	47	1	3	0.02	10	10	300	<50	30	25
F3	----------Discontinued----------										
G3	19	40	<1	1	0.38	5	20	200	<50	1,180	1,200
H3	18	28	<1	1	0.38	5	15	180	<50	1,170	1,170
HL3	16	34	2	<1	-	<5	7.2	170	40	1,200	1,100
HM3	18	32	11	10	-	<5	5.2	530	20	1,540	1,560
A4	17	32	8	3	0.40	45	13	4,210	3,160	1,220	1,210
B4	10	32	<1	1	0.04	<5	13	110	<50	50	15
C4	16	132	<1	4	0.38	30	52	1,170	220	1,200	1,200
D4	16	41	3	2	0.42	55	18	2,380	530	1,180	1,180
E4	19	50	2	1	0.02	15	14	390	<50	35	35
F4	----------Discontinued----------										
G4	18	56	<1	<1	0.38	5	19	240	<50	1,210	1,210
H4	18	31	1	2	0.38	5	12	220	<50	1,180	1,220
GL4	16	55	4	<1	-	10	5.6	130	<10	1,180	1,130
GM4	16	52	7	3	-	<5	5.7	640	80	1,540	1,100
HJ4	18	20	<1	<1	0.38	5	12	230	<50	1,180	1,200
HK4	18	23	1	<1	0.38	5	11	67	<50	1,540	930

(Continued)

Table A.6. Lake Lanier, Georgia, Bioassay Set II Run 3 (December 4-11, 1980)

Code	Alkalinity (mg/l)	TDS (mg/l)	TSS (mg/l)	TOC (mg/l)	NH_3 (mgN/l)	Color (CPU)	Hardness (mg/l)	Fe Total (µg/l)	Fe Diss. (µg/l)	Mn Total (µg/l)	Mn Diss. (µg/l)
A5	16	36	12	4	0.46	50	14	4,400	3,900	1,280	1,280
B5	10	30	2	2	0.04	5	9	125	<50	45	10
C5	16	106	2	2	0.46	10	50	1,200	300	1,220	1,240
D5	17	40	4	2	0.46	60	14	2,550	1,000	1,280	1,260
E5	18	50	2	1	<0.02	5	10	300	<50	20	20
EM5	17.6	63	4	<1	--	40	5.8	310	<10	440	20
G5	18	54	2	<1	0.46	5	20	300	<50	1,260	1,260
GJ5	17	42	2	<1	0.46	5	20	300	<50	1,260	1,220
GK5	18	38	2	1	0.46	<5	20	500	<50	1,600	1,260

Code:
First letter = treatment
Second Letter:
J = Duplicate sample (EPD)
K = Spiked sample (EPD)
L = Duplicate sample (Micro Methods)
M = Spiked sample (Micro Methods)

No second letter = regular sample to EPD
Number = sample set, e.g. 3 means composite samples for 3rd 24-hour period sampled.
Discontinued = discontinued due to high mortalities at end of 48 hours.
EPD = Environmental Protection Division, Geogia Department of Natural Resources.

Notes:

There were no Treatments F or H.
Chemical Analyses were performed by Environmental Protection Division (EPD), Georgia Department of Natural Resources.

Table A.7. Lake Lanier, Georgia, Bioassay Set II Run 3 Additional EPD Analyses and Micro Methods Data (December 4-11, 1980)

Set II Run 3 Additional Metals Analyses by EPD (All Values in mg/l)

Code	Cu Total	Cu Diss.	Zn Total	Zn Diss.	Al Total	Al Diss.
A2	<5	<5	<5	23*	100	<25
HN3	**	9	**	20.8*	**	<25
A4	<5	12	<5	28.5*	120	<25
A5	13	39	5.5	30.0*	115	<25

Set II Run 3 Additional Metals Analyses by Micro Methods

Code	Al
HL3	10
HM3	7
GL4	20
GM4	10
EM5	<10

Notes:
*Unidentified source of Zn contamination in dissolved metal samples.
**No sample for total metals.

Code:
First letter = treatment
Second letter:
L = Duplicate sample (Micro Methods)
M = Spiked Sample (Micro Methods)
N = Blank

Table A.8. Lake Lanier, Georgia, Bioassay Set II Run 4 (December 19-23, 1980)

Code	Alkalinity (mg/l)	TDS (mg/l)	TSS (mg/l)	TOC (mg/l)	NH_3 (mgN/l)	Color (CPU)	Hardness (mg/l)	Fe Total (µg/l)	Fe Diss. (µg/l)	Mn Total (µg/l)	Mn Diss. (µg/l)
A1	18	37	7	2	0.20	5	14	3,725	750	1,325	1,300
B1	9	12	<1	2	0.03	<5	7	80	50	<50	<50
E1	17	12	8	2	0.20	<5	13	3,925	850	1,325	1,280
EJ1	18	22	10	2	0.20	<5	13	4,075	*	1,275	*
EK1	18	15	9	1	0.21	5	14	3,975	800	1,325	1,300
F1	18	38	10	3	0.20	<5	30	3,775	850	1,325	1,280
G1	18	77	3	1	0.20	<5	38	3,775	1,225	1,325	1,260
H1	18	129	3	2	0.21	<5	60	3,725	1,075	1,325	1,280
HL1	17.5	181	7	6	0.22	-	7.7	3,700	800	1,220	1,210
HM1	18.8	164	12	9	0.22	-	4.1	3,480	*	1,190	1,180
A2	18	27	9	2	0.19	<5	11	3,125	320	1,400	1,320
AJ2	19	38	6	1	0.20	<5	14	3,875	330	1,325	1,280
AK2	18	35	5	1	0.20	<5	14	3,125	460	1,325	1,320
B2	11	32	<1	1	0.03	<5	7	190	<50	95	65
C2	-	-	-	-	-	-	-	50	<50	55	<50
D2	-	-	-	-	-	-	-	80	<50	95	65
E2	18	52	4	1	0.22	<5	12	3,925	390	1,340	1,280
F2	19	81	7	2	0.19	<5	25	3,175	360	1,340	1,300
G2	19	107	9	2	0.20	<5	39	3,000	350	1,340	1,280
GL2	18.8	131	11	10	0.42	60	2.6	2,920	370	1,230	1,200
GM2	17.5	127	4	8	0.32	60	3.1	2,950	370	1,200	1,170
H2	18	165	7	2	0.20	<5	66	3,000	380	1,300	1,300

Code:
First letter = treatment
Second letter:
J = Duplicate Sample (EPD)
K = Spiked Sample (EPD)
L = Duplicate Sample (Micro Methods)
M = Spiked sample (Micro Methods)
No second letter = regular sample to EPD
Number = sample set, e.g. 2 means composite samples for 2nd 24-hr. period sampled.

Notes:
* indicates no sample for this parameter
EPD = Environmental Protection Division, Georgia Department of Natural Resources.

Table A.9. Summary of QA/QC Data for Lake Lanier, Georgia, Bioassays, Fall 1980

Set I Run 1 QA/QC Data

	Background				Expected				Recovered				Percent Recovery			
	Fe_t	Mn_t	Cu	Zn	Fe_t	Mn_t	Cu	Zn	Fe_t	Mn_t	Cu	Zn	Fe_t	Mn_t	Cu	Zn
Micro Methods																
BM2	650	-	-	<10	1,650	-	-	250	1,630	-	-	230	98	-	-	92
CM3	420	290	9	-	920	540	119	-	900	540	92	-	98	100	77	-
EPD																
AK1	2,000	-	-	-	4,000	-	-	-	4,000	-	-	-	100	-	-	-
AK2	1,700	840	-	-	2,700	1,340	-	-	2,800	1,350	-	-	103	101	-	-

Set I Run 1 QA/QC Data

	Background				Expected				Recovered				Percent Recovery			
	Fe_t	Mn_t	Cu	Zn	Fe_t	Mn_t	Cu	Zn	Fe_t	Mn_t	Cu	Zn	Fe_t	Mn_t	Cu	Zn
Micro Methods																
DM1	10	-	-	-	1,010	-	-	-	930	-	-	-	92	-	-	-
CM2	-	270	4	-	-	670	24	-	-	650	6	-	-	97	25	-
AM3	2 960	1,000	3	10	3,210	1,200	23	40	3,200	1,200	5	55	99	100	22	138
EPD																
AK1	2,800	1,050	-	-	3,400	1,300	-	-	3,600	1,250	-	-	105	96	-	-
BK2	-	590	<5	-	-	990	20	-	-	980	20	-	-	99	100	-

(Continued)

Table A.9. Summary of QA/QC Data for Lake Lanier, Georgia, Bioassays, Fall 1980

Set II Run 1-Micro Methods QA/QC Data (all in ug/l)

	Background				Expected				Recovered				Percent Recovery			
	Fe Total	Fe Diss	Mn Total	Mn Diss	Fe Total	Fe Diss	Mn Total	Mn Diss	Fe Total	Fe Diss	Mn Total	Mn Diss	Fe Total	Fe Diss	Mn Total	Mn Diss
CM1	3,600	-	1,000	-	4,100	-	1,500	-	3,800	-	1,390	-	93	-	93	-
AM2	4,060	-	1,000	-	4,560	-	1,500	-	4,210	-	1,400	-	92	-	93	-

Set II Run 1-EPD QA/QC Data (all in ug/l)

DK1	2,910	500	1,120	1,080	3,410	1,000	1,620	1,580	3,070	1,110	1,480	1,438	90	111	91	91
FK2	1,050	655	330	290	1,550	1,155	830	790	1,475	1,135	885	950	95	98	106	120

(Continued)

Note: No QA/QC spiked samples for Set II Run 2.

Table A.9. Summary of QA/QC Data for Lake Lanier, Georgia, Bioassays, Fall 1980

Set II Run 3-Micro Methods QA/QC Data (all in µg/l)

	Background				Expected				Recovered				Percent Recovery			
	Fe Total	Fe Diss	Mn Total	Mn Diss	Fe Total	Fe Diss	Mn Total	Mn Diss	Fe Total	Fe Diss	Mn Total	Mn Diss	Fe Total	Fe Diss	Mn Total	Mn Diss
HM3	170	-	1,200	1,100	670	-	1,700	1,600	530	-	1,540	1,560	79	-	91	98
GM4	130	-	1,800	-	630	-	1,680	-	640	-	1,540	-	101	-	92	-
EM5	-	-	-	<50	-	-	-	500	-	-	-	440	-	-	-	88

Set II Run 3-EPD QA/QC Data (all in µg/l)

BK2	120	<50	50	<50	620	500	550	500	580	290	550	400	94	58	100	80
CK2	1,470	160	1,210	1,200	1,870	-	1,610	-	1,780	-	1,460	-	95	-	91	-
HK4	-	-	1,180	-	-	-	1,680	-	-	-	1,540	-	-	-	92	-

(Continued)

Note: No QA/QC spiked samples for Set II Run 2.

Table A.10. Lake Lanier, Georgia, Bioassay Set II Run 3 Special Chemical Samples (December 4-11, 1980)

	Total Fe µg/l	Dissolved Fe µg/l	Total Mn µg/l	Dissolved Mn µg/l
Hypo. Control	3,800		1,160	
BLK Tank #4	-	<50	-	1,320
Epi. Control (521B3)		<50		<5
Header Tank	3,650		1,280	
Header Tank Pesticide Grab		No pesticides detected. See Table A.1 for list of pesticides and detection limits.		
Filter Blanks Metals (filtered 0.1-um filter):				
GN4		<50		5
HN3		<50		20
EN2		<50		5

N = Blank

Table A.11. Lake Lanier, Georgia, Bioassay Simultaneous Sampling from Header Tank and Lake Hypolimnion (December 1980)

	Alkalinity mg/l	TOC mg/l	Sulfide mg/l	Total Fe µg/l	Total Mn µg/l	0.1-um Diss Fe µg/l	0.4-um Diss Fe µg/l	0.1-um Diss Mn µg/l	0.4-um Diss Mn µg/l
Lake	18	<1	<.1	3,300	1,100	2,380	2,380	1,100	1,160
Header Tank	16	1	<.1	4,300	1,160	3,780	3,880	1,160	1,160

*Hypolimnetic sample was taken at 116 feet by the intake. Approximately 4 minutes was allowed between the taking of the hypolimnetic sample and the taking of the header tank sample to allow the sample to travel through the system.

APPENDIX B. ROUTINE PHYSICAL MONITORING

Table B.1. Summary of Results of Routine Physical Monitoring of Set I Run 1, October 28 through November 2, 1980, Lake Lanier, Georgia

Treatment*	Day of Test	Ranges			
		Temperature °C	DO ppm	pH	Conductivity** umhos/cm
A	1	13.5-17.0	6.9-8.1	6.1-6.4	30-33
	2	11.0-14.1	7.1-9.1	5.9-6.4	22-25
	3	12.0-17.0	6.4-8.7	5.6-6.3	31-34
	4	11.5-17.0	4.4-9.2	5.5-6.5	32-35
	5	10.0-12.0	6.3-10.0	5.7-6.4	30
B	1	13.5-17.0	6.2-8.0	6.1-6.4	29-30
	2	12.0-13.8	6.9-8.9	5.8-6.5	26-28
	3	11.5-17.0	7.2-8.5	5.7-6.4	26-27
	4	11.5-17.0	3.8-8.6	5.9-6.6	29-32
	5	10.0-11.8	7.0-9.3	5.3-6.5	25
C	1	14.0-17.0	6.8-8.2	6.2-6.7	24-28
	2	11.5-14.4	6.7-8.5	5.9-6.4	21-22
	3	12.0-17.0	6.2-8.0	5.7-6.3	25-27
	4	11.9-17.0	6.1-8.0	6.0-6.5	27-31
	5	10.5-12.5	6.0-8.6	5.6-6.5	22
D	1	14.0-17.0	7.5-10.1	6.5-6.7	21-23
	2	12.0-14.0	8.9-10.0	6.0-6.6	22-24
	3	12.0-17.5	7.7-9.0	5.8-6.5	23
	4	12.0-17.5	6.3-9.4	6.0-6.6	25-27
	5	10.5-12.7	7.4-9.6	5.8-6.6	22

*Treatments are described in Section 4.0, Table 4.2.
**Conductivity readings made only once per day for SI1.

Table B.2. Summary of Results of Routine Physical Monitoring of Set I Run 2, November 6 through November 10, 1980, Lake Lanier, Georgia

Treatment*	Day of Test	Ranges			
		Temperature °C	DO ppm	pH	Conductivity µmhos/cm
A	1	8.5-14.0	6.1-8.4	5.8-6.5	29-33
	2	11.5-16.1	6.9-8.0	5.7-6.4	30-35
	3	12.2-15.0	7.0-8.4	5.5-6.4	31-35
	4	13.0-16.0	6.9-8.7	5.9-6.5	32-38
B	1	8.5-14.0	6.4-8.4	6.1-6.5	22-29
	2	11.5-14.9	7.1-8.4	5.9-6.6	24-29
	3	12.3-14.0	6.9-8.3	5.8-6.6	25-30
	4	12.5-15.5	6.4-8.4	6.0-6.6	26-30
C	1	8.5-15.0	6.8-8.4	6.0-6.5	22-30
	2	11.5-16.6	7.0-8.0	6.0-6.6	22-27
	3	12.3-15.5	6.8-8.0	5.9-6.5	24-29
	4	13.0-16.5	6.1-7.9	5.9-6.6	24-28
D	1	8.5-13.5	7.4-9.9	6.1-6.7	20-27
	2	11.0-16.9	7.9-9.4	6.1-6.7	21-26
	3	12.5-15.5	7.4-8.6	6.0-6.6	21-27
	4	12.6-16.0	6.8-8.8	6.1-6.6	22-25

*Treatments are described in Section 4.0, Table 4.2.

Table B.3. Summary of Results of Routine Physical Monitoring of Set II Run 1, November 21 through November 23, 1980, Lake Lanier, Georgia

Treatment*	Day of Test	Ranges			
		Temperature °C	DO ppm	pH	Conductivity µmhos/cm
A	1	11.5-12.5	6.4-8.4	5.8-6.4	33-57
	2	11.8-13.0	7.0-8.7	5.7-6.2	35-39
B	1	11.0-14.0	7.2-9.7	6.0-6.4	22-27
	2	11.5-13.0	6.7-9.7	5.7-6.4	24-27
C	1	12.0-13.0	6.7-8.3	6.1-6.6	37-40
	2	11.5-13.2	6.6-9.4	5.9-6.5	36-40
D	1	12.0-14.0	6.6-9.3	6.0-6.4	31-35
	2	12.0-13.5	7.1-9.8	5.7-6.4	30-35
E	1	12.0-13.0	5.8-7.6	5.8-6.2	39-41
	2	12.0-13.5	6.5-8.6	5.7-6.4	39-42
F	1	12.0-13.0	5.6-8.5	5.8-6.3	32-37
	2	12.0-12.5	6.6-9.6	5.8-6.5	31-36
G	1	11.5-13.0	5.6-8.3	5.9-6.2	34-38
	2	12.0-13.0	7.1-9.6	6.0-6.6	34-37
H	1	11.5-12.0	6.4-7.6	5.9-6.5	34-38
	2	11.8-12.5	6.5-9.1	5.5-6.5	35-39

*Treatments are described in Section 4.0, Table 4.2.

Table B.4. Summary of Results of Routine Physical Monitoring of Set II Run 2, November 23 through November 24, 1980, Lake Lanier, Georgia

Treatment*	Day of Test	Ranges			
		Temperature °C	DO ppm	pH	Conductivity µmhos/cm
A	1	12.0-13.0	6.0-8.2	5.9-6.3	31-35
B	1	11.5-12.5	6.9-9.4	6.1-6.4	22-25
C	1	12.0-13.0	7.0-7.9	6.1-6.5	44-50
F	1	12.0-12.5	6.6-8.4	5.9-6.6	20-25
G	1	12.5-13.0	6.8-8.4	5.8-6.6	29-37

*Treatments are described in Section 4.0, Table 4.2.

Table B.5. Summary of Results of Routine Physical Monitoring of Set II Run 3, December 4 through December 8, 1980, Lake Lanier, Georgia

Treatment*	Day of Test	Ranges			
		Temperature °C	DO ppm	pH	Conductivity µmhos/cm
A	1	12.0-13.5	7.4-8.4	5.6-6.5	35-39
	2	12.0-13.5	7.8-8.8	5.5-6.4	35-40
	3	12.5-13.0	7.8-9.2	5.5-6.5	36-40
	4	12.5-13.2	8.3-8.8	5.1-6.0	35-40
B	1	10.2-13.5	8.3-10.4	5.5-6.6	21-25
	2	10.0-13.0	7.8-10.4	5.5-6.2	22-29
	3	10.2-14.0	8.0-10.6	5.4-6.9	22-28
	4	11.0-15.0	8.1-9.5	5.5-6.4	24-28
C	1	12.0-14.5	7.9-9.6	5.3-6.2	102-109
	2	12.4-13.5	7.9-9.4	5.8-6.4	104-115
	3	12.5-13.7	8.4-9.5	5.6-6.3	105-115
	4	12.4-13.8	7.9-9.1	5.6-6.3	110-115
D	1	12.3-14.8	7.6-9.0	5.5-6.4	32-38
	2	11.5-13.5	8.4-9.6	5.7-6.5	32-46
	3	13.0-13.7	8.0-10.4	5.8-6.4	35-39
	4	13.0-13.8	8.6-9.9	5.6-6.3	35-39
E	1	11.8-14.0	6.7-9.0	5.9-7.0	42-50
	2	11.5-13.0	7.9-9.4	6.0-6.5	47-58
	3	12.5-12.8	7.7-9.1	6.0-6.6	48-51
	4	12.5-13.0	7.5-8.3	6.0-6.5	47-49
F	1	11.8-14.0	6.9-9.2	5.9-7.1	29-32
	2	12.0-12.5	7.9-8.8	6.2-7.0	32-33
G	1	11.9-13.5	7.1-8.9	5.8-6.7	41-42
	2	11.5-13.0	7.9-9.3	5.6-6.4	42-49
	3	12.3-13.0	8.0-10.5	5.7-6.5	42-48
	4	12.5-13.0	7.7-9.0	5.7-6.3	43-48
H	1	11.9-13.5	7.2-8.8	5.6-6.5	29-32
	2	12.0-13.0	7.9-9.6	5.7-6.6	29-33
	3	12.3-13.0	8.2-10.3	5.7-6.4	30-35
	4	12.4-13.0	8.2-9.0	5.7-6.4	31-33

*Treatments are described in Section 4.0, Table 4.2.

Table B.6. Summary of Results of Routine Physical Monitoring of Set II Run 4, December 19 through December 23, 1980, Lake Lanier, Georgia

Treatment*	Day of Test	Ranges			
		Temperature °C	DO ppm	pH	Conductivity µmhos/cm
A	1	11.0-13.0	9.1-10.0	6.2-6.7	31-39
	2	8.0-12.0	9.8-10.5	6.0-6.6	31-43
	3	7.7-9.7	9.9-11.2	5.8-6.8	29-37
	4	7.9-10.1	10.0-10.9	6.2-6.5	31-37
B	1	9.8-13.0	9.1-10.4	6.4-6.8	21-25
	2	6.0-12.2	9.8-11.5	6.1-6.7	20-24
	3	4.5-8.0	10.5-12.8	6.1-6.6	21-23
	4	6.2-9.6	10.2-11.8	6.2-6.5	22-23
E	1	11.0-12.1	8.9-10.1	6.2-6.8	31-38
	2	8.5-11.4	9.8-11.0	6.2-6.5	31-37
	3	7.0-9.8	10.5-11.8	5.9-6.9	32-35
	4	8.8-11.7	9.9-11.4	6.0-6.4	31-36
F	1	10.5-12.0	9.0-10.2	5.8-6.7	49-51
	2	8.0-10.0	9.8-10.5	6.2-6.4	40-52
	3	6.0-8.6	9.8-11.2	6.1-6.6	32-50
	4	8.0-9.6	9.8-11.3	6.0-6.4	49-52
G	1	10.0-11.2	8.7-10.1	5.9-6.7	72-80
	2	7.5-10.2	9.6-10.4	6.2-6.6	35-85**
	3	6.0-8.7	9.8-11.1	6.2-6.6	32-70**
	4	7.0-9.3	9.6-11.3	6.1-6.5	70-75
H	1	10.0-11.0	9.0-10.0	6.2-6.7	103-112
	2	7.0-10.1	9.8-10.8	6.3-6.9	60-118**
	3	6.0-9.1	9.8-10.9	6.2-6.6	39-110**
	4	8.0-10.3	9.4-11.4	6.2-6.4	102-120

* Treatments are described in Section 4.0, Table 4.2.

** The large variations in conductivity for these days are due to single low values when the stock reservoirs for hardness additions ran dry. Stock depletion occurred once only, but for the last reading of day 2 and the first reading of day 3.

APPENDIX C. RIVERINE BIOASSAY DATA

Table C.1. Physical Chemical Data for Riverine Bioassay Stations, Run 1, November 22-26, 1980, Chattahoochee River/Lake Lanier, Georgia

Date	Station	Temp (°C)	DO (ppm)	pH
November 22, 1980	1	12.5	7.2	6.4
	2	10.4	7.5	6.1
	3	11.0	1.3	5.9
	4	11.0	8.9	6.2
	5	11.0	5.1	6.0
	6	11.0	8.1	6.3
	7	10.5	8.5	6.6
	8	10.5	9.2	6.6
November 23, 1980	1	12.0	8.4	6.4
	2	10.5	8.4	6.1
	3	11.0	3.0	6.4
	4	10.8	9.2	5.3
	5	10.5	5.4	5.3
	6	10.5	6.5	6.5
	7	10.0	7.3	6.4
	8	9.5	8.8	6.2
November 24, 1980	1	13.0	7.4	6.7
	2	10.2	8.0	6.5
	3	11.0	2.0	6.2
	4	12.0	9.0	6.4
	5	11.5	5.1	6.4
	6	11.5	6.0	6.5
	7	11.5	6.5	6.3
	8	12.0	8.4	6.0
November 25, 1980	1	12.0	8.0	6.7
	2	10.0	7.2	6.2
	3	12.0	1.1	6.2
	4	12.2	10.2	6.2
	5	12.2	5.4	6.3
	6	11.0	7.2	6.3
	7	11.0	7.7	7.0
	8	12.0	7.6	6.5
November 26, 1980	1	12.0	7.8	6.5
	2	10.0	8.2	6.4
	3	11.0	3.0	6.0
	4	10.0	9.9	6.2
	5	10.0	7.4	6.3
	6	11.0	6.8	6.5
	7	10.0	8.0	6.0
	8	11.0	8.9	5.6

Table C.2. Physical Chemistry Data for Riverine Bioassay Stations, Run 2, February 5-9, 1981, Chattahoochee River/Lake Lanier, Georgia

Date	Station	Temp °C	DO ppm	pH	Conductivity (µmohs/cm)
February 5, 1981	1	5.0	12.5	6.7	30
	2	6.0	14.0	7.1	30
	3	6.0	13.5	7.4	25
	4	6.0	12.2	7.4	27
	5	6.0	11.2	7.3	26
	6	6.0	11.0	7.3	26
	7	6.0	11.0	7.3	25
	8	5.3	11.2	7.3	25
February 6, 1981	1	6.3	11.5	7.2	310
	2	6.0	12.0	7.3	350
	3	6.5	11.0	7.2	500
	4	6.0	11.5	7.2	500
	5	6.0	11.5	7.2	550
	6	5.5	11.5	7.3	800
	7	5.0	11.0	7.3	1,600
	8	5.0	11.0	7.1	1,600
February 7, 1981	1	5.0	12.0	7.3	90
	2	6.0	11.0	7.2	97
	3	6.0	11.0	7.25	97
	4	6.1	11.2	7.3	93
	5	6.2	11.2	7.15	100
	6	6.0	11.0	7.15	112
	7	5.8	11.5	7.2	98
	8	5.5	11.5	7.2	110
February 8, 1981	1	6.3	11.0	6.9	108
	2	6.2	12.0	7.4	102
	3	6.1	11.4	7.3	101
	4	6.2	11.0	6.2	102
	5	6.5	11.0	7.3	104
	6	6.2	11.0	7.3	108
	7	6.9	11.2	6.9	109
	8	6.8	11.2	7.2	110
February 9, 1981	1	6.5	11.0	7.3	137
	2	6.0	11.0	7.3	130
	3	6.0	11.0	7.3	132
	4	6.2	11.0	6.5	120
	5	6.9	11.0	7.2	121
	6	5.2	11.5	7.3	112
	7	5.0	11.0	7.2	98
	8	5.0	11.5	6.9	26

Table C.3. Survival Data (Salmo gairdneri Swim-Up Fry) from Riverine Bioassay Run 1, November 22 through November 26, 1980, Chattahoochee River/ Lake Lanier, Georgia

Station 1	Day 1	Day 2	Day 3	Day 4
Replicates				
1	10	10	10	10
2	10	10	10	10
3	10	10	10	10
4	10	10	10	10
5	10	10	10	10
6	10	10	10	10
7	10	10	10	10
8	10	10	10	10

Station 2	Day 1	Day 2	Day 3	Day 4
Replicates				
1	8	2	1	1
2	7	1	0	0
3	7	2	0	0
4	8	1	1	1
5	6	3	2	2
6	9	0	0	0
7	8	2	1	0
8	8	3	3	1

Station 3	Day 1	Day 2	Day 3	Day 4
Replicates				
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0

Station 4	Day 1	Day 2	Day 3	Day 4
Replicates				
1	8	2	1	1
2	7	1	0	0
3	7	2	0	0
4	8	1	1	1
5	6	3	2	2
6	9	0	0	0
7	8	2	1	0
8	8	3	3	1

(Continued)

Table C.3. Survival Data (Salmo gairdneri Swim-Up Fry) from Riverine Bioassay Run 1, November 22 through November 26, 1980, Chattahoochee River/ Lake Lanier, Georgia

Station 5	Day 1	Day 2	Day 3	Day 4
Replicates				
1	6	2	0	0
2	8	0	0	0
3	7	1	1	0
4	7	1	0	0
5	7	0	0	0
6	7	0	0	0
7	8	0	0	0
8	8	0	0	0

Station 6	Day 1	Day 2	Day 3	Day 4
Replicates				
1	6	0	0	0
2	7	2	1	0
3	7	0	0	0
4	9	0	0	0
5	10	1	0	0
6	9	0	0	0
7	7	1	0	0
8	10	0	0	0

Station 7	Day 1	Day 2	Day 3	Day 4
Replicates				
1	8	0	0	0
2	8	2	1	1
3	8	2	1	1
4	9	0	0	0
5	9	1	0	0
6	9	2	2	2
7	9	1	1	0
8	9	0	0	0

Station 8	Day 1	Day 2	Day 3	Day 4
Replicates				
1	8	2	1	1
2	9	3	2	2
3	9	3	3	3
4	10	2	2	2
5	10	2	2	2
6	10	4	4	3
7	10	2	2	2
8	10	4	4	3

Note:

1. Values represent accumulative number live by day.
2. Species: Salmo gairdneri (Fry).
3. Each station started with 8 replicates of 10 fish each.

Table C.4. Survival Data (*Salmo gairdneri* 15-Centimeter Trout) from Riverine Bioassay Run 1, November 22 through November 26, 1980, Chattahoochee River/Lake Lanier, Georgia

Station 1	Day 1	Day 2	Day 3	Day 4
Replicates				
1	10	10	10	10
2	10	10	10	10
3	10	10	10	10
Station 2	**Day 1**	**Day 2**	**Day 3**	**Day 4**
Replicates				
1	7	6	3	1
2	7	4	2	1
3	10	7	4	3
Station 3	**Day 1**	**Day 2**	**Day 3**	**Day 4**
Replicates				
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
Station 4	**Day 1**	**Day 2**	**Day 3**	**Day 4**
Replicates				
1	10	10	9	6
2	10	10	10	8
3	10	10	10	6
Station 5	**Day 1**	**Day 2**	**Day 3**	**Day 4**
Replicates				
1	9	8	8	8
2	9	9	8	6
3	10	10	10	8
Station 6	**Day 1**	**Day 2**	**Day 3**	**Day 4**
Replicates				
1	8	8	8	7
2	10	10	10	8
3	10	10	10	10
Station 7	**Day 1**	**Day 2**	**Day 3**	**Day 4**
Replicates				
1	10	10	10	9
2	10	10	10	10
3	10	10	10	10
Station 8	**Day 1**	**Day 2**	**Day 3**	**Day 4**
Replicates				
1	6	6	6	6
2	10	10	10	10
3	10	10	10	10

Notes:

1. Species: *Salmo gairdneri* (15-cm size).
2. Each station started with 3 replicates of 10 fish each.

Table C.5. Daily Survival Data for Rainbow Trout in February 1981 and Bluegills in November 1980 during Riverine Bioassays in the Chattahoochee River Below Buford Dam, Lake Lanier, Georgia

Station	Number Alive 24 hour	48 hour	72 hour	96 hour
	Bluegills (began with 30) November 22-26, 1980 (no bluegill bioassay in February)			
1	30	30	30	30
2	30	30	30	30
3	8, 9, 10*	27	27	27
4	30	30	30	30
5	30	30	30	9, 9, 10*
6	30	9, 10, 10*	29	29
7	30	30	30	30
8	30	30	30	30
	Rainbow Trout Fry (began with 80) February 5-9, 1981			
1	80	80	80	80
2	80	80	80	80
3	80	80	80	80
4	80	80	80	80
5	80	80	80	80
6	80	80	80	80
7	80	80	80	80
8	80	80	80	80
	Rainbow Trout Yearlings (began with 30) February 5-9, 1981			
1	30	30	30	30
2	30	30	30	30
3	30	30	30	30
4	30	30	30	30
5	30	30	30	30
6	30	30	30	30
7	30	30	30	30
8	30	30	30	30

Notes:
*Three numbers list survival in each of 3 replicates.
Station numbers:
1. Control
2. Sluice at dam
3. 300 m below dam
4. Hatchery raceway
5. River at hatchery
6. Settle's Bridge
7. McGinnis Bridge
8. Abbott's Bridge

Table C.6. Iron and Manganese Data From Two Riverine Bioassay Stations on the Chattahoochee River and from the Hypolimnion of Lake Sidney Lanier, Georgia, November 23 through November 26, 1980

Station	Date (Nov)	Flow Cond.	Iron and Manganese, ppb					
			Fe_t	Fe_d	Fe_d/Fe_t	Mn_t	Mn_d	Mn_d/Mn_t
Lake Lanier	23-24	-	3,200	1,940	0.6	-	1,000	
5	23**	High	-	-	-	-	-	-
5	23	Low	2,020	1,200	0.6	740	735	1
5	24	High	600	165	0.3	185	160	0.9
5	24	Low	1,980	1,125	0.6	730	735	1
5	25	High	760	280	0.4	300	270	0.9
5	25	Low	2,200	1,340	0.6	810	790	1
7	23**	High	-	-	-	-	-	-
7	23	Low	1,515	375	0.2	800	775	1
7	24	High	2,700	670	0.2	570	550	1
7	24	Low	1,160	185	0.2	560	535	1
7	25	High	1,225	100	0.1	315	280	0.9
7	25	Low	1,060	240	0.2	490	475	1

Notes:
1. ** No high flow occurred on November 23.
2. Station Location: Lake Lanier composite sample from lake hypolimnion collected 600 feet (180 meters) off-shore upstream of Buford Dam at 115-foot (35-meter) depth; Station No. 5 samples were from River at Buford Trout Hatchery. The Hatchery is approximately 1.5 miles (2.5 km) downstream from Buford Dam Lake Lanier); Station No. 7 samples were from River at McGinnis Bridge approximately 8.5 miles (13.7 km) downstream of Buford Dam.
3. Low flow condition based on average conditions is defined by a discharge of approximately 550 cfs from Buford Dam. Discharge during high flow conditions is approximately 8,000 cfs.
4. Fe_t = total iron; Fe_d = dissolved iron; Mn_t = total manganese; Mn_d = dissolved manganese.

Table C.7. Iron and Manganese Data (Recorded from Run 2) from Two Riverine Bioassay Stations on the Chattahoochee River, February 5 through February 9, 1981, Lake Lanier, Georgia

Station	Date (Feb)	Flow Cond.	Iron and Manganese, ppb					
			Fe_t	Fe_d	Fe_d/Fe_t	Mn_t	Mn_d	Mn_d/Mn_t
5	7	Low	70	70	.1	16	15.5	.969
5	8	Low	80	250	3.125	21.5	15.0	.698
5	9	High	110	<50	-	19.5	6.5	.333
5	9	Low	100	<50	-	18.5	12.5	.676
7	7	Low	110	<50	-	22.0	14.0	.636
7	8	Low	110	<50	-	23.5	20.5	.872
7	9	High	520	60	.115	60.0	12.0	.200
7	9	Low	140	50	.357	22.5	15.5	.689

Notes:

1. No high flow occurred on February 7 and 8, 1981.


A T E
L M E