GUIDELINES FOR ASSESSING AND PREDICTING EUTROPHICATION STATUS OF SMALL SOUTHEASTERN PIEDMONT IMPOUNDMENTS

EPA - REGION IV
ENVIRONMENTAL SERVICES DIVISION
ECOLOGICAL SUPPORT BRANCH
ATHENS, GA 30605-2720

SUMMARY

Seventeen small impoundment systems located in the southeastern Piedmont were sampled weekly or biweekly during the April to October growing season. Impoundments sampled represented a broad range of eutrophic response. The study was initiated with the objective of gathering sufficient data for predicting impoundment eutrophication status and developing guidelines for the purpose of facilitating regulatory permitting decisions within the Piedmont of the southeast.

This report contains a risk assessment component and predictive models. Guidelines were set after utilizing the study data, expert opinion, and the literature. Two eutrophication issues were addressed: (1) Nuisance blooms and scums, and (2) clarity of water. The variable, corrected chlorophyll A, was chosen to address the first issue because chlorophyll A has become a common surrogate for estimating phytoplankton biomass. It was determined that at a mean growing season limit of ≤15μg/L of chlorophyll A, that very few problems would be incurred with respect to water supply. For other uses, a mean growing season chlorophyll A of <25μg/L is recommended to maintain a minimal aesthetic environment for viewing pleasure, safe swimming, and good fishing and boating. Secchi disc transparency was the variable of choice to address the clarity issue. It was determined that a mean growing season Secchi disc transparency of ≥ 1.5 meters would minimize water supply problems. For non-water supply impoundments, a growing season mean of >1 meter is considered acceptable for fishing and swimming.

Regression and a version of BATHTUB (CNET.WK1) was used for predictive purposes. CNET applications are restricted to single-segment impoundments that are phosphorus limited or co-limited with nitrogen. Data from nine intensively studied impoundments and their streams were analyzed via the CNET program. Mean and median stream total phosphorus concentrations yielded an observed versus predicted chlorophyll A response error of ± 54% and ±34%, respectively. The seasonal mean prediction error of Secchi disc transparency ranged from -35% to +14%.

ACKNOWLEDGEMENTS

This report was prepared by the Project Leader, Ron Raschke of the Environmental Services Division's (ESD) Ecological Support Branch (ESB). Completion of the project was dependent upon the cooperation of management and the talents of Regional scientific and technical personnel. To all of them, the Branch extends its thank you.

Special thanks are extended to Cindy Stover and the office staff for typing the report.

Appreciation is extended to David Kamps of the Georgia Environmental Protection Division, Kathy Stecher of the South Carolina Department of Health and Environmental Control (SCDHEC), Jay Sauber and Mary Jaynes of the North Carolina Division of Environmental Management (NCDEM), Hiram Boone and his staff at the U. S. Soil Conservation Service-Athens and George Lewis of the University of Georgia for their assistance in providing information that was helpful in selecting impoundments and analyzing the data. Of course, access to the impoundments was crucial, and we thank Nancy Smith of the Athens-Clarke County Recreation and Parks Department for access to Lake Chapman, Ronnie Finch of the town of Union Point for access to Union Point Lake, Ben Hulsey of the city of Commerce for access to Commerce Lake, the Olgethorpe Lake Association for access to Lake Olgethorpe, Bruce Roper and Bill Tanner of the Georgia Department of Natural Resources for access to Lakes' Brantley, Rutledge, and High Falls, Arch Smith for access to Rock Eagle Lake, and Dennis Hammock of the Clayton County Water Authority for access to Lakes' Blalock and Shamrock.

Assistance in the field was provided by Bob Tilghman, Terri Phipps, Bobbi Carter, Tom Cavinder, Mark Koenig, Archie Lee, Don Lawhorn, Candice Halbrook, Phyllis Meyer, Mel Parsons, Bruce Pruitt, Dave Smith and Russ Todd of the ESB and John Williams of ESD's Environmental Compliance Branch.

Biological laboratory analyses were conducted by Don Schultz and Roxanne Jones. Bill McDaniel of the Analytical Support Branch-ESD and his staff conducted the chemical analyses.

State agencies and contractors who sampled some impoundments and provided information include the SCDHEC, NCDEM, and the Research Triangle Institute located in Research Triangle Park, North Carolina.

Study plans and draft report reviews were provided by Delbert Hicks, Tom Cavinder, Russ Todd, and Archie Lee of the ESB; Wade Knight of ESD's Laboratory Evaluation and Quality Assurance Section; Mike Carter of ESD's Environmental Compliance Branch; Mike MgGhee and his staff of Region 4's Water Management Division; and W. W. Walker, consultant.

Finally, a special thanks to ESB's Mark Koenig for providing the loading analyses and graphs and Mel Parson of ESB for drawings of depth isopleths and estimates of impoundment volumes.

TABLE OF CONTENTS

INTRODUCTION

EPA - Region IV recognizes that surface water impoundments are necessary for water supply and recreation in the southeastern Piedmont because groundwater storage is limited. In the 1980's, the southeastern Piedmont experienced severe droughts creating water shortages for many areas. A combination of drought years and expected population growth forced planners to develop strategies to accommodate projected water needs and recreation. Strategies included the selection of stream sites for potential impoundment of up to 3000 acres per site (Georgia, 1987).

Various federal and state environmental protection and natural resources agencies seek to protect valuable habitat, biological communities, and aesthetic values associated with potential sites. Post-impoundment water quality problems, especially eutrophication - one of the pervasive and world-wide water quality problems - are priority issues relative to planning and managing impoundments. By current definition, eutrophication includes excessive inputs of nutrients, organic matter, and sediments (Moore, 1987).

In 1989, EPA's Office of Water presented the water quality status of our nations lakes to Congress (EPA, 1989). Of the 12,413,837 acres assessed, 25% were found to be impaired or partially impaired and 20% threatened by pollution in terms of designated uses being met. States' identified twelve specific causes of pollution in lakes with impaired uses. Nutrients (primarily phosphorus) and silt were two significant pollutant groups. These types of pollutant inputs combine to produce increased populations of algae and rooted plants and decreased lake uses. Lakes with these conditions loose much of their beauty, their attractiveness for recreation, and their usefulness as water supplies (Cooke et al., 1986).

Beginning with Sakamoto's (1966) chlorophyll A vs. total phosphorus relationship and Edmondston's (1970) observations in the Lake Washington recovery, algal biomass (chlorophyll A) has been closely associated to phosphorus concentration and transparency. These three variables are now widely used conventional indicators of trophic state (Reckhow and Chapra, 1983; Cooke et al., 1986; EPA, 1988a; Welch, 1989). The determination that increased phosphorus levels cause increases of algal biomass (chlorophyll A) and in turn decreased transparency led many managers to base their approach on controlling phosphorus concentrations. Besides phosphorus usually being the limiting nutrient, phosphorus concentrations can be more easily controlled than elements with gaseous phases in their biogeochemical cycle such as nitrogen (Cooke et al., 1986). Therefore, successful efforts to improve lakes were directed toward reducing the concentration of phosphorus through advanced waste water treatment, diversion, bans on the sale of phosphoruscontaining detergents, and non-point best management practices (Cooke _et al_., 1986).

A phosphorus model may be used to evaluate management strategies with regard to a lake phosphorus standard or criterion (Anon., 1982; NALMS, 1988). Yet phosphorus by itself is not objectionable. A standard establishing phosphorus as the decision variable masks the true quality variable of concern (algal biomass) that lends value or human benefit to the water body (Reckhow and Chapra, 1983).

Algal biomass determinations are the most useful measurement of the amount of algae. The biomass measurement most frequently used is corrected chlorophyll A (EPA, 1988a; Wedepohl, 1990). It has become a surrogate for estimating phytoplankton biomass because of its specificity and ease of analysis. The response factor (chlorophyll A) plays a principal role in determining a lakes trophic state, therefore a few states have adopted a chlorophyll A standard or criterion (Anon., 1982; NALMS, 1988; NALMS, 1992).

Transparency is the other most widely used conventional indicator of trophic state (Welch, 1989). In fact, it is the most frequently used variable in limnology and monitoring because of the ease of measurement (Wedepohl, 1990). Transparency is based on the transmission of light through water and is related in part, to the natural light attenuation of the water being measured and the amount of organic and inorganic suspended solids (EPA, 1988a). The assumption is that the greater the transparencies, the better the water quality of the lake (EPA, 1988a; Ryding and Rast, 1989; Wedepohl, 1990). Low transparencies impede recreational activities like swimming, diving, and boating. Likewise, suspended solids can impede the efficiency of public water supplies (Moore, 1987; EPA, 1989).

Siltation is the process by which particles of soil or rock are transported by water to a lake and deposited as sediment. This process and/or faulty impoundment design of slopes and depth produces shallow conditions that encourage macrophyte growths that may effect recreational activities, create clogging and taste and odor problems for municipal water suppliers (Bennett, 1962; Crance, 1979; USDA, 1982; EPA, 1988a; EPA, 1989). Light is a key limiting factor of macrophyte growths. It is generally accepted that macrophyte growth cannot proceed where light intensity is less than 1% of incident light. The stratum of water receiving 1% or more of incident radiation is termed the euphotic zone.

The objective of EPA-Region IV in initiating a small impoundment study was to gather sufficient data for predicting impoundment eutrophication status and developing guidelines helpful in assessing potential post-impoundment water quality issues.

This document sets forth eutrophic guidelines for the purpose of facilitating regulatory permitting decisions within the piedmont physiographic province of the southeastern United States (EPA- Region IV). These guidelines are intended to help government authorities and private individuals in evaluating potential citing effects on water quality and developing management strategies to assure that environmentally acceptable impoundments are constructed without incurring untimely regulatory delays. This document contains a risk assessment component useful in the decision-making process, and models useful for predicting water quality responses.

Guidelines apply to impoundments defined as lakes which encompass an area greater than 10 acres with well defined basins and shores and lacking pronounced water courses being formed for the purpose of storage, regulation and control of water by catchment into depressions, or by the placement of man-made dams across streams retarding normal stream flow and causing stream waters to rise and remain beyond normal channel confinements possibly forming backwaters in pooled areas under normal conditions (Langbein and Iseri, 1960; Bennett, 1962; Getches, 1990; Kates, 1969; Odum and Odum, 1959; Welch, 1952; Wetzel, 1983; USDA, 1982; North Carolina, 1991).

For each specific guideline developed, the water quality issue is stated followed by the variable under consideration and the limits. A rationale is then presented justifying the selection of limits followed by a model section that may be useful in predicting response based on stream data.

STUDY AREA

The study area encompasses the southeastern physiographic province known as the Piedmont which is geographically located between the mountain and coastal plain extending from Alabama through Georgia, South Carolina, and into North Carolina. The Piedmont is characterized by rolling hills devoid of natural lakes. All lakes found in the Piedmont were formed from the impoundment of surface waters for conservation, water supply, flood control, recreation, hydro-power, and irrigation purposes. Impoundments chosen for study were based on the following considerations: 1) location, 2) acreage, 3) availability of data, 4) accessibility, and 5) perceived trophic condition. The location of each impoundment is listed in Table 1.

TABLE 1. IMPOUNDMENT LOCATIONS

IMPOUNDMENT	STATE	COUNTY	LONGITUDE	LATITUDE
Colbert	GA	Madison	83°13'32"	34°04'00"
Commerce	GA	Banks	83°30'08"	34°16'08"
Chapman	GA	Clarke, Madison, Jackson	83°22'58"	34°02'21"
Olgethorpe	GA	Olgethorpe	83°13'49"	33°52'12"
Union Point	GA	Greene	83°02'20"	33°36'18"
Blalock	GA	Clayton	84°17'29"	33°28'52"
Shamrock	GA	Clayton	84°18'05"	33°28'25"
Brantley	GA	Morgan	83°36'35"	33°48'03"
Rutledge	GA	Morgan	83°36'09"	33°38'54"
Devin	NC	Granville	78°37'27"	36°17'57"
High Falls	GA	Monroe	84°01'29"	33°11'12"
Michie	NC	Durham	78°49'49"	36°09'03"
Rock Eagle	GA	Putnam	83°23'42"	33°24'49"
Wheeler	NC	Wake	78°41'41"	35°41'33"
Bowen	SC	Spartenburg	82°03'19"	35°06'17.5"
Cunningham	SC	Greenville	82°15'20"	34°58'37.5"
Secession	SC	Abbeville, Anderson	82°35'26"	34°17'22"

METHODS

All sampling and measurements took place during April - October of 1989 and 1991 on a weekly or biweekly basis except where so noted. This seven month study period was selected because it is the time of maximum recreational use, maximum water supply use and maximum growth of aquatic plants which affect use.

Information on impoundment sites located in Georgia, South Carolina, and North Carolina was gathered by direct sampling or through EPA's 106 and 314 program contracts. Most sampling stations were located at mid-impoundment along the thalweg. Depth integrated water samples were collected from the mixing zone (the depth above a sharp temperature decline, i.e., the summer epilimnion after a thermocline forms), but at no greater depth than two meters (6.56 feet). The only exceptions were Lake Secession, South Carolina and Lake Wheeler, North Carolina. Lake Secession was sampled three times during the growing season from 1980 to 1990. Chlorophyll A and nutrient samples were collected as depth integrated water samples throughout the photic zone of Lake Wheeler.

Impoundment vertical profiles for dissolved oxygen (DO), temperature, pH, and conductivity were developed by measuring for each variable every 0.5 meter (1.6 feet) with calibrated probes. Secchi disc transparency (SD) was measured to the nearest 0.01 meter (0.03 foot) according to EPA procedures (EPA, 1988a). For purposes of developing a SD photic zone coefficient, light transmission was measured at selected times and sites with a LiCor 4R-1581 light photometer at two impoundments, phosphorus-enriched Rock Eagle and non-fertilized Olgethorpe. Phosphorus exchange between the water-sediment interface was determined with chambers at Rock Eagle and Oglethorpe according to the Region IV Ecological Support Branch SOP's (EPA, 1988b).

At stream sites entering impoundments, grab samples were collected from mid-depth. Water stage was either read from a tape down at a reference point on a bridge or from a staff gauge installed at the stream site. Stage-discharge curves were established using flow and water stage measurements over a wide range of stream flows. Flows were measured using a wading rod and a Gurley or Price AA current meter. Stream stage was noted at the beginning and end of each flow measurement at station cross sections. Discharge was computed using the mid-section method outlined in the USDI Water Measurement Manual (1975). During rainfall event sampling periods, 7-day stage recorders were set up to provide continuous flow information needed for calculating stream load to each impoundment. Stream stations were equipped with automatic sequential samplers set on 6-hour intervals for the purpose of sampling during high flow events. The intake lines were suspended for continuous submergence without stream bottom contact.

Impoundment water column samples were analyzed for corrected chlorophyll A, total phosphorus (TP), bioavailable phosphorus (BP), total nitrogen (TN), total suspended solids (TSS), limiting nutrient, and alkalinity according to EPA - Region IV SOP's (EPA 1988b; EPA 1990b). Stream samples were analyzed for TP, TN, TSS, and BP according to EPA - Region IV SOP's.

DATA ANALYSIS

The approach to setting water quality limits (guidelines) can vary from utilizing expert opinion, literature, or actual data. In determining acceptable limits, all three approaches were used by EPA - Region IV. Use of data within a risk analysis setting was emphasized, but expertise and literature were necessary to formulate limits related to eutrophication problems.

The risk analysis approach is derived from a classification system developed for South African impoundments (Walmsley, 1984; Walker, 1985a) and successfully used to estimate impairment in Minnesota (Heiskary and Walker, 1988; Wilson and Walker, 1989). This approach expresses impoundment condition based upon the frequency of extreme, chlorophyll A concentrations (blooms) as opposed to average or median concentrations. For this study, the risk or probability analysis was conducted for 19 impoundment stations by (1) dividing the growing season means for each site into intervals, (2) computing the frequency of each class (i.e., exceedance level greater than or equal to 20µg/L), and (3) plotting the frequency of each class (expressed in %) against the mean seasonal concentrations. This approach is reasonable because managers can better evaluate risk. Rather than making decisions based on a seasonal or yearly mean or maximum, one can evaluate the degree of exceedance with a given mean concentration. This approach was used to determine criteria for the corrected chlorophyll A and SD variables.

TSS stream concentrations were converted to load per day based on water level gauge readings and stream discharge curves for the piedmont streams studied. During one analysis, impoundment TSS concentrations were corrected for algal content by calculating algal weight in mg/L based on the assumption that chlorophyll A represents 1.5% of the algae by weight (APHA, 1989), and then subtracting the derived algae weight in mg/L from the TSS data. Non-algae SD corrections were made based on the work of Walker and Kuhner (1979), Classen (1980), Brezonik (1978), and Walker (1986) by subtracting chlorophyll A from the reciprocal of SD according to the following equation:

$$SD_o = 1/SD_m - bC$$

where: mean SD_o = transparency depth of impoundment at zero chlorophyll A (1/m)
SD_m = mean Secchi depth in meters
b = chlorophyll A/Secchi slope (m^2/mg)
b = 0.025
C = mean corrected chlorophyll A concentration (μg/L)

An impoundment with a Secchi depth (SD_m) transparency of 1.07 meters, chlorophyll A concentration of 1.11ug/L (c), and a chlorophyll A/Secchi slope of 0.025 would have a transparency free of chlorophyll A of 1.11 meters (SD_o).

Occasionally, decision-makers will have only minimal information about a site, such as proposed impoundment acreage, volume, and loading information, even though a means of predicting stream loading and impoundment response is necessary. EPA does not support the use of any one model and recognizes that simple models like a negative exponential loss, multiple regression, or more complicated models may be satisfactory.

One data analysis approach employed in this study for predictive purposes was the use of the CNET-Reservoir Eutrophication Modeling Worksheet Version 1.0 and the following information supplied by W. W. Walker, Jr., Environmental Engineer, 1127 Lowell Road, Concord, Massachusetts 01742. CNET.wk1 is a Lotus-123 worksheet which implements empirical models for predicting eutrophication and related water quality conditions in impoundments. The worksheet is a condensed and simplified version of BATHTUB, a program developed for the U. S. Army Corps of Engineers (Walker, 1987). The models of BATHTUB estimate impoundment eutrophication responses as measured by phosphorus, chlorophyll A, transparency, organic nitrogen, and hypolimnetic oxygen depletion, as a function of watershed runoff, inflow phosphorus concentrations, and impoundment morphometry. The formulation, calibration, and testing of the models based upon various impoundment and lake data sets are described in reports prepared for the Corps of Engineers (Walker, 1981, 1982, 1985c, 1987). BATHTUB documation (Walker, 1987) summarizes the relevant equations (Appendix F) and provides general guidance for using the model and interpreting the output. As distinct from BATHTUB, CNET.wk1 applications are restricted to single-segment impoundments in which nitrogen limitation of algal growth is not important. Optimal models for phosphorus sedimentation and chlorophyll A are identical to those described in the BATHTUB documentation (Walker, 1987, pp IV-1 to IV-15) (Appendix F).

To avoid untimely delays, EPA-Region IV recommends that predictive models acceptable to the state and EPA-Region IV be approved by said organizations.

Data used for the analyses has been filed on Lotus 123 worksheets and is available upon request.

QUALITY ASSURANCE

Standard operating procedures of the Region IV Environmental Service's Division were followed as the principle means of maintaining appropriate quality assurance and quality control checks on sample collection, physical measurements, chemical analyses, data gathering, and processing. Data were subject to verification and validation. Verification included range checks and internal consistency checks. Validation consisted of a review of the data from a data users perspective for consistency based on known numerical relationships.

IMPOUNDMENT CHARACTERISTICS

The impoundments and streams selected for this study exhibited a broad range of characteristics (Table 2) useful in developing eutrophication criteria.

The impoundments studied are monomictic (one thermal turnover in the autumn). Vertical zonation was in place by mid-June and remained until the latter part of September or October when water turnover occurred. The pH ranged from 4.88 at Lake Michie to 9.76 at Rock Eagle. With the on-set of temperature zonation, a DO chemocline began to form at the 1-to 2-meter depth. Dissolved oxygen was sufficient in at least the upper 1 - 2 meters (3.28 - 6.56 feet). By mid-summer the hypolimnion was void of oxygen. All of the impoundments were freshwater (Hutchinson, 1957; Odum and Odum, 1959; Wetzel, 1983). They had conductivities of <300 umhos/cm @25°C and most of the time <100 umhos. No fish kills or stressed fish were observed or reported under the above conditions. The impoundments were phosphorus limited or co-limited with nitrogen.

Trophic conditions for the set of impoundments studied ranged from a Carlson TSI of 50.2 to 71.6 (Table 2) which encompasses the classical eutrophication range from mesotrophic to hypereutrophic (EPA, 1988a). Even though hydraulic residence times were relatively short, some impoundments like Brantley and

Shamrock were quite productive. The relatively low mean standing crops of phytoplankton in relation to the TP concentrations is not surprising for southeastern piedmont waters where phosphorus availability commonly is less than 50% and can be as low as 3% of TP (Raschke and Schultz, 1987).

Light is one of the major factors which controls growth, especially the extent of macrophyte growth in impoundments. Because of equipment limitations and the nature of the sampling schedule, a conversion factor of 2.1 was developed to convert SD readings to euphotic zone depth (>1% light transmission) via the following equation:

$$\text{Euphotic zone depth} = (\text{SD}) \quad (2.1)$$

This coefficient is very close to the 2.0 conversion factor determined for experimental impoundments at Auburn University (Boyd, 1979). Application of the coefficient to SD data showed that the euphotic zone could attain a depth of 3.72 meters (12.2 feet).

Limiting nutrient status of impoundments was determined through chemical analysis and bioassay. The impoundments were phosphorus or phosphorus/nitrogen co-limited. These limitations are not unexpected for piedmont waters receiving non-point source nutrient runoffs and uninfluenced by extensive row crop agriculture, intensive animal farming, or waste water treatment plants effluents.

Internal as well as external sources of phosphorus must be considered in the determination of predictive modeling strategies of phytoplankton response. With the relatively high sediment loading and intensive fertilization in piedmont watersheds, many small impoundments have high sediment phosphorus levels (Garman et al., 1986). Impoundments in which the phosphorus is released from the sediments (internal phosphorus loading) can maintain a relatively high trophic condition (mesotrophic or eutrophic). The two Region IV studies of internal phosphorus loading showed that the loading amounted to 53% and 68% of the total phosphorus loading to the two impoundments.

TABLE 2. CHARACTERISTICS OF SMALL SOUTHEASTERN PIEDMONT IMPOUNDMENTS, 1989-1991.

LAKE SITE	STATE	TSI	AREA (HA)	MEAN DEPTH (meters)	MEAN HRT (days)	N	YEARS	MEAN TP ± SE (µg/L)	MEAN SD ± SE (meters)	MEAN CHL A ± SE (µg/L)	%≥15	%≥20	%≥25	%≥30	%≥40
Bowen	SC	50.2	648	4.7	111	36	1	30±4	1.78±.14	7.38±.89	8	3	3	3	0
Cunningham	SC	50.9	101	2.7	--	20	1	28±3	1.08±.04	7.94±.87	5	0	0	0	0
Michie	NC	52.6	202	8.2	48.0	12	1	36±2	1.31±.11	9.39±1.46	25	0	0	0	0
Oglethorpe	GA	53.2	28	2.3	79.5	25	1	24±4	1.61±.10	9.98±1.62	28	8	4	0	0
Wheeler1	NC	53.5	219	3.5	72.0	18	4	33+4	0.71±.06	10.3±1.33	22	6	0	0	0
Chapman	GA	53.9	105	3.3	40.2	26	1	25±5	1.37±.09	10.8±2.06	38	12	12	4	0
Union Point	GA	54.9	13	0.85	13.9	23	1	28±3	1.05±.07	11.1±2.30	39	30	13	9	0
Wheeler3	NC	54.9	219	3.5	72.0	28	4	30±3	0.94±.08	11.9±1.39	28	6	6	0	0
Secession5	SC	55.1	356	6.7	44	15	5	52±13	1.88±.15	12.2±2.04	40	14	7	0	0
Devin	NC	56.9	51	3.0	--	12	1	45±4	1.25±.13	14.6±3.32	27	18	9	9	9
Colbert	GA	57.4	19	1.9	5.1	26	1	41±9	0.91±.10	15.3±2.80	38	31	23	19	8
Brantley	GA	61.2	18	1.3	4.7	14	1	36±6	0.56±.03	22.6±8.71	43	21	14	14	14
Blalock	GA	61.3	105	3.2	17.2	14	1	42±4	1.05±.08	22.9±3.51	64	50	29	21	14
Rutledge	GA	63.3	115	1.6	24.9	14	1	44±6	0.72±.07	27.1±3.54	79	79	57	43	21
Commerce	GA	63.7	149	1.5	15.2	26	1	81±7	0.41±.02	29.3±3.44	85	65	62	54	35
Shamrock	GA	63.9	28	3.0	2.9	13	1	47±3	0.98±.08	29.7±5.42	77	54	46	38	38
Secession4	SC	63.9	356	6.7	3102	15	5	76±9	1.08±.13	29.8±4.53	80	53	47	33	27
High Falls	GA	64.8	243	3.7	15.5	14	1	52±4	0.96±.08	32.8±6.21	79	57	50	43	36
Rock Eagle	GA	71.6	45	1.5	13.7	14	1	54±3*	0.74±.07	65.3±7.97	100	100	100	93	79

TSI	Carlson Trophic State Index Based on Mean Chlorophyll A
HRT	Hydraulic Residence Time
N	Number of Samples used for Bloom Frequency Analysis
Years	Number of years where data available
TP	Total Phosphorus
SD	Secchi Disc Transparency
ChlA	Corrected Chlorophyll A
SE	Standard Error for Growing Season Mean
%≥	Percent of the Time Corrected Chlorophyll A equal to or greater than the instantaneous measurement
*	Rock Eagle impoundment was fertilized with an additional 500 lbs of phosphorus; therefore the resulting corrected chlorophyll A probably reflects availability of phosphorus

ISSUE: NUISANCE BLOOMS AND SCUMS
VARIABLE: GROWING SEASON MEAN CORRECTED CHLOROPHYLL A

GUIDELINE	
Non-Support $\geq 25\mu g/L$	Support $\leq 15\mu g/L$

Guideline

A mean growing season limit of ≤15ug chlorophyll A/L is recommended for water supply impoundments. At this concentration, few nuisance algal blooms or scums would be expected; therefore very few problems associated with filter clogging and taste and odor would be anticipated. For other uses a mean growing season chlorophyll A of <25ug/L is recommended to maintain a minimal aesthetic environment for viewing pleasure, safe swimming, and good fishing and boating.

Rationale

One common indicator of eutrophication and its impacts is the variable chlorophyll A (Carlson, 1977: EPA, 1988a; EPA, 1990a). Because of the specificity and ease of the chlorophyll A analysis, it has become a common surrogate for estimating phytoplankton biomass. In practice, this pigment is a useful yardstick for estimating phytoplankton blooms (chlorophyll A concentrations $\geq 15\mu g/L$) and associated water quality problems.

On the average, 1.5% of algal organic matter (ash-free-dry weight) is corrected chlorophyll A (APHA, 1989).

Based on the authors experience in phycology and limnology/oceanography over the past 30 years, generally, when chlorophyll A ranges from 0 to 10μg/L, there is no discoloration of the water and no problems. At a range of 10-15μg/L, water can become discolored and algal scums could develop. Between 20-30μg/L, the water is deeply discolored, scums are more frequent, and matting of algae can occur. Beyond 30μg/L of chlorophyll A, discolorations are more intense and mats occur more frequently.

Walker (1985), working on the hypothesis that water use impacts are more directly related to instantaneous chlorophyll A concentrations than to seasonal mean values, examined data from South Africa, U.S. Corps of Engineers (COE), and Vermont Lakes. Statistical frequency distribution models were calibrated and the curves generated were found to be similar. Soon thereafter, Walker collaborated with the State of Minnesota (Heiskary and Walker, 1988; Wilson and Walker, 1989) using the bloom frequency approach to successfully estimate percent impairment.

This approach is reasonable because managers can better evaluate risk. Rather than making decisions based on just an average or maximum, they can evaluate the degree of bloom frequency (maxima) in association with a growing season mean concentration. A few days of algal scums during the growing season may be tolerable, but 1-2 days per week of scums may be undesirable.

The EPA-Region IV population of impoundments show that percent of occurrence of bloom frequencies (i.e. ≥15ug chlorophyll A/L) decreases as bloom frequency increases (Figure 1). Quenching of the bloom frequency curves begins at a mean chlorophyll A of 30μg/L whereupon the curves converge toward the 100% ordinate. Figure 2 presents an interpolation of Figure 1 data between a seasonal mean of 10 to 30μg chlorophyll A/L. The following straight line equations were derived for each exceedance class within the 10-30 ug chlorophyll A/ L limit.

$$\% \geq 15 \pm .43 = 2.88\ (\bar{X}) - 12.92$$

$$\% \geq 20 \pm .36 = 2.77\ (\bar{X}) - 25.58$$

$$\% \geq 25 \pm .54 = 2.31\ (\bar{X}) - 24.46$$

$$\% \geq 30 \pm 4.3 = 1.90\ (\bar{X}) - 21.26$$

$$\% \geq 40 \pm .15 = 1.18\ (\bar{X}) - 14.16$$

Where: $\bar{X}$ = Mean season corrected chlorophyll A

EPA-Region IV data (Figures 1 and 2)shows that a mixing zone growing season average of ≤15μg/L of chlorophyll A should satisfactorily meet multiple uses (Carlson, 1977; Lillie and Mason, 1983; Burden <u>et al</u>., 1985; Walmsley, 1984; Heiskary and

Walker, 1988). At a growing season (April - Oct.) average chlorophyll A of 15μg/L, one could expect that 30% of the time chlorophyll A would exceed 15μg/L and 7% of the time it would exceed 30μg/L. Based on this study and others (Carlson, 1977; Lillie and Mason, 1983; Walmsey, 1984; Burden et al. 1985; Heiskary and Walker, 1988), a mixing zone growing season mean of $\leq$15μg/L corrected chlorophyll A for impounded piedmont waters should satisfactorily meet multiple uses. Reduction of organic material in waters with chlorophyll A concentrations of 15ug/L would be necessary most of the time to comply with the Safe Drinking Water Act standard of 0.1mg/L for trihalomethanes (THM's) in finished drinking water (Arruda and Fromm, 1988). Based on the work of Walker (1983) and Arruda and Fromm (1988), 15ug/L of chlorophyll A is equivalent to approximately 7mg/L of total organic carbon (TOC) which converts to approximately 0.2 mg/L of THM's after chlorination. According to Singer (1992), concentrations of TOC $\geq$10mg/L (40-50ug chlorophyll A/L) are problematic and relatively expensive to reduce, and at concentrations $\geq$25mg/L of TOC, reduction is very difficult and very expensive. To remain within the THM standard, it is necessary to maintain waters with standing crops of approximately 4-5ug/L of chlorophyll A which is equivalent to approximately 4mg/L of TOC (Walker, 1983; Arruda and Fromm, 1988).

At an average growing season concentration of 25μg/L, one could expect that 26% of the time or approximately 2 days per week (Figures 1 and 2), chlorophyll A would be ≥30μg/L, and 59.1% of the time said waters would be discolored by algal growth accompanied with a few scums.

North Carolina has put a high priority on nutrient impacts as evidenced by their annual bloom reports (North Carolina, 1988-1991) and their numerical chlorophyll A standard for the nutrient sensitive waters classification (North Carolina, 1991). Presently, they are reassessing this standard because most warm waters have a small probability of exceeding 40μg/L (Figure 2).

An examination of North Carolina's bloom reports (North Carolina, 1989-1991) revealed no discernable association between fish kills and chlorophyll A concentrations, but a greater frequency of fish kills were associated with occurrences at 25μg/L of chlorophyll A. The standard (North Carolina, 1991) applicable to North Carolina piedmont waters states that corrected chlorophyll A should not be >40μg/L as an absolute upper limit. At a growing season mean of 10μg/L one would not expect exceedances ≥40μg/L (Figure 2), but at mean chlorophyll A concentrations of 15, 20, 25, and 30μg/L the percent ≥40μg/L would be 3.5 (0.25 day/week), 9.4 (0.7 day/week), 15.3 (1.1 days/week), and 21.2 (1.5 days/week) of the growing season, respectively.

A mean chlorophyll A of <25μg/L is a generous upper limit that should minimize water quality problems, and maintain a minimal aesthetic environment.

CNET.WK1

Prediction of nuisance blooms in piedmont impoundments is dependent upon phosphorus load, internal impoundment phosphorus concentration, and phytoplankton response to these available phosphorus inputs. Necessary predictions of phytoplankton response is based on loading models. One model that predicts reasonably well is a simplified phosphorus-limited version (CNET.WK1) of the U.S. COE's BATHTUB model (Walker, 1986). CNET is a Lotus 123 worksheet which implements empirical models for predicting eutrophication and related water quality conditions in impoundments. It performs a water and nutrient balance in steady-state, accounting for advective and diffusive transport and nutrient sedimentation.

Working on the hypothesis that small impoundments are similar to tributary embayments because they are both impeded by a dam, earthen or water, respectively, the CNET version of BATHTUB was used to estimate phytoplankton response.

Data from nine intensively studied impoundments and their streams were analyzed via the CNET program. Utilizing the maximum mean stream concentration of TP, that is, the internal impoundment plus the surface load, the observed versus the predicted mean corrected chlorophyll A was ±54% (Figure 3) using empirical models 2 and 5, a Beta of 0.025, P-decay calibration of 4, and a chlorophyll A calibration of 0.95 (Appendix F). The error was ±34% (Figure 4) when using the median stream TP concentration and observed median chlorophyll A under the same conditions except the P-decay calibration was 1.95.

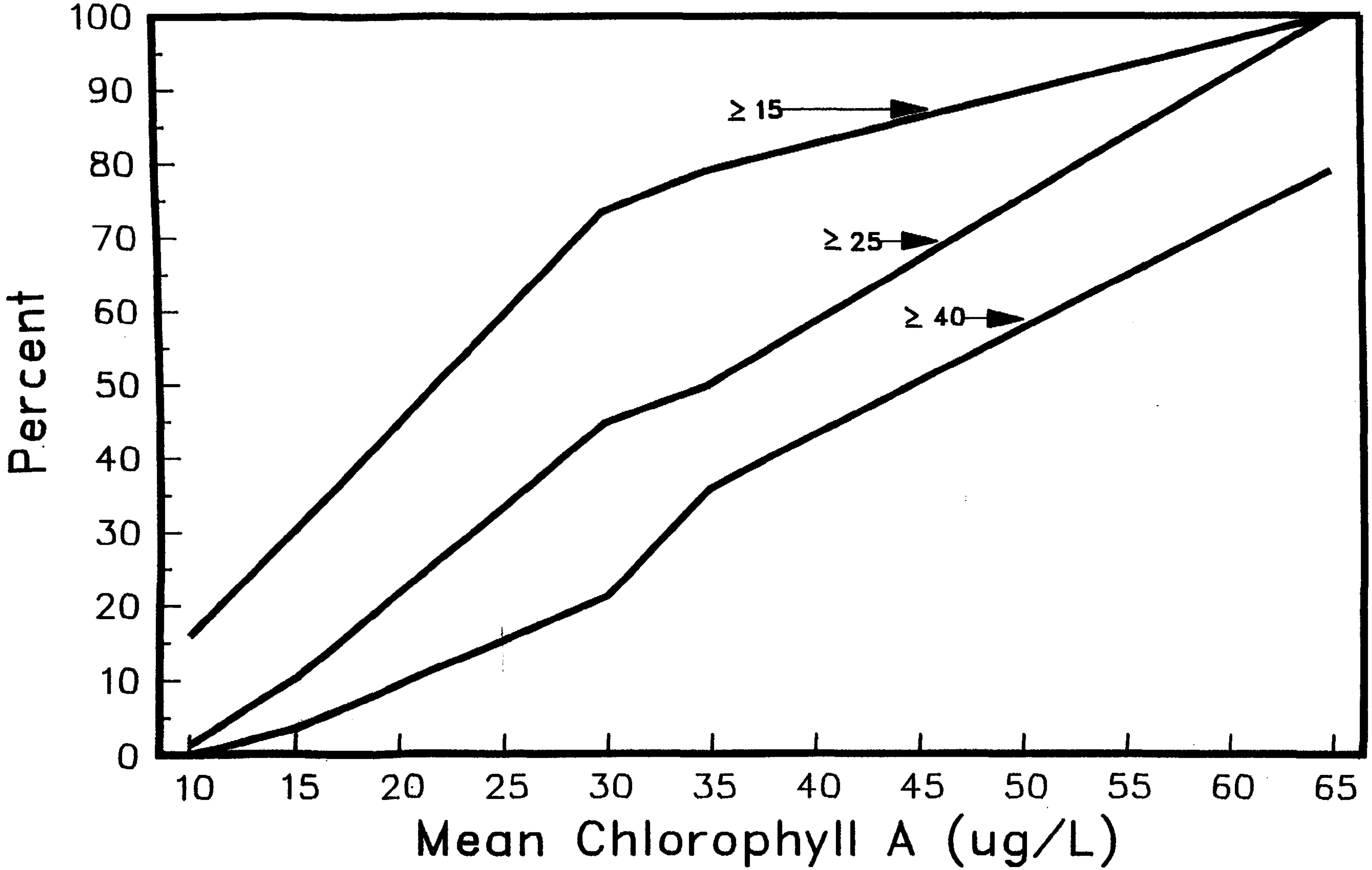
Figure 1. Percent occurrence of bloom frequencies (i. e. ≥15ug chlorophyll A/L) for southeastern piedmont growing season mean chlorophyll A concentrations.

Figure 2. Predicted percent occurrence of bloom frequencies of chlorophyll A concentrations as a function of mean chlorophyll A.

Figure 3. CNET version of BATHTUB model comparing observed mean chlorophyll A and predicted mean chlorophyll A for nine intensively studied Georgia impoundments.

Figure 4. CNET version of BATHTUB model comparing observed median chlorophyll A and predicted median chlorophyll A for nine intensively studied Georgia impoundments.

FIGURE 1.



100
90
80
70
60
50
40
30
20
10
0
Percent
≥ 15
≥ 25
≥ 40
10
15
20
25
30
35
40
45
50
55
60
65
Mean Chlorophyll A (ug/L)

FIGURE 2.

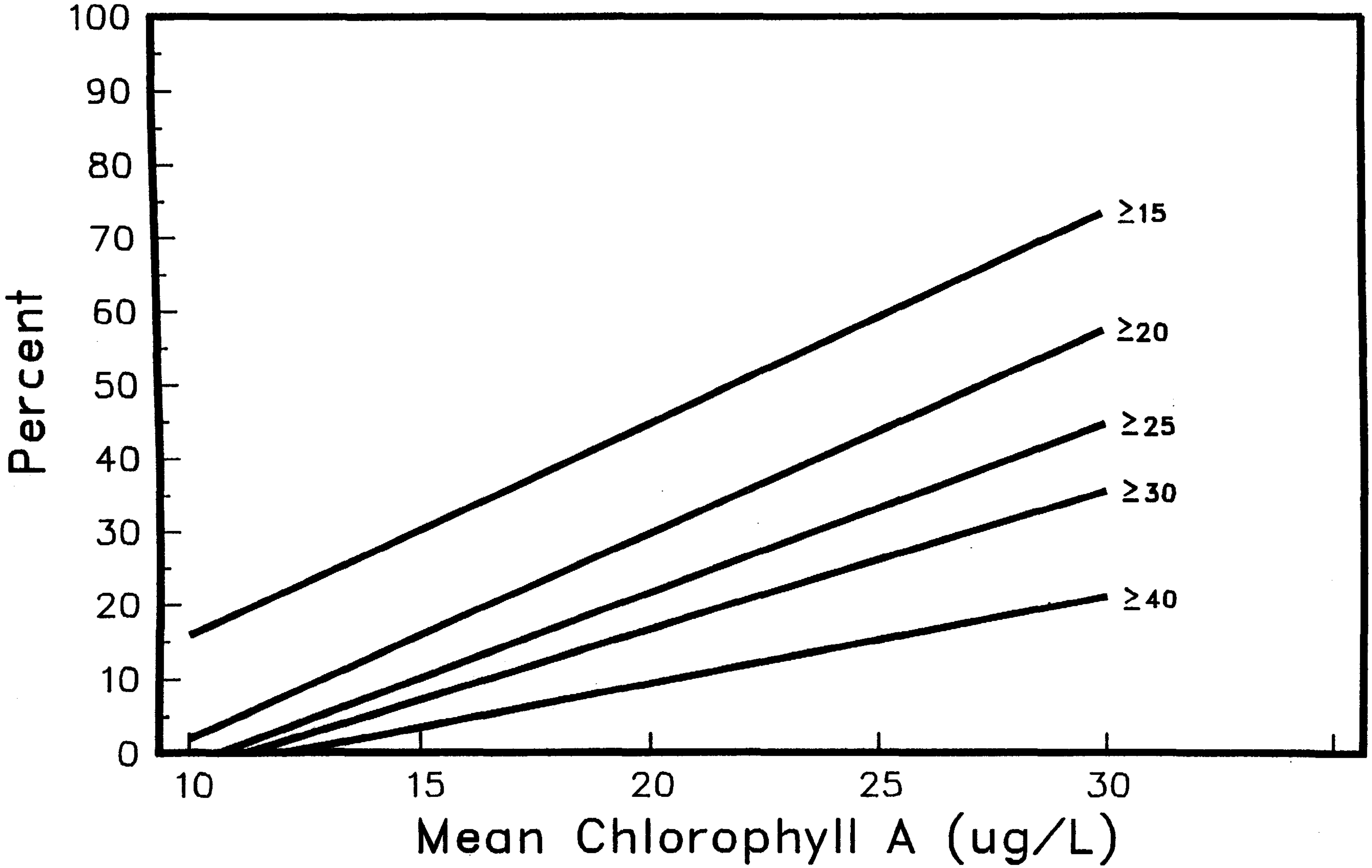
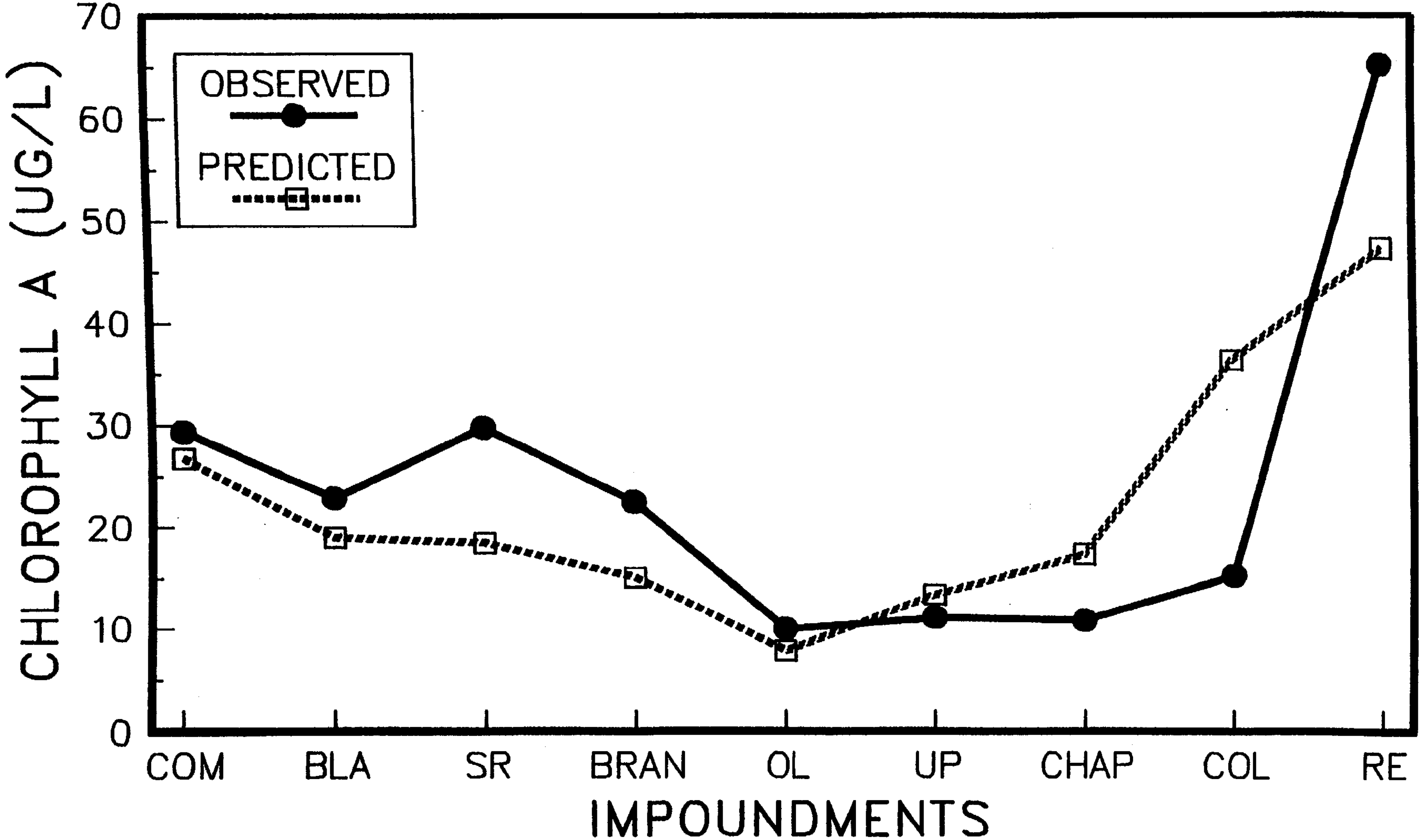
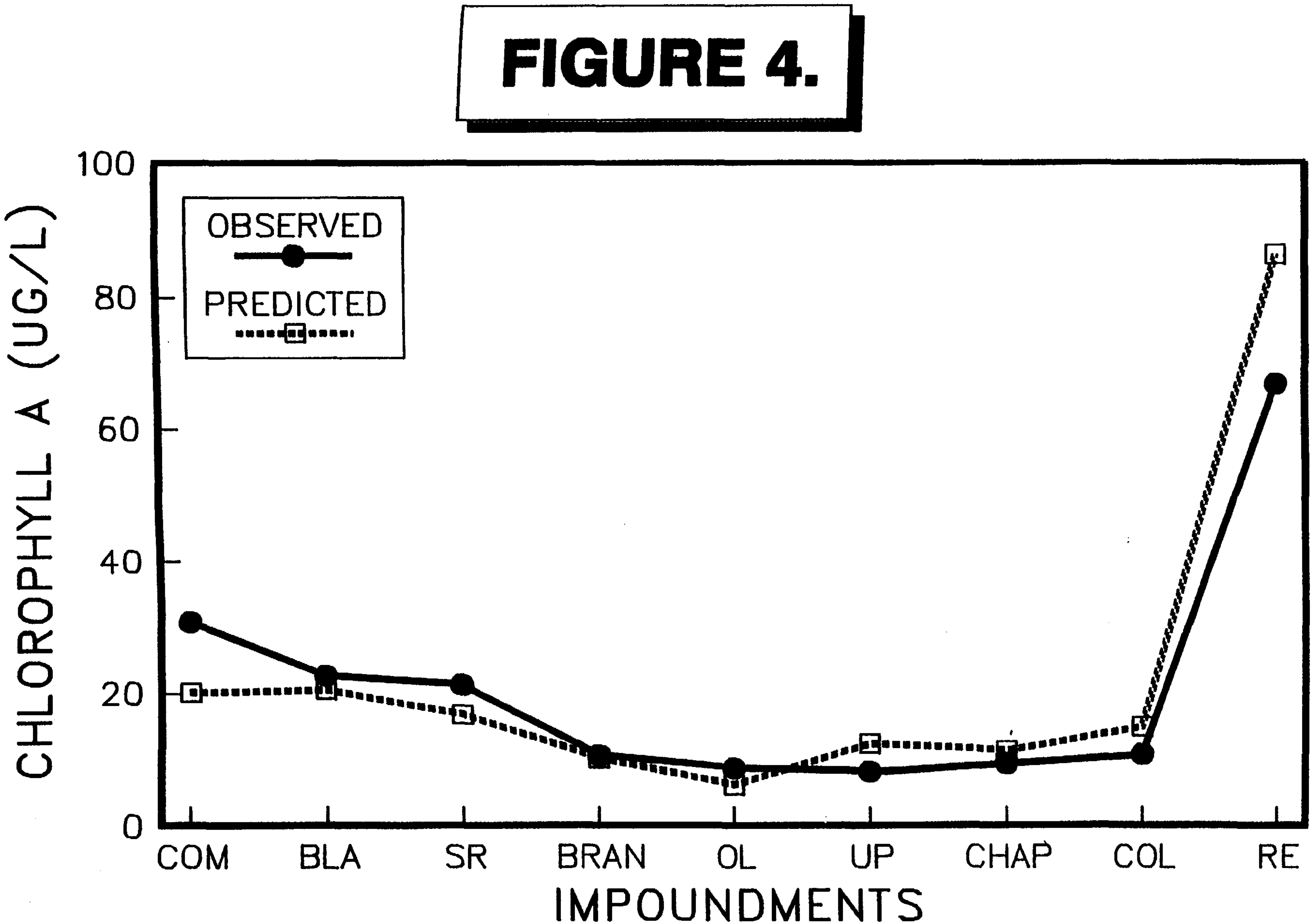

100
90
80
70
60
50
40
30
20
10
0
Percent
≥15
≥20
≥25
≥30
≥40
10
15
20
25
30
Mean Chlorophyll A (ug/L)

FIGURE 3.



Seasonal Means (April – Oct.)



Seasonal Medians (April – Oct.)

ISSUE: CLARITY OF WATER
VARIABLE: GROWING SEASON MEAN SECCHI DEPTH TRANSPARENCY

GUIDELINE	
Non-Support **≤1 meter** **≤3.28 feet**	**Support** **≥1.5 meters** **≥4.92 feet**

Guideline

For water supply impoundments, a mean growing season Secchi disc transparency of ≥1.5 meters is desirable. Minimal clogging of filters, a low risk of nuisance weed infestations, a very low risk of fish-kills because of low dissolved oxygen, normal fish production, and 60-65% safe swimming conditions would be expected. For non-water supply impoundments, a growing season mean of >1 meter is acceptable for fishing and some swimming. Impoundments with growing season mean Secchi disc transparencies ≤1 meter are aesthetically undesirable, offer few swimming opportunities, and are subject to a greater risk of fish-kills or lower fish production.

Rationale

Because of the nature of piedmont soils and land-use practices, streams of the Piedmont are known for carrying high suspended solid loads into impoundments which subsequently effect impoundment quality. Visibility is reduced when solids and dissolved substances are added to a water body (Boyd, 1979).

Clarity or transparency of piedmont impoundments is primarily influenced by incoming sediment loads of suspended and colloidal solids and internal impoundment phytoplankton blooms. These constituents in large amounts affect impoundment uses (Sawyer, 1960; EPA 1988a).

The National Academy of Sciences recommends that a Secchi disc transparency depth of >4 feet be maintained in swimming areas (National Academy of Sciences, 1973). Swimming and diving take place in waters that are clear enough to see submerged objects. Boating does not require as much clarity, but submerged objects should be visible at least to the depth permitting safe navigation (Moore, 1987).

Figure 5 represents the risk assessment approach (Heiskary and Walker, 1988; Wilson and Walker, 1989) where probability of exceedance for Secchi disc transparency is determined for 19 impoundment stations. At a growing season mean depth of one meter (3.28 feet), Secchi depth would be 13%, 72%, and 100% of the time at ≤0.5m, ≤1m, ≤2.0m, respectively. A one meter Secchi disc transparency translates into a Carlson trophic state index (TSI)(Carlson, 1977) of 64 which on a sliding scale of 0 to 110 is considered eutrophic to hypereutrophic water. At a mean transparency of one meter, unsafe swimming conditions would occur 72% of the time. Thirteen percent of the time conditions of low dissolved oxygen and muddy water could become a problem with respect to fish survival and production (Boyd, 1979; Boyd, 1990). Buck (1956) divided impoundments into three categories: clear with TSS <25mg/L (SD >0.46 meter); intermediate with TSS 25-100 mg/L (SD 0.46 to 0.08 meter); and muddy impoundments with TSS >100mg/L (SD <0.08 meter). The mean harvest of game fish were: clear impoundments, 162 lbs/ac; intermediate 94 lbs/ac; and muddy impoundments 30lbs/ac. Techniques are available (Boyd, 1979; EPA, 1988a) to clear muddy waters, however, they are ineffective if impoundments receive large amounts of muddy runoff after each rain (Boyd, 1990).

The higher limit of ≥1.5 meters Secchi depth transparency is a reasonable number for piedmont waters. The 1.5-meter limit is a safe level for swimming most of the time. One could expect unsafe swimming conditions 35-40% (Figure 5) of the time (National Academy of Sciences, 1973) at the 1.5-meter limit. At the 1.5 meter level or greater, low dissolved oxygen concentrations affecting fish survival are minimal, and on the average TSS at approximately 10mg/L would be non-determental to fish production (Buck, 1956; Boyd, 1990). The EPA-Region IV study of 17 impoundments showed that the mean photic zone (>1% light transmission) from the surface downward was 2.10 meters (6.9 feet) ranging from 0.80 meter to 3.72 meters (2.8 feet to 12.2 feet). At a mean photic zone of 6.9 feet one could expect that about 34% of the time the photic zone would exceed 6.9 feet (Figure 5), and 2% of the time it would exceed 10 feet. Only one impoundment, Union Point, because of low slopes had weed infestations that affected water supply taste and odor. According to Boyd (1990), at a Secchi transparency depth of 1.5 meters, no macrophyte growths were observed in Auburn University impoundments at the two-meter depth even though the photic zone extended from the surface down to the three-meter level. With an edge slope of 2:1 or 3:1 (EPA, 1988a; USDA, 1982) and a growing season mean Secchi disc depth transparency of ≥1.5 meters, it is highly improbable that conditions would allow for nuisance weed coverage (>40%) in piedmont impoundments (Aurand, 1982; Edmiston and Myers, 1984; Personal communication from Joe Joyce, Chief, University of Florida Center for Aquatic Plants).

Upon conducting multivariate analysis and limited modeling, two models are recommended for use when assessing impacts during the planning stage.

Model # 1

Mean TSS_S stream loading, mean TSS_I impoundment concentration, and non-algal Secchi disc transparency (see Data Analysis Section) were selected as the variables of choice after conducting a multivariate analysis. It was determined that two equations would satisfactorily predict the mean non-algal Secchi depth, if the mean stream TSS load in lbs/day/ was known. The following equations are based on a data base which included intensive sampling of 11 impoundments and 16 streams during the growing season (April-October) (Figures 6 and 7).

$$TSS_I = 0.0011(TSS_s) + 6.40$$
$$SD_I = 31.44(TSS_I)^{-1.31}$$

Where: TSS_I = $\bar{X}$ non-algal impoundment TSS in mg/L
TSS_s = $\bar{X}$ stream TSS in lbs/ft-day
SD_I = $\bar{X}$ impoundment non-algal influenced SD in meters
ft = $\bar{X}$ impoundment depth in feet

Model #1 disregards the effects of phytoplankton on impoundment Secchi disc transparency, whereas the CNET.WK1 program accounts for the non-biological and biological components affecting clarity.

CNET.WK1

Utilizing the same data set of Model #1 and the CNET worksheet of the BATHTUB model discussed under the Nuisance Bloom Section, the observed Secchi transparency was compared to the predicted (Figure 8). The prediction error ranged from -35% to +14%.

Figure 5. Percent Secchi depth frequencies for southeastern piedmont growing season mean Secchi depth transparency.

Figure 6. Functional relationship of mean stream TSS to mean impoundment non-algal TSS.

Figure 7. Functional relationship of mean impoundment non-algal TSS to mean impoundment non-algal influenced Secchi depth transparency.

Figure 8. Cnet version of BATHTUB model comparing observed Secchi depth transparency and predicted Secchi depth transparency for nine intensively studied impoundments.

FIGURE 5.

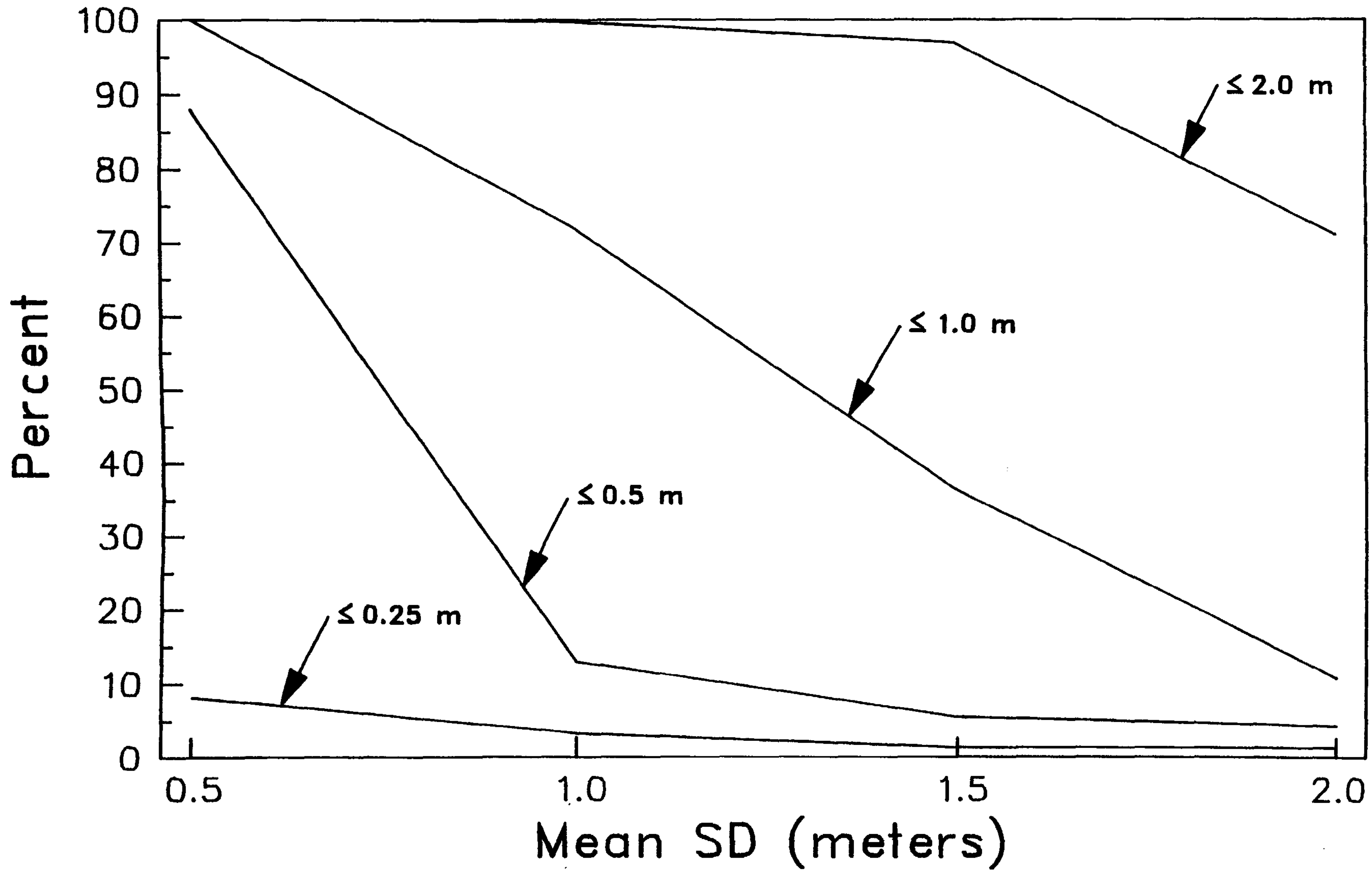
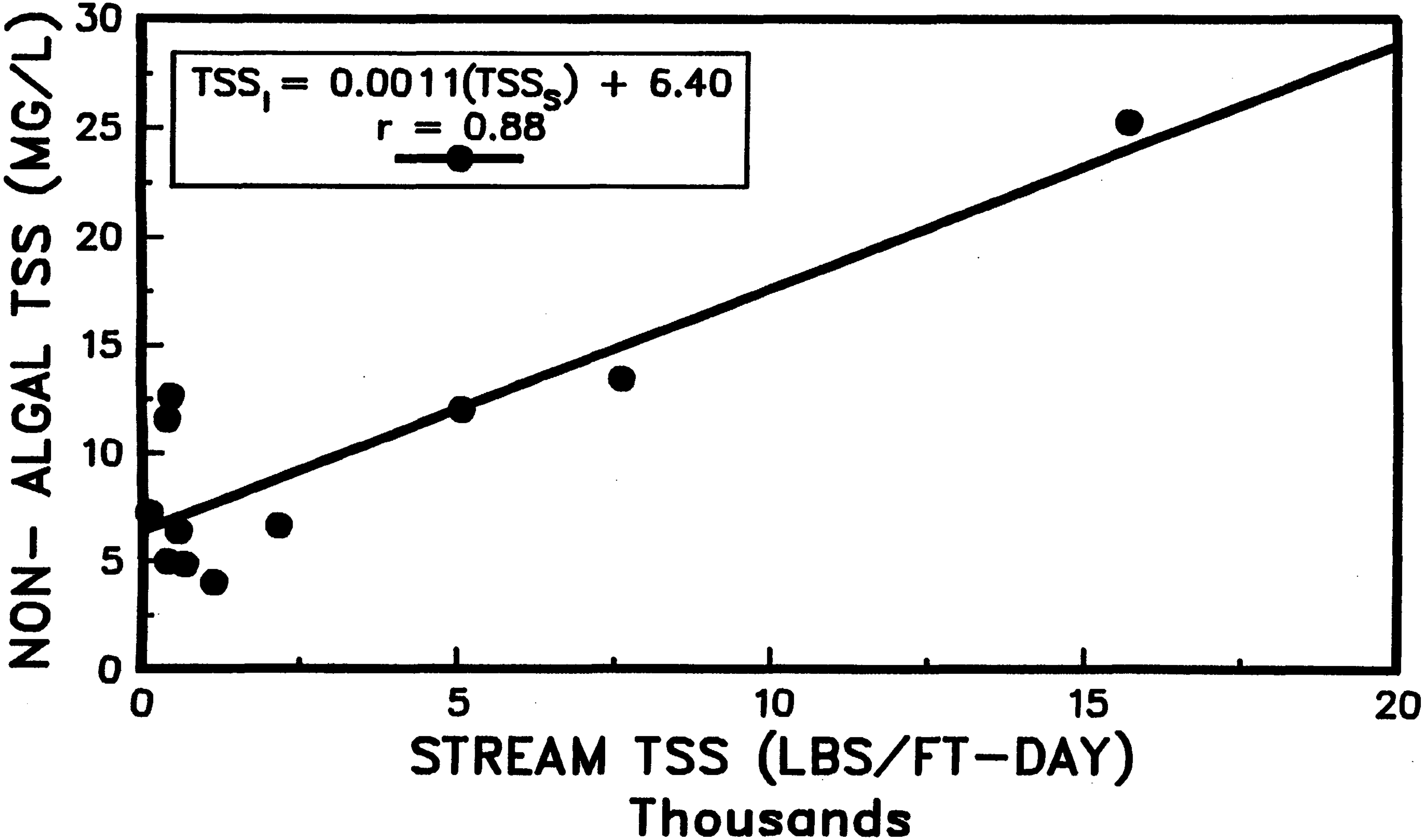
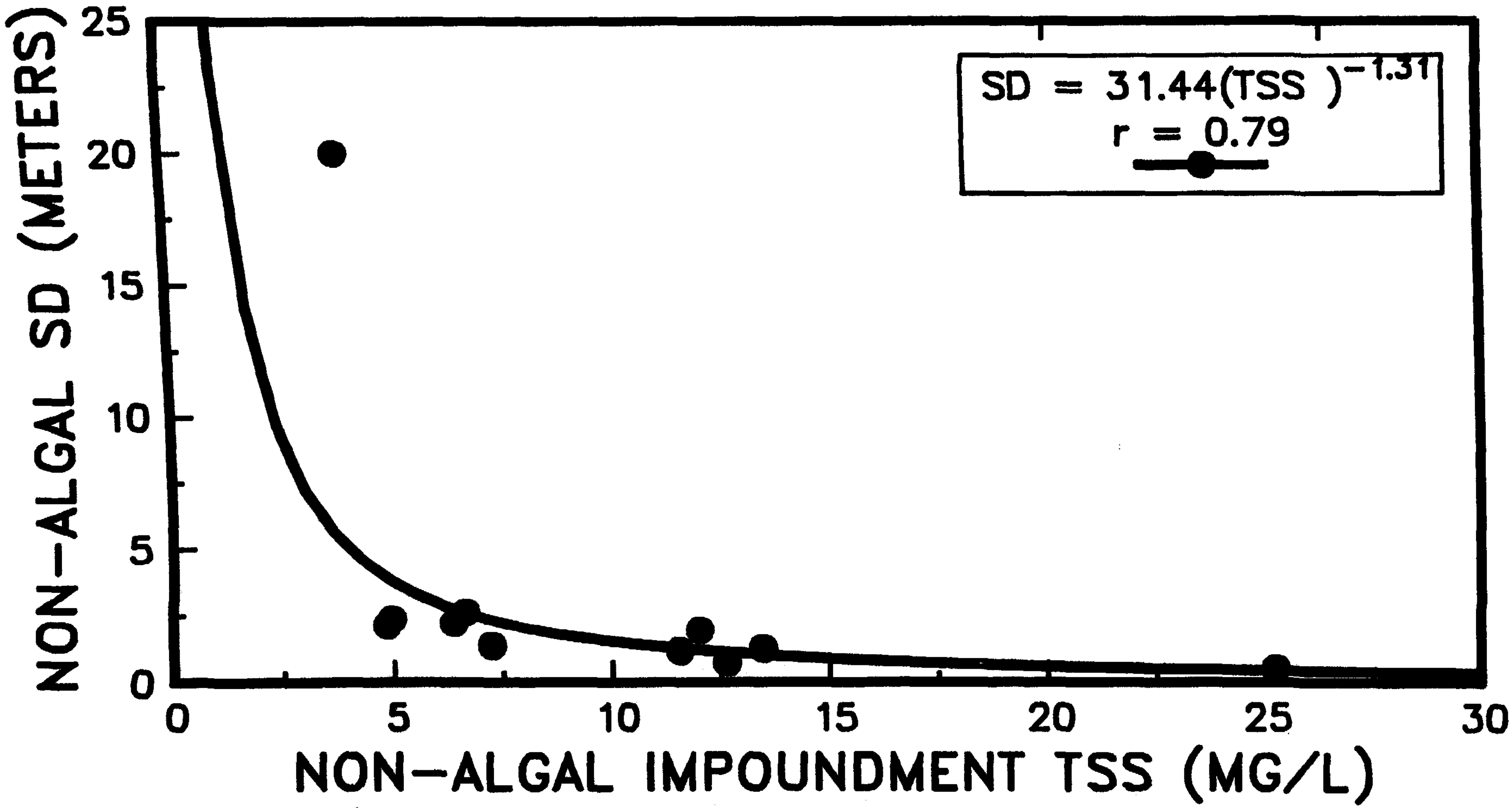

≤ 2.0 m
≤ 1.0 m
≤ 0.5 m
≤ 0.25 m
Percent
100
90
80
70
60
50
40
30
20
10
0
0.5
1.0
1.5
2.0
Mean SD (meters)

FIGURE 6.



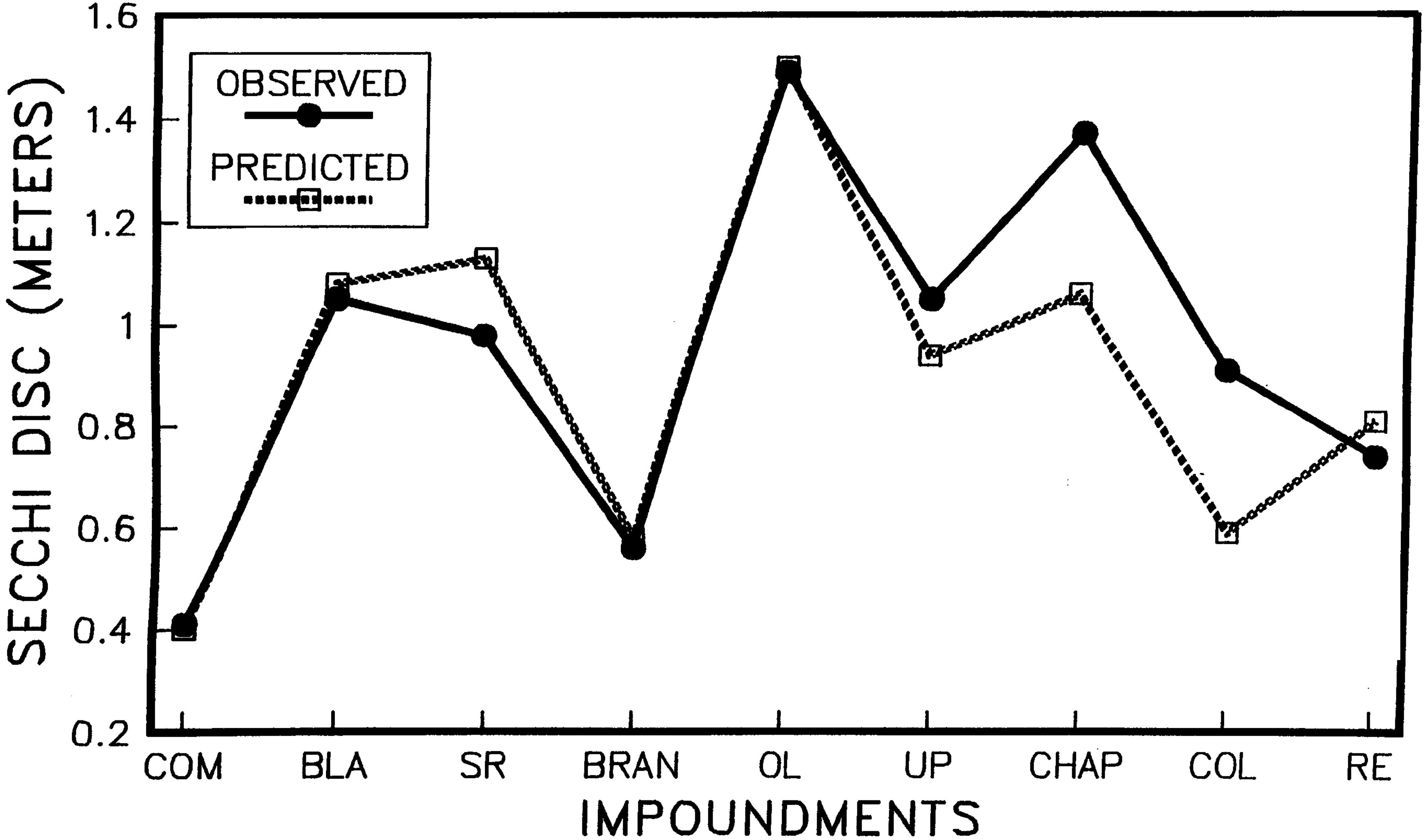
Seasonal Means; April – Oct.

FIGURE 7.



Seasonal Means; April – Oct.

FIGURE 8.



Seasonal Means (April – Oct.)

REFERENCES

APHA. 1989. Standard Methods for the Examination of Water and Wastewater (Seventeenth Edition). American Public Health Association. 1015 Fifteenth St., NW, Washington, DC 20005.

Arruda, J. A. and C. H. Fromm. 1988. The relationships among trihalomethane formation potential, organic carbon, and lake trophic state in eastern Kansas drinking water supply lakes. Kansas Department of Health and Environment, Topeka, KN 66620-7315.

Aurand, D. 1982. Nuisance Aquatic Plants and Aquatic Plant Management Programs in The United States. Vol. 2. S.E. Region. MTR-82w47-02, The MITRE Corp., Metrek Division. 1820 Dolly Madison Blvd., McLean, VA 22102.

Bennett, G. W. 1962. Management of Artificial Lakes and Ponds. Reinhold Publ. Corp., New York 10020.

Boyd, C. E. 1979. Water Quality in Warmwater Fish Ponds. Auburn University Agricultural Experiment Station, Auburn Alabama.

Boyd, C. E. 1990. Water Quality in Ponds for Aquaculture. Auburn University Agricultural Experiment Station, Auburn Alabama.

Brezonik, P. L. 1978. Effects of organic color and turbidity on Secchi disk transparency. J. Fish, Res. Board Can. 35: 1410-1416.

Buck, D. H. 1956. Effects of turbidity on fishing. Trans. N. Amer. Wildlife Conf. 21:249-261.

Burden, D. G., R. F. Malone, and J. Geaghen. 1985. Development of a condition index for Louisiana Lakes. In: Lake and Reservoir Management: Practical Applications. Proceedings 4th Annual Conference and International Symposium, October 16-19, McAffee, N.J. North American Lake Management Society. One Progress Boulevard, Box 27, Alachua, FL 32615.

Carlson, R. E. 1977. A trophic state index for lakes. Limno. and Oceanogr. 22(2):361-369.

Classen, J. 1980. OECD Cooperative Program for Monitoring of Inland Waters - Regional Project - Shallow Lakes and Reservoirs. Organization for Economic Coop-Develop.

Cooke, G. D., E. B. Welch, S. A. Peterson, P. R. Newroth. 1986. Lake and Reservoir Restoration. Butterworth Publ., Boston.

Crance, J. H. 1979. Alabama Fish Ponds. Alabama Department of Conservation and Natural Resources, 64 Union Street, Montgomery AL.

Edmiston, H. L. and V. B. Myers. 1984. Florida Lakes Assessment: Combining Macrophyte, Chlorophyll, Nutrient, and Public Benefit Parameters into a Meaningful Lake Management Scheme. Lake and Reservoir Management. EPA 440/5/84-001. EPA Office of Water Regulations and Standards. Washington, D.C. 20460.

Edmondson, W. T. 1970. Phosphorus, nitrogen and algae in Lake Washington after diversion of sewage. Science 169:690-691.

EPA. 1988a. The Lake and Reservoir Restoration Guidance Manual. EPA 440/5-88-002. EPA Criteria and Standards Division, Non-point Sources Branch. Washington, D.C. 20460.

EPA. 1988b. Region IV Ecological Support Branch SOP and QA Manual, Environmental Services Division. EPA-Region IV, Athens, GA 30613.

EPA. 1989. Report to Congress: Water Quality of the Nations's Lakes. EPA 440/5-89-003. U. S. Environmental Protection Agency, Office of Water, Nonpoint Source Control Branch, Washington D. C. 20460.

EPA. 1990a. Monitoring Lake and Reservoir Restoration. EPA 440/4-90-007. EPA Office of Water (WH553). Washington, D.C. 20460.

EPA. 1990b. Region IV Analytical Support Branch SOP and QA Manual, Environmental Services Division. EPA-Region IV, Athens, Ga 30605-2720.

Garman, G. D., G. B. Good and L. M. Hinsman. 1986. Phosphorus: A Summary of Information Regarding Lake Water Quality. Division of Water Pollution Control, Illinois Environmental Protection Agency, 2200 Churchhill Road, Springfield, IL 62706.

Georgia. #1987. Regional Water Supply and Fishing Lake Reports.

Georgia Department of Natural Resources. Environmental Protection Division Water Resources Management Branch. Atlanta, GA 30334.

Getches, D. H. 1990. Water Law in a Nutshell. Second Edition. West Publ. Co., St. Paul, MN.

Heiskary, S. A. and W. W. Walker Jr. 1988. Developing phosphorus criteria for Minnesota lakes. Lake and Reserv. Manage. 4(1):1-10.

Hutchinson, G.E. 1957. A Treatise on Limnology. Vol 1. John Wiley & Sons Inc. NY, NY 10158-0012.

Kates, R. C. 1969. Georgia Water Law. Institute of Government, Univ. of Georgia, Athens, GA 30605.

Langbein, W. B. and K. T. Iseri. 1960. General Introduction and Hydrologic Definitions. Manual of Hydrology: Part I. General Surface Water Techniques. Geological Survey Water-Supply Paper 1541-A. Methods and Practices of The Geological Survey. Superintendent of Documents, U.S. Government Printing Office. Washington, D.C. 20402.

Lillie, R. A. and J. W. Mason. 1983. Limnological Characteristics of Wisconsin Lakes. Tech. Bull. 138. Department of Natural Resources. Madison, WI 53707-7921.

Moore, M. L. 1987. NALMS Management Guide for Lakes and Reservoirs. North America Lake Management Society. Box 27, Alachua, FL 32615-9536.

NALMS. 1988. Water Quality Standards for Lakes. A Survey. North American Lake Management Society. One Progress Blvd., Box 27, Alachua, FL 32615-9536.

NALMS. 1992. Developing Eutrophication Standards for Lakes and Reservoirs. North American Lake Management Society, One Progress Blvd., Box 27, Alachua, FL 32615-9536.

Nation Academy of Sciences and National Academy of Engineering. 1973. Water Quality Criteria, 1972. Superintendent of Documents, U.S. Government Printing Office, Washington, D. C. 20402.

North Carolina. 1988-1991. Algal Bloom Reports. State of North Carolina Department of Environment, Health and Natural Resources, Division of Environmental Management. Raleigh, NC 27611.

North Carolina. 1991. Administrative Code Section 15A NCAC 2B.0211(b3A). State of North Carolina Department of

Environment, Health and Natural Resources, Division of Environmental Management. Classification and Water Quality Standards Applicable to Surface Waters of North Carolina. Environmental Management Commission. Raleigh, NC 27611.

Odum, E. P. and H. T. Odum. 1959. Fundamentals of Ecology. 2nd Edition. W. B. Saunders Co. Philadelphia, PA 19106-3399.

Palmstrom, N. S., R. E. Carlson and G. D. Cooke. 1988. Potential links between eutrophication and the formation of carcinogens in drinking water. Lake and Reserv. Manage. 4(2):1-16.

Raschke, R. L. and D. A. Schultz. 1987. The use of the algal growth potential test for data assessment. J. Water Poll. Cont. Fed. 59(4):222-227.

Reckhow, K. H. and S. C. Chapra. 1983. Engineering Approaches for Lake Management. Butterworth Publ., Boston.

Ryding, S. and W. Rast. 1989. The Control of Eutrophication of Lakes and Reservoirs. The Parthenon Publishing Group, Inc., Park Ridge, N. J.

Sakamoto, M. 1966. Primary production by phytoplankton communities in some Japanese lakes and its dependency on lake depth. Arch. Hydrobiol. 62:1-28.

Sawyer, C. N. 1960. Chemistry for Sanitary Engineers. McGraw-Hill Book Company, Inc. New York 10020.

Singer, P. 1992. Personal communication from Dr. Phil Singer, University of North Carolina at Chapel Hill, NC.

USDA. 1982. Ponds - Planning, Design, and Construction. Agricultural Handbook No. 590. U. S. Dept. of Agriculture. Washington, D.C. 20402.

USDI. 1975. Water Measurement Manual. U.S. Department of The Interior, Bureau of Reclamation, Denver, CO. Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

Walker, W. W. Jr. and J. Kuhner. 1979. An Empirical Analysis of Factors Controlling Eutrophication in Midwestern Impoundments. Environmental Effects of Hydraulic Engineering Works, E. E. Driver and W. O. Wunderlich, eds. TVA, Knoxville, TN 37902.

Walker, W. W., Jr. 1981. Empirical Methods for Predicting Eutrophication in Impoundments - Report 1 Phase I: Data Base Development, Prepared for Department of the Army, U. S. Army

Corps of Engineers, Washington, D. C., Technical Report E-81-9, Environmental Laboratory, USAE Waterways Experiment Station, Vicksburg, MS.

Walker, W. W. Jr. 1982. Empirical Methods for Predicting Eutrophication in Impoundments - Report 2 Phase II: Model Testing, prepared for Department of the Army, U. S. Army Corps of Engineers, Washington, D. C., Technical Report E-81-9, Environmental Laboratory, USAE Waterways Experiment Station, Vicksburg, MS.

Walker, W. W. Jr. 1983. Significance of eutrophication in water supply reservoirs. Jour. Amer. Wat. Works Assoc. 75:38-42.

Walker, W. W. Jr. 1985a. Statistical basis for mean chlorophyll A criteria. In: Lake and Reservoir Management: Practical Applications. Proceedings of 4th Annual Conference and International Symposium, October 16-19, McAffee, N.J. North American Lake Management Society. One Progress Boulevard, Box 27, Alachua, FL 32615.

Walker, W. W. Jr. 1985b. Urban nonpoint source impacts on a surface water supply. In: Perspectives on Nonpoint Source Pollution. Proceeding of a National Conference Kansas City, MO. May 19-22, 1985. U.S. Environmental Protection Agency EPA 440/5-85-01. Criteria and Standards Division, Nonpoint Sources Branch. Washington, D. C. 20460.

Walker, W. W. Jr. 1985c. Empirical Methods for Predicting Eutrophication in Impoundments - Report 3 Phase II: Model Refinements, Prepared for Department of the Army, U. S. Army Corps of Engineers, Washington, D. C., Technical Report E-81-9, Environmental Laboratory, USAE Waterways Experiment Station, Vicksburg, MS.

Walker, W. W. Jr. 1987. Empirical Methods for Predicting Eutrophication in Impoundments: Report 4, Phase III: Applications Manual. Technical Report E-81-9. Prepared by W. W. Walker, Jr., Environmental Engineer, Concord, Mass., for the U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS 39180-6299.

Walmsley, R.D. 1984. A chlorophyll A trophic status classification system for South African impoundments. J. Environ. Qual. 13:97-104.

Wedepohl, R. E., D. R. Knauer, G. B. Wolbert, H. Olem, P. J. Garrison, and K. Kepford. 1990. Monitoring Lake and Reservoir Restoration. EPA 440/4-90-007. Prepared by the North American Lake Management Society for the U. S. Environmental Protection Agency, Washington D. C.

Welch E. B. 1989. Alternative Criteria for Defining Lake Quality for Recreation pp. 7-15. In: Proceedings of a National Conference on Enhancing States' Lake Management Programs, N.E. Illinois Planning Commission, 400 W. Madison St., Suite 200, Chicago, Illinois 60606.

Welch, P. S. 1952. Limnology. McGraw Hill Book Co. New York 10020.

Wilson, C. B. and W. W. Walker Jr. 1989. Development of lake assessment methods based upon the aquatic ecoregion concept. Lake and Reserv. Manage. 5(2): 11-22

Wetzel, R. G. 1983. Limnology. Second Edition. Saunders College Publ., Philadelphia, PA 19106-3399.

APPENDICES

APPENDIX A

APPENDIX
A

List of Other Regulatory Factors That Affect The Planning of Impoundments.

Loss of historic and cultural artifacts
Loss of protected natural areas
Loss of wilderness areas
Loss of proposed wilderness areas
Loss of designated wild life management areas
Loss of national lakeshore recreation areas
Loss of wild and scenic river designation
Loss of designated recreational river reach
Loss of critical habitat for endangered species
Loss of proposed habitat for endangered or threatened species
Loss of areas of lakes identified as critical habit
Loss of spawning areas critical for the maintenance of a fish or shellfish species
Loss of feeding areas critical for the maintenance of a fish or shellfish species
Loss of designated wilderness area
Loss of a monument
Loss of a national park
Loss of a preserve
Loss of a wildlife refuge
Loss of wetlands
Potential leachate from landfill
Hazardous waste site as potential source of leachate
Sewage lines on lake bottom or along shore
Highways or railway lines over or next to impoundments
Direct input of industrial, municipal or stormwater waste
Stream segments not attaining water quality standards
Fish kill history in feeder stream/s
Poor fish health history in feeder streams
Dam outfall at the bottom
Less than maintain 7Q10 flow

APPENDIX B

APPENDIX
B

TABLE B-1

LAKE SITE: COLBERT	DRAINAGE AREA: 29.77 SQ. MI.	
LAKE FILLED: 1978		
COUNTY: MADISON GA		
UPSTREAM BRUSH CREEK STATION:	LONGITUDE:83 14′ 50"	LATITUDE:34 04′ 25"
UPSTREAM BIGER CREEK STATION:	LONGITUDE:83 14′ 25.5"	LATITUDE:34 03′ 13"
LAKE STATION COL-10 LOCATION:	LONGITUDE:83 13′ 32"	LATITUDE:34 04′ 00"
GEOGRAPHICAL PROVINCE: PIEDMONT		
LAKE MORPHOMETRY:		
SUFACE AREA: 47.0 AC.		
MAXIMUM DEPTH: 14.0 FT.		
MEAN DEPTH: 6.1 FT.		
VOLUME: 289 AC.-FT.		
INFLOW: BRUSH CREEK (26.76 CFS)		
INFLOW: BIGER CREEK (29.35 CFS)		
OUTFLOW: BIGER CREEK		

LAKE SITE: COMMERCE	DRAINAGE AREA: 19.10 SQ. MI.	
LAKE FILLED: 1978		
COUNTY: BANKS GA		
UPSTREAM GROVE RIVER STATION:	LONGITUDE:83 31′ 32"	LATITUDE:34 16′ 18"
LAKE STATION COM-6 LOCATION:	LONGITUDE:83 30′ 08"	LATITUDE:34 16′ 08"
GEOGRAPHICAL PROVINCE: PIEDMONT		
LAKE MORPHOMETRY:		
SURFACE AREA: 368 AC.		
MAXIMUM DEPTH: 13.0 FT.		
MEAN DEPTH: 4.8 FT.		
MEAN VOLUME: 1780 AC.-FT.		
INFLOW: GROVE RIVER (58.92 CFS)		
OUTFLOW: GROVE RIVER		

LAKE SITE: CHAPMAN	DRAINAGE AREA: 45.38 SQ. MI.	
LAKE FILLED: 1978		
COUNTY: CLARKE, MADISON, JACKSON GA		
UPSTREAM LI'L SANDY CREEK STATION:	LONGITUDE:83 22′ 50.6"	LATITUDE:34 04′ 15.5"
UPSTREAM SANDY CREEK STATION:	LONGITUDE:83 23′ 20.6"	LATITUDE:34 04′ 15.5"
LAKE STATION SC-2 LOCATION:	LONGITUDE:83 22′ 58.1"	LATITUDE:34 02′ 20.6"
GEOGRAPHICAL PROVINCE: PIEDMONT		
LAKE MORPHOMETRY:		
SURFACE AREA: 260 AC.		
MAXIMUM DEPTH: 21.0 FT.		
MEAN DEPTH: 10.8 FT.		
MEAN VOLUME: 2791 AC.-FT.		
INFLOW: LITTLE SANDY CREEK (10.66 CFS)		
INFLOW: SANDY CREEK (59.39 CFS)		
OUTFLOW: SANDY CREEK		

LAKE SITE: OLGETHORPE
LAKE FILLED: 1971
COUNTY: OLGETHORPE GA
UPSTREAM GOULDING CREEK STATION:
LAKE STATION OL-13 LOCATION:
GEOGRAPHICAL PROVINCE: PIEDMONT
LAKE MORPHOMETRY:
SURFACE AREA: 68.1 AC.
MAXIMUM DEPTH: 28.0 FT.
MEAN DEPTH: 7.4 FT.
MEAN VOLUME: 504 AC.-FT.
INFLOW: GOULDING CREEK (3.33 CFS)
OUTFLOW: GOULDING CREEK

DRAINAGE AREA: 3.46 SQ. MI.

LONGITUDE:83 13' 19.5" LATITUDE:33 52' 27.8"
LONGITUDE:83 13' 49.2" LATITUDE:33 52' 12"

LAKE SITE: UNION POINT
LAKE FILLED: 1967
COUNTY: GREENE GA
UPSTREAM SHERRILLS CREEK STATION:
LAKE STATION UP-16 LOCATION:
GEOGRAPHICAL PROVINCE: PIEDMONT
LAKE MORPHOMETRY:
SURFACE AREA: 32.7 AC.
MAXIMUM DEPTH: 14.0 FT.
MEAN DEPTH: 2.8 FT.
VOLUME: 93.0 AC.-FT.
INFLOW: SHERRILLS CREEK (3.38 CFS)
OUTFLOW: SHERRILLS CREEK

DRAINAGE AREA: 2.61 SQ. MI.

LONGITUDE:83 02' 58" LATITUDE:33 36' 18"
LONGITUDE:83 02' 20" LATITUDE:33 36' 18"

LAKE SITE: BLALOCK
LAKE FILLED: 1989
COUNTY: CLAYTON GA
UPSTREAM BLALOCK CREEK STATION:
UPSTREAM PATES CREEK STATION:
LAKE STATION BL-5 LOCATION:
GEOGRAPHICAL PROVINCE: PIEDMONT
LAKE MORPHOMETRY:
SURFACE AREA: 260 AC.
MAXIMUM DEPTH: 23.0 FT.
MEAN DEPTH: 10.5 FT.
MEAN VOLUME: 2731 AC.-FT.
INFLOW: BLALOCK CREEK, PATES CREEK (30.17 CFS)
OUTFLOW: PATES CREEK

DRAINAGE AREA: 5.73 SQ. MI.

LONGITUDE:84 17' 46" LATITUDE:33 28' 20"
LONGITUDE:84 17' 41" LATITUDE:33 28' 50"
LONGITUDE:84 17' 29" LATITUDE:33 28' 52"

LAKE SITE: BRANTLEY
LAKE FILLED: ~1932
COUNTY: MORGAN GA
UPSTREAM HARD LABOR CREEK STATION:
LAKE STATION LB-2 LOCATION:
GEOGRAPHICAL PROVINCE: PIEDMONT
LAKE MORPHOMETRY:

SURFACE AREA: 44.9 AC.
MAXIMUM DEPTH: 13.1 FT.
MEAN DEPTH: 4.3 FT.
MEAN VOLUME: 193 AC.-FT.

INFLOW: HARD LABOR CREEK (32.35 CFS)
OUTFLOW: HARD LABOR CREEK (31.58 CFS)

DRAINAGE AREA: 19.10 SQ. MI.

LONGITUDE:83 33' 61" LATITUDE:33 39' 54"
LONGITUDE:83 36' 35" LATITUDE:33 40' 03"

LAKE SITE: HIGH FALLS
LAKE FILLED: 1902
COUNTY: MONROE GA
UPSTREAM BUCK CREEK STATION:
UPSTREAM TOWALIGA RIVER STATION:
LAKE STATION HF-4 LOCATION:
GEOGRAPHICAL PROVINCE: PIEDMONT
LAKE MORPHOMETRY:

SURFACE AREA: 600 AC.
MAXIMUM DEPTH: 24.0 FT.
MEAN DEPTH: 12.1 FT.
MEAN VOLUME: 7,289 AC.-FEET

INFLOW: TOWALIGA RIVER (176.90 CFS)
INFLOW: BUCK CREEK (59.44 CFS)
INFLOW: BRUSHY CREEK ?
OUTFLOW: TOWALIGA RIVER

DRAINAGE AREA: 110.6 SQ. MI.

LONGITUDE:84 04' 48" LATITUDE:33 11' 03"
LONGITUDE:84 03' 40" LATITUDE:33 14' 50"
LONGITUDE:84 01' 29" LATITUDE:33 11' 12"

LAKE SITE: ROCK EAGLE
LAKE FILLED: 1938
COUNTY: PUTNAM GA
UPSTREAM NO NAME CREEK STATION:
UPSTREAM NO NAME CREEK STATION:
UPSTREAM NO NAME CREEK STATION:
UPSTREAM NO NAME CREEK STATION:
LAKE STATION RE-2 LOCATION:
GEOGRAPHICAL PROVINCE: PIEDMONT
LAKE MORPHOMETRY:

SURFACE AREA: 110 AC.
MAXIMUM DEPTH: 23.
MEAN DEPTH: 5.0 FT
MEAN VOLUME: 552 AC.-FT.

INFLOW: : MULTIPLE TRIBUTARIES (5.08 CFS)
OUTFLOW: LITTLE GRADY CREEK

DRAINAGE: 1.96 SQ. MI.

LONGITUDE:83 23' 26" LATITUDE:33 25' 30"
LONGITUDE:83 23' 57" LATITUDE:33 25' 22"
LONGITUDE:83 23' 03" LATITUDE:33 25' 12"
LONGITUDE:83 23' 04" LATITUDE:33 25' 15"
LONGITUDE:83 23' 42" LATITUDE:33 24' 49"

LAKE SITE: RUTLEDGE
LAKE FILLED: 1932
COUNTY: MORGAN GA
UPSTREAM HARD LABOR CREEK STATION:
UPSTREAM ROCKY CREEK STATION:
LAKE STATION RL-5 LOCATION:
GEOGRAPHICAL PROVINCE: PIEDMONT
LAKE MORPHOMETRY:
SURFACE AREA: 285 AC.
MAXIMUM DEPTH: 13.1 FT.
MEAN DEPTH: 5.2 FT.
MEAN VOLUME: 1496 AC.-FT.
INFLOW: HARD LABOR CREEK (31.58 CFS)
INFLOW: ROCKY CREEK (6.02 CFS)
OUTFLOW: HARD LABOR CREEK

DRAINAGE AREA: 19.2 SQ. MI.

LONGITUDE:83 36' 07" LATITUDE:33 39' 51"
LONGITUDE:83 37' 03" LATITUDE:33 40' 02"
LONGITUDE:83 36' 09" LATITUDE:33 38' 54"

LAKE SITE: SHAMROCK
LAKE FILLED: 1955
COUNTY: CLAYTON GA
UPSTREAM NO NAME CREEK STATION:
UPSTREAM NO NAME CREEK STATION:
UPSTREAM NO NAME CREEK STATION:
UPSTREAM NO NAME CREEK STATION:
LAKE STATION SR-2 LOCATION:
GEOGRAPHICAL PROVINCE: PIEDMONT
LAKE MORPHOMETRY:
SURFACE AREA: 68.0 AC.
MAXIMUM DEPTH: 23.0 FT.
MEAN DEPTH: 10.0 FT.
MEAN VOLUME: 680 AC.-FT.
INFLOW: NO NAME CREEK(S) (49.01 CFS)
OUTFLOW: BLALOCK CREEK

DRAINAGE AREA: 5.62 SQ. MI.

LONGITUDE:84 18' 53 LATITUDE:33 29' 03"
LONGITUDE:84 18' 32" LATITUDE:33 29' 02"
LONGITUDE:84 18' 17" LATITUDE:33 29' 03"
LONGITUDE:84 18' 00" LATITUDE:33 29' 01"
LONGITUDE:84 18' 05" LATITUDE:33 28' 25"

LAKE SITE: DEVIN
LAKE FILLED: 1953
COUNTY: GRANVILLE NC
INCOMING STREAM: HACHERS RUN
OUTGOING STREAM: HACHERS RUN
LAKE LOCATION:
GEOGRAPHICAL PROVINCE: PIEDMONT
LAKE MORPHOMETRY:
SURFACE AREA: 125 AC.
MAXIMUM DEPTH: 30.0 FT.
MEAN DEPTH: 10.0 FT.
MEAN VOLUME: 1300 AC.-FT.

DRAINAGE AREA: 1.1 SQ. MI.

LONGITUDE:78 37' 27" LATITUDE:36 17' 57"

LAKE SITE: MICHIE — DRAINAGE AREA: 170.0 SQ. MI.
LAKE FILLED: 1926
COUNTY: DURHAM NC
INCOMING STREAMS: FLAT, DIAL, DRY, ROCKY
OUTGOING STREAM: FLAT
LAKE LOCATION: LONGITUDE:78 49' 49" LATITUDE:36 04'03"
GEOGRAPHICAL PROVINCE: PIEDMONT
LAKE MORPHOMETRY:
SURFACE AREA: 500 AC.
MAXIMUM DEPTH: 75.0 FT.
MEAN DEPTH: 27.0 FT.
MEAN VOLUME: 11,068 AC.-FT.

LAKE SITE: WHEELER — DRAINAGE AREA: 35.8 SQ. MI.
LAKE FILLED: 1956
COUNTY: WAKE NC
INCOMING STREAMS: INCOMING STREAMS: SWIFT, DUTCHMANS BRANCH
OUTGOING STREAM: SWIFT
LAKE LOCATION: LONGITUDE:78 41'41" LATITUDE:35 41' 33"
GEOGRAPHICAL PROVINCE: PIEDMONT
LAKE MORPHOMETRY:
SURFACE AREA: 540 AC.
MAXIMUM DEPTH: 30.7 FT.
MEAN DEPTH: 11.6 FT.
MEAN VOLUME: 6161 AC.-FT.

LAKE SITE: BOWEN — DRAINAGE AREA: 82.1 SQ. MI.
LAKE FILLED: 1961
COUNTY: SPARTENBURG
INCOMING STREAM: SOUTH PACOLET
OUTGOING STREAM: SOUTH PACOLET
LAKE LOCATION: LONGITUDE:82 03' 19" LATITUDE:35 06' 17.5"
GEOGRAPHICAL PROVINCE: PIEDMONT
LAKE MORPHOMETRY:
SURFACE AREA: 1599 AC.
MAXIMUM DEPTH: 41.0 FT.
MEAN DEPTH: 15.4 FT.
MEAN VOLUME: 24547 AC.-FT.

LAKE SITE: CUNNINGHAM
LAKE FILLED: 1955
COUNTY: GREENVILLE SC
INCOMING STREAMS: SOUTH TYGER
OUTGOING STREAM: SOUTH TYGER
LAKE LOCATION:
GEOGRAPHICAL PROVINCE: PIEDMONT
LAKE MORPHOMETRY:
SURFACE AREA: 250 AC.
MAXIMUM DEPTH: 19.0 FT.
MEAN DEPTH: 8.9 FT.
MEAN VOLUME: 2200 AC.-FT.

DRAINAGE AREA: 47.9 SQ. MI.

LONGITUDE:82 15′ 20″ LATITUDE:34 58′ 37.5″

LAKE SITE: SECESSION
LAKE FILLED: 1941
COUNTY: ABBEVILLE, ANDERSON
INCOMING STREAM: ROCKY
OUTGOING STREAM: ROCKY
LAKE LOCATION:
GEOGRAPHICAL PROVINCE: PIEDMONT
LAKE MORPHOMETRY:
SURFACE AREA: 879 AC.
MAXIMUM DEPTH: 91.9 FT.
MEAN DEPTH: 22 FT.
MEAN VOLUME: 19358 AC.-FT.

DRAINAGE AREA: 139 SQ. MI.

LONGITUDE:82 35′ 26″ LATITUDE:34 17′ 22″

APPENDIX C

APPENDIX C

TABLE C-1

SECCHI DEPTH TRANSPARENCY (M)

LAKE	COLBERT	COMMERCE	CHAPMAN	OLGETHORPE	UNION POINT	BLALOCK	SHAMROCK	RUTLEDGE	BRANTLEY	ROCK EAGLE	HIGH FALLS	SECCESSION	WHEELER	MICHIE	DEVIN	BOWEN	CUNNINGHAM
	0.13	0.14	0.24	0.21	0.23	0.60	0.58	0.16	0.34	0.11	0.22	0.30	0.35	1.40	0.60	0.50	0.7
	0.13	0.22	0.73	1.10	0.64	0.65	0.64	0.49	0.35	0.46	0.80	0.50	0.45	1.40	0.90	0.70	1.0
	0.28	0.28	0.81	1.14	0.72	0.78	0.71	0.50	0.40	0.58	0.83	0.50	0.45	1.70	1.10	1.10	1.4
	0.49	0.28	0.95	1.19	0.73	0.82	0.81	0.53	0.53	0.63	0.84	0.50	0.45	1.45	1.10	1.10	0.60
	0.62	0.29	0.95	1.23	0.76	0.83	0.82	0.59	0.54	0.64	0.86	0.50	0.45	1.40	1.20	1.20	0.90
	0.63	0.29	1.08	1.24	0.82	0.99	0.84	0.63	0.54	0.74	0.89	0.50	0.50	1.30	1.30	1.20	1.00
	0.69	0.30	1.09	1.24	0.83	1.00	0.86	0.73	0.58	0.74	0.94	0.60	0.50	1.00	1.30	1.40	1.00
	0.71	0.35	1.16	1.28	0.92	1.06	0.88	0.76	0.60	0.80	0.95	0.60	0.55	0.90	1.30	1.50	1.00
	0.75	0.35	1.18	1.38	0.93	1.07	1.04	0.78	0.62	0.82	0.96	0.75	0.60	0.85	1.50	1.50	1.00
	0.76	0.36	1.19	1.39	1.00	1.08	1.04	0.79	0.63	0.82	1.03	0.80	0.60	0.90	2.20	1.50	1.10
	0.78	0.36	1.27	1.41	1.00	1.34	1.06	0.89	0.64	0.87	1.12	0.90	0.60	2.10		1.60	1.10
	0.78	0.42	1.30	1.42	1.05	1.35	1.42	0.96	0.65	0.92	1.13	1.00	0.65			1.70	1.10
	0.86	0.43	1.46	1.45	1.05	1.45	1.43	1.10	0.69	1.04	1.33	1.00	0.65			1.70	1.10
	0.89	0.44	1.54	1.59	1.08	1.64	1.62	1.20	0.76	1.27	1.49	1.00	0.70			1.70	1.10
	0.92	0.44	1.61	1.67	1.10							1.00	0.70			1.80	1.10
	0.94	0.45	1.61	1.78	1.11							1.10	0.80			1.80	1.10
	0.96	0.46	1.64	1.78	1.12							1.10	0.80			1.90	1.20
	1.02	0.47	1.65	1.85	1.24							1.30	0.80			2.00	1.30
	1.03	0.49	1.68	1.92	1.29							1.30	0.90			2.00	1.30
	1.04	0.50	1.70	1.93	1.36							1.40	0.90			2.10	1.40
	1.06	0.50	1.76	2.12	1.42							1.50	0.90			2.20	
	1.07	0.50	1.76	2.14	1.44							1.50	0.92			2.80	
	1.28	0.52	1.86	2.17	1.55							1.70	1.00			2.80	
	1.42	0.52	1.95	2.22	1.93							1.80	1.00			2.90	
	1.46	0.60	1.98	2.45								1.90	1.00			3.80	
	2.86	0.61		2.54								1.90	1.00				
												2.00	1.00				
												2.00	1.00				
												2.00	1.00				
												2.00	1.00				
												2.00	1.10				
												2.00	1.18				
												2.20	1.30				
												2.40	1.40				
												2.50	1.40				
												2.50	1.40				
												2.50	1.50				
												2.50					
												2.50					
												3.00					

TABLE C-2

CHLOROPHYLL A (UG/L)

LAKE	COLBERT	COMMERCE	CHAPMAN	OLGETHORPE	UNION POINT	BLALOCK	SHAMROCK	RUTLEDGE	BRANTLEY	ROCK EAGLE	HIGH FALLS	SECCESSION	WHEELER	MICHIE	DEVIN	BOWEN	CUNNINGHAM
	0.00	0.00	0.00	0.00	0.00	7.80	2.30	6.00	0.00	28.51	6.20	3.40	2.00	2.14	5.76	2.25	1.71
	0.00	0.00	0.00	0.00	0.00	8.80	10.68	6.70	1.90	31.30	13.99	5.90	4.00	3.38	7.48	2.49	2.50
	0.00	0.00	0.00	0.00	0.00	10.80	11.87	13.35	5.34	34.00	14.69	6.10	4.00	6.33	9.41	3.00	3.10
	0.00	0.10	0.00	0.00	0.00	14.24	16.02	20.02	5.34	42.70	16.02	6.30	4.00	6.40	9.44	3.10	3.24
	0.20	15.20	0.00	0.00	0.00	14.83	18.02	21.36	7.60	46.73	16.02	7.00	5.00	6.69	10.30	3.49	4.55
	3.81	16.70	0.00	0.00	0.00	19.42	18.69	23.36	7.80	55.63	17.00	9.60	6.00	7.73	11.04	3.89	5.07
	4.01	18.70	0.00	5.10	0.00	19.42	24.03	25.98	9.35	61.41	23.69	11.60	6.00	9.03	11.07	4.09	6.20
	6.68	18.70	0.00	5.30	0.00	22.70	26.70	29.37	10.55	66.75	26.70	13.20	6.00	10.08	11.80	4.27	7.03
	6.70	18.70	0.00	7.10	0.10	22.70	42.72	30.42	15.71	67.59	35.60	13.90	6.00	11.09	16.60	4.55	7.60
	7.12	22.70	2.67	8.00	8.00	24.03	47.80	32.04	17.36	75.25	42.72	14.90	6.00	15.21	22.98	4.59	7.95
	8.90	28.60	6.70	8.00	8.00	25.37	50.38	34.10	18.32	77.43	46.15	15.70	7.00	16.63	44.69	4.62	8.30
	9.70	29.70	8.90	8.50	8.30	32.04	53.40	42.72	23.73	88.11	48.06	15.80	8.00	18.00		4.77	8.49
	10.70	30.80	9.40	8.80	9.70	48.06	64.08	45.39	82.77	101.46	62.30	16.60	8.00			4.78	9.05
	12.70	30.90	9.70	8.90	13.40	50.73		48.55	110.83	136.22	90.28	16.80	9.00			5.00	9.77
	14.10	31.83	11.40	9.40	15.40							17.90	10.00			5.14	10.24
	14.20	35.90	14.60	10.70	16.00							18.00	10.00			5.23	10.87
	16.00	36.40	16.70	11.60	21.30							19.70	10.00			5.90	11.15
	17.70	40.00	17.00	13.80	21.30							22.10	11.00			6.02	12.44
	21.40	40.05	17.30	17.00	21.60							22.30	11.00			6.05	12.54
	23.70	42.46	17.80	17.80	23.72							22.80	11.00			6.18	16.96
	26.70	43.30	18.40	18.70	27.10							26.90	11.00			6.44	
	30.50	44.50	18.70	19.10	30.00							27.80	11.00			6.58	
	31.00	47.51	19.30	19.10	31.40							28.80	12.00			6.66	
	38.10	53.40	26.70	23.70								36.10	13.00			6.73	
	43.50	53.40	27.80	28.80								46.00	13.00			7.57	
	51.40	62.60	37.40									50.30	13.00			7.67	
												62.10	13.00			7.95	
												63.20	14.00			8.26	
													16.00			9.17	
													16.00			9.41	
													17.00			9.75	
													17.00			9.83	
													18.00			9.94	
													18.00			10.50	
													26.00			17.01	
													27.00			17.94	
																32.34	

TABLE C-3

TOTAL PHOSPHORUS (MG/L)

LAKE	COLBERT	COMMERCE	CHAPMAN	OLGETHORPE	UNION POINT	BLALOCK	SHAMROCK	RUTLEDGE	BRANTLEY	ROCK EAGLE	HIGH FALLS	SECCESSION	WHEELER	MICHIE	DEVIN	BOWEN	CUNNINGHAM
	0.02	0.05	0.00	0.00	0.00	0.02	0.03	0.00	0.00	0.04	0.03	0.00	0.01	0.03	0.02	0.00	0.02
	0.03	0.03	0.00	0.00	0.00	0.02	0.03	0.02	0.00	0.04	0.04	0.00	0.01	0.03	0.02	0.00	0.02
	0.04	0.05	0.00	0.00	0.00	0.03	0.03	0.03	0.02	0.04	0.04	0.00	0.02	0.03	0.04	0.00	0.02
	0.00	0.05	0.00	0.00	0.00	0.03	0.04	0.03	0.03	0.05	0.04	0.00	0.02	0.03	0.04	0.00	0.02
	0.00	0.05	0.00	0.00	0.02	0.04	0.04	0.04	0.03	0.05	0.04	0.02	0.02	0.03	0.04	0.00	0.02
	0.00	0.05	0.00	0.00	0.02	0.04	0.05	0.04	0.03	0.05	0.05	0.02	0.02	0.03	0.05	0.00	0.02
	0.00	0.06	0.00	0.02	0.02	0.04	0.05	0.04	0.03	0.05	0.05	0.02	0.02	0.03	0.05	0.00	0.02
	0.00	0.06	0.02	0.02	0.03	0.04	0.05	0.05	0.04	0.05	0.05	0.02	0.02	0.04	0.05	0.00	0.02
	0.02	0.06	0.02	0.02	0.03	0.05	0.05	0.05	0.04	0.06	0.05	0.02	0.02	0.04	0.06	0.00	0.02
	0.02	0.06	0.02	0.02	0.03	0.05	0.05	0.05	0.04	0.06	0.05	0.02	0.02	0.04	0.06	0.00	0.02
	0.02	0.06	0.02	0.02	0.03	0.05	0.06	0.05	0.06	0.06	0.06	0.02	0.02	0.04	0.07	0.00	0.02
	0.03	0.07	0.02	0.02	0.03	0.06	0.06	0.05	0.06	0.06	0.06	0.03	0.02	0.05		0.00	0.02
	0.03	0.07	0.02	0.02	0.03	0.06	0.06	0.06	0.06	0.06	0.08	0.03	0.02	0.05		0.00	0.02
	0.03	0.07	0.02	0.02	0.03	0.07	0.06	0.11	0.07	0.08	0.09	0.03	0.03			0.00	0.02
	0.03	0.08	0.03	0.02	0.03							0.03	0.03			0.00	0.03
	0.03	0.08	0.03	0.02	0.03							0.04	0.03			0.00	0.03
	0.04	0.08	0.03	0.02	0.03							0.04	0.03			0.00	0.03
	0.04	0.08	0.03	0.02	0.04							0.04	0.03			0.00	0.03
	0.04	0.09	0.03	0.03	0.04							0.04	0.03			0.00	0.03
	0.04	0.09	0.03	0.03	0.04							0.04	0.03			0.00	0.03
	0.05	0.11	0.03	0.03	0.04							0.05	0.03			0.00	0.03
	0.05	0.11	0.03	0.03	0.04							0.05	0.03			0.00	0.05
	0.06	0.11	0.05	0.04	0.05							0.06	0.03			0.00	0.08
	0.10	0.12	0.05	0.05	0.05							0.07	0.03			0.02	
	0.14	0.17	0.05	0.06								0.08	0.03			0.02	
	0.17	0.17	0.12	0.11								0.09	0.04			0.02	
												0.09	0.04			0.02	
												0.10	0.04			0.02	
												0.10	0.04			0.02	
												0.11	0.04			0.02	
												0.11	0.05			0.02	
												0.11	0.05			0.02	
												0.11	0.05			0.02	
												0.12	0.06			0.02	
												0.13	0.06			0.03	
												0.13	0.07			0.03	
												0.13				0.04	
												0.13				0.05	
												0.14				0.05	
												0.20				0.06	
																0.06	

TABLE C-4

TOTAL NITROGEN (MG/L)

LAKE	COLBERT	COMMERCE	CHAPMAN	OLGETHORPE	UNION POINT	BLALOCK	SHAMROCK	RUTLEDGE	BRANTLEY	ROCK EAGLE	HIGH FALLS	MICHIE	DEVIN	BOWEN	CUNNINGHAM
	0.27	1.75	0.27	0.27	0.34	1.63	1.34	0.59	0.82	0.60	0.55	0.39	0.11	0.24	0.31
	0.27	0.59	0.32	0.32	0.37	1.54	1.28	0.54	0.72	0.72	0.55	0.39	0.17	0.25	0.32
	0.29	0.59	0.35	0.34	0.40	1.10	0.59	0.55	0.80	1.36	0.78	0.39	0.17	0.26	0.35
	0.30	0.60	0.36	0.34	0.44	0.94	0.76					0.40	0.57	0.27	0.36
	0.32	0.62	0.42	0.37	0.50							0.41	0.60	0.27	0.36
	0.34	0.64	0.43	0.37	0.52							0.42	0.63	0.27	0.36
	0.37	0.76	0.44	0.40	0.53							0.47	0.65	0.28	0.37
	0.39	0.77	0.45	0.41	0.54							0.48	0.71	0.28	0.38
	0.43	0.77	0.45	0.42	0.56							0.61	0.71	0.29	0.39
	0.44	0.77	0.46	0.42	0.56							0.67	0.78	0.29	0.39
	0.45	0.80	0.48	0.44	0.57							0.89	0.85	0.31	0.43
	0.48	0.81	0.48	0.48	0.58									0.31	0.43
	0.53	0.82	0.49	0.50	0.63									0.33	0.44
	0.54	0.85	0.51	0.51	0.64									0.33	0.45
	0.63	0.86	0.54	0.51	0.67									0.34	0.46
	0.66	0.94	0.57	0.53	0.74									0.34	0.46
	0.69	0.99	0.61	0.54	0.75									0.34	0.46
	0.72	1.02	0.62	0.54	0.88									0.35	0.47
	0.81	1.11	0.63	0.57	1.40									0.35	0.48
	1.27	1.26	0.68	0.74										0.36	0.49
														0.36	0.62
														0.37	0.69
														0.37	4.30
														0.38	
														0.39	
														0.40	
														0.40	
														0.40	
														0.40	
														0.41	
														0.42	
														0.42	
														0.43	
														0.43	
														0.43	
														0.44	
														0.45	
														0.46	
														0.47	
														0.48	
														0.80	

TABLE C-5

TOTAL SUSPENDED SOLIDS (MG/L)

LAKE	COLBERT	COMMERCE	CHAPMAN	OLGETHORPE	UNION POINT	BLALOCK	SHAMROCK	RUTLEDGE	BRANTLEY	ROCK EAGLE	HIGH FALLS	MICHIE	DEVIN	BOWEN	CUNNINGHAM
	4.00	26.00	2.00	0.00	3.00	4.50	2.00	6.50	7.00	4.00	4.80	4.00	5.00	0.00	0.40
	5.00	14.00	2.50	2.00	3.00	5.50	4.00	8.00	8.50	6.00	5.00	5.00	5.00	0.40	0.50
	5.50	16.00	3.25	2.00	4.00	5.50	4.00	9.00	8.50	6.00	5.00	5.00	5.00	0.40	0.50
	5.50	16.00	3.50	2.50	4.50	6.00	5.50	9.00	9.00	7.00	7.00	5.00	6.00	0.40	1.60
	7.00	16.00	3.50	2.50	4.50	6.80	6.00	9.50	9.00	8.00	8.00	5.00	6.00	0.80	1.80
	7.00	17.00	4.00	2.50	5.00	7.00	6.00	10.00	11.00	8.00	8.00	6.00	7.00	0.80	2.00
	7.00	17.00	4.00	2.50	5.00	7.00	6.00	10.00	11.00	8.00	9.00	6.00	7.00	0.80	2.40
	8.00	17.00	4.00	3.00	5.00	7.00	7.00	11.00	12.00	8.00	9.00	7.00	8.00	0.80	2.40
	8.00	19.00	4.50	3.00	5.50	8.00	7.00	13.00	13.00	9.00	9.00	8.00	9.00	1.20	2.80
	8.00	20.00	4.50	3.00	6.00	9.00	8.00	15.00	16.00	9.00	9.00	8.00	13.00	1.20	3.00
	9.00	20.00	5.00	3.50	6.00	9.50	9.00	16.00	16.00	9.70	10.00	9.00	18.00	1.20	3.20
	9.00	21.00	5.00	3.50	6.50	10.00	10.00	20.00	20.00	10.00	10.00			1.40	3.50
	9.00	22.50	5.00	4.00	7.00	10.00	11.00	20.00	21.00	11.00	13.00			1.50	4.00
	9.00	24.00	5.00	4.00	7.00	15.00	12.00	30.00	36.00	13.00	17.00			1.50	4.00
	9.50	24.00	5.50	4.00	8.00									1.60	4.00
	9.50	25.00	6.00	4.00	9.00									1.60	4.00
	10.00	25.00	6.00	4.25	9.50									1.60	5.00
	10.00	26.00	6.00	4.35	10.00									1.60	5.00
	10.00	26.00	7.00	4.50	10.00									1.60	5.00
	12.00	31.00	8.00	5.00	10.00									2.00	6.80
	12.00	35.00	9.00	5.00	10.00									2.00	8.40
	14.00	43.00	10.00	5.70	11.00									2.00	
	34.00	48.00	11.00	6.00	12.00									2.00	
	64.00	49.00	12.00	7.75	14.00									2.20	
	76.00	52.00	35.00	16.00	24.00									2.40	
		58.00	160.00	39.00										2.40	
														2.40	
														2.40	
														2.60	
														3.00	
														3.20	
														3.40	
														3.60	
														4.50	
														5.60	
														5.60	
														6.80	
														6.80	

APPENDIX D

APPENDIX
D

TABLE D-1

FLOW (CFS)

LAKE	COLBERT		COMMERCE	CHAPMAN		OLGETHORPE	UNION POINT	HIGH FALLS		BRANTLEY	BLALOCK		ROCK EAGLE	RUTLEDGE		SHAMROCK
STREAM	BIGER	BRUSH	GROVE	L. SANDY	SANDY	GOULDING	SHERRILLS	TOWALIGA	BUCK	HARD LABOR	PATES	BLALOCK	NO NAME	HARD LABOR	ROCK	NO NAME
	11.36	40.67	31.29	1.34	21.31	1.23	10.17	264.85	20.94	43.96	25.53	47.57	2.46	43.96	9.07	47.57
	15.63	25.83	42.04	1.65	48.11	1.94	10.24	148.50	56.00	46.99	32.28	33.62	1.23	46.99	7.49	33.62
	71.94	31.83	60.66	1.65	50.39	2.78	10.50	480.87	287.52	43.96	166.43	57.80	6.15	43.96	10.76	57.80
	43.19	27.92	58.07	1.20	44.43	2.63	10.11	402.66	61.64	32.53	44.02	36.18	3.94	32.53	8.27	36.18
	8.39	11.14	34.21	1.82	23.23	1.57	10.01	273.27	23.31	24.75	31.58	47.02	2.46	24.75	6.40	47.02
	32.13	17.30	66.68	11.02	28.48	1.94	10.11	62.36	38.68	41.00	5.97	46.03	0.05	41.00	4.15	46.03
	49.32	0.06	50.64	4.73	22.26	8.17	10.81	192.23	12.27	43.96	38.00	85.00	0.44	43.96	7.49	85.00
	15.63	16.76	30.35	4.43	22.50	3.78	10.06	186.76	47.16	29.86	48.72	45.88	0.24	29.86	5.71	45.88
	15.63	9.71	28.50	4.14	17.36	1.45	9.94	168.95	45.21	13.47	13.39	59.71	1.23	13.47	4.74	59.71
	3.63	2.49	20.86	5.37	13.25	1.94	10.11	70.02	54.59	22.32	0.32	51.68	0.33	22.32	3.13	51.68
	2.69	6.85	24.97	3.86	19.49	0.09	9.40	107.58	42.19	29.86	1.22	61.31	0.44	29.86	3.88	33.62
	0.20	1.49	20.86	4.73	13.25	0.00	9.90	63.62	52.95	15.54	13.39	30.00	52.03	22.32	5.38	61.31
	22.64	8.64	374.62	55.91	38.23	0.05	9.30	18.58	53.72		0.25	50.78	0.08	15.54	4.15	30.00
	3.63	4.60	55.54	2.20	35.64	0.05	9.30	36.37	35.93		1.22		0.00		3.61	50.78
	0.16	37.79	36.22	44.51	15.40	0.13	10.18	176.90								
	237.13	257.64	2.00	5.70	257.77	0.94	9.90									
	24.86	55.74	31.29	2.40	57.58	2.34	9.90									
	5.81	24.20	35.21	0.67	25.25	1.69	9.30									
	0.45	1.01	20.86	0.85	7.36	1.13	10.00									
	3.63	1.99	18.56	0.53	10.75	1.57	10.01									
	5.81	0.53	13.03	0.47	6.29	1.13	10.00									
	1.10	2.49	13.67	0.53	13.51	2.63	10.01									
	7.05	1.01	13.67	0.53	5.45	1.13	10.16									
	9.83	4.06	15.00	0.53	5.23	0.39	10.36									
	2.69	77.08	14.33	31.08	5.99	0.68										
	73.86	94.31	178.98	85.30	131.30	45.11										
	98.73		298.65		663.65											

TABLE D-2

TOTAL PHOSPHORUS (MG/L)

LAKE	COLBERT		COMMERCE	CHAPMAN		OLGETHORPE	UNION POINT	HIGH FALLS		BRANTLEY	BLALOCK		ROCK EAGLE	RUTLEDGE		SHAMROCK
STREAM	BIGER	BRUSH	GROVE	L. SANDY	SANDY	GOULDING	SHERRILLS	TOWALIGA	BUCK	HARD LABOR	PATES	BLALOCK	NO NAME	HARD LABOR	ROCK	NO NAME
	0.02	0.00	0.02	0.02	0.00	0.00	0.02	0.00	0.00	0.00	0.08	0.03	0.02	0.02	0.02	0.02
	0.02	0.00	0.03	0.02	0.00	0.02	0.02	0.00	0.00	0.00	0.08	0.03	0.03	0.02	0.02	0.03
	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.00	0.00	0.00	0.10	0.03	0.03	0.02	0.02	0.04
	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.00	0.02	0.10	0.03	0.03	0.02	0.03	0.04
	0.02	0.02	0.03	0.03	0.02	0.02	0.03	0.02	0.00	0.02	0.10	0.03	0.03	0.03	0.03	0.04
	0.02	0.03	0.03	0.03	0.02	0.02	0.03	0.03	0.02	0.02	0.11	0.04	0.04	0.03	0.03	0.04
	0.03	0.03	0.04	0.04	0.03	0.02	0.03	0.03	0.02	0.03	0.11	0.04	0.04	0.03	0.03	0.05
	0.03	0.03	0.04	0.04	0.03	0.02	0.03	0.03	0.02	0.03	0.11	0.04	0.04	0.03	0.04	0.05
	0.04	0.03	0.05	0.05	0.03	0.02	0.03	0.04	0.02	0.03	0.12	0.04	0.04	0.03	0.04	0.05
	0.04	0.03	0.05	0.05	0.03	0.03	0.03	0.04	0.02	0.03	0.13	0.05	0.04	0.03	0.04	0.05
	0.04	0.03	0.05	0.05	0.03	0.03	0.03	0.05	0.03	0.04	0.13	0.06	0.04	0.03	0.04	0.07
	0.04	0.03	0.05	0.05	0.03	0.03	0.04	0.06	0.03	0.04	0.15	0.06	0.05	0.05	0.04	0.10
	0.04	0.04	0.06	0.05	0.04	0.03	0.04	0.07	0.04	0.04	0.17	0.06	0.05	0.06	0.05	0.11
	0.04	0.04	0.07	0.05	0.04	0.03	0.04	0.08	0.08	0.04	0.25	0.07	0.21	0.06	0.05	0.26
	0.05	0.04	0.07	0.06	0.04	0.03	0.04			0.05				0.08	0.06	
	0.05	0.04	0.08	0.06	0.04	0.03	0.05									
	0.05	0.04	0.08	0.06	0.05	0.03	0.05									
	0.05	0.04	0.09	0.07	0.06	0.04	0.05									
	0.05	0.04	0.11	0.07	0.08	0.04	0.06									
	0.06	0.05	0.12	0.14	0.11	0.04	0.06									
	0.08	0.10	0.17	0.17	0.11	0.05	0.06									
	0.11	0.11	0.18	0.18	0.20	0.05	0.07									
	0.13	0.11	0.18	0.27	0.20	0.05	0.16									
	0.23	0.13	0.23	0.35	0.21	0.05										
	0.23	0.14	0.40		0.26	0.19										
	0.31	0.24	0.56		0.33	0.37										

TABLE D-3

TOTAL PHOSPHORUS (LBS./DAY)

LAKE	COLBERT		COMMERCE	CHAPMAN		OLGETHORPE	UNION POINT	HIGH FALLS		BRANTLEY	BLALOCK		ROCK EAGLE	RUTLEDGE		SHAMROCK
STREAM	BIGER	BRUSH	GROVE	L. SANDY	SANDY	GOULDING	SHERRILLS	TOWALIGA	BUCK	HARD LABOR	PATES	BLALOCK	NO NAME	HARD LABOR	ROCK	NO NAME
	1.84	6.57	5.06	0.29	2.87	0.33	0.68	57.08	2.26	7.11	13.75	15.39	0.40	7.10	1.95	10.25
	7.75	6.86	19.62	0.27	8.15	0.30	2.09	16.00	6.04	10.13	22.61	10.87	0.27	7.10	1.21	9.06
	4.65	4.51	12.52	0.39	7.19	0.43	1.25	207.26	124.00	7.11	224.17	9.35	1.33	5.26	1.78	15.57
	2.26	1.80	12.91	0.49	3.76	0.25	0.53	130.16	6.65	5.26	28.46	7.80	0.64	4.00	1.38	50.68
	6.92	4.66	143.79	20.80	9.21	0.31	1.46	73.61	3.77	0.00	18.72	7.60	0.53	13.25	0.45	10.13
	29.23	0.04	46.41	1.27	24.00	8.37	7.69	0.00	0.00	8.84	3.22	9.93	0.01	7.11	2.02	27.28
	5.05	9.93	19.63	0.45	6.06	1.02	0.77	72.50	2.65	7.11	30.71	32.08	0.09	3.22	1.54	32.06
	2.53	2.09	7.68	1.45	0.00	0.16	0.31	40.25	5.08	0.00	44.62	9.89	0.04	2.18	0.77	12.36
	0.39	0.27	10.12	0.42	4.20	0.21	0.42	27.31	7.31	1.45	7.94	12.88	0.27	3.61	0.51	16.08
	0.29	0.00	6.73	1.27	0.00	0.02	0.12	11.32	5.89	3.22	0.14	8.36	0.09	3.22	0.84	8.35
	0.02	0.00	2.25	81.37	41.22	0.00	0.43	17.39	0.00		0.52	9.92	0.12	2.40	0.58	7.25
	6.10	1.86	1130.94	0.71	15.37	0.01	0.01	0.00	0.00		7.94	4.85	58.87	1.67	0.67	6.61
	0.98	0.74	53.89	43.19	3.32	0.01	0.02	0.00	0.00		0.18	16.42	0.01		0.39	16.16
	0.03	4.07	21.48	2.15	458.56	0.01	1.39	3.92	0.00		0.66		0.00			10.94
	396.04	333.14	0.86	0.78	34.14	0.15	0.29									
	10.72	30.03	11.81	0.11	14.98	0.50	0.72									
	1.57	5.22	15.19	0.18	0.79	0.18	0.01									
	0.05	0.14	5.62	0.09	2.32	0.12	0.52									
	2.54	0.21	5.00	0.18	0.68	0.25	0.53									
	1.25	0.09	2.11	0.14	2.19	0.12	0.52									
	0.30	0.54	2.95	0.09	0.59	0.43	0.71									
	1.52	0.22	2.21	0.14	0.56	0.18	1.12									
	2.12	0.87	2.43	23.46	0.97	0.04	1.18									
	0.58	53.99	2.32	78.17	148.64	0.11										
	91.52	71.14	221.92		930.19	89.99										
	122.35		289.80													

TABLE D-4

TOTAL NITROGEN (MG/L)

LAKE	COLBERT		COMMERCE	CHAPMAN		OLGETHORPE	UNION POINT	HIGH FALLS		BRANTLEY	BLALOCK		ROCK EAGLE	RUTLEDGE		SHAMROCK
STREAM	BIGER	BRUSH	GROVE	L. SANDY	SANDY	GOULDING	SHERRILLS	TOWALIGA	BUCK	HARD LABOR	PATES	BLALOCK	NO NAME	HARD LABOR	ROCK	NO NAME
	0.34	0.26	0.78	0.55	0.46	0.48	0.26	0.41	0.47	0.77	1.84	1.31	0.30	0.77	0.56	0.89
	0.49	0.43	0.37	0.62	0.49	0.50	0.27	0.53	0.40	0.85	2.12	1.24	0.34	0.79	0.65	0.98
	0.51	0.48	0.42	0.64	0.51	0.53	0.27	0.48	0.51	0.71	2.14	0.73	0.31	0.77	0.65	0.99
	0.53	0.50	0.44	0.70	0.51	0.57	0.31			0.76	1.84	0.80	0.23	0.72	0.69	1.06
	0.60	0.54	0.47	0.71	0.51	0.58	0.31									
	0.60	0.55	0.47	0.74	0.57	0.59	0.35									
	0.61	0.55	0.53	0.76	0.59	0.59	0.39									
	0.61	0.55	0.70	0.83	0.61	0.60	0.43									
	0.65	0.57	0.70	0.85	0.70	0.64	0.43									
	0.73	0.63	0.78	0.88	0.76	0.65	0.44									
	0.74	0.66	0.84	1.15	0.80	0.65	0.44									
	0.75	0.67	0.84	1.19	0.82	0.66	0.46									
	0.76	0.70	0.85	1.25	0.86	0.68	0.52									
	0.77	0.71	0.90	1.33	0.93	0.69	0.57									
	0.81	0.72	0.91	1.33	0.94	0.71	0.65									
	0.92	0.77	1.13	1.53	1.01	0.72	0.69									
	1.07	0.80	1.41	1.53	1.13	0.76	0.92									
	1.49	0.86	1.42	1.94	1.25	0.76										
	1.96	1.06	1.89		1.39	0.99										
	2.04	1.41	3.43		1.96	1.28										

TABLE D-5

TOTAL NITROGEN (LBS./DAY)

LAKE	COLBERT		COMMERCE		CHAPMAN	OLGETHORPE	UNION POINT	HIGH FALLS		BRANTLEY	BLALOCK		ROCK EAGLE	RUTLEDGE		SHAMROCK
STREAM	BIGER	BRUSH	GROVE	L. SANDY	SANDY	GOULDING	SHERRILLS	TOWALIGA	BUCK	HARD LABOR	PATES	BLALOCK	NO NAME	HARD LABOR	ROCK	NO NAME
	44.68	146.80	79.29	6.00	70.07	4.39	7.06	328.03	141.89	182.37	253.07	335.94	3.98	182.36	22.60	271.67
	236.44	132.03	255.07	5.52	154.83	9.01	19.88	548.91	26.46	155.73	368.70	224.74	2.25	170.09	26.23	305.18
	79.12	64.68	131.49	9.91	122.16	6.81	6.45	278.22	115.99	55.15	438.16	334.50	0.73	86.58	14.42	407.57
	27.12	28.81	167.83	8.65	73.89	5.49	9.17				12.06	0.00	0.55			179.32
	112.51	58.74	1233.02	115.28	122.84	5.95	9.57									
	199.28	0.28	0.00	18.87	149.98	43.60	44.21									
	44.63	63.22	137.43	27.88	61.85	10.19	5.18									
	63.99	37.68	81.43	21.98	54.28	5.56	10.10									
	14.47	10.74	158.57	13.31	106.13	6.16	8.94									
	8.83	20.30	114.41	18.10	36.43	0.30	1.04									
	0.55	2.09	49.48	400.84	177.23	0.00	5.61									
	73.18	26.52	3816.91	13.64	157.53	0.17	0.23									
	15.84	13.63	425.17	319.15	93.79	0.20	15.95									
	0.80	111.97	220.66	11.02	2723.58	0.47	6.18									
	2504.01	1957.22	9.07	3.65	126.61	3.49	4.68									
	33.51	86.05	132.87	3.91	40.55	6.54	4.51									
	39.90	7.60	70.04	1.56	33.51	6.42	7.86									
	4.54	7.25	34.64	199.39	983.84	7.52										
	25.94	10.93	29.92			1.25										
	592.89	618.75	868.38			311.31										

TABLE D-6

TOTAL SUSPENDED SOLIDS (MG/L)

LAKE	COLBERT		COMMERCE	CHAPMAN		OLGETHORPE	UNION POINT	HIGH FALLS		BRANTLEY	BLALOCK		ROCK EAGLE	RUTLEDGE		SHAMROCK
STREAM	BIGER	BRUSH	GROVE	L. SANDY	SANDY	GOULDING	SHERRILLS	TOWALIGA	BUCK	HARD LABOR	PATES	BLALOCK	NO NAME	HARD LABOR	ROCK	NO NAME
	7.50	10.00	3.00	4.00	4.50	2.00	1.00	2.00	0.00	3.20	10.50	2.00	2.40	3.50	5.00	3.20
	8.20	10.00	5.00	5.00	5.50	4.00	2.50	3.40	2.00	5.00	13.00	5.00	2.40	5.00	6.00	6.50
	8.50	10.00	5.00	5.50	7.50	5.00	2.50	4.40	2.60	5.00	14.00	6.00	3.20	5.50	8.00	8.00
	8.50	11.00	6.00	6.00	7.50	5.00	2.50	4.50	3.60	7.20	16.00	6.00	3.20	7.00	8.00	8.50
	9.00	11.00	10.00	6.00	8.80	5.50	3.00	6.80	4.00	8.80	17.00	6.50	3.80	8.00	8.50	9.00
	9.20	12.00	10.00	8.00	9.00	5.50	3.00	8.00	4.80	10.00	20.00	7.00	4.00	9.00	9.00	9.00
	10.00	12.00	10.00	9.00	12.00	5.80	4.00	8.00	6.40	11.00	21.00	7.00	4.40	10.00	10.00	9.60
	10.00	12.00	10.00	10.00	13.00	7.00	4.50	8.50	9.50	11.50	22.00	8.00	4.40	11.00	10.00	10.00
	10.00	13.00	11.00	10.00	18.00	8.20	6.00	22.00	11.00	12.00	22.00	8.00	4.50	12.00	10.00	11.00
	11.00	13.00	12.00	11.00	18.00	9.00	6.00	22.00	11.00	16.00	26.00	8.00	6.00	13.00	12.00	13.00
	12.00	14.00	15.00	11.00	18.00	9.00	7.00	22.00	14.00	16.00	27.00	12.00	6.50	14.00	14.00	23.00
	12.00	14.00	16.00	12.00	21.00	10.00	7.00	23.00	17.00	18.50	44.00	14.00	8.80	16.00	16.00	24.00
	13.00	14.00	21.00	12.00	21.00	11.00	9.00	24.00	54.00	20.00	59.00	16.00	9.00	21.00	17.00	34.00
	14.00	15.00	28.00	14.00	22.00	12.00	9.00	34.00		24.00	130.00	20.00	280.00	23.00	18.00	44.00
	16.00	15.00	29.00	14.00	27.00	13.00	9.00									
	19.00	16.00	30.00	16.00	29.00	14.00	10.00									
	20.00	16.00	31.00	17.00	47.00	14.00	10.00									
	24.00	24.00	36.50	18.00	50.00	19.00	12.50									
	31.00	33.00	39.00	20.00	50.00	20.00	16.00									
	32.00	33.00	42.00	25.00	81.00	24.00	18.00									
	43.00	34.00	62.00	83.00	82.00	24.00	24.00									
	56.00	44.00	92.00	92.00	130.00	28.00	78.00									
	160.00	50.00	180.00	130.00	140.00	28.00										
	220.00	88.00	190.00	210.00	170.00	29.00										
	400.00	92.00	270.00		180.00	130.00										
		200.00	640.00		300.00	480.00										

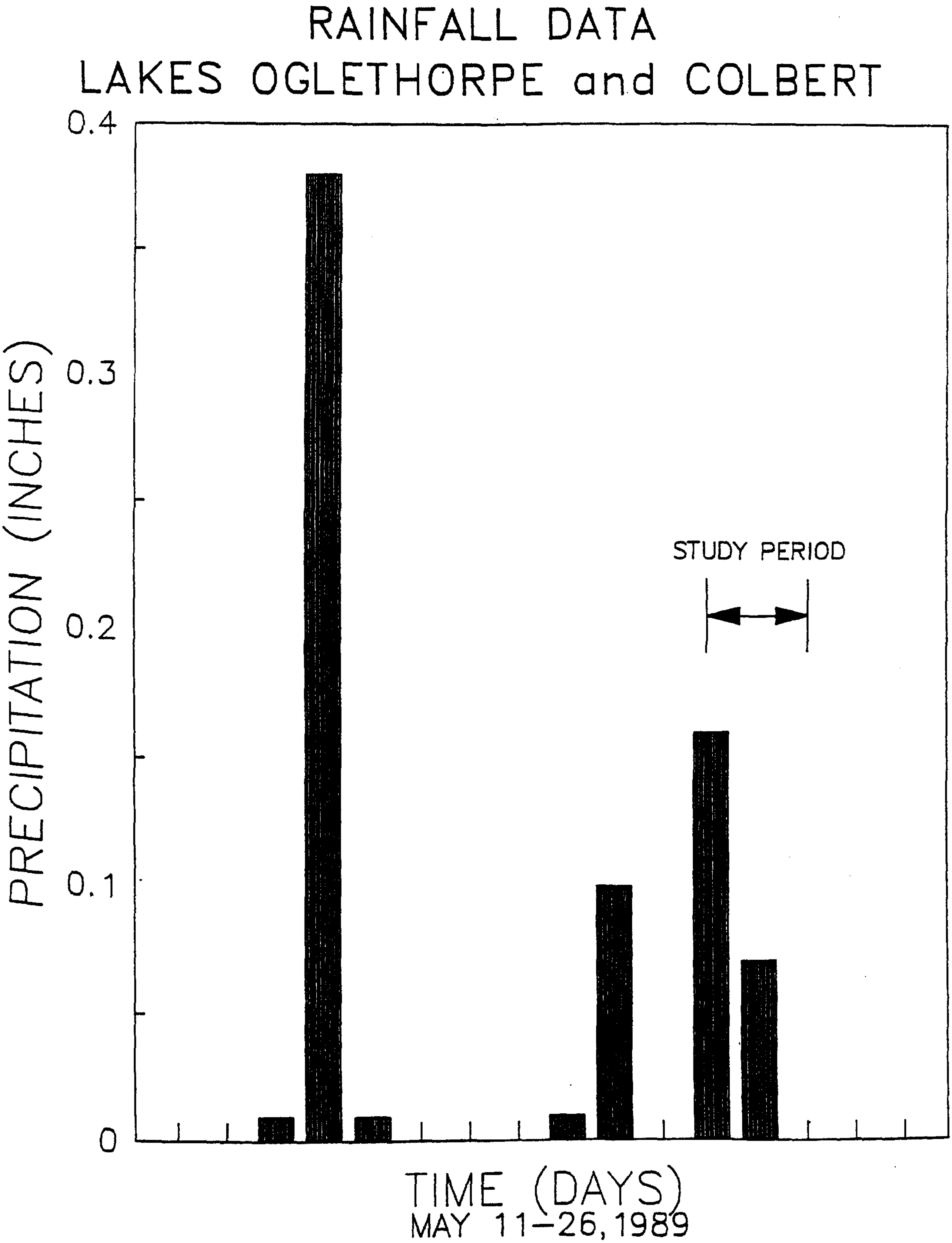
TABLE D-7

TOTAL SUSPENDED SOLIDS (LBS./DAY)

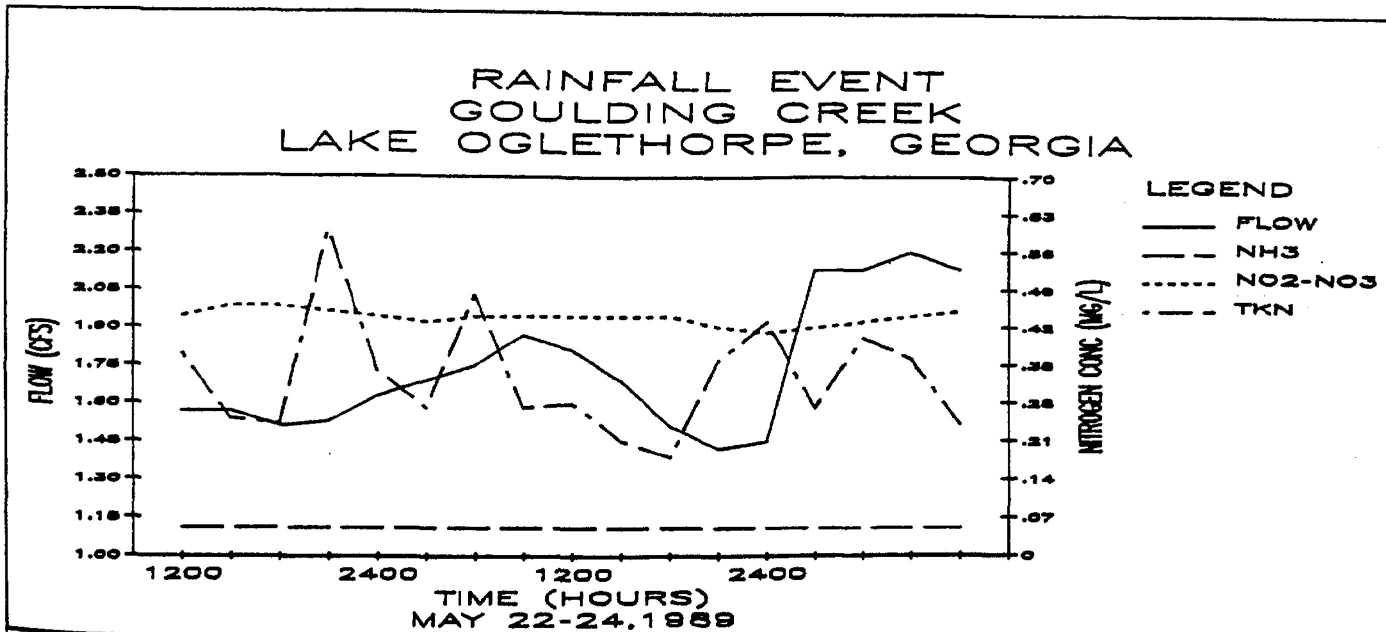
LAKE	COLBERT		COMMERCE		CHAPMAN	OLGETHORPE	UNION POINT	HIGH FALLS		BRANTLEY	BLALOCK		ROCK EAGLE	RUTLEDGE		SHAMROCK
STREAM	BIGER	BRUSH	GROVE	L. SANDY	SANDY	GOULDING	SHERRILLS	TOWALIGA	BUCK	HARD LABOR	PATES	BLALOCK	NO NAME	HARD LABOR	ROCK	NO NAME
	612.08	2410.17	1687.03	72.28	2067.76	73.21	91.13	11415.54	1580.39	2605.25	3025.88	1666.88	59.64	2842.00	390.93	2050.32
	3294.68	1714.65	3597.19	106.88	1493.93	123.10	313.85	17601.36	1207.55	4050.64	3826.09	2174.89	39.76	3315.66	322.83	1992.46
	2559.86	2106.02	3756.82	110.08	4311.55	78.07	124.80	88085.05	83699.08	3789.45	116568.59	6231.85	215.37	1928.01	757.01	4048.27
	1401.25	960.34	3872.91	177.01	2254.17	46.45	220.53	52065.84	4652.11	1752.60	6403.43	975.21	191.05	1733.36	482.47	8576.69
	3288.80	3076.63	33072.30	12478.59	7677.55	146.10	374.41	32390.27	2136.24	960.08	4424.03	1774.35	58.32	4638.76	223.78	2431.94
	14879.73	14.14	16925.55	407.96	15597.93	5724.97	3748.24	2855.69	1334.52	4086.52	546.97	3970.27	1.19	2368.41	726.36	8431.76
	2020.87	2980.34	6380.80	133.83	3517.21	285.38	172.79	22784.85	727.61	2842.09	9008.89	3665.79	9.48	1447.85	307.63	10532.84
	1178.84	1779.37	4609.37	404.92	2527.31	187.86	139.88	23142.07	2415.22	1850.06	15486.66	1484.00	4.14	362.86	306.45	2101.07
	176.03	174.50	1124.58	207.96	928.49	104.36	145.60	7282.10	2680.93	638.63	1514.99	1931.33	58.32	661.39	143.39	3216.96
	188.18	553.71	4172.67	280.47	4938.50	13.01	56.75	2565.37	1412.58	362.86	24.14	2228.80	6.76	1286.98	125.42	2505.90
	12.93	120.55	1799.33	3616.63	1499.87	0.00	28.76	2550.35	591.35	3861.00	85.22	2313.60	5.69	420.79	289.86	1177.36
	234.71	511.78	12575.42	130.49	35033.53	3.45	3.08	1542.39	0.00	0.00	1442.81	323.45	78489.29	586.13	111.79	2972.85
	8.64	346.92	5662.96	31195.24	9605.73	7.70	2.31	200.19	579.20	0.00	21.55	3832.48	1.03		175.12	3879.10
	5760.05	2443.05	2051.60	768.08	1743.02	3.94	369.92	666.30	697.30		69.02		0.00			875.47
	626.37	15014.07	4723.69	259.28	416875.21	96.21	35.95									
	24.11	3129.10	6928.16	14.35	25451.54	252.49	100.67									
	312.95	70.41	1124.58	63.95	11027.58	81.79	0.51									
	1002.20	128.47	1000.57	17.04	356.90	30.51	52.01									
	48.39	45.51	1053.51	20.42	1274.41	236.50	52.93									
	284.96	187.92	737.04	15.62	406.88	42.72	43.34									
	449.99	64.99	368.52	14.20	546.34	127.75	52.93									
	133.18	218.68	485.19	25.55	132.33	30.51	224.48									
	63666.46	36543.88	386.24	15415.24	211.38	8.49	294.99									
		46746.71	260512.56	38167.26	283.96	7.34										
			289795.78		99091.49	116739.63										
					643977.69											

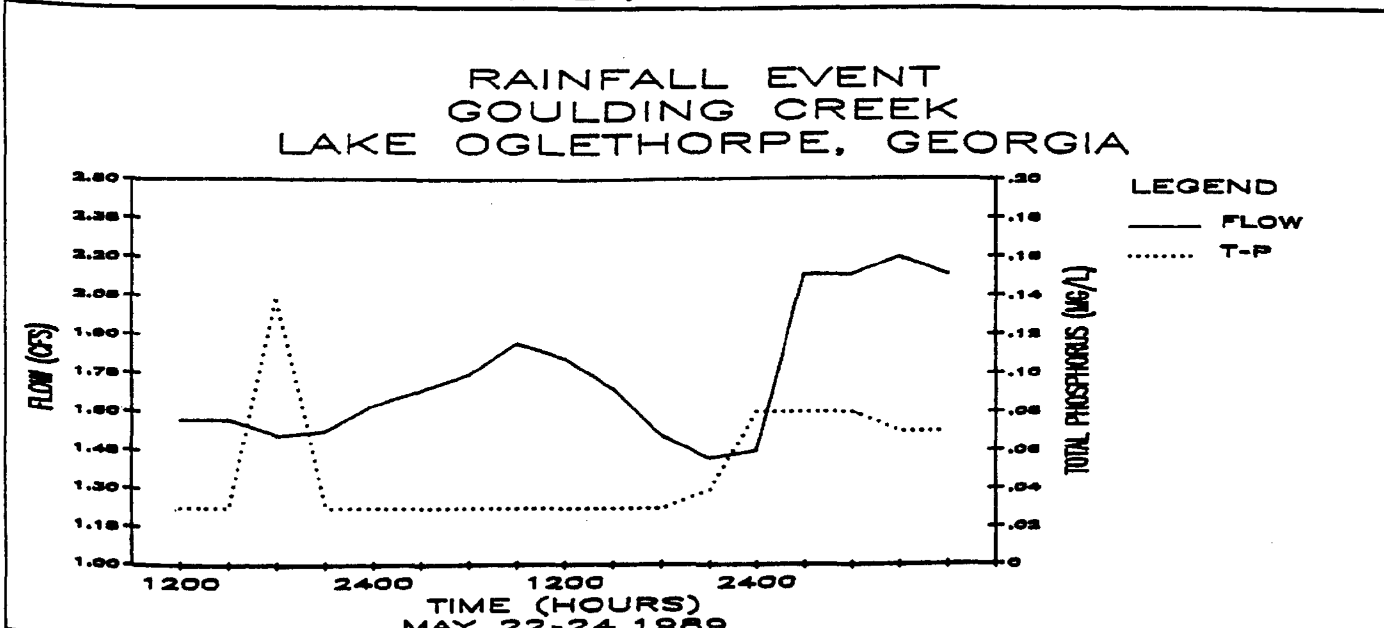
APPENDIX E

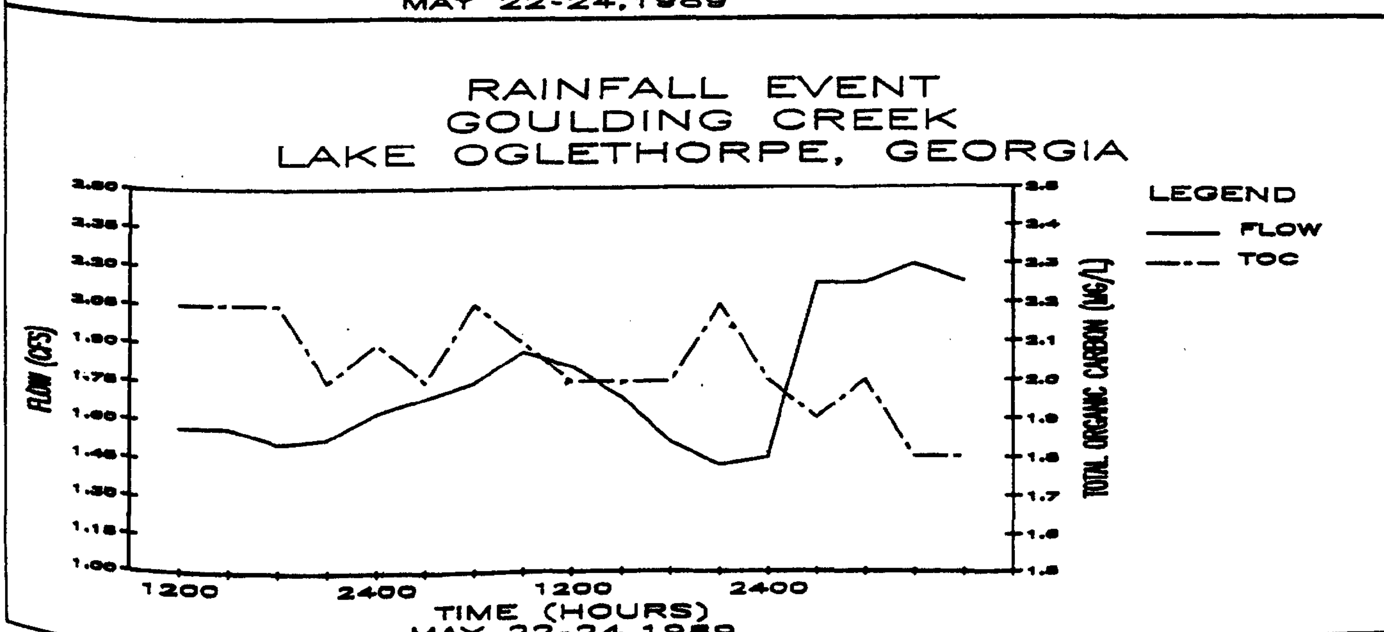
APPENDIX
E



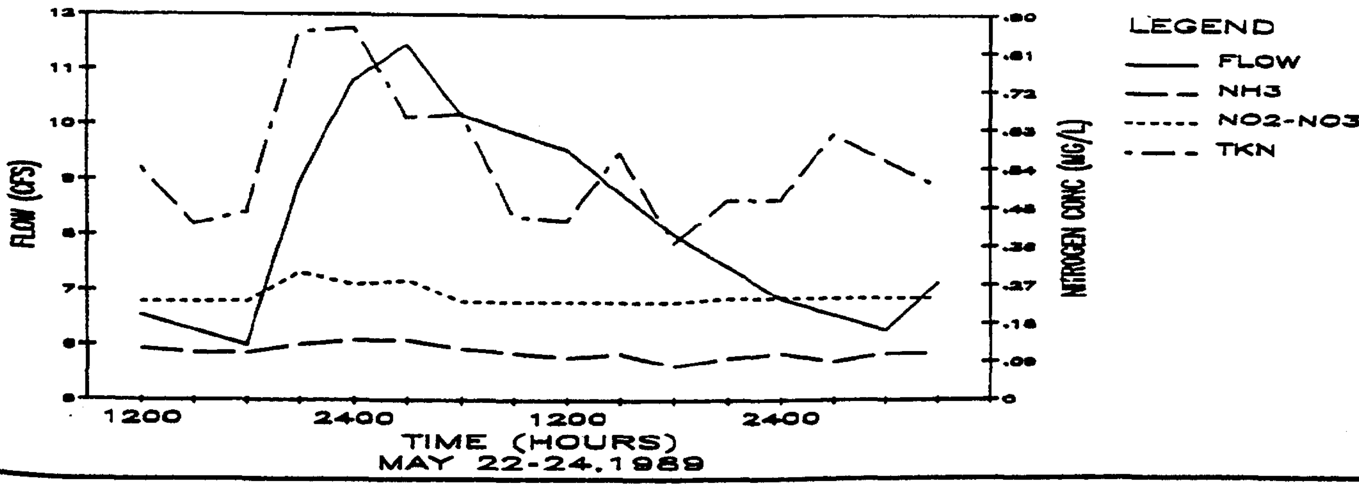
RAINFALL DATA
LAKES OGLETHORPE and COLBERT
PRECIPITATION (INCHES)
0.4
0.3
0.2
0.1
0
STUDY PERIOD
TIME (DAYS)
MAY 11–26, 1989


RAINFALL EVENT
GOULDING CREEK
LAKE OGLETHORPE, GEORGIA
LEGEND
FLOW
NH3
NO2-NO3
TKN
FLOW (CFS)
NITROGEN CONC (MG/L)
1200
2400
1200
2400
TIME (HOURS)
MAY 22-24,1989

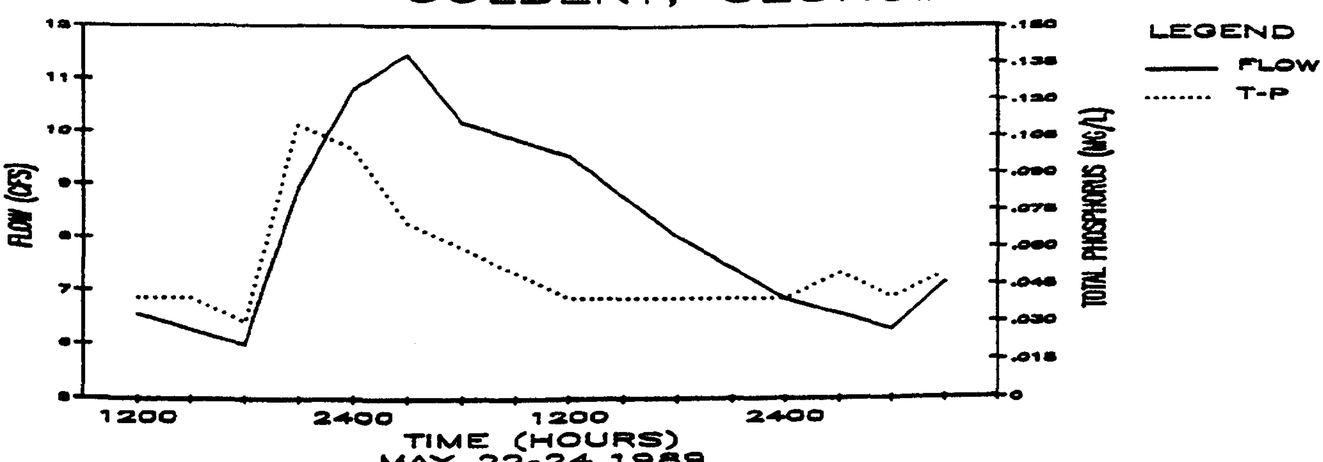

RAINFALL EVENT
GOULDING CREEK
LAKE OGLETHORPE, GEORGIA
LEGEND
FLOW
T-P
FLOW (CFS)
TOTAL PHOSPHORUS (MG/L)
1200
2400
1200
2400
TIME (HOURS)
MAY 22-24,1989


RAINFALL EVENT
GOULDING CREEK
LAKE OGLETHORPE, GEORGIA
LEGEND
FLOW
TOC
FLOW (CFS)
TOTAL ORGANIC CARBON (MG/L)
1200
2400
1200
2400
TIME (HOURS)
MAY 22-24,1989

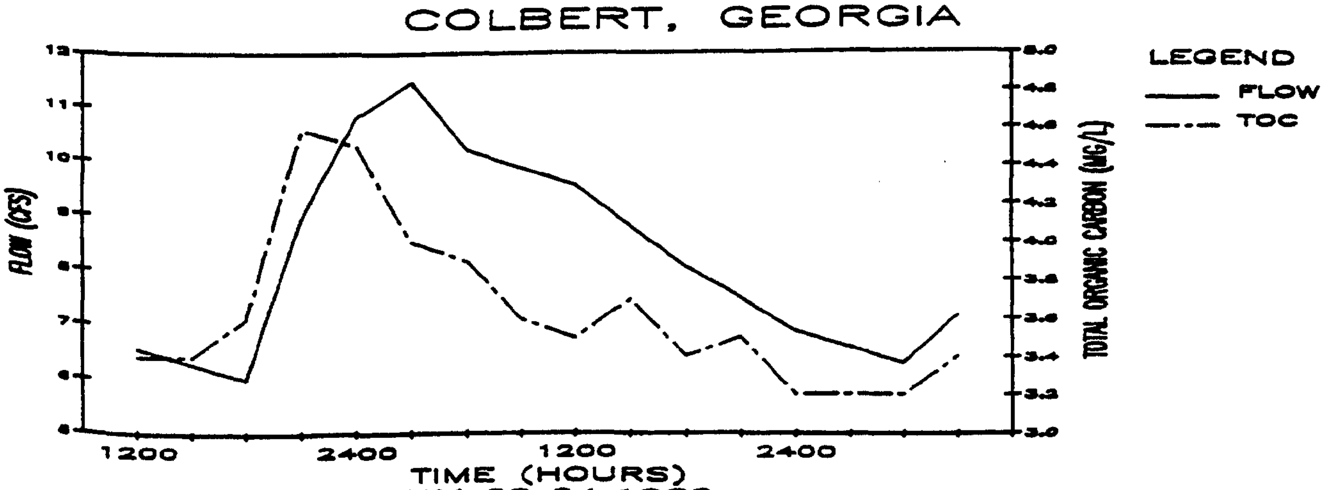
RAINFALL EVENT
BRUSH CREEK
COLBERT, GEORGIA

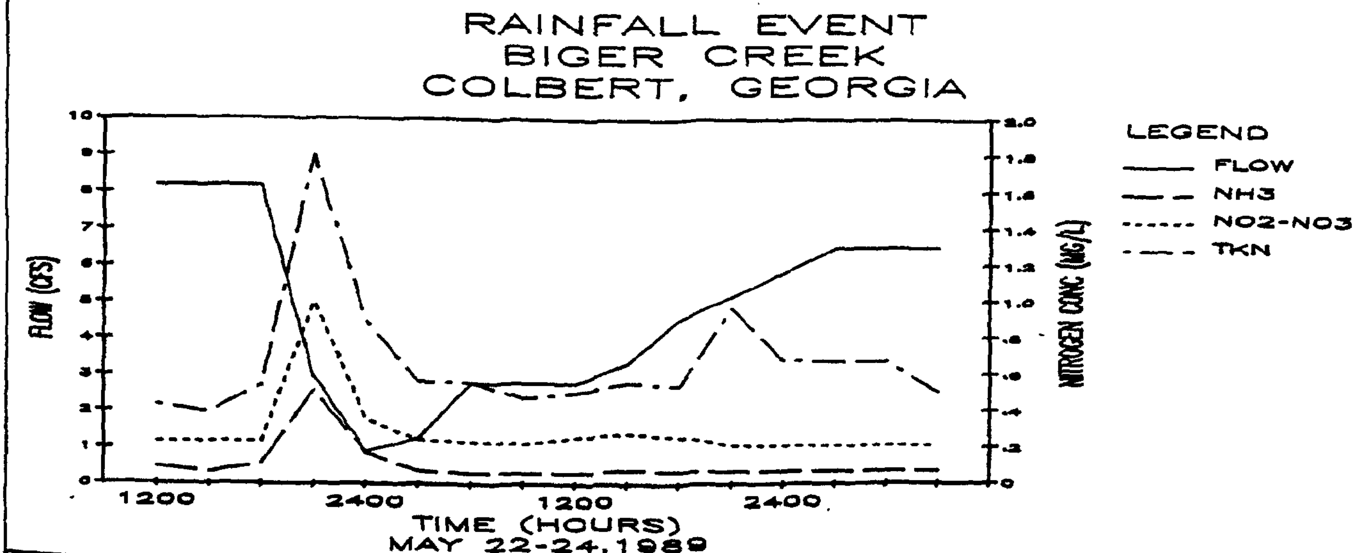


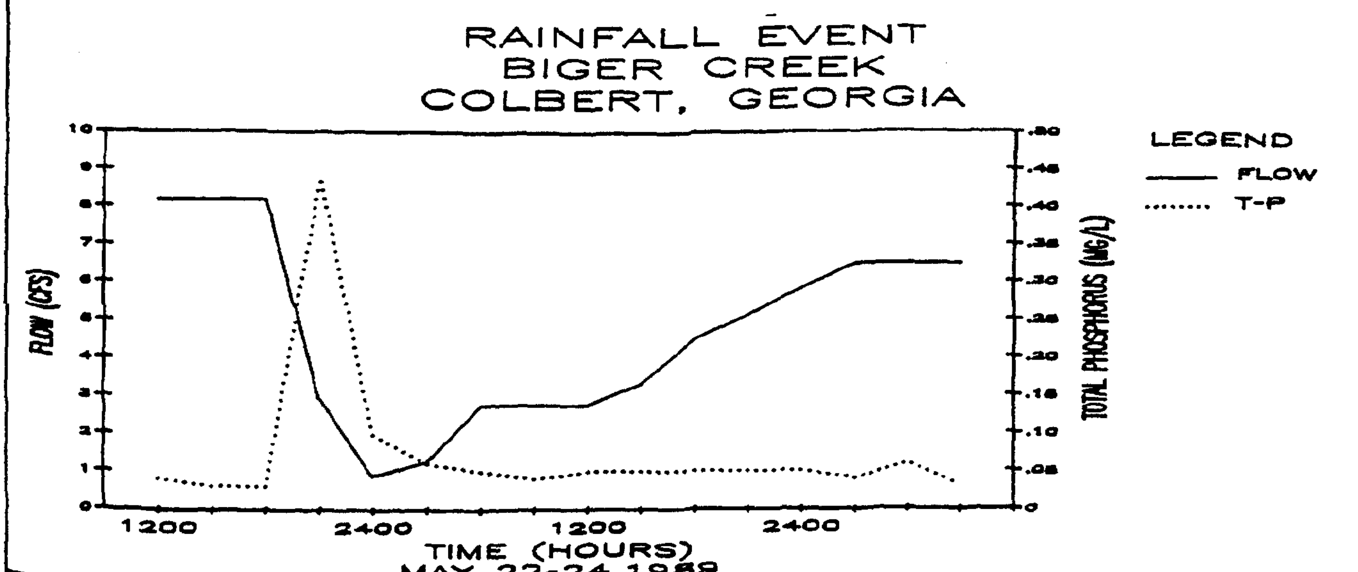
RAINFALL EVENT
BRUSH CREEK
COLBERT, GEORGIA

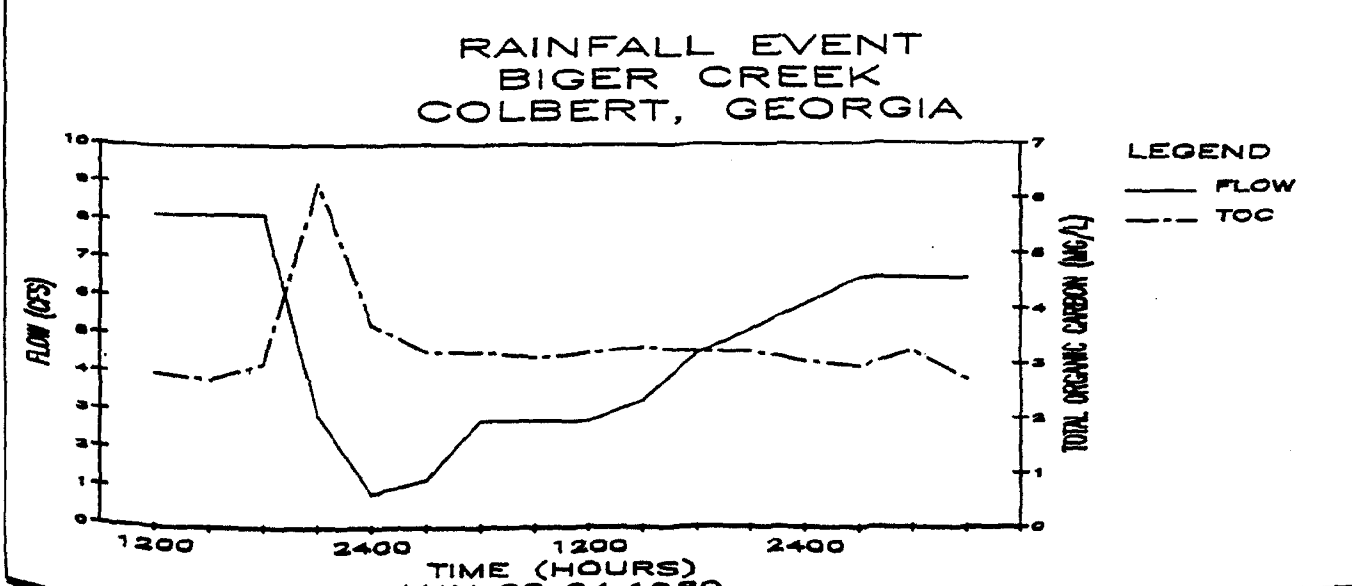


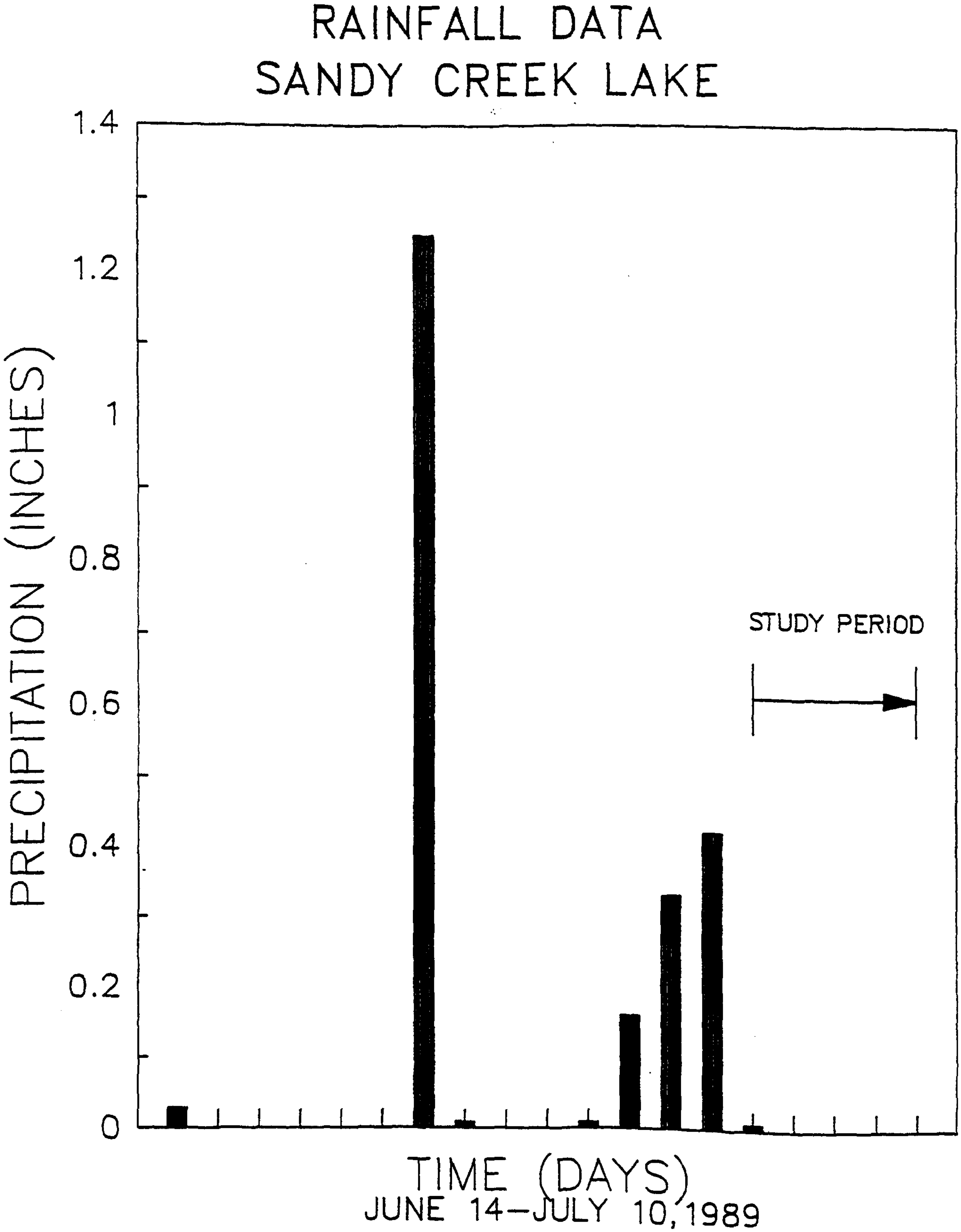
RAINFALL EVENT
BRUSH CREEK
COLBERT, GEORGIA

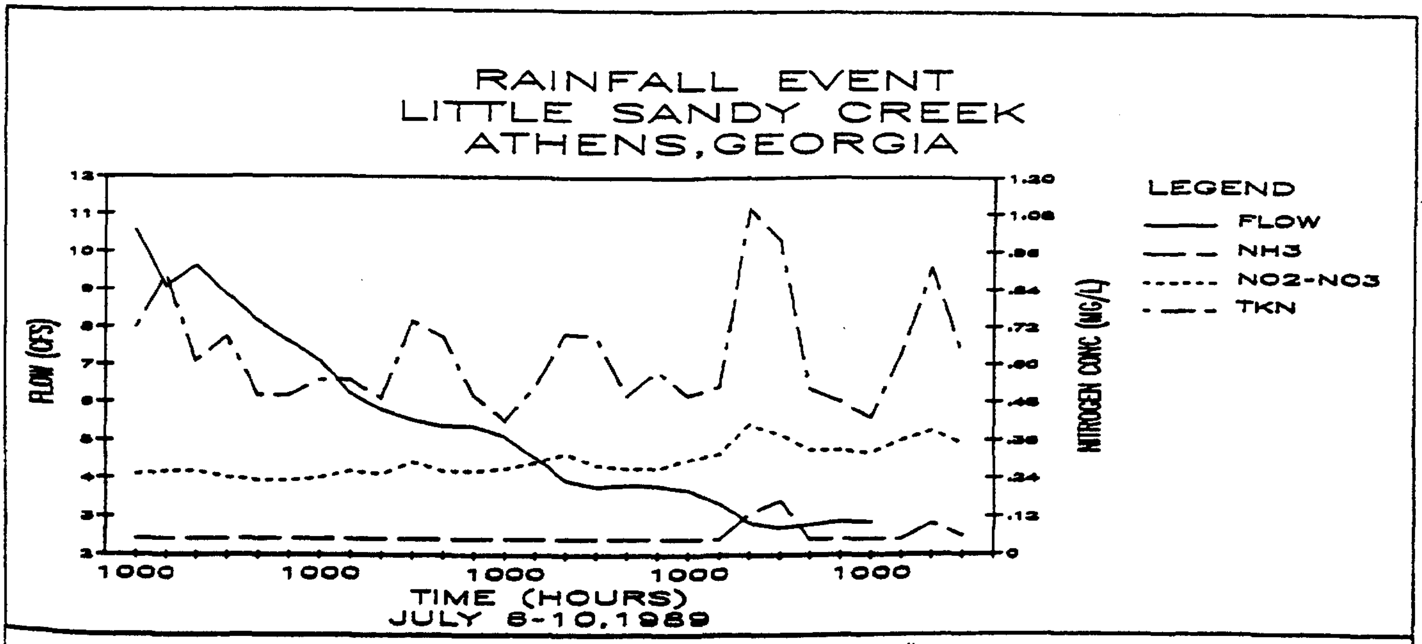


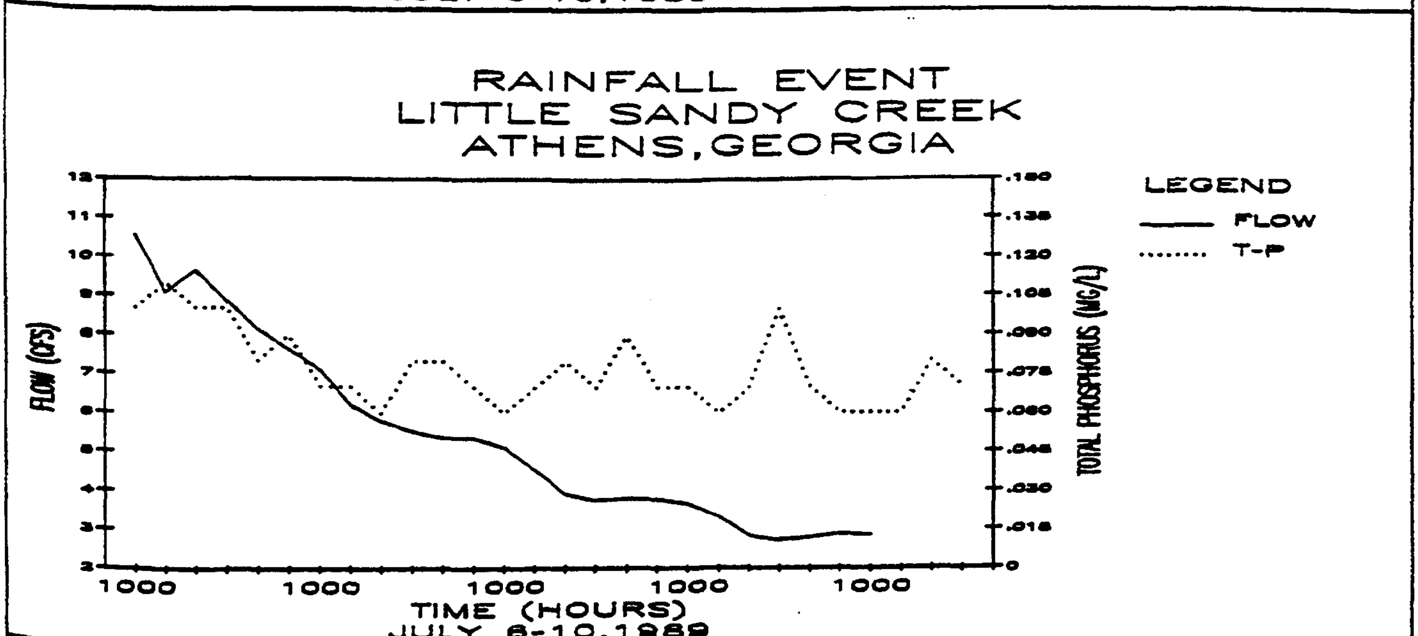

RAINFALL EVENT
BIGER CREEK
COLBERT, GEORGIA
FLOW (CFS)
NITROGEN CONC (MG/L)
LEGEND
FLOW
NH3
NO2-NO3
TKN
1200
2400
1200
2400
TIME (HOURS)
MAY 22-24,1989

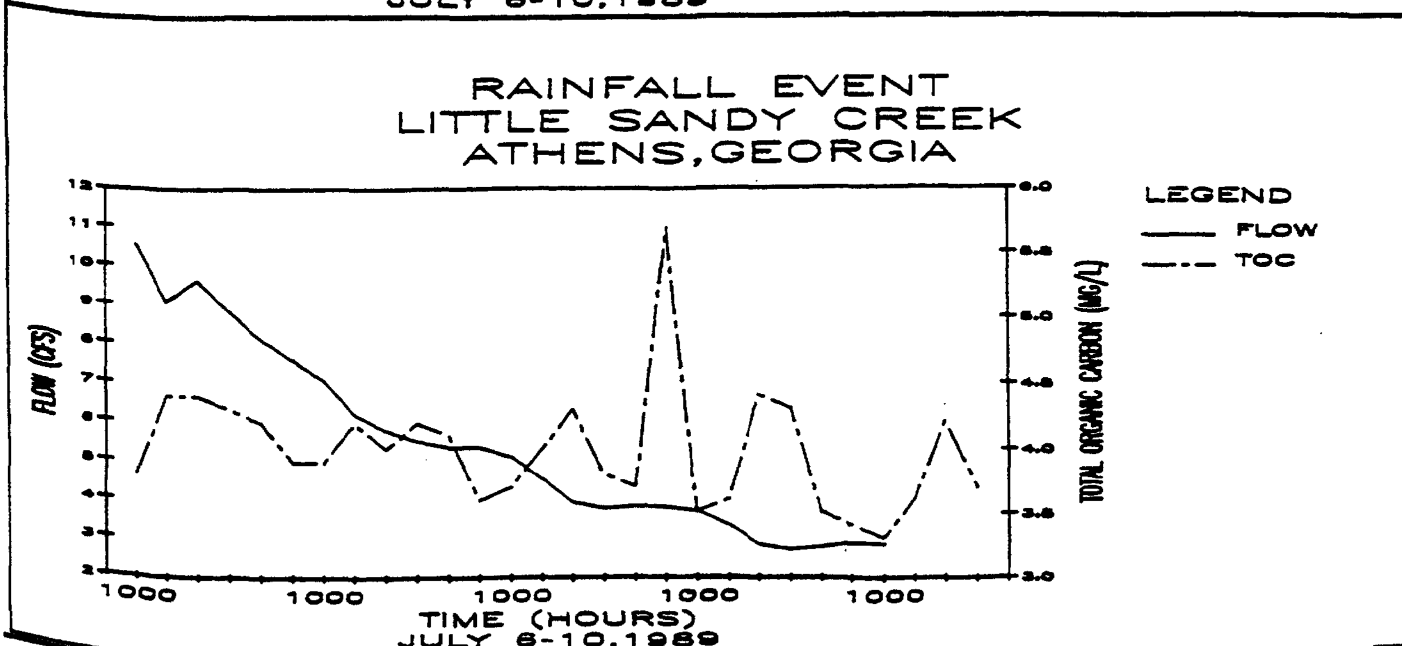

RAINFALL EVENT
BIGER CREEK
COLBERT, GEORGIA
FLOW (CFS)
TOTAL PHOSPHORUS (MG/L)
LEGEND
FLOW
T-P
1200
2400
1200
2400
TIME (HOURS)
MAY 22-24,1989

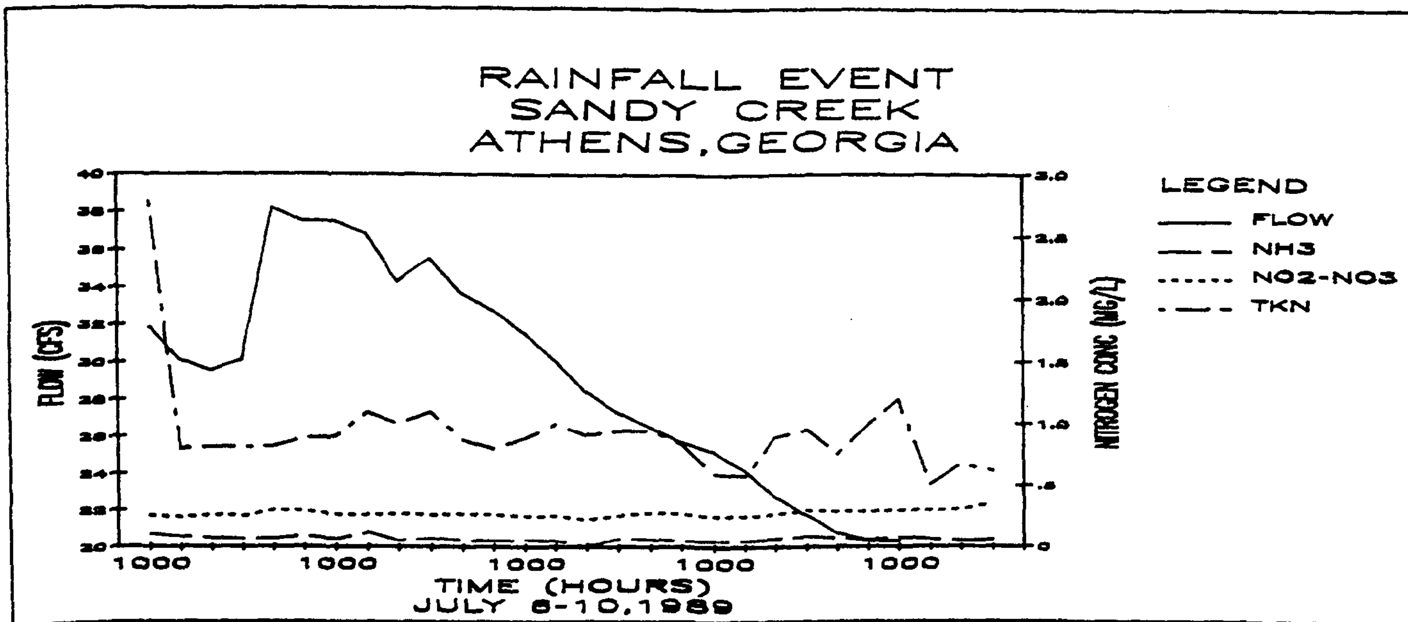

RAINFALL EVENT
BIGER CREEK
COLBERT, GEORGIA
FLOW (CFS)
TOTAL ORGANIC CARBON (MG/L)
LEGEND
FLOW
TOC
1200
2400
1200
2400
TIME (HOURS)
MAY 22-24,1989


RAINFALL DATA
SANDY CREEK LAKE
1.4
1.2
1
0.8
0.6
0.4
0.2
0
PRECIPITATION (INCHES)
STUDY PERIOD
TIME (DAYS)
JUNE 14–JULY 10, 1989

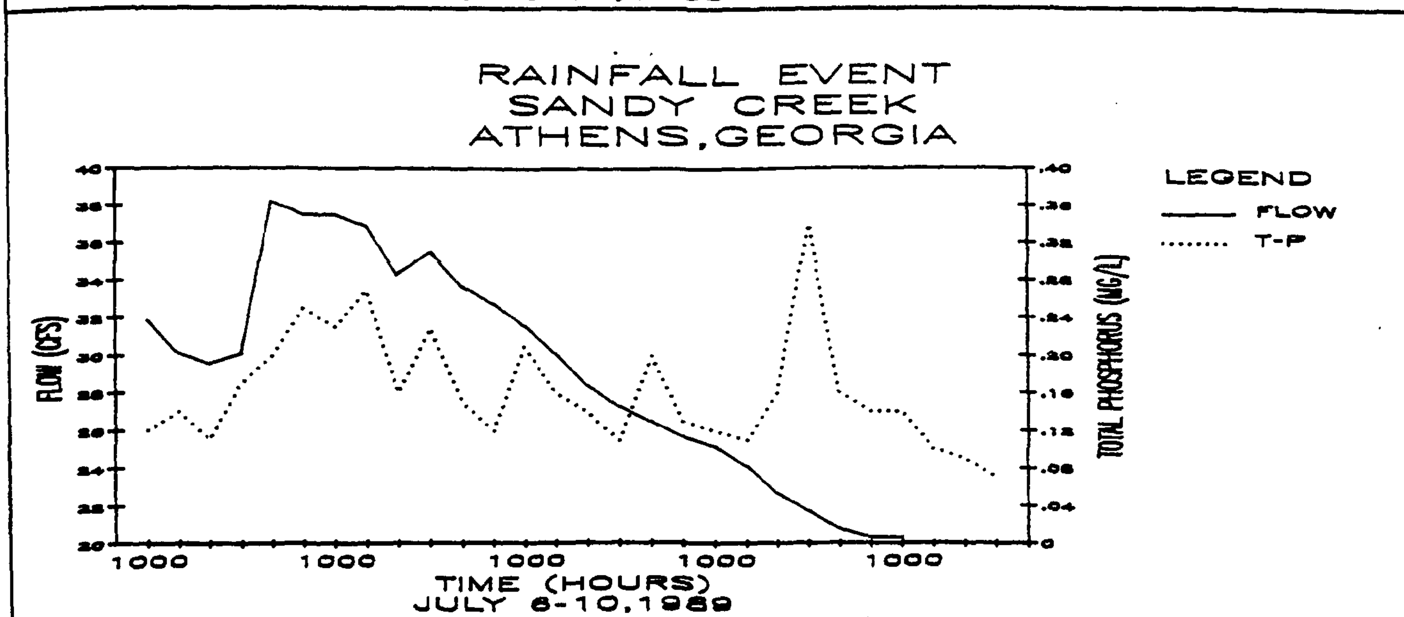

RAINFALL EVENT
LITTLE SANDY CREEK
ATHENS, GEORGIA
FLOW (CFS)
NITROGEN CONC (MG/L)
TIME (HOURS)
JULY 6-10, 1989
LEGEND
FLOW
NH3
NO2-NO3
TKN


RAINFALL EVENT
LITTLE SANDY CREEK
ATHENS, GEORGIA
FLOW (CFS)
TOTAL PHOSPHORUS (MG/L)
TIME (HOURS)
JULY 6-10, 1989
LEGEND
FLOW
T-P

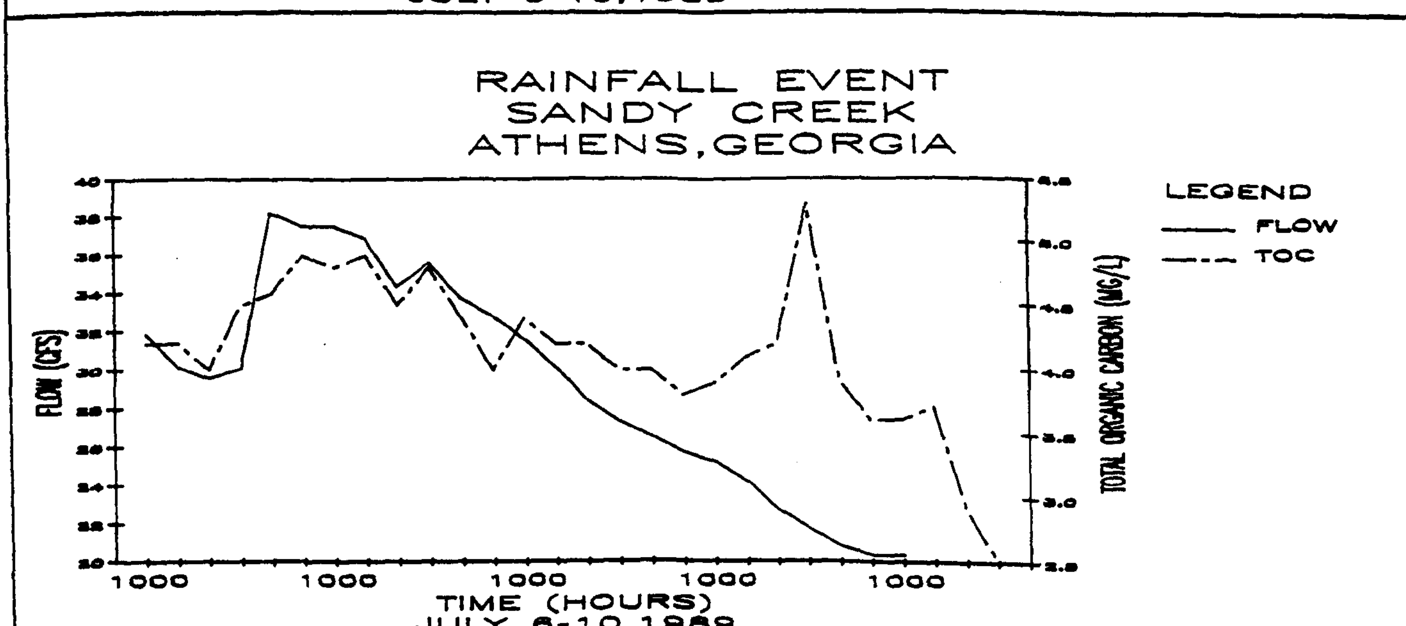

RAINFALL EVENT
LITTLE SANDY CREEK
ATHENS, GEORGIA
FLOW (CFS)
TOTAL ORGANIC CARBON (MG/L)
TIME (HOURS)
JULY 6-10, 1989
LEGEND
FLOW
TOC



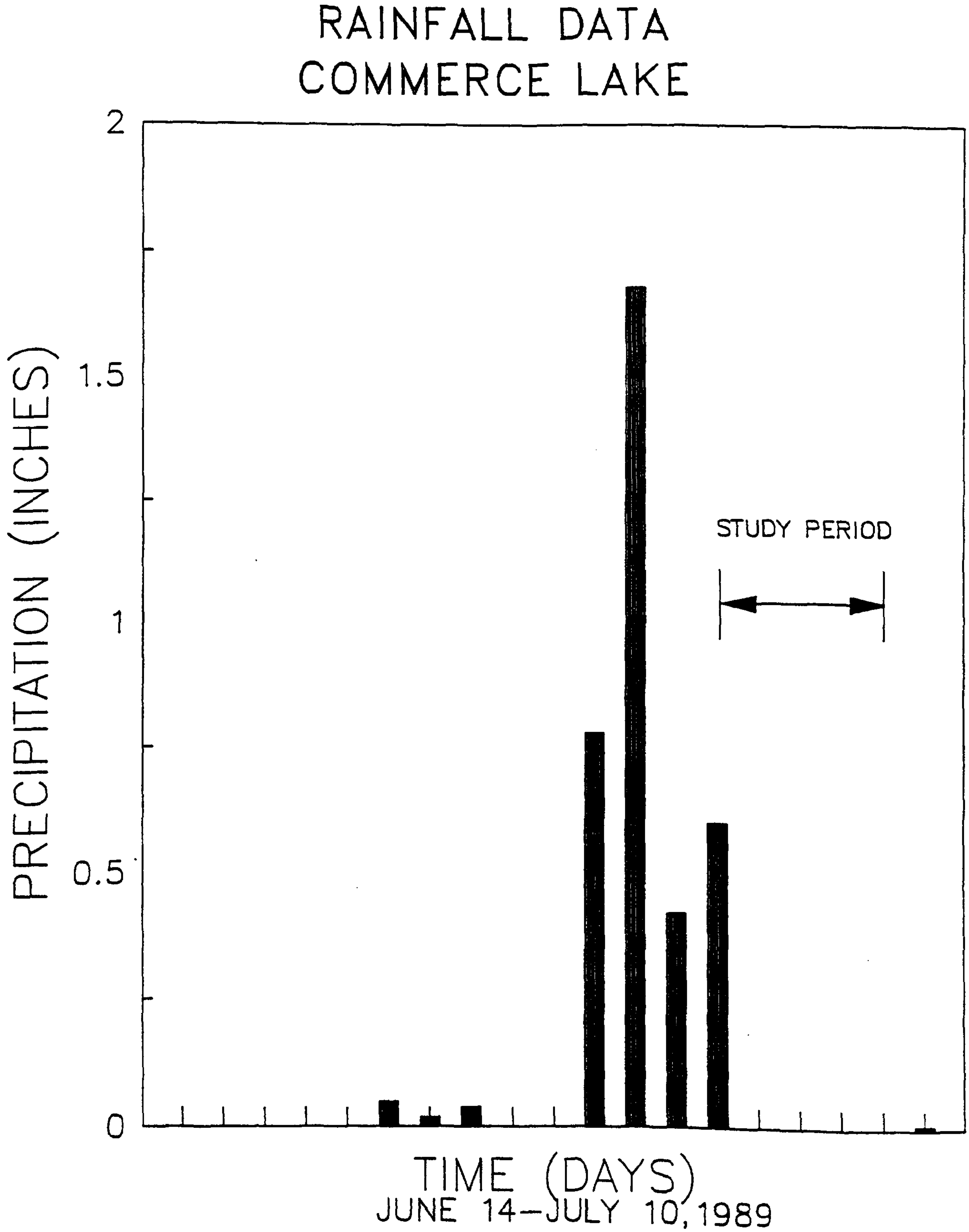
RAINFALL EVENT
SANDY CREEK
ATHENS, GEORGIA
LEGEND
FLOW
NH3
NO2-NO3
TKN
FLOW (CFS)
NITROGEN CONC (MG/L)
TIME (HOURS)
JULY 6-10, 1989

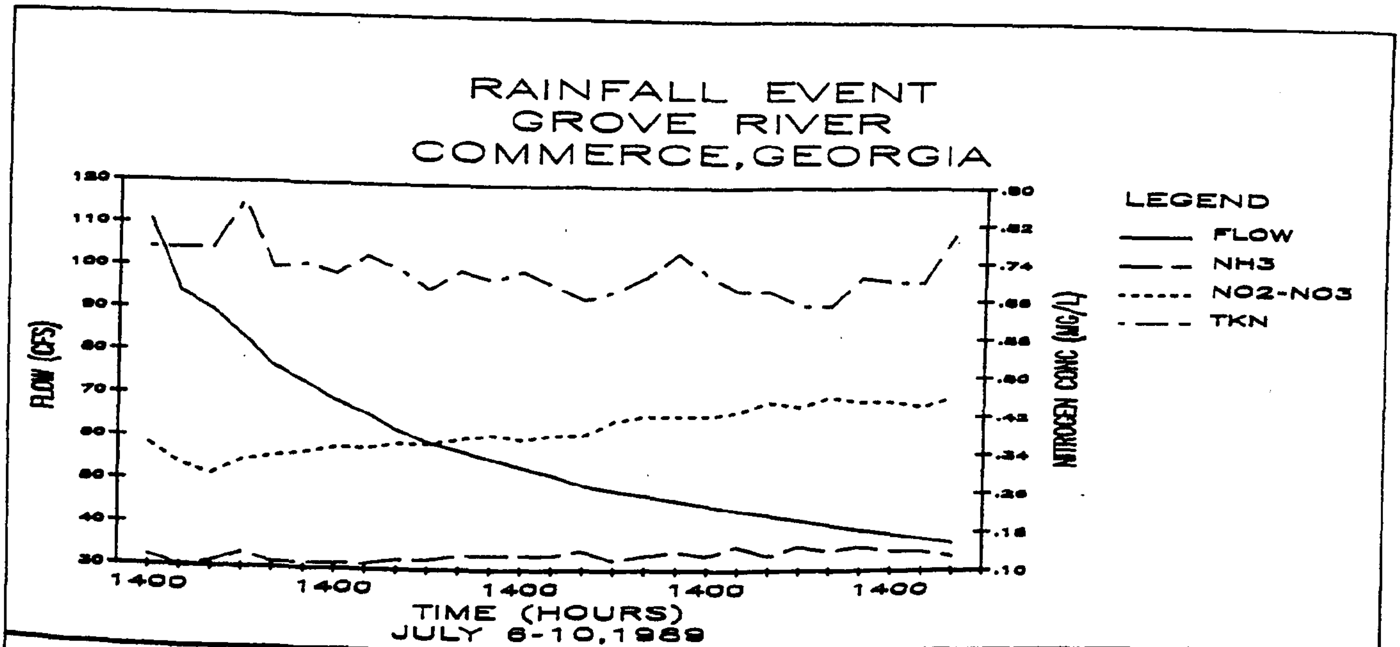


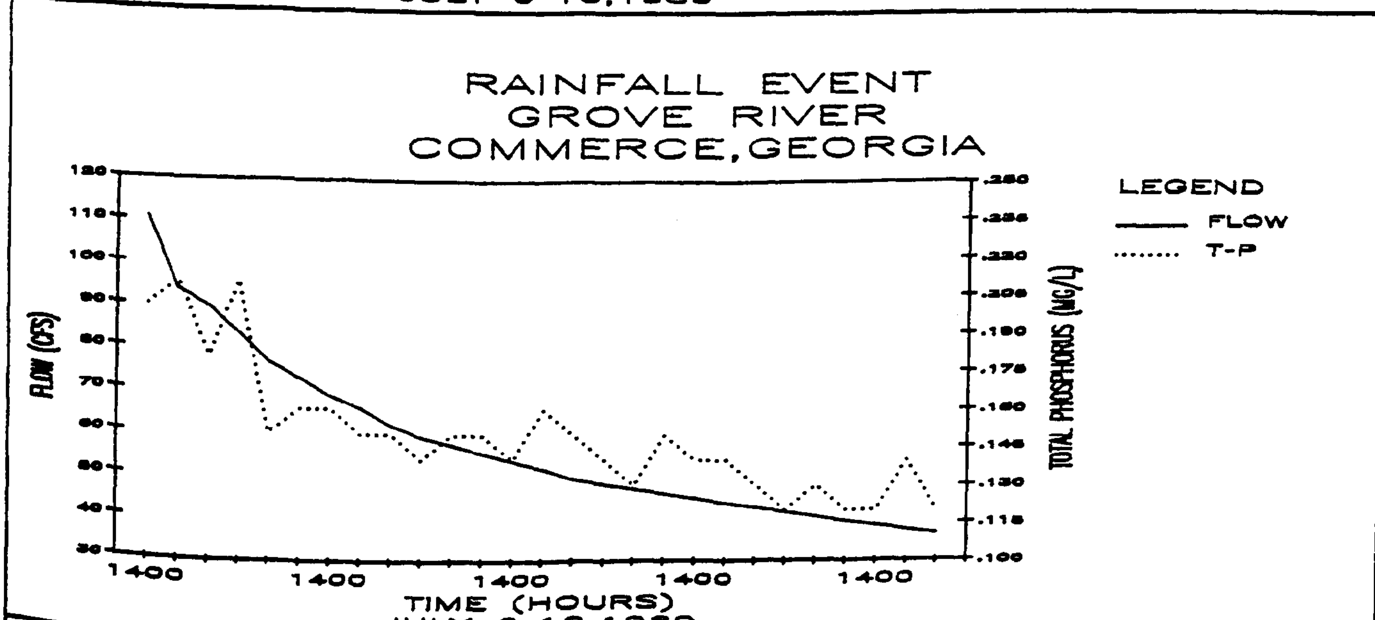
RAINFALL EVENT
SANDY CREEK
ATHENS, GEORGIA
LEGEND
FLOW
T-P
FLOW (CFS)
TOTAL PHOSPHORUS (MG/L)
TIME (HOURS)
JULY 6-10, 1989

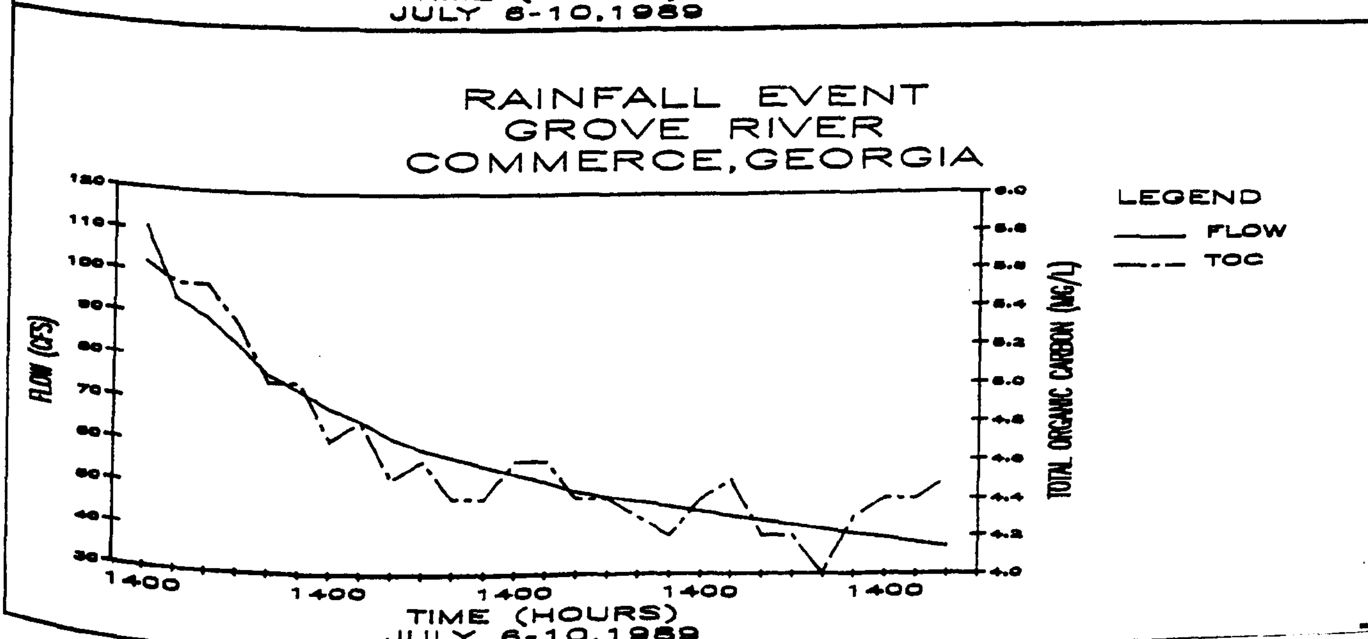


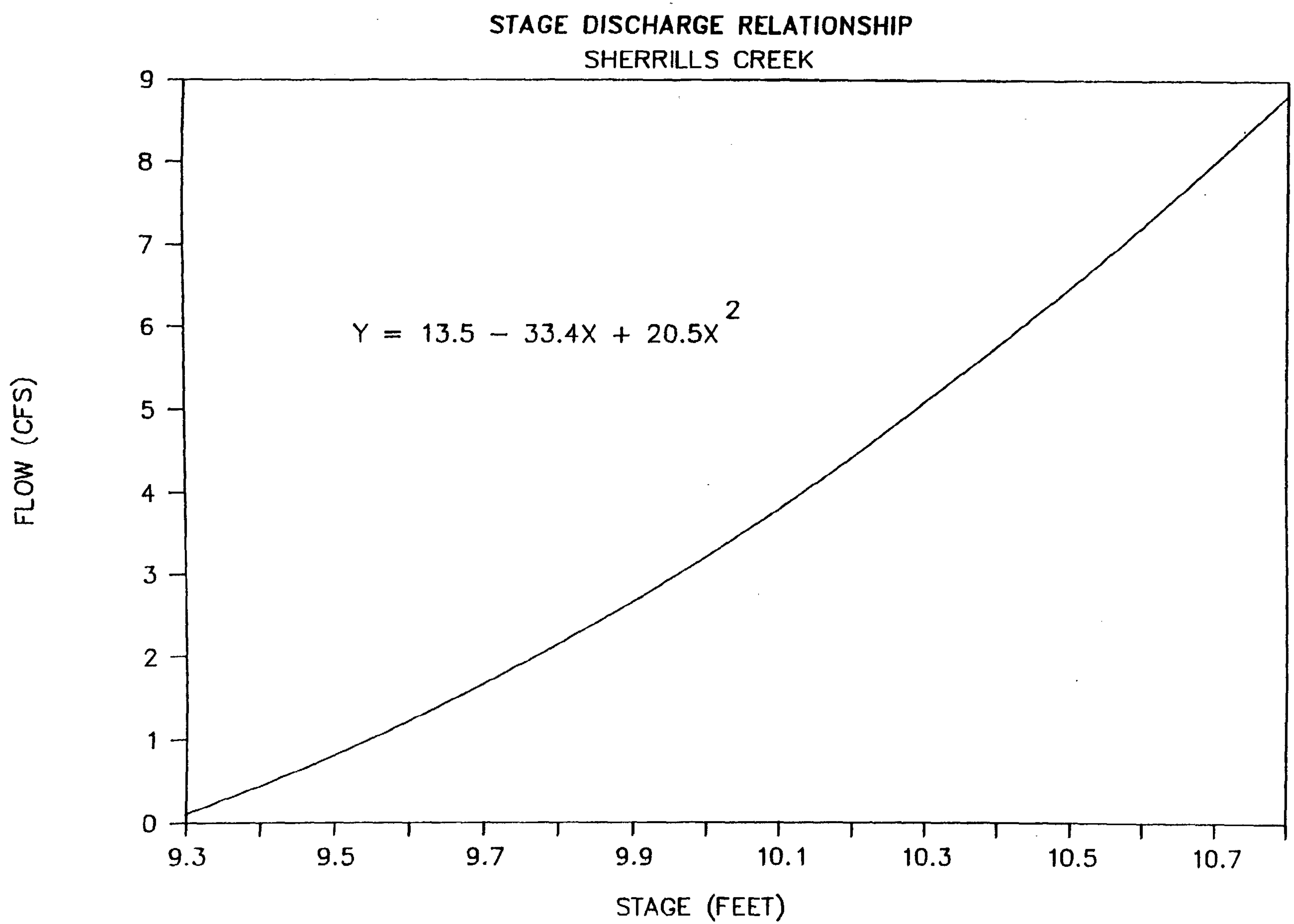
RAINFALL EVENT
SANDY CREEK
ATHENS, GEORGIA
LEGEND
FLOW
TOC
FLOW (CFS)
TOTAL ORGANIC CARBON (MG/L)
TIME (HOURS)
JULY 6-10, 1989

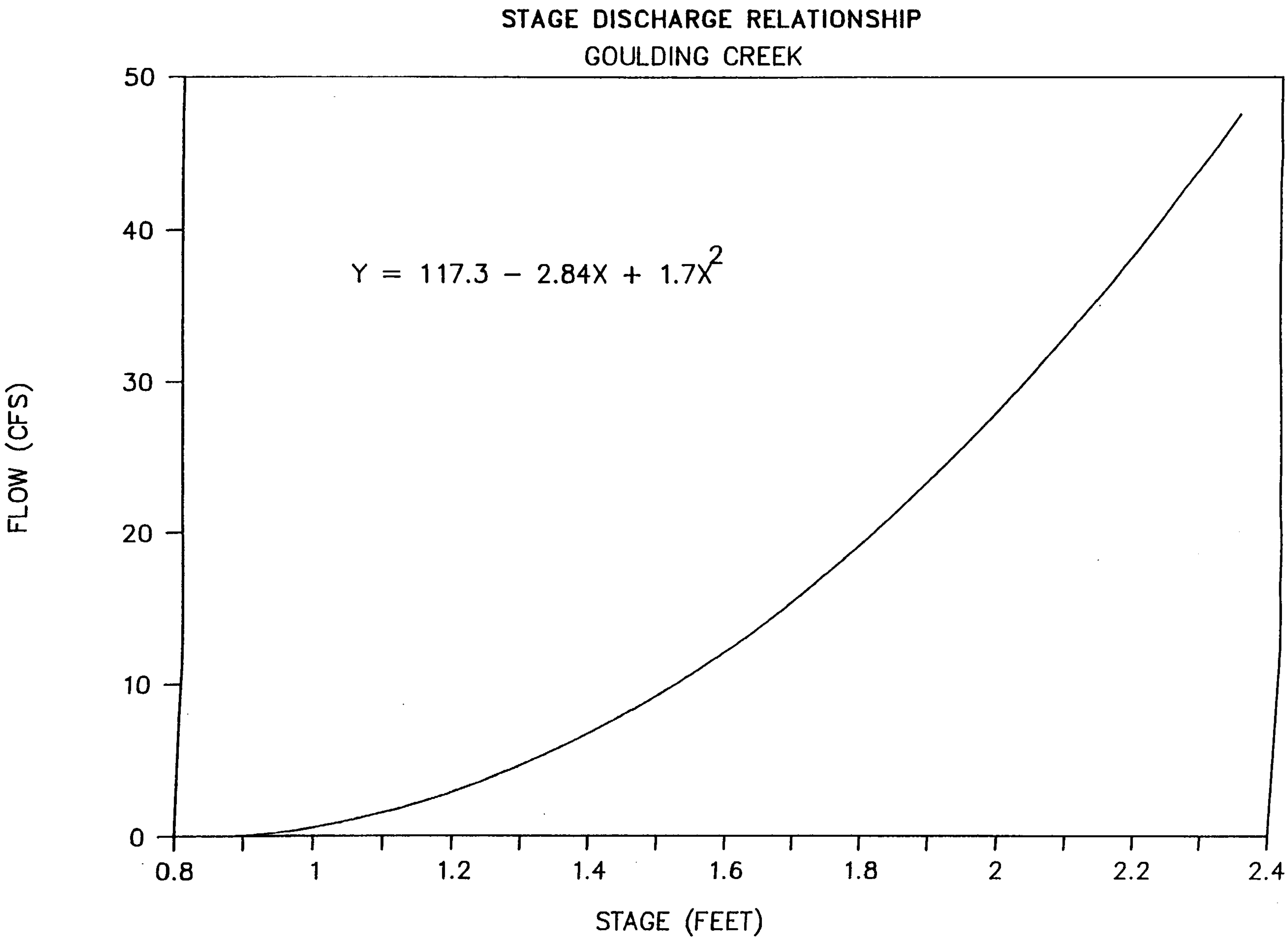

RAINFALL DATA
COMMERCE LAKE
PRECIPITATION (INCHES)
2
1.5
1
0.5
0
STUDY PERIOD
TIME (DAYS)
JUNE 14–JULY 10, 1989


RAINFALL EVENT
GROVE RIVER
COMMERCE, GEORGIA
FLOW (CFS)
NITROGEN CONC (MG/L)
TIME (HOURS)
JULY 6-10, 1989
LEGEND
FLOW
NH3
NO2-NO3
TKN

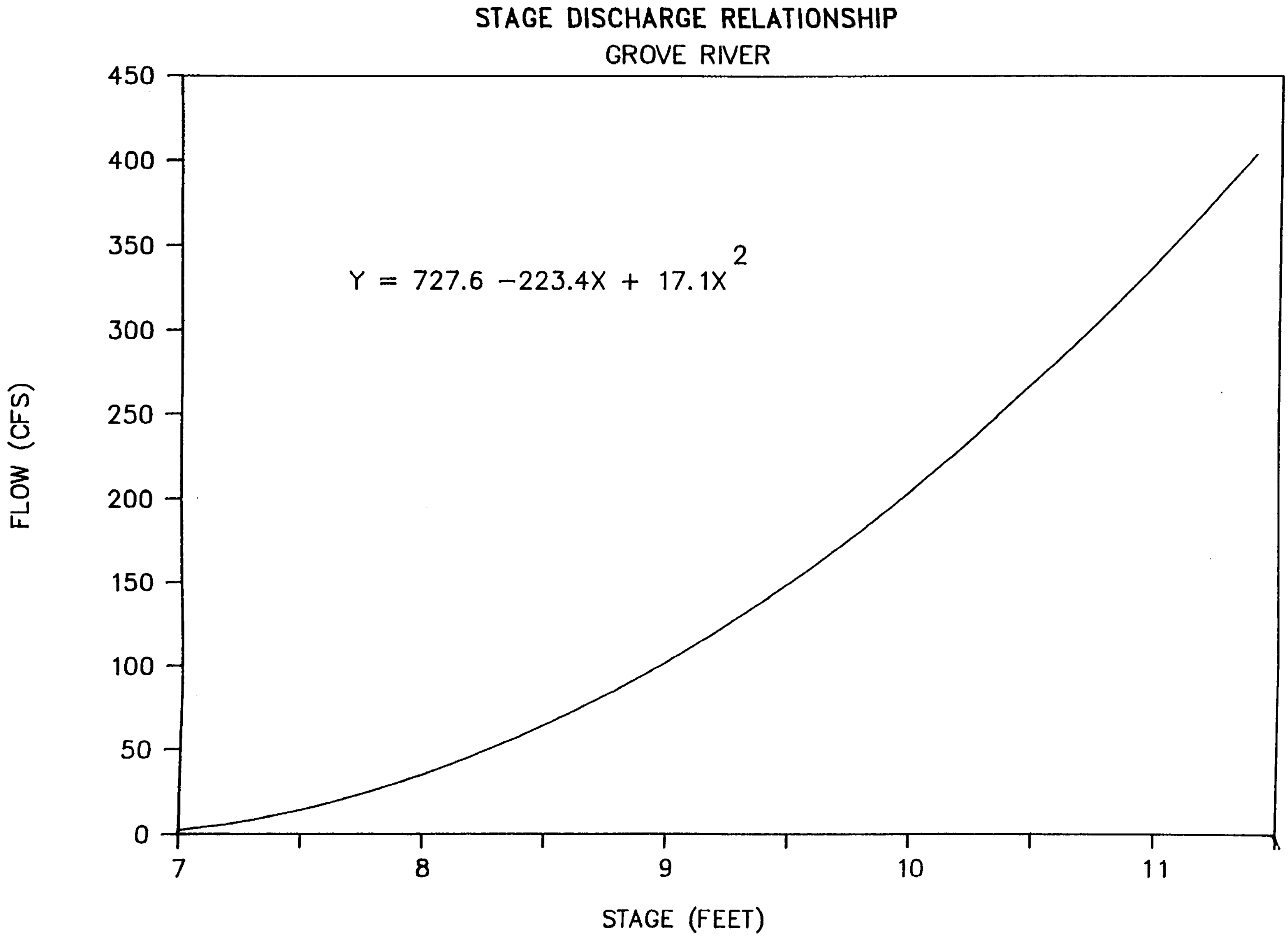

RAINFALL EVENT
GROVE RIVER
COMMERCE, GEORGIA
FLOW (CFS)
TOTAL PHOSPHORUS (MG/L)
TIME (HOURS)
JULY 6-10, 1989
LEGEND
FLOW
T-P

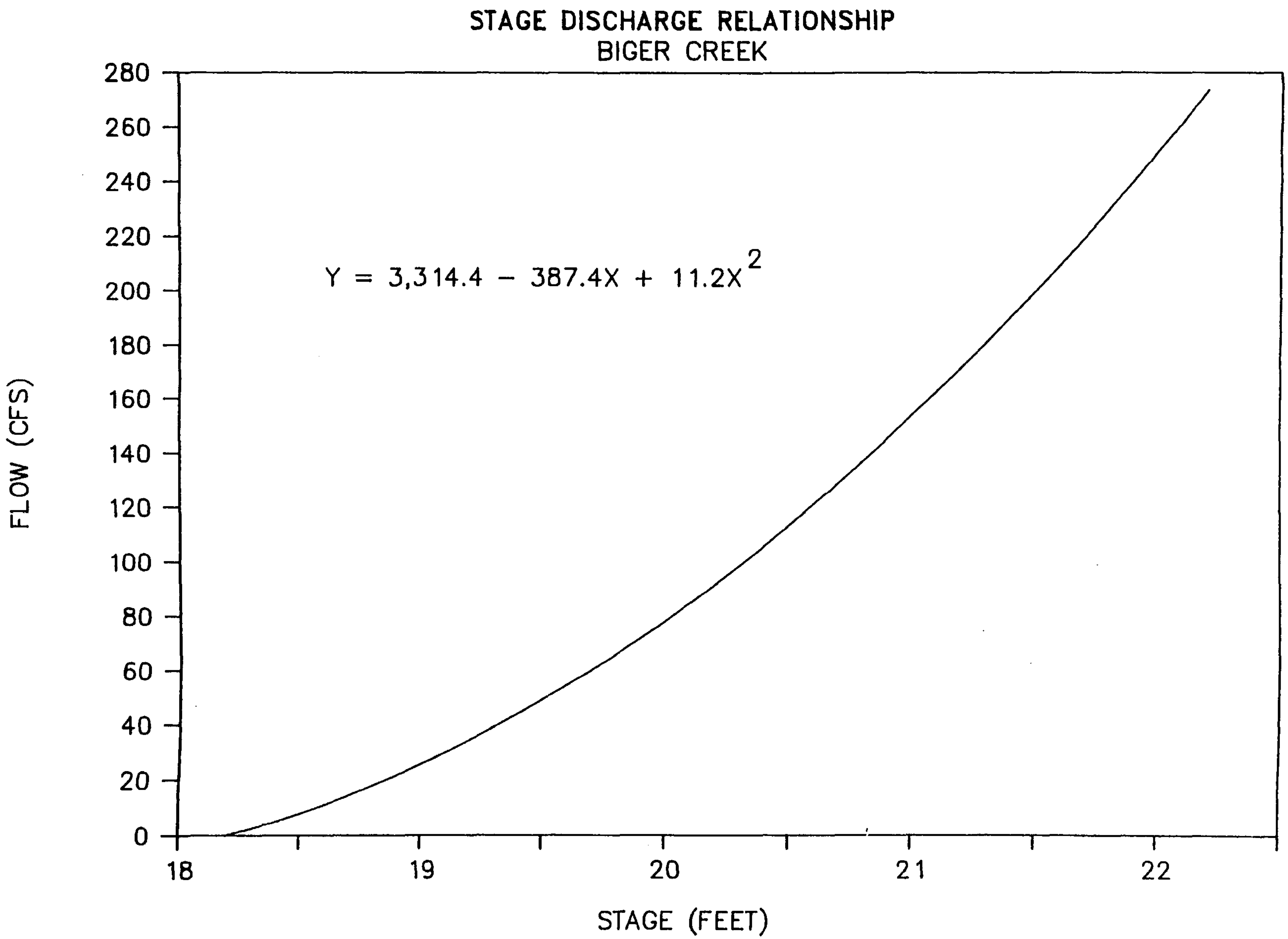

RAINFALL EVENT
GROVE RIVER
COMMERCE, GEORGIA
FLOW (CFS)
TOTAL ORGANIC CARBON (MG/L)
TIME (HOURS)
JULY 6-10, 1989
LEGEND
FLOW
TOC

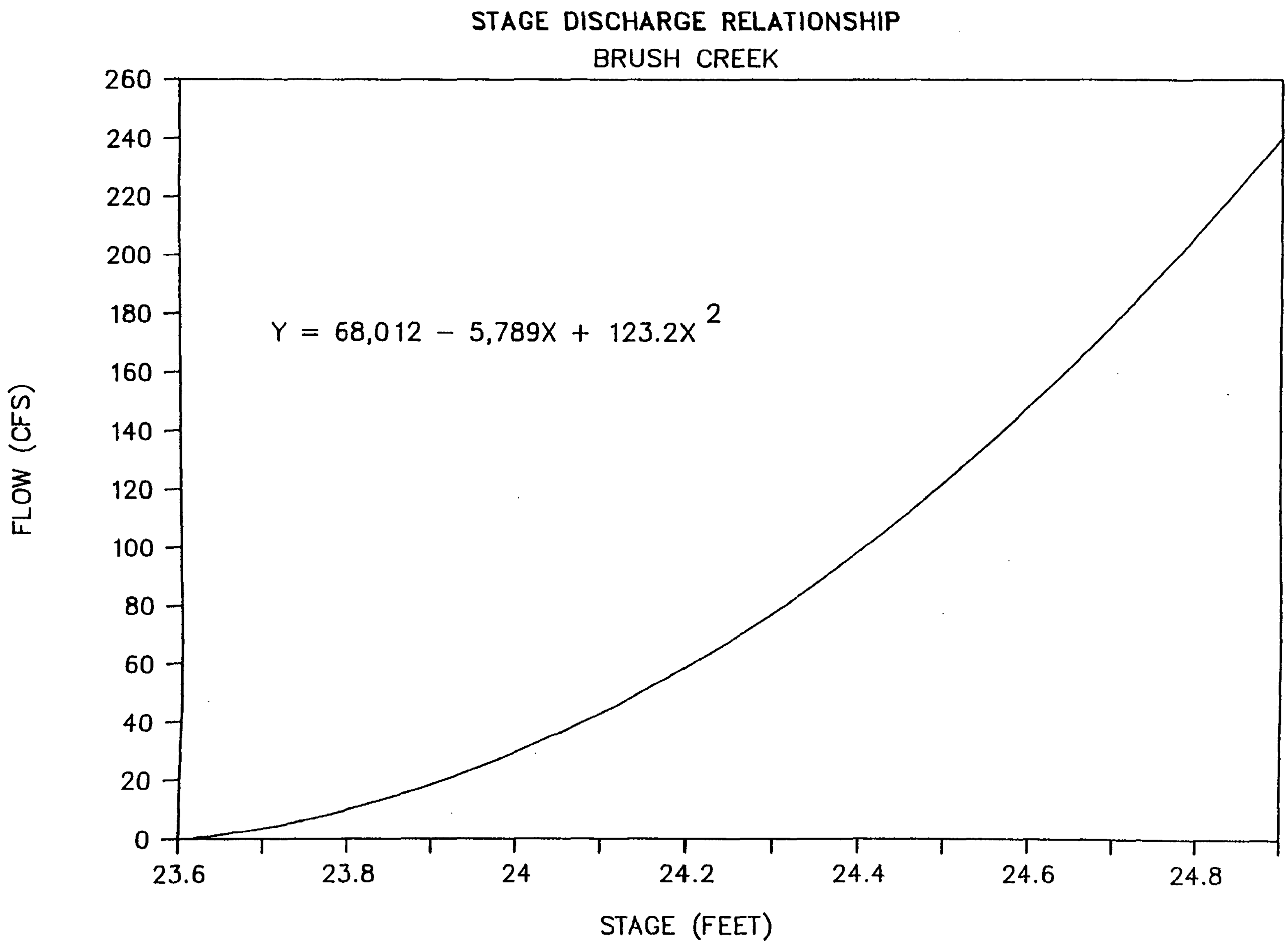

STAGE DISCHARGE RELATIONSHIP
SHERRILLS CREEK
$Y = 13.5 - 33.4X + 20.5X^2$
FLOW (CFS)
0
1
2
3
4
5
6
7
8
9
9.3
9.5
9.7
9.9
10.1
10.3
10.5
10.7
STAGE (FEET)

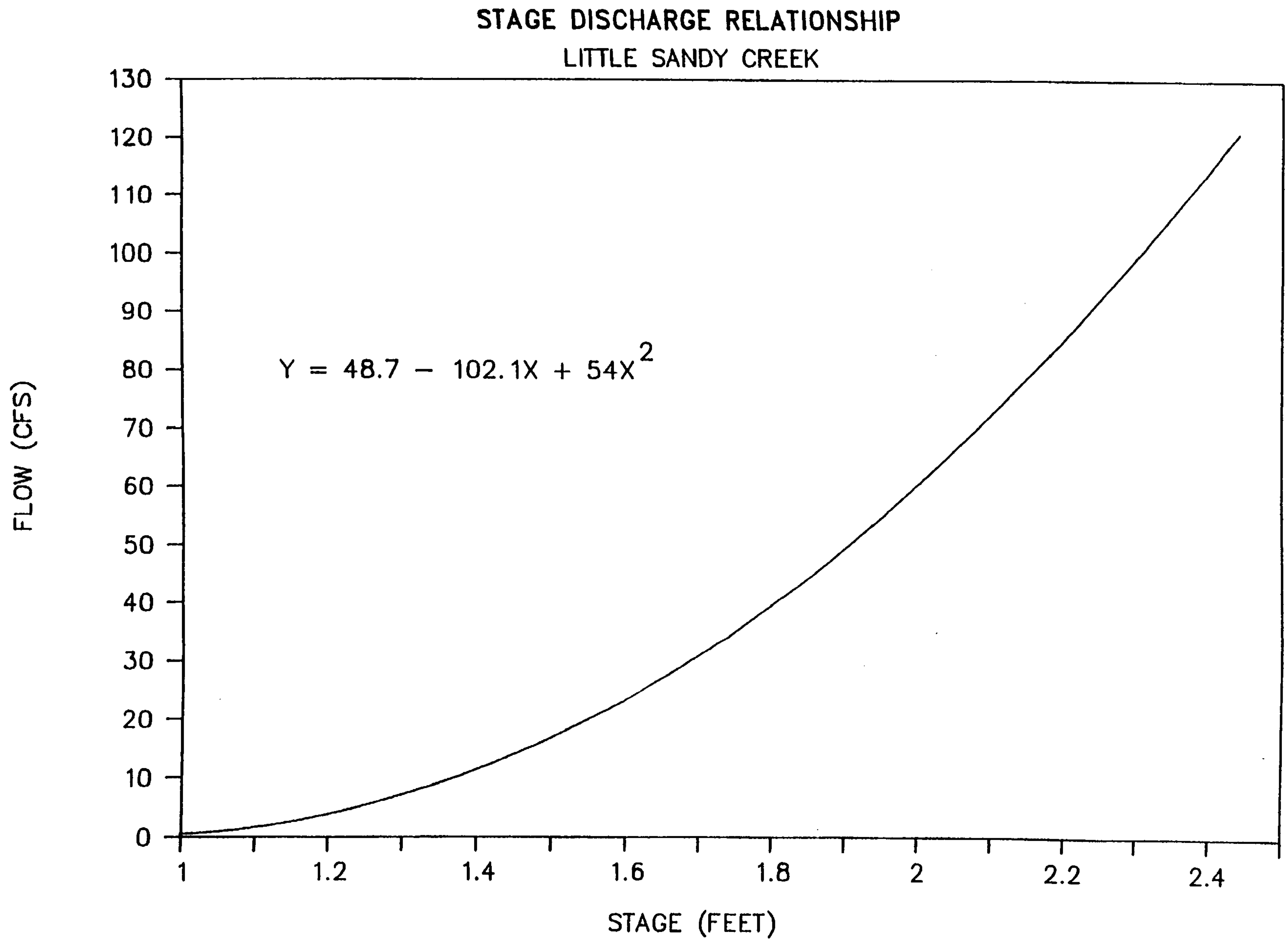


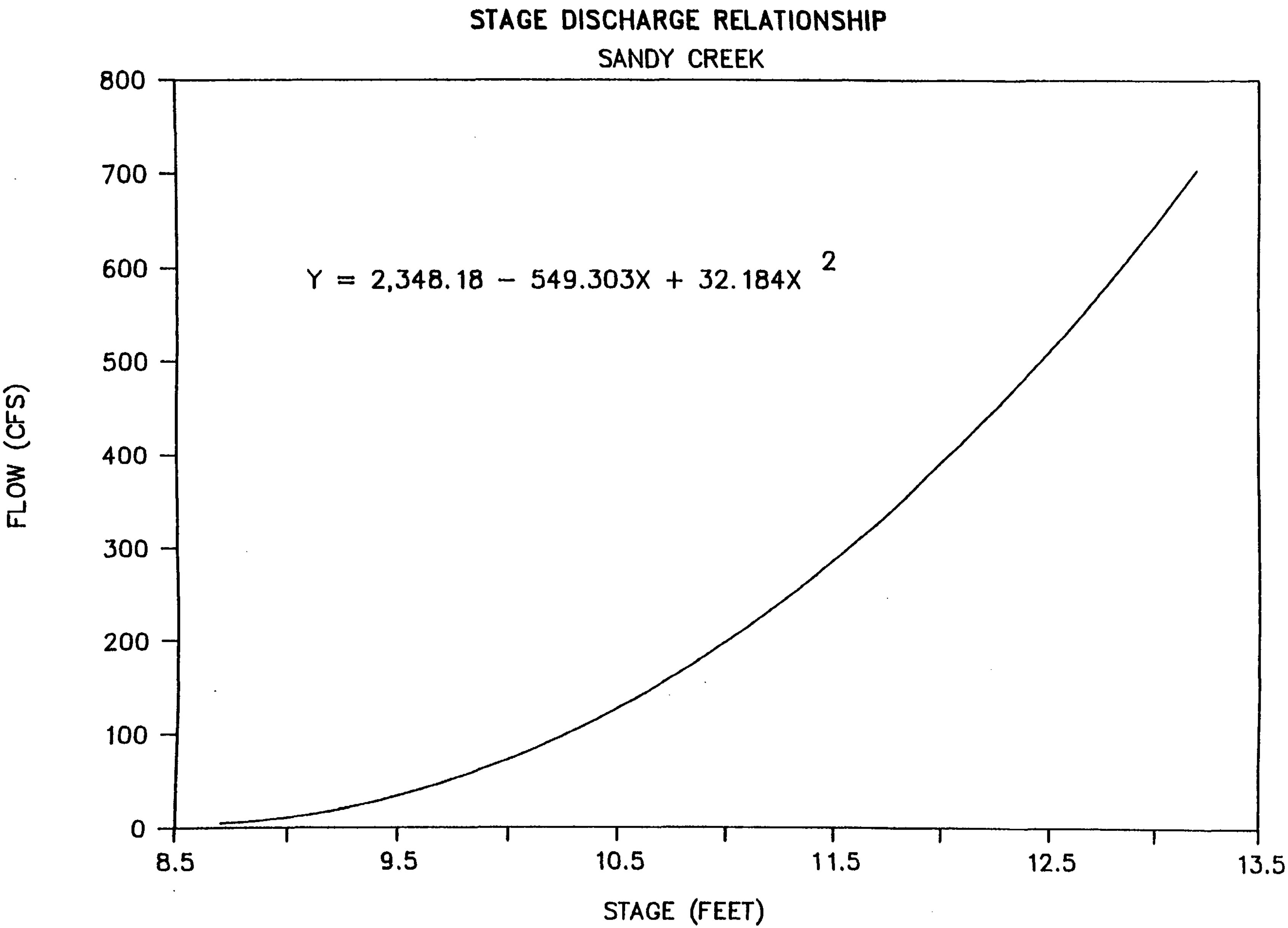
STAGE DISCHARGE RELATIONSHIP
GOULDING CREEK
Y = 117.3 - 2.84X + 1.7X^2
FLOW (CFS)
STAGE (FEET)
0
10
20
30
40
50
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4


STAGE DISCHARGE RELATIONSHIP
GROVE RIVER
Y = 727.6 −223.4X + 17.1X²
FLOW (CFS)
450
400
350
300
250
200
150
100
50
0
7
8
9
10
11
STAGE (FEET)

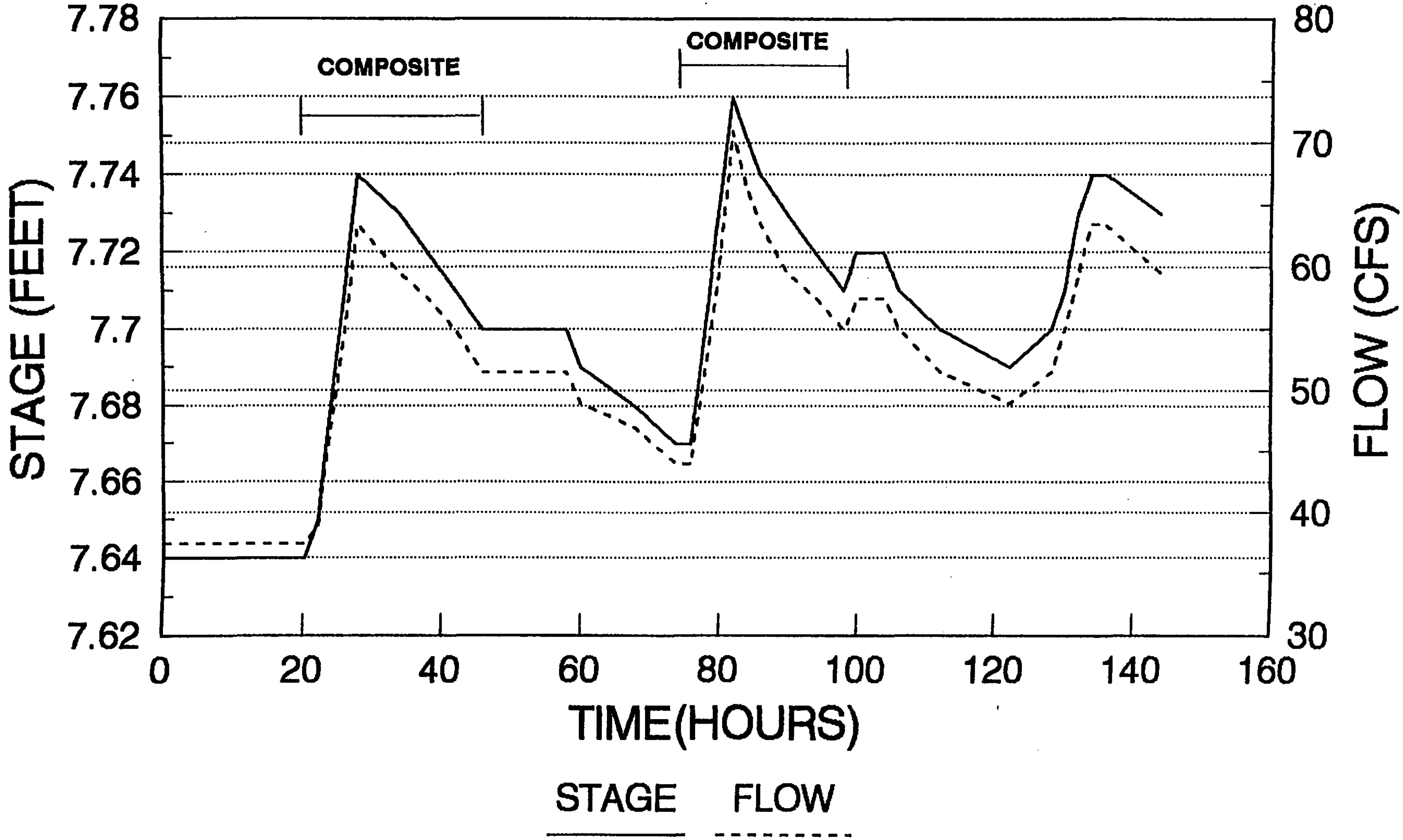

STAGE DISCHARGE RELATIONSHIP
BIGER CREEK
Y = 3,314.4 − 387.4X + 11.2X²
FLOW (CFS)
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
18
19
20
21
22
STAGE (FEET)


STAGE DISCHARGE RELATIONSHIP
BRUSH CREEK
Y = 68,012 − 5,789X + 123.2X 2
FLOW (CFS)
260
240
220
200
180
160
140
120
100
80
60
40
20
0
23.6
23.8
24
24.2
24.4
24.6
24.8
STAGE (FEET)

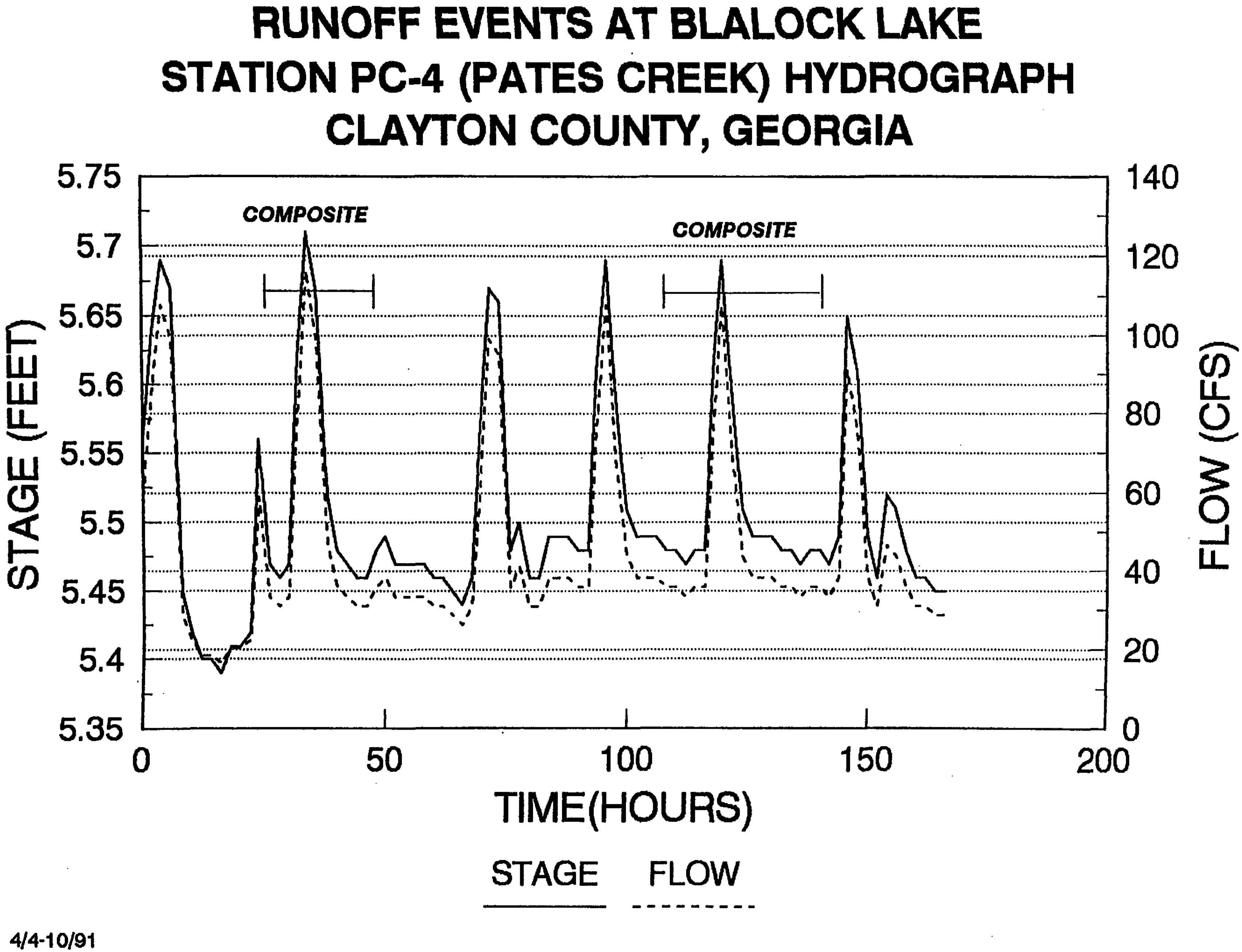

STAGE DISCHARGE RELATIONSHIP
LITTLE SANDY CREEK
$Y = 48.7 - 102.1X + 54X^2$
FLOW (CFS)
STAGE (FEET)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
1
1.2
1.4
1.6
1.8
2
2.2
2.4


STAGE DISCHARGE RELATIONSHIP
SANDY CREEK
Y = 2,348.18 - 549.303X + 32.184X 2
FLOW (CFS)
800
700
600
500
400
300
200
100
0
8.5
9.5
10.5
11.5
12.5
13.5
STAGE (FEET)

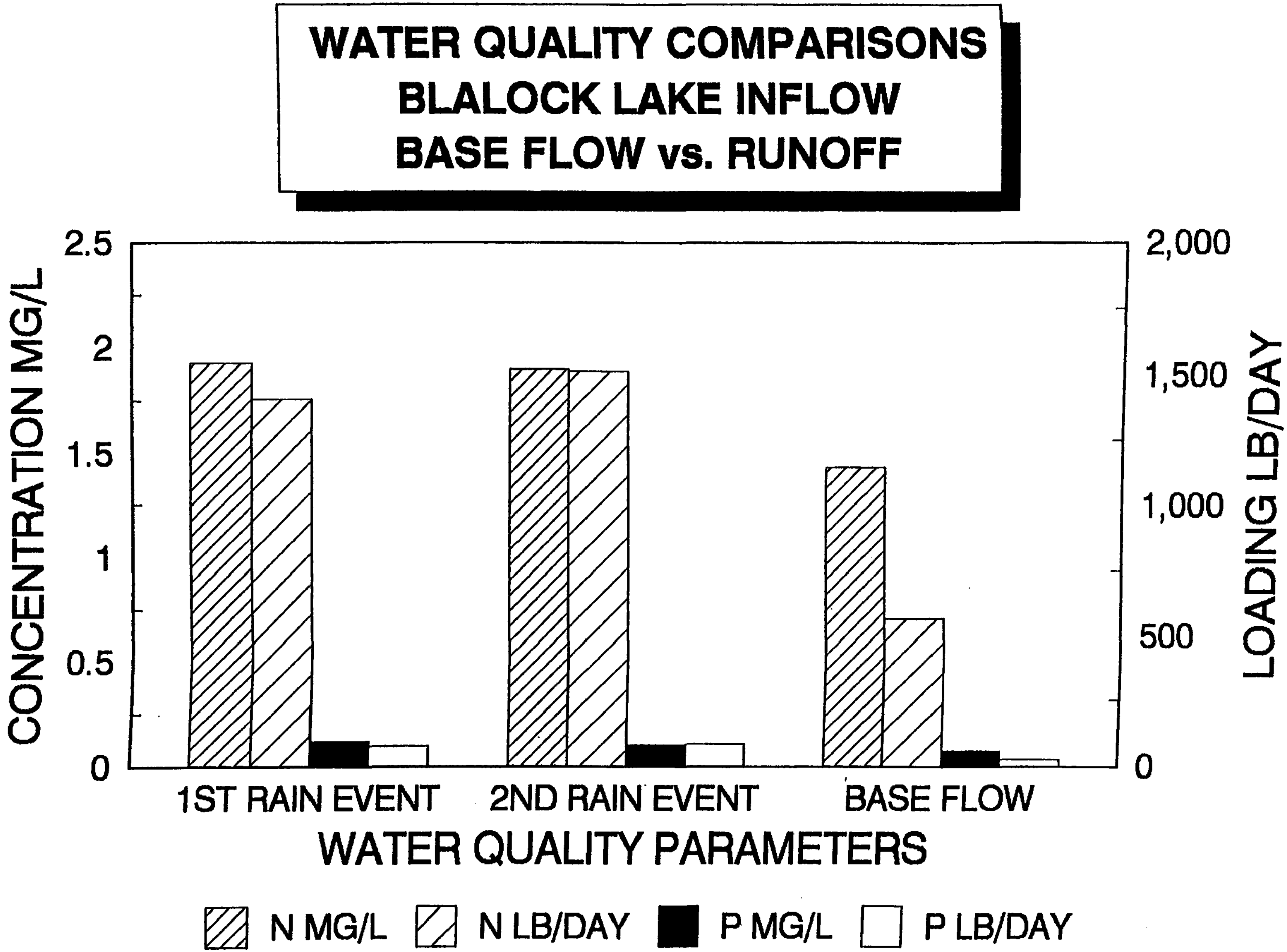
RUNOFF EVENTS AT BLALOCK LAKE
STATION BL-3 (BLALOCK CREEK) HYDROGRAPH
CLAYTON COUNTY, GEORGIA



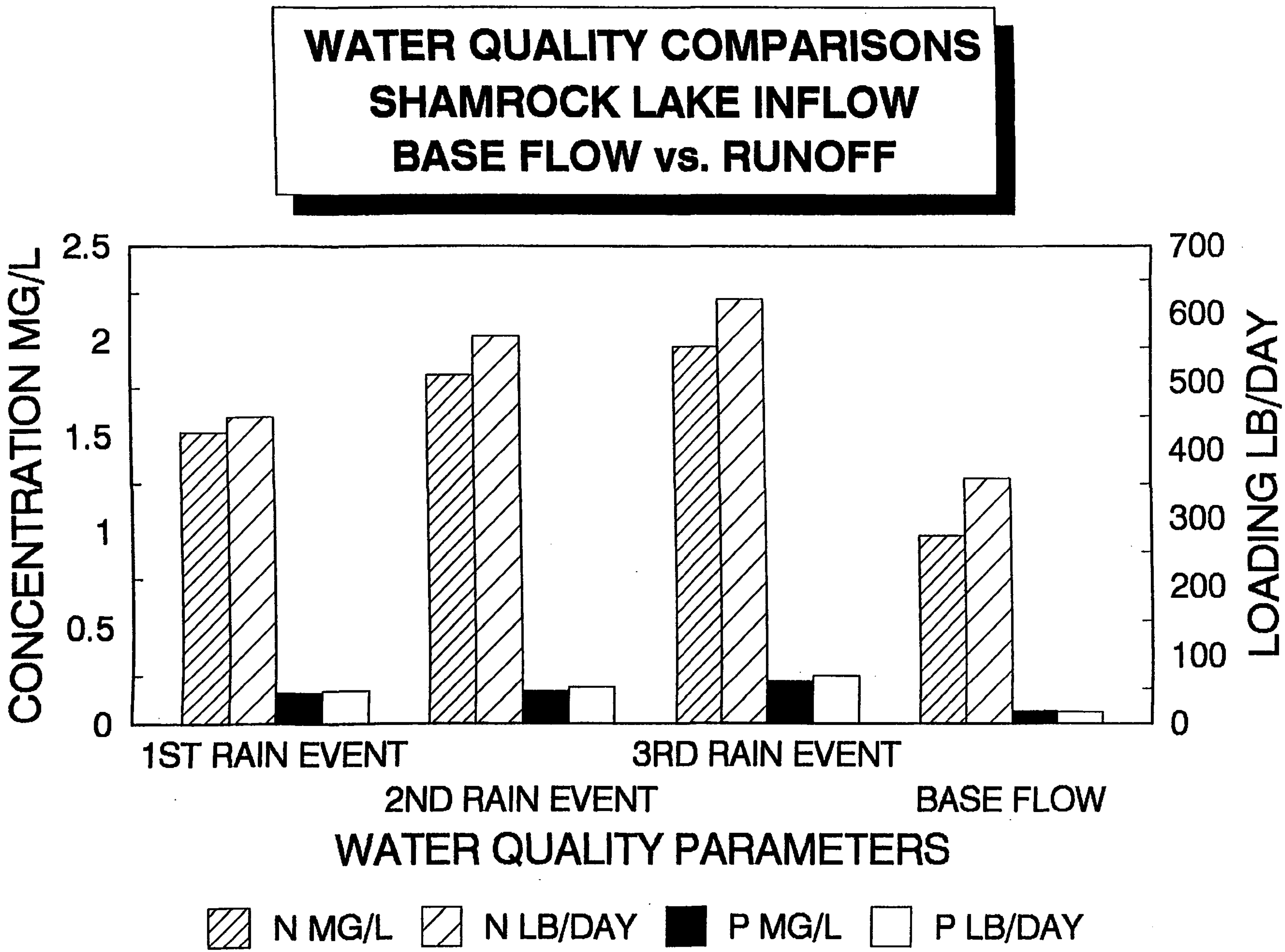
4/4-10/91



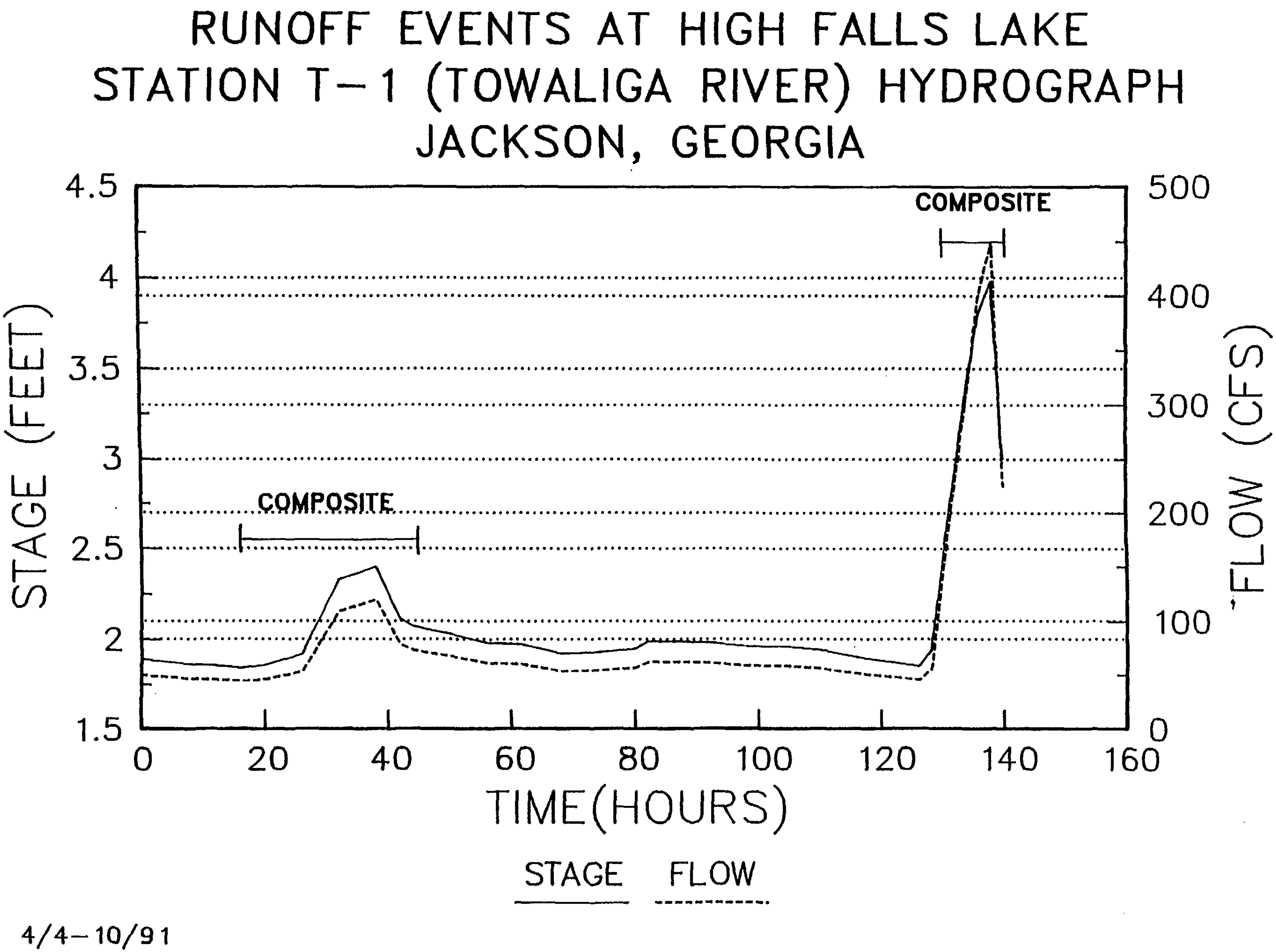
RUNOFF EVENTS AT BLALOCK LAKE
STATION PC-4 (PATES CREEK) HYDROGRAPH
CLAYTON COUNTY, GEORGIA
STAGE (FEET)
5.75
5.7
5.65
5.6
5.55
5.5
5.45
5.4
5.35
FLOW (CFS)
140
120
100
80
60
40
20
0
COMPOSITE
COMPOSITE
0
50
100
150
200
TIME(HOURS)
STAGE
FLOW
4/4-10/91


WATER QUALITY COMPARISONS
BLALOCK LAKE INFLOW
BASE FLOW vs. RUNOFF
CONCENTRATION MG/L
2.5
2
1.5
1
0.5
0
LOADING LB/DAY
2,000
1,500
1,000
500
0
1ST RAIN EVENT
2ND RAIN EVENT
BASE FLOW
WATER QUALITY PARAMETERS
N MG/L
N LB/DAY
P MG/L
P LB/DAY

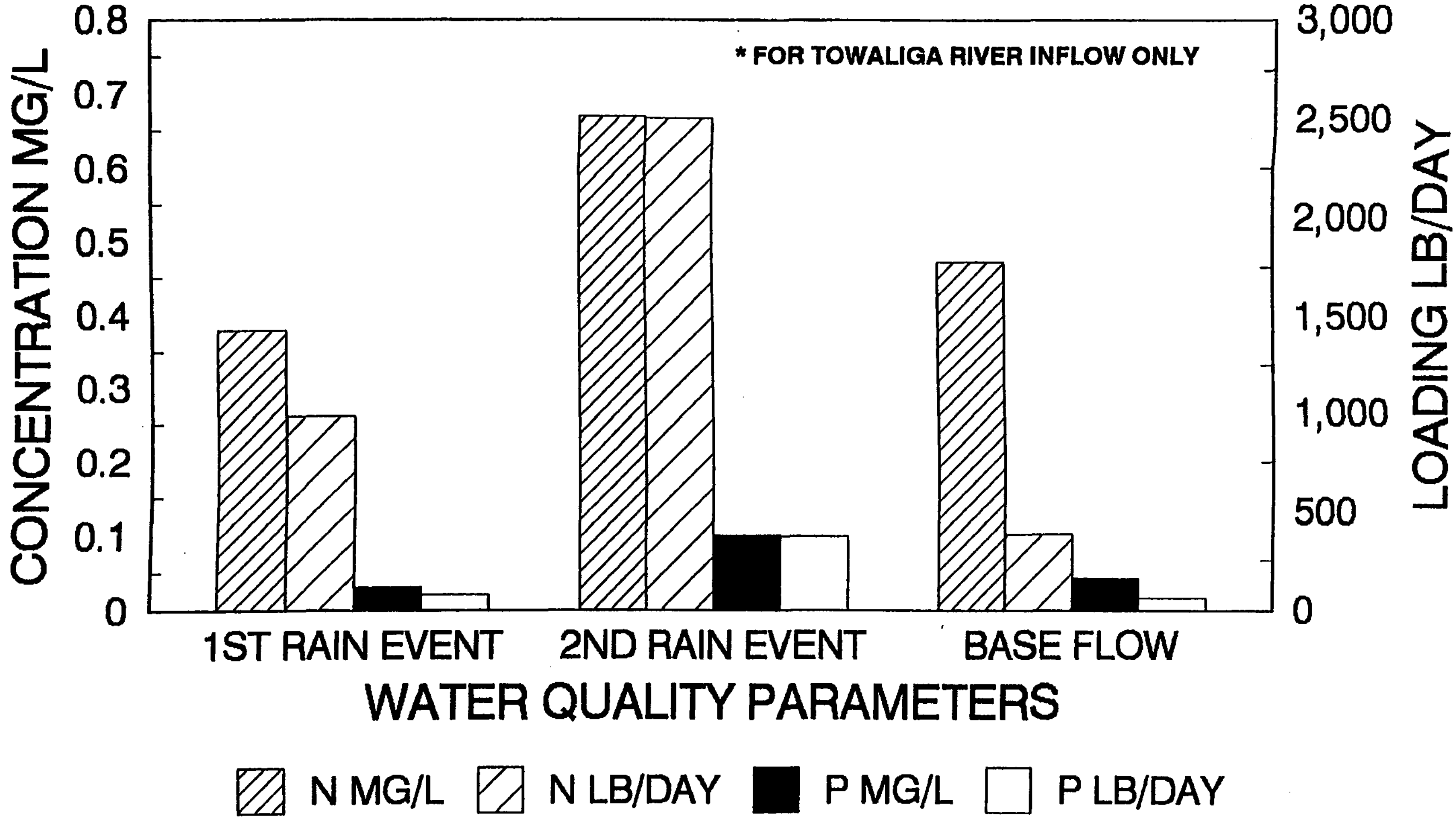
4/3-11/91


WATER QUALITY COMPARISONS
SHAMROCK LAKE INFLOW
BASE FLOW vs. RUNOFF
CONCENTRATION MG/L
2.5
2
1.5
1
0.5
0
LOADING LB/DAY
700
600
500
400
300
200
100
0
1ST RAIN EVENT
2ND RAIN EVENT
3RD RAIN EVENT
BASE FLOW
WATER QUALITY PARAMETERS
N MG/L
N LB/DAY
P MG/L
P LB/DAY

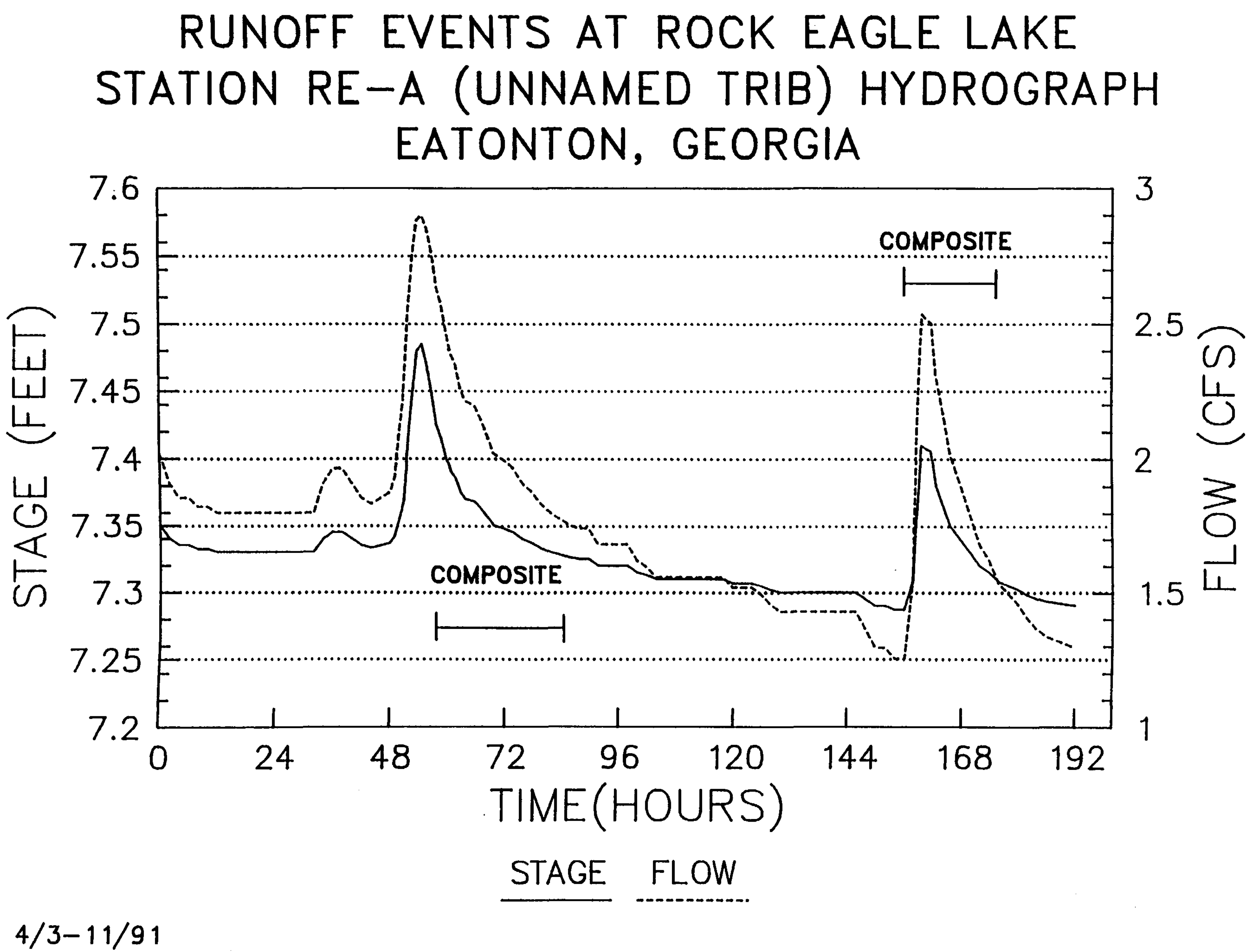
4/3-11/91

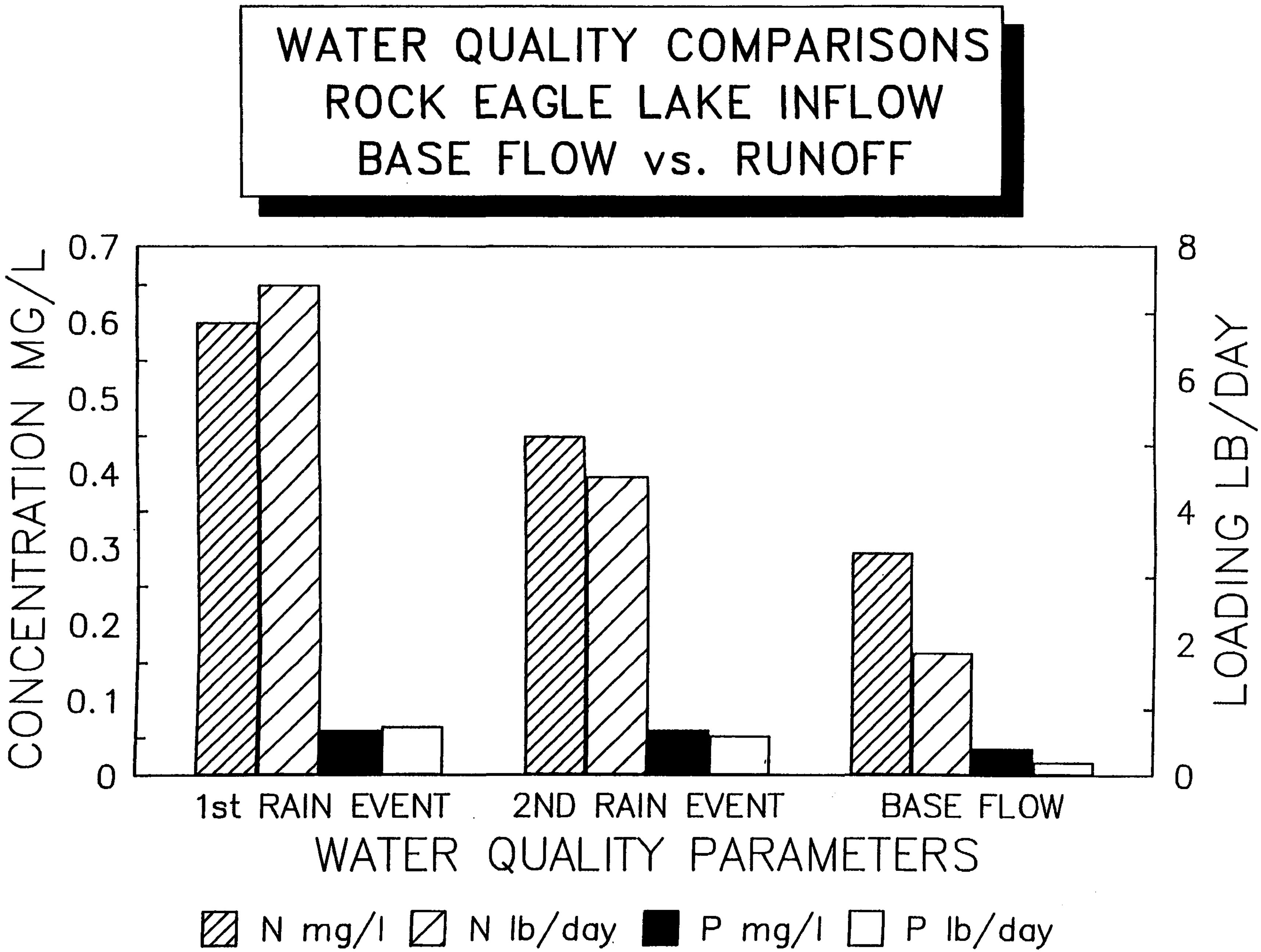

RUNOFF EVENTS AT HIGH FALLS LAKE
STATION T-1 (TOWALIGA RIVER) HYDROGRAPH
JACKSON, GEORGIA
STAGE (FEET)
FLOW (CFS)
TIME(HOURS)
COMPOSITE
COMPOSITE
4.5
4
3.5
3
2.5
2
1.5
500
400
300
200
100
0
0
20
40
60
80
100
120
140
160
STAGE
FLOW
4/4-10/91

WATER QUALITY COMPARISONS
HIGH FALLS LAKE INFLOW
BASE FLOW vs. RUNOFF

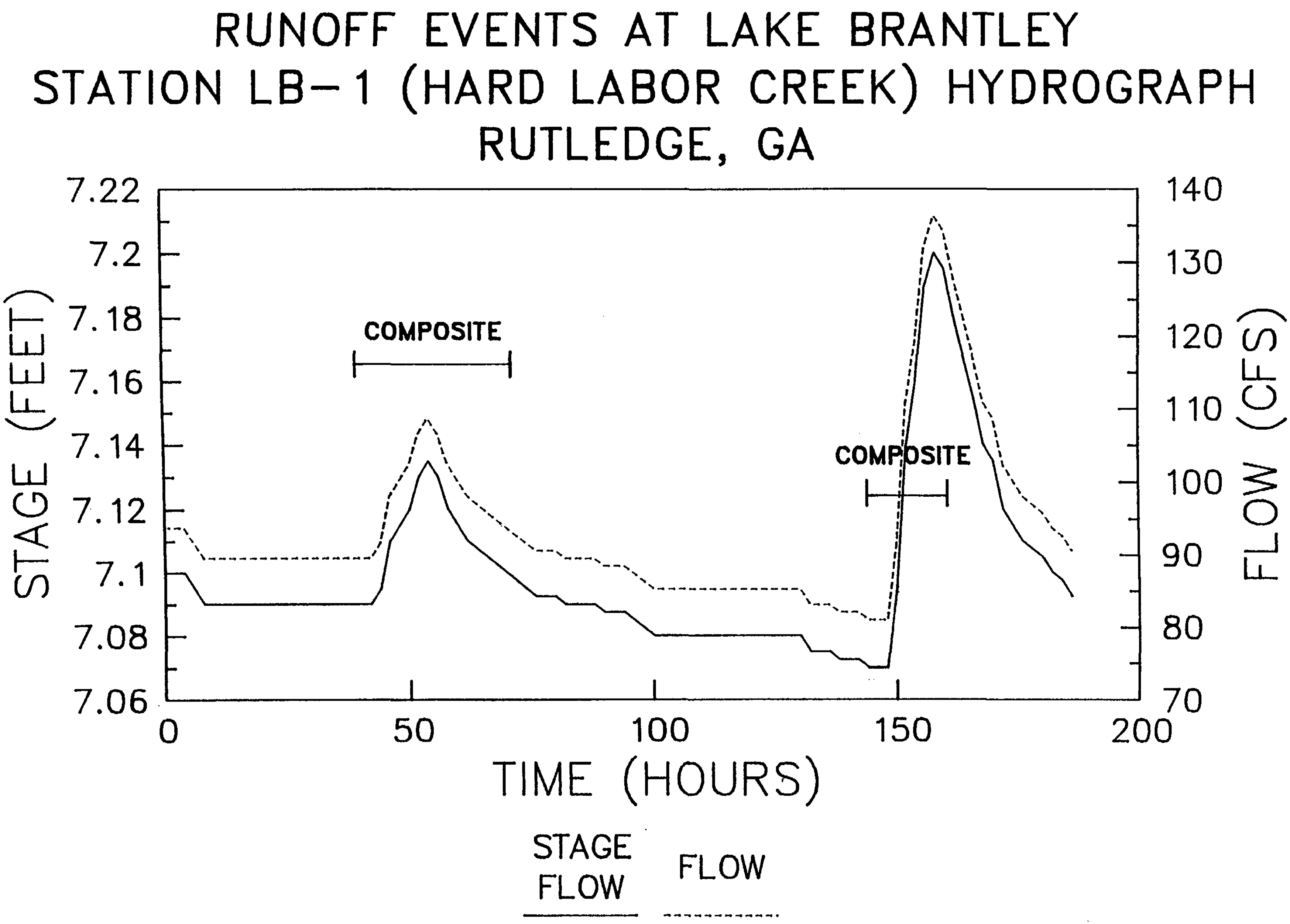


4/3-11/91

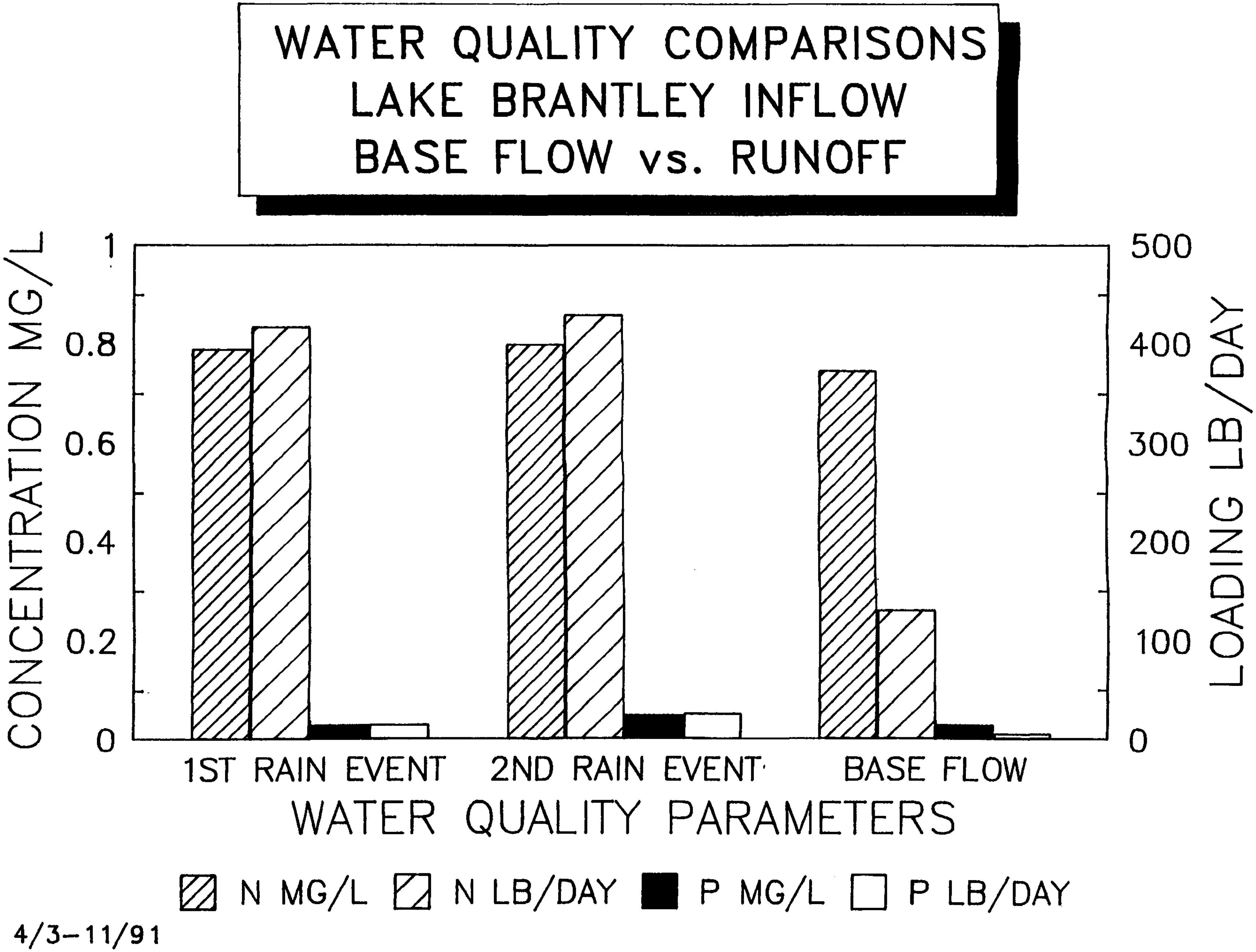

RUNOFF EVENTS AT ROCK EAGLE LAKE
STATION RE-A (UNNAMED TRIB) HYDROGRAPH
EATONTON, GEORGIA
STAGE (FEET)
FLOW (CFS)
7.6
7.55
7.5
7.45
7.4
7.35
7.3
7.25
7.2
3
2.5
2
1.5
1
COMPOSITE
COMPOSITE
0
24
48
72
96
120
144
168
192
TIME(HOURS)
STAGE
FLOW
4/3-11/91



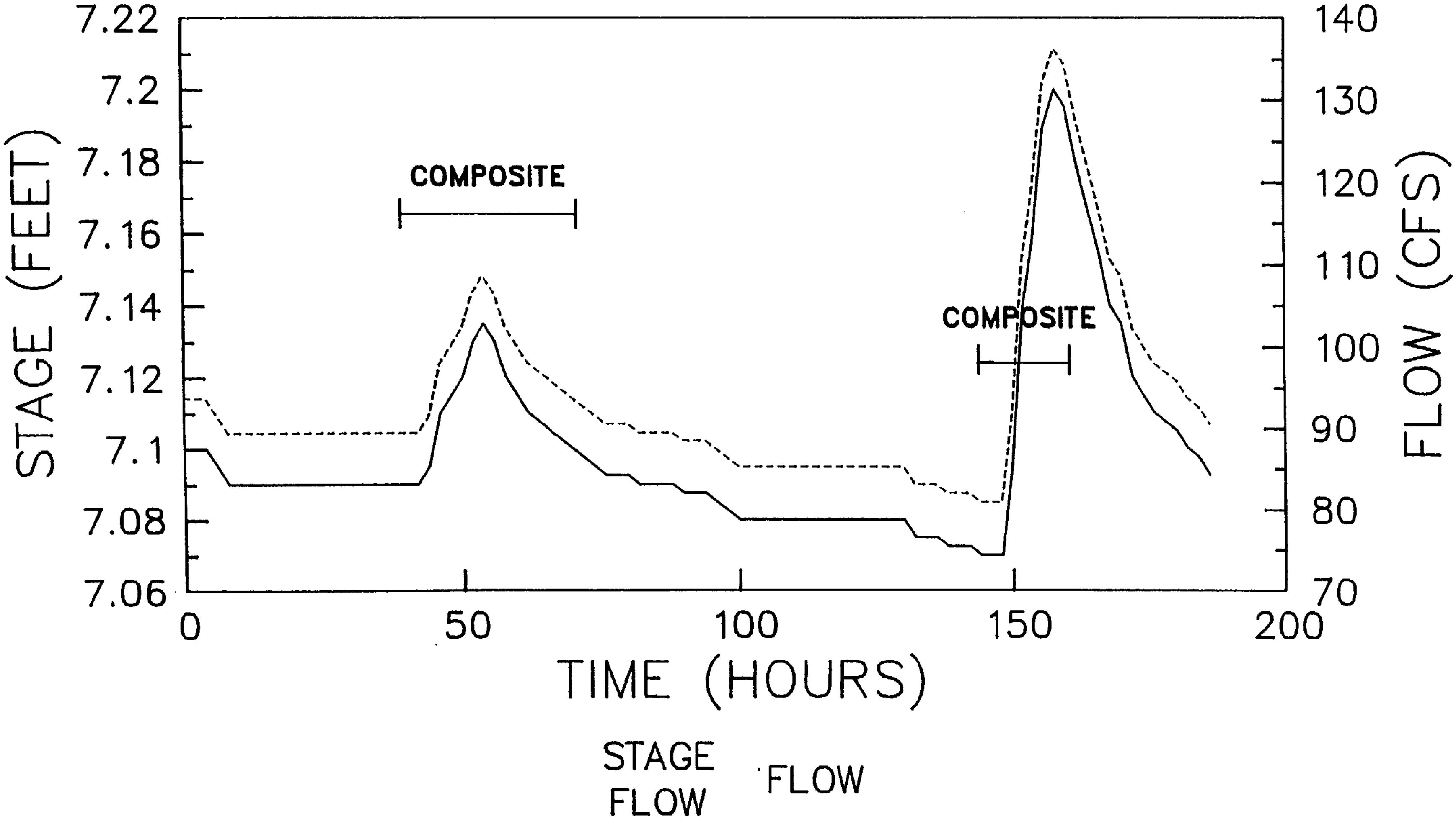
WATER QUALITY COMPARISONS
ROCK EAGLE LAKE INFLOW
BASE FLOW vs. RUNOFF
CONCENTRATION MG/L
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
LOADING LB/DAY
8
6
4
2
0
1st RAIN EVENT
2ND RAIN EVENT
BASE FLOW
WATER QUALITY PARAMETERS
N mg/l
N lb/day
P mg/l
P lb/day


RUNOFF EVENTS AT LAKE BRANTLEY
STATION LB-1 (HARD LABOR CREEK) HYDROGRAPH
RUTLEDGE, GA
STAGE (FEET)
7.22
7.2
7.18
7.16
7.14
7.12
7.1
7.08
7.06
FLOW (CFS)
140
130
120
110
100
90
80
70
COMPOSITE
COMPOSITE
0
50
100
150
200
TIME (HOURS)
STAGE
FLOW
FLOW

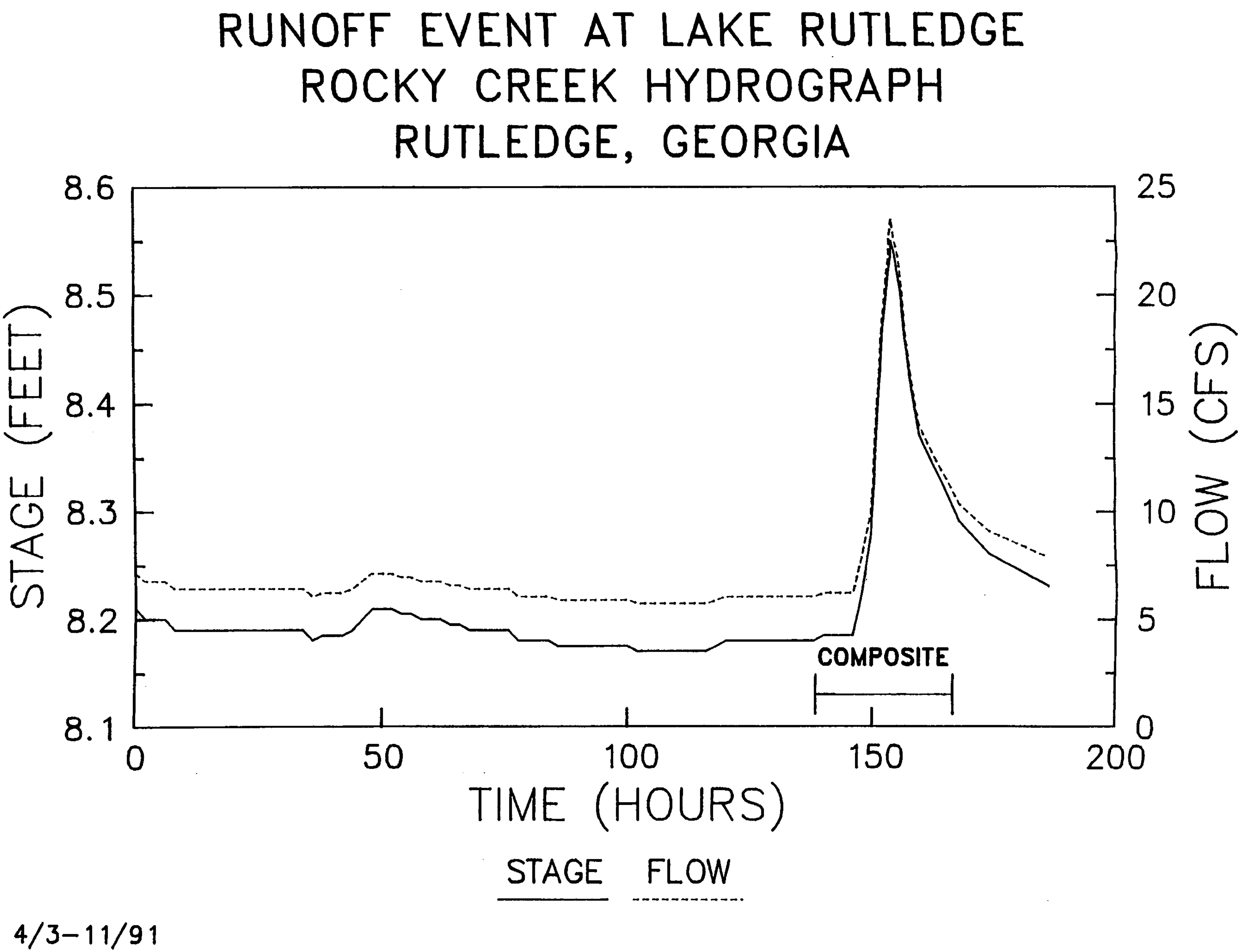
4/3-11/91

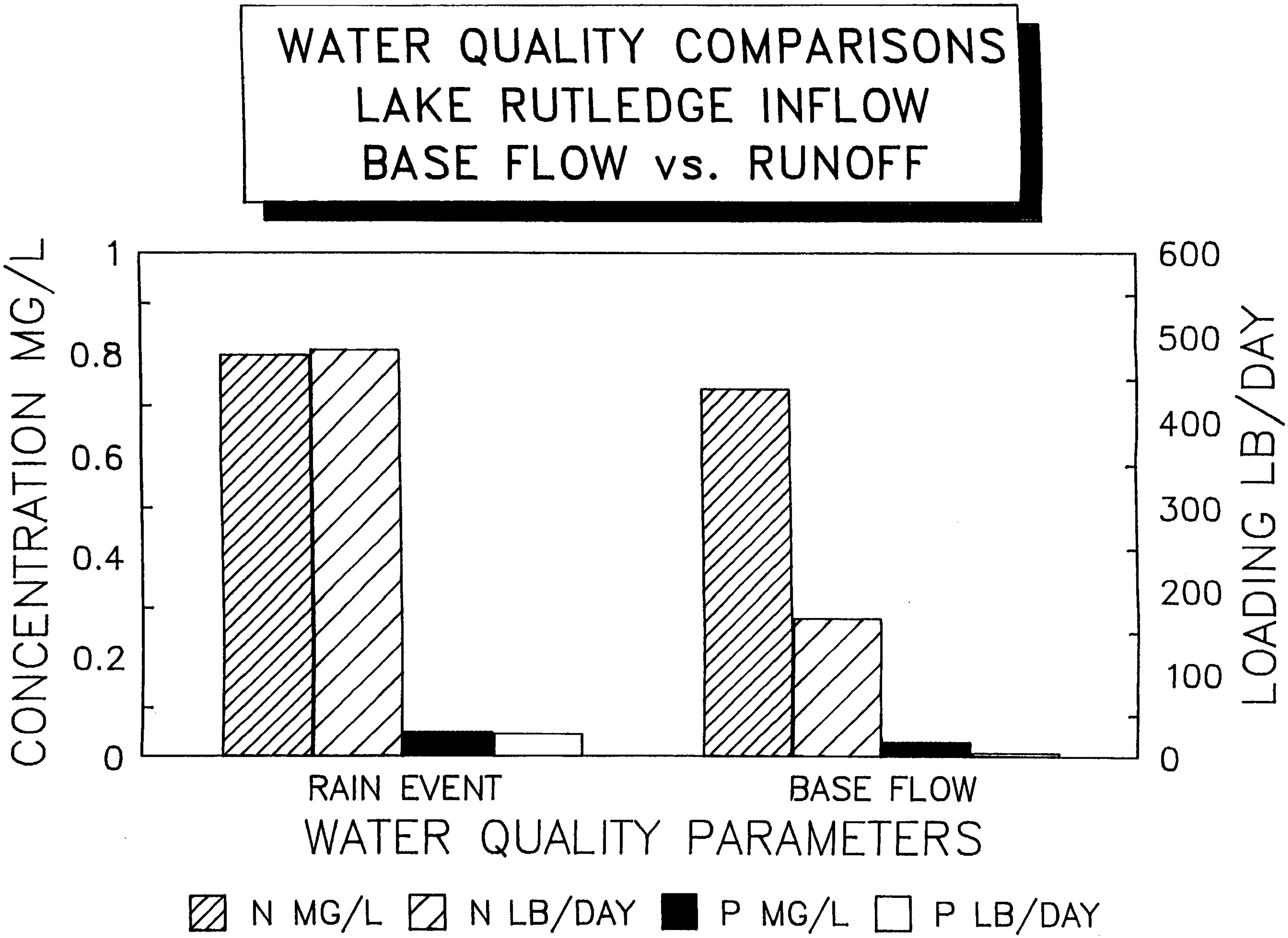

WATER QUALITY COMPARISONS
LAKE BRANTLEY INFLOW
BASE FLOW vs. RUNOFF
CONCENTRATION MG/L
LOADING LB/DAY
1
0.8
0.6
0.4
0.2
0
500
400
300
200
100
0
1ST RAIN EVENT
2ND RAIN EVENT
BASE FLOW
WATER QUALITY PARAMETERS
N MG/L
N LB/DAY
P MG/L
P LB/DAY
4/3-11/91

RUNOFF EVENTS AT LAKE RUTLEDGE
STATION LB-3 (HARD LABOR CREEK) HYDROGRAPH
RUTLEDGE, GA



4/3-11/91


RUNOFF EVENT AT LAKE RUTLEDGE
ROCKY CREEK HYDROGRAPH
RUTLEDGE, GEORGIA
STAGE (FEET)
8.6
8.5
8.4
8.3
8.2
8.1
FLOW (CFS)
25
20
15
10
5
0
COMPOSITE
0
50
100
150
200
TIME (HOURS)
STAGE
FLOW
4/3-11/91



4/9–10/91 RUNOFF EVENT

APPENDIX F

APPENDIX F

PART IV: BATHTUB - MODEL IMPLEMENTATION

BATHTUB is designed to facilitate application of empirical eutrophication models to morphometrically complex reservoirs. The program performs water and nutrient balance calculations in a steady-state, spatially segmented hydraulic network which accounts for advective transport, diffusive transport, and nutrient sedimentation. Eutrophication-related water quality conditions (expressed in terms of total phosphorus, total nitrogen, chlorophyll-a, transparency, organic nitrogen, nonortho-phosphorus, and hypolimnetic oxygen depletion rate) are predicted using empirical relationships previously developed and tested for reservoir applications (Walker 1985). To provide regional perspectives on reservoir water quality, controlling factors, and model performance, BATHTUB can also be configured for simultaneous application to collections or networks of reservoirs. As described in Part I, applications of the program would normally follow use of the FLUX program for reducing tributary monitoring data and use of the PROFILE program for reducing pool monitoring data, although use of the data reduction programs is optional if independent estimates of tributary loadings and/or average pool water quality conditions are used.

The functions of the program can be broadly classified as diagnostic or predictive. Typical applications would include:

a. Diagnostic.
   (1) Formulation of water and nutrient balances, including identification and ranking of potential error sources.
   (2) Ranking of trophic state indicators in relation to user-defined reservoir groups and/or the CE reservoir data base.
   (3) Identification of factors controlling algal production.

b. Predictive.
   (1) Assessing impacts of changes in water and/or nutrient loadings.
   (2) Assessing impacts of changes in mean pool level or morphometry.
   (3) Estimating nutrient loadings consistent with given water quality management objectives.

The program operates in a batch mode (noninteractive) and generates output in various formats, as appropriate for specific applications. Predicted confidence limits can be calculated for each output variable using a first-order error analysis scheme which incorporates effects of uncertainty in model input values (e.g., tributary flows and loadings, reservoir morphometry, monitored water quality) and inherent model errors.

Input formats and output listings are described at the end of this Part. The following sections review underlying theory, input data specifications, output formats, and suggested application procedures.

THEORY

Introduction

A flow diagram for BATHTUB calculations is given in Figure IV-1. The model core consists of the following procedures:

a. Water balance.

b. Nutrient balance.

c. Eutrophication response.

Using a first-order error analysis procedure (Walker 1982), the model core is executed repeatedly in order to estimate output sensitivity to each input variable and submodel and to develop variance estimates and confidence limits for each output variable. The remainder of the program consists of output routines designed for various purposes.

Control pathways for predicting nutrient levels and eutrophication response in a given model segment are illustrated in Figure IV-2. Predictions are based upon a network of models which has been empirically calibrated and tested for reservoir applications (Walker 1985). Model features are documented as follows: symbol definitions (Table IV-1), model options (Table IV-2), guidance for selecting model options (Table IV-3), supplementary response models (Table IV-4), error statistics (Table IV-5), and diagnostic variables and interpretations (Table IV-6).

As listed in Table IV-2, several options are provided for modeling nutrient sedimentation, chlorophyll-a, and transparency. In each case, Models 1 and 2 are the most general (and most accurate) formulations, based upon model testing results. Alternative models are included to permit sensitivity analyses and application of the program under various data constraints (see Table IV-3). Table IV-4 specifies submodels for predicting supplementary response variables (organic nitrogen, particulate phosphorus, principal

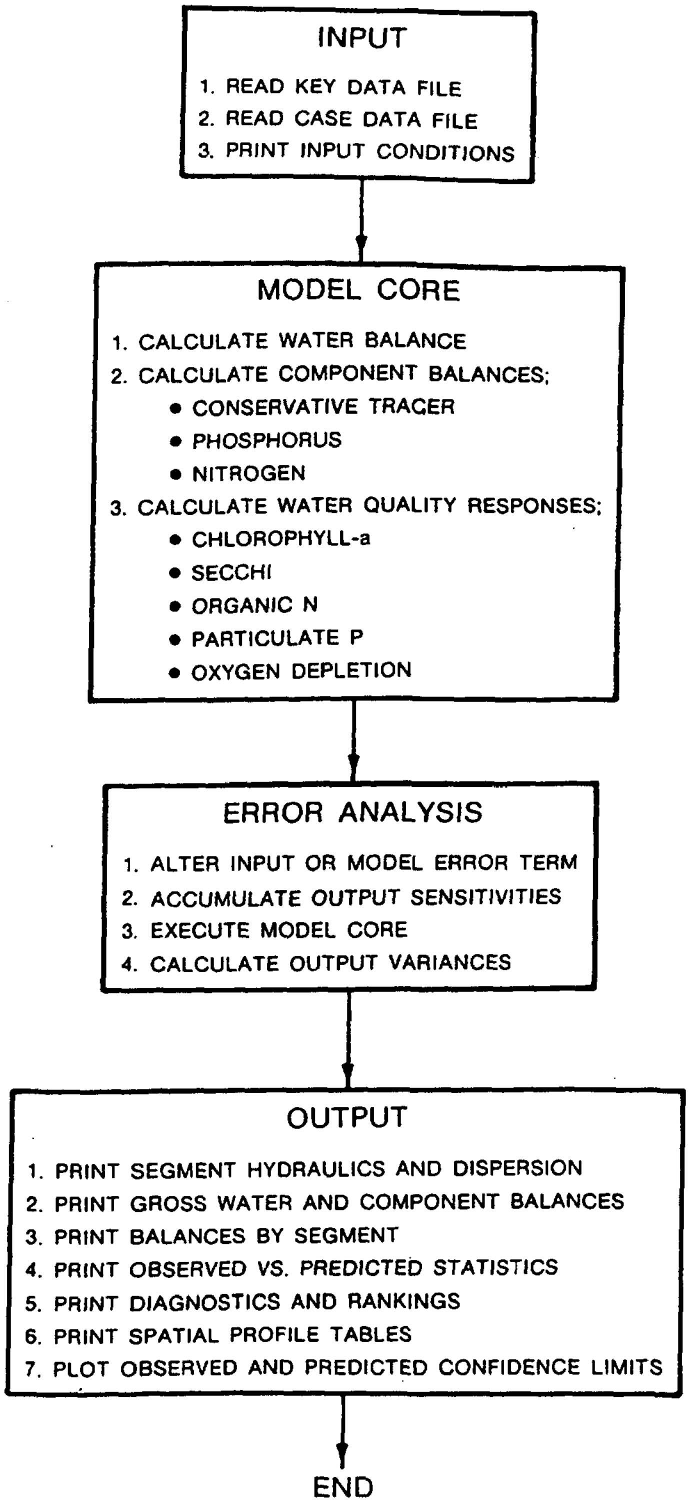


Figure IV-1. Schematic of BATHTUB calculations

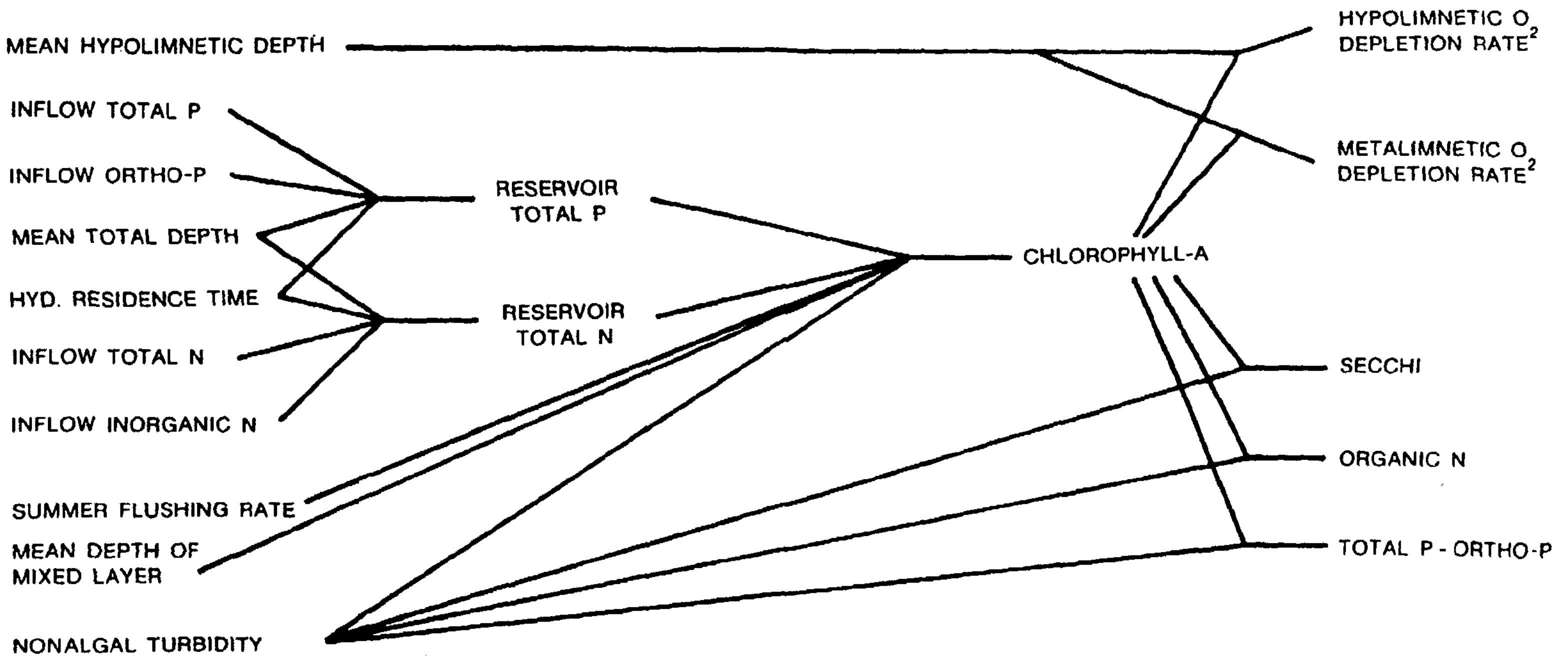


Figure IV-2. Control pathways in empirical eutrophication models developed for CE reservoir applications

Table IV-1

Symbol Definitions

a	= Nonalgal Turbidity (1/m) = 1/S - 0.025 B
As	= Surface Area of Segment (km^2)
Ac	= Cross-Sectional Area of Segment (km*m)
A1	= Intercept of Phosphorus Sedimentation Term
A2	= Exponent of Phosphorus Sedimentation Term
B1	= Intercept of Nitrogen Sedimentation Term
B2	= Exponent of Nitrogen Sedimentation Term
B	= Chlorophyll-a Concentration (mg/m^3)
Bm	= Reservoir Area-Weighted Mean Chlorophyll-a Concentration (mg/m^3)
Bp	= Phosphorus-Potential Chlorophyll-a Concentration (mg/m^3)
Bx	= Nutrient-Potential Chlorophyll-a Concentration (mg/m^3)
CB	= Calibration Factor for Chlorophyll-a (segment-specific)
CD	= Calibration Factor for Dispersion (segment-specific)
CN	= Calibration Factor for N Decay Rate (segment-specific)
CO	= Calibration Factor for Oxygen Depletion (segment-specific)
CP	= Calibration Factor for P Decay Rate (segment-specific)
CS	= Calibration Factor for Secchi Depth (segment-specific)
D	= Dispersion Rate (km^2/yr)
Dn	= Numeric Dispersion Rate (km^2/yr)
E	= Diffusive Exchange Rate between Adjacent Segments (hm^3/yr)
Fs	= Summer Flushing Rate = (Inflow-Evaporation)/Volume (yr^{-1})
Fin	= Tributary Inorganic N Load/Tributary Total N Load
Fot	= Tributary Ortho-P Load/Tributary Total P Load
FD	= Dispersion Calibration Factor (applied to all segments)
G	= Kinetic Factor Used in Chlorophyll-a Model
HODv	= Near-Dam Hypolimnetic Oxygen Depletion Rate (mg/m^3-day)
L	= Segment Length (km)
MODv	= Near-Dam Metalimnetic Oxygen Depletion Rate (mg/m^3-day)

(Continued)

Table IV-1 (Concluded)

N	=	Total Nitrogen Concentration (mg/m^3)
Ni	=	Inflow Total N Concentration (mg/m^3)
Nin	=	Inflow Inorganic N Concentration (mg/m^3)
Nia	=	Inflow Available N Concentration (mg/m^3)
Ninorg	=	Inorganic Nitrogen Concentration (mg/m^3)
Norg	=	Organic Nitrogen Concentration (mg/m^3)
P	=	Total Phosphorus Concentration (mg/m^3)
Pi	=	Inflow Total P Concentration (mg/m^3)
Pio	=	Inflow Ortho-P Concentration (mg/m^3)
Pia	=	Inflow Available P Concentration (mg/m^3)
Portho	=	Ortho-Phosphorus Concentration (mg/m^3)
PC-1	=	First Principal Component of Response Measurements
PC-2	=	Second Principal Component of Response Measurements
Q	=	Segment Total Outflow (hm^3/yr)
Qs	=	Surface Overflow Rate (m/yr)
S	=	Secchi Depth (m)
T	=	Hydraulic Residence Time (years)
U	=	Mean Advective Velocity (km/yr)
V	=	Total Volume (hm^3)
W	=	Mean Segment Width (km)
Wp	=	Total Phosphorus Loading (kg/yr)
Wn	=	Total Nitrogen Loading (kg/yr)
Xpn	=	Composite Nutrient Concentration (mg/m^3)
Z	=	Mean Total Depth (m)
Zx	=	Maximum Total Depth (m)
Zh	=	Mean Hypolimnetic Depth of Entire Reservoir (m)
Zmix	=	Mean Depth of Mixed Layer (m)

Table IV-2

BATHTUB Model Options

OPTION 1 - Conservative Substance Balance

Model 0: Do Not Compute (Set Predicted = Observed)
Model 1: Compute Mass Balances

OPTION 2 - Phosphorus Sedimentation

Unit P Sedimentation Rate (mg/m^3-yr) = $CP\ A1\ P^{A2}$
Solution for Mixed Segment:
Second-Order (A2 = 2)
$$P = [-1 + (1 + 4\ CP\ A1\ Pi\ T)^{0.5}]/(2\ CP\ A1\ T)$$
First-Order (A2 = 1)
$$P = Pi/(1 + CP\ A1\ T)$$

Model	A1	A2
0 - Do Not Compute (Set Predicted = Observed)	--	-
1 - Second-Order, Available P	0.17 Qs/(Qs + 13.3)	2
Qs = MAX(Z/T,4)		
Inflow Available P = 0.33 Pi + 1.93 Pio		
2 - Second-Order Decay Rate Function	$0.056\ Fot^{-1} Qs/(Qs + 13.3)$	
3 - Second-Order	0.10	2
4 - Canfield and Bachman (1981)	$0.11\ (Wp/V)^{0.59}$	1
5 - Vollenweider (1976)	$T^{-0.5}$	1
6 - Simple First-Order	1	1
7 - First-Order Settling	1/Z	1

(Continued)

Note: For purposes of computing effective rate coefficients (A1), Qs, Wp, Fot, T, and V are evaluated separately for each segment group based upon external loadings and segment hydraulics.

(Sheet 1 of 5)

TABLE F-1

RESERVOIR EUTROPHICATION MODELING WORKSHEET
FLAPNET1: MEDIAN STREAM P & CHL — SMALL SOUTHEASTERN IMPOUNDMENTS, GROWING SEASON, 1989-1991

VARIABLE	UNITS	COL	COM	CHAP	OL	UP	FALL	BRAN	BLA	ROCK	RUT	SHAM
PROBLEM TITLE ----------------------->		FLAP										
CASE LABELS ------------------------->		COL	COM	CHAP	OL	UP	FALL	BRAN	BLA	ROCK	RUT	SHAM
WATERSHED CHARACTERISTICS...												
Drainage Area	km2	77.1	49.47	117.53	8.96	6.76	286.4	49.5	14.8	5.1	49.7	14.6
Precipitation	m/yr	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22
Evaporation	m/yr	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04
Unit Runoff	m/yr	0.65	1.07	0.53	0.33	0.45	0.7	0.6	4.9	3.6	0.7	3.1
Stream Total P Conc.	ppb	40	70	45	30	40	25	30	75	370	35	50
Stream Ortho P Conc.	ppb	9.9	17.4	11.2	7.4	9.9	6.2	7.4	18.6	54.8	8.7	12.4
Atmospheric Total P Load	kg/km2-yr	30	30	30	30	30	30	30	30	30	30	30
Atmospheric Ortho P Load	kg/km2-yr	15	15	15	15	15	15	15	15	15	15	15
POINT SOURCE CHARACTERISTICS...												
Flow	hm3/yr	0	0	0	0	0	0	0	0	0	0	0
Total P Conc	ppb	0	0	0	0	0	0	0	0	0	0	0
Ortho P Conc	ppb	0	0	0	0	0	0	0	0	0	0	0
RESERVOIR CHARACTERISTICS...												
Surface Area	km2	0.19	1.79	1.05	0.28	0.13	2.43	0.18	1.05	0.44	1.15	0.28
Mean Depth	m	2	1.6	3.5	2.4	0.9	4	1.3	3.4	1.6	1.6	3.3
Non-Algal Turbidity	1/m	0.79	1.85	0.51	0.47	0.73	0.38	1.34	0.45	0.05	0.85	0.42
Mean Depth of Mixed Layer	m	1.16	1.15	1.96	1.69	1.07	1.41	1.41	1.41	1.41	1.41	1.41
Mean Depth of Hypolimnion	m	0.18	0.1	0.62	0.43	0.46	0.36	0.36	0.36	0.36	0.36	0.36
Observed Phosphorus	ppb	36.2	78.1	25	23.8	28	52.1	36.4	42.5	53.6	44.3	47.1
Observed Chl-a	ppb	10.7	30.8	9.4	8.6	8.15	24.84	10.55	22.7	66.75	29.37	21.36
Observed Secchi	meters	0.91	0.41	1.37	1.49	1.05	0.96	0.56	1.05	0.74	0.72	0.98
MODEL PARAMETERS...												
BATHTUB Total P Model Number	(1-8)	2	2	2	2	2	2	2	2	2	2	2
BATHTUB Total P Model Name		DECAY	FUDECAY	FUDECAY	FUDECAY	FUDECAY	FUDECAY	FUDECAY	FUDECAY	FUDECAY	FUDECAY	FUNC
BATHTUB Chl-a Model Number	(2,4,5)	5	5	5	5	5	5	5	5	5	5	5
BATHTUB Chl-a Model Name		JONES	JONES	JONES	JONES	JONES	JONES	JONES	JONES	JONES	JONES	JONES
Beta = 1/S vs. C Slope	m2/mg	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
P Decay Calibration (normally =1)		1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95
Chlorophyll-a Calib (normally = 1)		0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Chla Temporal Coef. of Var.		1.06	1.2	0.51	0.44	1.1	0.57	0.86	0.86	0.86	0.86	0.86
Chla Nuisance Criterion	ppb	25	25	25	25	25	25	25	25	25	25	25
WATER BALANCE...												
Precipitation Flow	hm3/yr	0.23	2.18	1.28	0.34	0.16	2.96	0.22	1.28	0.54	1.40	0.34
NonPoint Flow	hm3/yr	50.12	52.93	62.29	2.96	3.04	200.48	29.70	72.52	18.36	34.79	45.26
Point Flow	hm3/yr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Inflow	hm3/yr	50.35	55.12	63.57	3.30	3.20	203.44	29.92	73.80	18.90	36.19	45.60
Evaporation	hm3/yr	0.20	1.86	1.09	0.29	0.14	2.53	0.19	1.09	0.46	1.20	0.29
Outflow	hm3/yr	50.15	53.26	62.48	3.01	3.07	200.92	29.73	72.71	18.44	35.00	45.31

TABLE F-2

RESERVOIR EUTROPHICATION MODELING WORKSHEET
FLAPNET4:MAX MEAN STREAM P & CHL SMALL SOUTHEASTERN IMPOUNDMENTS, GROWING SEASON, 1989-1991

VARIABLE	UNITS	COL	COM	CHAP	OL	UP	FALL	BRAN	BLA	ROCK	RUT	SHAM
PROBLEM TITLE ----------------------->		FLAP										
CASE LABELS ----------------------->		COL	COM	CHAP	OL	UP	FALL	BRAN	BLA	ROCK	RUT	SHAM
WATERSHED CHARACTERISTICS...												
Drainage Area	km2	77.1	49.47	117.53	8.96	6.76	286.4	49.5	14.8	5.1	49.7	14.6
Precipitation	m/yr	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22
Evaporation	m/yr	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04
Unit Runoff	m/yr	0.65	1.07	0.53	0.33	0.45	0.7	0.6	4.9	3.6	0.7	3.1
Stream Total P Conc.	ppb	104	176	128	80	64	40	48	128	370	80	80
Stream Ortho P Conc.	ppb	21.4	36.3	26.4	16.5	13.2	8.2	9.9	26.4	54.8	16.5	16.5
Atmospheric Total P Load	kg/km2-yr	30	30	30	30	30	30	30	30	30	30	30
Atmospheric Ortho P Load	kg/km2-yr	15	15	15	15	15	15	15	15	15	15	15
POINT SOURCE CHARACTERISTICS...												
Flow	hm3/yr	0	0	0	0	0	0	0	0	0	0	0
Total P Conc	ppb	0	0	0	0	0	0	0	0	0	0	0
Ortho P Conc	ppb	0	0	0	0	0	0	0	0	0	0	0
RESERVOIR CHARACTERISTICS...												
Surface Area	km2	0.19	1.79	1.05	0.28	0.13	2.43	0.18	1.05	0.44	1.15	0.28
Mean Depth	m	2	1.6	3.5	2.4	0.9	4	1.3	3.4	1.6	1.6	3.3
Non-Algal Turbidity	1/m	0.79	1.85	0.51	0.47	0.73	0.38	1.34	0.45	0.05	0.85	0.42
Mean Depth of Mixed Layer	m	1.16	1.15	1.96	1.69	1.07	1.41	1.41	1.41	1.41	1.41	1.41
Mean Depth of Hypolimnion	m	0.18	0.1	0.62	0.43	0.46	0.36	0.36	0.36	0.36	0.36	0.36
Observed Phosphorus	ppb	36.2	78.1	25	23.8	28	52.1	36.4	42.5	53.6	44.3	47.1
Observed Chl-a	ppb	15.3	29.3	10.8	10	11.1	32.8	22.6	22.9	65.2	27.1	29.8
Observed Secchi	meters	0.91	0.41	1.37	1.49	1.05	0.96	0.56	1.05	0.74	0.72	0.98
MODEL PARAMETERS...												
BATHTUB Total P Model Number	(1-8)	2	2	2	2	2	2	2	2	2	2	2
BATHTUB Total P Model Name		DECAY FUDECAY	FUDECAY	FUDECAY	FUDECAY	FUDECAY	FUDECAY	FUDECAY	FUDECAY	FUDECAY	FUDECAY	FUNC
BATHTUB Chl-a Model Number	(2,4,5)	5	5	5	5	5	5	5	5	5	5	5
BATHTUB Chl-a Model Name		JONES	JONES	JONES	JONES	JONES	JONES	JONES	JONES	JONES	JONES	JONES
Beta = 1/S vs. C Slope	m2/mg	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
P Decay Calibration (normally =1)		4	4	4	4	4	4	4	4	4	4	4
Chlorophyll-a Calib (normally = 1)		0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Chla Temporal Coef. of Var.		1.06	1.2	0.51	0.44	1.1	0.57	0.86	0.86	0.86	0.86	0.86
Chla Nuisance Criterion	ppb	25	25	25	25	25	25	25	25	25	25	25

VARIABLE	UNITS	COL	COM	CHAP	OL	UP	FALL	BRAN	BLA	ROCK	RUT	SHAM
AVAILABLE P BALANCE...												
Precipitation Load	kg/yr	6	54	32	8	4	73	5	32	13	35	8
NonPoint Load	kg/yr	2005	3705	2803	89	122	5012	891	5439	6793	1218	2263
Point Load	kg/yr	0	0	0	0	0	0	0	0	0	0	0
Total Load	kg/yr	2010	3759	2835	97	126	5085	896	5471	6806	1252	2271
Sedimentation	kg/yr	206	1519	1058	42	31	1294	73	2375	4772	358	544
Outflow	kg/yr	1805	2240	1777	56	95	3791	823	3095	2034	894	1727
PREDICTION SUMMARY...												
P Retention Coefficient	-	0.102	0.404	0.373	0.428	0.244	0.254	0.082	0.434	0.701	0.286	0.240
Mean Phosphorus	ppb	36.0	42.1	28.4	18.5	31.0	18.9	27.7	42.6	110.3	25.5	38.1
Mean Chlorophyll-a	ppb	14.4	18.1	10.2	5.4	11.6	5.6	9.8	18.4	73.9	8.7	15.7
Algal Nuisance Frequency	%	14.7	19.2	2.2	0.0	10.5	0.2	6.5	21.6	79.7	4.9	16.5
Mean Secchi Depth	meters	0.87	0.43	1.31	1.65	0.98	1.92	0.63	1.10	0.53	0.94	1.23
Hypol. Oxygen Depletion A	mg/m2-d	910.5	1020.3	766.8	559.9	815.9	568.3	752.0	1029.3	2062.9	709.1	949.6
Hypol. Oxygen Depletion V	mg/m3-d	5058.4	10202.5	1236.7	1302.0	1773.6	1578.7	2088.9	2859.2	5730.2	1969.7	2637.8
Organic Nitrogen	ppb	544.6	708.3	428.1	316.5	475.5	313.5	481.8	610.2	1845.2	420.0	545.6
Non Ortho Phosphorus	ppb	40.2	71.9	26.2	16.7	33.8	14.9	45.1	39.3	128.6	31.6	33.7
Chl-a x Secchi	mg/m2	12.5	7.9	13.3	9.0	11.3	10.8	6.2	20.2	38.9	8.2	19.3
PC-1	-	2.60	2.99	2.29	1.94	2.46	1.90	2.57	2.63	3.62	2.36	2.51
PC-2	-	0.87	0.70	0.90	0.80	0.84	0.86	0.64	1.02	1.18	0.74	1.01
Carlson TSI P		55.9	58.1	52.5	46.3	53.7	46.6	52.1	58.3	72.0	50.9	56.7
Carlson TSI Chl-a		56.8	59.0	53.4	47.2	54.6	47.5	53.0	59.2	72.8	51.9	57.6
Carlson TSI Secchi		62.0	72.0	56.1	52.8	60.3	50.6	66.6	58.6	69.2	61.0	57.0
OBSERVED / PREDICTED RATIOS...												
Phosphorus		1.01	1.86	0.88	1.29	0.90	2.76	1.31	1.00	0.49	1.73	1.24
Chlorophyll-a		0.74	1.70	0.92	1.58	0.71	4.43	1.07	1.23	0.90	3.36	1.36
Secchi		1.05	0.94	1.05	0.90	1.07	0.50	0.89	0.96	1.40	0.77	0.80
OBSERVED / PREDICTED T-STATISTICS...												
Phosphorus		0.02	2.28	-0.47	0.93	-0.37	3.74	1.01	-0.01	-2.66	2.03	0.78
Chlorophyll-a		-1.09	1.96	-0.30	1.68	-1.29	5.48	0.26	0.77	-0.37	4.47	1.14
Secchi		0.17	-0.21	0.17	-0.38	0.25	-2.56	-0.44	-0.17	1.25	-0.97	-0.84

VARIABLE	UNITS	COL	COM	CHAP	OL	UP	FALL	BRAN	BLA	ROCK	RUT	SHAM
RESPONSE CALCULATIONS...												
Reservoir Volume	hm3	0.38	2.864	3.675	0.672	0.117	9.72	0.234	3.57	0.704	1.84	0.924
Residence Time	yrs	0.0076	0.0538	0.0588	0.2235	0.0382	0.0484	0.0079	0.0491	0.0382	0.0526	0.0204
Overflow Rate	m/yr	263.9	29.8	59.5	10.7	23.6	82.7	165.2	69.2	41.9	30.4	161.8
Total P Availability Factor		1	1	1	1	1	1	1	1	1	1	1
Ortho P Availability Factor		0	0	0	0	0	0	0	0	0	0	0
Inflow Ortho P/Total P		0.249	0.252	0.251	0.270	0.255	0.252	0.248	0.249	0.149	0.255	0.249
Inflow P Conc	ppb	40.1	70.6	45.4	32.3	41.0	25.3	30.1	75.2	369.1	35.8	50.1
P Reaction Rate - Mods 1 & 8		0.1	0.9	0.7	1.1	0.3	0.3	0.1	1.0	3.5	0.4	0.3
P Reaction Rate - Model 2		0.1	1.1	0.9	1.3	0.4	0.5	0.1	1.4	7.8	0.6	0.4
P Reaction Rate - Model 3		0.1	0.7	0.5	1.4	0.3	0.2	0.0	0.7	2.7	0.4	0.2
1-Rp Model 1 - Avail P		0.919	0.642	0.673	0.607	0.792	0.785	0.936	0.613	0.408	0.754	0.800
1-Rp Model 2 - Decay Rate		0.898	0.596	0.627	0.572	0.756	0.746	0.918	0.566	0.299	0.714	0.760
1-Rp Model 3 - 2nd Order Fixed		0.947	0.669	0.726	0.560	0.803	0.834	0.958	0.673	0.448	0.778	0.854
1-Rp Model 4 - Canfield & Bachman		0.796	0.556	0.611	0.526	0.665	0.706	0.820	0.556	0.352	0.654	0.695
1-Rp Model 5 - Vollenweider 1976		0.855	0.689	0.679	0.520	0.724	0.700	0.853	0.698	0.724	0.691	0.782
1-Rp Model 6 - First Order Decay		0.985	0.905	0.897	0.696	0.931	0.914	0.985	0.913	0.931	0.907	0.962
1-Rp Model 7 - First Order Setting		0.993	0.938	0.968	0.846	0.924	0.977	0.988	0.973	0.956	0.940	0.988
1-Rp Model 8 - 2nd Order Tp Only		0.919	0.642	0.673	0.607	0.792	0.785	0.936	0.613	0.408	0.754	0.800
1-Rp - Used		0.898	0.596	0.627	0.572	0.756	0.746	0.918	0.566	0.299	0.714	0.760
Reservoir P Conc	ppb	36.0	42.1	28.4	18.5	31.0	18.9	27.7	42.6	110.3	25.5	38.1
Gp		0.863	0.308	0.512	0.353	0.321	0.390	1.020	0.389	0.423	0.381	0.558
Bp	ppb	27.8	34.4	20.1	11.1	22.6	11.5	19.4	34.9	128.8	17.4	30.0
Chla vs. P, Turb, Flushing	2	9.8	16.4	12.0	8.3	14.7	8.5	5.2	21.1	50.7	10.7	16.3
Chla vs. P Linear	4	9.6	11.2	7.6	4.9	8.2	5.0	7.4	11.3	29.3	6.8	10.1
Chla vs. P 1.46	5	14.4	18.1	10.2	5.4	11.6	5.6	9.8	18.4	73.9	8.7	15.7
Chla Used	ppb	14.4	18.1	10.2	5.4	11.6	5.6	9.8	18.4	73.9	8.7	15.7
ml - Nuisance Freq Calc.		2.1	2.2	2.2	1.6	1.8	1.6	1.9	2.5	3.9	1.8	2.4
z		1.051	0.870	2.011	3.685	1.251	2.907	1.517	0.787	-0.830	1.653	0.974
v		0.230	0.273	0.053	0.000	0.182	0.006	0.126	0.293	0.283	0.102	0.248
w		0.741	0.775	0.599	0.449	0.706	0.508	0.665	0.793	0.784	0.645	0.755
x		0.147	0.192	0.022	0.000	0.105	0.002	0.065	0.216	0.203	0.049	0.165

VARIABLE	UNITS	COL	COM	CHAP	OL	UP	FALL	BRAN	BLA	ROCK	RUT	SHAM
ORTHO P LOADS...												
Precipitation	kg/yr	3	27	16	4	2	36	3	16	7	17	4
NonPoint	kg/yr	497	919	695	22	30	1243	220	1349	1006	302	561
Point	kg/yr	0	0	0	0	0	0	0	0	0	0	0
Total	kg/yr	500	946	711	26	32	1279	222	1365	1013	319	565
TOTAL P LOADS...												
Precipitation	kg/yr	6	54	32	8	4	73	5	32	13	35	8
NonPoint	kg/yr	2005	3705	2803	89	122	5012	891	5439	6793	1218	2263
Point	kg/yr	0	0	0	0	0	0	0	0	0	0	0
Total	kg/yr	2010	3759	2835	97	126	5085	896	5471	6806	1252	2271

VARIABLE	UNITS	COL	COM	CHAP	OL	UP	FALL	BRAN	BLA	ROCK	RUT	SHAM
RESPONSE CALCULATIONS...												
Reservoir Volume	hm3	0.38	2.864	3.675	0.672	0.117	9.72	0.234	3.57	0.704	1.84	0.924
Residence Time	yrs	0.0076	0.0538	0.0588	0.2235	0.0382	0.0484	0.0079	0.0491	0.0382	0.0526	0.0204
Overflow Rate	m/yr	263.9	29.8	59.5	10.7	23.6	82.7	165.2	69.2	41.9	30.4	161.8
Total P Availability Factor		1	1	1	1	1	1	1	1	1	1	1
Ortho P Availability Factor		0	0	0	0	0	0	0	0	0	0	0
Inflow Ortho P/Total P		0.249	0.252	0.251	0.270	0.255	0.252	0.248	0.249	0.149	0.255	0.249
Inflow P Conc	ppb	40.1	70.6	45.4	32.3	41.0	25.3	30.1	75.2	369.1	35.8	50.1
P Reaction Rate - Mods 1 & 8		0.1	0.9	0.7	1.1	0.3	0.3	0.1	1.0	3.5	0.4	0.3
P Reaction Rate - Model 2		0.1	1.1	0.9	1.3	0.4	0.5	0.1	1.4	7.8	0.6	0.4
P Reaction Rate - Model 3		0.1	0.7	0.5	1.4	0.3	0.2	0.0	0.7	2.7	0.4	0.2
1-Rp Model 1 - Avail P		0.919	0.642	0.673	0.607	0.792	0.785	0.936	0.613	0.408	0.754	0.800
1-Rp Model 2 - Decay Rate		0.898	0.596	0.627	0.572	0.756	0.746	0.918	0.566	0.299	0.714	0.760
1-Rp Model 3 - 2nd Order Fixed		0.947	0.669	0.726	0.560	0.803	0.834	0.958	0.673	0.448	0.778	0.854
1-Rp Model 4 - Canfield & Bachman		0.796	0.556	0.611	0.526	0.665	0.706	0.820	0.556	0.352	0.654	0.695
1-Rp Model 5 - Vollenweider 1976		0.855	0.689	0.679	0.520	0.724	0.700	0.853	0.698	0.724	0.691	0.782
1-Rp Model 6 - First Order Decay		0.985	0.905	0.897	0.696	0.931	0.914	0.985	0.913	0.931	0.907	0.962
1-Rp Model 7 - First Order Setting		0.993	0.938	0.968	0.846	0.924	0.977	0.988	0.973	0.956	0.940	0.988
1-Rp Model 8 - 2nd Order Tp Only		0.919	0.642	0.673	0.607	0.792	0.785	0.936	0.613	0.408	0.754	0.800
1-Rp - Used		0.898	0.596	0.627	0.572	0.756	0.746	0.918	0.566	0.299	0.714	0.760
Reservoir P Conc	ppb	36.0	42.1	28.4	18.5	31.0	18.9	27.7	42.6	110.3	25.5	38.1
Gp		0.863	0.308	0.512	0.353	0.321	0.390	1.020	0.389	0.423	0.381	0.558
Bp	ppb	27.8	34.4	20.1	11.1	22.6	11.5	19.4	34.9	128.8	17.4	30.0
Chla vs. P, Turb, Flushing	2	9.8	16.4	12.0	8.3	14.7	8.5	5.2	21.1	50.7	10.7	16.3
Chla vs. P Linear	4	9.6	11.2	7.6	4.9	8.2	5.0	7.4	11.3	29.3	6.8	10.1
Chla vs. P 1.46	5	14.4	18.1	10.2	5.4	11.6	5.6	9.8	18.4	73.9	8.7	15.7
Chla Used	ppb	14.4	18.1	10.2	5.4	11.6	5.6	9.8	18.4	73.9	8.7	15.7
ml - Nuisance Freq Calc.		2.1	2.2	2.2	1.6	1.8	1.6	1.9	2.5	3.9	1.8	2.4
z		1.051	0.870	2.011	3.685	1.251	2.907	1.517	0.787	-0.830	1.653	0.974
v		0.230	0.273	0.053	0.000	0.182	0.006	0.126	0.293	0.283	0.102	0.248
w		0.741	0.775	0.599	0.449	0.706	0.508	0.665	0.793	0.784	0.645	0.755
x		0.147	0.192	0.022	0.000	0.105	0.002	0.065	0.216	0.203	0.049	0.165

VARIABLE	UNITS	COL	COM	CHAP	OL	UP	FALL	BRAN	BLA	ROCK	RUT	SHAM
ORTHO P LOADS...												
Precipitation	kg/yr	3	27	16	4	2	36	3	16	7	17	4
NonPoint	kg/yr	497	919	695	22	30	1243	220	1349	1006	302	561
Point	kg/yr	0	0	0	0	0	0	0	0	0	0	0
Total	kg/yr	500	946	711	26	32	1279	222	1365	1013	319	565
TOTAL P LOADS...												
Precipitation	kg/yr	6	54	32	8	4	73	5	32	13	35	8
NonPoint	kg/yr	2005	3705	2803	89	122	5012	891	5439	6793	1218	2263
Point	kg/yr	0	0	0	0	0	0	0	0	0	0	0
Total	kg/yr	2010	3759	2835	97	126	5085	896	5471	6806	1252	2271

VARIABLE	UNITS	COL	COM	CHAP	OL	UP	FALL	BRAN	BLA	ROCK	RUT	SHAM
WATER BALANCE...												
Precipitation Flow	hm3/yr	0.23	2.18	1.28	0.34	0.16	2.96	0.22	1.28	0.54	1.40	0.34
NonPoint Flow	hm3/yr	50.12	52.93	62.29	2.96	3.04	200.48	29.70	72.52	18.36	34.79	45.26
Point Flow	hm3/yr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Inflow	hm3/yr	50.35	55.12	63.57	3.30	3.20	203.44	29.92	73.80	18.90	36.19	45.60
Evaporation	hm3/yr	0.20	1.86	1.09	0.29	0.14	2.53	0.19	1.09	0.46	1.20	0.29
Outflow	hm3/yr	50.15	53.26	62.48	3.01	3.07	200.92	29.73	72.71	18.44	35.00	45.31
AVAILABLE P BALANCE...												
Precipitation Load	kg/yr	6	54	32	8	4	73	5	32	13	35	8
NonPoint Load	kg/yr	5212	9316	7973	237	195	8019	1426	9283	6793	2783	3621
Point Load	kg/yr	0	0	0	0	0	0	0	0	0	0	0
Total Load	kg/yr	5218	9370	8005	245	199	8092	1431	9314	6806	2818	3629
Sedimentation	kg/yr	1812	6444	5446	174	93	3905	324	6147	5308	1615	1692
Outflow	kg/yr	3406	2926	2559	71	105	4187	1107	3167	1498	1202	1937
PREDICTION SUMMARY...												
P Retention Coefficient	-	0.347	0.688	0.680	0.710	0.470	0.483	0.227	0.660	0.780	0.573	0.466
Mean Phosphorus	ppb	67.9	54.9	41.0	23.6	34.3	20.8	37.2	43.6	81.2	34.4	42.8
Mean Chlorophyll-a	ppb	36.4	26.7	17.4	7.8	13.4	6.5	15.1	19.0	47.3	13.5	18.5
Algal Nuisance Frequency	%	43.0	29.3	16.7	0.2	13.3	0.4	15.5	22.7	62.2	12.5	21.8
Mean Secchi Depth	meters	0.59	0.40	1.06	1.50	0.94	1.84	0.56	1.08	0.81	0.84	1.13
Hypol. Oxygen Depletion A	mg/m2-d	1447.6	1240.1	1000.6	669.9	879.9	611.1	933.2	1046.7	1649.9	880.3	1032.7
Hypol. Oxygen Depletion V	mg/m3-d	8042.1	12401.1	1613.9	1558.0	1912.8	1697.6	2592.2	2907.4	4583.1	2445.2	2868.5
Organic Nitrogen	ppb	1045.9	905.1	591.7	370.0	518.4	333.5	602.6	624.5	1238.3	527.7	610.7
Non Ortho Phosphorus	ppb	79.4	87.3	38.9	20.9	37.1	16.4	54.6	40.4	81.2	40.0	38.8
Chl-a x Secchi	mg/m2	21.4	10.6	18.4	11.7	12.6	12.0	8.8	20.6	38.4	11.3	21.0
PC-1	-	3.20	3.20	2.61	2.12	2.54	1.97	2.79	2.65	3.22	2.58	2.62
PC-2	-	1.01	0.78	0.99	0.87	0.87	0.89	0.74	1.02	1.19	0.84	1.03
Carlson TSI P		65.0	62.0	57.7	49.8	55.2	48.0	56.3	58.6	67.6	55.2	58.3
Carlson TSI Chl-a		65.9	62.8	58.6	50.8	56.1	48.9	57.3	59.5	68.4	56.1	59.2
Carlson TSI Secchi		67.6	73.3	59.2	54.1	60.9	51.2	67.8	58.9	63.0	62.5	58.2
OBSERVED / PREDICTED RATIOS...												
Phosphorus		0.53	1.42	0.61	1.01	0.82	2.50	0.98	0.98	0.66	1.29	1.10
Chlorophyll-a		0.42	1.10	0.62	1.28	0.83	5.06	1.49	1.20	1.38	2.01	1.61
Secchi		1.55	1.03	1.29	0.99	1.12	0.52	0.96	0.97	0.91	0.85	0.87

VARIABLE	UNITS	COL	COM	CHAP	OL	UP	FALL	BRAN	BLA	ROCK	RUT	SHAM
OBSERVED / PREDICTED T-STATISTICS...												
Phosphorus		-2.32	1.29	-1.82	0.03	-0.75	3.37	-0.08	-0.09	-1.53	0.94	0.36
Chlorophyll-a		-3.19	0.34	-1.75	0.92	-0.70	5.97	1.48	0.68	1.18	2.58	1.75
Secchi		1.60	0.12	0.95	-0.03	0.41	-2.40	-0.14	-0.11	-0.34	-0.58	-0.53
RESPONSE CALCULATIONS...												
Reservoir Volume	hm3	0.38	2.864	3.675	0.672	0.117	9.72	0.234	3.57	0.704	1.84	0.924
Residence Time	yrs	0.0076	0.0538	0.0588	0.2235	0.0382	0.0484	0.0079	0.0491	0.0382	0.0526	0.0204
Overflow Rate	m/yr	263.9	29.8	59.5	10.7	23.6	82.7	165.2	69.2	41.9	30.4	161.8
Total P Availability Factor		1	1	1	1	1	1	1	1	1	1	1
Ortho P Availability Factor		0	0	0	0	0	0	0	0	0	0	0
Inflow Ortho P/Total P		0.206	0.208	0.207	0.216	0.212	0.209	0.207	0.207	0.149	0.210	0.207
Inflow P Conc	ppb	104.0	175.9	128.1	81.5	64.8	40.3	48.1	128.1	369.1	80.5	80.1
P Reaction Rate - Mods 1 & 8		0.5	4.4	4.2	5.5	1.1	1.1	0.2	3.6	7.3	2.0	1.0
P Reaction Rate - Model 2		0.8	7.1	6.7	8.4	1.7	1.8	0.4	5.7	16.1	3.1	1.6
P Reaction Rate - Model 3		0.3	3.8	3.0	7.3	1.0	0.8	0.2	2.5	5.6	1.7	0.7
1-Rp Model 1 - Avail P		0.729	0.375	0.384	0.344	0.606	0.595	0.834	0.407	0.308	0.500	0.614
1-Rp Model 2 - Decay Rate		0.653	0.312	0.320	0.290	0.530	0.517	0.773	0.340	0.220	0.427	0.534
1-Rp Model 3 - 2nd Order Fixed		0.799	0.399	0.434	0.308	0.620	0.660	0.882	0.462	0.342	0.528	0.689
1-Rp Model 4 - Canfield & Bachman		0.521	0.263	0.293	0.239	0.425	0.471	0.628	0.309	0.210	0.363	0.458
1-Rp Model 5 - Vollenweider 1976		0.742	0.519	0.508	0.346	0.561	0.532	0.738	0.530	0.561	0.522	0.636
1-Rp Model 6 - First Order Decay		0.971	0.823	0.810	0.528	0.868	0.838	0.969	0.836	0.868	0.826	0.925
1-Rp Model 7 - First Order Setting		0.985	0.881	0.937	0.729	0.855	0.954	0.976	0.945	0.913	0.884	0.976
1-Rp Model 8 - 2nd Order Tp Only		0.729	0.375	0.384	0.344	0.606	0.595	0.834	0.407	0.308	0.500	0.614
1-Rp - Used		0.653	0.312	0.320	0.290	0.530	0.517	0.773	0.340	0.220	0.427	0.534
Reservoir P Conc	ppb	67.9	54.9	41.0	23.6	34.3	20.8	37.2	43.6	81.2	34.4	42.8
Gp		0.863	0.308	0.512	0.353	0.321	0.390	1.020	0.389	0.423	0.381	0.558
Bp	ppb	66.3	49.6	33.1	15.6	26.0	13.1	29.1	36.1	84.7	26.1	35.2
Chla vs. P, Turb, Flushing	2	15.4	21.7	17.5	11.2	16.6	9.6	6.7	21.6	41.6	15.0	18.2
Chla vs. P Linear	4	18.1	14.6	10.9	6.3	9.1	5.5	9.9	11.6	21.6	9.1	11.4
Chla vs. P 1.46	5	36.4	26.7	17.4	7.8	13.4	6.5	15.1	19.0	47.3	13.5	18.5
Chla Used	ppb	36.4	26.7	17.4	7.8	13.4	6.5	15.1	19.0	47.3	13.5	18.5
ml - Nuisance Freq Calc.		3.0	2.6	2.7	2.0	2.0	1.7	2.3	2.6	3.5	2.2	2.5
z		0.176	0.545	0.968	2.870	1.114	2.653	1.015	0.748	-0.310	1.151	0.779
v		0.393	0.344	0.250	0.006	0.214	0.012	0.238	0.302	0.380	0.206	0.294
w		0.945	0.846	0.756	0.512	0.730	0.531	0.748	0.801	0.906	0.723	0.794
x		0.430	0.293	0.167	0.002	0.133	0.004	0.155	0.227	0.378	0.125	0.218

VARIABLE	UNITS	COL	COM	CHAP	OL	UP	PALL	BRAN	BLA	ROCK	RUT	SHAM
ORTHO P LOADS...												
Precipitation	kg/yr	3	27	16	4	2	36	3	16	7	17	4
NonPoint	kg/yr	1073	1919	1643	49	40	1652	294	1912	1006	573	746
Point	kg/yr	0	0	0	0	0	0	0	0	0	0	0
Total	kg/yr	1076	1946	1658	53	42	1688	296	1928	1013	591	750
TOTAL P LOADS...												
Precipitation	kg/yr	6	54	32	8	4	73	5	32	13	35	8
NonPoint	kg/yr	5212	9316	7973	237	195	8019	1426	9283	6793	2783	3621
Point	kg/yr	0	0	0	0	0	0	0	0	0	0	0
Total	kg/yr	5218	9370	8005	245	199	8092	1431	9314	6806	2818	3629

* U.S. GOVERNMENT PRINTING OFFICE 1993-736-277

8/94