Limnology of the Suwannee River, Florida

March 1985

Biology Section
Division of Environmental Programs

State of Florida
DEPARTMENT OF ENVIRONMENTAL REGULATION

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EXECUTIVE SUMMARY

Introduction

This report documents the results of a study of the Suwannee River made during 1982 and 1983. The goals of this study were to determine 1) the existing conditions of the river and 2) the effects of the major river dischargers with regard to present and future regulatory concerns. To accomplish these goals, eleven stations were established along the course of the river to be monitored for a wide array of parameters at monthly intervals. An additional 23 stations were established for further chemical monitoring: 17 in the Suwannee River and 6 in tributaries to the Suwannee.

Project Setting: Geology, Hydrology, and Man-Made Influences

The Suwannee River Basin drains about 28,500 km^2 of southern Georgia and north central Florida. From its origin in the Okefenokee Swamp, the river passes through two major physiographic districts as it flows to the Gulf of Mexico: the Northern Highlands District and the Gulf Coastal Lowlands District. In the Northern Highlands, the river channel is superimposed on thick Miocene deposits of the Hawthorn Formation which isolate the channel from the underlying Floridan Aquifer. Flow in this portion of the river is supplied primarily by surface runoff, supplemented by seepage from the surficial aquifer. Near White Springs, the Suwannee enters the Gulf Coastal Lowlands. Considerable portions of the lower Suwannee channel are cut into the Suwannee and Ocala Limestones, and the middle reaches of the river receive a great deal of flow from numerous springs of the Floridan Aquifer.

Relatively continuous hydrologic data are available for three stations along the course of the river for the period of study, as well as for stations on the Santa Fe and Withlacoochee Rivers. There were two high flow periods and two low flow periods at these stations during 1982. Flow during 1983 was dominated by spring flooding.

Population density throughout the Suwannee River Basin is comparatively low, and much of the land is devoted to agricultural uses. Non-point source pollution loading may be significant but is largely unmeasured. A number of substantial point sources of pollution exist: Goldkist Inc. (poultry processing) and Florida Power Corp. at Live Oak along the Suwannee itself; the Cities of Valdosta and Tifton, Ga. (sewage) and Owens-Illinois (pulp waste) discharging eventually through the Withlacoochee; and E. I. Dupont de Nemours (sand mining) and the City of Lake City (sewage) entering the Suwannee via the Santa Fe. In many ways, though, point-source pollution loading to the Suwannee tends to be dominated by the phosphate mining and

fertilizer manufacturing waste generated by Occidental Chemical Agricultural Products ("Oxy") and discharged through Hunter and Swift Creek.

Water Chemistry

Some of the more important or informative water quality parameters in the Suwannee River are shown in generalized form in Figure 1. This figure reflects approximate average conditions encountered as one progresses downstream from a point slightly south of the state line to Manatee Springs, where distinct tidal influence on current velocity may be noted. Most of the observed fluctuations in these water quality parameters can be attributed to three factors:

a) The origin of the river in a swamp, explaining, for example, the initial high color and low pH.

b) The substantial groundwater input through springs, resulting in depression of dissolved oxygen in the area most dominated by springs, gradual elevation of pH, and dilution of point source discharges.

c) The relatively massive contribution from Occidental Chemical Agricultural Products, causing the large increases at Swift Creek in a number of parameters, including phosphorus, soluble inorganic nitrogen, and fluoride.

The gradual increase in turbidity along the length of the river and the increase in soluble inorganic nitrogen below the Withlacoochee River are probably due to other pollution sources.

Physical-Chemical Relationships

Multivariate statistical techniques were used to investigate relationships among 18 physical-chemical variables, as well as relationships among the 11 main sampling stations based on these data. These techniques indicated the importance of four main factors in understanding the physical-chemical variations within the Suwannee River: a) basin physiography (accounting for 37% of the variation), b) discharges from Occidental (20-21% of the variation), c) seasonal factors such as temperature and water level (14% of the variation), and d) inputs primarily from the Withlacoochee River (7-8% of the variation).

The results from these statistical analyses correspond quite closely with those of the more subjective analysis detailed under "Water Chemistry", above, since "basin physiography" includes most of those factors related to swamp and spring discharges.

The dominant effects of physiography and of the discharges from Oxy were also apparent in a cluster analysis of the 11 stations. Stations in the two physiographic divisions were found to be quite distinct, and the station below Swift Creek was found to be separate from the other upper river stations.

Field Biology

Fish

Fish populations were examined at eight stations along the course of the Suwannee River. A tendency was observed for these populations to increase downstream, probably because of changes in the physical-chemical nature of the river, from acidic, highly colored, and with low nutrients in upstream areas to more neutral, less colored, and with high nutrients downstream. The presence of limestone bottoms and increased shoreline vegetation downstream, along with more stable flows, may also be important factors.

Significant differences in fish populations were observed between stations upstream and downstream of Swift Creek: a) greater sport fish populations below Swift Creek, b) increased biomass of invertebrate- and filter-feeding fishes below Swift Creek, and c) decreased biomass of predatory fishes below Swift Creek. These changes may be related to increases in macroinvertebrate production downstream of Swift Creek.

Two substantial reductions in the diversity of fish populations in the Suwannee River were observed: downstream of Hunter Creek and downstream of Swift Creek. Creel census techniques revealed that the river supports a high quality sport fishery with extremely high fisherman success rates.

Benthic Macroinvertebrates

The benthic macroinvertebrates, organisms such as worms, snails, and insect larvae, are quite important to the functioning of aquatic ecosystems and are sensitive indicators of environmental quality. On the basis of these organisms, the Suwannee River is generally in excellent condition.

Particularly in the upper river, abiotic factors such as pH and alkalinity had a great impact on the number of kinds of organisms which were observed. Also, especially in the upper river, recruitment of organisms from tributaries may play an important role in enriching the taxonomic composition of the Suwannee. The most notable geographic trend observed was a tendency for diversity to increase downstream. Analysis of seasonal changes indicated the general occurrence of population peaks during the summer and winter.

Multivariate statistical analyses based on the macroinvertebrate data indicated three distinct station groups: a) the most upstream station (above Hunter Creek), b) the next three stations (below Hunter Creek and above and below Swift Creek), and c) the remaining stations, from the area of the

Withlacoochee River downstream. This type of analysis also allowed the kinds of organisms found in the river to be divided into four species groups.

Impacts on the Suwannee River due to tributary discharges are believed to have been partially masked by pH and alkalinity effects as well as by the introduction of organisms drifting out of tributaries to the Suwannee. The most notable effects observed which may have been due to point source discharges through tributary streams were: a) taxa and numbers of organisms increased downstream of Hunter Creek, b) taxa decreased at the point of confluence with Swift Creek and macroinvertebrate abundance increased, whereas the various measures of diversity uniformly showed small decreases, and c) both taxa and numbers of organisms decreased below the Withlacoochee River.

Periphyton

Algae which coat substrates are termed periphyton. These generally microscopic plants are, in flowing systems, usually much more important than those algae which float in the water column - the plankton. Periphyton, in the Suwannee River, form an important base of the aquatic food web, and were found to be a diverse and healthy component of the ecosystem.

Several types of variation were noted in the periphyton community along the length of the river. Measurements of diversity were both lower and more variable in the upper river (from Swift Creek upstream) than in the lower river (from the area of the Withlacoochee downstream). Quantities of periphyton increased downstream. The organisms making up the periphyton collected on the glass samplers used in this study were largely diatoms. Multivariate statistical analysis of periphyton data clearly separated the stations into two groups, the upper river stations and the lower river stations. Several groups of species were found to have distinctive distributions within the river using this same type of analysis.

Observed effects which may be attributable to tributary discharges were: a) decreased chlorophyll a and increased diversity and number of taxa downstream of the Withlacoochee River, b) a tendency for individual measurements of diversity to decrease at Swift Creek while pooled measurements tend to increase implying increased biological variation with time below Swift Creek, and c) variation in diversity below Hunter Creek of the same type as noted below Swift Creek as well as a decreased number of taxa below Hunter Creek.

Algal Growth Potential, Limiting Nutrients, and Toxicity

The algal growth potential test measures the maximum amount of growth that could be expected to occur in a sample of water in which the only growth-limiting characteristics are those involving the natural chemical constituents of the water. The sample is first sterilized and then innoculated with a test

organism, the alga Selenastrum capricornutum. The algal culture is then allowed to grow for a fixed length of time and the resultant growth is measured. Algal growth potential was found to increase significantly downstream throughout the length of the river. The largest increase was at Swift Creek, due to the input of nutrients at that point. Dilution effects led to lower nutrient concentrations during periods of high flow, and algal growth potential was thus found to be strongly inversely correlated with stage height.

The nutrients which are limiting to algal growth are determined in much the same way as algal growth potential. Concentrations of various nutrient substances are, however, increased in different subsamples in order to determine which nutrient (or combination of nutrients) is responsible for limiting algal growth. Stations along the upper Suwannee, downstream to Swift Creek, were often found to exhibit poor growth responses to nutrient additions, reflecting the unusual water chemistry of the Okefenokee headwaters (extremely soft and acidic), but were generally weakly nitrogen limited. The middle reach of the river was found to be strongly nitrogen limited in most cases, due almost certainly to sizeable pollution generated phosphorus loading. Both nitrogen and phosphorus limiting conditions were found in the lower river.

The chronic bioassays of Oxy's Swift Creek and mine process water discharges, using Suwannee River diluent, tended to exhibit a characteristic effect upon the hatch rate, growth, and survival of Notropis leedsi. This effect was statistically significant for hatch rate in assays of Swift Creek water and was highly significant for hatch rate in assays of mine process water. Plots of the effect generally demonstrated a "saddle" shaped curve denoting an effect in the lower concentrations. The lack of this characteristic shape in assays using well water rather than Suwannee River water for diluent suggested that the toxicity of the effluent occurs at low pH and/or low ionic strength. This "saddle" curve is also evident in results from assays for Heterandria formosa survival and growth, though not statistically significant. Assays using Daphnia pulex were inconclusive due to difficulties controlling nutritional variables. In assays using Suwannee River water for diluent, rather than well water, there are pronounced pH effects which make analyses of plots and data difficult. Assay treatments taking place at a pH above approximately 6.5 - 7.0 showed no effects. No specific pathological effects or deformities were found to be linked to effluent concentration.

In some lower concentration treatments, Oxy's effluents had a detrimental effect upon the bioassay test animals. It is logical, in view of the bioassay data, and the upper Suwannee River's chemistry, to surmise that the effects observed in the laboratory (reduced hatching, and possible reduced survival and growth, in the lower concentration treatments at low pH) are the result of some component(s) of the effluents that are toxic at low pH and/or in low ionic strength water. This inverse relationship between pH and toxicity is not uncommon. However,

it is not possible, with present data, to extrapolate with any certainty the toxicity effects demonstrated in these laboratory data to the existence of these effects in the Suwannee River.

Conclusions

The following are believed to be the most substantive findings of this study:

1) Water chemistry in the Suwannee River is largely controlled by input from the Okefenokee Swamp, by upper and mid-river groundwater input, and by discharges from Occidental.

2) Biologically, the upper river is quite different from the lower river. Generally, numbers of organisms, numbers of kinds of organisms, and species diversity show increases downstream. These changes are believed to be primarly due to changes in water chemistry, especially pH.

3) Directly measured impacts of dischargers upon the biota of the river were small, although large changes in algal growth potential are attributed to the Occidental discharge at Swift Creek.

4) Undiluted discharges from Occidental to Swift Creek (as sampled at NPDES point 001) as well as undiluted mine process water of the type discharged to Hunter Creek were never found to be toxic, apparently due to the relatively high pH of the effluent. Chronic toxicity (as measured by statistically significant reductions in hatching sucess of fish eggs) was sometimes found when effluents were mixed with high proportions of the acidic and low ionic strength upper Suwannee River water. Field effects cannot be accurately predicted based on these laboratory measurements without further ecological investigation.

5) Benthic macroinvertebrate organisms in the Suwannee River were found to be in generally excellent condition. Impacts on these organisms in the Suwannee River due to tributary discharges are believed to have been partially masked by pH and alkalinity effects as well as by the introduction of organisms drifting out of tributaries to the Suwannee. The most notable effects observed which may have been due to point source discharges through tributary streams were: a) taxa and numbers of organisms increased downstream of Hunter Creek, b) taxa decreased at the point of confluence with Swift Creek and macroinvertebrate abundance increased, whereas the various measures of diversity uniformly showed small decreases, and c) both taxa and numbers of organisms decreased below the Withlacoochee River.

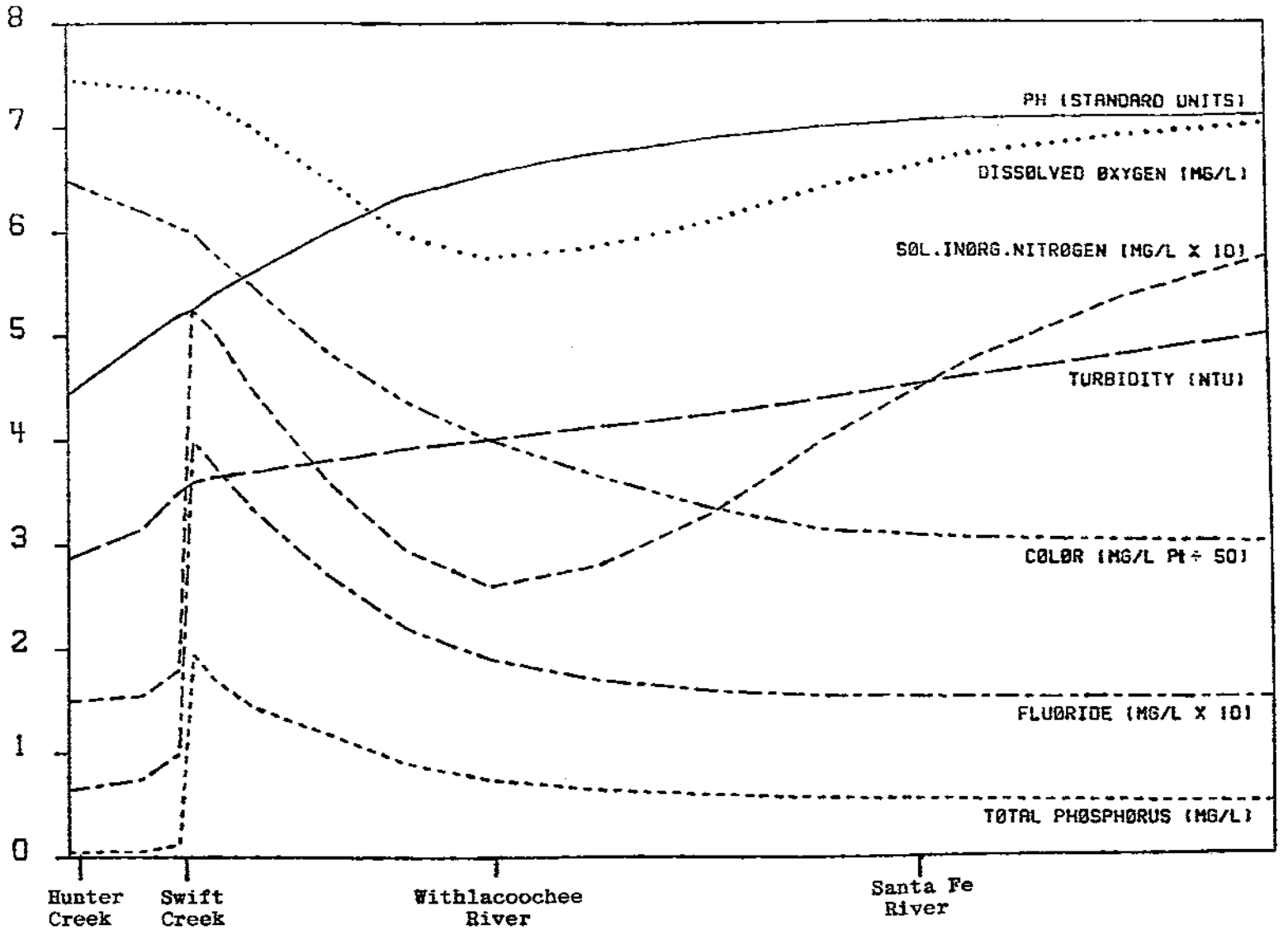

FIGURE 1. GENERALIZED WATER QUALITY ALONG STUDIED LENGTH OF THE SUWANNEE RIVER

INTRODUCTION

The Suwannee River has been designated an Outstanding Florida Water (OFW) according to the water quality standards of the State of Florida (Chapter 17-3.041 FAC). This special designation has been provided because of the river's exceptional ecological and recreational significance. OFW's are to be protected through the permitting process in which any stationary installation will not be allowed to significantly degrade water quality (Chapter 17-4.242 FAC). A court settlement between the Florida Department of Environmental Regulation and Occidental Chemical Company (now Occidental Chemical Agricultural Products, abbreviated Oxy) (Case Number 79-72, Hamilton County, Florida) stipulated that $200,000 will be used for "...certain biological studies of the Suwannee River in conjunction with the Outstanding Florida Waters Program...". The intent of this agreement was to obtain data on the biological water quality of the Suwannee River related to the assessment of significant degradation.

The Biology Section of the Department of Environmental Regulation has conducted a biological and water quality assessment through a two year study of the Suwannee River. The goals for this study were to: 1) determine the existing conditions in the river by obtaining appropriate biological data, and 2) determine the biological effects of the major river dischargers with regard to present and future regulatory concerns.

To accomplish the goals of this study, our research involved characterization of the fish, macroinvertebrate and periphytic algal communities, as well as determination of the algal growth potential of the river system from State Road 6 near the Florida - Georgia border to Manatee Springs. Stations were established so that effects from Oxy's discharge and several tributaries could also be determined (Table 1). The second area of investigation was to determine the sensitivity of aquatic organisms to Oxy's effluent through chronic bioassay testing.

General Methods

Biological sample collections began in February, 1982, and were made every four weeks at eleven stations (Fig. 2, Table 1). The biological samples consisted of: 1) subsurface water grab samples for algal growth potential and limiting nutrient tests; 2) retrieval of periphyton samples that were incubated for four weeks; 3) retrieval of macroinvertebrate artificial substrate samplers that were also incubated for four weeks. Fish populations were sampled by the Florida Game and Freshwater Fish Commission at eight stations coincident with DER stations once or twice during the study. In addition to the biological samples, a

subsurface water grab sample was taken at each station for chemical analysis by DER's Jacksonville laboratory. Additional water chemistry samples were taken at 23 stations by DER's Jacksonville Laboratory.

The remainder of our report will address details of the individual portions of the biological study, i.e., fish, macroinvertebrates, periphyton, algal growth potential, chronic bioassays, and water chemistry, as well as a summary of general information on the Suwannee River watershed.

Station Descriptions

These station descriptions are qualitative in nature and are included to familiarize the reader with important geographical and/or physical aspects (e.g., substrate type) that characterize each sampling location. Locations and decriptions of the 23 Jacksonville stations are presented in the chapter on water chemistry.

Stations 1 and 2, are located at 14.0 and 14.5 river miles from the Florida - Georgia state line, respectively. Here, the river has very steep limestone banks, with a scoured limestone bottom which is the result of the swift current at this point. The river is narrow here with no spring inputs. However, some pockets of deposited sand and many submerged logs may be observed. The floodplain vegetation is dominated by oak, cypress and palmetto. Hunter Creek empties into the Suwannee midway between these two stations.

Stations 3 and 4 are located at river mile 40.9 and 41.8, respectively. Station 4 is immediately upstream of the Interstate 75 bridge. The flow is still swift, the banks are steep, although the river is slightly wider. The substrate and banks are composed of limestone rock with large amounts of deposited sand. Two second magnitude springs (average flow 10 cfs - 100 cfs) enter the Suwannee some miles upstream of Station 3, while Swift Creek enters the river midway between Stations 3 and 4. Floodplain vegetation here consists of oak, cypress, willow, and palmetto.

Station 5 at 79.1 river miles is 1.6km upstream of the Withlacoochee River. Two first magnitude springs (average discharge 100 cfs), one second magnitude spring and 1 third magnitude spring (flow < 10 cfs) discharge into the river some miles upstream of this station. The river is wider here and the flow is moderate compared to the other upstream stations. The banks are still steep, though composed mainly of sand and some limestone outcroppings. The substrate is sand/limestone with an abundance of live roots from trees along the banks. Oak, cypress, willow, and beech are prevalent along the banks and floodplain and there is a surprising amount of beaver activity in the vicinity.

Station 6 is 1 km downstream of the Withlacoochee River at river mile 80.7. The flow, basin morphology, and dominant vegetation are similar to Station 5, although the banks are not as steep or quite as high. The sediment consists of sand

overlain with organic detritus.

Stations 7, 8, and 9 are located at river miles 93.0 (near Dowling Park), 108.1 (near Luraville), and 128.8 (near Branford), respectively. The current is moderate since the river channel gradually widens. The substrate is composed of sand with organic debris and numerous tree roots. Station 7 has steep limestone banks and receives discharge from several springs, including 1 first, 2 second, and 1 third magnitude. At Station 8, the banks slope gently, but at Station 9 the banks are again fairly steep. Station 8 is downstream of four springs (3 second and 1 third magnitude). Between Stations 8 and 9, twelve springs discharge into the Suwannee, including 1 first, 2 second, and 9 third magnitude springs. Vegetation along the banks and floodplain is similar to that found at Station 6, although there is considerably more underbrush and shrub growth at Stations 7, 8, and 9.

Station 10, near Rock Bluff, is found at river mile 150.8. The current is slower, the banks are wider, lower, and moderately sloped. The substrate consists of clay, fine sand, organic detritus, and numerous tree roots and cypress knees. Ten springs enter the river several miles upstream of this station (2 first, 7 second, and 1 third magnitude).

The final sampling point is Station 11 at river mile 183.0, located adjacent to Manatee Springs State Park. This station exhibits the slowest flow, and the widest, lowest banks. Although this area contains only freshwater, tidal influences can have a decided effect on current velocity. Sediment at this station consists of clay and fine sand with a heavy layer of organic detritus. A marshy floodplain which contains cypress, willow, and beech trees is contiguous with the river bank. Twelve springs discharge between Stations 10 and 11. Of these, 2 are first magnitude, 5 are second magnitude, and 5 are third magnitude springs. Emergent aquatic vegetation, such as water lillies, is prevalent along the littoral zone.

Based on these described factors, three distinct parts of the Suwannee River can be established. Stations 1 - 4 represent the narrow upper river where there is fast current, high steep banks, a fairly scoured bottom, and little or no spring input. Stations 5 - 10 represent the middle river and have wider, gently sloping banks, relatively slower current velocities, an increase in sandy, organic detritus rich sediment, and are affected by enormous quantities of spring water. Station 11 characterizes the lower river with low, wide banks, slow flow, mucky bottom, and water quality that integrates the effects of all the major tributaries and discharges from the entire drainage basin.

Personnel

The following individuals were involved in this report, with the specified areas of concentration. Unless specified, all are or were associated with the Florida Department of Environmental Regulation, Biology Section.

Craig W. Dye:	field and laboratory direction, benthic macroinvertebrates, editing
J. Marshall Faircloth:	algal assays
Russel B. Frydenborg:	benthic macroinvertebrates
Randy Kautz:	fishery resources (Florida Game and Fresh Water Fish Commission)
Jerry Krummrich:	fishery resources (Florida Game and Fresh Water Fish Commission)
Manitia L. Moultrie:	water chemistry
Landon T. Ross:	planning, editing
Harry M. Savage:	hydrology, geology
M. Ellen Slater:	algal assays
Victoria K. Tauxe:	periphyton
A. Robert Thompson:	periphyton, diatom taxonomy
Sherri L. Thorpe:	manuscript preparation
Loretta E. Wolfe:	statistics, programing
Steven H. Wolfe:	toxicity bioassays

We also wish to acknowledge the contributions of:

William C. Burnett	(radiochemistry - Florida State Univ.)
John Couch	(fish pathology - U.S. Env. Prot. Agency, Gulf Breeze)
Suchint Deetae	(radiochemistry - Florida State Univ.)
Carter Gilbert	(fish taxonomy - Florida State Museum)
Charles T. Love	(chemical data - Florida Dept. Env. Reg., Northeast Dist.)
Dennis T. Murrin	(chemical data - Florida Dept. Env. Reg., Northeast Dist.)
Ruth O. Reese	(fish histology - Florida Dept. Nat. Res., St. Petersburg Marine Lab.)

Finally, the following biologists with the Florida Department of Environmental Regulation provided useful assistance in the identification of benthic invertebrates: Jerrell J. Daigle, Eric S. Pluchino, and Donald H. Ray.

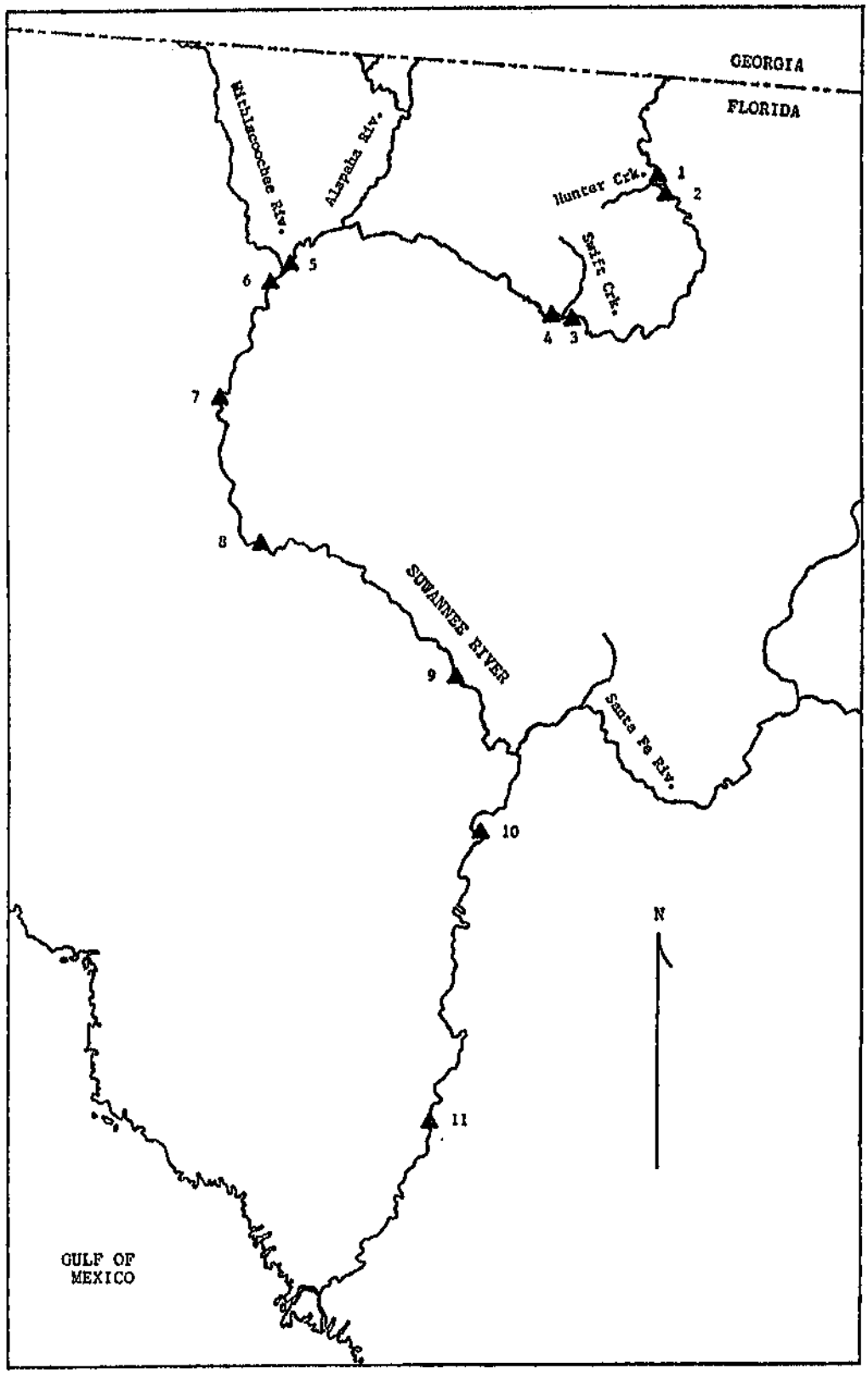

FIGURE 2. LOCATION OF SAMPLING STATIONS

TABLE 1

Suwannee River Study

Biological Sampling Stations

Station 1 - 400m upstream of Hunter Creek
Station 2 - 400m downstream of Hunter Creek
Station 3 - 350m upstream of Swift Creek
Station 4 - 300m downstream of Swift Creek, above the Interstate Hwy. 75 bridge.
Station 5 - 1.6km upstream of the Withlacoochee River
Station 6 - 1km downstream of the Withlacoochee River; approximately 300m upstream of the Florida Power Corp's Suwannee River Plant intake canal
Station 7 - 3km upstream of the Fla. Hwy. 250 bridge; near Dowling Park
Station 8 - 2.5km upstream of the Fla. Hwy. 51 bridge; near Luraville
Station 9 - 5km upstream of U.S. Hwy. 27 bridge; near Branford
Station 10 - 700m upstream of the Fla. Hwy. 340 bridge; near Rock Bluff
Station 11 - 6km downstream of New Pine Landing; adjacent to Manatee Springs State Park

POPULATION AND POINT SOURCE DISCHARGERS WITHIN THE SUWANNEE BASIN

Population and Development

The Suwannee River and its tributaries are relatively unspoiled at the present time due to the generally undeveloped nature of the basin. In the Floridan portion of the basin, much of the land is forested and managed for paper pulp production, while agricultural land use becomes increasingly dominant in the Withlacoochee and Alapaha River Basins of Georgia. The Suwannee Basin is not heavily industrialized and most point sources are associated with domestic sewage treatment plants, paper pulp mills, mining activities, and various small businesses (Fig. 3).

The population of the Georgian portion of the Suwannee Basin has shown a general upward trend from 1950-1980 except for a flat period during the 1960's (Table 2). The majority of the Georgian populace reside in the Withlacoochee and Alapaha Basins as is evident from the abundance of surfacewater dischargers in these areas (Fig. 3). While the population in these Basins is projected to increase (Table 2), large increases in migration rates are not expected as development is projected to center around agricultural and rural lines (U.S. Army Corps of Engineers 1983).

Historically, the Floridan portion of the Suwannee Basin has been sparsely populated. However, since 1960 the population of this eleven county area has increased at rates much greater than in the Georgian portion of the Basin (Table 3). The greatest population increases between 1970-1980 occurred in the southern and eastern counties (U.S. Army Corps of Engineers 1983) due largely to the proximity of urban centers such as Gainesville and Jacksonville. Levy and Gilchrist counties in the lower basin experienced a 55-69.99% population increase between 1970-1980 (Fig. 4) due in part to an influx of people desiring river-front vacation homes. The population of Alachua, Dixie, Suwannee, and Columbia counties increased 40-54.99% during this same period (University of Florida 1981). Only Madison and Hamilton Counties, which are in the northern portion of the basin in Florida, had population increases of less than 20% between 1970-1980 (Fig. 4).

Point Source Dischargers

Selected surfacewater point source dischargers within the Suwannee River Basin and lower Withlacoochee and Alapaha Basins are mapped in Fig. 3 and listed in Table 4 and Table 5 based on data obtained from FDER's NPDES section. The distribution of

point source dischargers corresponds to previous population levels and land use patterns. The upper Suwannee Basin in Georgia or the Okefenokee Swamp Basin, and the lower Suwannee Basin, which have historically been sparsely populated and forested, have few dischargers. Conversely, the Withlacoochee and Alapaha Basins in Georgia, which have historically been major agricultural areas, have the highest density of dischargers (Fig. 3).

Twenty substantial point sources of domestic and industrial wastewater discharge to the Suwannee River or to one of its three main tributaries (Alapaha River, Withlacoochee River and Santa Fe River). Domestic wastewater discharged from sewage treatment plants is common throughout the basin with effluent constituents typical of sewage: nitrogen and phosphorus compounds, suspended solids, chlorine, and coliform bacteria. Industrial wastewater constituents typically vary greatly depending on the industrial operation. A brief description of these facilities follows, including the maximum design flow, effluent constituents of the industrial wastewaters and the receiving body of water for each facility. This information is also summarized in Table 5.

Discharges to the Suwannee River

1. The City of White Springs operates a 0.15 MGD design flow sewage treatment plant in Hamilton County. The facility treats domestic waste from a population of approximately 800. Wastewater passes through contact stabilization, a polishing pond and chlorination before discharge to a ditch which flows eastward to the Suwannee River.

2. Occidental Chemical Agricultural Products Inc. (Oxy) produces phosphatic fertilizers, superphosphoric acid, and associated by-products at two chemical and mining complexes in southwestern Hamilton County near the town of White Springs (No. 4, Fig. 3). The Occidental facility includes two mines, two beneficiation plants, and two fertilizer and phosphoric acid processing plants. The mining and recovery of phosphate includes removal of phosphate ore from the ground by draglines and transport of the ore to beneficiation plants where clays and sand are removed (U.S. EPA 1978). The remaining phosphate concentrate, approximately 20% of the ore (U.S. EPA 1978), is stored and graded. Wet phosphate rock is carried to the processing plants by conveyor. The processing plants produce concentrated phosphoric acid, and a gypsum by-product which is stored in an impoundment serving as both a storage area and as an evaporation pond (U.S. EPA 1978). The phosphoric acid concentrate is further processed to produce various granular fertilizers, animal feed supplements, and superphosphoric acid. The processing plants produce acidic process wastewaters that undergo a neutralization treatment with limestone and lime in settling ponds. After the neutralization and settling treatment, process wastewater is discharged to Swift Creek (U.S. EPA 1978). Nonprocess water, consisting of vacuum pump seal water, filter vacuum scrubber water, evaporator condensate and filter skirt sprays, and rainfall run-off is discharged to Swift and Hunter

Creeks (U.S. EPA 1978). The Suwannee River Mine and Chemical Complex discharges 4.32 MGD, while the Swift Creek Mine and Chemical Complex discharges 1.40 MGD (Fig. 5). Effluent from Oxy contains, but is not limited to, the following: phosphorus, fluoride, sulfate, nitrate, ammonia, radium, and suspended solids (FDER 1980).

3. GoldKist Incorporated, located in Live Oak, Florida, processes live poultry into fresh and frozen poultry products, and processes poultry by-products into protein meal. Wastewater treatment includes screening, primary clarification, extended aeration activated sludge, secondary clarification, final polishing pond, and disinfection. Maximum raw material usage is approximately 130,000 birds/day. The treated effluent contains permitted quantities of BOD_5, suspended solids, ammonia and organic nitrogen.

4. Florida Power operates three oil and gas fueled power generating units 14 miles west of Live Oak Florida. The plant's condenser cooling system obtains approximately 176 MGD of cooling water from the Suwannee River and returns the same amount via a discharge canal to the river. Effluent in the form of heated water is the only major constituent discharged into the river.

Discharges to the Alapha River

The Alapaha River originates in the coastal plain of Georgia and flows south for 125 miles to its confluence with the Suwannee River in southern Hamilton County. The Alapaha River contributes about 15% of the average flow in this area. Only three significant domestic surface water dischargers are found in the Alapaha basin.

1. The City of Alapaha, Georgia, sewage treatment plant operates a 0.10 MGD design flow facility which treats the domestic waste from a population of approximately 700. Effluent is discharged directly to the Alapaha River.

2. The City of Lakeland, Georgia, operates a 0.20 MGD design flow sewage treatment plant in Lanier County. This facility serves a population of approximately 2600. Effluent is discharged to the Big Creek tributary of the Alapaha River.

3. The City of Jasper, Florida, operates a 0.40 MGD design flow sewage treatment plant in Hamilton County. The facility serves a population of approximately 900 and discharges wastewater through Bell Creek which drains into the Alapaha River.

Discharges to the Withlacoochee River

The Withlacoochee River headwaters are located near Tifton, Georgia from which the river flows about 86 miles to the Suwannee River, contributing 24% of the average flow. The New River converges with Withlacoochee near Nashville, Georgia. The municipal sewage and industrial waste from Tifton enter the upper reaches of the New River.

1. The City of Tifton sewage treatment plant located in Tifton, Georgia, treats domestic and industrial waste from a population of approximately 22,500. Wastewater treatment consist

of grit removal, biological treatment, clarification, chlorination and post aeration. Treated effluent is discharged directly to the New River at a maximum flow of 8.0 MGD.

2. The City of Lenox sewage treatment plant treats sewage and wastewater from a population of 900. This facility is located in Cook County, Georgia, and also discharges into the Little River. Effluent is discharged at a maximum design flow of 0.17 MGD.

3. Tift Oil Company, a petroluem product distributor, operates a 0.8 MGD facility for on-site domestic wastewater. Effluent is discharged to the Middle Creek tributary of the New River in Georgia. The waste constituents are suspended solids and fecal coliform bacteria.

4. The City of Nashville sewage treatment plant located in Nashville, Georgia, operates a 0.63 MGD design flow facility. Discharge is into the Reedy Creek tributary of the Withlacoochee River, just before it joins the New River.

5. The City of Ray City, operates a 0.10 MGD design flow sewage treatment plant in Cook County, Georgia. This facility serves a population of approximately 700. Wastewater discharge is to Cat Creek, a tributary of the Withlacoochee River.

6. The City of Valdosta sewage treatment plant is located in Lowndes County, Georgia. The facility serves a population of 30,000 and has a maximum design flow of 4.0 MGD. The wastewater treatment process consists of screening, grit removal, and primary clarification. The filtered influent is then aerated, chlorinated, and discharged to the Withlacoochee River.

7. Owens Illinois, Incorporated, Forest Product Division is a paper mill which produces about 875 tons per day of unbleached Kraft pulp and liner board at Clyattville, Georgia, near Valdosta. The facility's wastewater treatment system consists of a settling basin followed by seven lagoons operated in series. Total flow capacity of the system is 12.7 MGD. Wastes undergo screening, clarification, and skimming. Discharge from the lagoons goes to Bevel Creek and then to Jumping Gulley Creek. Jumping Gulley Creek crosses the Georgia-Florida line and continues about 0.5 miles to discharge into the Withlacoochee River. Effluent constituents include ammonia, cadmium, cyanide, zinc, and suspended solids.

Discharges to the Santa Fe River

The Santa Fe River is the third major tributary of the Suwannee River. It joins the Suwannee at Wilcox, Florida, about 66 miles north of the Gulf of Mexico. The New River converges with the Santa Fe River near Starke, Florida, and forms the boundary between Union and Bradford Counties. It flows 30 miles through agricultural areas, forest, and wetlands before draining into the Santa Fe River.

1. The Florida State Prison Sewage Treatment Plant in Starke, Florida, treats wastewater and sewage from two correctional institutes, The Florida State Prison at Starke, and the Union Correctional Institute in Raiford. The facility

utilizes a trickling filter design with additional treatment through land application. Discharge is into the New River near State Road 16. The Union Correctional Institute has a design capacity of 1.3 MGD. The Florida State Prison has a design capacity of 2.0 MGD, and includes waste from an on site laundry, and a slaughter house.

2. The City of Lake Butler sewage treament plant is located in Union County. The facility has a design flow capacity of 0.5 MGD and treats waste from a population of approximately 4000. The facility's treatment process consist of rotating biological contactors, and post aeration. Effluent is discharged to the New River.

3. The Lake City sewage treatment plant is located in Lake City, Columbia County, Florida. The facility has a design flow capacity of 3.0 MGD and treats waste from a population of approximately 30,000. The wastewater treatment process consist of biological treatment using activated sludge, clarification, and chlorination. Final treated effluent is discharged through Aliigator Lake to the New River.

4. The City of Starke operates a sewage treatment plant in Bradford County which discharges treated effluent to Alligator Creek. Alligator Creek is part of the headwaters in the Santa Fe river sub-basin of the Suwannee River. A major portion of the headwaters of the Alligator Creek basin are contained within the E.I. Dupont de Nemours, Trail Ridge property. The facility has a design flow capacity of 1.0 MGD and serves a population of approximately 7000. The treatment process consist of screening, grit removal, and biological treatment using contact stabilization.

5. E.I. Dupont de Nemours is a dredge mining operation which produces ilmenite, zircon, and staurolite. The operation discharges approximately 7.0 MGD into the Santa Fe River via Alligator Creek. The wastewater treatment system consist of acidification, settling, neutralization, and final settling before disposal. The discharged effluent contains small amounts of aluminum, cadmium, calcium, chromium, copper, cyanide, iron, mercury, phosphorus, sulfate, ammonia, nitrate, and zinc.

6. The St. John's Chemical Corporation manufactures synthetic resins which are used in printing inks. The resins are produced by reacting resin acid with various organic acids. The wastewater generated on-site is incinerated, but effluent consisting of cooling water and boiler blowdown is discharged into Alligator Creek. Constituents of the effluent are resin acid, synthetic resin, zinc, toluene, ethylbenzene, calcium, and magnesium.

Summary

The Suwannee River Basin includes the Suwannee River itself and its three main tributaries, the Alapaha River, the Withlacoochee River, and the Santa Fe River. Land use in the basin is primarily agricultural and although non-point source discharges in the basin may be significant they have not been

adequately measured. However, several significant point source dischargers exist in the basin that contribute domestic and industrial wastewater to the Suwannee River: Goldkist Incorporated and Florida Power Corp. located at Live Oak discharge directly to the Suwannee River, Owens-Illinois Paper Products and The City of Valdosta enter the Suwannee through the Withlacoochee River, and E.I. Dupont de Nemours and The City of Lake City enter the river via The Santa Fe River. However, the waste discharged by Occidental Chemical and Agricultural Products through Hunter and Swift Creeks is responsible for the high concentrations of phosphorus and nitrogen found in the river.

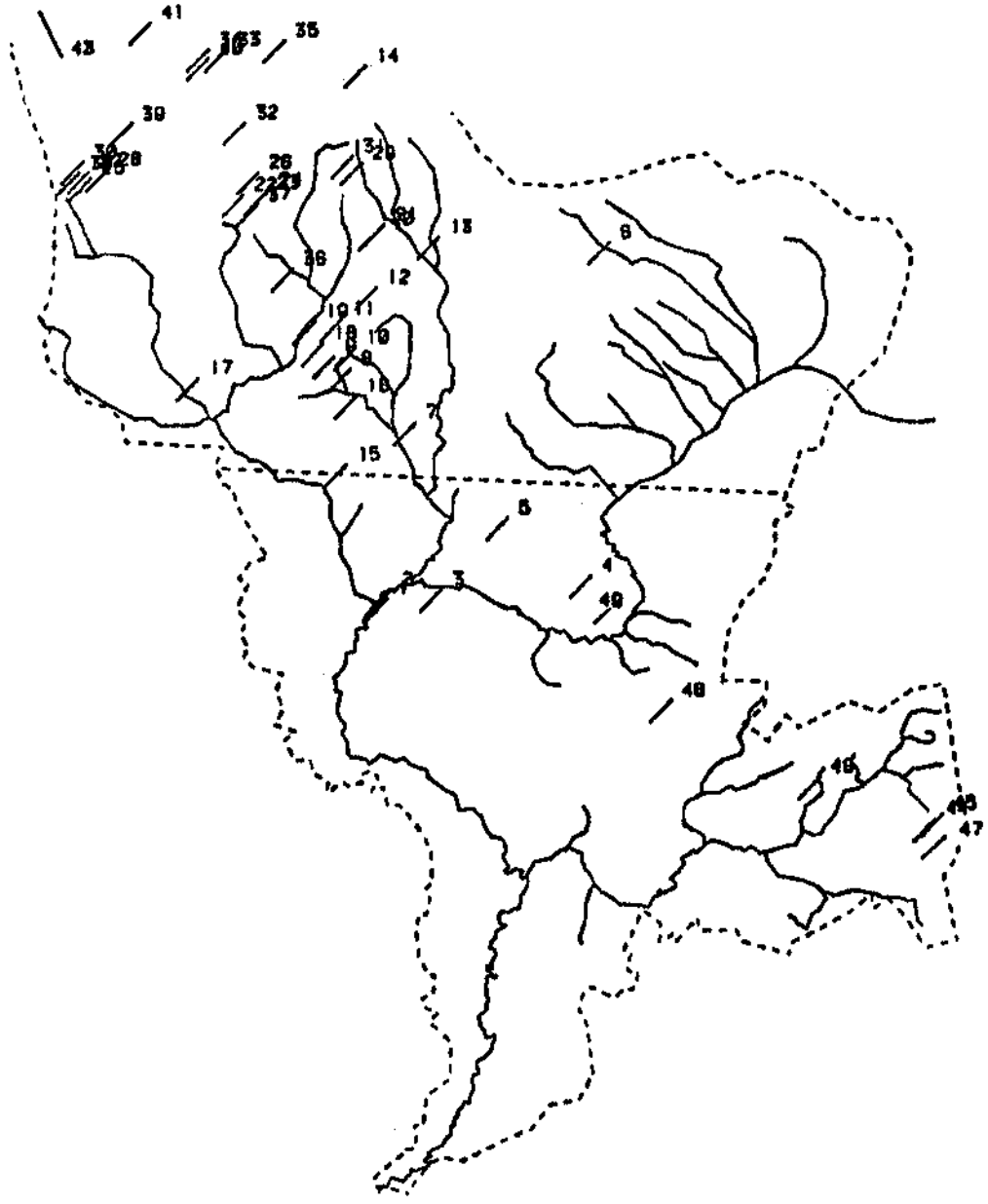

FIGURE 3. SELECTED SURFACEWATER POINT DISCHARGERS WITHIN THE SUWANNEE RIVER BASIN AND LOWER WITHLACOOCHEE AND ALAPAHA BASINS (DISCHARGERS ENUMERATED IN TABLE 4).

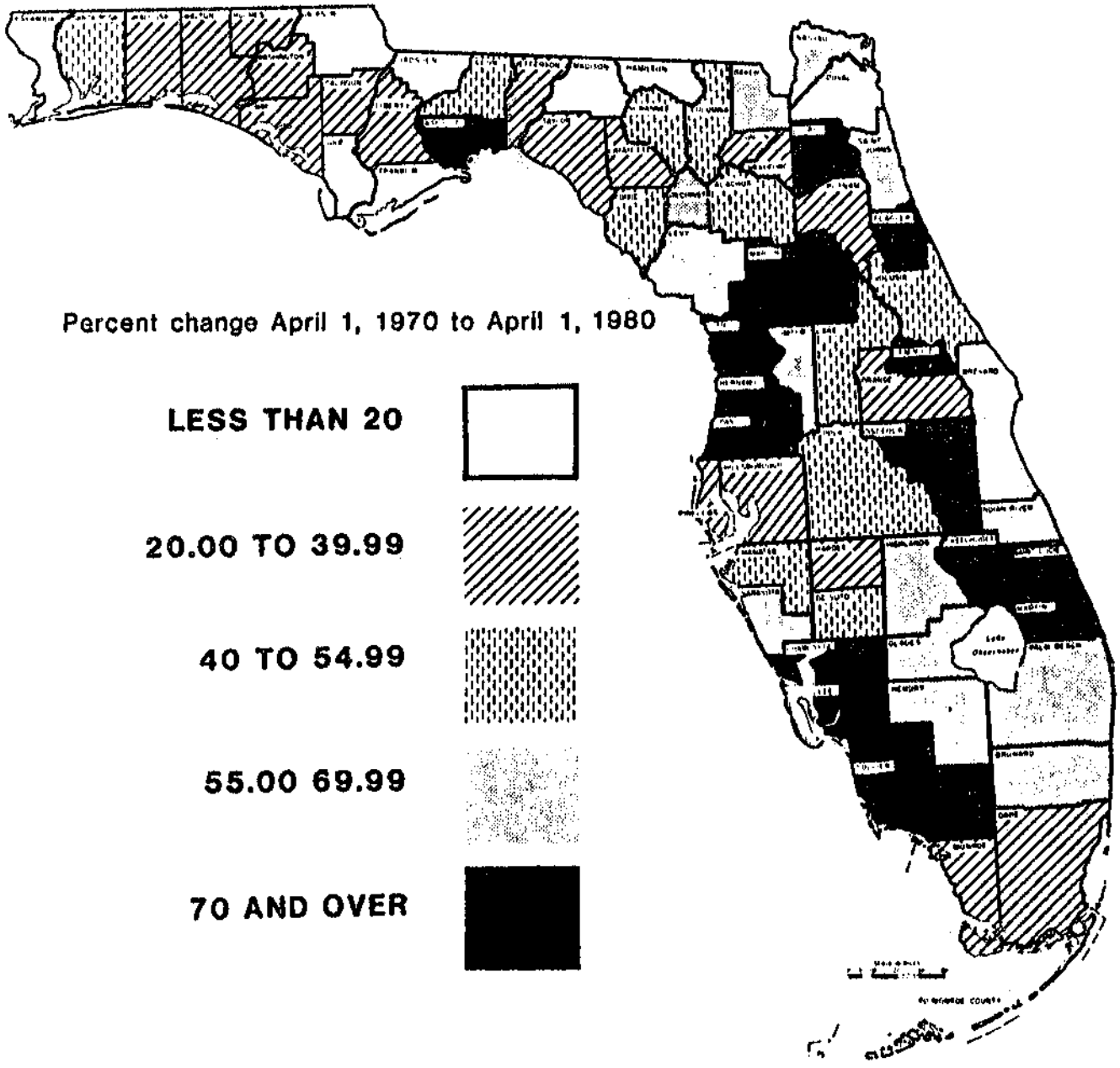

FIGURE 4. PERCENT CHANGE IN POPULATION BY COUNTY BETWEEN 1970 AND 1980 (FROM BUREAU OF ECONOMIC AND BUSINESS RESEARCH 1981)

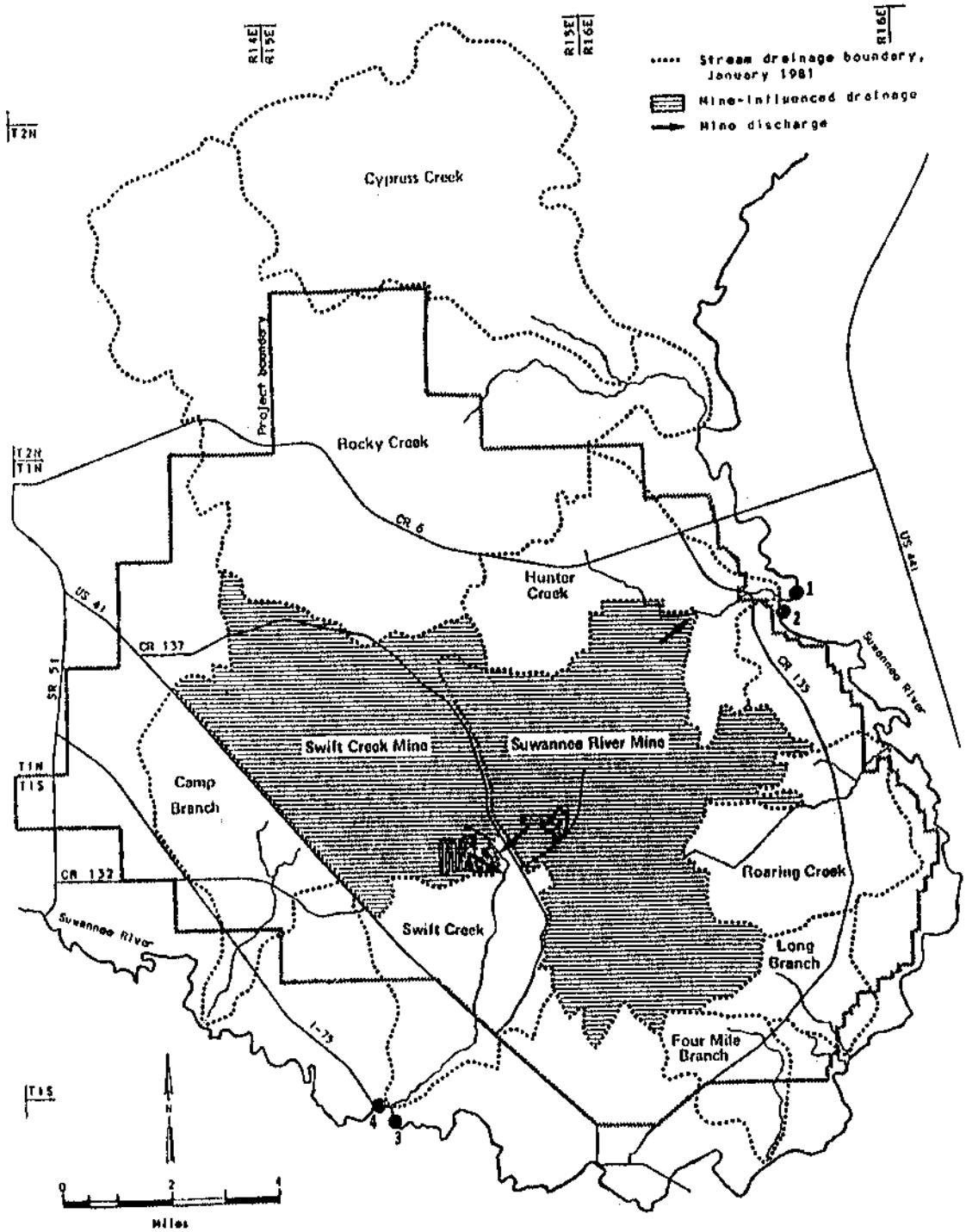

FIGURE 5. LOCATION OF THE SWIFT CREEK AND SUWANNEE RIVER MINES WITH SMALL STREAM BOUNDARIES

SOLID CIRCLES WITH NUMBERS INDICATE LOCATION OF FDER STATIONS 1-4

TABLE 2. EXISTING AND PROJECTED POPULATIONS FOR THE 19 GEORGIAN COUNTIES IN THE SUWANNEE RIVER BASIN (from U.S. Army Corps of Engineers 1983).

	U.S. CENSUS				PROJECTIONS			
COUNTY	1950	1960	1970	1980	1990	2000	2010	2020
ATKINSON	6,050	6,188	5,879	6,141	6,871	7,447	7,904	8,823
BEN HILL	13,373	13,633	13,171	16,000	17,681	19,197	20,495	23,344
BERRIEN	11,809	12,038	11,556	13,525	14,328	15,139	15,843	17,601
BROOKS	15,001	15,292	13,743	15,255	16,213	17,221	18,084	19,953
CHARLTON	5,212	5,313	5,680	7,343	8,009	8,646	9,192	10,390
CLINCH	6,420	6,545	6,405	6,660	7,127	7,579	7,983	8,928
COFFEE	21,535	21,953	22,828	26,894	27,746	29,499	31,167	35,100
COLQUITT	33,399	34,048	32,298	35,376	37,568	40,322	42,848	48,479
COOK	11,597	11,822	12,129	13,490	14,196	15,032	15,806	17,577
CRISP	17,430	17,768	18,087	19,489	20,007	21,376	22,802	25,998
ECHOLS	1,840	1,876	1,924	2,297	2,349	2,456	2,553	2,782
IRWIN	9,036	9,211	8,036	8,988	9,636	10,278	10,824	11,996
LANIER	5,000	5,097	5,031	5,654	5,780	6,128	6,462	7,213
LOWNDES	48,331	49,270	55,112	67,972	72,807	78,478	83,702	95,360
TIFT	23,040	23,487	27,288	32,862	36,611	39,818	42,432	48,224
TURNER	8,278	8,439	8,790	9,510	10,030	10,680	11,275	12,621
WARE	33,567	34,219	33,525	37,180	39,339	42,444	45,371	51,859
WILCOX	7,754	7,905	6,998	7,682	7,946	8,470	8,970	10,072
WORTH	16,364	16,682	14,770	18,064	20,147	21,751	23,020	25,713
TOTALS	295,036	300,786	303,250	350,382	366,445	401,964	427,033	482,033

TABLE 3. EXISTING AND PROJECTED POPULATIONS FOR THE 11 FLORIDAN COUNTIES IN THE SUWANNEE RIVER BASIN (from U.S. Army Corps of Engineers 1983).

	FLORIDA POPULATION 1950 - 1980				PROJECTIONS TO 2020			
	U.S. CENSUS				PROJECTIONS			
COUNTY	1950	1960	1970	1980	1990	2000	2010	2020
ALACHUA	57,026	74,074	104,764	151,348	176,200	200,000	213,400	222,800
BRADFORD	11,457	12,446	14,625	20,023	22,400	24,800	26,500	27,700
COLUMBIA	18,216	20,077	25,250	35,399	39,900	44,400	47,300	49,400
DIXIE	3,928	4,479	5,480	7,751	9,300	10,500	11,200	11,700
GILCHRIST	3,499	2,868	3,551	5,767	7,600	8,900	9,500	10,000
HAMILTON	8,981	7,705	7,787	8,761	9,100	9,500	10,100	10,600
LaFAYETTE	3,440	2,889	2,892	4,035	4,700	5,400	5,800	6,000
LEVY	10,637	10,364	12,756	19,870	23,300	26,200	28,000	29,200
MADISON	14,197	14,154	13,481	14,894	15,400	15,800	16,800	17,600
SUWANNEE	16,986	14,961	15,559	22,287	26,300	29,500	31,500	32,900
UNION	8,906	6,043	8,112	10,166	10,500	10,600	11,300	11,800
TOTALS	157,273	170,060	214,257	300,301	344,700	385,600	411,400	429,700

TABLE 4. SELECTED SURFACEWATER DISCHARGERS WITHIN THE SUWANNEE RIVER BASIN AND THE LOWER WITHLACOOCHEE AND ALAPAHA RIVER BASINS.

MAP NUMBER	DISCHARGER	LOCATION	RECEIVING WATER
1	GOLD KIST POULTRY LIVE OAK	S. OF ELLAVILLE, FL	SUWANNEE RIVER
2	FL PWR CORP-SUWANNEE RIV	1 MI. S. OF ELLAVILLE, FL	SUWANNEE RIVER
3	LIVE OAK STP	LIVE OAK, FL	NATURAL SINK HOLE
4	OCCIDENTAL CHEMICAL CO.	WHITE SPRINGS, FL	SWIFT AND HUNTER CREEKS
5	JASPER-WWTP	JASPER, FL	BELLS CREEK
6	HOMERVILLE WPCP	HOMERVILLE, GA	WOODYARD CREEK
7	TWIN LAKES WWTP	TWIN LAKES, GA	CAINEY BRANCH
8	VALDOSTA SO-SIDE WWTP	VALDOSTA, GA	MUD CREEK
9	ITT VALDOSTA #1	VALDOSTA, GA	DUKE'S CREEK
10	UNION CAMP	VALDOSTA, GA	KNIGHTS CREEK
11	PINERIDGE WTR SUP OAK ST S/D	VALDOSTA, GA	TR TO CHERRY CREEK
12	TANGLEWOOD ACRES S/D	TANGLEWOOD ACRES, GA	GRAND BAY SWAMP
13	LAKELAND WTP	LAKELAND, GA	BIG CREEK
14	ALAPAHA WPC PLT	ALAPAHA, GA	ALAPAHA RIVER
15	OWENS ILLINOIS PAPER MILL	CLYATTVILLE, GA	WITHLACOOCHEE RIVER
16	LOWNDES CNTY-OUTPOST MOTEL ST.	LOWNDES, GA	BEVEL CREEK
17	QUITMAN STP	QUITMAN, GA	OKAPILCO CREEK
18	VALDOSTA ACTIVATED SLUDGE PLT	VALDOSTA, GA	SUGAR CREEK
19	FOXBOROUGH S/D	FOXBOROUGH, GA	WITHLACOOCHEE RIVER
20	RAY CTY HOUSING PROJ WPC PLT	RAY CITY, GA	CAT CREEK
21	RAY CITY WPC PLT	RAY CITY, GA	CAT CREEK
22	ADEL WPCP #2	ADEL, GA	WILLIAMSON CREEK
23	ADEL MUN WASTE TREATMENT FAC	ADEL, GA	BEAR B DAYS CREEK
24	PRODUCTION PLATING PLT 1 ADEL	ADEL, GA	D. TO BEAR CREEK
25	MOULTRIE-SPENCE FIELD STP	MOULTRIE, GA	L. INDIAN CREEK
26	SPARKS STP	SPARKS, GA	BEAR CREEK
27	COLUMBIA NITROGEN CORP	MOULTRIE, GA	OKAPILCO CREEK
28	CE BUILDING PRODUCTS	MOULTRIE, GA	OKAPILCO CREEK
29	PATCHOGUE PLYMOUTH	NASHVILLE, GA	CAT CREEK
30	SWIFT FRESH MEATS	MOULTRIE, GA	OKAPILCO CREEK
31	NASHVILLE-OXIDATION POND	NASHVILLE, GA	NEW RIVER
32	LENOX WPCP	LENOX, GA	LITTLE RIVER
33	TIFTON ALUM	TIFTON, GA	TR. OF NEW RIVER
34	TIFTON IND PARK PLT	TIFTON, GA	NEW RIVER
35	TIFTON NO-SIDE PLT	TIFTON, GA	TR. OF NEW RIVER
36	HAHIRA WPC PLT	HAHIRA, GA	FRANKS CR. TO LITTLE R.
37	PRODUCTION PLATING PLT 2	ADEL, GA	MORRISON CREEK
38	MOULTRIE-BRIDGEPORT BRASS STP	MOULTRIE, GA	L. INDIAN CREEK
39	NORMAN PARK WPC PLT	NORMAN PARK, GA	REEDY CREEK
40	TIFTON SO-SIDE PLT	TIFTON, GA	LITTLE CREEK
41	TY TY STP	TY TY, GA	TY TY CREEK
42	SYLVESTER-STP	SYLVESTER, GA	WARRIOR CREEK
43	SYLVESTER STP-TOWN CREEK DRIV	SYLVESTER, GA	TOWN CREEK
44	STARKE-MUNICIPAL STP	STARKE, FL	ALLIGATOR CREEK
45	FL STATE PRISON STP	STARKE, FL	NEW RIVER
46	LAKE BUTLER-STP	LAKE BUTLER, FL	LAKE BUTLER
47	DU PONT DE NEMOURS, TRAILRIDGE	NEAR STARKE, FL	ALLIGATOR CREEK
48	LAKE CITY, STP	LAKE CITY, FL	ALLIGATOR LAKE
49	WHITE SPRINGS STP	WHITE SPRINGS, FL	SUWANNEE RIVER

TABLE 5. SELECTED POINT SOURCE DISCHARGERS IN THE SUWANNEE RIVER BASIN

Facility (city)	Maximum Flow (MGD)	Receiving Water	Maximum Effluent Limitations (mg/l)					
			TSS	NH	TKN	OrgN	PO	Fluor
City of White Springs	.15	Suwannee	30		40			
GoldKist Incorporated	1.04	Suwannee			33			
Florida Power Corp.	176.	Suwannee						
City of Jasper	.40	Bells Ck to Alapaha Riv.	30					
City of Lakeland	.20	Big Ck to Alapaha Riv.	90					
City of Alapaha	.10	Alapaha Riv.	90					
Owens-Illinois	12.7	Jumping Galley Creek to Withlacoochee Riv.		1.4				
City of Valdosta	4.0	Withlacoochee Riv.	30	2.0 5.0				
City of Ray City	.10	Cat Ck. to Withlacoochee Riv.	90	5.0				
City of Lenox	.17	Little Riv. Withlacoochee Riv.	90					
City of Nashville	.63	Withlacoochee Riv.	90	10				
Tift Oil Company	.8	New River	30					
City of Tifton	.8	New River	30	2.0 10.0				
City of Lake Butler	.5	New River to Santa Fe		2.0	3.0	3.0		
Florida State Prison	2.0	New River to Santa Fe			2.0			
Union Correctional Institute	1.3	New River to Santa Fe	30	2.0	2.0			
E.I. Dupont de Nemours	7.0	Alligator Cr. to Santa Fe	30					
St. Johns Chem. Corp.	.018	Alligator Cr. to Santa Fe	30					
City of Starke	1.0	Alligator Cr. to Santa Fe	30	15		5.0		
City of Lake City	3.0	Alligator Lake	20				5.0	
Occidental Chem. Agric. Products								
Suwannee River Chem. Complex	4.32	Hunter Creek/ Swift Creek						
Outfall 002		Hunter Creek	60	.02				10
Outfall 001.8		Swift Creek	150				105	75
Outfall 001.7		Swift Creek	60					
Outfall 001.17		Swift Creek					105	75
Swift Creek Mine	1.40	Swift Creek						
Outfall 001.18		Swift Creek	60				10	10
Outfall 001.22		Swift Creek					105	75
Outfall 001.28		Swift Creek	150				105	75

HYDROLOGY AND GEOLOGY

Basin Location and General Description

The Suwannee River Basin drains 11,030 square miles of the Coastal Plains Region in southern Georgia and northcentral Florida (Fig. 6). The Suwannee River originates in the second largest swamp in the United States, the Okefenokee Swamp, and drains roughly 85% of the 685 square mile Okefenokee Swamp Basin (Finn and Rykiel 1979). The river begins as a network of slender threads of open water flowing south to Billy's Lake in the Okefenokee Swamp National Wildlife Refuge. After flowing nearly 28 miles through the swamp the Suwannee exits to the southwest through an earthen sill originally constructed in 1960. Below the sill the acidic, soft, blackwaters of the Suwannee River flow southward through a broad flood plain densely wooded with bottomland hardwoods. The upper Suwannee River channel is superimposed on thick Miocene deposits of sandy clays, clayey sands, sandstone, and limestone referred to as the Hawthorn Formation which isolates the channel from the underlying Floridan aquifer. The Hawthorn Formation is exposed continually along the banks of the Suwannee River from the Florida-Georgia border to White Springs, and intermittently from White Springs to the confluence of the Alapaha River (Ceryak et al. 1983). The flow in this portion of the river is supplied by surface runoff from tributaries draining the surrounding swamps and forest, and by seepage from the surficial aquifer. The upper portions of the Miocene Hawthorn Formation and overlying lower Pliocene deposits (Brooks 1981a) consist of phosphatic clayey sands and phosphatic clays that form the commercial phosphate deposits mined by Occidental Chemical Agricultural Products, Inc. (Oxy) in Hamilton County.

Near White Springs the Hawthorn Formation thins and the river enters the Gulf Coastal Lowlands, or the Ocala Uplift District (Brooks 1981b). Here the river cuts into the Suwannee Limestone of the Floridan Aquifer, and bends strongly to the northwest as the river aligns its course parallel to the major fracture pattern in this region (Ceryak et al. 1983). From White Springs downstream, the river receives increasing amounts of circum-neutral, hard, clear water from over 50 springs, including 9 first magnitude springs (Fig. 7), and from base flow associated with the Ocala Uplift.

Near Ellaville, the Suwannee River returns to its southern course as it is joined from the north by the Alapaha and Withlacoochee Rivers which together drain 4130 square miles (Fig. 8) and contribute about 15% and 24%, respectively, to the average flow of the Suwannee River at Ellaville (Leadon 1980). The Alapaha River intermittantly flows the entire length of its

stream bed, discharging directly to the Suwannee only about 50% of the time. During dry periods the river is captured by a group of sink holes four miles south of the Georgia-Florida state line. Waters of the Alapaha River travel through solution channels in the underlying limestone for approximately 19 miles and emerge at the Alapaha Rise and Holton Creek (Ceryak 1977). During the Alapaha's course underground the dissolved oxygen in the water becomes depleted, and the emergence of these oxygen depleted waters at the Alapaha Rise can significantly reduce dissolved oxygen levels in the Suwannee River.

Below Ellaville the Suwannee River enters a region of thin sandy soil overlying the Ocala Limestone of the Floridan Aquifer. This region is characterized by low relief, few tributaries, and increasingly numerous springs that significantly alter the flow and water quality of the river. Near Branford, the flow of the Suwannee becomes sluggish as the channel broadens between low banks bordered by marshes and hardwood hammocks (FDER 1980) typical of the lower coastal plain counties. Roughly 10 miles below Branford and 66 miles above the Gulf of Mexico the third major tributary, the Santa Fe River, enters the Suwannee. The Santa Fe drains approximately 1,620 square miles (Fig. 8) and contributes about 15% of the Suwannee River flow at Wilcox (FDER 1980).

After flowing 236 miles from the Okefenokee, the waters of the Suwannee River enter the Gulf of Mexico through two main distributaries and numerous tidal creeks near the Lower Suwannee National Wildlife Refuge in Levy and Dixie Counties.

Geological History and Structure of the Suwannee River Basin

The two major physiographic districts within the Suwannee River Basin are the Gulf Coastal Lowlands or the Ocala Uplift District, and the Northern Highlands or the Sea Island District (Brooks 1981b). These two physiographic districts are separated by the Cody Scarp (Fig. 9) which is the most persistent topographic break in Florida (Puri and Vernon 1964). The continuity of the scarp is unbroken within the Basin except by the valleys of the Suwannee and its main tributaries. Differences between these two districts stem largely from events of the Tertiary (Fig. 10) and are associated with the principal geological features that influenced the basin, including: 1) the shallow marine sea that covered the Floridan Plateau; 2) the Ocala Uplift; and 3) the transport of clastic sediments carried by rivers draining the Appalachian mountains to the north.

During most of the Tertiary, the Floridan Plateau was a shallow marine shelf upon which chemically precipitated limestone and dolomite, along with shells and shell fragments derived from the abundant marine life were deposited. The Eocene deposits of nearly pure $CaCO_3$ (Brooks 1981a), or Ocala Limestone, are very thick and extensive, covering Florida and portions of southern Alabama, Georgia, and South Carolina. During the Oligocene, the Ocala Limestone was overlain by a thinner layer of pure to slightly sandy limestone referred to as Suwannee Limestone.

Together, the Ocala and Suwannee Limestones constitute the Floridan Aquifer (Fig. 11) which is the principal source of spring waters in the state.

During the later part of the Oligocene and early Miocene, uplifting occurred in the northwestern part of peninsular Florida including the lower portion of the Suwannee Basin. This uplift, referred to as the Ocala Uplift, occurred in an elongate, diagonal, northwest-southeast directed band with the crest of uplift located in eastern Citrus and Levy counties (Vernon 1951). As the Ocala Uplift proceeded, the clastic-sediment veneer on the uplifted strata of the future lower Suwannee Basin was deposited more thinly and was more readily eroded than in northern areas of the Basin. This uplifted area, referred to as the Gulf Coastal Lowlands or Ocala Uplift District (Fig. 9), presently consists of gently sloping Karst plains extending from the base of the highlands coastward with elevations of less than 100 feet above sea level (NGVD) (Crane 1983). Due to the thinness of the surficial clastic sediments, a well integrated pattern of streams never developed in much of this district (Crane 1983) and precipitation either evaporates, percolates into the ground, or enters the underlying limestone through Karst features. The Suwannee River cuts into the Suwannee and Ocala Limestones of the Floridan Aquifer near Suwannee Springs and begins receiving discharge from springs near the town of White Springs (Fig. 7).

At the beginning of the Miocene, ever increasing amounts of clay, silt, and sand were transported into Florida by the numerous river systems draining the Appalachian Mountains to the north. The Ocala Uplift region, including the lower Suwannee Basin, received only thin deposits due to its increased elevation; however, the lower areas to the north received large amounts of terrestrial clastics which were intermixed with marine limestone deposits to form the clay, clayey sand, sand, and clayey limestone deposits of the Lower Hawthorn Formation. In the Middle and Upper Miocene, terregenous clastics became increasingly dominant and resulted in deposition of the thick impermeable strata of the Mid and Lower Hawthorn Formation. The thickness and low permeability of the Hawthorn Formation in the northeastern part of the Suwannee Basin functions as an aquaclude which separates the Suwannee River from the hard, clear waters of the Floridan Aquifer (Fig. 11). Thick, uneroded accumulations of the Hawthorn Formation overlain by fine sandy soils form a structurally high (150 to 202 ft) ridge referred to as the Lake City Ridge (Brooks 1981c; Ceryak et al. 1983). This narrow ridge runs east-west from near Lake City to the North Prong of the St. Mary's River and forms the drainage boundary between the Upper Suwannee and Santa Fe River Basins (Fig. 12).

From the Upper Miocene to Lower Pliocene the shallow sea environment covering the northeastern portion of the Suwannee Basin in Florida favored the precipitation of large amounts of phosphorite in the form of phosphatic clay and sand. These deposits form the commercial deposits of phosphate mined presently in Hamilton county.

In Plio-Pleistocene times the region was highly influenced by glaciation events with drastic changes in sea level and

climate. During portions of this time, the climate favored the formation of terrace deposits. These terrace deposits consist of fine- to medium-grained quartz sand with minor amounts of organic material and heavy minerals, over gray to greenish clayey sand and clay (Brooks 1981a; Ceryak et al. 1983). One of the principal terrace deposits is the Trail Ridge which is a long, narrow, sandy ridge with elevations of 150-240 feet above sea level (Brooks 1981c), or 10-40 feet above the surrounding land. This ridge forms the nearly straight east boundry of the Okefenokee Swamp in Georgia and the Santa Fe River Basin in Bradford County, Florida (Fig. 12). Additional sand dune deposits are found in the lower Suwannee Basin and are generally associated with scarps corresponding to previous sea levels.

While the geological surface on which the Okefenokee Swamp occurs developed in the Pliocene and Pleistocene, the swamp itself originated and developed more recently. The post-glacial period was characterized by a more humid and warmer climate, and by rising sea levels (Emiliani 1970). According to the Holocene Freshwater Origin Theory (Parrish and Rhykiel 1979), the Okefenokee Swamp developed during the Holocene primarily as a result of the wetter and more humid climate. The accumulation of water from increased precipitation and higher water tables associated with rising sea levels favored the formation of peat. The peat deposits retained water, blocked drainage, and as a result decreased the frequency of fire. Areas of peat formation spread upstream and laterally connecting numerous stream-swamp segments to form the Okefenokee Swamp.

Groundwater-Surfacewater Relationships

The Suwannee River Basin includes three aquifer systems as depicted by Fig. 11. All three aquifers are generally present in the upper Suwannee Basin, or Northern Highlands, while below the Cody Scarp in the Ocala Uplift District, or Coastal Lowlands, only the Floridan Aquifer is well represented. An aquifer is a saturated permeable geologic unit that can transmit significant quantities of water under ordinary hydraulic gradients (Freeze and Cherry 1979).

Studying of water chemistry from wells tapping various strata demonstrates that the three aquifers transmit water of distinctly different composition (Ceryak et al. 1983). An understanding of groundwater composition is central to comprehension of surfacewater chemistry in the Suwannee River Basin as surfacewater composition is largely dependent upon the degree of contact between the river channel and the three aquifers. Correlation analysis of well water chemistry results in three clusters (Fig. 13) that correspond to the three aquifers within the basin (Ceryak et al. 1983).

A perched, unconfined, surficial aquifer overlies most of the Northern Highlands, or areas northeast of the Cody Scarp (Figs. 9, 11). The surficial aquifer is composed of Miocene and younger sands and clayey sands that range in thickness from 20 to

150 feet (Ceryak et al. 1983). Water levels within the surficial aquifer parallel the surface topography and often coincide with surfacewater levels observed in swamps and lakes. Recharge comes from regional precipitation and is strongly influenced by seasonal variations in rainfall and evapotranspiration. Principal discharges of the surficial aquifer include areas of low relief such as streams and swamps that drain into the upper Suwannee River, and leakage to the underlying aquifers through breaks in the usually impermeable Hawthorn Formation Member B (Fig. 11).

The parameters in Cluster 2 of the well water correlation matrix (Fig. 13) correspond to waters of the surficial aquifer (Ceryak et al. 1983). The surficial aquifer is primarily composed of sand which is relatively inert. The high chloride, sodium, and potassium values of the surficial aquifer correspond to inputs from precipitation and marine aerosols (Hem 1959). The high nitrate values observed in the surficial aquifer result largely from human activities including the use of chemical fertilizers, farm animal excrement, and septic tanks (Ceryak et al. 1983), but also from nitrogen fixing soil microbes (Hem 1959).

In contrast to the high values for the above parameters, waters of the surficial aquifer, which drain into the upper Suwannee River, are characterized by relatively low values for pH, specific conductance, alkalinity, calcium, and magnesium as compared to the other two aquifers in the Suwannee Basin.

The secondary artesian aquifer corresponds to the more permeable units of the Miocene Hawthorn Formation which is well represented throughout the Northern Highlands (Figs. 9, 11). The secondary aquifer is composed of phosphatic sands, clays, and carbonates (Ceryak et al. 1983) and varies widely in depth and thickness. This aquifer is isolated from the overlying surficial aquifer and the underlying Floridan aquifer by low-permeability deposits of the Hawthorn Formation referred to as aquitards (Ceryak et al. 1983; Freeze and Cherry 1979).

Dissolution of the fluorapatite deposits of the Hawthorn Formation results in high concentrations of fluoride and phosphate in waters of the secondary aquifer (Ceryak et al. 1983). These variables are highly correlated and form Cluster 3 (Fig. 13). Waters of the secondary aquifer also display high sodium and potassium values which are likely associated with the weathering of montmorillonite clays (Garrels and Christ 1965; Ceryak et al. 1983). Other chemical parameters display values similar to the waters of the underlying Floridan Aquifer.

The Floridan Aquifer, which includes the Suwannee and Ocala Limestones, is ubiquitous to the Suwannee River Basin (Fig. 11). In the upper Suwannee Basin, or the Northern Highlands (Figs. 9, 11), the Floridan Aquifer is confined by the Hawthorn Formation and isolated from the surfacewaters. In the Gulf Coastal Lowlands (Fig. 9), the Hawthorn Formation is thin or lacking, and the Floridan Aquifer has direct access to the river channel via springs and baseflow.

The limestones of the Floridan Aquifer along the river have developed high secondary porosity due in part to contact with the

acidic river waters during periods of high flow. During low and moderate flows the chemical composition of the river is strongly influenced by the input of groundwaters from the Floridan Aquifer. At low and moderate flows, springs (Fig. 7) appear along both sides of the river below the town of White Springs and discharge waters of the Floridan Aquifer directly into the river. During high river stage the springs reverse flow, and the river water directly recharges the aquifer (Ceryak et al. 1983).

Waters of the Floridan Aquifer are characterized by relatively high values for calcium, magnesium, alkalinity, pH, and specific conductance (Fig. 13, Cluster 1) which are associated with the dissolution of limestone and dolomite (Hem 1959), and relatively high concentrations of sulfate due to the dissolution of gypsum and anhydrite (Ceryak et al. 1983).

Climate and Streamflow

The Suwannee River Basin experiences long, warm, humid summers and mild winters with an annual mean temperature of 19°C (Ceryak et al. 1983) and an annual mean rainfall of 52 inches (Hughes et al. 1971). During the summer months the mean maximum temperature (period of record 1931-1960) is 33°C and the mean minimum temperature is 22°C (Bradley 1972; Crane 1983). In winter, low temperatures of -5 to -7°C associated with Canadian air masses may occur (Crane 1983); however, cold spells are generally of short duration. In January the mean maximum temperature ranges from 19°C in the northern basin to 21°C in the southern basin, while mean minimums in January range from 5°C in the north to 9°C in the south (Bradley 1972; Crane 1983).

The streams of Florida display two types of seasonal streamflow patterns (Kenner 1975). Streams in the northern part of the state including the Alapaha, Withlacoochee (Fig. 14), and upper Suwannee (Figs. 15, 16) typically have peak discharges from January to April, and minimum discharges from May to July and October to December. Streams in the southern portion of the state generally have peak discharges during the late summer and fall (August - December), low flows from January to April, and minimum flows in May and June (Kenner 1975). The Santa Fe River Basin lies within the transition zone between the two primary flow regimes and may display both the August - October peak of the southern zone and the February - April peak of the northern zone (Fig. 14).

Precipitation and streamflow patterns within the state are associated with the position of the transition zone between the continental weather pattern of the Southeastern U.S. and the tropical weather pattern of the Caribbean Sea (Kenner 1969). However, seasonal differences in temperature and evapotranspiration rates, and regional differences in stream channel access to aquifer inputs, strongly modify the effects of rainfall on streamflow.

During the late winter and early spring, the high pressure continental air masses move southeasterly from western Canada across the central U.S. and into northern Florida (Kenner 1975).

Contact between the cold continental air masses and the warmer, moist air masses of the Gulf region over northern Florida results in frontal weather that produces severe storms and widely distributed, long-duration rainfalls. Frontal activity decreases rapidly southward and river basins in southern Florida experience lower winter precipitation levels and correspondingly low winter streamflows. The effect of precipitation derived from frontal activity on streamflow in northern Florida is greatly enhanced by the reduced evapotranspiration rates of winter and early spring which are associated with cold temperatures and reduced (growth of vegetation).

Florida's summer climate is sub-tropical (Kenner 1975) as the entire state is dominated by moist air masses from the Caribbean Sea. Precipitation throughout the state reaches maximum values (Hughes et al. 1971) and local convectional rainstorms are common. However, the effect of the increased summer rainfall on streamflow (Fig. 15) is diminished by high evapotranspiration rates associated with high temperatures and active growth of vegetation. Additionally, the summer rains tend to be of reduced areal extent and duration (Ceryak et al. 1983), and therefore do not result in widespread soil saturation and increased runoff.

With the approach of autumn the moist Caribbean air masses continue to move north over southern and central Florida dropping large amounts of precipitation. However, these moist air masses dissipate over the Santa Fe River Basin before reaching the upper Suwannee River Basin. Due to the input of autumn rainfall and reduced evapotranspiration rates, the Santa Fe typically displays an August to November flow peak (Fig. 14). On the other hand, the Withlacoochee, Alapaha, and upper Suwannee River Basins are generally not affected by the southern air masses during the autumn, and minimum streamflow occurs during this period (Figs. 14, 15, 16).

Hydrological Stations, Methods of Reporting Data, and Flow Patterns During the Study Period

The location of the five U.S.G.S. gaging stations used to represent changes in streamflow during the study period, January 1982 - January 1984, are indicated in Fig. 17.

Two of the five stations are located on major tributaries of the Suwannee, the Withlacoochee River near Pinetta and the Santa Fe River near Fort White (Fig. 17). As noted in the discussion of Climate and Streamflow, these two tributaries display different seasonal flow patterns (Figs. 14).

The three remaining stations are located on the Suwannee River. The most upstream gaging station, White Springs (Fig. 17), is located approximately 6 miles upstream from our water chemistry, periphyton, and benthos sampling Station 3. The hydrograph at White Springs, referred to as Station 3 in this report, is indicative of streamflow in the upper portion of the Suwannee Basin (Figs. 14-16). The gaging station at Branford (Fig. 17) corresponds closely to our sampling Station 9, being

located approximately 1.5 miles downstream from our station. The hydrograph at Branford, Station 9, is indicative of streamflow along the middle Suwannee River below the confluence of the Withlacoochee River (Figs. 14-16). The U.S.G.S. gaging station near Wilcox (Fig. 17) is located approximately 8 miles upstream from Station 11. Hydrological data at Wilcox was used to represent variation at Station 11, as streamflow at both localities is tidally influenced.

The monthly mean of daily discharges by calender months for 1982 at the five gaging stations in Fig. 11 is plotted in Fig. 14. This figure provides data on the relative contribution to discharge of two main tributaries and data on seasonal variations in flow at the five gaging stations. While variations between stations are obvious, (e.g., the Withlacoochee River vs. the Santa Fe River) streamflow at all five stations can be characterized by two annual high flow periods and two annual low flow periods (Fig. 14). Maximum high flow typically occurs between February and April, with a second smaller high flow period in August (Fig. 14). The August high flow of 1982, observed at the three Suwannee River stations (Figs. 14, 16), was actually slightly higher than normal, while the February to April peak in 1982 was considerably lower than the long-term average (Fig. 15). Lowest flow typically occurs from October to December and occasionally into January. A secondary low flow period associated with maximum growth vegetation and higher evapotranspiration rates occurs between May and July (Figs. 14, 15).

Figures 16 and 18 provide data on gage height variations for the three Suwannee River stations during the 25 sampling months. Gage heights in these figures (Figs. 16, 18) are reported as standardized gage heights. Standardized gage heights were calculated by subtracting the minimum gage height value observed at each station over the 25 month study period from all other station values. The use of station standardized gage heights allows direct comparisons of height variations between stations without reference to the datum of the gaging station.

The sampling-months in Fig. 16 and the upper portion of Fig. 18 correspond to the 28-day months used to incubate the periphyton and benthos artificial substrate samplers. In Fig. 18, the mean, maximum, and minimum gage heights during each of the twenty-five, 28-day incubation periods are plotted for Stations 3 (top), 9, and 11 (bottom). In the lower portion of Fig. 18, the gage heights on the 25 sampling-days, at which time water samples for chemical analyses were collected, are provided for Stations 3, 9, and 11. As expected, Figs. 16, and 18 reveal that both seasonal and monthly variations in gage heights decrease downstream as the river channel and floodplain widen.

The most prominent feature of the hydrographs in Figs. 16 and 18 is the very high water levels of February - April, 1983. The height of the 1983 peak, while significant in its effect on the river, is exaggerated by the abnormally low water levels of the February - April, 1982 period. Gage heights reached during the peak flow period of 1983 have a Recurrence Interval of

roughly three years and were only several feet below flood stage. Flood stage, as established by the National Oceanographic and Atmospheric Administration, is the height at which overflow of the natural banks begins to cause damage to human property (Ceryak et al. 1983). The peak flow of late winter-early spring in 1983 receded so slowly that the typical May - June low flow period and secondary peak in August are discernable only in the hydrograph for White Springs (Fig. 16, top).

Summary

The Suwannee River Basin drains 11,030 square miles of the Coastal Plains in southern Georgia and northcentral Florida (Fig. 6). The Basin may be divided into two major physiographic districts (Fig. 9) based upon features that stem largely from events of the Tertiary (Brooks 1981a, b). The upper portion of the Suwannee Basin lies within the Northern Highlands District while the lower portion is located in the Gulf Coastal Lowlands. These two physiographic districts are separated by the Cody Scarp (Fig. 9), which is the most persistent topographic break in Florida (Puri and Vernon 1964).

The Suwannee River originates in the second largest swamp in the United States, the Okefenokee Swamp, which is largely protected by the Okefenokee Swamp National Wildlife Refuge. After exiting the swamp through an earthen sill, the acidic, soft, blackwaters of the Suwannee flow southward through a broad floodplain wooded with bottomland hardwoods. In the Northern Highlands (Figs. 9, 11), the river channel is superimposed on thick Miocene deposits of the Hawthorn Formation which isolate the channel from the underlying Floridan Aquifer. The flow in this portion of the river is supplied by surface runoff from tributaries draining the surrounding swamps and forest and by seepage from the surficial aquifer. Waters of the surficial aquifer display high concentrations of chloride, sodium, potassium, and nitrate, and low values for pH, specific conductance, alkalinity, calcium, and magnesium.

Near the town of White Springs, the Hawthorn Formation thins and the Suwannee enters the Gulf Coastal Lowlands. Here the river cuts into Suwannee Limestone of the Floridan Aquifer and bends strongly to the northwest. From White Springs downstream the river receives increasing amounts of circum-neutral, hard, clear water from the Floridan Aquifer via base flow and over 50 springs (Fig. 7).

Near Ellaville, the Suwannee River returns to its southern course as it is joined from the north by the Alapaha and Withlacoochee Rivers. Below Ellaville the Suwannee River enters a region of thin sandy soil overlying the Ocala Limestone of the Floridan Aquifer. This region is characterized by flatter relief, fewer tributaries, and increasingly numerous springs that significantly alter the flow and water quality of the river.

Near Branford, the flow of the Suwannee becomes sluggish as the channel broadens between low banks bordered by marshes and hardwood hammocks typical of the lower coastal plain counties.

Roughly 10 miles below Branford and 66 miles above the Gulf of Mexico the third major tributary, the Santa Fe River, enters the Suwannee. After flowing 236 miles from the Okefenokee, the waters of the Suwannee River enter the Gulf of Mexico through two main distributaries near the Lower Suwannee National Wildlife Refuge in Dixie and Levy Counties.

The location of the five U.S.G.S. gaging stations used to represent changes in streamflow during the study period, January 1982 - January 1984, are indicated in Fig. 17. Two of the five stations are located on major tributaries of the Suwannee, while the three remaining stations are located on the Suwannee River.

The most upstream gaging station on the Suwannee, at White Springs (Fig. 17), corresponds closely to our sampling Station 3. The hydrograph at White Springs, Station 3, is indicative of streamflow in the upper portion of the Suwannee Basin (Figs. 14, 18). The gaging station at Branford (Fig. 17) corresponds closely to our Station 9, and the hydrograph at Branford (Figs. 14, 18) is indicative of streamflow along the middle Suwannee River below the confluence of the Withlacoochee River (Figs. 14, 18). The U.S.G.S. gaging station near Wilcox (Fig. 17) is located approximately 8 miles upstream from our Station 11. Hydrological data at Wilcox were used to represent variation at Station 11 as streamflow at both localities is tidally influenced.

Figures 16 and 18 provide data on gage height variation for the three Suwannee River stations during the 25 sampling-months. Gage heights in these figures (Figs. 16, 18) are reported as standardized gage heights. Standardized gage heights were calculated by subtracting the minimum gage height value observed at each station over the 25 month study period from all other station values. The use of station standardized gage heights allows direct comparisons of height variations between stations without reference to the datum of the gaging station.

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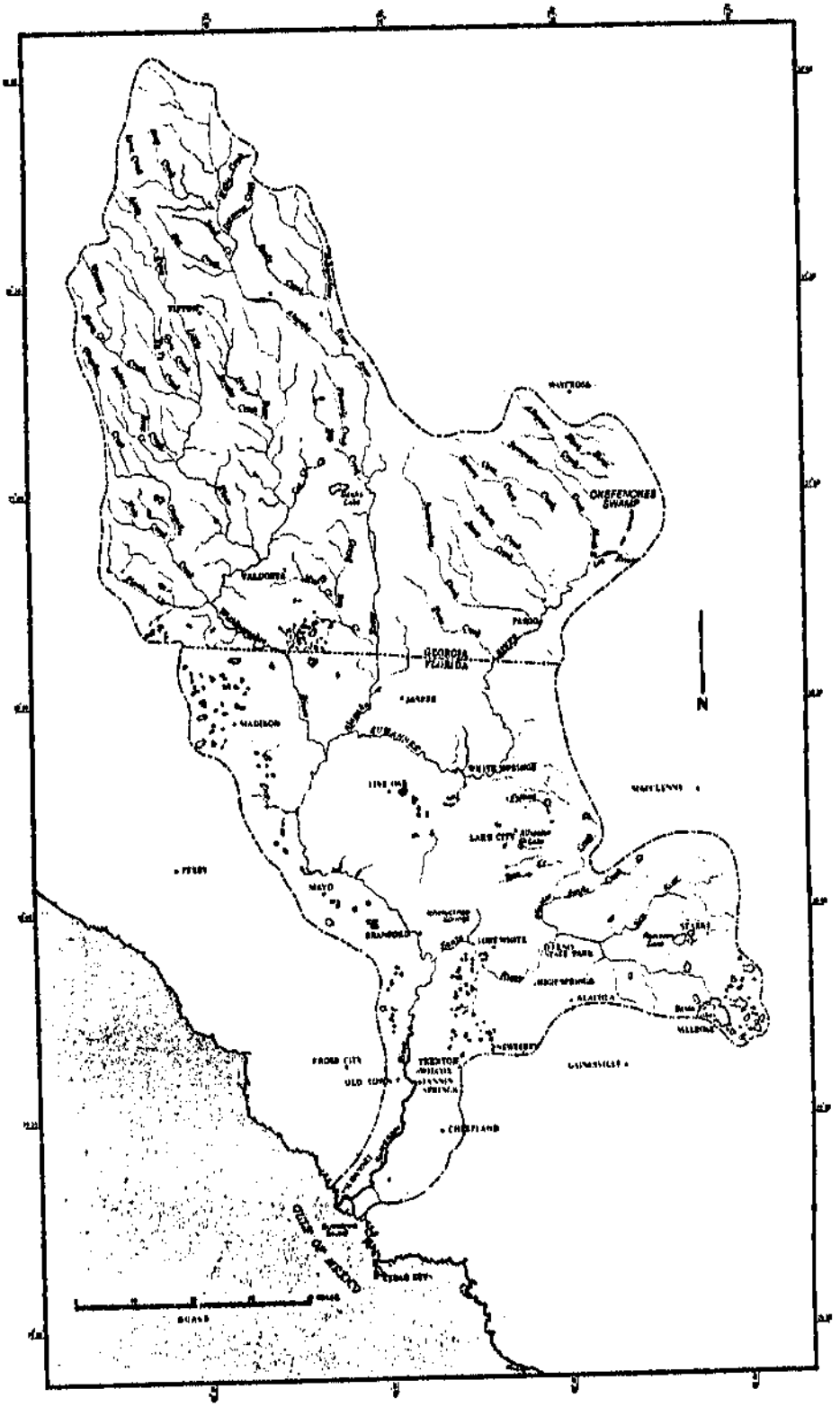


FIGURE 6. THE SUWANNEE RIVER BASIN IN GEORGIA AND FLORIDA (LEADON 1980)

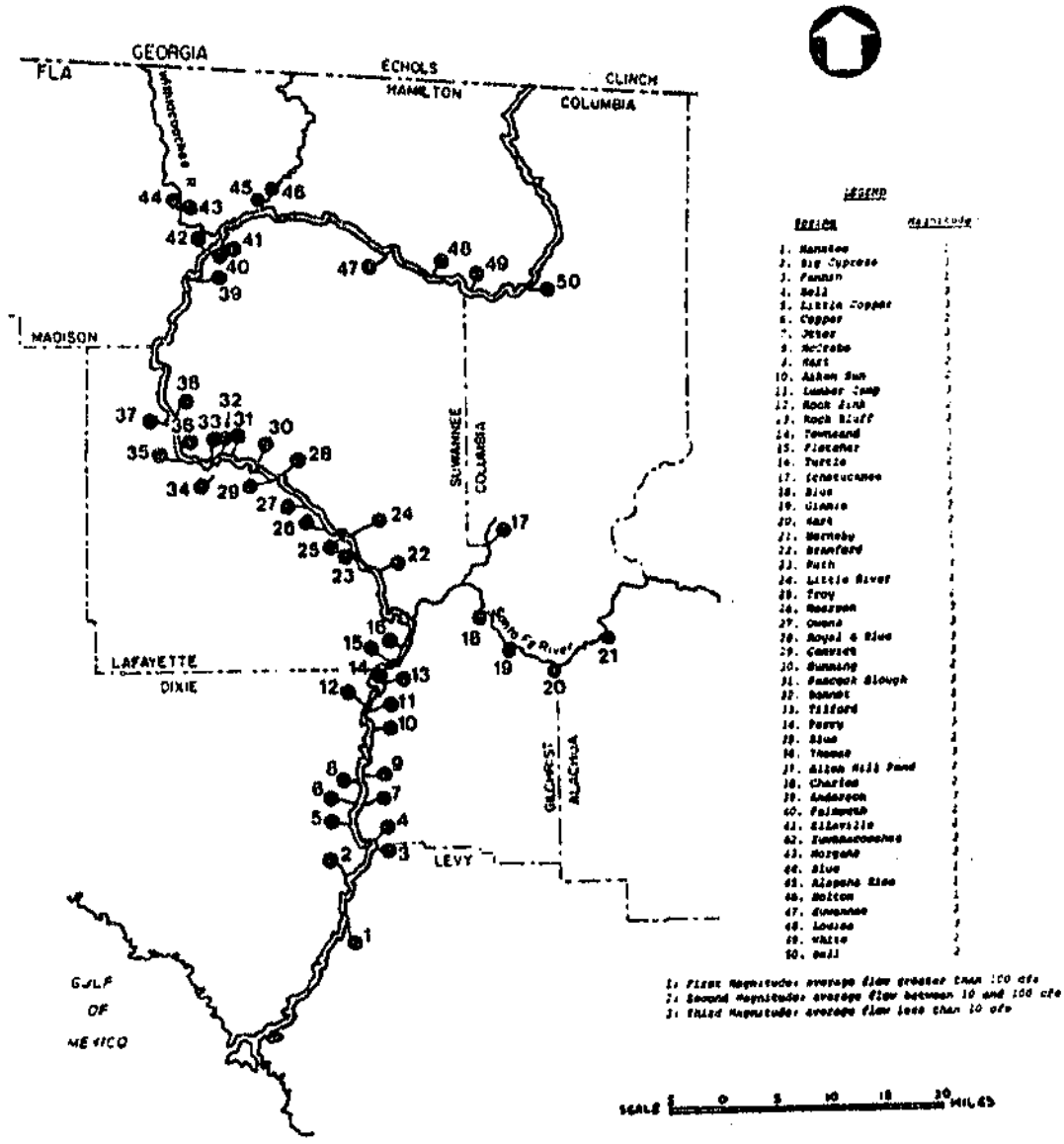


FIGURE 7. MAJOR SPRINGS IN THE SUWANNEE RIVER BASIN (FLORIDA DEPARTMENT OF ADMINISTRATION 1977)

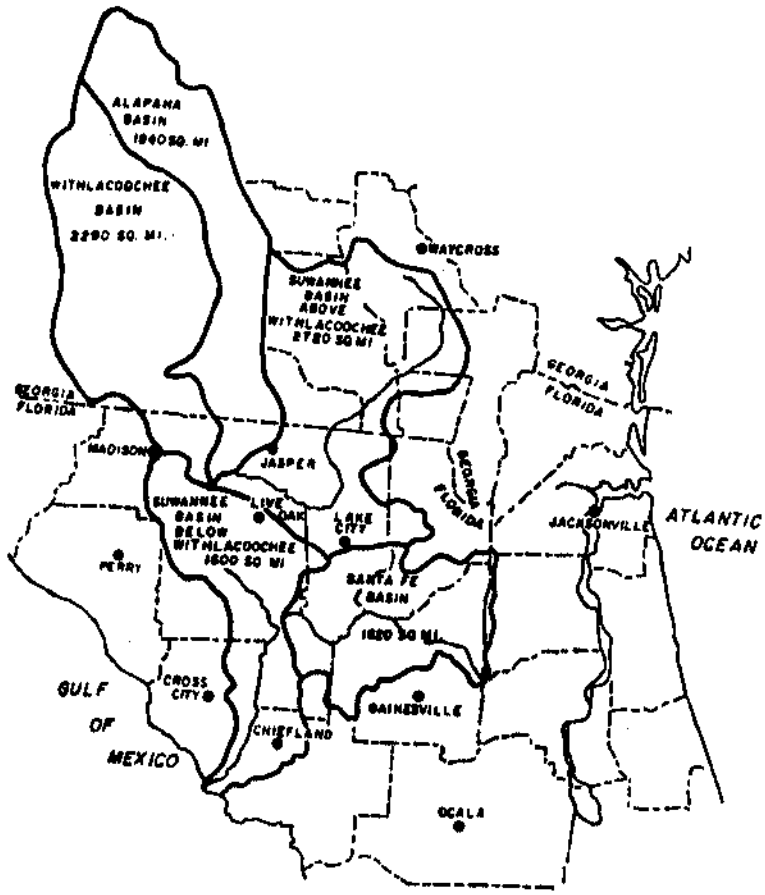


FIGURE 8. SUWANNEE RIVER DRAINAGE BASIN AND SUBBASINS (CRANE 1983)

SUWANNEE RIVER BASIN

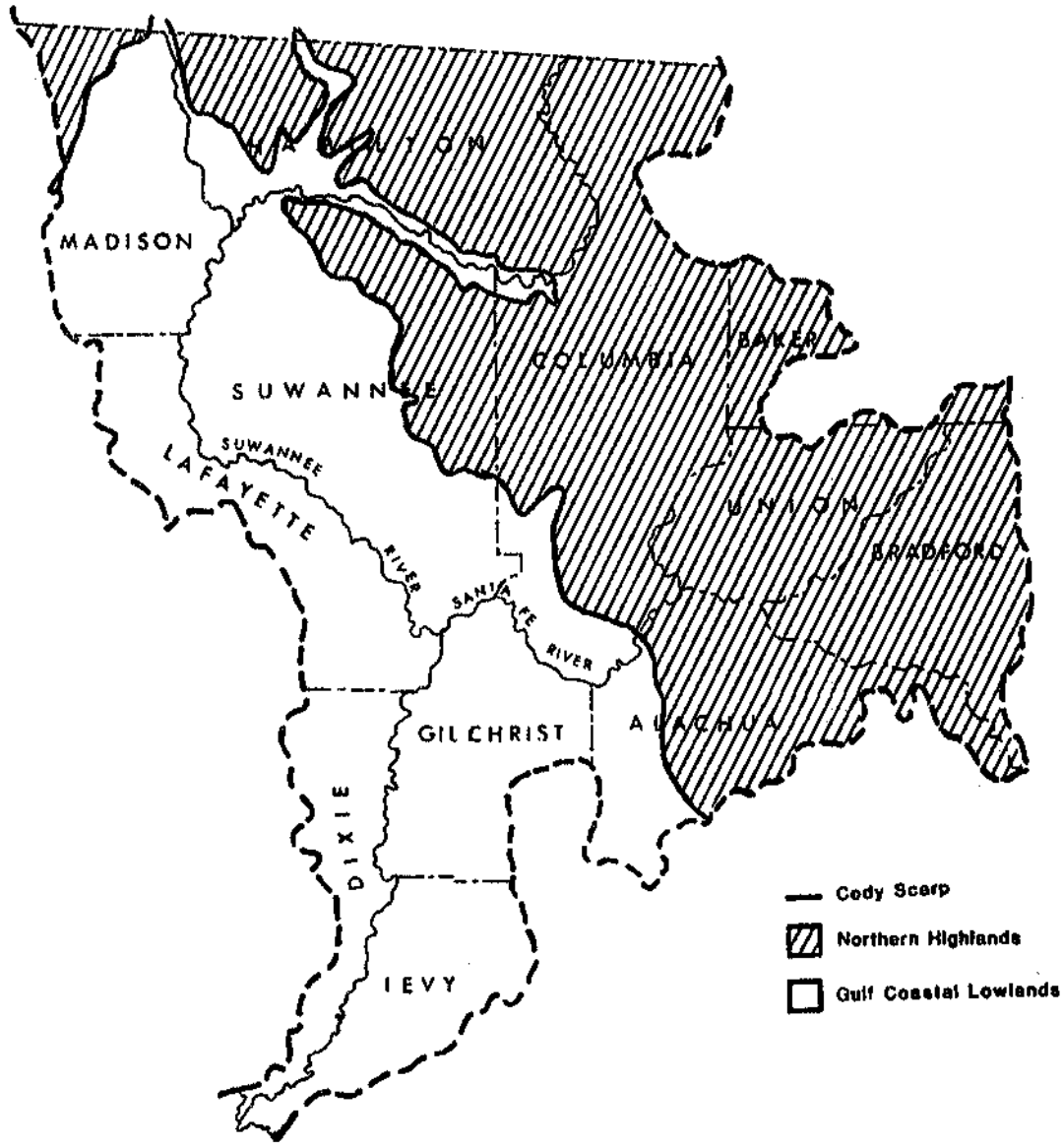


FIGURE 9. LOCATION OF THE CODY SCARP AND THE TWO MAJOR PHYSIOGRAPHIC DISTRICTS WITHIN THE SUWANNEE RIVER BASIN, THE NORHERN HIGHLANDS AND THE GULF COASTAL LOWLANDS (BROOKS 1981a, b;CERYAK et al. 1983)

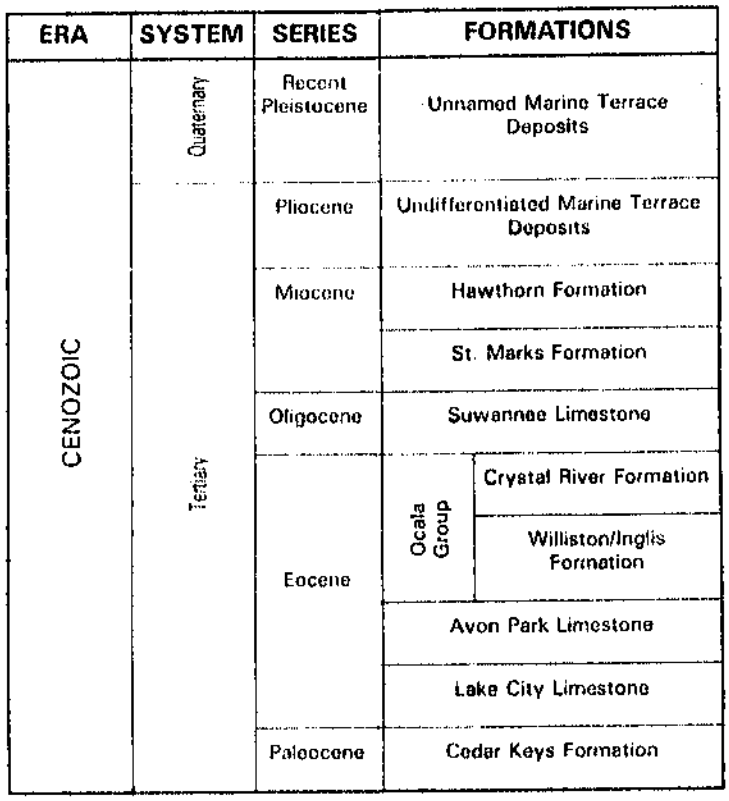


FIGURE 10. THE GEOLOGIC TIME SCALE AND STRATIGRAPHIC NOMENCLATURE FOR GEOLOGIC FORMATIONS IN THE SUWANNEE RIVER BASIN (MODIFIED FROM CERYAK et al. 1983)

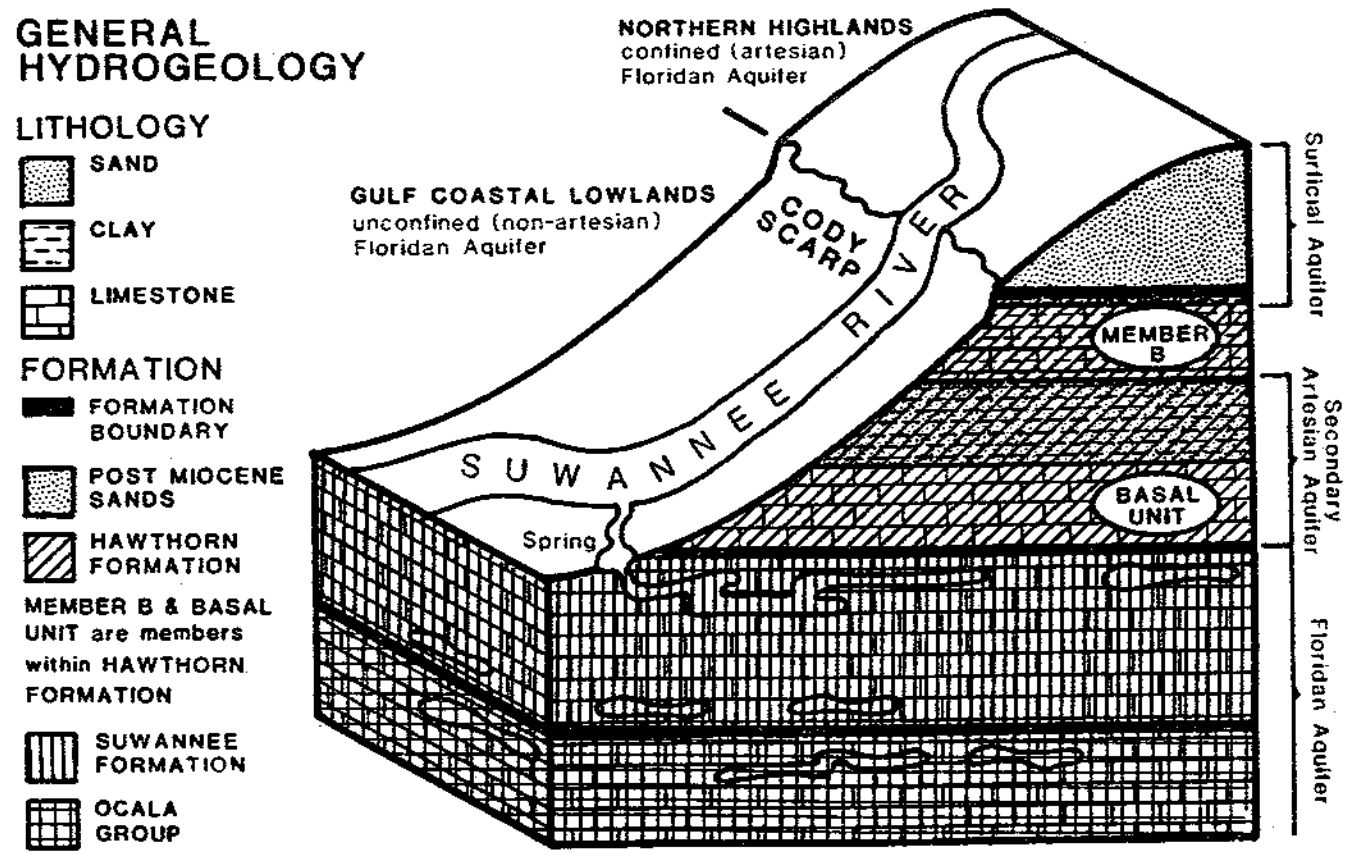


FIGURE 11. GENERALIZED HYDROGEOLOGY OF THE SUWANNEE RIVER BASIN (MODIFIED FROM CERYAK et al. 1983)

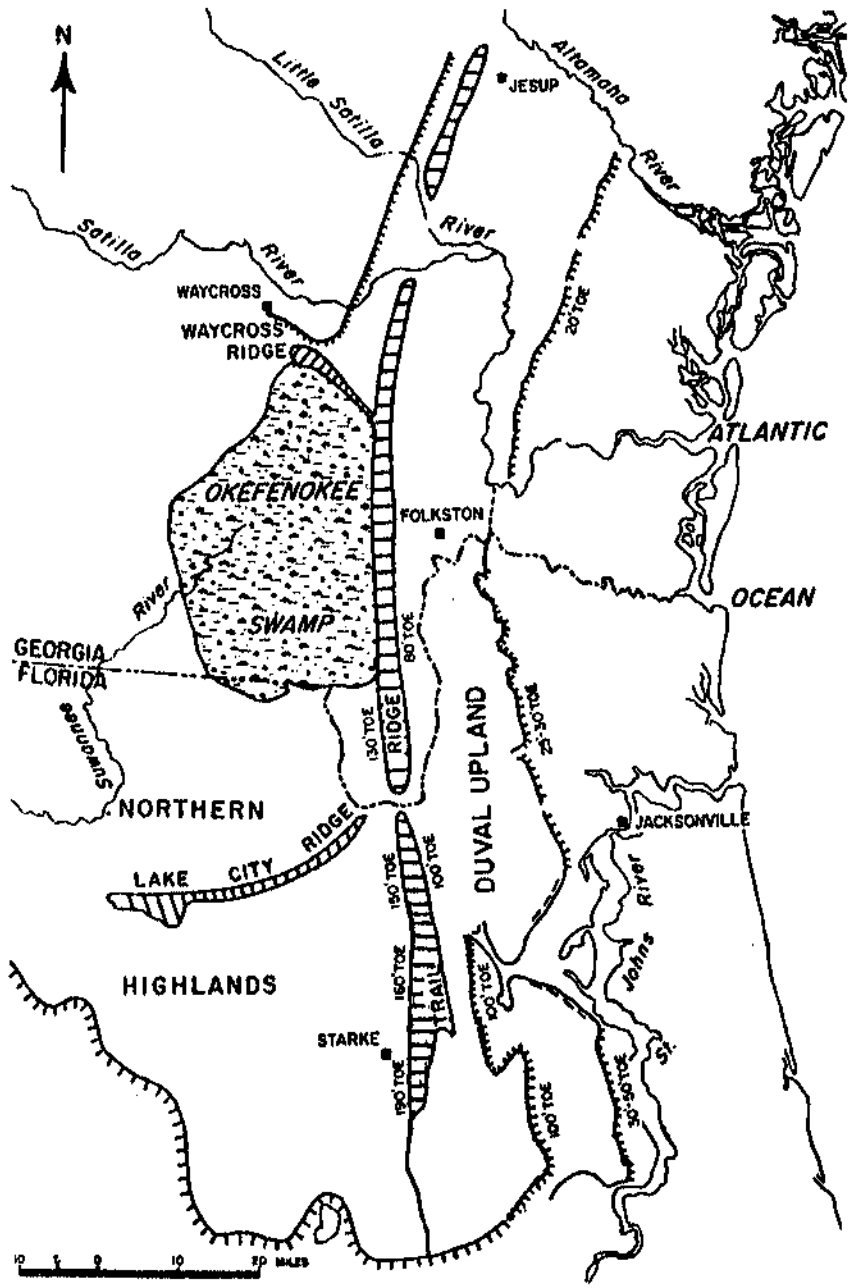


FIGURE 12. LOCATION OF THE TRAIL RIDGE, LAKE CITY RIDGE, AND THE OKEFENOKEE SWAMP IN NORTHCENTRAL FLORIDA AND SOUTHEASTERN GEORGIA (MODIFIED FROM PIRKLE, PIRKLE, AND YOHO 1977)

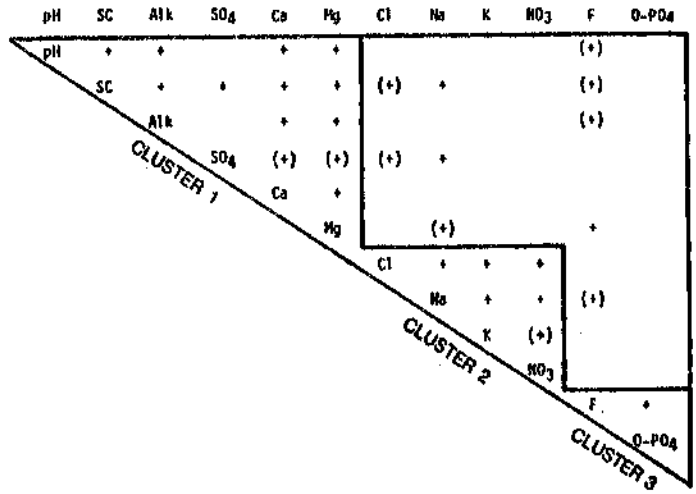


FIGURE 13. CORRELATION ANALYSIS OF WELL WATER PARAMETERS FOR WELLS TAPPING DIFFERENT STRATA WITHIN THE SUWANNEE RIVER BASIN (FROM CERYAK ET AL. 1983). CLUSTERS GROUP PARAMETERS THAT SHARE HIGH VALUES. CLUSTER 1 GROUPS PARAMETERS ASSOCIATED WITH THE FLORIDAN AQUIFER, CLUSTER 2 GROUPS PARAMETERS ASSOCIATED WITH THE SURFICIAL AQUIFER, AND CLUSTER 3 INCLUDES PARAMETERS ASSOCIATED WITH THE SECONDARY AQUIFER OF THE HAWTHORN FORMATION.

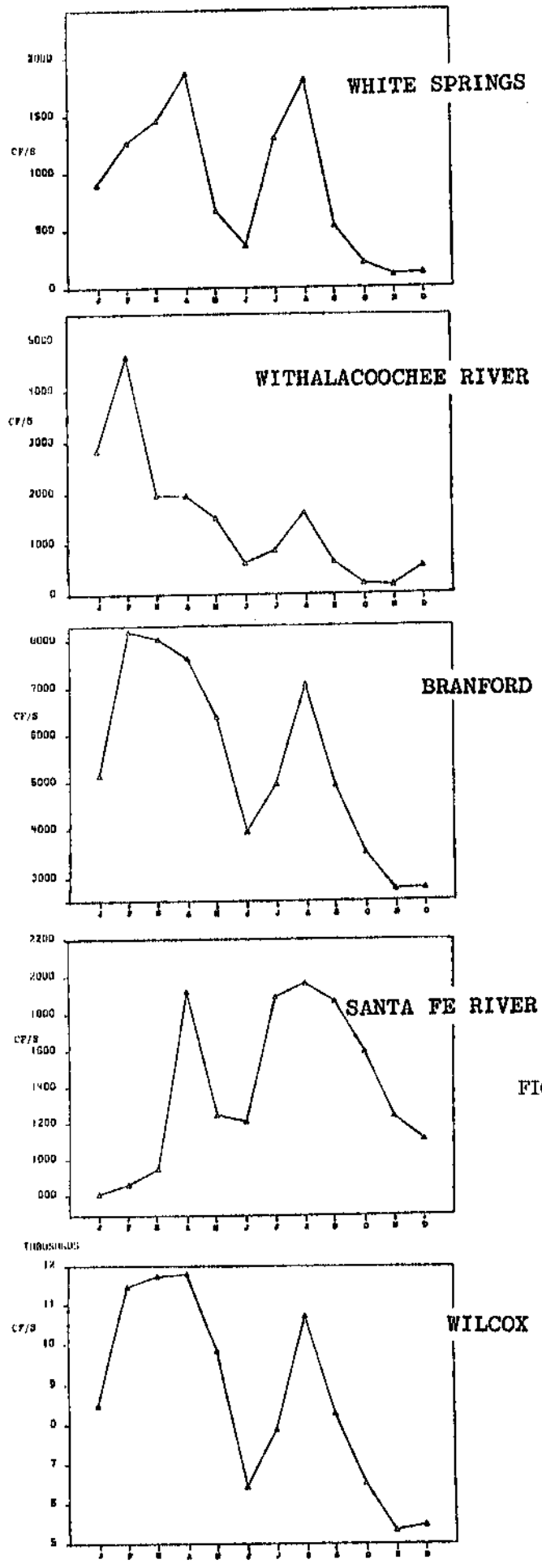


FIGURE 14. MONTHLY MEAN OF DAILY DISCHARGES BY CALENDAR MONTHS FOR 1982 AT THE FIVE U.S.G.S. GAGING STATIONS IN FIGURE 17. GAGING STATIONS ARE ARRANGED FROM UPSTREAM (TOP) TO DOWN-STREAM (BOTTOM), (UNPUBLISHED DATA FROM U.S.G.S., TALLAHASSEE)

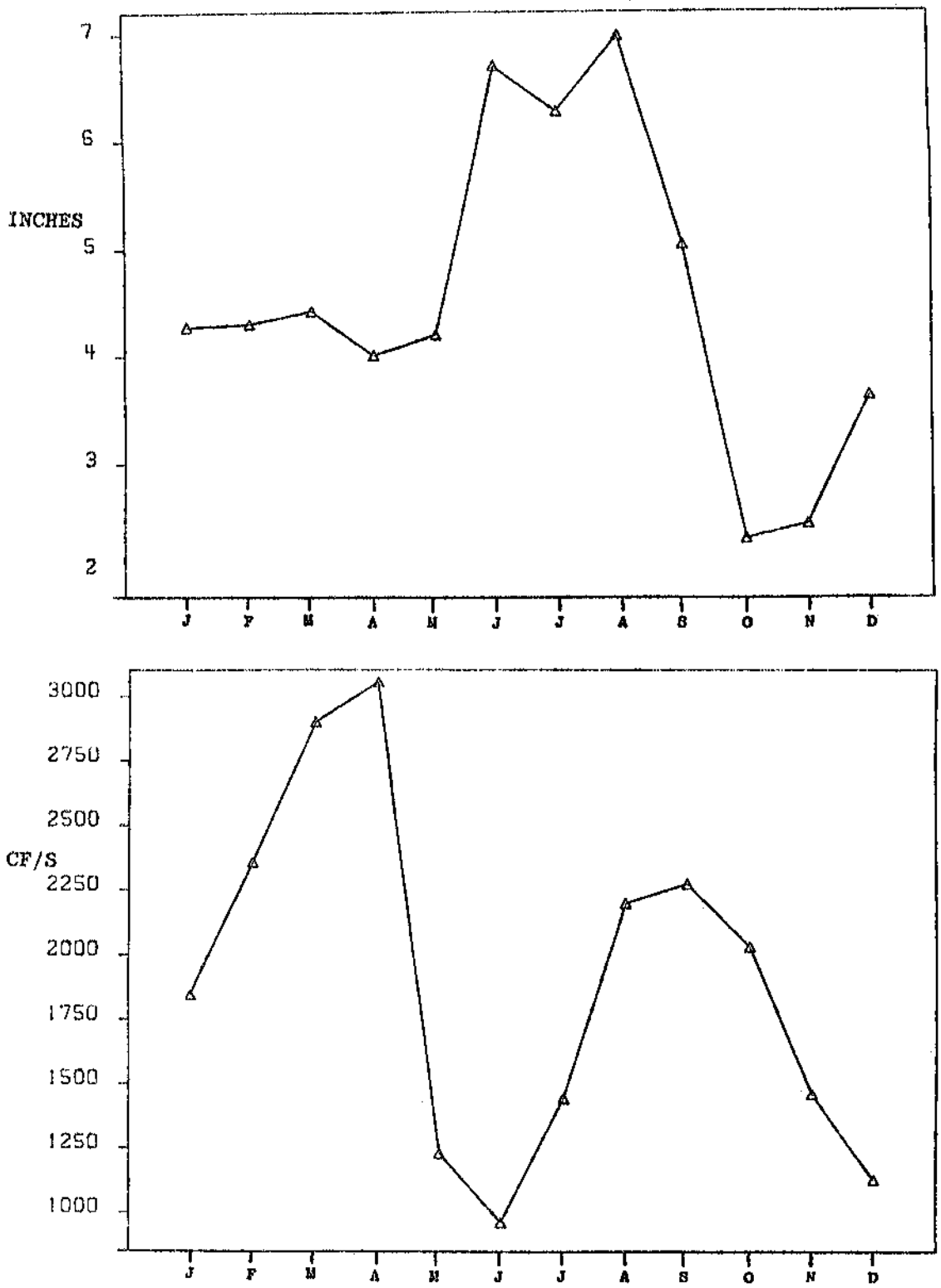


FIGURE 15. LONG-TERM MONTHLY PRECIPITATION AND RIVER DISCHARGE IN THE UPPER SUWANNEE RIVER BASIN. LONG-TERM (1952-1978) MEAN MONTHLY PRECIPITATION (INCHES) AT JASPER, FLORIDA (UPPER); AND LONG-TERM (1924-1978) MONTHLY MEAN OF DAILY DISCHARGES AT WHITE SPRINGS, FLORIDA (DATA FROM CERYAK et al. 1983)

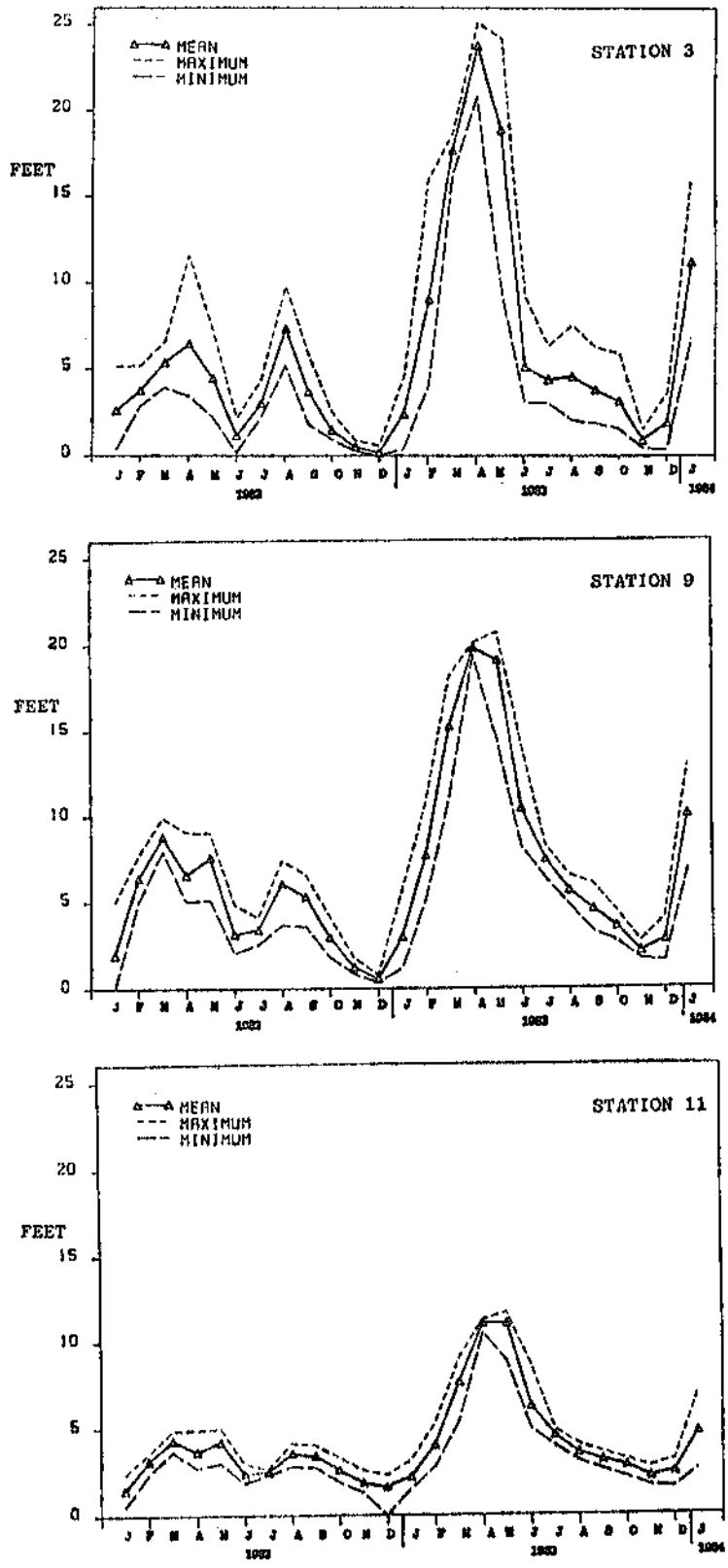


FIGURE 16. SAMPLING-MONTH MEAN, MAXIMUM AND MINIMUM OF DAILY STANDARDIZED GAGE HEIGHTS FOR STATION 3 (WHITE SPRINGS), STATION 9 (BRANFORD), AND STATION 11 (WILCOX) DURING THE 25 SAMPLING-MONTH STUDY PERIOD, JANUARY 1982-JANUARY 1984 (UNPUBLISHED DATA FROM U.S.G.S., TALLAHASSEE).

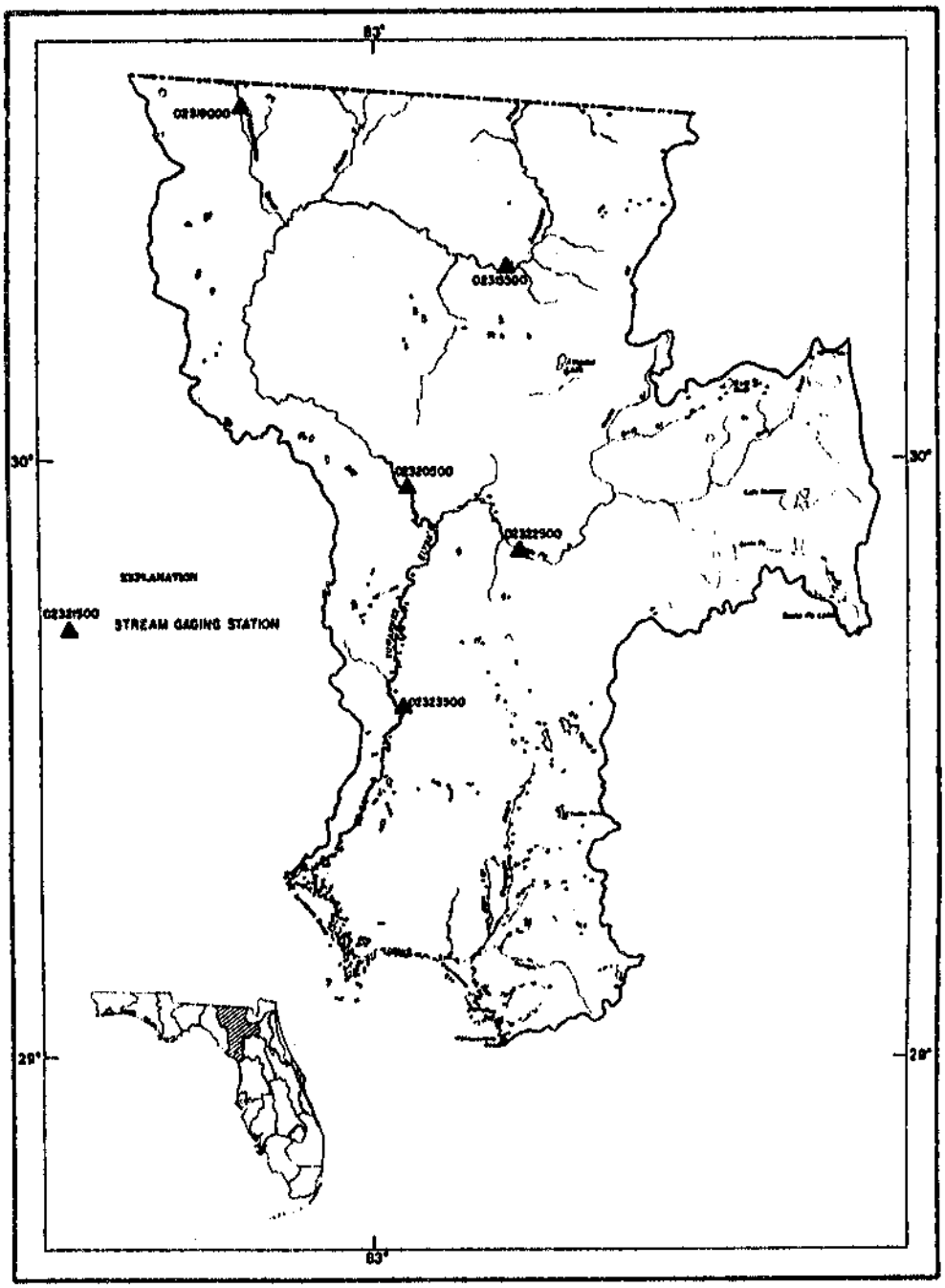


FIGURE 17. LOCATION OF U.S.G.S. STREAM GAGING STATIONS:
02315500-SUWANNEE RIVER AT WHITE SPRINGS;
02320500-SUWANNEE RIVER AT BRANFORD;
02323500-SUWANNEE RIVER NEAR WILCOX;
02319000-WITHLACOOCHEE RIVER NEAR PINETTA;
02322500-SANTA FE RIVER NEAR FORT WHITE
(MODIFIED FROM U.S.G.S. 1982)

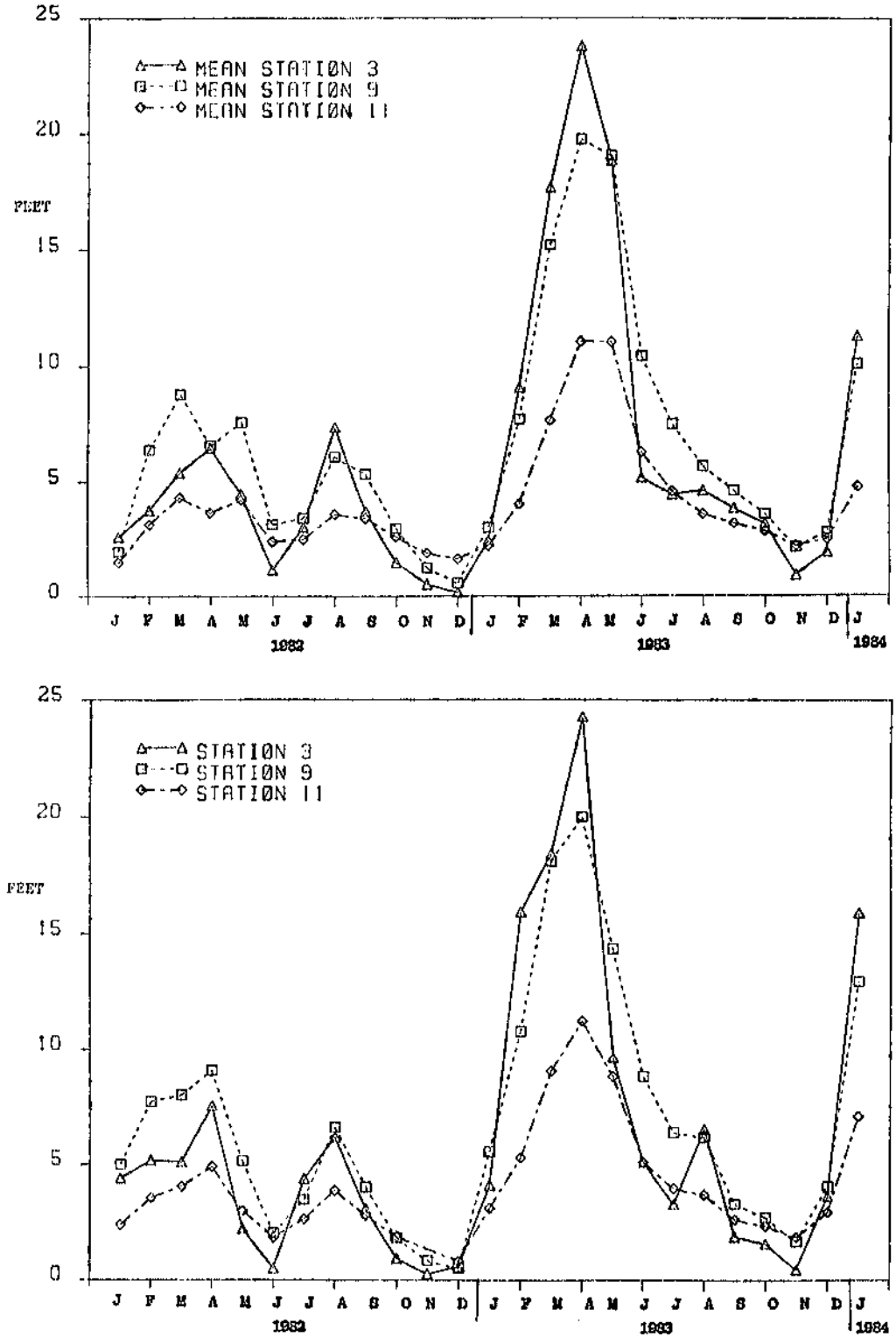


FIGURE 18. SAMPLING-MONTH MEAN OF DAILY STANDARDIZED GAGE HEIGHTS (UPPER), AND SAMPLING-DAY STANDARDIZED GAGE HEIGHTS (LOWER) FOR STATIONS 3, 9, AND 11 DURING THE 25 MONTH STUDY PERIOD, JANUARY 1982-JANUARY 1984 (UNPUBLISHED DATA FROM U.S.G.S., TALLAHASSEE).

WATER CHEMISTRY

Introduction

The chemical content of natural water varies from region to region and is a reflection of local geography and climate. The Suwannee River is unique in that several environmental and geological factors influence the water chemistry throughout the river. The stations of the upper river receive water from the Okefenokee Swamp which is high in organic matter, acidity, and color. As the river flows southward the chemical characteristics are affected by three aquifers, about 50 springs, the discharge of three rivers (the Withlacoochee, Alapaha, and Santa Fe), and numerous streams. In addition to variation in the above inputs, cultural influences such as municipal sewage treatment plants, and Occidental Chemical and Agricultural Products (Oxy) as well as other industrial dischargers (particularly in Georgia) introduce nutrients and waste products into the river. Droughts and periods of unusually low flow occur in the summer and winter months while floods and high waters often occur in the spring and fall.

The combination of hydrology, geology, and industrial activity results in distinct chemical characteristics for the water at each station; from the acidic, highly colored water near the state line to relatively alkaline, and nutrient enriched water near the mouth.

To assess the ambient water quality of the Suwannee River, several physical and chemical parameters, including pH, the major ions, and the primary nutrients were analyzed over the two year study.

Methods

Surface water samples were collected monthly at each station in 2 liter polyethylene containers, by Tallahassee DER staff, placed on ice, and transported to Jacksonville's DER chemistry laboratory. The samples were analyzed for the chemical parameters listed in Table 6. Physical parameters such as D.O., pH, temperature, and conductivity were measured in situ at the time of sampling and upon arrival at the biology laboratory in Tallahassee.

The Jacksonville DER staff collected mid-depth samples from 23 stations on a monthly basis. By monitoring 23 stations (including the major tributaries) in addition to the 11 biological

stations, a more complete data set is presented for several of the major parameters. The Jacksonville office made 3 sampling trips per month (upper Suwannee River - 11 stations, middle Suwannee River - 6 stations, and lower Suwannee River - 6 stations). Samples were analyzed in the Jacksonville DER chemistry laboratory for the parameters listed in Table 7. Physical parameters were measured in situ at the time of sampling, and upon arrival at the Jacksonville laboratory. Mean values for the major tributaries are presented in Table 8. All Jacksonville and Tallahassee DER station descriptions are listed in Table 9.

All laboratory procedures followed Methods for Chemical Analysis of Water and Wastes (U.S. EPA 1979), and Standard Methods (APHA 1980).

The laboratory methods and procedures used to analyze the Jacksonville chemistry samples were reviewed and compared to those used by the Tallahassee staff. For two of the parameters, D.O. and pH, different methods of analysis were used. The D.O. values recorded by Jacksonville were obtained using the Winkler or Iodometric method, while the Tallahassee DER staff utilized the membrane electrode or electrometric method. Values for pH were obtained by Jacksonville staff using a standard pH probe, while Tallahassee staff utilized an Orion-Ross combination epoxy shield pH electrode (H4100-1) which is the preferred method in low ionic strength waters. Consequently, to be consistent, the summary of pH and D.O. trends will include Tallahassee data values only.

In cases where the sampling method and/or depth of the water column was a significant factor and caused a variation in data (e.g., color,turbidity,temperature, and Secchi disc), it was necessary to review the Jacksonville and Tallahassee data separately.

Additional water samples were collected by the DER biology section in 20 liter polyethylene containers at five to seven of the biological monitoring stations. These samples were transported to Florida State University for analysis of Radium 226 by W. C. Burnett and S. Deetae. Detailed methology for radium analysis is presented in Radium In The Suwannee River (Burnett and Deetae 1984).

Results

pH

Rivers, such as the Suwannee, which drain swamps, often contain large amounts of dissolved and particulate organic matter and are characterized by acidic, low pH, soft, and highly colored water (Rai and Hill 1981). The color is derived from dissolved or suspended organic substances originating from partial decomposition of decaying vegetation. The organic sources are humic acids, fulvic acids (Berg 1962; Obneaus 1963 in Rai and Hill 1981), and humnolimnic acids (Gessner 1964; Shapiro 1965 in

Rai and Hill 1981) of mostly allocthonous origin. Humic acids in concentrations high enough to color the water contribute to the reduction of pH below 4.5 (Rai and Hill 1981). The pH is influenced by both the organic matter and the ionic interaction of the water. Low pH results from low alkalinity and a scarcity of bicarbonates, and may have toxic effects on aquatic organisms when compounded with other physical and chemical characteristics of the water (Fritz 1980).

Although pH of the river ranged from 3.6 to 8.0 during our study (Appendix A), means for the eleven sampling stations showed an increase of approximately 2 SU's in the upper river (Fig. 19). This change in pH may have been due to several factors: the organic content of the water, significant alkaline groundwater inflow and spring inputs, and activities within the river basin (Kaufman 1975).

Waters of the surficial aquifer, which discharge into streams and swamps of the upper Suwannee basin, are characterized by low pH, alkalinity, and conductivity and have a pronounced effect on the water chemistry of the upper river. The upper river stations are weakly buffered and tend to exhibit wide fluctuations in pH in response to river stage height. During periods of high flow, the pH in the upper river basin reached a low of 3.6 (Appendix A), presumably because of acidic swamp drainage. During droughts and periods of low flow, the pH is strongly influenced by input from groundwater and deeper aquifers. For example, pH at the sampling station above Swift Creek (river mile 40.9) reached a maximum of 7.1 during the lowest stage that occurred over the two years.

Between the second and third sampling stations (river miles 14.5 and 40.9) the chemical character of the water begins to be affected by springs (White Springs), aquifer inputs, and alkaline influents from Hunter Creek. The small increase in pH between river miles 40.9 and 41.8, above and below Swift Creek (Fig. 19), may be attributed to small alkaline spring inputs as well as to Swift Creek. Waters of the Floridan Aquifer which are usually high in alkalinity, pH, and conductivity begin to discharge through numerous springs into the river after Swift Creek which results in the increase in pH observed at river mile 79.1 above the Withlacoochee River (Fig. 19). Spring inputs increase as the river flows downstream, which results in the continuous gradual increase in pH values to river mile 183.0 near the mouth of the river.

Monthly mean pH values of the eleven sampling stations were inversely related to river stage height (Fig 20). Heavy rainfall occurred annually during early spring (March to April) and August resulting in the increase in river stage height. Minimum pH values occurred concomitant with maximum river stage when the acidic swamp drainage was most pronounced. Periods of drought and low flow occurred annually during June and late November, and during these months the pH approached neutrality due to the increased influence of discharges from the Floridan aquifer and other groundwater influents.

Alkalinity

Alkalinity is the ability of water to neutralize acids and is directly related to pH (Bouwer 1978). Alkalinity values in the river ranged from 0 to 143mg/L (Appendix A). The lowest values occurred in the upper basin and were indicative, as was pH, of the drainage from the Okefenokee Swamp, as well as seepage from the surficial aquifer (Crane 1983).

Alkalinity begins to increase at river mile 40.9 below Swift Creek. However, the greatest increase was noted between river mile 45.0 and 79.1 (Fig. 21) due to inflow from the Floridan Aquifer and White Springs. Alkalinity values continued to increase downstream to river mile 192.3 (near the mouth) as additional springs entered the river. Alkalinity varied inversely with stage height, with highest values tending to occur coincident with periods of low flow (Fig. 22). Low values were observed when alkaline ground water inflow was insignificant as a result of the increased acidic swamp runoff during periods of heavy rainfall and consequent high flow.

Color

Natural waters that exhibit a yellow to brown color are often the result of decomposition of organic matter. Organic sources may include humic materials (vegetation, tannins, peat) and aquatic plants (Kaufman 1975), as previously discussed. Color in the waters of the Suwannee River ranged from 640mg/L at the uppermost station to 5 mg/L near the mouth (Appendix A). While color is not an indication of the actual amount of organic material present, there is a direct relationship between color and organic content and an inverse relationship between color and pH (Fig. 23). Figure 24 shows Tallahassee subsurface and Jacksonville mid-depth color values. As the number of springs and groundwater inputs increase downstream the water column may sometimes become somewhat stratified due to partial mixing. Consequently mid-depth color values are consistently lower than surface water color values.

High color values coincided with low pH in the upper Suwannee and decreased as pH and alkalinity increased downstream (Fig. 23). This was most likely due to the greater influence of springs and alkaline groundwater inflows downstream. Increased color was usually observed immediately following periods of rainfall, and consequently high river stage (Fig. 25), due to the flush of organic matter into the river from swamp drainage.

Conductivity

Specific conductance is a measure of the ability of water to conduct an electrical current and is an indicator of the presence of inorganic chemicals in the water such as chlorides, sulfates, and carbonates.

Lowest conductivity values were noted in the upper basin but conductivity increased downstream as springs, groundwater inflows, and the discharges from Hunter and Swift Creeks contributed additional amounts of fluorides, chlorides, and sulfates. This was particularly evident between river miles 40.9 and 45.0, above and below Swift Creek (Fig. 26). Additionally, industrial and municipal waste materials from discharges to the Withlacoochee River in Georgia, and the Santa Fe River (Appendix A) may have resulted in the increase in conductivity at the confluence of these rivers at river miles 80.1 and 150.8 respectively. Those types of facilities are known to discharge high concentrations of inorganic ions (Dye et al. 1979). Conductivity values increased progressively from river mile 80.3 downstream, with highest values observed at river mile 192.3 near the mouth of the river.

An inverse relationship between stage height and conductivity was noted (Fig. 27). During periods of high water, the dilution of dissolved solids reduced specific conductance, while during low water periods, the concentrated soluble minerals and inorganic ions resulted in higher conductivity values. Similar trends in specific conductance have been noted by Dye et al. (1980) at Lake Kissimmee.

Temperature

Water temperature may often be a limiting factor for aquatic organisms because they are generally less tolerant of large temperature fluctuations than terrestrial organisms (Odum 1953). Temperature is also an important factor in bacterial metabolism and such processes as nitrification (Hutchinson 1957).

Mean temperature ranged from 8.5°C to 26.5°C during the period of this study. Values fluctuated, as expected, seasonally, with the highest temperatures occurring in July and the lowest in January (Fig. 28). The sub-tropical climate of the basin accounts for these seasonal trends. The river never freezes and prolonged heating starts early in February and continues through the fall, resulting in the variation of temperature from spring to winter. Local conditions can alter the temperature over distance and can be significant. Temperature fluctuations were evident at stations in close proximity to spring and groundwater inputs. In relation to air temperatures spring water is cold in the summer and usually warm in the winter (Rosenau et al. 1977).

During January, 1983, temperatures rose from 7.1°C at river mile 14.0 near the state line to 12°C at river mile 183.0 near the mouth of the river (Fig. 29). Spring inputs after river mile 41.8 located below Swift Creek, Suwannee Springs, Alapaha Rise, Ellaville, and springs in the Withlacoochee River result in increased temperature values downstream to river mile 79.1. Spring water from the shallow aquifer in the upper stations is at or near air temperature, (Rosenau et al. 1977) resulting in relatively constant temperature values in the lower river.

In July, temperature values in the river varied from 29.0°C at river mile 14.0 to 26.5°C at river mile 183.0. A decrease at river mile 79.1 is observed due to the significant inflow of colder spring water from Alapaha Rise, Falmouth, and Ellaville springs (Rosenau et al. 1977). Temperatures increased slightly after the confluence with the Withlacoochee River downstream to river mile 183.0.

Dissolved Oxygen

Dissolved oxygen (D.O.) levels in natural waters are the result of numerous physical, chemical, and biological activities in a body of water. D.O. is essential to the metabolism of all aquatic organisms that possess aerobic respiratory biochemistry.

D.O. values ranged from 2.5 to 12.6mg/L during the study (Appendix A). Mean percent saturation and mean D.O. values are plotted in Figs. 30 and 31 and indicate a maximum mean saturation of 69% for the river. D.O. values were influenced to a great extent by spring and groundwater influents which vary throughout the river. Lowest values for saturation occurred at river mile 79.1 and 80.7 above and below the Withlacoochee River (Fig. 30) due to the low D.O. values found in the springs which discharged above river mile 79.1. D.O. increased markedly at river mile 93.0 (possibly due to turbulent reaeration through this portion of the river) and then gradually increased to river mile 183.0, the lower sampling station.

The solubility of oxygen varies inversely with temperature and D.O. and the Suwannee River reflected this pattern. D.O. was lowest in the summer but increased during the fall to wintertime peaks (Fig. 32). This pattern, of course, may also reflect seasonal changes in periphyton populations.

Sulfate

Sulfate is present in rainwater and is also formed through the dissolution of evaporites such as gypsum and anhydrite which occur in the Floridan Aquifer (Bouwer 1978, Crane 1983). Sulfate values ranged from 0 to 40mg/L (Appendix A) during our study, with the lowest values found at the upper stations. Mean sulfate values remained high after river mile 41.8 as a result of the sulfate ions entering the river via Swift Creek (Fig. 33). The original source of sulfate in the Suwannee basin may have been from waters circulating through the aquifer (Crane 1983), but the substantial increase noted at Swift Creek is due to drainage of Oxy's gypsum ponds into Swift Creek (U.S. EPA 1978).

Mean sulfate values for Hunter and Swift Creek were 44.7 and 101.0 mg/L respectively (Table 8). Periodic peaks in sulfate concentration can be attributed to flow variations which display seasonal patterns (Fig. 34). As with most chemical constituents the winter high waters diluted the concentration of sulfate ions, while during the summer, low waters concentrated the ions.

Fluoride

The dissolution of fluor-phosphate minerals that are present in the Hawthorn formation, which underlies much of the river basin, and the mining of these same minerals at Oxy's phosphate mining operation, result in the fluctuation of fluoride levels in the upper Suwannee River (Crane 1983).

Mean fluoride values ranged from .024mg/L to .360mg/L during the study (Appendix A), although highest values were noted at river mile 40.9 (to 1.2 mg/L) below Swift Creek. This was not surprising since fluoride is a known waste product of phosphate processing (Florida State Board of Health 1965; U.S. EPA 1978) and mining waste is discharged through Swift Creek. Mining waste may also have contributed to the small increase in fluoride observed below Hunter Creek at river mile 14.0.

Mean values of fluoride concentrations for the eleven sampling stations (Fig. 35) indicate that fluoride concentrations increased substantially after the confluence of Swift Creek at river mile 40.9 and then dropped rapidly at river mile 80.1 below the Withlacoochee River. Fluoride concentration continued to decrease downstream to river mile 192.3 in the absence of substantial additional sources.

Mean fluoride concentrations varied seasonally in response to river stage (Fig. 36). During early spring and autumn, periods of high flow diluted the concentrations of fluoride, while the highest concentrations of fluoride occurred during periods of low flow.

Chloride

Chloride is one of the major inorganic anions in water and waste water. Primary sources of chloride in natural waters are precipitation, marine aerosols, and the phosphate mineral apatite (Hem 1959).

Mean chloride concentrations ranged from 5.70 to 7.70mg/L (Fig. 37). Although small in magnitude, chloride values fluctuated in the river due to several factors: 1) spring inputs of Cl^- upstream of the respective stations (White Springs at river mile 41.8, Ellaville and the Alapaha Rise at river mile 93.0 (Rosenau et al. 1977) combining with, 2) mining discharge at river miles 14.3 (Hunter Creek) and 41.8 (Swift Creek) (Oxy's mining operation utilizes apatite). Surface runoff from agricultural operations and effluents from a paper mill and municipal sewage treatment plants in Southern Georgia may also have contributed to the increased chloride levels at river mile 93.0.

Mean chloride values fluctuated to river mile 128.8 below the Santa Fe River and thereafter increased to river mile 174.4. This increase may have been a function of chloride from several sources including the numerous springs that enter this portion of the basin (Rosenau et al. 1977). Additionally, the Santa Fe River receives effluents from a Dupont titanium mining operation,

from numerous municipal sewage treatment plants, and from industrial operations, which may account for the increase observed (Fig. 37). The fluctuating values observed at the lower sampling stations may be related to marine aerosols due to the proximity of these stations to the Gulf of Mexico (Crane 1983), as well as the combined effect of all the previously mentioned sources. Ceryak et al. (1983) noted, in an earlier study of the Suwannee River, that precipitation, evapotranspiration, and river stage accounted for the seasonal variation in chloride concentration. Mean chloride concentrations and river stage were inversely related as a result of dilution (Fig. 38). During periods of low flow (summer), chloride concentrations varied directly with stage height which suggests a relationship between chloride in the rainfall and surface water.

Turbidity

Turbidity is a measurement of suspended solid content caused by clay, silt, and other fine particulate matter present in the water. Mean values fluctuated from 2.8 NTU to 5.6 NTU over the eleven stations sampled by the DER-Tallahassee group. The results of DER-Jacksonville study are plotted in Fig. 39. A large variation in data values was observed due to different sampling methods (ie. surface and mid-depth) by the two groups and to possible stratification of the water column in the proximity of spring and groundwater inputs. Mean turbidity values increased at sampling stations where there was an influx of turbid waters from industrial effluents, and was more evident where the Jacksonville staff collected mid-depth samples. Oxy discharged turbid mining waste into the river above river miles 14.0 and 40.9 that increased turbidity values at these stations and immediately downstream. Turbidity increased proceeding downstream, due not only to Oxy's influence but also to the influx of the turbid waters from the Withlacoochee River. Turbidity was directly related to river stage. As expected, surface runoff during rainfall flushed sufficient amounts of particulate matter into the river to result in increased turbidity values during periods of high flow (Fig. 40).

Light Penetration (Secchi Disc)

The Secchi disc depth denotes water transparency and is often inversely related with organic color levels, algal biomass, and other suspended material in the water column (Brezonik 1978). The Secchi disc depth is the point where a weighted disc suspended in a water column disappears. The depth is influenced by the absorption characteristics of the water and the dissolved and particulate matter it contains (Wetzel 1975).

Secchi disc depth varied from .2 to 3.1m over the eleven stations sampled by DER-Tallahassee staff. However the DER-Jacksonville staff obtained values which were somewhat lower, (Appendix A). Mean values indicate that water clarity increased downstream, particularly after river mile 41.8 below Swift-Creek (Fig. 41). The clear water discharged from the springs along

the Suwannee likely accounted for this increase in transparency downstream.

At river mile 80.7, the influx of suspended solids from the Withlacoochee River may account for the decreased transparency values observed there. Water clarity increased during periods of low flow as a result of the springs and aquifers which provide a significant amount of the river volume during these drier periods (Fig. 42). During periods of rainfall, high flow, and increased swamp runoff, there was an increase in dissolved solids and particulates that were flushed into the river resulting in decreased water clarity.

Phosphorus

Phosphorus is a primary nutrient that regulates plant growth in natural waters. The inorganic phosphates are of major biological importance. They are found in the orthophosphate form, or as condensed phosphates which gradually hydrolyze in aqueous solution to the orthophosphate form (Task Group Report 1966). Orthophosphate includes the three ionized forms of phosphoric acid, $H_2PO_4^{-1}$, HPO_4^{-2}, PO_4^{-3}, and serves as an index of the total soluble phosphorus by which the trophic state of a body of water can be determined (Dye and Jones 1978).

Phosphates are one of the end products of the decomposition of organic matter and may result from the leaching of naturally occurring phosphatic minerals such as apatite which is present in the Hawthorn formation (Crane 1983). Other sources may contribute to phosphate levels found in the Suwannee River: industrial waste, sewage treatment plant discharges, and surface drainage from agricultural activities such as fertilizer applications (Kaufman 1975). However, the largest sources of phosphate in the basin are the effluents from Oxy's mining operation along the upper part of the river.

Mean total phosphate and orthophosphate values plotted by river miles (Figs. 43 and 44) showed a small increase from river mile 14.0 to 14.5 above and below Hunter Creek which was likely due to phosphate mining waste being discharged into Hunter Creek. The substantial increase in phosphorus at river mile 41.8 below Swift Creek was a direct result of the discharge from Oxy's Swift Creek Complex (U.S. EPA 1978). Figs. 45 and 46 depict the maximum, mean, and ranges of total phosphate and orthophosphate found at each station, and show the excess of phosphates usually present at the confluence of the river with Swift Creek. Since the hydrolysis of condensed phosphates to orthophosphates may take only a matter of hours (Englebrecht and Morgan 1959; Devey and Harkness 1973), the orthophosphates then can readily be utilized by algal populations.

Oxidized metals, such as iron, major cations, and calcium, can induce precipitation of phosphate at optimum pH levels. Increased pH at river mile 56.9 above the Withlacoochee River could have led to the formation of calcium carbonate which

coprecipitates phosphate (Otsuki and Wetzel 1972). The sorption of phosphates onto clay minerals by chemical bonding of the anions to the cation edges of the clay is favored at pH 5 - 6 (Wetzel 1972). This complex ionic reaction, along with some utilization of phosphates by algae and phytoplankton, may account for the decrease in phosphate and orthophosphate concentration observed at river mile 56.9. Phosphate levels decreased to somewhat above background levels downstream to river mile 192.3 (the lowest sampling station) in the absence of additional significant phosphate sources (Fig. 43).

Total phosphate and orthophosphate concentrations were inversely related to river stage. Minimum phosphate levels were recorded during periods of high flow and rainfall, likely due to dilution (Fig. 47). An increase in phosphate concentration occurred concurrent with periods of low flow perhaps due to the increased proportion of the river volume that the discharges at Swift and Hunter Creeks contributed.

Nitrogen

Like phosphates, various forms of nitrogen are involved in biological activities in natural waters. Nitrogen exists in fresh waters in numerous forms: dissolved molecular nitrogen, organic compounds such as amino acids, proteins, and humic compounds, ammonia (NH_3), nitrite (NO_2), and nitrate (NO_3). In aerobic conditions, ammonia is oxidized to nitrite, then nitrate by nitrifying bacteria. These forms of nitrogen can then be utilized by phytoplankton (Wetzel 1975). Several sources contribute to the presence of nitrogen in the river basin: precipitation, nitrogen fixation, influents from surface and land drainage, effluents from sewage treatment plants and industrial operations, and groundwater sources (Biggar 1969; Wetzel 1975).

The most bioavailable forms of nitrogen for phytoplankton growth are ammonia and nitrate (Harvey 1940; MacIsaac and Dugdale 1972; Morris 1974 in Dye and Jones 1978). Ammonia values in the river, with the exception of the station below Swift Creek at river mile 41.8, ranged from .010 to .520mg/L (Table 8). A significant increase in the NH_3 was noted at river mile 41.8, but ammonia values then decreased to background concentrations by river mile 79.1 above the Withlacoochee River (Fig. 48). The major input of NH_3 during our study was from Swift Creek, and a maximum of 3.02mg/L NH_3 was observed immediately downstream of Swift Creek (Appendix A).

The low values for nitrogen at the first three stations are probably a function of few inputs of NH_3 and NO_3. However, the nitrification of ammonia likely resulted in the increased NO_2 + NO_3 concentrations observed downstream (Fig. 49). Nitrite + nitrate nitrogen (NO_2+NO_3-N) values in the river ranged from .017 to .990mg/L (Appendix A) and, as noted earlier, increased downstream. The application of inorganic fertilizers, surface runoff, and waste products from sewage treatment plants and industrial sources in the basin probably also contributed to

the high levels of this nitrogen form down river.

Total Kjeldahl nitrogen (TKN-N) is the sum of organic nitrogen and ammonia and includes a variety of organic decomposition products, including proteins, amino acids, urea, and methylamines (Wetzel 1975) found in sewage or other industrial discharges (Task Group 2610-P 1967 in Dye and Jones 1978). Additionally, large quantities of organic nitrogen are released into the water column as aquatic vegetation decays (Wetzel 1975). The organic nitrogen products present in effluents and decomposed matter can eventually be converted to bio-available nitrogen for aquatic primary productivity (Wetzel 1975). TKN, which varied directly with ammonia increased at river mile 20.9 and 41.8 below Hunter and Swift Creeks, probably due to the ammonia content of Oxy's effluent, discharged through Hunter and Swift Creeks (Fig. 50). The industrial operations and agricultural sources in the lower river may also have contributed TKN-nitrogen through various effluents and surface runoff.

Ammonia and TKN were inversely related to river stage height (Figs. 51 and 52). Maximum concentrations of both TKN and NH_3 were noted during periods of low flow probably due to the continuous discharge in the absence of dilution of nitrogenous material from Swift Creek, the Withlacoochee River, and other sources. With one exception, ammonia decreased during periods of high flow as a result of dilution. During March, 1983, a high level of ammonia was observed, concomittant with high river stage (Fig. 51) (below Swift Creek), which suggests that a substantial amount of ammonia was discharged into the river from Oxy during this time.

Radium*

Radium is a radioactive element having 13 isotopes, of which the natural uranium decay-series isotope radium 226 is the most common. According to Burnett and Deetae (1984), the mean concentration of Ra-226 in the river was 10.09 pCi/100L over the two year study. The upper river stations exhibited large fluctuations in radium content and ranged from 2.5 to 29.3 pCi/100L, while the lower river ranged from 1.8 to 19.2 pCi/100L (Fig. 53). The mean radium activity observed at the sampling station below Swift Creek was slightly lower than at the upper stations, which suggests there was no immediate influence from Oxy's phosphate mining activities on Ra-226 levels in the river.

The high radium concentrations present in the river are the result of the uranium enriched phosphate rock, present in the basin. Several factors, however, control the fluctuation of

* A more complete treatment of this subject is available in Burnett and Deetae (1984). Recent measurements of total radium activities in Suwannee River water by a new technique which doesn't require a preconcentration step indicate that these results may only represent the ionic or uncomplexed form. If confirmed by studies now in progress, this could be a significant finding implying the total radium burden may be higher than indicated by this and previous studies.

radium concentrations: the influx of groundwater via springs which are relatively high in radium content (Kaufman and Beiss 1977 in Burnett and Deetae 1984), and the interaction between soluble radium and particulate matter in the river (Burnett and Deetae 1984). Radium concentrations varied during extreme fluctuations of flow, with low radium concentrations observed during periods of high flow due to dilution by surface water runoff.

Burnett and Deetae (1984) noted a weak seasonal variation of radium concentration at the downstream stations: High radium values were measured in the early winter and summer while low values occurred in the early spring and fall. They hypothesize that this cycle may be related to the primary production cycle in the river.

Historical Chemistry Data

Several previous studies have been conducted in the Suwannee River to assess chemical water quality. Data from studies conducted from 1956 to present were retrieved from STORET for comparison with results obtained during the Biology Study. (STORET is a computerized data base utility maintained by EPA for storage and retrieval of physical and chemical data taken as part of individual monitoring programs by local, state, and federal agencies).

The compilation of water chemistry data from the following studies is presented in Appendix A. Sample station locations are presented in Figure 54.

1. The Environmental Protection Agency collected water chemistry samples from February, 1966, through March, 1966, in the lower river and March, 1966, through June, 1966, in the upper river as part of an environmental surveillance project.
2. The United States Geological Survey systematically collects water chemistry data throughout the state of Florida. Water Chemistry data from the Suwannee River are available from 1956 to present.
3. Environmental Services and Permitting collected water chemistry data bi-weekly from November, 1979, through July, 1981, and monthly from August, 1981, through March, 1982, as part of an environmental impact study prepared for the U. S. Army Corp of Engineers.
4. DER's Jacksonville District Office collected water chemistry data as part of the Permanent Network System of monitoring stations from 1970 to present.
5. Jacksonville DER collected water chemistry data from the Suwannee River from January, 1982, through December, 1983, to supplement the Tallahassee DER Biology Study.

Due to the large volume of data, only mean, maximum, and minimum values for the parameters are presented (Appendix A). Although this background data base is extensive, it is often difficult to make direct comparisons of the various values due to many inconsistencies. For example periods of sample collection

vary between agencies, and sampling frequency was often inconsistent from station to station and irregular for many of the parameters. It should also be noted that while sampling periods may have been similar, actual sample collections occured at different times, and this, combined with the large variations in river stages as well as fluctuations in industrial waste discharges, may have resulted in large variations in many of the mean values observed in the data.

Data Comparisons

Similar trends in mean pH, alkalinity, and conductivity were noted for all six studies with values increasing downstream. Generally, the pH values observed by each agency were similar with the exception of ESP and EPA. Several unusually low pH values were observed in the upper river by ESP (e.g., minimum of 2.8 was recorded at Benton compared to the minimum recorded by the Biology Study of 3.6). Low pH values were also observed throughout the river during the EPA study in 1966, most likely as a result of sampling in spring and early summer during periods of heavy rainfall and increased swamp discharge.

Alkalinity values generally fluctuated more than other parameters due to fluctuating inputs of springs, ground water, and river stage height although values observed during the EPA study were lower than others (e.g., a maximum of 36 mg/l (as $CaCO_3$) was recorded at Rock Bluff compared to the maximum recorded by the Biology Study of 143 mg/l (as $CaCO_3$)).

Conductivity values for the various studies were generally in close agreement. However, values observed during the EPA study in 1966 were lower than those observed by other studies perhaps as a consequence of sampling during the spring when rainfall runoff is greatest. A maximum of 104 umhos/cm was recorded at Rock Bluff below the Santa Fe confluence compared to a maximum of 331 umhos/cm measured during the Biology Study at the same station. Fluoride, chloride, and sulfate values collected by USGS and FDER were consistently higher at most stations than those of other agencies. This may have been due in part to the variety of sampling regimes although the actual reason is unknown. During the study conducted by EPA, values for these parameters remained low throughout the river, perhaps due not only to sampling during high river stage but also to the absence of many industrial and municipal discharges which were present during the more recent studies.

Turbidity values varied between the six studies most likely due to different sampling regimes as well as to the fluctuating discharges at Swift Creek and the Withlacoochee River. Mean Secchi (water transparency) values were relatively similar between agencies at comparable stations throughout the river.

Temperature values however, were indicative of sampling periods: Mean values for the study conducted by EPA from

February through early summer were lower compared to values observed during other studies in which sampling was conducted for an entire year.

Values for the phosphorus and nitrogen forms were expected to fluctuate in response to stage height, discharges from the mining operation at Swift Creek, and various industrial discharges which enter the river through the Withlacoochee and Santa Fe Rivers. Several discrepancies were observed between the various agencies and the Biology Study; mean values observed during the FDER district study were higher at most stations as were the orthophosphate values measured by USGS at the lower river stations. Values measured during the ESP study were lower at the station near White Springs and below Swift Creek but higher at the station near Suwannee Springs than values observed during the Biology Study. Phosphate values observed above Hunter Creek during this study were substantially higher than the phosphate and orthophosphate values measured at this station in previous studies.

Though comparing individual mean values for parameters measured by different agencies is difficult, comparing trends in these parameters throughout the river can be valuable. The results of the six studies that have been conducted in the Suwannee River from 1956 to present concluded with similar trends. Conductivity, alkalinity, pH, and sulfate increased downstream in response to major inputs of spring water, while parameters such as phosphate, orthophosphate, ammonia, and fluoride were elevated at stations immediately downstream of Hunter and Swift Creeks and subsequently decreased downstream.

Conclusions

The water chemistry of the Suwannee is regulated primarily by its hydrology and geography as well as by man induced alterations. Our chemical data suggest the presence of two distinctly different rivers. The upper river, river miles 10.5 through 45.0, and the lower river consisting of river miles 56.0 through 198.0. The upper stations were characterized by highly acidic water rich in dissolved in particulate organic matter but relatively nutrient-poor. The waters downstream became progressively higher in alkalinity, pH, and nutrients as a result of inputs from aquifers, springs, and industrial sources downstream.

The major influx of inorganic ions such as chlorides, sulfates, fluorides, and the major nutrients (nitrogen and phosphorus) occurred between river miles 38.0 and 42.0 from Oxy's Swift Creek discharge. The highest concentrations of these compounds were observed during periods of low flow, while dilution of these materials was evident during periods of high flow.

Other nutrient sources such as Goldkist Incorporated, municipal sewage treatment plants, and pulp operations on the Withlacoochee River, and mining operations and agricultural

drainage in the lower river, contributed lesser amounts of sulfates, chlorides, and nitrogen forms via treated effluent and surface runoff.

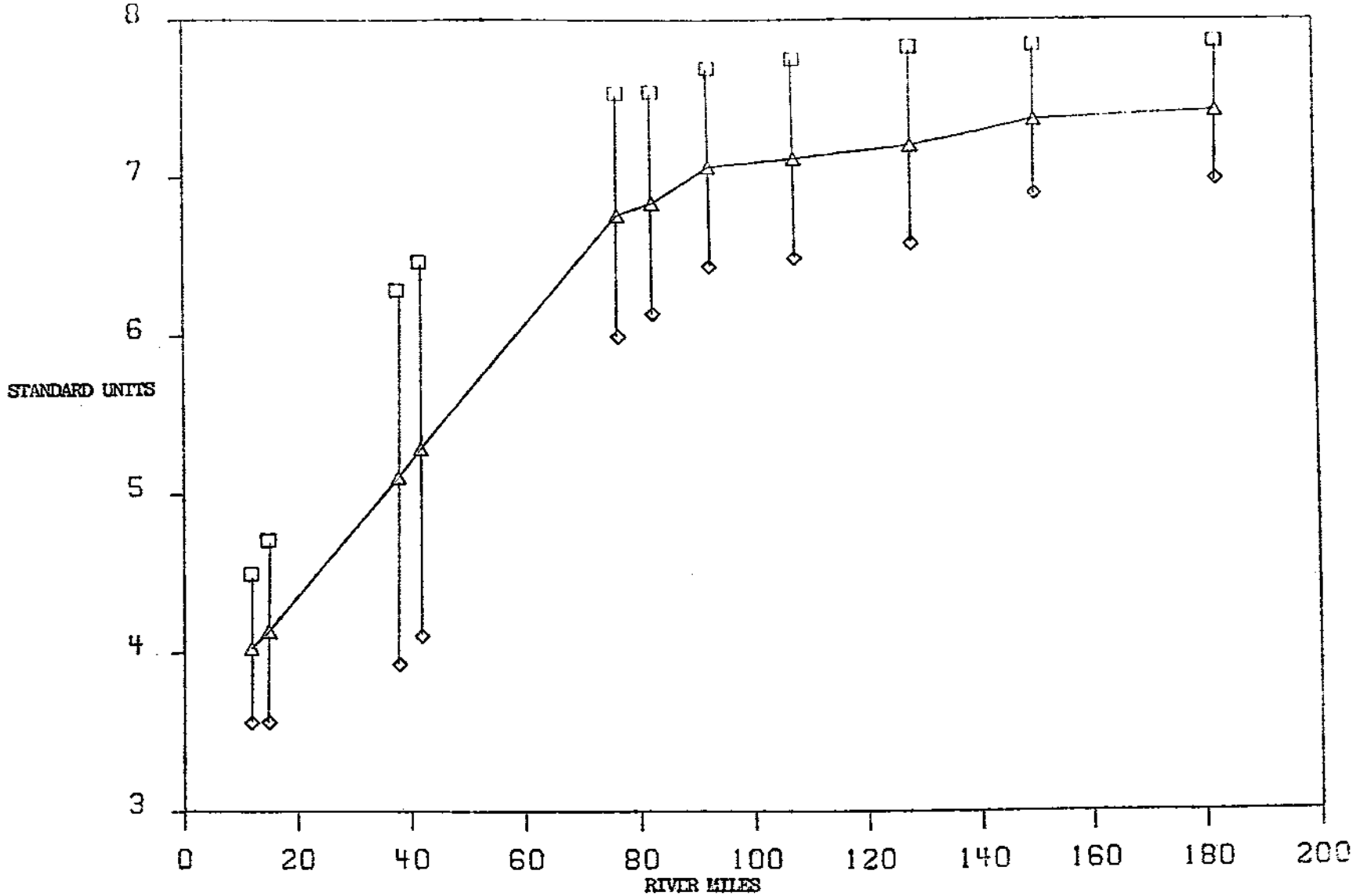


FIGURE 19. MEAN PH AND STANDARD DEVIATIONS BY SAMPLING STATIONS (DER-TLH DATA ONLY).

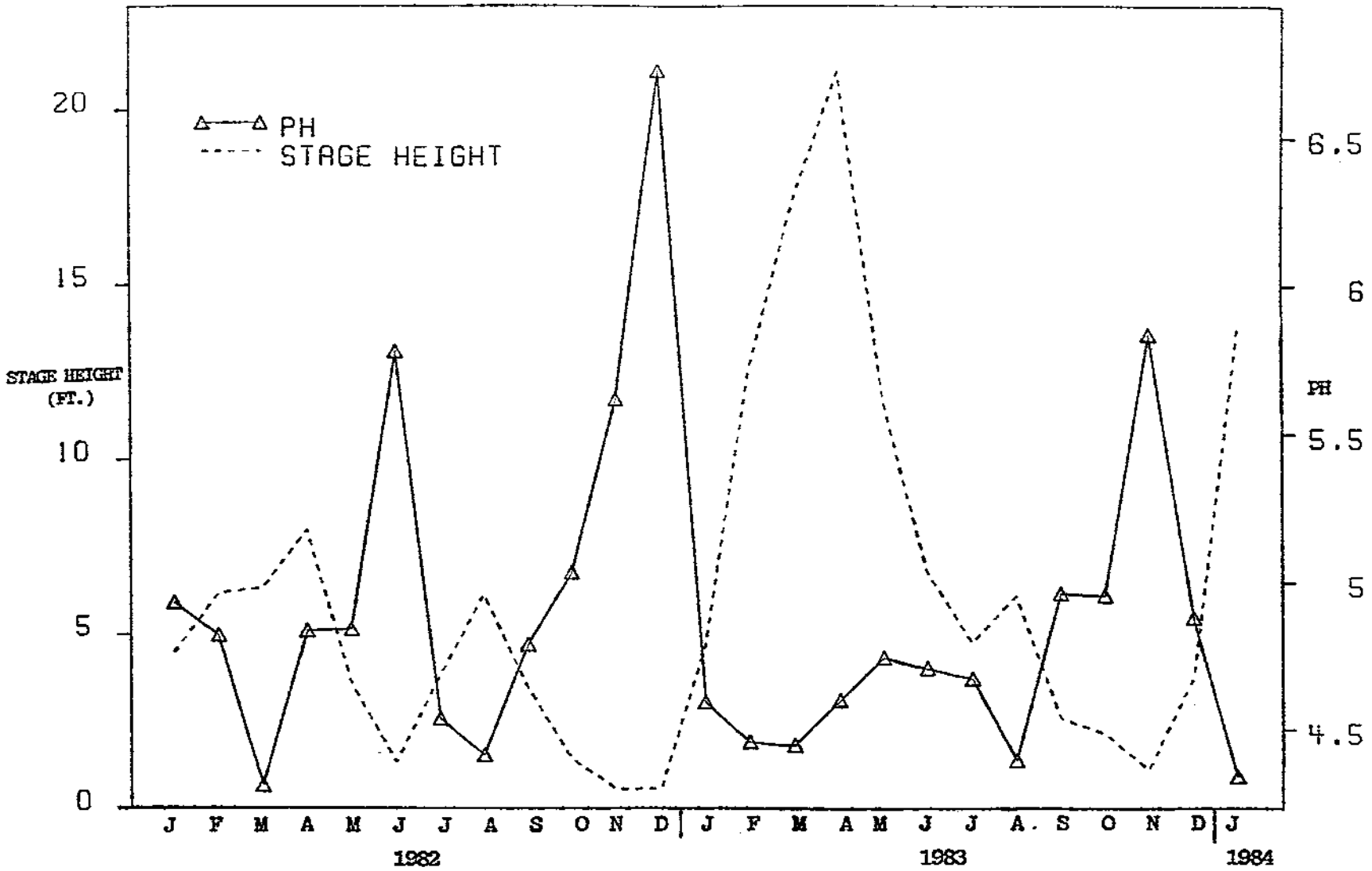


FIGURE 20. MONTHLY MEAN PH vs. RIVER STAGE HEIGHT.

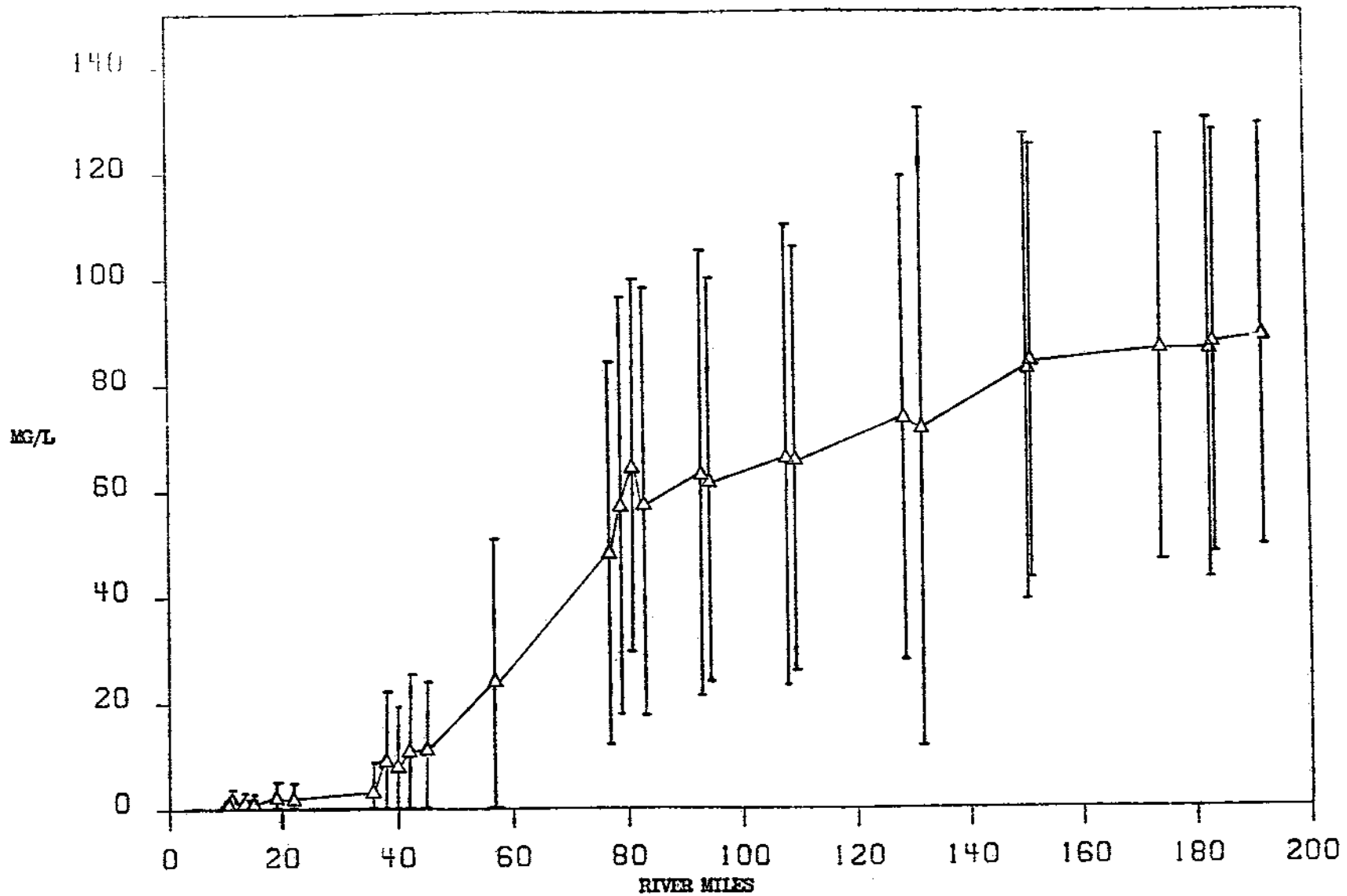


FIGURE 21. MEAN ALKALINITY ($CaCO_3$) AND STANDARD DEVIATIONS BY SAMPLING STATION.

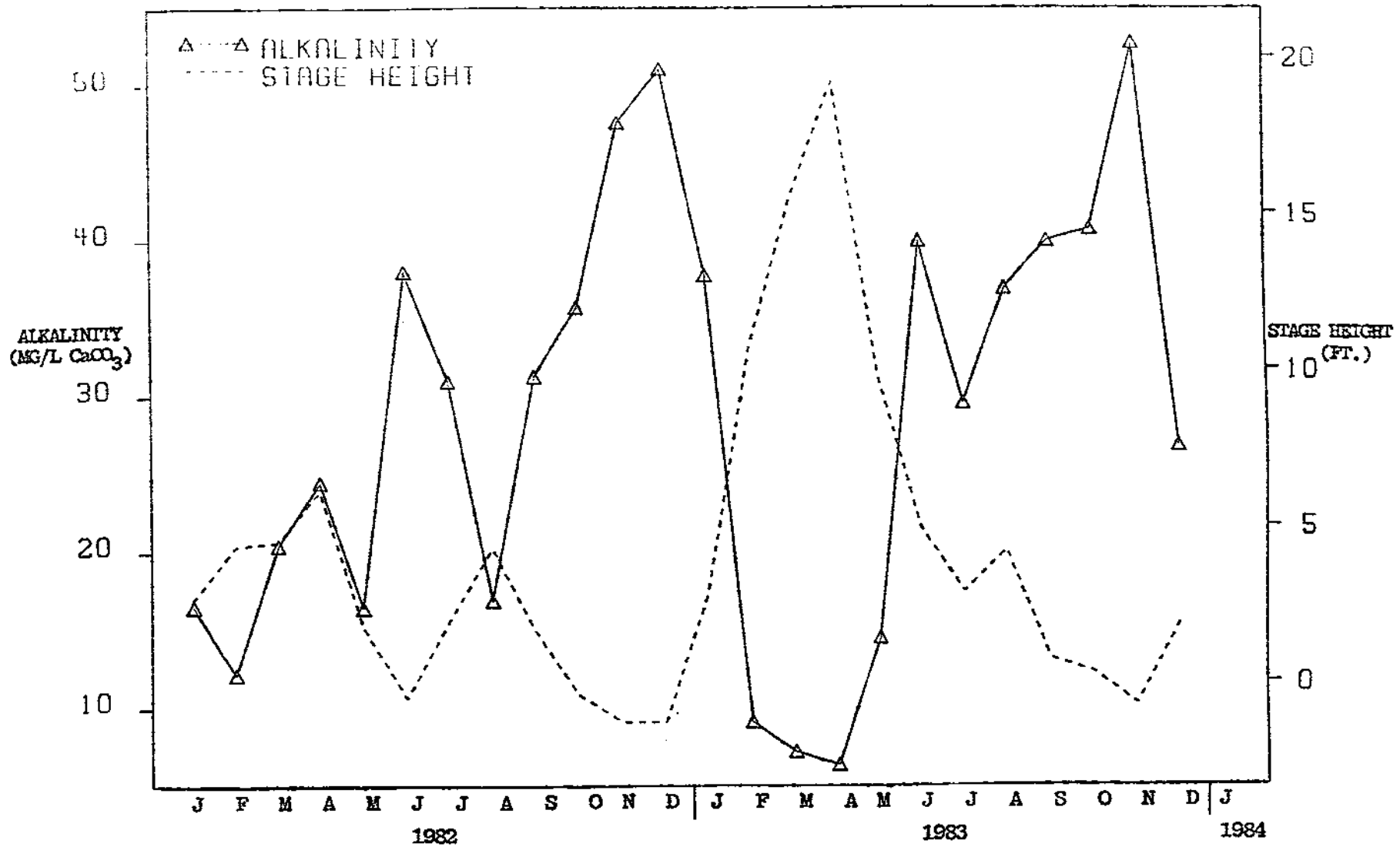


FIGURE 22. MONTHLY MEAN ALKALINITY ($CaCO_3$) vs. RIVER STAGE HEIGHT.

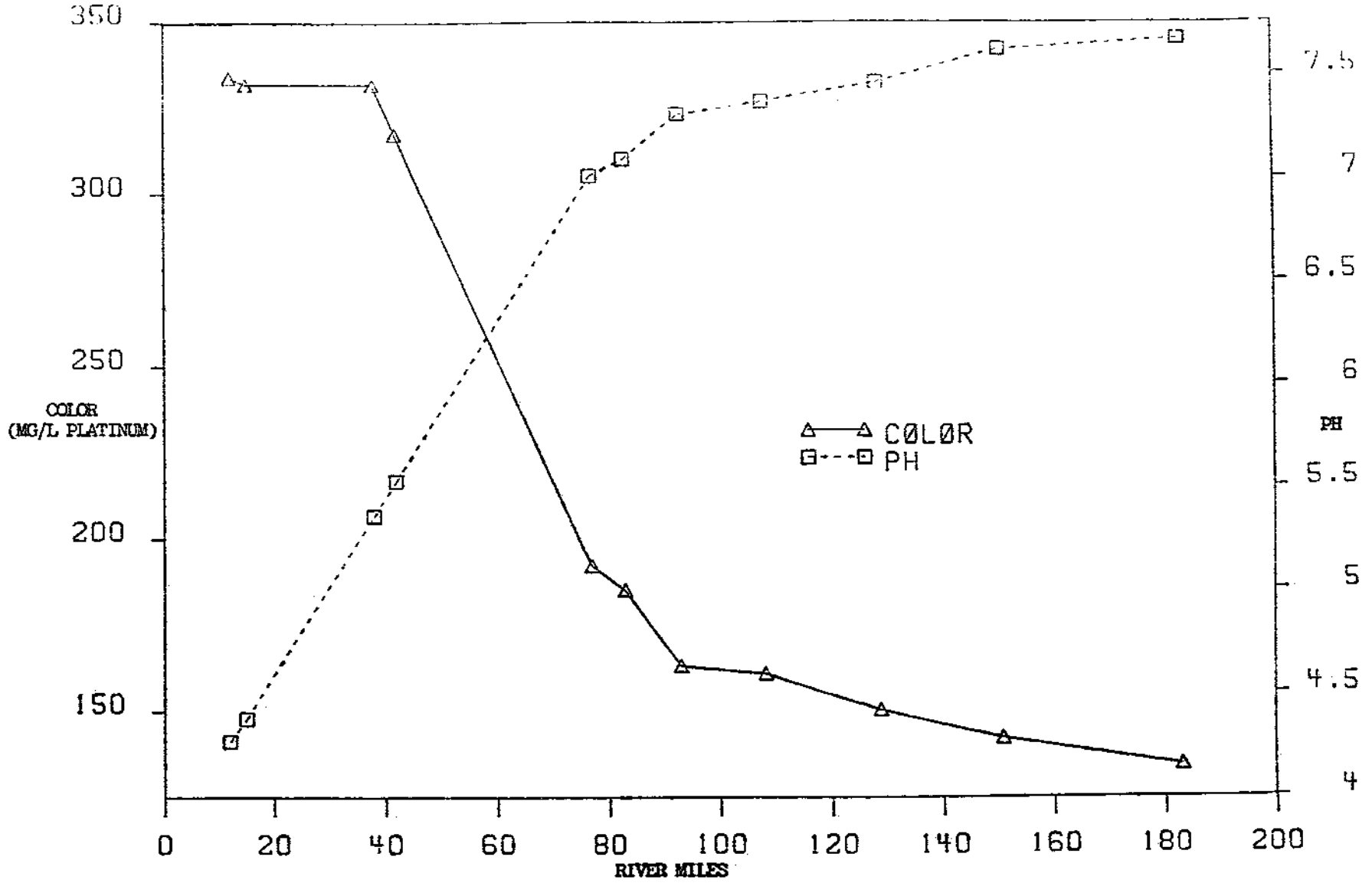


FIGURE 23. MEAN COLOR VALUES vs. MEAN PH (DER-TLH DATA ONLY).

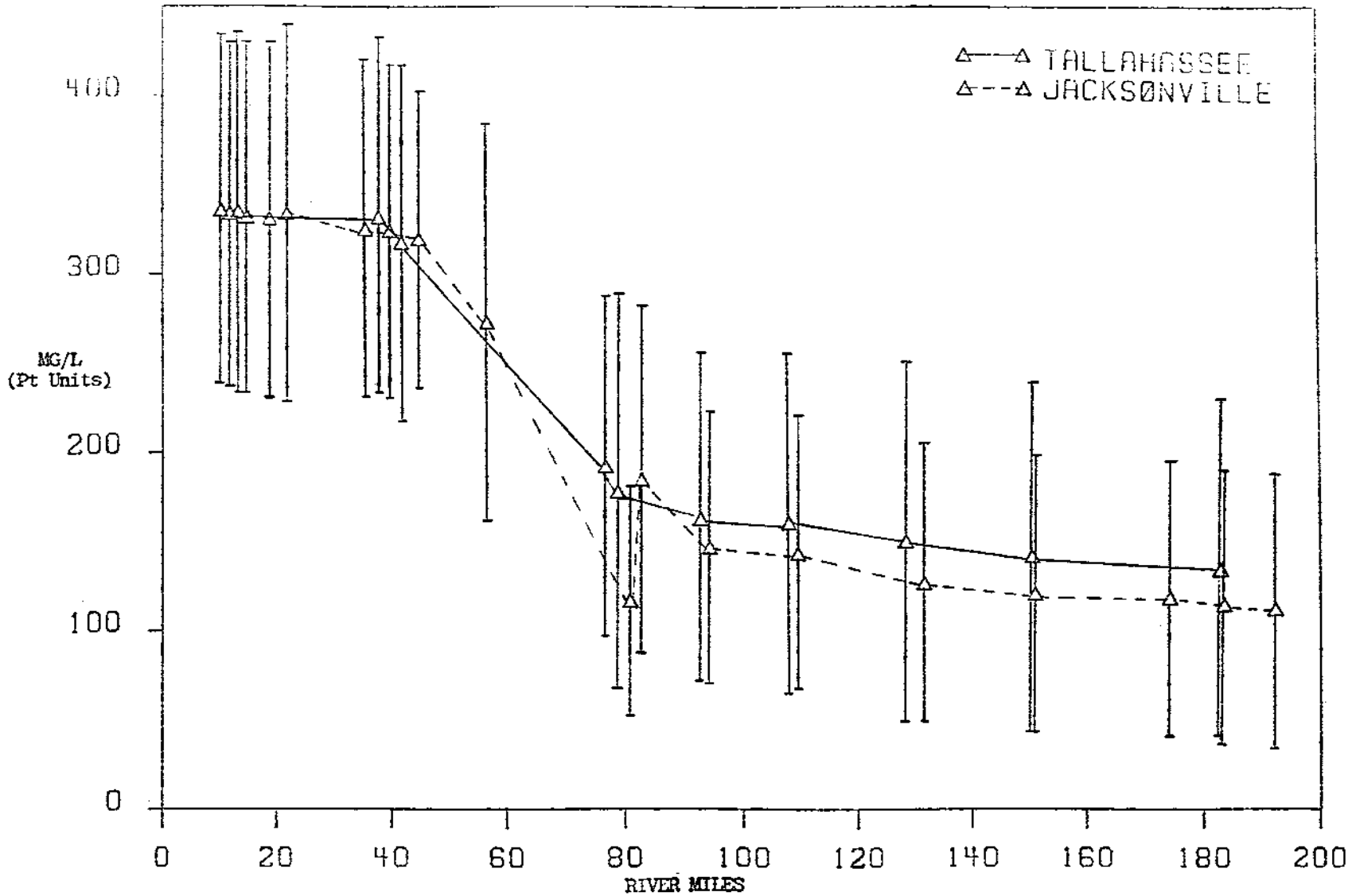


FIGURE 24. MEAN COLOR VALUES AND STANDARD DEVIATIONS FOR DER-TLH AND DER-JAX SAMPLING STATIONS.

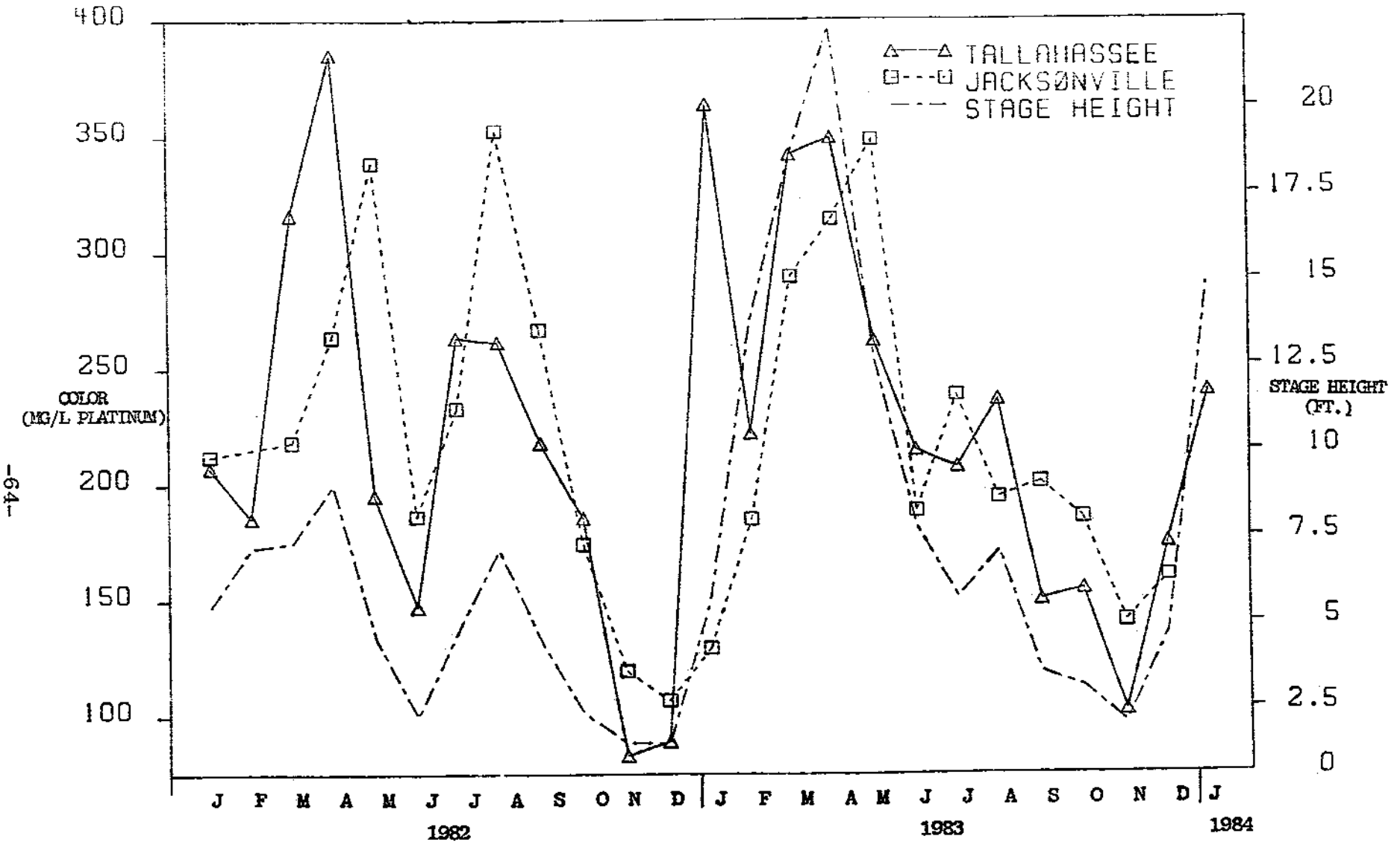


FIGURE 25. MONTHLY MEAN COLOR VALUES vs. RIVER STAGE HEIGHT(DER-JAX AND DER-TLH).

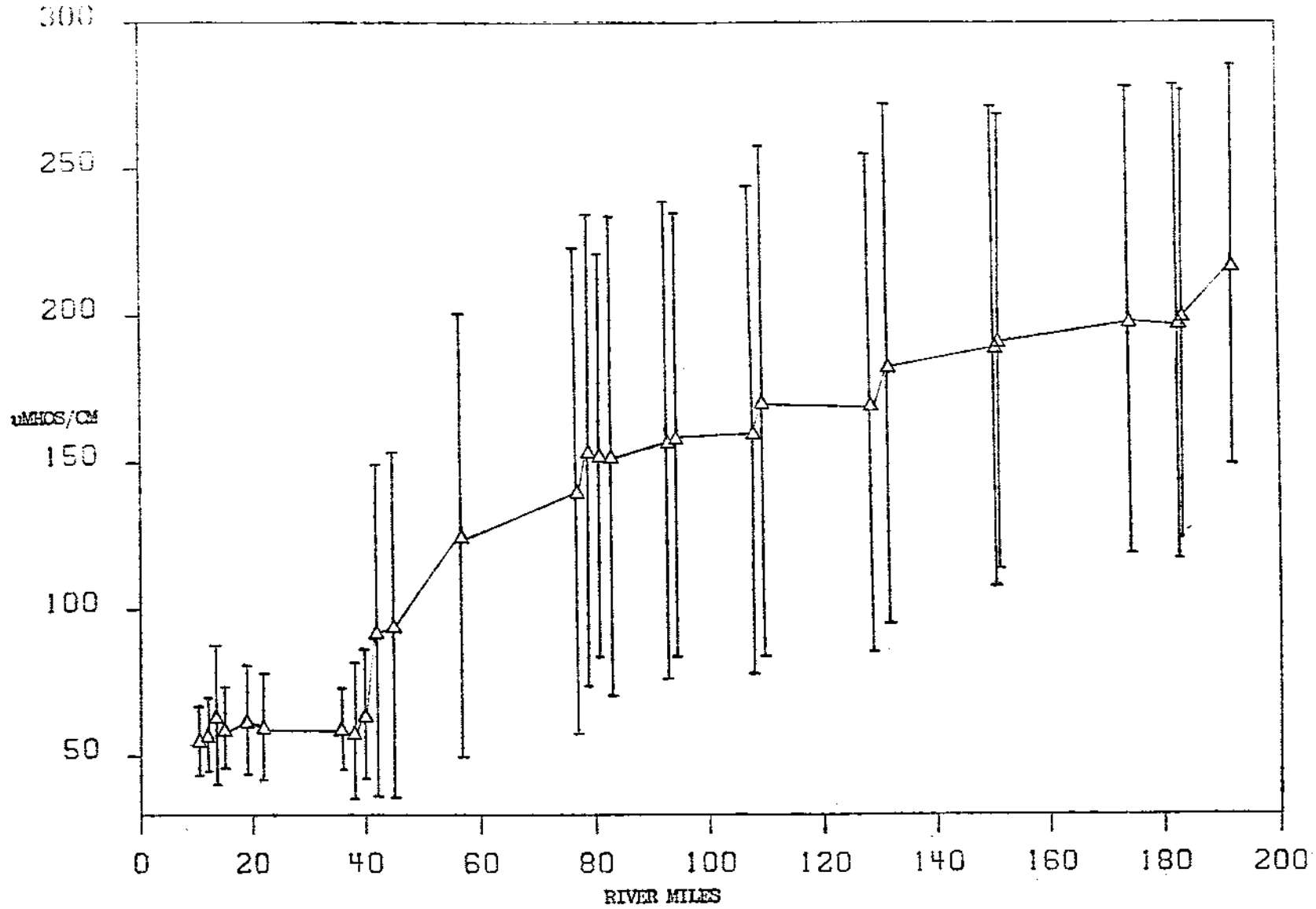


FIGURE 26. MEAN CONDUCTIVITY AND STANDARD DEVIATIONS BY STATION.

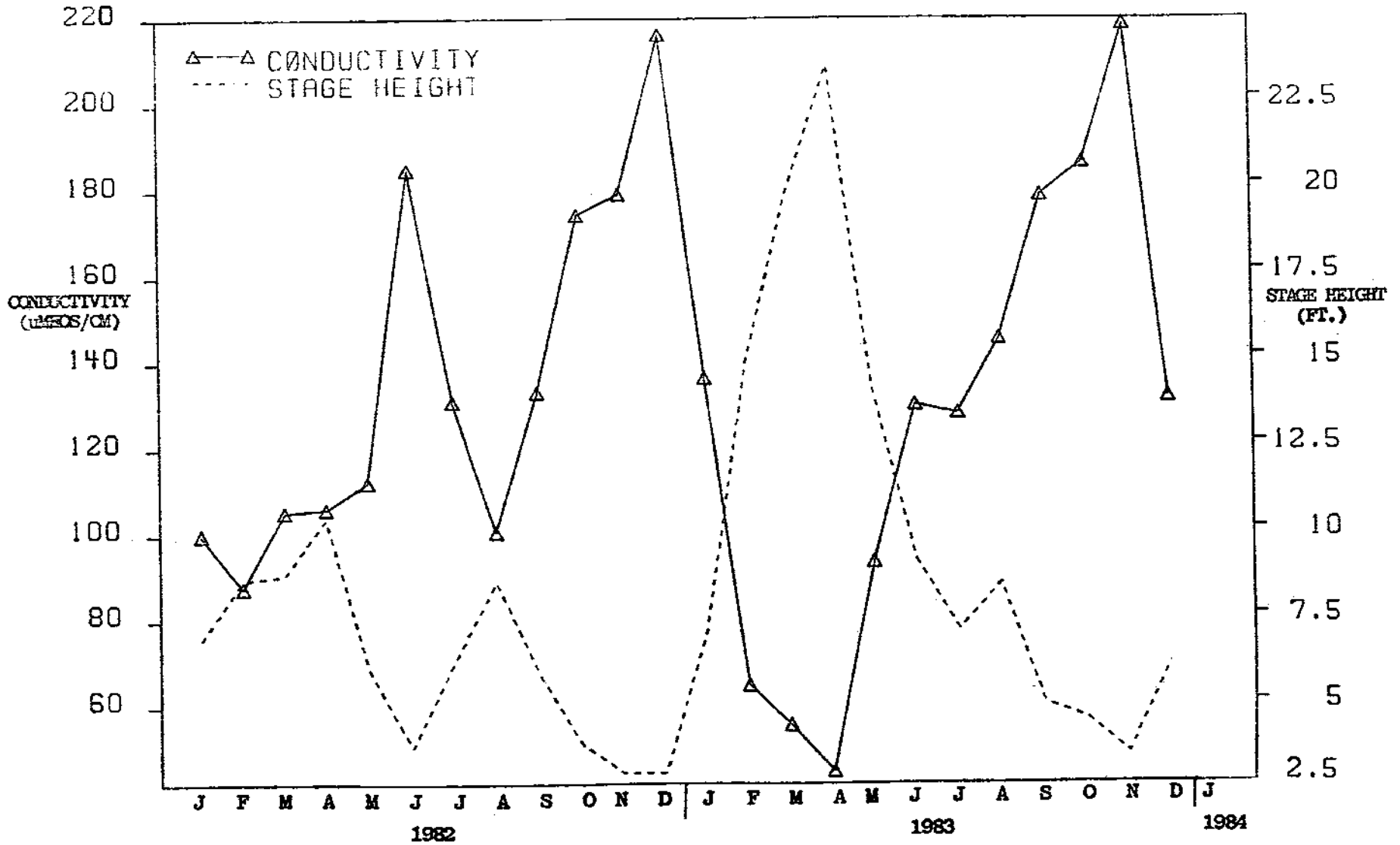


FIGURE 27. MONTHLY MEAN CONDUCTIVITY vs. RIVER STAGE HEIGHT.

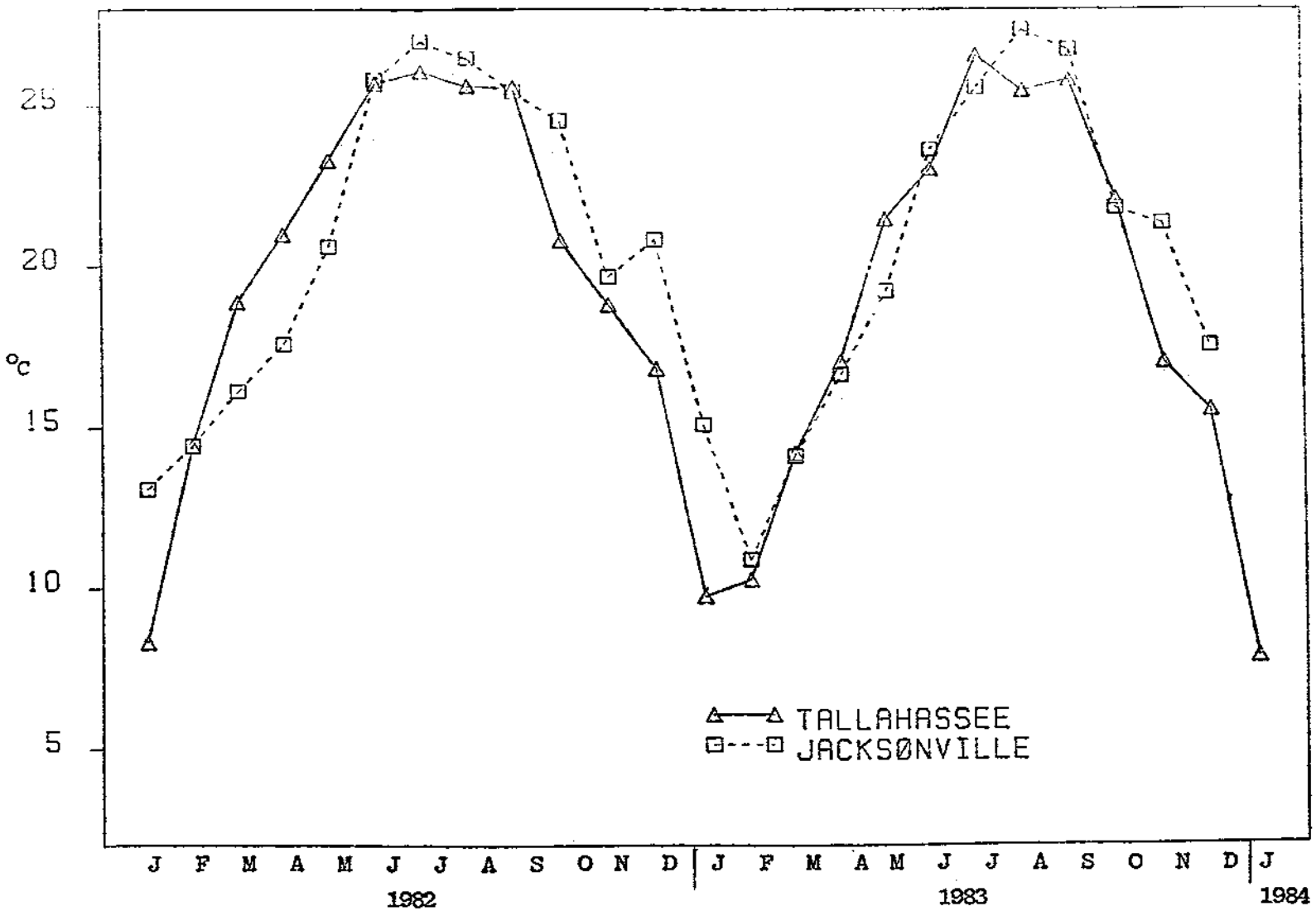


FIGURE 28. MONTHLY MEAN TEMPERATURES (DER-JAX AND DER-TLH).

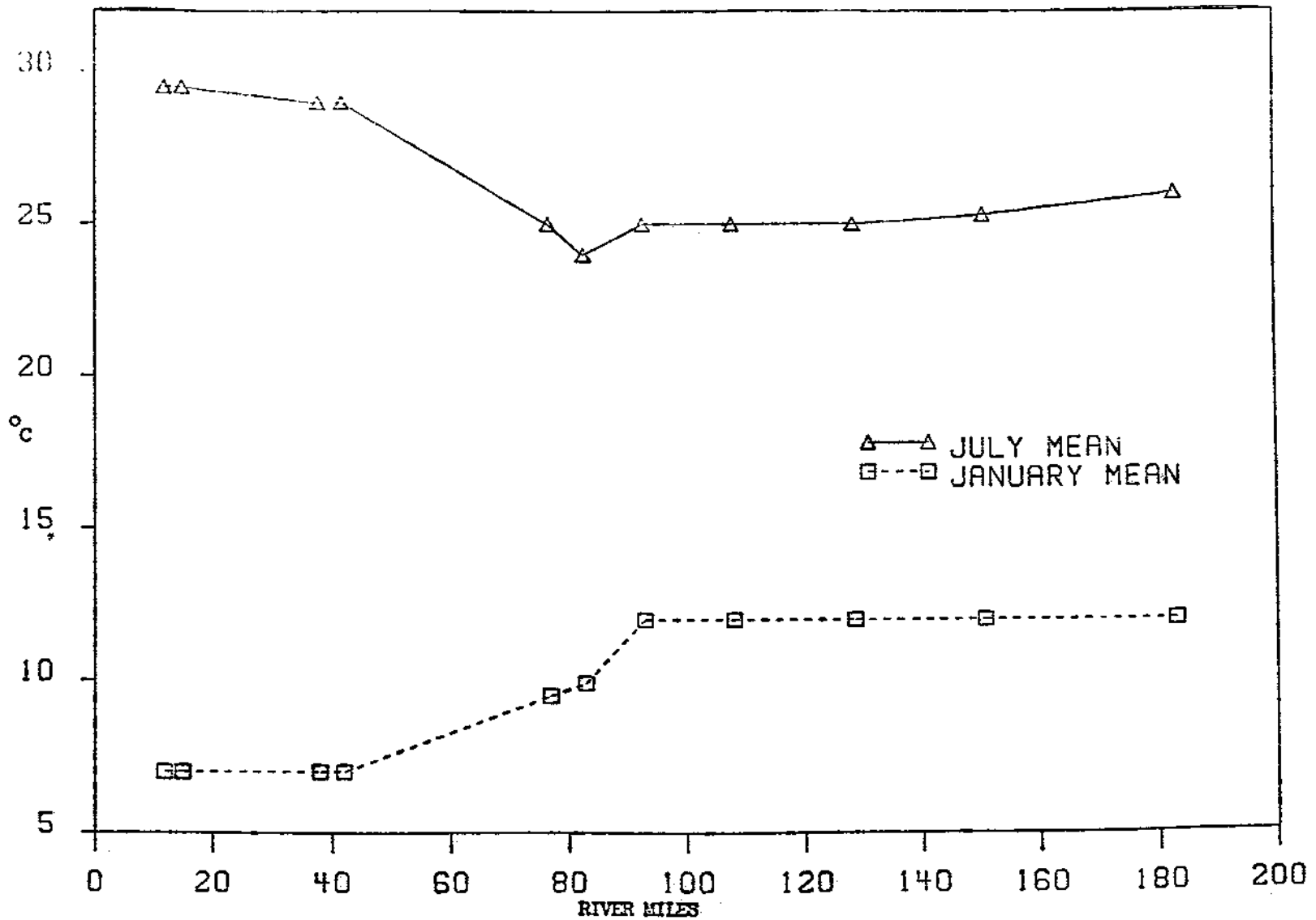


FIGURE 29. MEAN TEMPERATURE VALUES FOR JANUARY AND JULY BY STATION.

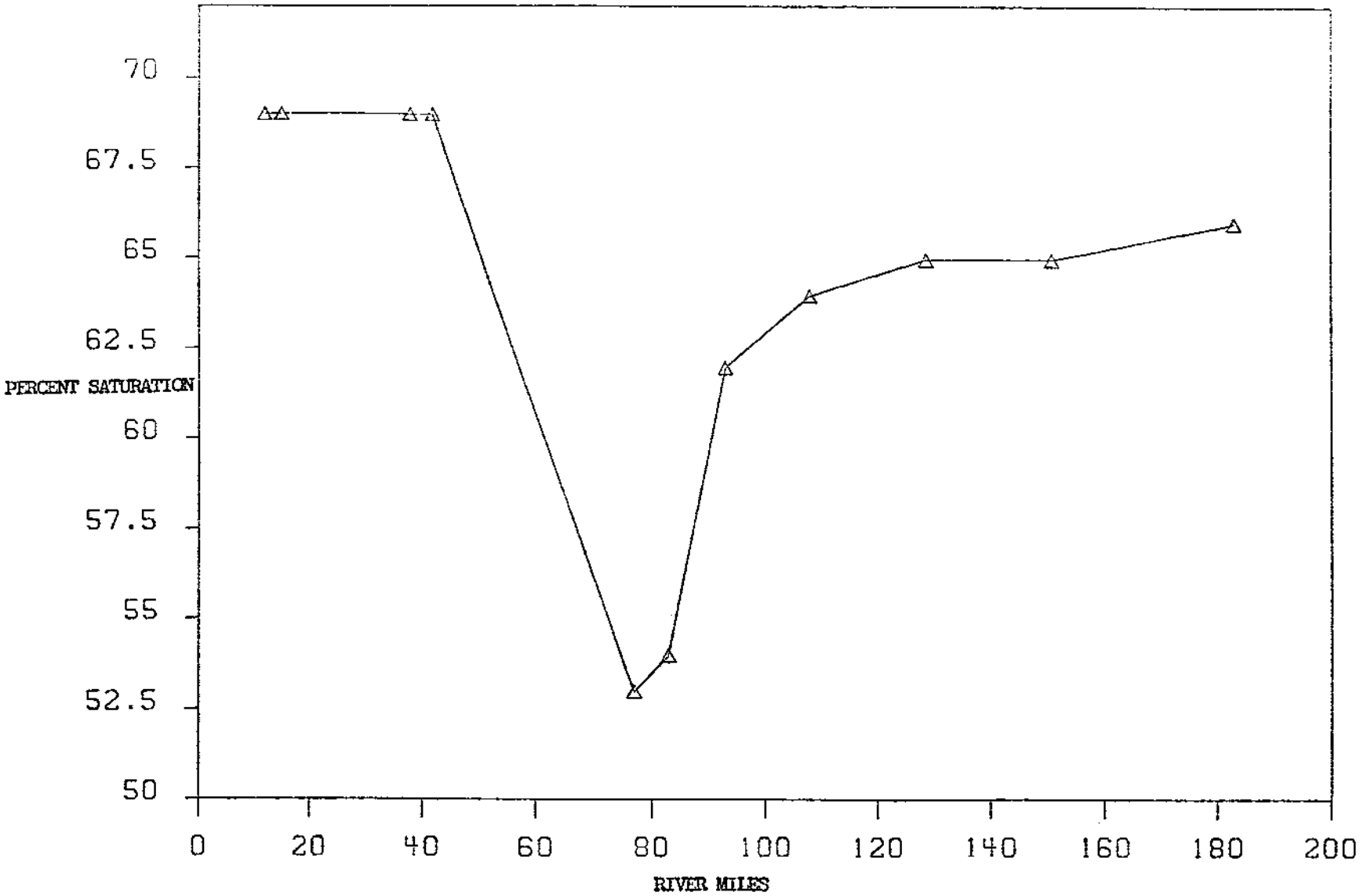


FIGURE 30. MEAN PERCENT DISSOLVED OXYGEN SATURATION CURVE (DER-TLH DATA ONLY).

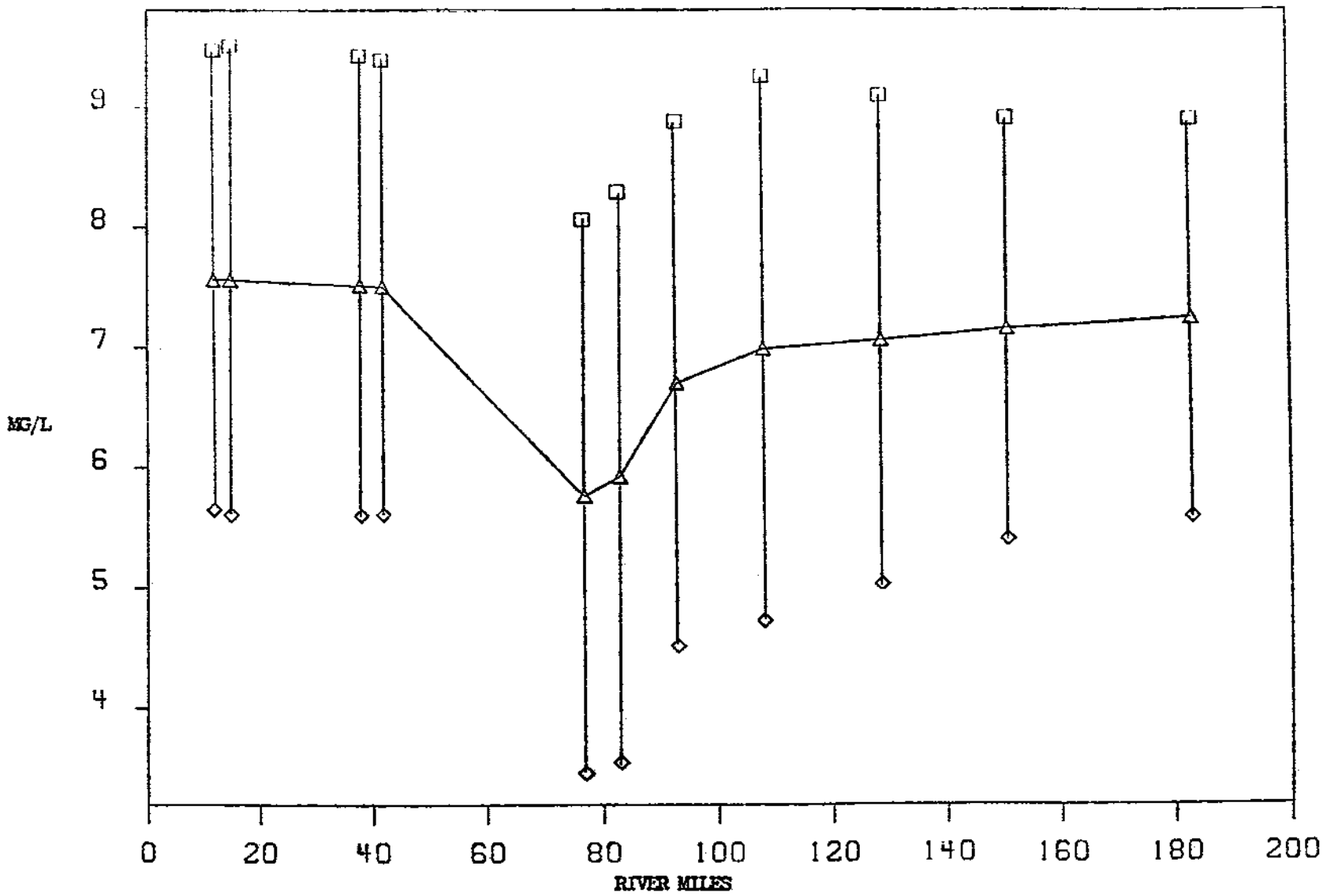


FIGURE 31. MEAN DISSOLVED OXYGEN CONCENTRATIONS AND STANDARD DEVIATIONS BY STATION (DER-TLH DATA ONLY).

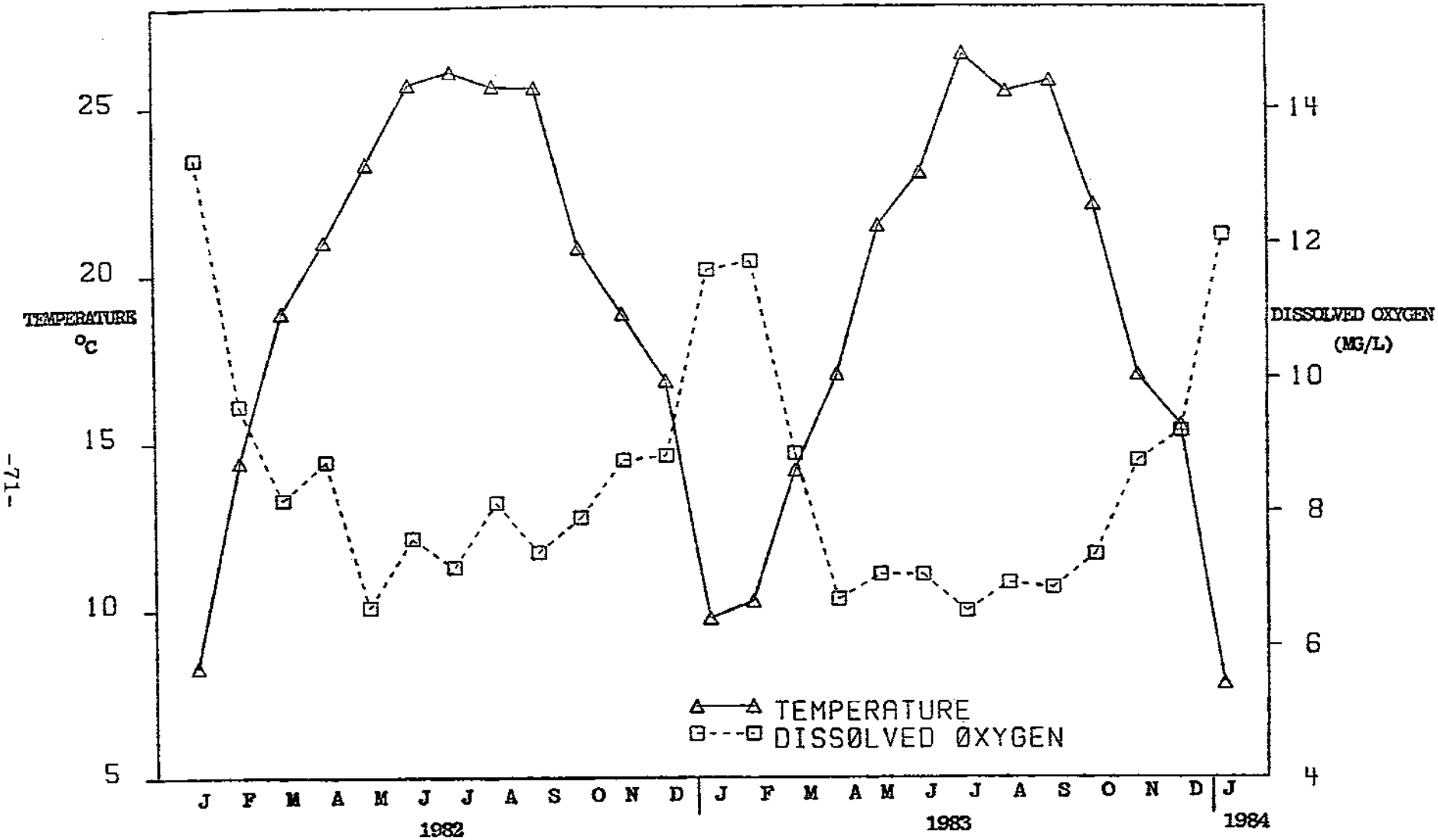


FIGURE 32. MONTHLY MEAN DISSOLVED OXYGEN vs. MONTHLY MEAN TEMPERATURE (DER-TLH DATA ONLY).

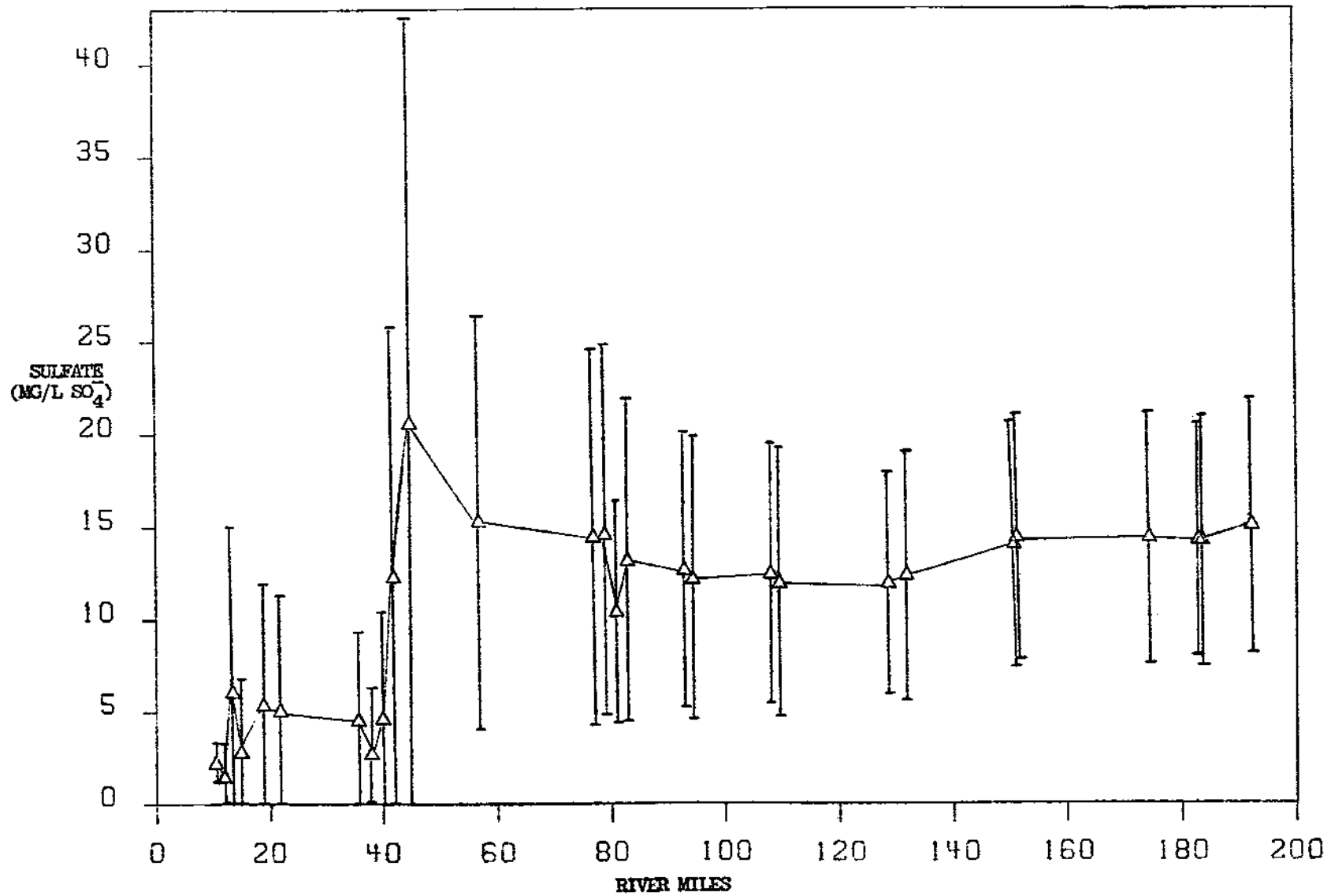


FIGURE 33. MEAN SULFATE CONCENTRATIONS AND STANDARD DEVIATIONS BY SAMPLING STATIONS.

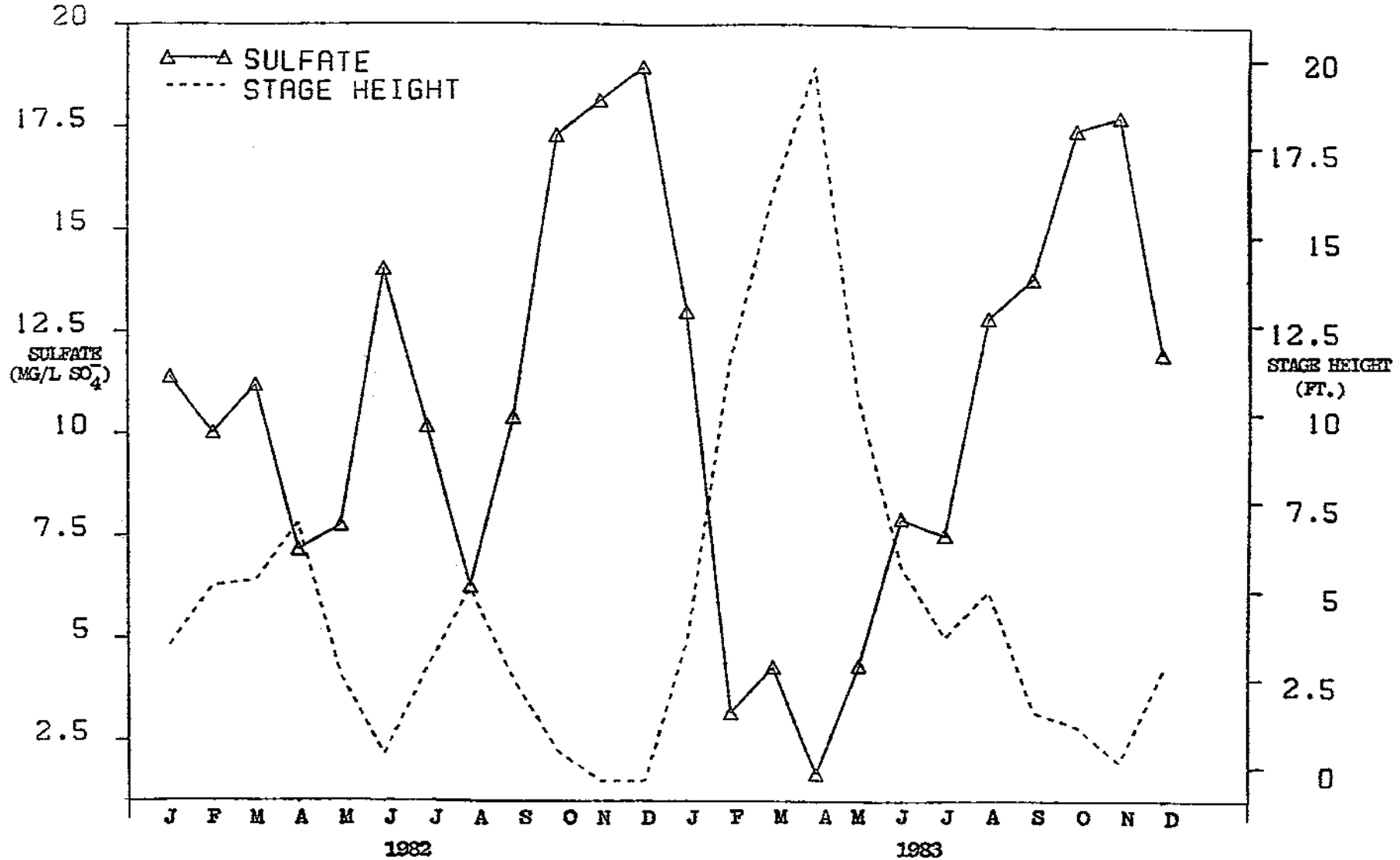


FIGURE 34. MONTHLY MEAN SULFATE CONCENTRATIONS vs. RIVER STAGE HEIGHT.

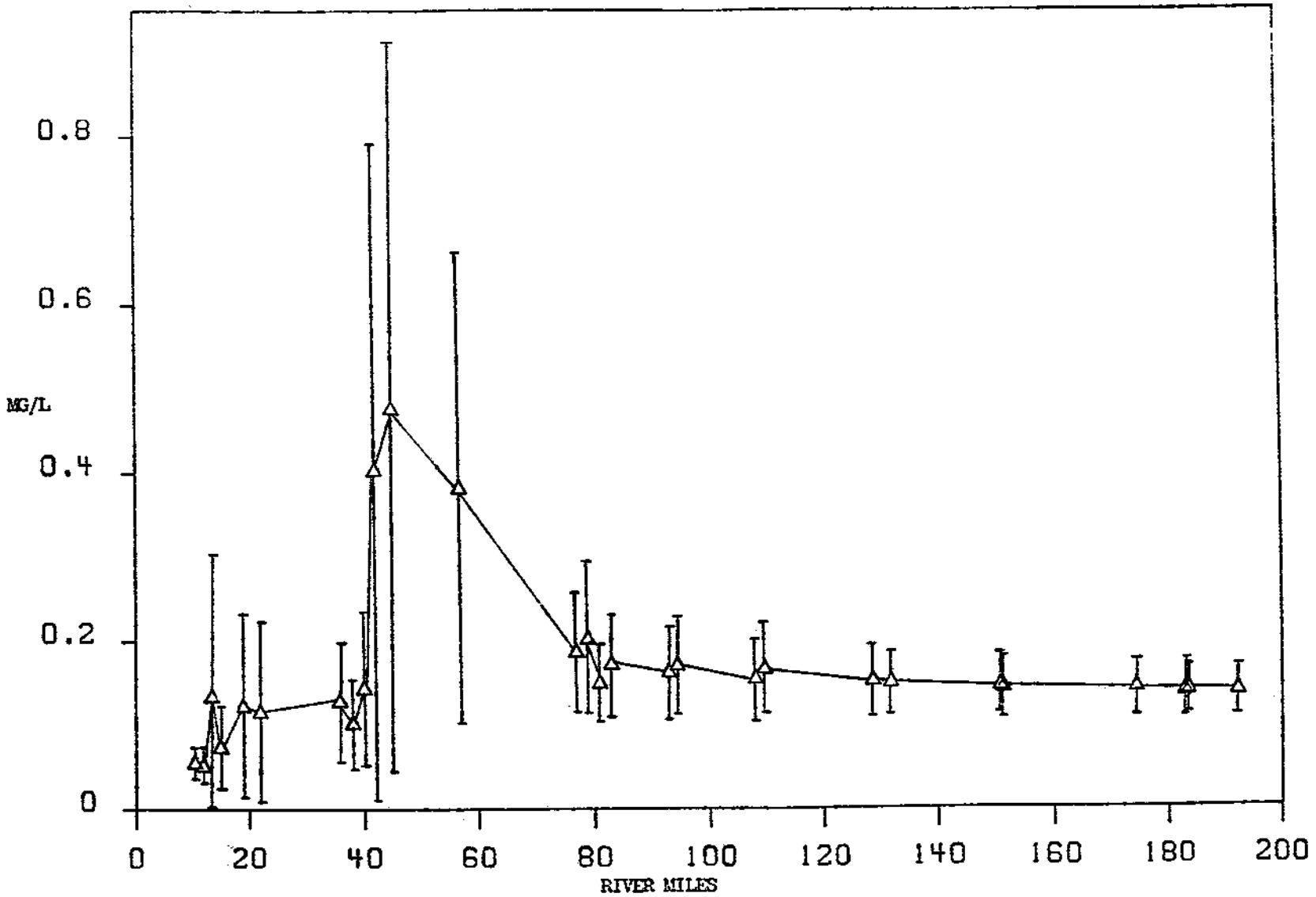


FIGURE 35. MEAN FLUORIDE CONCENTRATIONS AND STANDARD DEVIATIONS BY SAMPLING STATIONS.

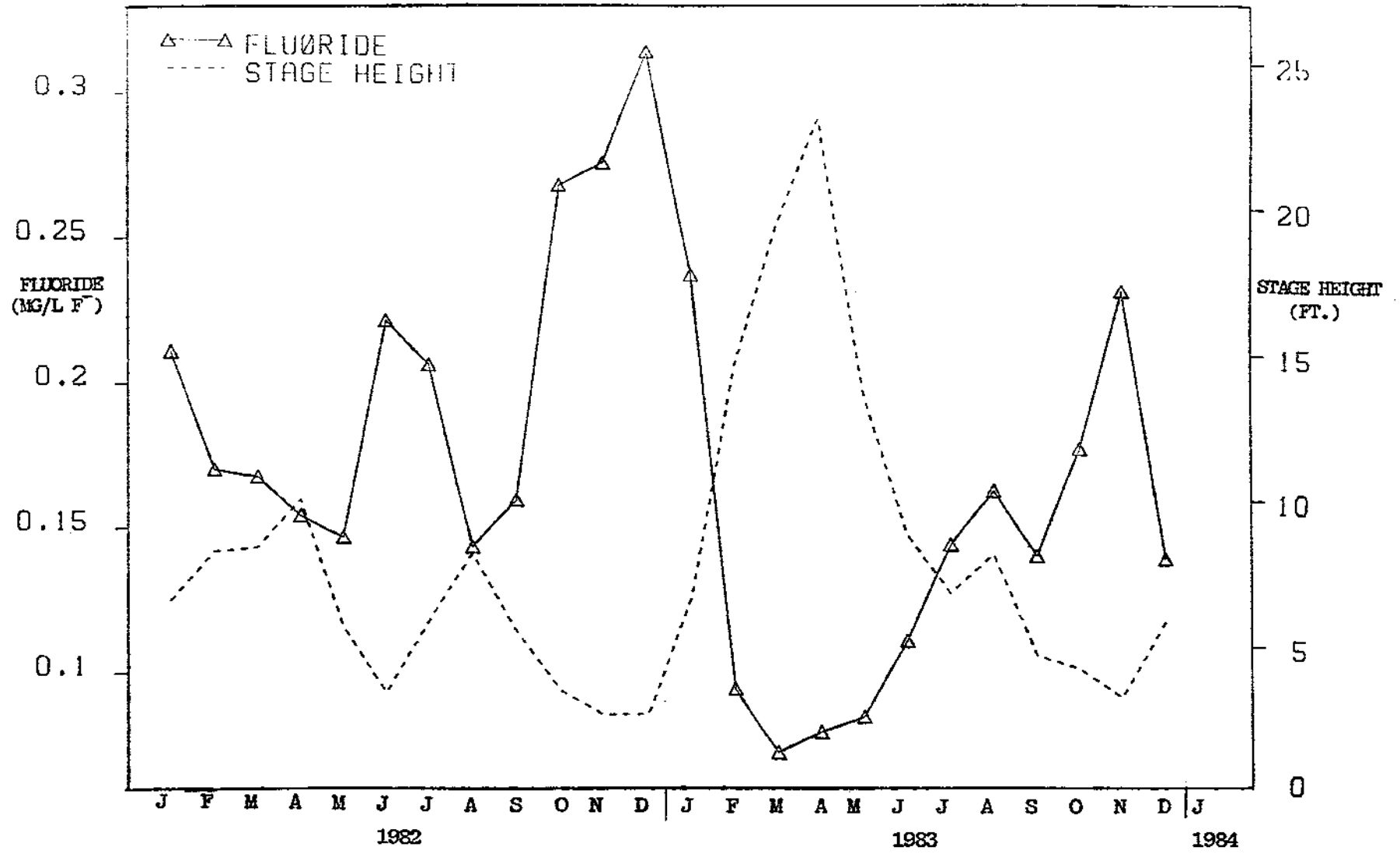


FIGURE 36. MONTHLY MEAN FLUORIDE CONCENTRATIONS vs. RIVER STAGE HEIGHT.

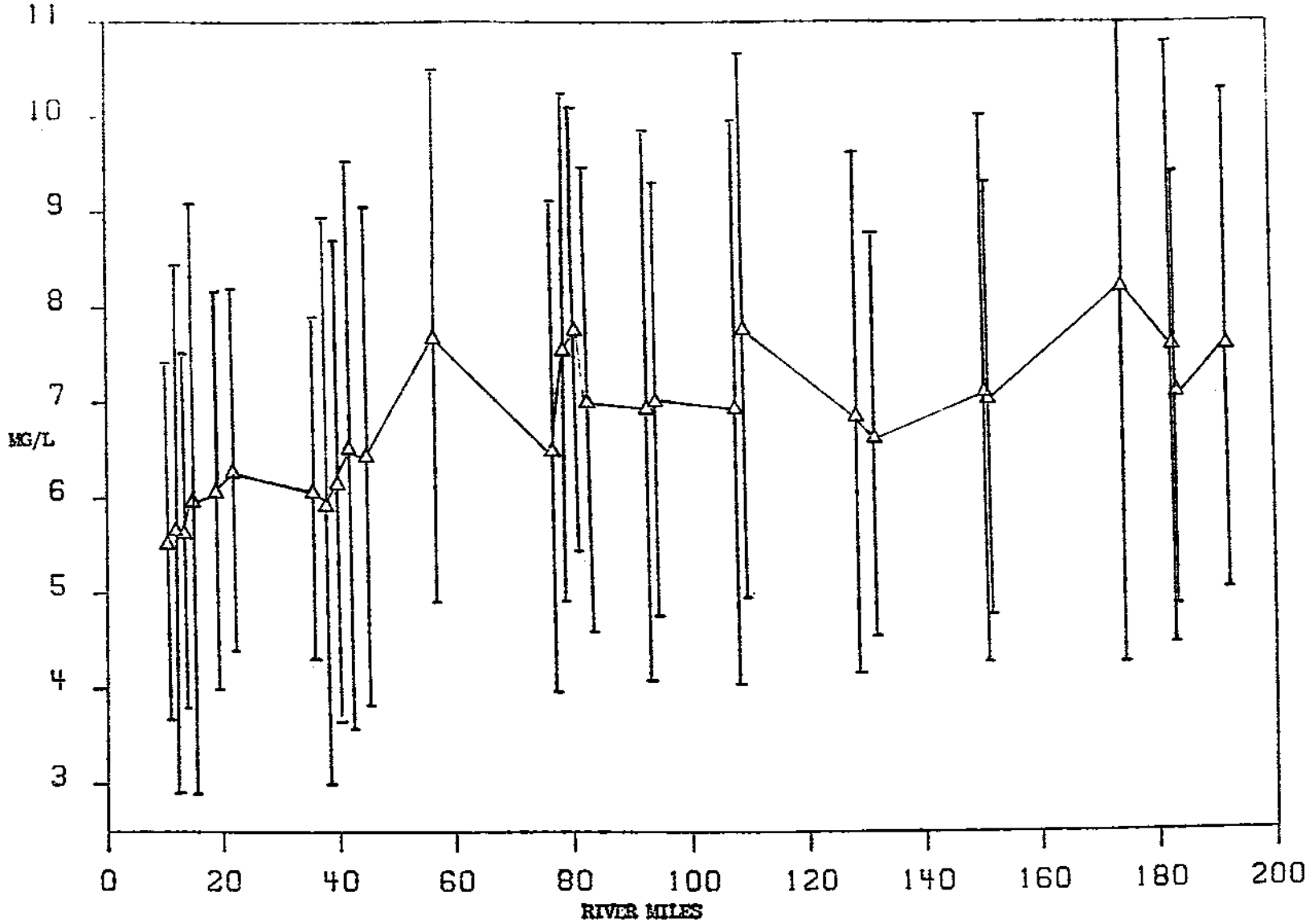


FIGURE 37. MEAN CHLORIDE CONCENTRATIONS AND STANDARD DEVIATIONS BY SAMPLING STATIONS.

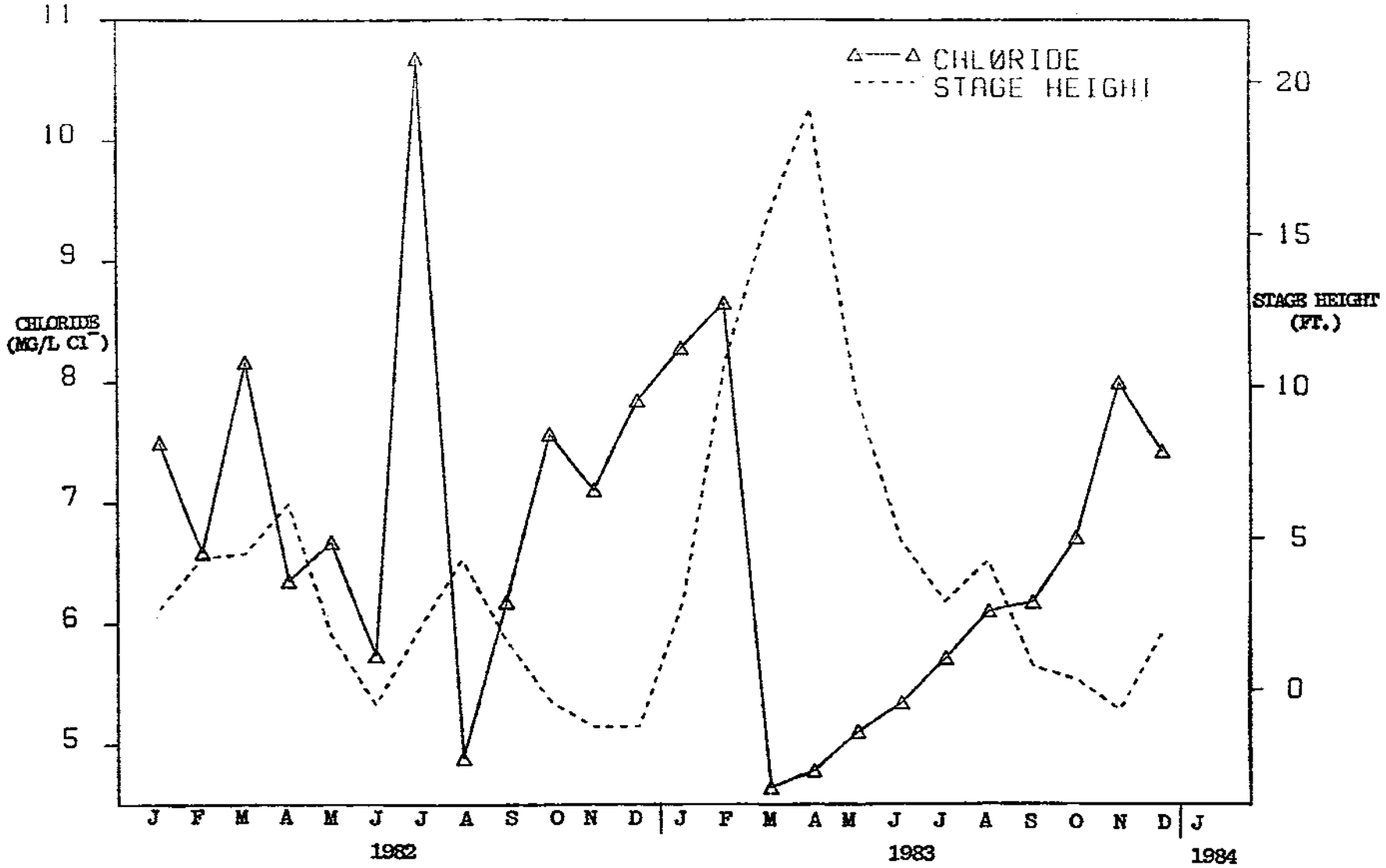


FIGURE 38. MONTHLY MEAN CHLORIDE CONCENTRATIONS vs. RIVER STAGE HEIGHT.

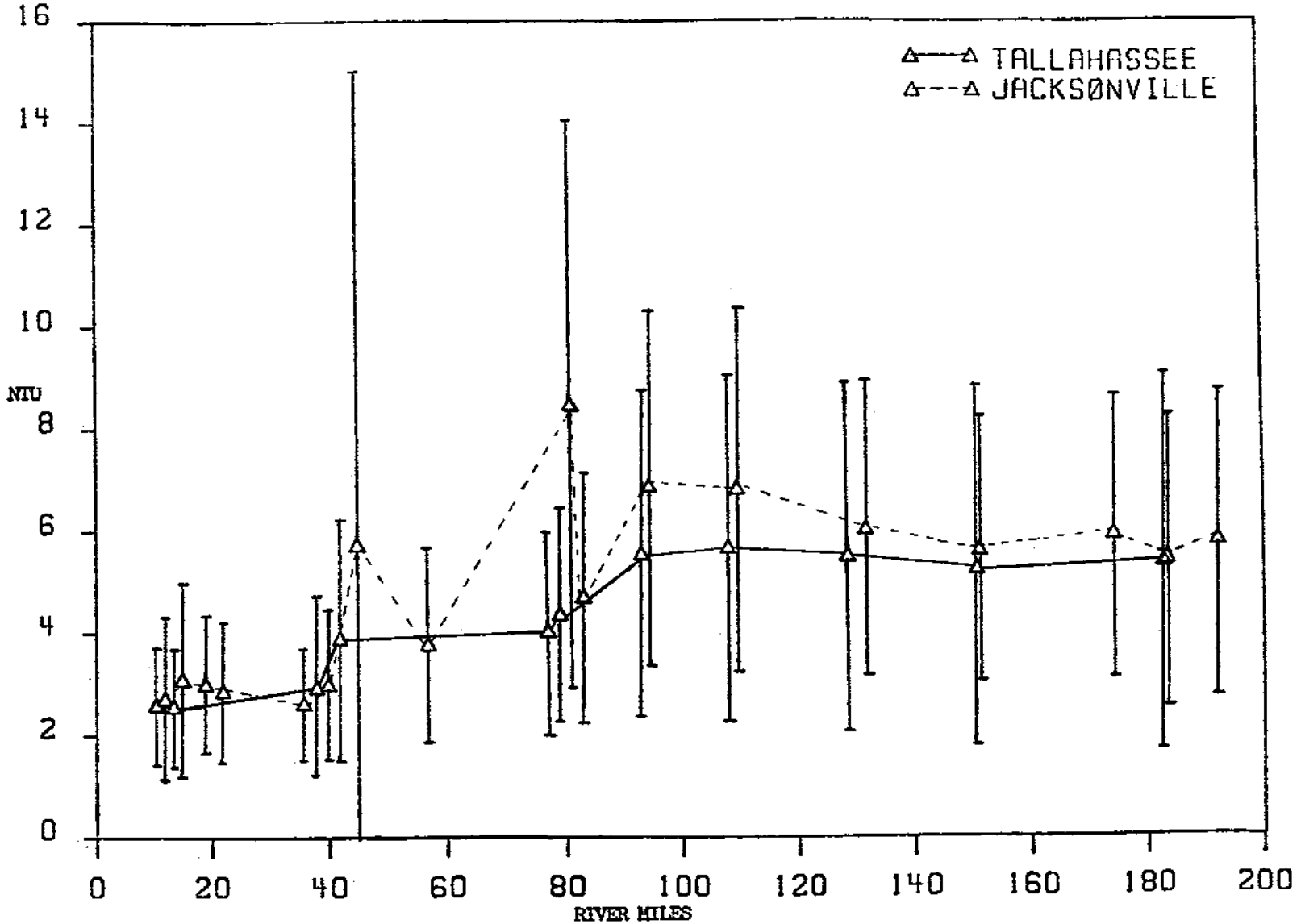


FIGURE 39. MEAN TURBIDITY VALUES AND STANDARD DEVIATIONS FOR DER-JAX AND DER-TLH SAMPLING STATIONS.

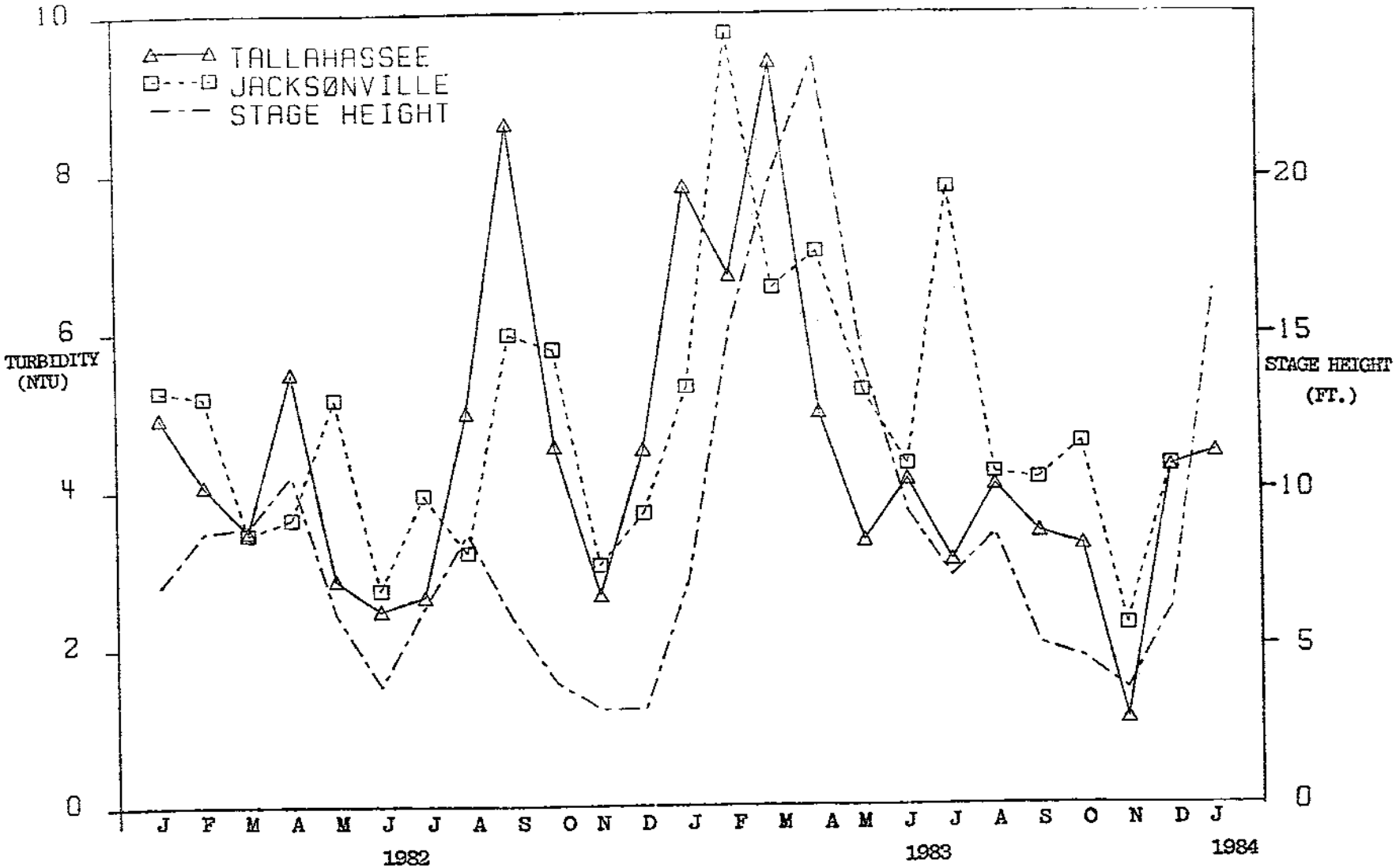


FIGURE 40. MONTHLY MEAN TURBIDITY VALUES vs. RIVER STAGE HEIGHT (DER-JAX AND DER-TLH).

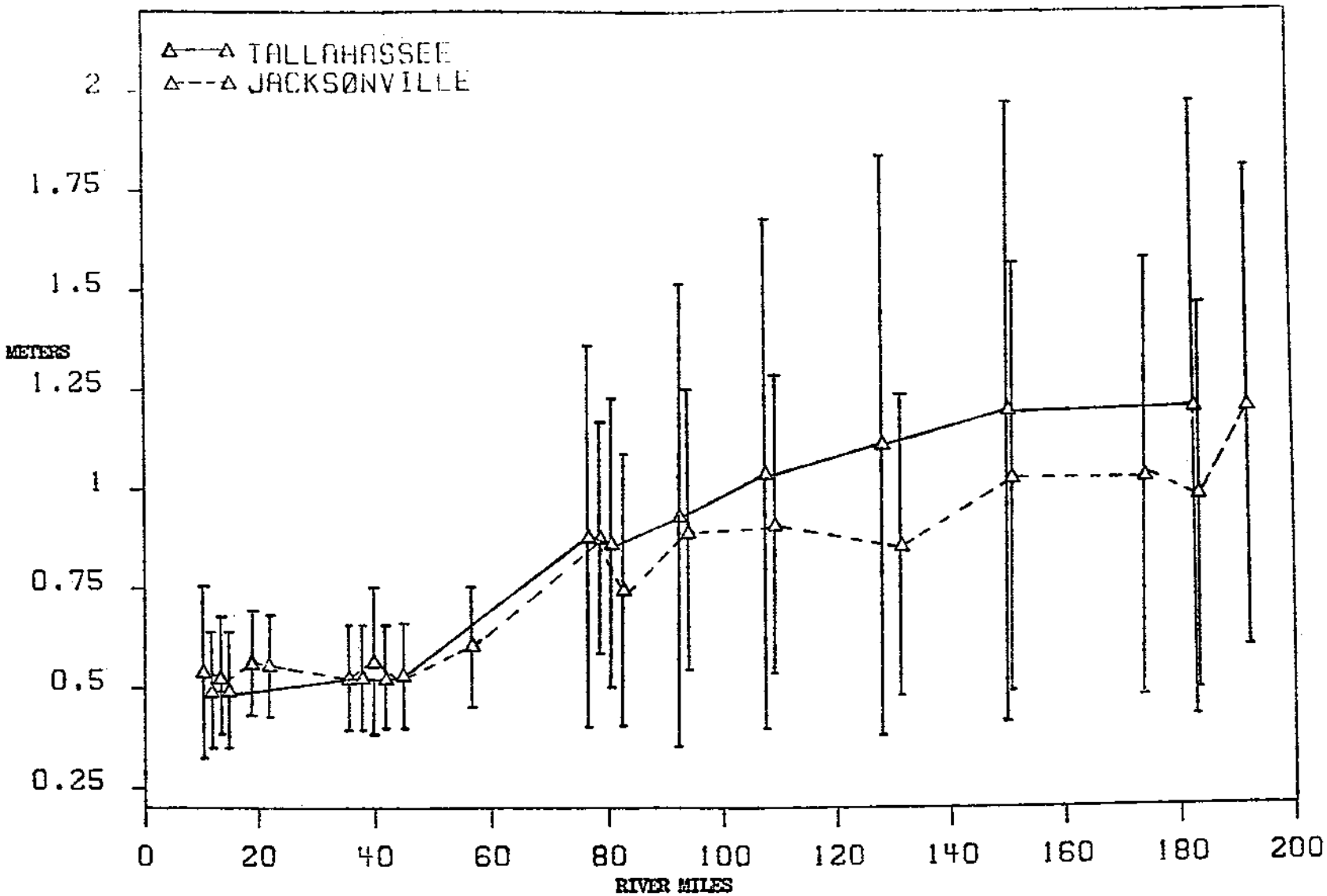


FIGURE 41. MEAN SECCHI DISC DEPTH AND STANDARD DEVIATIONS FOR DER-JAX AND DER-TLH SAMPLING STATIONS.

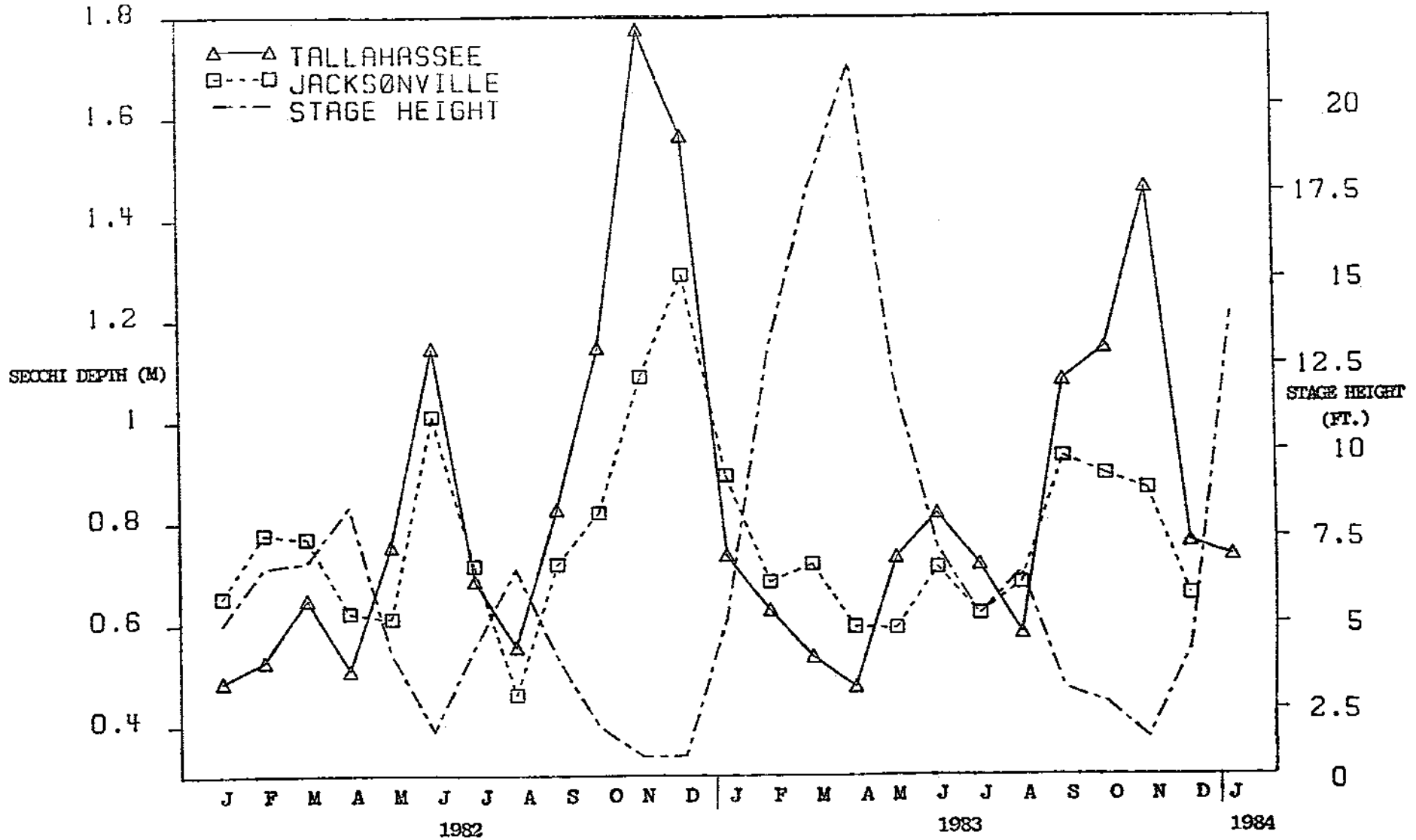


FIGURE 42. MONTHLY MEAN SECCHI DISC VALUES vs. RIVER STAGE HEIGHT (DER-JAX AND DER-TLH).

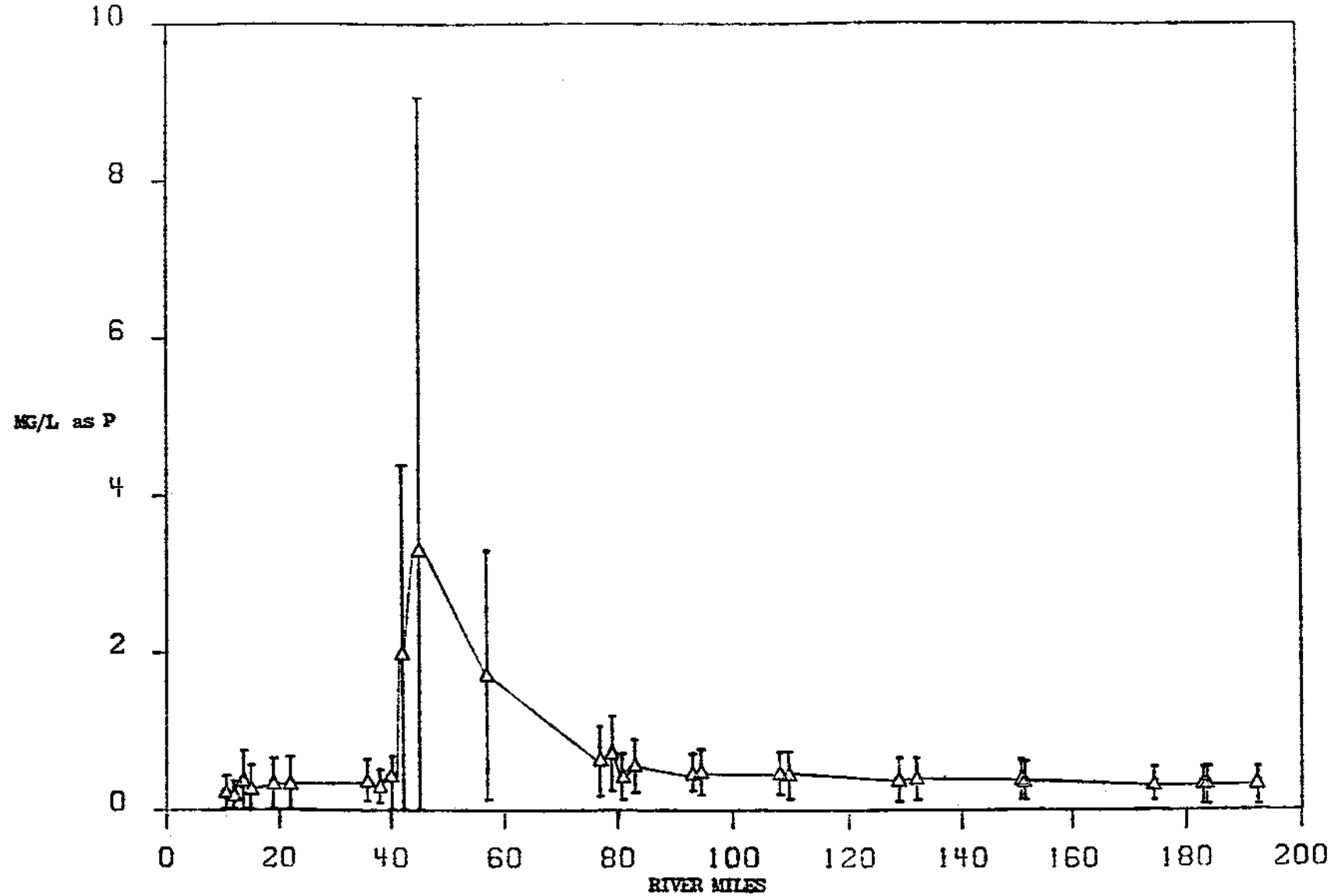


FIGURE 43. MEAN TOTAL PHOSPHATE CONCENTRATIONS AND STANDARD DEVIATIONS BY SAMPLING STATIONS.

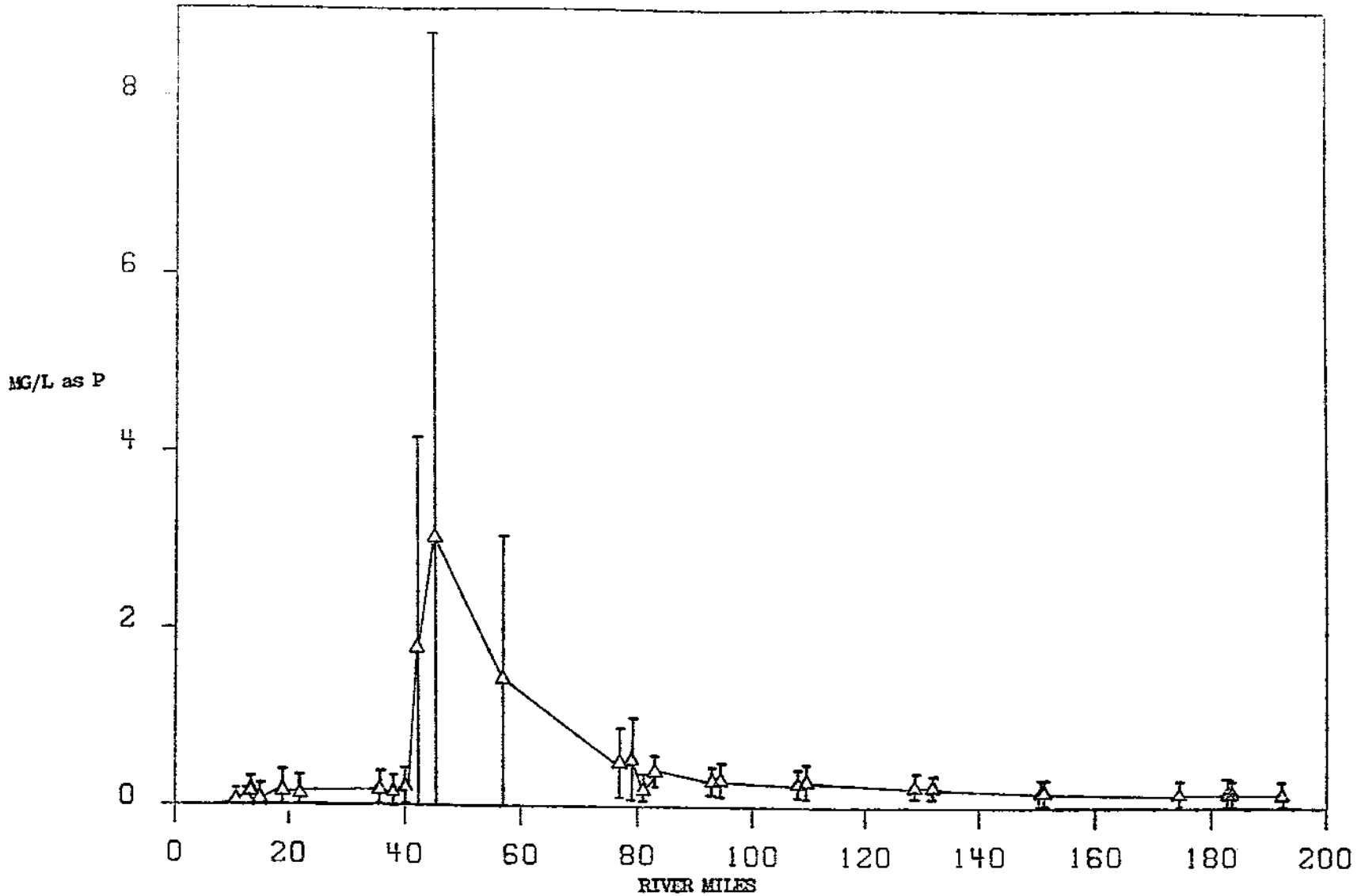


FIGURE 44. MEAN ORTHOPHOSPHATE CONCENTRATIONS AND STANDARD DEVIATIONS BY SAMPLING STATION.

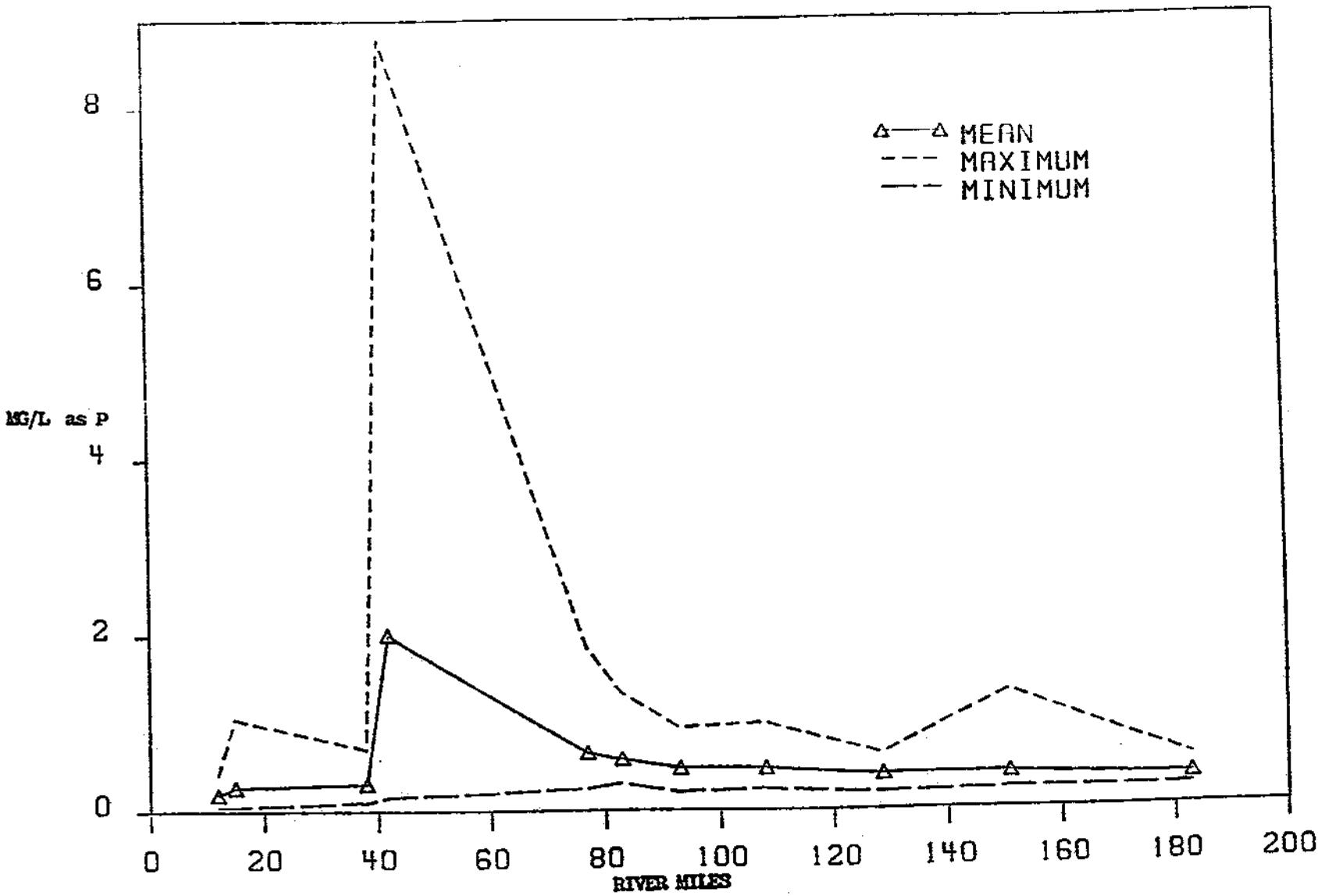


FIGURE 45. TOTAL PHOSPHATE: MAXIMUM, MEAN AND MINIMUM VALUES FOR DER-TLH SAMPLING STATIONS.

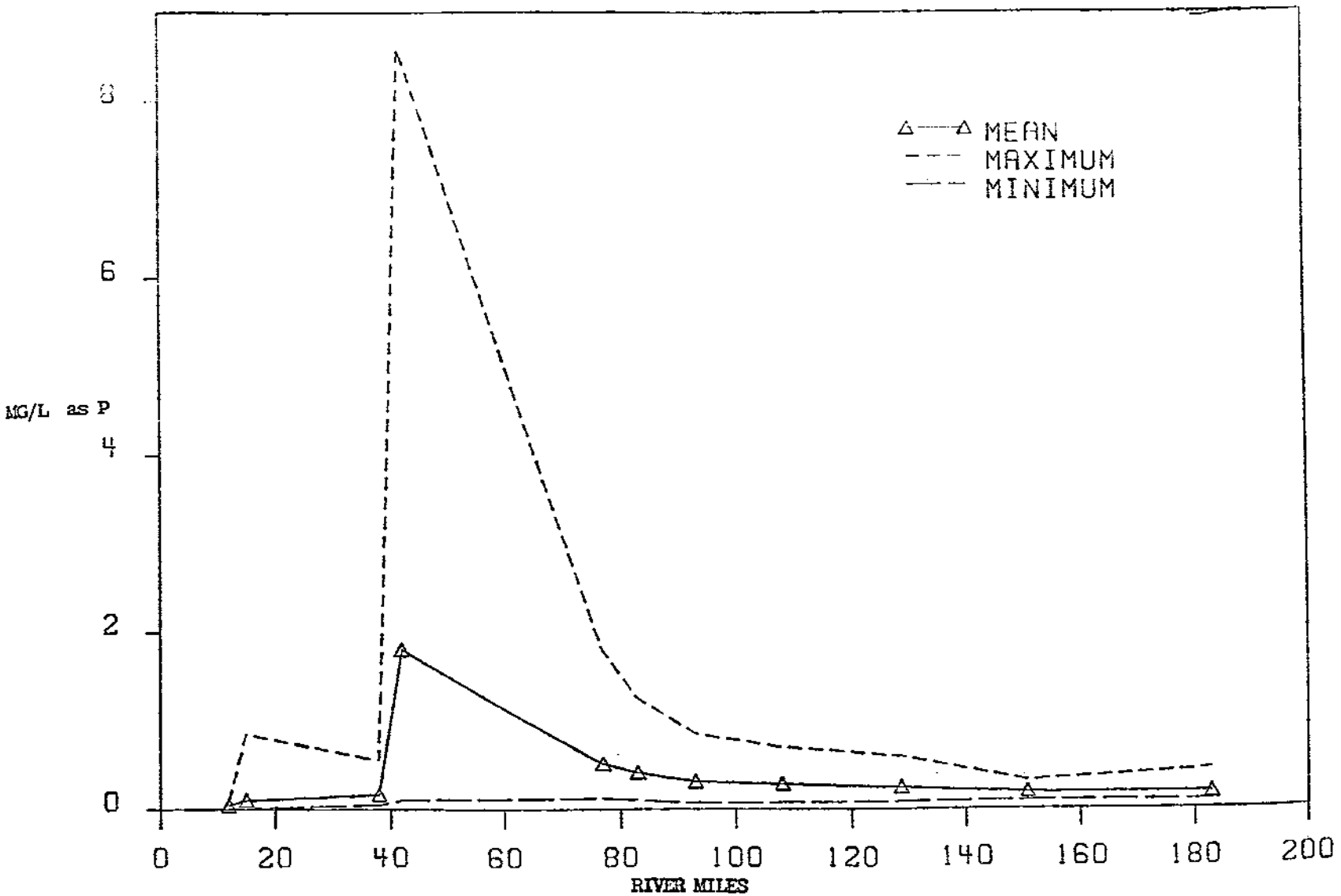


FIGURE 46. ORTHO-PHOSPHATE: MAXIMUM, MEAN AND MINIMUM VALUES FOR DER-TLH SAMPLING STATIONS.

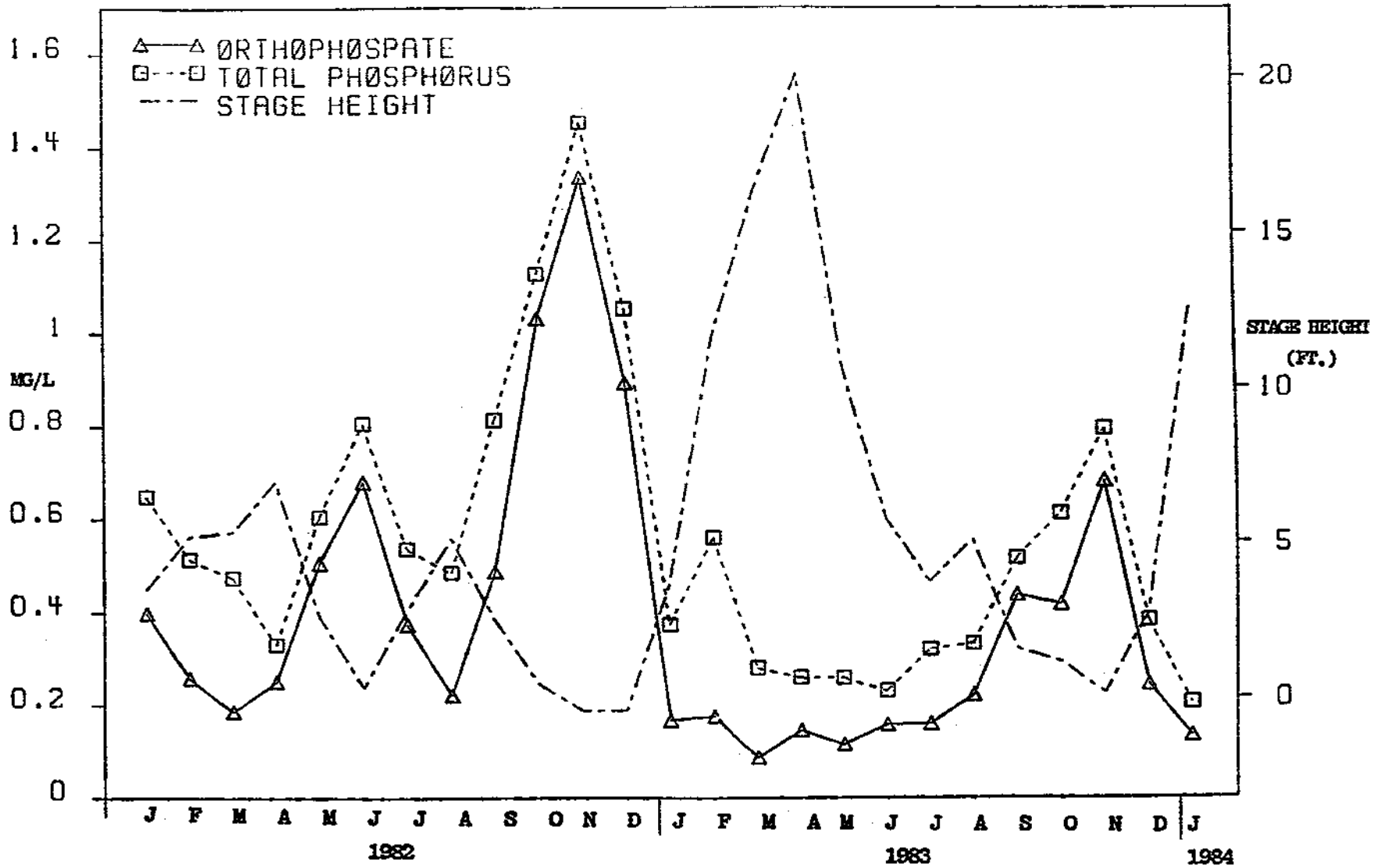


FIGURE 47. MONTHLY MEAN VALUES FOR TOTAL PHOSPHATE AND ORTHOPHOSPHATE vs. RIVER STAGE HEIGHT.

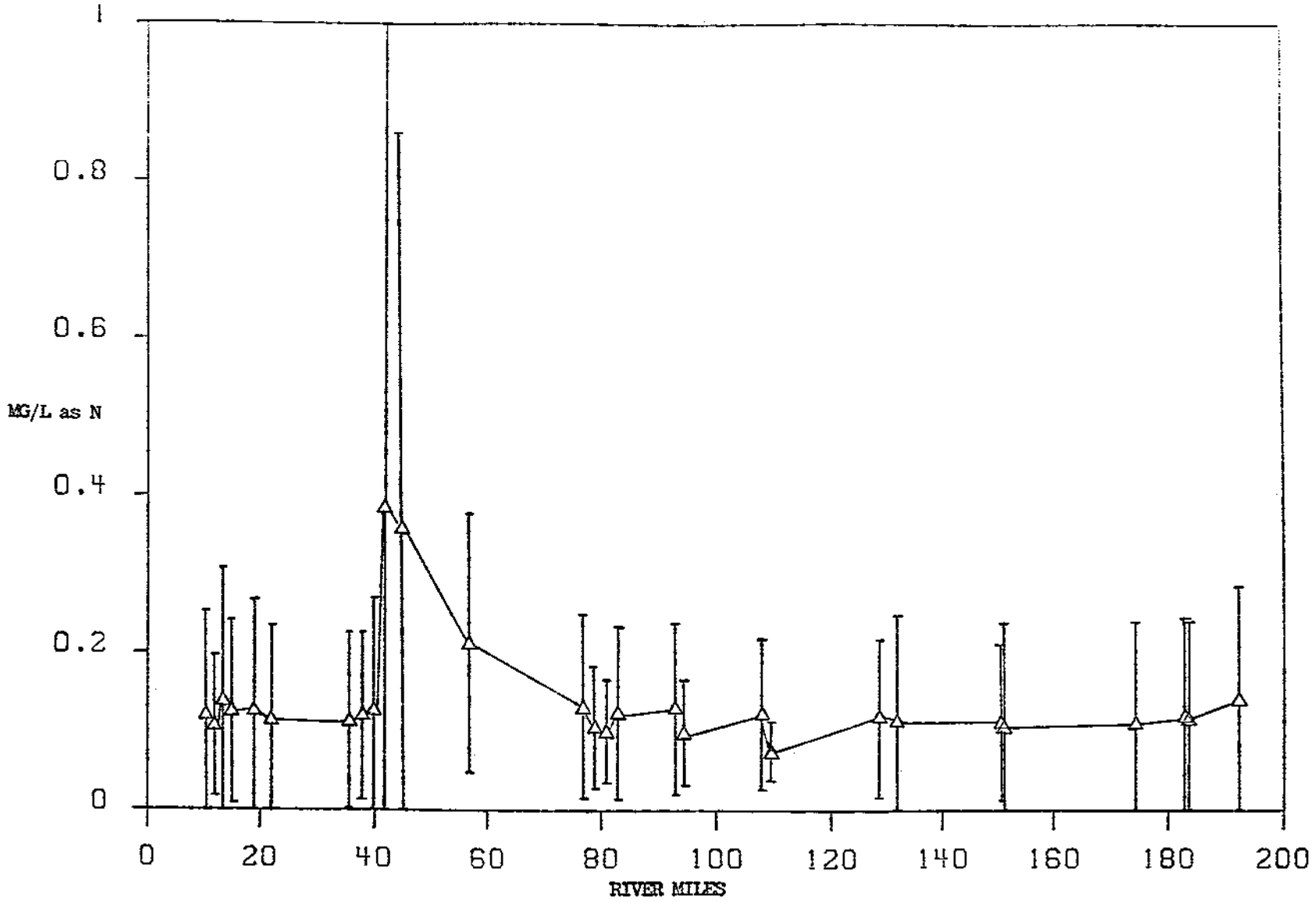


FIGURE 48. MEAN AMMONIA CONCENTRATIONS AND STANDARD DEVIATIONS BY SAMPLING STATIONS.

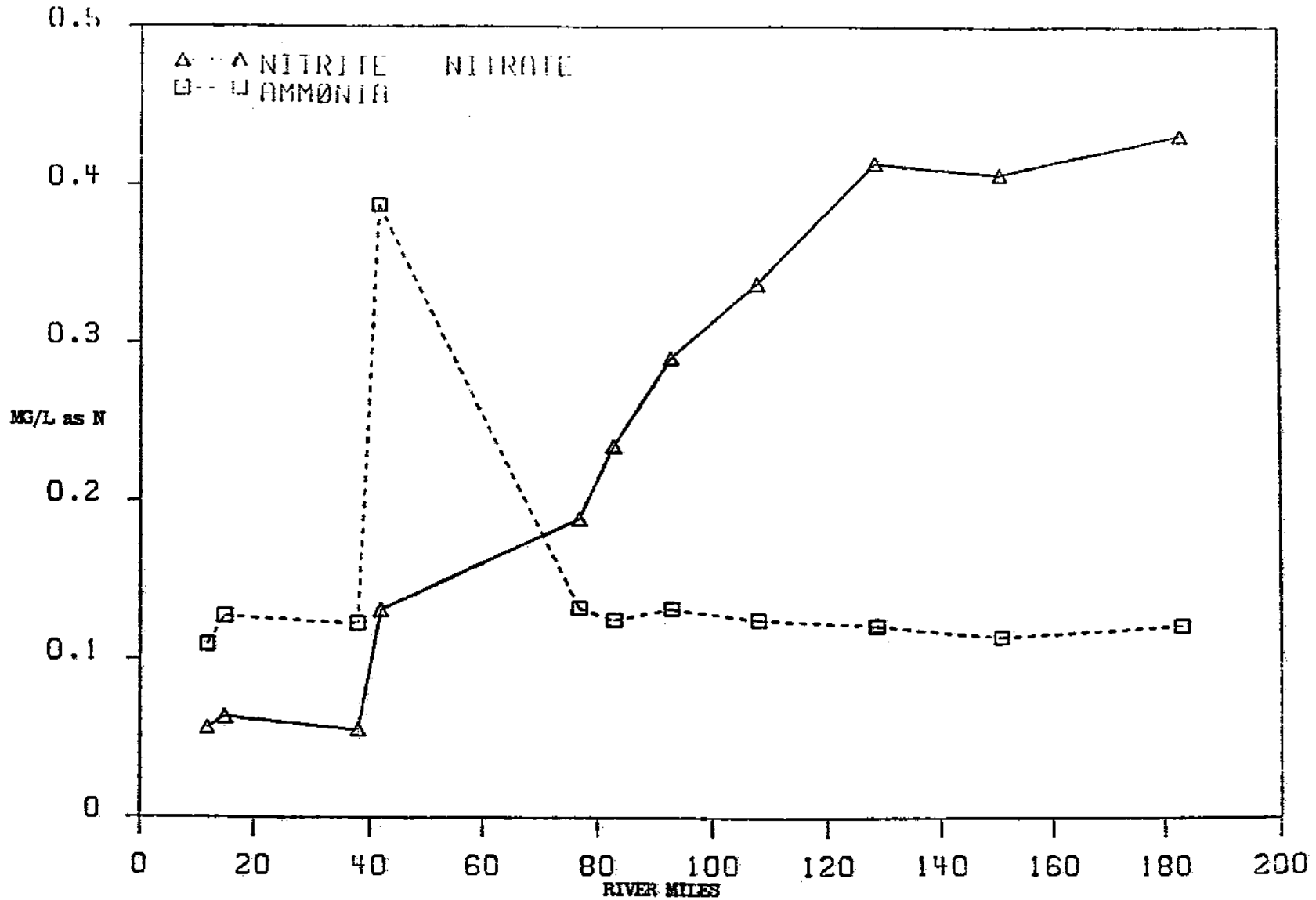


FIGURE 49. MONTHLY MEAN AMMONIA vs. NITRITE-NITRATE NITROGEN CONCENTRATIONS BY SAMPLING STATIONS. (DER-TLH DATA ONLY).

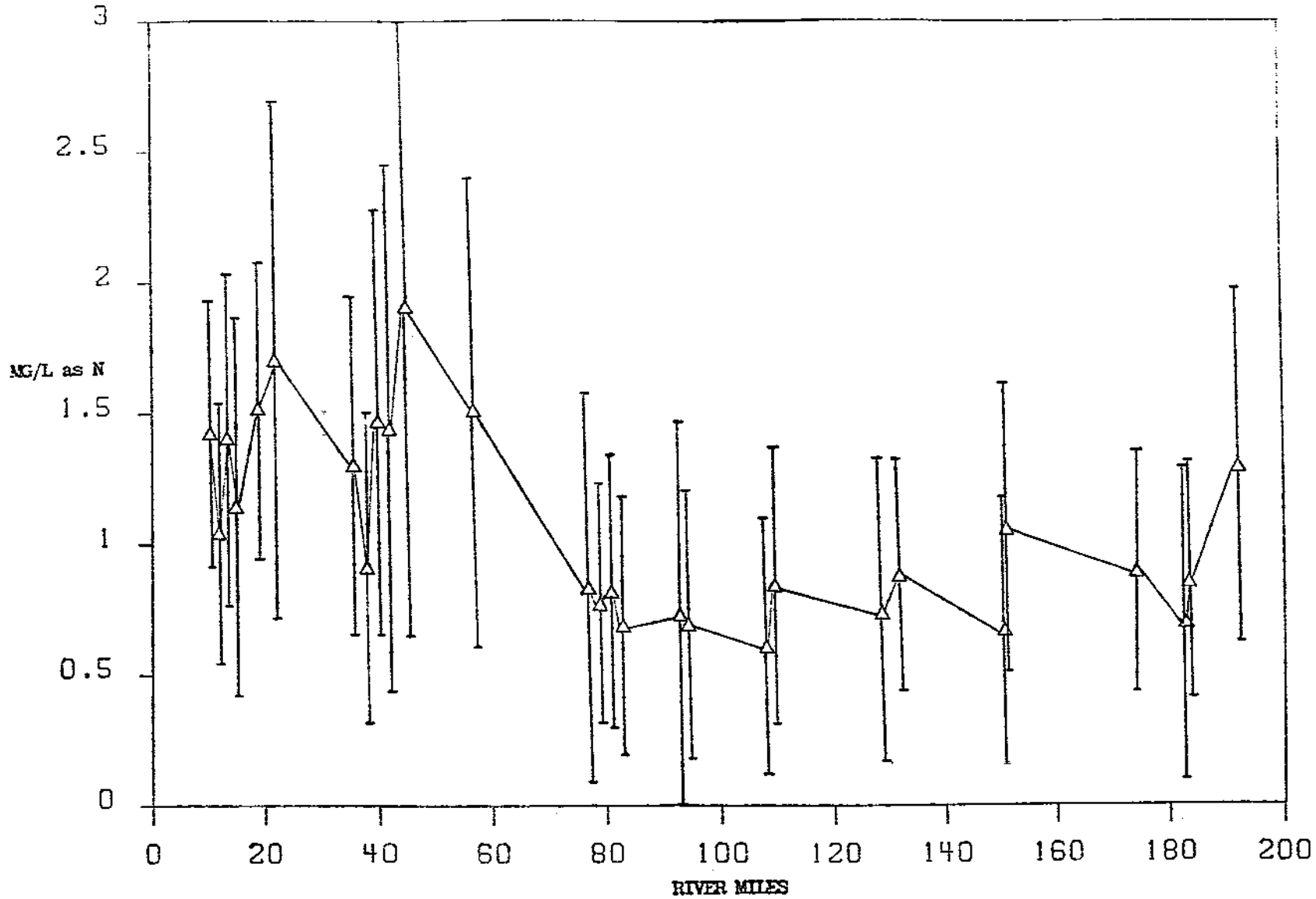


FIGURE 50. MEAN TOTAL KJELDAHL NITROGEN CONCENTRATIONS BY SAMPLING STATION WITH STANDARD DEVIATIONS.

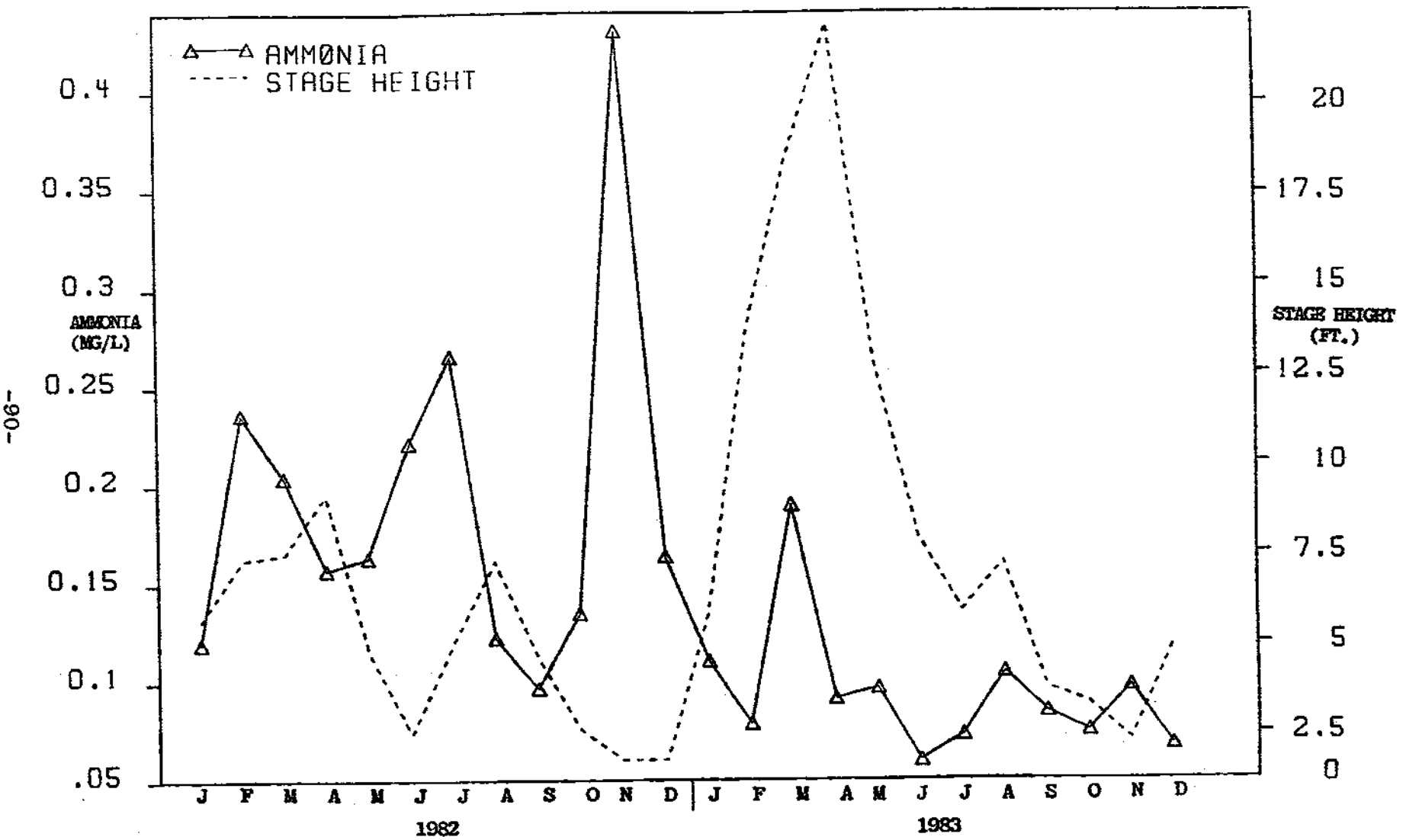


FIGURE 51. MONTHLY MEAN AMMONIA CONCENTRATIONS (MG/L) AND RIVER STAGE HEIGHT.

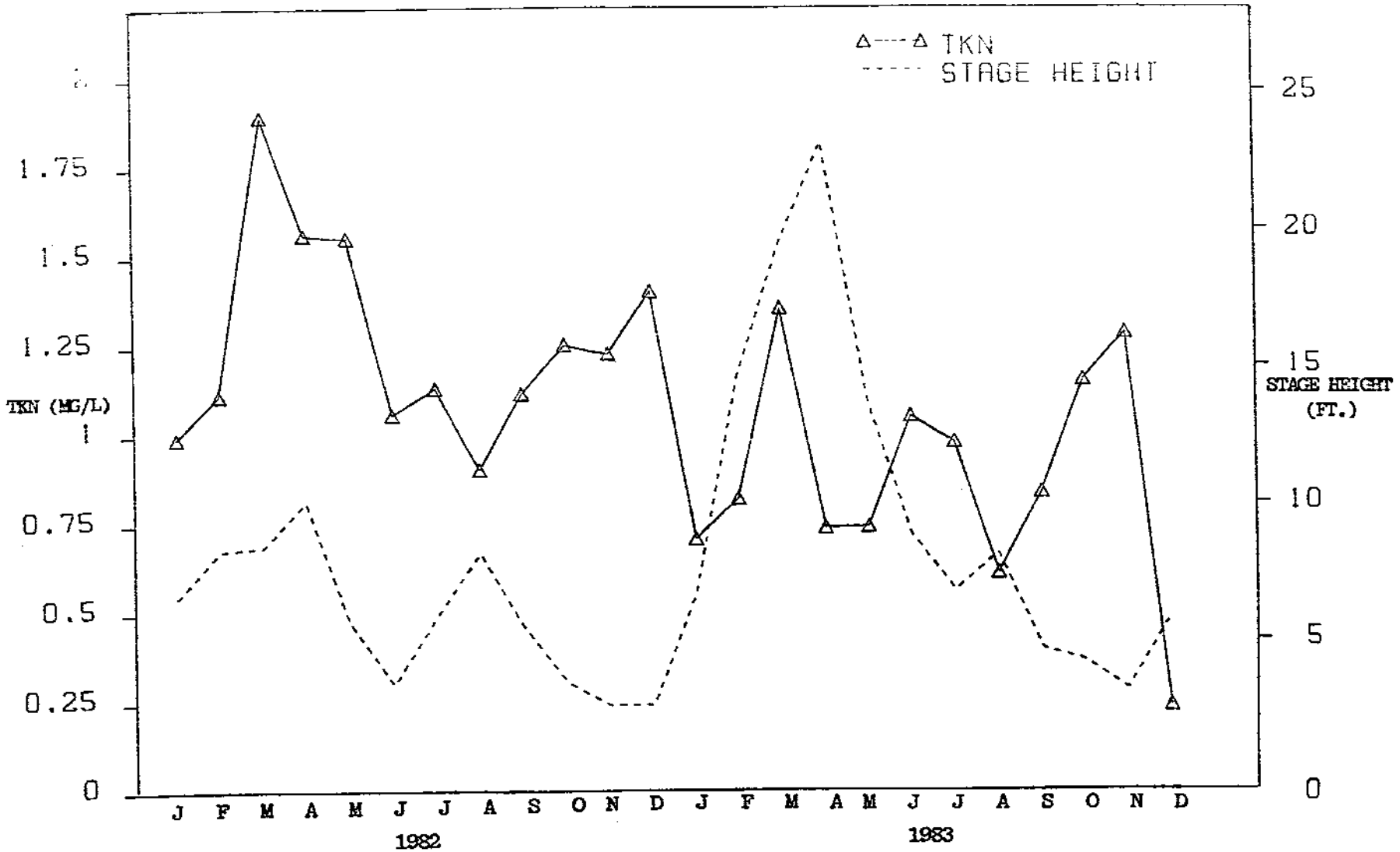


FIGURE 52. MONTHLY MEAN TKN vs. RIVER STAGE HEIGHT.

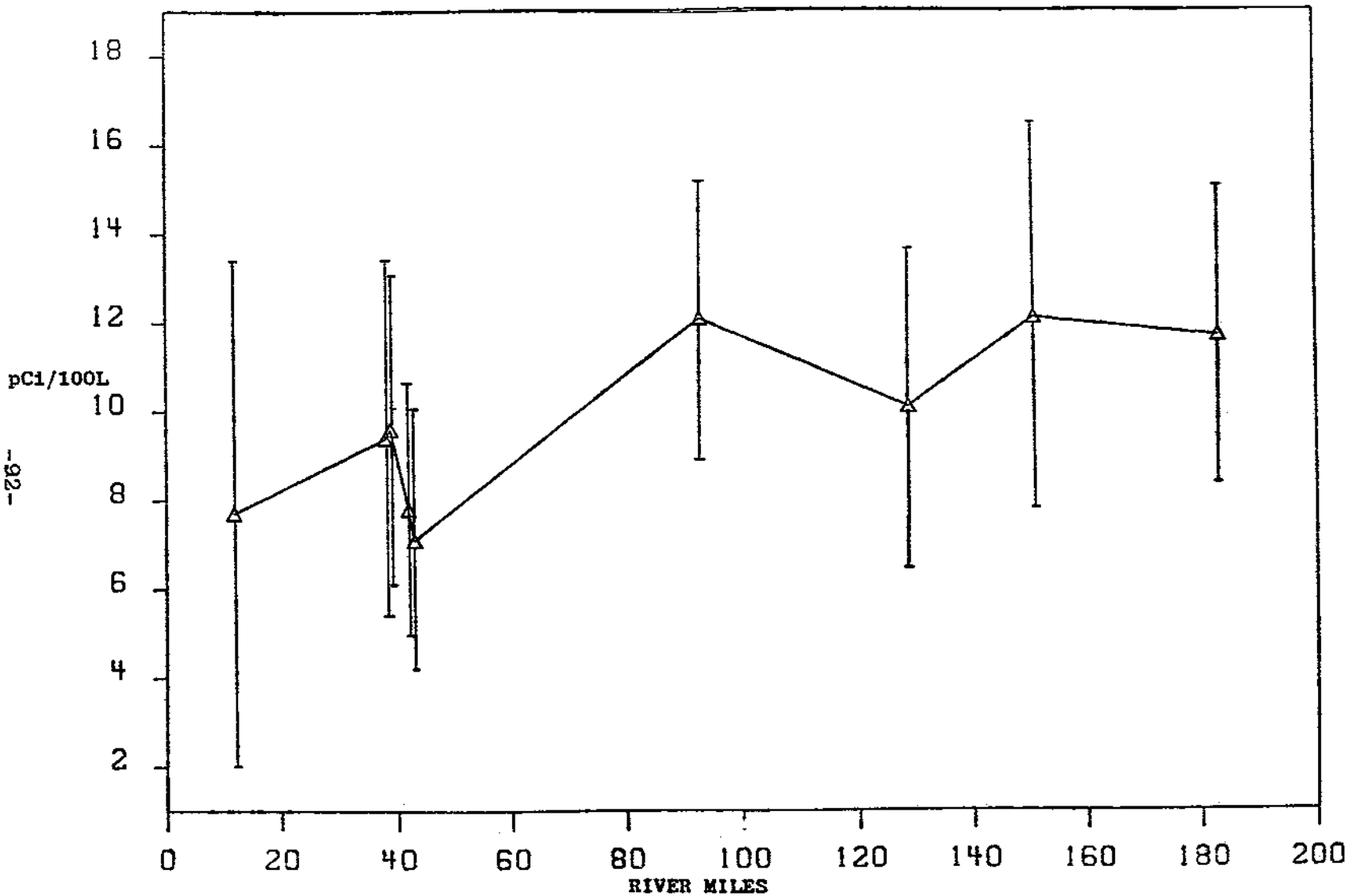


FIGURE 53. MEAN SOLUBLE RADIUM CONCENTRATIONS AND STANDARD DEVIATIONS BY SAMPLING STATIONS. (DATA FROM BURNETT AND DEETAE 1984).

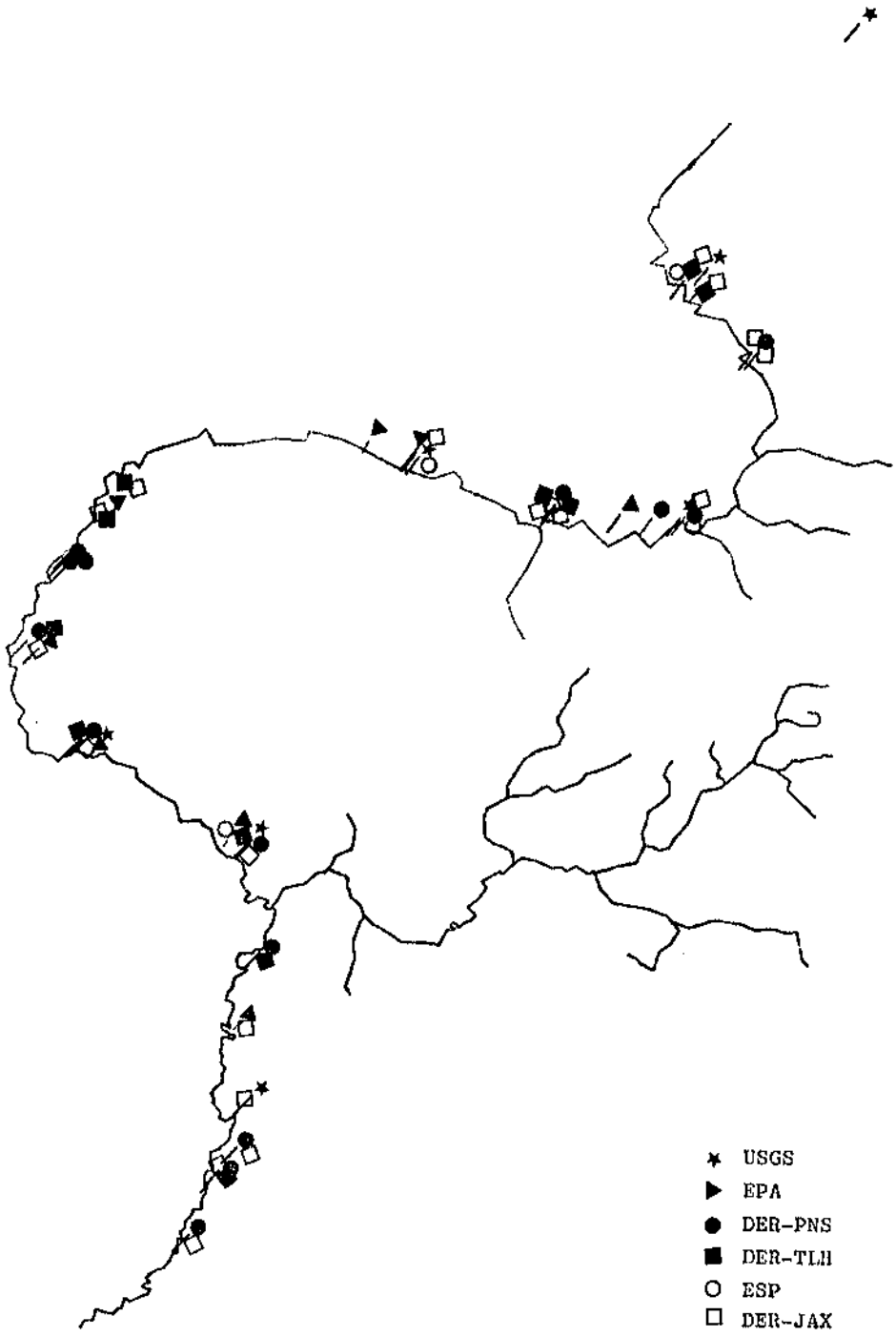


FIGURE 54. HISTORICAL STUDY STATION LOCATIONS.

TABLE 6. Physical - Chemical Methods

PARAMETER	METHOD	UNITS	REFERENCE
pH	Electrometric	SU	U.S. EPA 1979
Alkalinity	Titrimetric	mg/L $CaCO_3$	U.S. EPA 1979
Conductivity	YSI SCT Probe	umhos/cm	APHA 1980
Color	Visual Comparison	mg/L platinum	APHA 1980
Temperature	YSI Thermistor	°C	APHA, 1980
Dissolved Oxygen	Membrane Electrode	mg. D.O.	APHA, 1980
Sulfate	Turbidimetric	mg/L S	U.S. EPA 1979
Fluoride	Fluoride Ion Electrode	mg/L F	APHA 1980
Chloride	Argentometric	mg/L Cl	APHA 1980
Silica	Molybdosilicate	mg/L SiO	APHA 1980
Turbidity	Turbidimeter	NTU	APHA 1980
Total Phosphate	Ascorbic Acid	mg/L P	U.S. EPA 1979
Orthophosphate	Ascorbic Acid	mg/L P	U.S. EPA 1979
Ammonia	Ammonia Electrode	mg/L N	U.S. EPA 1979
Nitrite-Nitrogen	Spectrophotometric Diazotization	mg/L N	U.S. EPA 1979
Nitrite-Nitrate Nitrogen	Colorimetric, Cadmium Reduction	mg/L N	U.S. EPA 1979
Total Kjeldahl Nitrogen	Electrometric	mg/L N	U.S. EPA 1979

TABLE 7. Jacksonville Chemical Parameter List

PARAMETER	METHOD	UNITS	REFERENCE
Lab pH	Electrometric	SU	U.S. EPA 1979
Alkalinity	Titrimetric	mg/L $CaCO_3$	U.S. EPA 1979
Conductivity	YSI SCT Probe	umhos/cm	APHA 1980
Color	Visual Comparison	mg/L platinum	APHA 1980
Temperature	Hydrolab	°C	
Dissolved Oxygen	Winkler Method	mg. D.O.	APHA, 1980
Sulfate	Turbidimetric	mg/L S	U.S. EPA 1979
Fluoride	Fluoride Ion Electrode	mg/L F	APHA 1980
Chloride	Argentometric	mg/L Cl	APHA 1980
Silica	Molybdosilicate	mg/L SiO	APHA 1980
Turbidity	Turbidimeter	NTU	APHA 1980
Total Phosphate	Ascorbic Acid	mg/L P	U.S. EPA 1979
Orthophosphate	Ascorbic Acid	mg/L P	U.S. EPA 1979
Ammonia	Ammonia Electrode	mg/L N	U.S. EPA 1979
Nitrite-Nitrogen	Spectrophotometric Diazotization	mg/L N	U.S. EPA 1979
Nitrite-Nitrate Nitrogen	Colorimetric, Cadmium Reduction	mg/L N	U.S. EPA 1979
Total Kjeldahl Nitrogen	Electrometric	mg/L N	U.S. EPA 1979

TABLE 7. Jacksonville Chemical Parameter List

PARAMETER	METHOD	UNITS	REFERENCE
Lab pH	Electrometric	SU	U.S. EPA 1979
Alkalinity	Titrimetric	mg/L $CaCO_3$	U.S. EPA 1979
Conductivity	YSI SCT Probe	umhos/cm	APHA 1980
Color	Visual Comparison	mg/L platinum	APHA 1980
Temperature	Hydrolab	°C	
Dissolved Oxygen	Winkler Method	mg. D.O.	APHA, 1980
Sulfate	Turbidimetric	mg/L S	U.S. EPA 1979
Fluoride	Fluoride Ion Electrode	mg/L F	APHA 1980
Chloride	Argentometric	mg/L Cl	APHA 1980
Silica	Molybdosilicate	mg/L SiO	APHA 1980
Turbidity	Turbidimeter	NTU	APHA 1980
Total Phosphate	Ascorbic Acid	mg/L P	U.S. EPA 1979
Orthophosphate	Ascorbic Acid	mg/L P	U.S. EPA 1979
Ammonia	Ammonia Electrode	mg/L N	U.S. EPA 1979
Nitrite-Nitrogen	Spectrophotometric Diazotization	mg/L N	U.S. EPA 1979
Nitrite-Nitrate Nitrogen	Colorimetric, Cadmium Reduction	mg/L N	U.S. EPA 1979
Total Kjeldahl Nitrogen	Electrometric	mg/L N	U.S. EPA 1979

TABLE 9. Suwannee River Study
Jacksonville and Tallahassee - DER Chemical Sampling Stations

Suwannee River @ SR 6, Near Benton; river mile 11.2

Hunter Creek @ SR 135

*Suwannee River, 400m upstream of Hunter Creek; river mile 14.0

Suwannee River, downstream of Hunter Creek; river mile 14.3

*Suwannee River, 400m downstream of Hunter Creek; river mile 14.5

Suwannee River @ Cone Bridge - off SR 135; river mile 20.4

Roaring Creek @ SR 135

Suwannee River, downstream of Roaring Creek; river mile 20.9

Suwannee River @ U.S. 41 White Springs; river mile 35.8

Swift Creek @ U.S. 41

*Suwannee River, 350m upstream of Swift Creek; river mile 40.9

Suwannee River, upstream of Swift Creek; river mile 41.0

Swift Creek @ mouth off SR 225A

*Suwannee River, 300m downstream of Swift Creek above the Interstate Hwy. 75 bridge; river mile 41.8

Suwannee River @ I-75; river mile 45.0

Suwannee River @ Suwannee Springs; river mile 56.9

*Suwannee River, 1.6 km upstream of the Withlacoochee River; river mile 79.1

Suwannee River, upstream of Withlacoochee; river mile 80.1

Withlacoochee River @ Suwanacoochee Springs

Suwannee River @ Ellaville, U.S. 90; river mile 80.3

*Suwannee River, 1km downstream of the Withlacoochee River, approximately 300m upstream of Florida Power Corp's Suwannee River Plant intake canal; river mile 80.7

Table 9, Suwannee River Study Cont.

*Suwannee River, 3km upstram of the Florida Hwy. 250 bridge, near Dowling Park; river mile 93.0

Suwannee River @ Dowling Park, SR 250; river mile 94.5

*Suwannee River, 2.5km upstream of the Florida Hwy. 51 bridge, near Luraville; river mile 108.1

Suwannee River @ Luraville, SR 51; river mile 109.7

*Suwannee River, 5km upstream of U.S. Hwy. 27 bridge, near Branford; river mile 128.8

Suwannee River @ Branford, U.S. 27; river mile 131.9

Santa Fe River, U.S. 129

*Suwannee River, 700m upstream of the Florida Hwy. 340 bridge, near Rock Bluff; river mile 150.8.

Suwannee River @ Rock Bluff Landing; river mile 151.3

Suwannee River @ Fanning Springs, U.S. 19-98; river mile 174.4

*Suwannee River, 6 km downstream of New Pine Landing, adjacent to Manatee Springs State Park; river mile 183.0

Suwannee River @ Manatee Springs, SR 320; river mile 183.6

Suwannee River @ Fowler's Bluff, SR 347; river mile 192.3

* = Tallahassee DER Stations

PHYSICAL-CHEMICAL RELATIONSHIPS - MULTIVARIATE ANALYSES

Introduction

As part of an intensive study of the Suwannee River over a 25 month period, January 1982 - January 1984, data on 18 physical-chemical variables plus gage height were collected monthly at 11 stations. The goal of this chapter is to reduce the dimensionality of this huge mass of data to a few general or underlying factors, and to use these general factors to interpret variation in the parameters surveyed. The multivariate techniques of Cluster Analysis and Factor Analysis were employed to group the variables into larger units, and to reduce the dimensionality of the data to a few underlying factors. Cluster Analysis and Factor Analysis operate in entirely different ways, yet they result in very similar interpretations of variation within the physical-chemical variables surveyed. Spatial and temporal variations in each of the physical-chemical variables are comprehensively treated in the preceding Water Chemistry chapter, while gage height variation is treated in detail in the Hydrology and Geology chapter. The multivariate analyses serve to unite and augment the above two portions of this report, but the three must be read as a unit to fully understand variation in the physical variables surveyed.

Methods

Sample Collection and Analytical Methods

Mid-channel water chemistry was sampled once per month at each of 11 stations (Fig. 2) during the 25 month study period, January 1982 - January 1984. All samples were collected between 0700 and 1400 EST on a single day each month. Water temperature, dissolved oxygen (DO), and pH were determined in the field using electronic probes along with standard Secchi disc measurements (Wetzel and Likens 1979).

Mid-channel subsurface water samples were collected in rinsed 1 liter polyethylene containers, placed on ice and transported to FDER's chemistry laboratory in Jacksonville, Florida. Parameters in Table 10 were determined in the laboratory by the methods indicated. Both total (unfiltered) and dissolved (filtered) values were determined for nitrite, nitrite-nitrate, ammonia, Kjeldahl nitrogen, orthophosphate, and total phosphate.

In addition to the above standard sampling procedures, 19 liter water samples were regularly collected in a similar manner from stations 1, 3, and 4, and irregularly collected from stations 9, 10, and 11. These samples were analyzed for dissolved (filtered) calcium, magnesium, potassium, and sodium by W. C. Burnett and S. Deetae, Department of Oceanography, Florida State University, Tallahassee, using atomic absorption spectroscopy and the EDTA titrimetric method (APHA 1976).

Variable Selection for Multivariate Analyses

All variables were screened for redundancy by inspection of correlation coefficients and comparisons of their temporal and spatial patterns of variation. Variables were eliminated or modified to reduce redundancy.

The dissolved phosphate fractions, dissolved orthophosphate and dissolved total phosphate, accounted for the majority ($\bar{x}$=95-98%, n=270-294) of their respected constituents, and because all four phosphate variables were highly intercorrelated (for all pairs $r \geq .989$, n=270-275) the dissolved phosphate variables were eliminated. Total phosphate was also eliminated and orthophosphate chosen as the single measure of phosphate because total phosphate and orthophosphate were highly correlated (r=.991, n=275) and because the difference between total phosphate and orthophosphate values were small and did not display any distinct seasonal or spatial patterns.

Similarly, the dissolved and total values of nitrite (r=.944, n=272), nitrite-nitrate (r=.992, n=272), and ammonia (r=.974, n=274) were also highly correlated. The dissolved fractions accounted for the bulk ($\bar{x}$=96-100%, n=271-274) of the respective total values, and were again eliminated from further consideration. Total nitrite was also dropped from the analysis as values were very small, and displayed the same spatial and temporal patterns as the nitrite-nitrate variable. Therefore, the 2 inorganic nitrogen variables, nitrite-nitrate and ammonia, were retained for further analyses.

Total and dissolved Kjeldahl nitrogen were not as highly correlated (r=.847, n=271) as other constituent pairs, but the dissolved fraction was again eliminated as the two variables displayed the same spatial and temporal patterns. Originally, total Kjeldahl nitrogen was retained for further analyses, but it soon became apparent that the behavior of Kjeldahl nitrogen in the multivariate analyses was dominated by the pattern of variation of its ammonia component. Therefore, ammonia was subtracted from Kjeldahl nitrogen to produce a new nitrogen variable, organic nitrogen. This new variable displays patterns of variation distinctly different from those of ammonia and Kjeldahl nitrogen. All multivariate analyses presented herein use this new organic nitrogen variable. Therefore, nitrogen was represented in the system by nitrite-nitrate, ammonia, and organic nitrogen.

Field pH measurements were eliminated and lab pH values used in the analyses as the two data sets were highly correlated (r=.953, n=274). A series of experiments in the initial phases of the study demonstrated that the buffering capacity of the river water was sufficient to stabilize pH values if samples were carefully collected so as to assure that no air was trapped in the sample bottle. Lab pH values were selected for retention because some early field measurements were inaccurate due to the effects of the very low ionic strength in the upper river.

Secchi disc measurements were eliminated as this variable is a function of the color and turbidity variables that were retained for further analysis.

Silica, calcium, magnesium, potassium, and sodium were dropped from the original statistical analyses due to the large number of missing values.

The variable selection process resulted in the retention of the following 14 variables for multivariate analyses: water temperature; pH; conductivity; alkalinity; dissolved oxygen; color; turbidity; chloride; fluoride; orthophosphate; nitrite + nitrate nitrogen; ammonia; organic nitrogen; and sulfate. After the original set of multivariate analyses were completed, data on the four cations, calcium, magnesium, sodium, and potassium were added, and all statistical analyses were repeated on this new set of 18 variables.

The relationships between the above physical-chemical variables and water level fluctuations were investigated by employing standardized gage heights on the chemical sampling days as indices of discharge and flow rates. Standardized gage heights were calculated as explained in the hydrology section.

Statistical Methods

Statistical treatment included cluster analysis and factor analysis of both the log e transformed and normalized data sets. The two data transformations produced very similar results, and to avoid repetition only the results of analyses on the normalized data are presented here. Normalized data, i.e., values for each variable adjusted to zero mean and unit variance, are preferred when variables are expressed in different units, and when one wishes each variable to be given equal weight.

Cluster analyses of the physical-chemical variables and sampling stations were conducted to make preliminary assessments of the relationships among the physical-chemical variables, and geographic-geologic relationships within the basin. Cluster analyses were conducted on both the correlation matrix (CORR) and absolute values of the correlation matrix (ABSCORR) employing average linkage clustering using the BMDP statistical package (Dixon 1981).

Ordination by factor analysis (Dixon 1981) was employed to further elucidate relationships between the physical-chemical variables. The analyses were conducted on the correlation matrix of the normalized variables using varimax rotation of the factor loadings from Principal Components Analysis. Varimax rotation is orthogonal and results in new factors which are uncorrelated. The first four factors had eigenvalues larger than 1.00, accounted for approximately 79% of the variance in the data, were directly interpretable, and augmented patterns detected in the cluster analyses.

Results and Discussion

Cluster Analyses of Variables

Cluster analysis on the absolute values of the correlation matrix (ABSCORR) results in three multivariable clusters and two monotypic clusters. The largest cluster (Fig. 55), referred to as the physiography cluster, includes the variables pH, conductivity, alkalinity, nitrite-nitrate, color, sulfate, and organic nitrogen. Variation in the physiography variables is associated largely with the geography and geology of the basin, and these 7 variables display strong upstream-downstream trends. However, these variables need not vary together because this analysis was conducted on the absolute values of the correlation matrix. Indeed, the physiography variables may be further divided into two groups, a Coastal Lowlands group, and a Northern Highlands group. The Coastal Lowlands group contains the variables pH, conductivity, alkalinity, nitrite-nitrate, and sulfate which display increasing values downstream with noticeable increases as the Suwannee enters the Coastal Lowlands below Station 4. The two variables in the Northern Highlands group, color, and organic nitrogen, have high upstream values associated with inputs from the Okefenokee Swamp, and low downstream values due largely to dilution by spring inputs as the Suwannee enters the Coastal Lowlands (Fig. 9).

The second largest cluster (Fig. 55), or the Oxy cluster, includes 3 variables, orthophosphate, fluoride, and ammonia, that are discharged in significant quantities by Occidental Chemical and Agricultural Products, Inc., as a result of their phosphate mining activities. Concentrations of these variables are low at the three upper stations, abnormally high at the station immediately below Swift Creek, Station 4, and then decrease rapidly (between Stations 4 and 5) downstream due to dilution, oxidation, and assimilation (Figs. 35, 44, 48).

Cluster 3 (Fig. 55), or the season-temperature cluster, includes two variables, temperature and dissolved oxygen. The inverse relationship between temperature and dissolved oxygen is well known to limnologists (Wetzel 1975), and as expected these two variables display opposing seasonal patterns (Figs. 32).

Chloride clusters between the physiography cluster and the Oxy cluster (Fig. 55), and variation in this variable is related to both the geography of the basin and Oxy's discharge. Concentrations of chloride increase downstream due to significant inputs from Oxy via Hunter and Swift Creeks (Hull, Dysart, and Mann 1981), from the Withlacoochee River, and from marine aerosols below Station 9 due to the proximity of the Gulf of Mexico (Fig. 37).

Turbidity joins the other variables as a single member of a 4th cluster (Fig. 55). Like chloride, turbidity displays increased values between Stations 3 and 4 due to input of Oxy's effluent via Swift Creek, and increased values between Stations 5-6 due to the higher turbidity of the Withlacoochee River (Fig.

39). Turbidity values continue to increase between Stations 6 and 7 and remain at elevated levels in the lower river.

Cluster analysis of the original variables was repeated employing the correlation matrix (CORR). Results of the cluster analyses on the ABSCORR and CORR were similar for members of the Oxy and physiography clusters. The three Oxy variables, F, OPO_4, and NH_3, cluster tightly in both analyses. Variables in the physiography cluster of the ABSCORR analysis (Fig. 55) were divided into two groups by the CORR analysis (Fig. 56). Variables in the Coastal Lowlands group, which display increasing values downstream, clustered together, while the Northern Highlands variables, color and organic nitrogen, fused to form a separate cluster (Fig. 56).

The season-temperature cluster of the ABSCORR analysis (Fig. 55) breaks down in the CORR analysis because the relationship between dissolved oxygen and temperature is inverse. Therefore, cluster analysis on the correlation matrix separates these variables rather than joining them. However, cluster analysis on the CORR matrix produces a new season-gage height cluster that includes the variables dissolved oxygen, chloride, and turbidity. The formation of this cluster is largely fortuitous as dissolved oxygen values display increasing fall values and decreasing spring values due to the inverse temperature effect, while turbidity and chloride display similar seasonal patterns due to the seasonal nature of river discharge and flow rates.

Concentrations of chloride vary with dissolved oxygen ($r=.20$, $n=275$, $P<.01$) primarily because of the dilution-concentration effects on chloride of seasonal variations in discharge (Fig. 38, Table 11). Seasonal variations in average chloride concentrations in rainfall occur within the basin (Rykiel 1977), but are far less important than the dilution effects of gage height variation. The high intensity, long duration rainfalls of late winter and early spring, which coincide with early spring floods, result from frontal activity between continental and oceanic air masses (Hughes *et al.* 1971; Kenner 1975). These frontal rainfalls have reduced average chloride values due to the influence of the continental air masses, and the early depletion of marine aerosols during a long duration rainfall. The more frequent, short duration rainfalls of late spring and summer stem from convection of ocean-derived moisture and result in higher average chloride values.

Dissolved oxygen and turbidity are weakly correlated ($r=.19$, $n=275$, $P<.01$) as both show increasing mean values between stations 6-11 (Figs. 31, 39), winter highs, and summer lows (Figs. 32, 40). The seasonal correspondence between turbidity and dissolved oxygen results from high late winter-early spring turbidity due to positive correlation between turbidity and gage height (Table 11). Late winter-early spring is typically a period of high water, and flows during this period include a larger proportion of runoff with associated increased turbidity. The late spring-early summer and fall are periods of low flows and reduced stream velocities that result in reduced turbidity values.

Data on the four cations calcium, magnesium, sodium, and potassium, were added to data on the original 14 variables and cluster analyses repeated on both the new ABSCORR and CORR matrices. However, as explained in the methods section, data on these variables are lacking for Stations 2, 5, 7, and 8. The placements of these four cations were similar in both the ABSCORR and CORR analyses. Both calcium and magnesium are strongly correlated with conductivity and alkalinity ($r \geq .88$) and as a result they join the Coastal Lowlands group of the physiography cluster (Figs. 57, 58). Potassium also joins this group but at much lower similarity levels. On the other hand, sodium clustered with the three primary Oxy variables in both analyses (Figs. 57, 58). The spatial pattern of variation in sodium concentration is typical of variables strongly modified by Oxy's discharge. Concentrations of sodium are low above Station 3, display a significant jump between Stations 3 and 4 due to inputs from Swift Creek, and decrease downstream due to dilution (Fig. 59). Sodium does differ from the other 3 Oxy variables in that concentrations increase between stations 9-11 as they do for chloride due to increased inputs of marine aerosols.

The previous cluster analyses classified the variables into groups that are helpful in simplifying, or providing preliminary interpretation of the data (Figs. 55-58, Table 2). However, differences between these analyses result from deficiencies of the cluster analysis method (Field, Clarke, and Warwick 1982). A particularly important criticism of cluster analysis in the study of variation in physical-chemical parameters is the loss or obscuring of data on secondary sources of variation by the placement of each variable in a single cluster. Generally, cluster analysis groups variables that share the same dominant pattern of variation, in this case as measured by the correlation coefficient. However, variation in many parameters such as sulfate and chloride results from more than one source. For example, the variation in sulfate is associated primarily with two factors, inputs from the Floridan Aquifer via springs and baseflow in the Coastal Lowlands, and inputs from Oxy via Swift Creek. However, cluster analysis must place sulfate in only one cluster, which in this case is the physiography cluster (Fig. 55). As a result the significant increases in sulfate contributed by Swift Creek (increase between Stations 3 and 4, Fig. 33) is ignored or lost. This problem of a secondary Oxy effect being masked by a more dominant factor also occurs for organic nitrogen, conductivity, chloride, and as will be seen in subsequent analyses, by the cations magnesium and calcium.

The role of variations in stream flow upon the physical-chemical variables was investigated using correlation and cluster analyses. Standardized gage heights for the chemical sampling days were employed as indices of discharge and flow rates (see hydrology section for an explanation of standardized gage heights). In cluster analyses of ABSCORR matrices, gage height clustered with members of the physiography cluster, while gage height clustered with color, organic nitrogen, and turbidity in analyses conducted on CORR matrices. Variations in flow have considerable influence on most parameters, and relationships

between gage height and the physical-chemical variables are best summarized by survey of their correlation coefficients (Table 11).

Most variables display an inverse relationship with gage height (negative correlation coefficients, Table 11) that correspond to a dilution-concentration effect. High water levels dilute the various constituents resulting in lower concentrations, while periods of low flow result in higher concentrations. This is true for all negatively correlated variables in Table 11 except pH and temperature. Because pH is a negative inverse function of $[H^+]$, lower pH values actually correspond to higher hydrogen ion concentrations. Higher gage heights result in high hydrogen ion concentrations because a large proportion of discharge is contributed by the Okefenokee, marginal swamps and precipitation, while lower water levels correspond to lower $[H^+]$ because of the larger proportion of groundwater and spring inputs. The negative correlation coefficient between gage height and temperature results from the seasonal nature of variation in these two variables (Figs. 28, 16).

Gage height is positively correlated ($P<.01$) with only two of the variables studied, color and turbidity (Table 11). The positive relationship between color and gage height parallels that between $[H^+]$ and gage height discussed above. During high flow increased amounts of dissolved and particulate organic matter including humic and fulvic compounds are flushed from the tannic swamps into the river, while during periods of low flow the relative contribution of swamp inputs is reduced. The positive relationship between turbidity and gage height (Figs. 39, 40, Table 11) stems in part from the increased particulate matter derived from swamps, but also from increased tributary inputs and possibly the increased resuspension of bottom sediments due to increased stream velocities.

Cluster Analyses of Stations

Cluster analysis of the 11 stations using data on the original 14 physical-chemical variables resulted in two distinct station clusters that correspond to the two major physiographic districts within the basin. The four stations (1-4) located in the Northern Highlands clustered together, while the 7 stations (5-11) located in the Coastal Lowlands formed a very tight, distinct cluster (Fig. 60). However, the secondary effects of Oxy's discharge is also reflected in the dendrogram by the dissimilarity (distance) between station 4 and the cluster of stations 1-3.

The station data set was then divided into 3 subsets to investigate the effects of water level changes on the physical-chemical characterization of the stations. The twenty-five monthly sampling days were separated into three groups: 7 low water months; 11 middle, or average, water level months; and 7 high water months. Cluster analyses of stations were conducted using the three water-level data sets. At all

three water levels, the 7 lower river stations (5-11) fused tightly into a Coastal Lowlands cluster (Figs. 60). However, changes in water levels had significant effects on relationships between the upper 4, or Northern Highlands' stations. Stations 1-3 clustered tightly at average water levels and were joined by Station 4 at a lower similarity level due to differences in parameters associated with Oxy's discharge via Swift Creek (Fig. 60). At high water levels the difference between stations 1-4 is greatly diminished by dilution and Stations 1-4 cluster tightly and at roughly the same similarity level (Fig. 60). At low water levels, Stations 1-4 appear to differ along a downstream gradient that suggests modification of the predominantly Okefenokee Swamp drainage by inputs from small tributary streams (base flow and Oxy's effluent from Hunter and Swift Creeks) which occur between Stations 1-2 and 3-4 (Fig. 60).

Factor Analysis of Variables

Factor analysis was employed to further investigate relationships among the physical-chemical variables. While the previous cluster analysis grouped highly correlated variables that displayed similar patterns of variation into clusters (Table 12), factor analysis explains variation in the data by reconstructing the correlation matrix in terms of a reduced number of new variables, or factors. The chief advantage of factor analysis is the reduction of dimensionality to a small number of underlying factors that account for a large proportion of variance in the data.

Factor analysis of the original 14 physical-chemical variables produced four factors that had eigenvalues greater than 1.00, accounted for approximately 79% of the variance in the data, were directly interpretable, and augmented patterns of variation detected in the cluster analyses. Each factor has an associated eigenvalue that corresponds to the proportion of variance in the original data explained by that factor. The first factor explains the largest amount of variance, in this case 37%, with each succeeding factor explaining a smaller additional proportion of the variance (Table 13). The relationship between each physical-chemical variable and factor is expressed by a factor score coefficient, or factor loading. Factor loadings indicate the strength and sign of the relationship between the factors and original variables. Interpretation of factors is facilitated by analyzing the factor loadings for the variables, and by a series of contrasts and comparisons between groups of variables with similar loadings.

Factor 1 accounts for roughly 37% of the variation in the data, and corresponds to the physiography cluster in the cluster analyses. Variables with large loadings on factor 1 are strongly influenced by the geology and geography of the basin and display strong upstream-downstream gradients in concentration. Factor 1 contrasts the Coastal Lowlands variables, alkalinity, conductivity, nitrite-nitrate, pH, and sulfate, which have large positive loadings with the Northern Highlands variables, color and organic nitrogen, which have large negative loadings (Table 13,

Figs. 61-63). Chloride displays a positive, but smaller loading on the physiography factor, factor 1, due in part to increased inputs from marine aerosols near the coast.

While variations in temperature and dissolved oxygen are dominated by seasonal changes, these two variables also display small loadings of opposite sign on the physiography factor, or factor 1 (Table 13). Temperature and dissolved oxygen display upstream-downstream gradients that vary seasonally, and sharp changes between Stations 4 and 5 (Figs. 29-31). At low and moderate water levels, the Suwannee receives large inputs of groundwater from the Floridan Aquifer via springs and baseflow as the river enters the Coastal Lowlands below Station 4. Waters from springs along the Suwannee River maintain relatively constant temperatures and low dissolved oxygen levels due to depletion during their underground residence. Survey of data in Rosenau et al. (1977) shows that these springs have a mean temperature of 21.6°C (range = 19-22.6°C, n=34) and a mean dissolved oxygen of 2.8 mg/l (range = 1.0-5.0 mg/l, n=26). Spring water temperatures are warm relative to the river water in winter and cool relative to the river water in summer. Inputs of spring water and baseflow have a downstream warming effect during the winter months and a downstream cooling effect during the summer months (Fig. 29), which after mixing results in the opposite effect on dissolved oxygen. Despite, or in conjunction with the temperature effect on dissolved oxygen, inputs of large quantities of oxygen depleted water from sources such as Alapaha Rise and Holton Creek (Fig. 31) below Station 4 can significantly reduce local dissolved oxygen levels in the river and produce the low percent dissolved oxygen saturation in this reach of the river (Fig. 30).

Factor 2 explains roughly 20% of the variation in the data and represents variation resulting from effluent discharged by Oxy. Fluoride, orthophosphate, and ammonia have very large positive loadings on the Oxy factor (Table 13, Fig. 61) as Oxy contributes substantial amounts of these constituents to the Suwannee River via Swift Creek. The longitudinal patterns of concentration along the river for these three variables (Figs. 35, 44, 48) are typical of significant point source discharges. Concentrations of these variables are very low above Oxy's primary discharge point (Stations 1-3), but jump to abnormally high levels at Station 4 immediately downstream of Swift Creek. Concentrations of these three constituents decrease rapidly downstream of station 4 due to dilution, oxidation, and assimilation.

Sulfate shows a significant positive loading on the Oxy factor, factor 2, that was not detected by the cluster analyses. Sulfate concentrations increase dramatically between Stations 3 and 4 (Fig. 33) due primarily to drainage of Oxy's gypsum ponds into Swift Creek (U.S. EPA 1978), and are maintained at high levels in the Coastal Lowlands below Station 4 due to spring and groundwater inputs.

In addition to the 4 variables with large positive loadings on the Oxy factor, chloride, conductivity, and organic nitrogen

also have small positive loadings on factor 2 (Fig. 61, Table 13). While the cut-off point for significance of factor loadings is arbitrary, the small loadings for these three constituents appear to represent genuine inputs from Oxy. Of the above 3 variables, the previous cluster analyses associated only chloride with Oxy. Inspection of longitudinal concentration patterns indicate that all three constituents show increases between Stations 3 and 4. Additionally, chemical sampling of Swift Creek shows significantly higher levels of chloride and conductivity than are typical for streams in the area (Hull, Dysart, and Mann 1977), and Oxy's mining process is known to produce these constituents as by-products (U.S. EPA 1978). Increased chloride and conductivity levels result from the processing and leaching of the primary fluorapatite mineral, $Ca_5(PO_4)_3(F,Cl,OH)$, and from drainage of gypsum ponds, while the increased organic nitrogen levels are associated with the large ammonia fraction in the effluent.

Factor 3 accounts for an additional 14 percent of variation in the data, and may be interpreted as a general seasonal factor that includes both seasonal-temperature and seasonal-gage height components (Fig. 62, Table 13). As expected, DO and temperature load vary strongly and with opposite signs on factor 3 due to the inverse relationship between temperature and dissolved oxygen. Chloride also loads quite strongly on the season factor, factor 3, and as discussed previously this results from the large dilution-concentration effects of seasonal fluctuations in gage height (Fig. 38). Organic nitrogen loads with a small value of opposite sign to chloride because increased gage heights result in higher organic inputs from the Okefenokee and marginal swamps.

Factor 4, which explains 7.8% of the variation in the data (Fig. 63, Table 13), corresponds largely to variation in the single variable turbidity. Inspection of the longitudinal concentration pattern for turbidity (Fig. 39) reveals that turbidity displays high downstream values as do members of the Coastal Lowlands group, and significant increases due to inputs from Oxy. However, turbidity is unique among variables with high downstream values as turbidity does not display increased values between Stations 4-5 associated with inputs from the Floridan Aquifer, but does display significant increases due to inputs from the Withlacoochee River between Stations 5-7. Turbidity differs from the Oxy variables by not displaying the typical dilution-assimilation pattern downstream from Station 4. Also pH loads on the turbidity factor, but at a much lower level. This increased pH-turbidity association appears to result from the increased buffering and cation exchange capacity of the particulate material.

After completion of the factor analysis on the original 14 variables, data on the four cations, calcium, magnesium, sodium, and potassium, were added to the data set and the factor analysis repeated. However, as explained previously, data on these variables are lacking for Stations 2, 5, 7, and 8, and incomplete for stations 9, 10, and 11. Therefore, the data set analyzed is

actually smaller (n=132) due to the missing value-case elimination procedure of the computer program (Dixon 1981).

As expected from the previous cluster analyses, calcium and magnesium loaded very strongly and positively on the physiography factor, factor 1 (Table 14). These two variables are typical members of the Coastal Lowlands group and display high downstream values associated with the Floridan Aquifer (Fig. 59). Sodium and potassium also load on the physiography factor but at much lower levels (Table 14). Sodium loaded most strongly on the Oxy factor, factor 2 (Table 14), and the longitudinal concentration pattern of sodium is typical of Oxy variables with a strong peak at Station 4 followed by downstream dilution (Fig. 59). Potassium loads very strongly on the turbidity factor, factor 4 (Table 14). The positive and nearly equal loadings of turbidity and potassium on factor 4 suggest that the increased potassium levels between Stations 4-6 are associated with the clay fraction of the turbidity plus soluble potassium leached from the clays of the Withlacoochee Basin.

Summary

The two multivariate techniques employed produced similar results. Both the cluster analysis (Table 12) and factor analysis (Table 15) of variables pointed out the importance of four main factors in understanding the physical-chemical variation within the Suwannee River. The most important factor was the physiography of the basin which in the factor analyses accounted for 37% of the variation in the physical-chemical variables surveyed. The physiography factor accounts for the effect of basin location, including variation in inputs of marine aerosols due to the proximity of the Gulf, as well as differences between the two major geologic and geographic divisions within the basin. In Table 16, the physiography variables are grouped into categories that reflect the three main components of the physiography factor. The majority of variables (Table 16) were affected in some way by the principal physiographic division between the Northern Highlands and the Coastal Lowlands due to changes in the quality and quantity of groundwater and spring inputs. The thick Hawthorn deposits of the Northern Highlands serve to isolate the river from the underlying Floridan Aquifer, and the physical-chemical composition of the river water is dominated by inputs from the Okefenokee and marginal swamps, the surficial aquifer, and precipitation. Below Station 4 the Suwannee enters the Coastal Lowlands and significant quantities of water from the Floridan Aquifer begin to enter the river via baseflow and springs (Fig. 7). Waters of the Floridan Aquifer differ markedly from the tannic, acidic, and low ionic strength waters typical of the Northern Highlands. Groundwater from the Floridan Aquifer is high in conductivity and associated dissolved solids, well buffered and of neutral to slightly basic pH, clear, low in dissolved oxygen, and of relatively constant temperature.

Effluent from Occidental Chemical Agricultural Products, Inc. dominates variation in fluoride, phosphate, and ammonia, and

plays an important role in the variation of other parameters including sulfur, sodium, chloride, conductivity, organic nitrogen, and nitrate (Table 16). Results of the factor analysis indicate that effluent from Oxy accounts for about 20-21% of the variation in the 18 physical-chemical variables surveyed. However, the effect of Oxy on some variables remained undetected by both analyses. Neither turbidity nor nitrite-nitrate were associated with Oxy by any of the multivariate analyses conducted, yet the association is obvious by inspection of the longitudinal variation patterns for these variables (Figs. 39, 49). The isolation of turbidity, factor 4, as a separate factor due to its unique pattern of variation results in low loadings for this variable on other factors. On the other hand, Oxy's effect on nitrite-nitrate variation was masked by a dominant physiography effect, and the status of each variable as a separate entity. Nitrite-nitrate differs from all other variables analyzed in that it is an oxidation product of another variable, ammonia. Occidental's effluent contains a significant ammonia component that appears as a large spike below the Swift Creek outfall in the longitudinal concentration pattern (Fig. 49). Nitrite-nitrate concentration also shows a large jump between Stations 3-4 associated with Swift Creek, but nitrite-nitrate concentrations between Stations 4-6 continue to rise as ammonia concentrations rapidly decrease to background levels. While some of the increased nitrite-nitrate levels between Stations 4-6 result from spring inputs, the bulk of the increase results from oxidation of the available ammonia. The further increases in nitrite-nitrate between Stations 6 and 11 result from the high levels of nitrate in the springs (x=.41 mg/l, n=19, data summarized from Rosenau et al. 1977), plus additional inputs from human activities. The effect of Oxy on these variables, and the lack of detection by the multivariate analyses are indicated in Table 16.

The dominant effects of physiography and Oxy can also be seen in the cluster analyses of stations. In each analysis, stations in the Coastal Lowlands (5-11) cluster tightly together, while the 4 stations in the Northern Highlands (1-4) form a separate cluster. However, the clustering levels, or degree of similarity among the four Northern Highlands' stations varies with gage height (Fig. 60) due to the dilution-concentration effect on variables dominated by effluent from Oxy. At moderate water levels Station 4 differs significantly from the three stations upstream of Swift Creek (Fig. 60); however, at high water levels the effect of Swift Creek is diluted to such an extent that the 4 stations in the Northern Highlands cluster tightly at a very high similarity level (Fig. 60). At low water levels Stations 1-4 differ along a downstream gradient that suggest modification of the predominant Okefenokee Swamp drainage by inputs from tributary streams, base flow, and Oxy's effluent from both Hunter and Swift Creeks (Fig. 60).

Seasonal variation accounts for about 14% of the variation in the parameters surveyed and includes both a season-temperature and a season-gage height component (Table 16). The inverse

relationship between temperature and dissolved oxygen is well known among limnologists (Wetzel 1975) and as expected dissolved oxygen and temperature display inverse seasonal patterns (Fig. 32). Although only chloride, turbidity, color, and organic nitrogen were linked to the seasonal factor by the multivariate analyses, seasonal changes in gage height affect the majority of variables analyzed (Table 11). Most constituents surveyed display a significant inverse relationship with gage height (negative correlation coefficients, Table 11) that corresponds to a dilution-concentration effect. High water levels dilute the various constituents resulting in lower concentrations, while periods of low flow result in higher concentrations. On the other hand, high gage heights result in increased color, $[H^+]$, and organic nitrogen due to the flushing of organic matter including humic and fulvic compounds from the tannic swamps into the river.

The fourth factor, which accounts for 7-8% of the variation in the data, corresponds largely to variation in turbidity and potassium (Tables 13, 14, and 16). Inspection of the longitudinal concentration pattern for turbidity (Fig. 39) reveals that turbidity displays high downstream values as do members of the Coastal Lowlands variable group, and significant increases due to inputs from Oxy. However, turbidity is unique among variables with high downstream values as turbidity does not display increased values between Stations 4-5 associated with inputs from the Floridan Aquifer, but does display significant increases due to inputs from the Withlacoochee River between Stations 5-7. Turbidity differs from the Oxy variables by not displaying the typical dilution-assimilation pattern downstream of Station 4. Potassium loads very strongly on the turbidity factor, and pH also loads but at a much lower level. This turbidity-potassium-pH association appears to be associated with the buffering and cation exchange capacity of the clay fraction of the turbidity, plus soluble potassium leached from the Withlacoochee Basin.

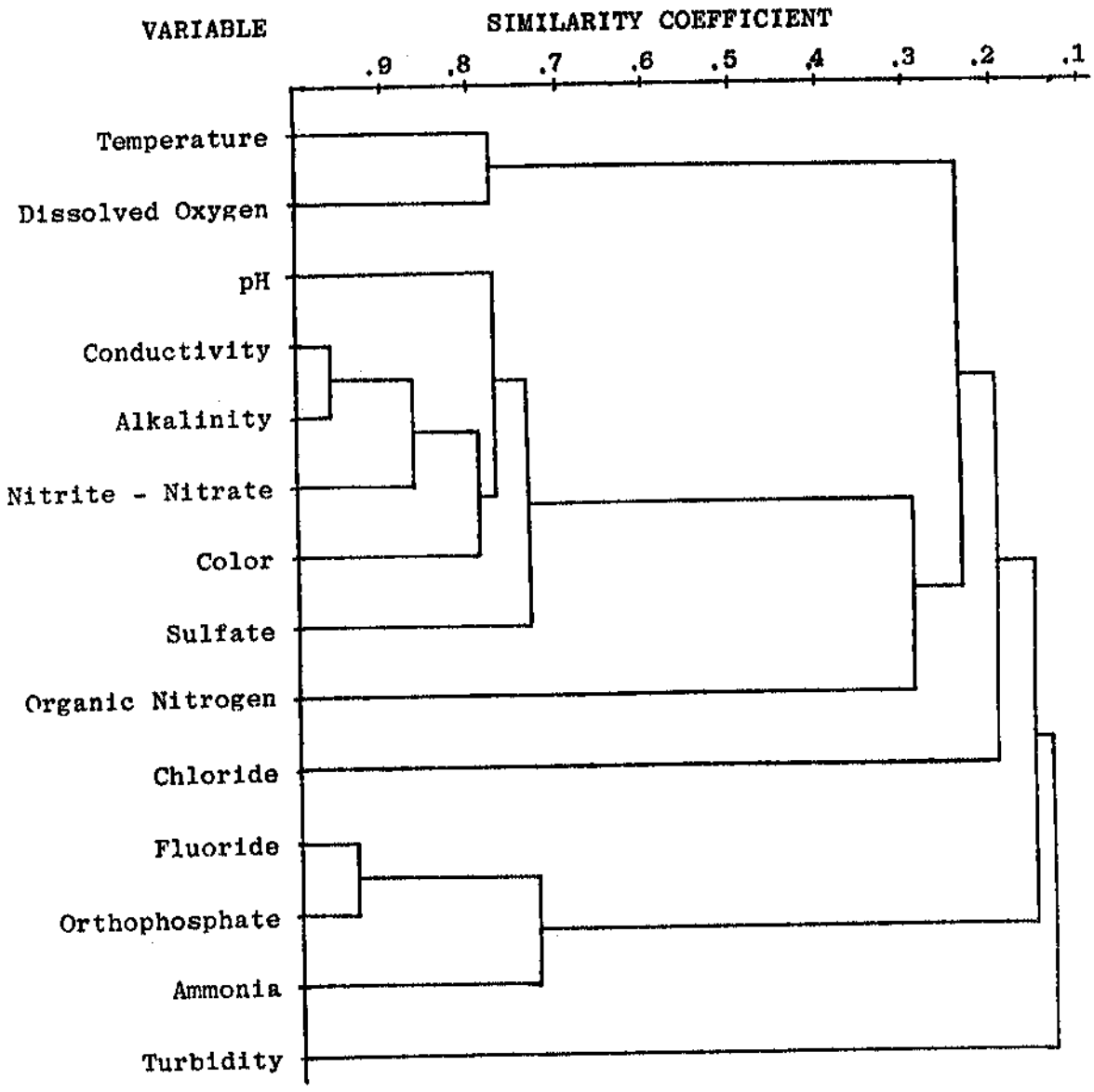


FIGURE 55. DENDROGRAM FROM CLUSTER ANALYSIS ON THE ABSOLUTE VALUE OF THE CORRELATION MATRIX FOR 14 PHYSICAL-CHEMICAL VARIABLES.

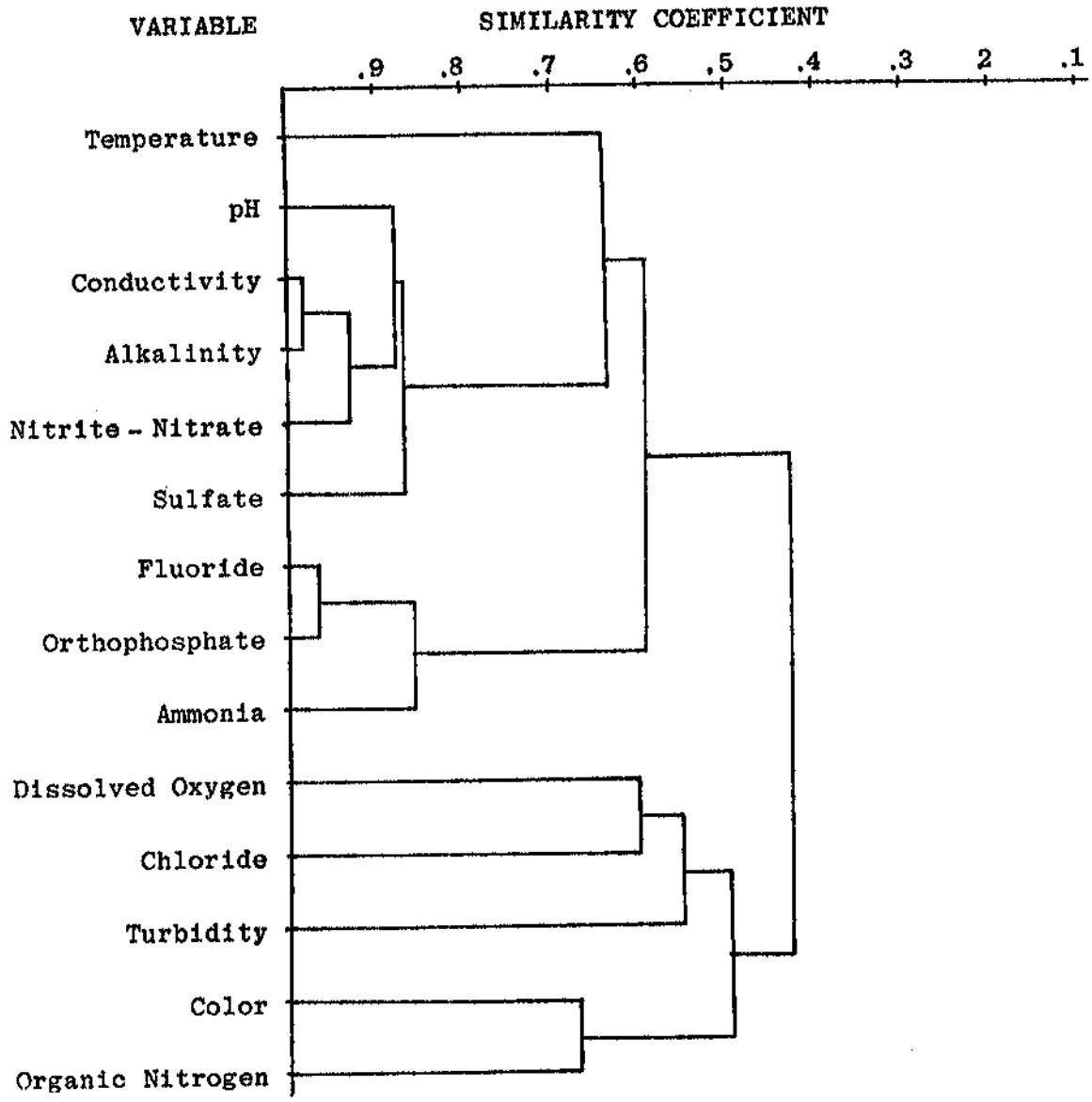


FIGURE 56. DENDROGRAM FROM CLUSTER ANALYSIS ON THE CORRELATION MATRIX OF 14 PHYSICAL-CHEMICAL VARIABLES.

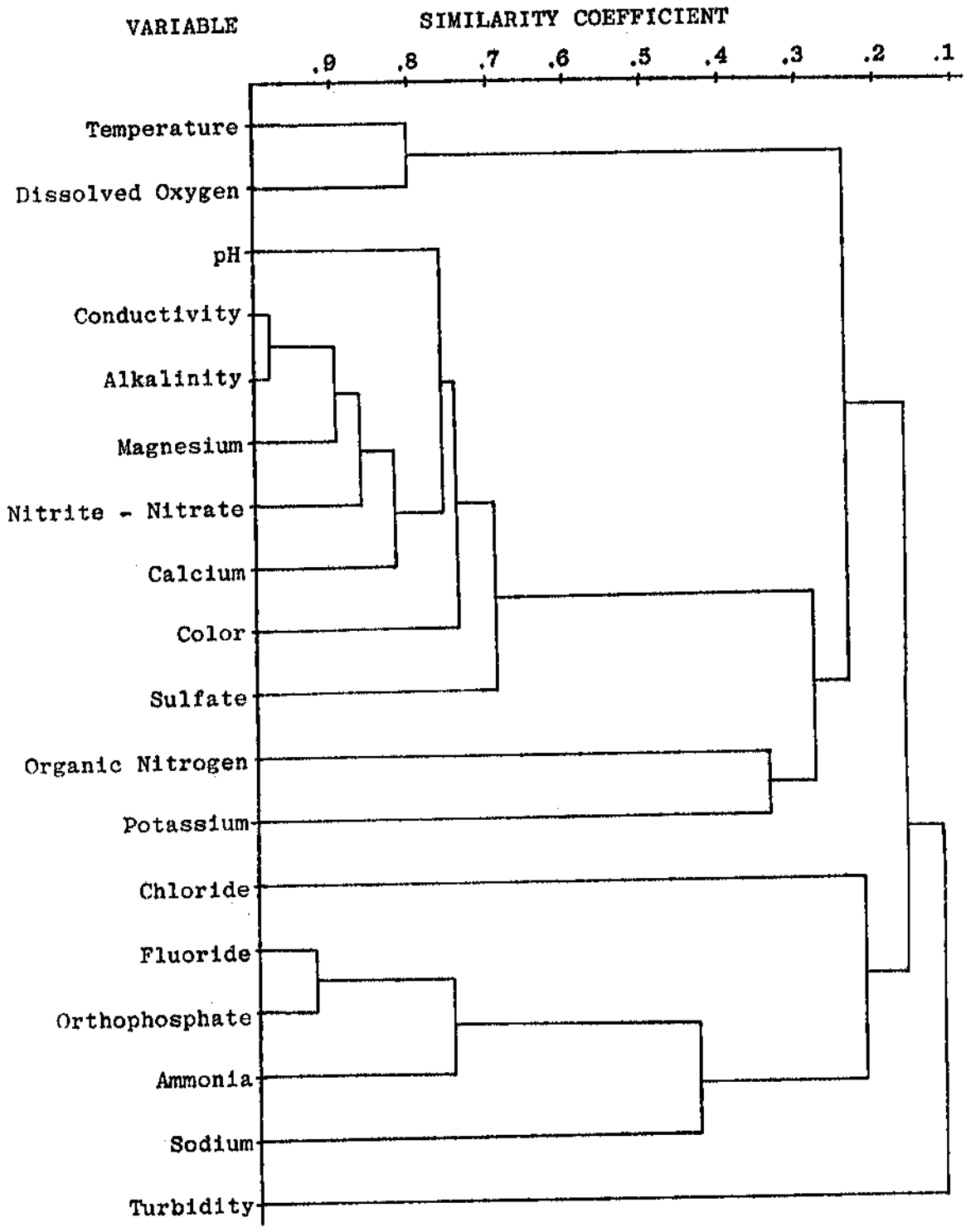


FIGURE 57. DENDROGRAM FROM CLUSTER ANALYSIS ON THE ABSOLUTE VALUE OF THE CORRELATION MATRIX FOR 18 PHYSICAL-CHEMICAL VARIABLES.

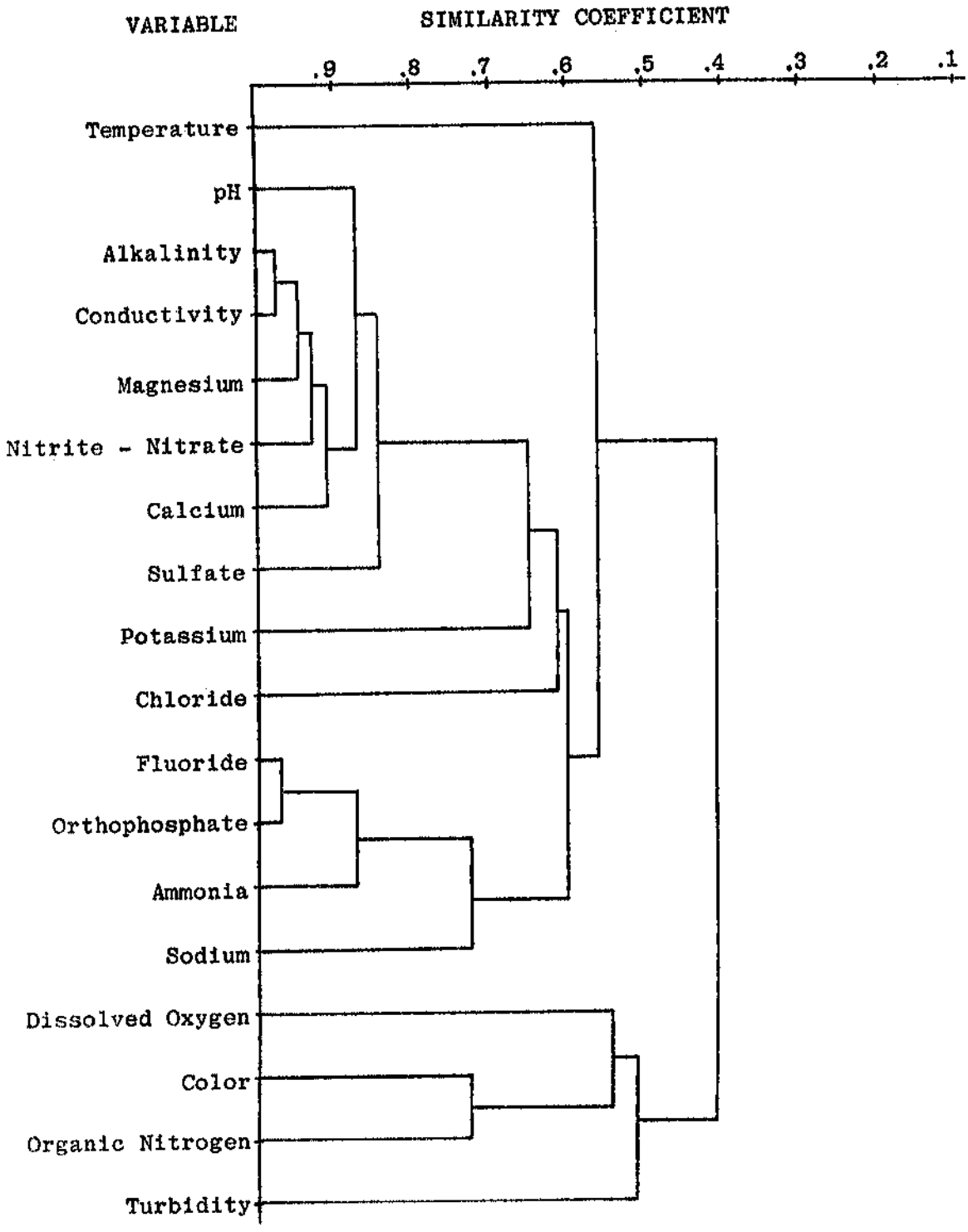


FIGURE 58. DENDROGRAM FROM CLUSTER ANALYSIS ON THE CORRELATION MATRIX OF 18 PHYSICAL-CHEMICAL VARIABLES.

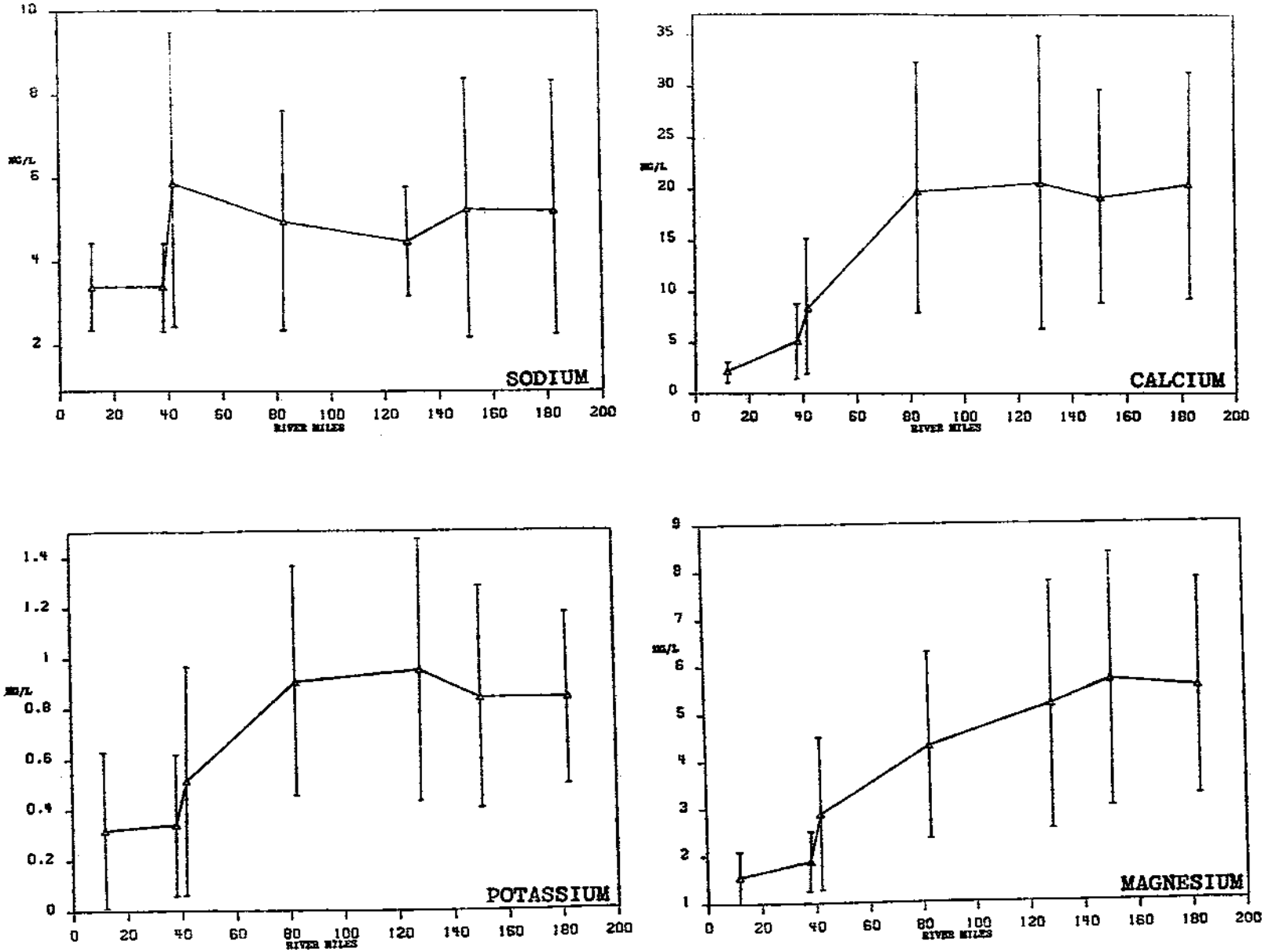
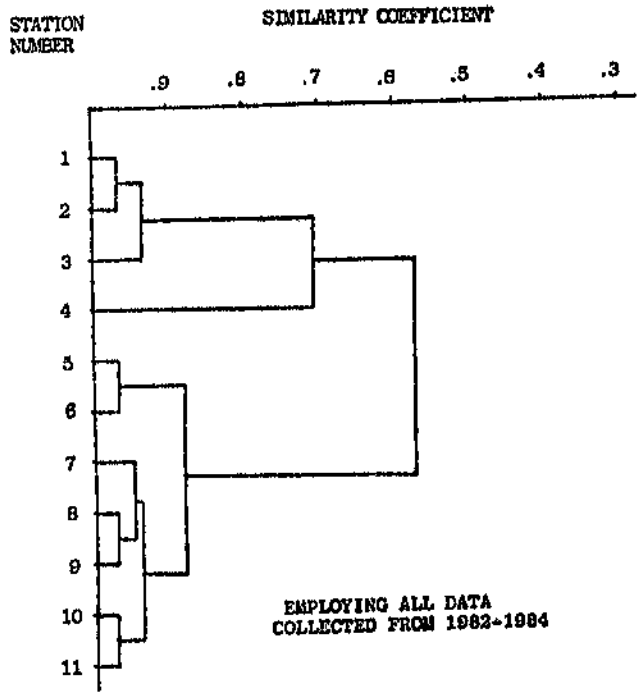
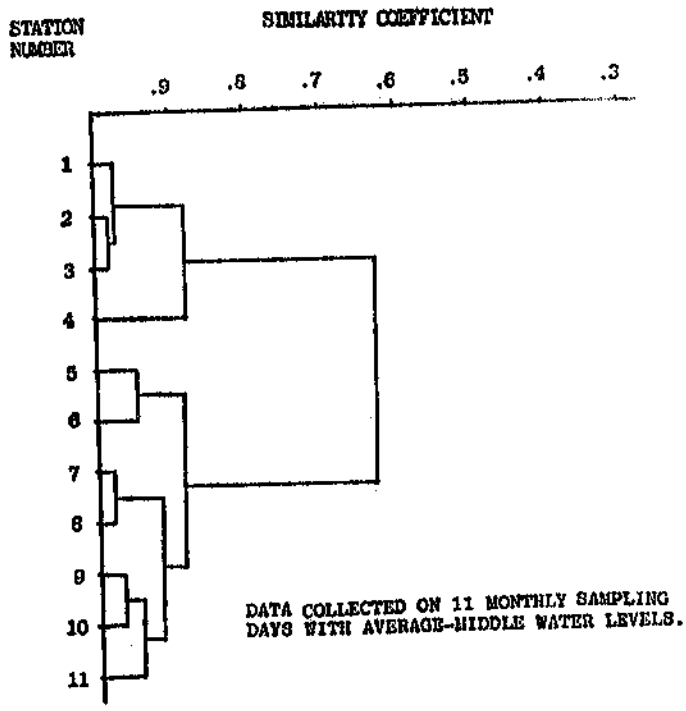
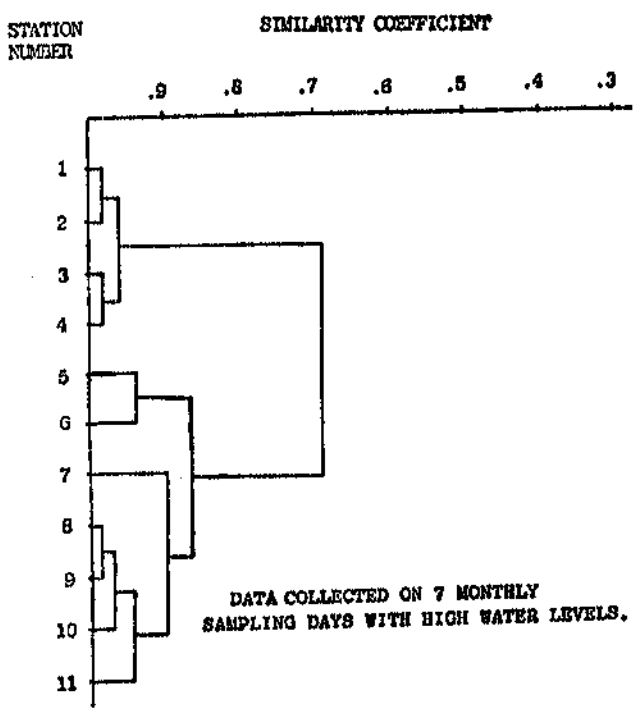


FIGURE 59. MEAN CATION CONCENTRATIONS AND STANDARD DEVIATIONS BY SAMPLING STATIONS.







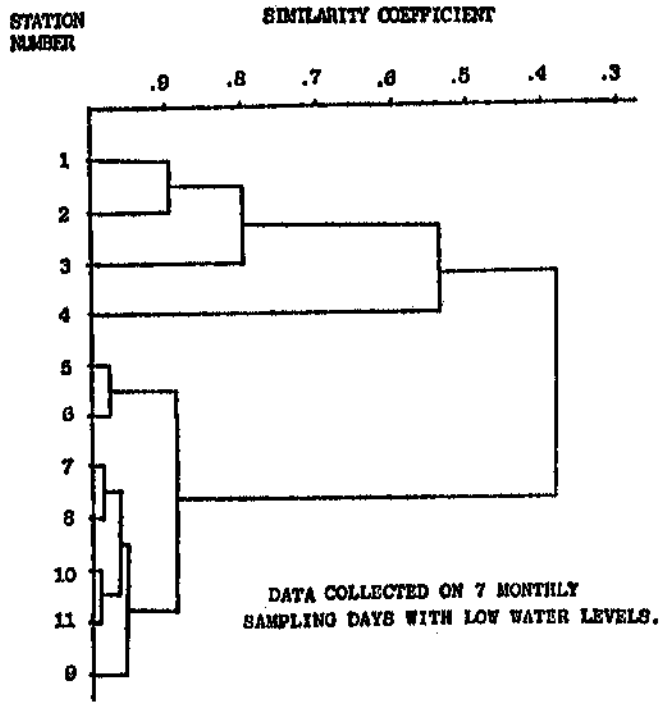


FIGURE 60. CLUSTER ANALYSIS OF STATIONS EMPLOYING DATA ON 14 PHYSICAL-CHEMICAL VARIABLES

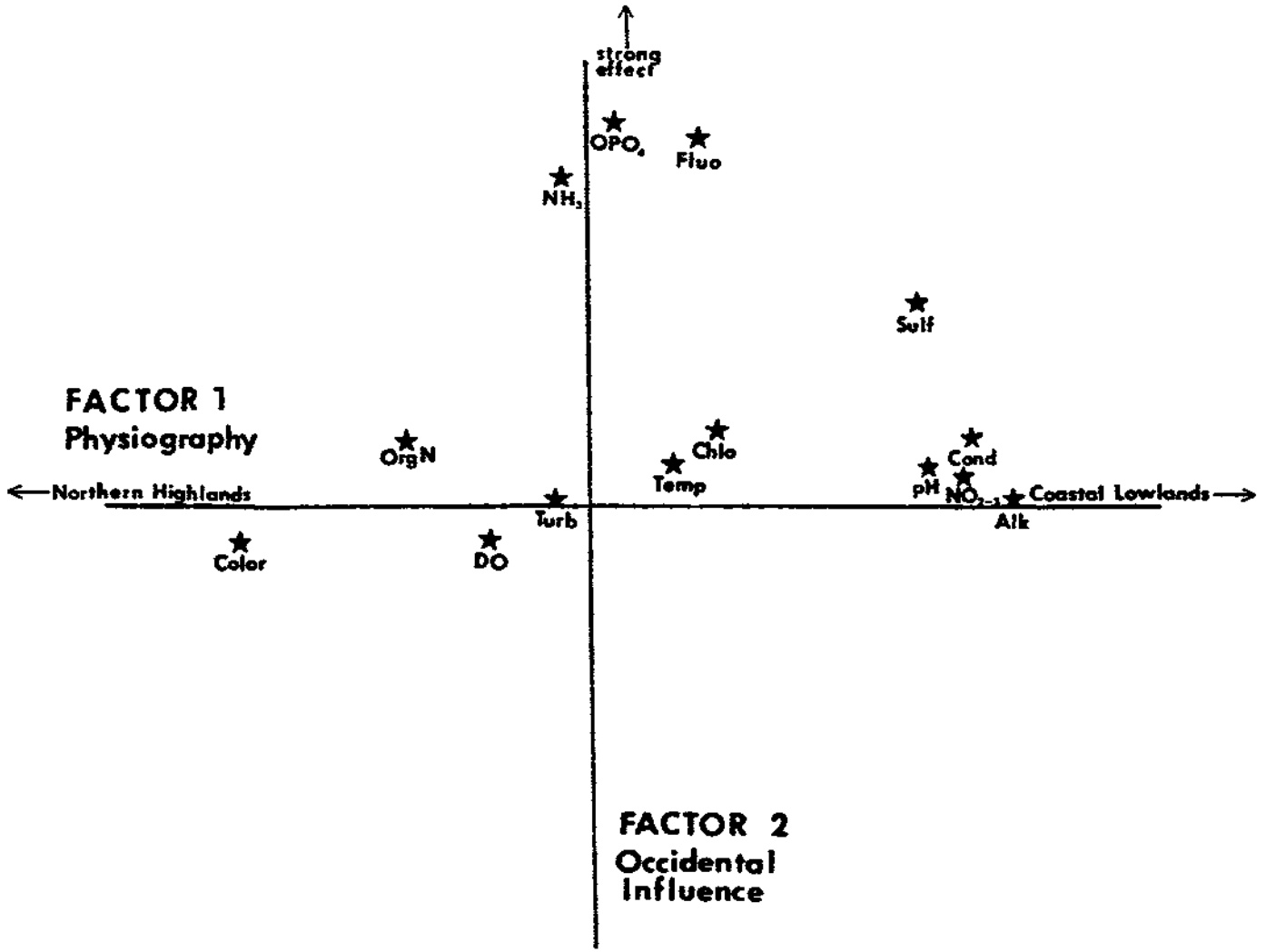


FIGURE 61. ORDINATION OF 14 PHYSICAL-CHEMICAL VARIABLES ON FACTOR 1 vs FACTOR 2.

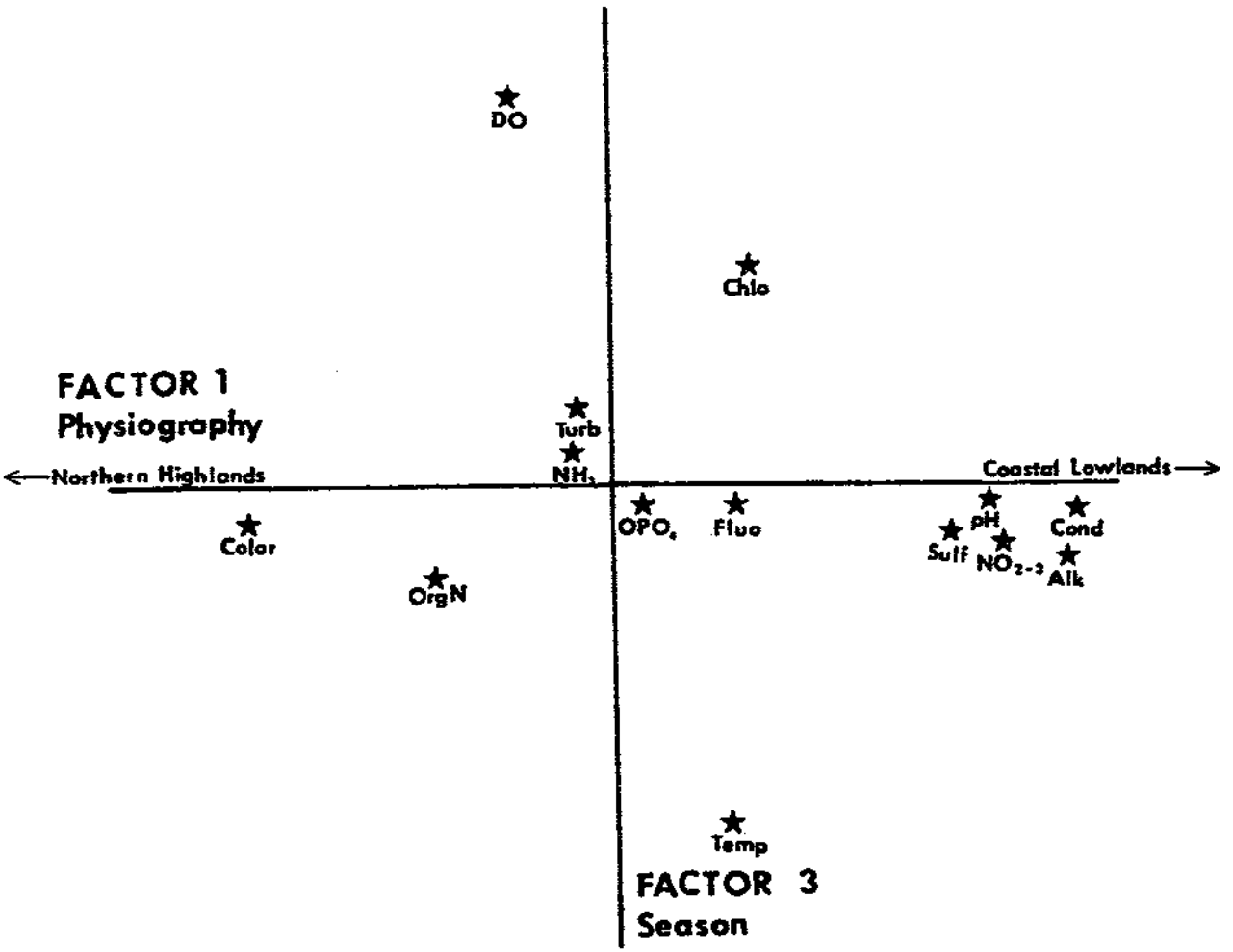


FIGURE 62. ORDINATION OF 14 PHYSICAL-CHEMICAL VARIABLES ON FACTOR 1 vs FACTOR 3.

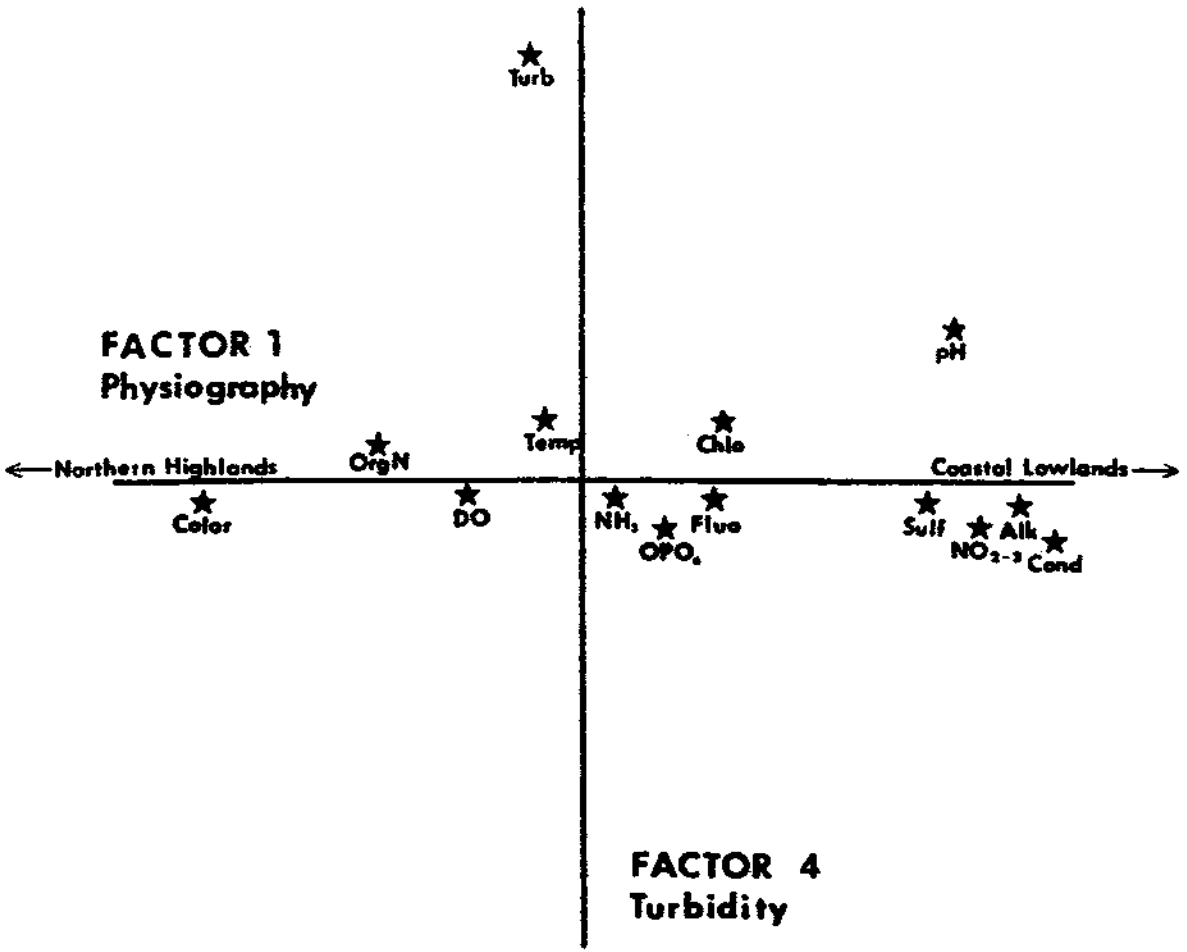


FIGURE 63. ORDINATION OF 14 PHYSICAL-CHEMICAL VARIABLES ON FACTOR 1 vs FACTOR 4.

TABLE 10. Physical - Chemical Methods

PARAMETER	ABBREVIATION	METHOD	UNITS	REFERENCE
pH	pH	Electrometric	Su	U.S. EPA 1979
Alkalinity	Alk	Titrimetric	mg/L CaCo3	U.S. EPA 1979
Conductivity	Cond	YSI SCT Probe	umhos/cm	APHA 1980
Color	Col	Visual Comparison	mg/L platinum	APHA 1980
Sulfate	Sulf	Turbidimetric	mg/L S	U.S. EPA 1979
Fluoride	F	Fluoride Ion Electrode	mg/L F	APHA 1980
Chloride	Cl	Argentometric	mg/L Cl	APHA 1980
Silica	SiO	Molybdosilicate	mg/L SiO	APHA 1980
Turbidity	Turb	Turbidimeter	NTU	APHA 1980
Total Phosphate	TPO	Ascorbic Acid	mg/L P	U.S. EPA 1979
Orthophosphate	OPO	Ascorbic Acid	mg/L P	U.S. EPA 1979
Ammonia	NH	Ammonia Electrode	mg/L N	U.S. EPA 1979
Nitrite-Nitrogen	NO	Spectrophotometric Diazotization	mg/L N	U.S. EPA 1979
Nitrite-Nitrate Nitrogen	NO	Colorimetric, Cadmium Reduction	mg/L N	U.S. EPA 1979
Total Kjeldahl Nitrogen	TKN	Electrometric	mg/L N	U.S. EPA 1979

TABLE 11. Relationships between gage height and physical-chemical variables at 11 stations on the Suwannee River between January 1982 - January 1984, r = correlation coefficient, n = sample size, P = probability levels.

Negative, P <.01			Positive, P <.01			None, P >.05		
	r	n		r	n		r	n
SULF	-.49	275	Color	+.37	275	K	-.15	139
COND	-.45	275	TURB	+.24	275	NH	-.11	274
Mg	-.45	141				DO	+.09	275
Ca	-.42	136				OrgN	-.01	272
Alk	-.40	275						
Temp	-.35	275						
NO	-.34	275						
F	-.34	275						
pH	-.34	274						
Cl	-.32	275						
OPO	-.24	275						
Na	-.24	143						

TABLE 11. Relationships between gage height and physical-chemical variables at 11 stations on the Suwannee River between January 1982 - January 1984, r = correlation coefficient, n = sample size, P = probability levels.

Negative, P <.01			Positive, P <.01			None, P >.05		
	r	n		r	n		r	n
SULF	-.49	275	Color	+.37	275	K	-.15	139
COND	-.45	275	TURB	+.24	275	NH	-.11	274
Mg	-.45	141				DO	+.09	275
Ca	-.42	136				OrgN	-.01	272
Alk	-.40	275						
Temp	-.35	275						
NO	-.34	275						
F	-.34	275						
pH	-.34	274						
Cl	-.32	275						
OPO	-.24	275						
Na	-.24	143						

TABLE 13. Results of Factor Analysis on 14 physical-chemical variables at 11 stations on the Suwannee River between January 1982 - January 1984. Complete results are presented in the upper portion. The lower portion presents a simplified format in which the factor loadings are arranged by size, and loadings of less than .25 are replaced by zero.

	Factor 1	Factor 2	Factor 3	Factor 4
Temperature	.178	.064	-.885	-.063
pH	.868	.125	-.109	.306
Conductivity	.932	.151	-.171	-.124
Alkalinity	.951	.010	-.216	-.049
Dissolved oxygen	-.241	-.046	.878	.027
Color	-.896	-.047	-.043	.034
Turbidity	-.099	.040	.130	.968
Chloride	.320	.183	.491	.098
Fluoride	.228	.918	-.011	.000
Orthophosphate	.059	.975	.010	.014
Sulfate	.793	.466	-.072	-.078
Nitrite-Nitrate	.883	.036	-.051	-.113
Ammonia	-.052	.860	.008	.053
Organic nitrogen	-.449	.181	-.236	.069
Eigenvalues	5.197	2.863	1.967	1.091
% Variance explained by factor	37.12	20.45	14.05	7.79

	Factor 1	Factor 2	Factor 3	Factor 4
Alkalinity	.951	.000	.000	.000
Conductivity	.932	.000	.000	.000
Color	-.896	.000	.000	.000
Nitrite-Nitrate	.883	.000	.000	.000
pH	.868	.000	.000	.306
Sulfate	.793	.466	.000	.000
Orthophosphate	.000	.975	.000	.000
Fluoride	.000	.918	.000	.000
Ammonia	.000	.860	.000	.000
Temperature	.000	.000	-.885	.000
Dissolved Oxygen	.000	.000	.878	.000
Turbidity	.000	.000	.000	.968
Chloride	.320	.000	.491	.000
Organic Nitrogen	-.449	.000	.000	.000

TABLE 14. Complete results of Factor Analysis on 18 physical-chemical variables for the Suwannee River, January 1982 - January 1984.

	Factor 1	Factor 2	Factor 3	Factor 4
Temperature	.205	.071	-.880	-.130
pH	.797	.155	-.165	.405
Conductivity	.960	.154	-.091	-.008
Alkalinity	.968	-.034	-.158	.050
Dissolved oxygen	-.306	-.039	.882	-.028
Color	-.858	-.002	-.080	-.194
Turbidity	-.196	.162	-.007	.746
Chloride	.279	.271	.481	.038
Fluoride	.176	.926	.010	-.009
Orthophosphate	.048	.964	.017	-.017
Sulfate	.726	.563	-.039	.046
Nitrite-Nitrate	.901	.019	.020	.061
Ammonia	-.079	.850	-.016	.081
Organic nitrogen	-.338	.243	-.137	-.458
Sodium	.236	.582	.057	.180
Potassium	.294	.139	.077	.755
Magnesium	.906	.141	-.094	-.029
Calcium	.878	.181	-.147	.007
Eigenvalues	6.707	3.450	1.912	1.605

TABLE 15. Summary of physical-chemical variable groupings based on factor analyses (Figs. 61, 62, 63, Tables 13, 14).

PHYSIOGRAPHY			OCCIDENTAL	SEASON		TURBIDITY
Northern Highlands	Coastal Lowlands	Marine Aerosols		Season-Temperature	Season-Gage-Height	
Color	pH*	Cl*	F	TEMP*	Cl*	TURB*
OrgN*	COND*	Na*	OPO	DO*	OrgN*	K*
	Alk		NH_3			pH*
	NO		SULF			
	SULF*		Na*			
	Mg		Cl*			
	Ca		COND*			
	K*		OrgN*			
	Temp*					
	DO*					

*Variable in more than one group

TABLE 16. Summary of primary physical-chemical variable groupings based on cluster and factor analyses (Figs 61, 62, 63, Tables 12, 15).

PHYSIOGRAPHY			OCCIDENTAL	SEASON		TURBIDITY
Northern Highlands	Coastal Lowlands	Marine Aerosols		Season-Temperature	Season-Gage-Height	
Color*	pH*	Cl*	F	TEMP*	Cl*	TURB*
OrgN*	COND*	Na*	OPO	DO*	TURB*	K*
	Alk		NH_3		COLOR*	pH*
	NO		SULF		OrgN*	
	SULF		Na*			
	Mg		Cl*			
	Ca		COND*			
	K*		OrgN*			
	Temp*		NO			
	DO*		TURB			

* Variable in more than one group

FISHERY RESOURCES

Introduction

In many ways, the fish population in a body of water is of great importance. Fish tend to occupy the higher trophic levels, and may be quite sensitive to perturbations of other organisms forming the basis of the aquatic ecosystem. Fish are also of high concern because of their very substantial recreational utilization and because of their obvious economic importance.

Methods

Fish Population Sampling - Originally, six sites along the Suwannee River were selected for fish population sampling. Those sites were: above and below Swift Creek (Stations 3 and 4), Luraville (Station 8), Branford (Station 9), Wannee (Station 10), and New Clay Landing (just upstream from Manatee Springs) (Station 11). While it was originally planned that each site would be sampled each spring and each fall during the study period, flood stages during spring sampling periods precluded the taking of accurate, comparable fish population samples. Thus, fish population samples collected in October, 1982, and October, 1983, comprise the only samples used for data analysis. During the fall, fish are more confined to the river because of lower water elevations, and population fluctuations resulting from the spring breeding season have been dampened by juvenile mortality during spring and summer. Subsequent to the 1982 samples, it was decided that fish population samples were needed upstream and downstream of Hunter Creek (Stations 1 and 2), and these sites were sampled on a one-time basis in October, 1983. No fish population data were collected at Stations 5 (upstream of Withlacoochee River), 6 (downstream of Withlacoochee River), and 7 (Dowling Park).

All fish population samples were collected in the daytime using an electrofishing technique. A standard electrofishing sample was collected by applying an electrical current to the water through two circular arrays of positive electrodes suspended from booms off the bow of an aluminum boat (negative). The field was produced by a 220-volt AC generator stepped up to approximately 750 volts by a Smith Root Electrofisher VI-A Variable Voltage Pulsator. All fish stunned were collected with dip nets, sorted to species, and measured and weighed by size groups. Shocking was restricted to the shoreline and was quantified according to catch per unit effort of time. The technique is thus an index to the relative abundance of fishes in the river, not an absolute measure of fish density.

For data analysis, the species of fish occurring in the samples were divided into the following value and trophic groups: sport fishes, rough fishes, commercial fishes, forage fishes, piscivorous fishes, fishes that feed on drift macroinvertebrates, fishes that feed on benthic macroinvertebrates, fishes that feed on small aquatic insects and zooplankton, and filter-feeding fishes. Species diversity at each site was calculated with the Shannon-Weaver formula using natural logarithms (rather than base 2 logarithms as used elsewhere in this report). Data for the sites that were sampled twice were averaged, and the results were plotted according to site to determine trends moving downstream.

In addition to the data collected during the current study, data from previous and ongoing Florida Game and Fresh Water Fish Commission studies of the Suwannee River were reviewed for inclusion in the Suwannee River study. Fish population samples above and below Swift Creek were collected in each of the following months: October 1980, March 1981, November 1981, June 1982, October 1982, and October 1983. Student's t-test was used to test for significant differences in the species of fishes and various fish groups upstream and downstream of Swift Creek to evaluate what impacts, if any, the Occidental Chemical Agricultural Products discharge has had on fish populations. In addition, the results from the Suwannee River were compared with the results of Commission studies of other north Florida streams.

Fluoride Effects on Fish - To determine whether or not the high fluoride concentrations in the Occidental discharge were affecting fish in the Suwannee River, the bones of various centrarchids and ictalurids were analyzed for fluoride content in 1980. Sample collection was performed by the Lake City fisheries staff of the Florida Game and Fresh Water Fish Commission. Sample preparation and analysis was performed by the Commission's Eustis Chemistry Laboratory.

Radium-226 Burdens of Fish - Commission biologists conducted a one-time study of the Ra-226 burdens of fish in 1980 to determine whether the unusually high Ra-226 concentrations associated with phosphate discharges were affecting fish. Fish were collected from the Suwannee River and Altman Bay by electroshocking and baited hoop nets. Flesh was filleted from the specimens and frozen in one pint quantities for each of three sample sites and two species groups. The skeletons were boiled and meat removed to provide one pint quantities of crushed dry bone material for each sample. Frozen flesh and dried bones were analyzed by the Department of Environmental Engineering Sciences, University of Florida, using gamma spectrometry.

Fisherman Creel Survey - A non-uniform probability roving creel survey (see Vaughn et al. 1978) was conducted during the 12 week period from March 25 to June 15, 1982. The 22-mile creel survey area was from the boat ramp at Suwannee River State Park to approximately one mile above the old Suwannee Springs swimming beach near U.S. 129. The lower access point was the starting point for all samples. Five days were sampled every two-week period with the days selected to include two weekend days and

three weekdays. Creel intervals were four hours long and were sampled during either morning, mid-day, or evening. An instantaneous count was made either at the start of the sample going upstream or at the end coming downstream after interviewing on the way upstream. Species and numbers of fish caught and hours spent fishing when interviewed were recorded. Species categories were bass, redbreast, bluegill, other bream (redear sunfish, spotted sunfish, warmouth), and catfish. Anglers were often fishing for "bream", and hours effort was applied to whatever species they were successfully catching. Bank versus boat fishing data were recorded during interviews but not during the instantaneous count.

The lower Santa Fe creel surveys in 1982 and 1972-73 were conducted in the 15-mile stretch of river between Hollingsworth Bluff and the confluence of the Santa Fe with the Suwannee River. The survey period was from March 25 to June 15, 1982, and the design was identical to that described for the upper Suwannee.

The middle Suwannee River creel survey, conducted by similar design in 1970-71, covered the 63-mile stretch from Luraville to Fannin Springs (Bass and Hitt 1973).

The spring 1983 creel survey of the lower Suwannee River was an access point survey of the 31 miles from Fannin Springs to the Gulf of Mexico. The access point creel method is described by Krummrich et al. (1984) and was chosen because there were too many miles of fishable creeks in the area to be surveyed by a roving creel clerk.

Results and Discussion

Fish Population Data - Table 17 lists 63 species of fishes taken or observed in the Suwannee River during Commission activities since 1969. Nine of these are essentially marine forms found only in the lower river reaches. Table 18 shows the relative biomass and abundance of fishes in the Suwannee River. The five most abundant species in the Suwannee River by weight are bowfin, largemouth bass, striped mullet, spotted sucker, and Florida gar. Based on the results of the current study, mullet occur in the river only below Luraville, but nonetheless comprise a significant portion of the weight of fish overall because of their abundance in the lower river. The five most abundant species numerically are redbreast sunfish, largemouth bass, spotted sunfish, bowfin, and bluegill. These results suggest that, overall, the habitats of the Suwannee River are best suited to large predatory fishes, medium-sized macroinvertebrate-feeding fishes, and, to a lesser extent, medium-sized bottom-feeding fishes. Filter-feeding species such as mullet only occur in the lower reaches of the river where flows are slower and the production of phytoplankton and zooplankton is more likely.

Figures 64-67 show the trends of sport, rough, commercial, and forage species moving downstream in the Suwannee River. The biomass of all these groups of fishes is greater above than below Hunter Creek, a source of phosphate mine discharge. The high sport and rough fish biomass above Hunter Creek is probably a result of the influence of the Okefenokee Swamp on riverine

biota. Holder (1970) has demonstrated that large numbers of bowfin and yellow bullhead enter the river by passing over the dike in Okefenokee Swamp. At the station above Hunter Creek, bowfin accounted for 58% of the total fish biomass, and yellow bullhead accounted for 5% of the total biomass (see Appendix B). If these two species are removed from the sample, the remaining biomass of fish upstream of Hunter Creek is comparable to that observed below. Thus, it would appear that the fish community at the station above Hunter Creek was within the range of influence of Okefenokee Swamp. The lower biomass of fish at the station below Hunter Creek apparently was not related to phosphate mine discharge but rather reflected approximately natural conditions outside the range of influence of Okefenokee Swamp.

Downstream of Swift Creek, a major source of phosphate mine and chemical plant discharge, there is a dramatic increase in sport fish populations compared to the stations above Swift Creek (Figure 64). Sport fish biomass reached highest values for the entire river below Swift Creek. Based on the six fish population samples collected between October, 1980, and October, 1983, mean sport fish biomass of 16.19 pounds/hour in the Suwannee River below Swift Creek was significantly ($p < 0.05$) greater than the mean biomass of 8.48 pounds/hour observed above Swift Creek. Although the relative biomass of rough fishes also increased below Swift Creek (Figure 65), the difference was not significant ($p > 0.05$). Detailed electrofishing results (see Appendix B) indicate that sport fish populations upstream and downstream of Swift Creek were adequate to support a quality fishery.

Moving from Swift Creek to Luraville, sport and rough fish biomass declined sharply, and forage fishes declined slightly. Commercial species (i.e., striped mullet and American eel) first appeared in abundance at the Luraville station where they comprised 29% of total fish biomass. The Luraville station was the first fish population sample station downstream of the Withlacoochee River, the Gold Kist poultry plant outfall, and the Florida Power Corporation power plant outfall. The extent to which these sources of pollutants vis-a-vis natural habitat conditions or sampling error contribute to reduced fish biomass at the Luraville station remains unknown. The curves in Figures 64, 65, and 67 suggest that the apparent decrease in fish populations between Swift Creek and Luraville was not real. Rather, the Luraville fish population was more nearly what would be expected to occur naturally whereas the fish population below Swift Creek was artifically high due to nutrient-rich, less acidic wastewaters discharging to the river. The effect of Swift Creek on Suwannee River fish populations appears to have disappeared by the time water from Swift Creek has reached the Luraville station.

Generally speaking, fish biomass tends to increase downstream from Luraville with maximum total biomass occurring at the Manatee Springs station, the most downstream station sampled for fish. Sport and commercial fish populations appear to have declined between the Branford and Wannee stations, but whether or not this fluctuation is real or the result of sampling error or

other variables remains unknown. Qualitatively (i.e., percent composition of sport fishes, percent by weight of harvestable sport fishes, etc.), the fishery resource was similar and in acceptable ranges at all stations (data tabulated in Appendix B).

Figures 68-75 depict the changes that were observed in fish populations in the Suwannee River based on the feeding habits of fishes. Fishes that are predatory on other fish were much more abundant above Hunter Creek than below, but this is due to the high biomass of bowfin that probably originated in Okefenokee Swamp. The biomass of predatory fishes was relatively low at both stations above Swift Creek (Figure 68). Below Swift Creek, predatory fishes increased sharply, but the difference in mean biomass above and below Swift Creek was not significant ($p > 0.05$), based on all available data. Predatory fish biomass declined between Swift Creek and Luraville, but downstream of Luraville predatory fishes increased, reaching maximum values at Manatee Springs. Again, the apparent lower biomass of predatory fishes at Luraville was probably the normal situation vis-a-vis the artificially high biomass just below Swift Creek.

The relative biomass of fishes that feed on aquatic insect larvae, drift macroinvertebrates, and occasionally benthic macroinvertebrates was markedly higher above Hunter Creek than below (Figure 69). These species increased downstream of Swift Creek and continued to increase to a high value at Luraville but declined between Luraville and Wannee. Maximum biomass occurred at Manatee Springs. Although the mean biomass of these fishes was higher below than above Swift Creek, the difference was not significant ($p > 0.05$).

Benthophagic fishes (i.e., fishes that feed on benthic macroinvertebrates) comprised a greater proportion of the fish communities of the upper reaches of the Suwannee River than they did in the lower reaches. Benthophagic fishes accounted for 12 to 42 percent of the biomass at the upper four stations but for only one to five percent at downstream stations. Maximum biomass occurred below Swift Creek (Figure 70), and the difference above and below Swift Creek was dramatic. Mean biomass of 11.4 pounds/hour of benthophagic fishes below Swift Creek was significantly greater than the 4.58 pounds/hour above Swift Creek ($p < 0.10$).

Fishes that feed on small aquatic insects and zooplankton generally comprised less than 1% of the fish community at all stations. These species appear to be more abundant in the vicinity of Hunter Creek (Figure 71) than other river stations except Manatee Springs where maximum biomass occurred. Fewer of these fishes occurred below Swift Creek than above, but the difference was not statistically significant.

Filter-feeding fishes (i.e., striped mullet and gizzard shad) were found in the Suwannee River from Luraville downstream to Manatee Springs (Figure 72). This was probably due to the greater width and more sluggish flow in the lower river as these conditions are more suitable to the production of phytoplankton

and zooplankton upon which these species feed.

Figure 73 shows that the composite biomass of all invertebrate- and filter-feeding fishes was greatest immediately downstream of Swift Creek. The mean biomass of 16.25 pounds/hour below Swift Creek was significantly ($p < 0.05$) greater than the 7.86 pounds/hour observed above Swift Creek. Total biomass of all invertebrate- and filter-feeders was lower below Hunter Creek than above but all other stations, except Manatee Springs, were comparable in biomass.

The total biomass of fish in the Suwannee River follows an increasing trend as one moves from upstream to downstream stations in the river (Figure 74). Water quality in the Suwannee changes from a low pH, nutrient-poor, blackwater stream in its upper reaches to a higher pH, more fertile, and less colored stream in its lower reaches (Coffin 1982). Kautz (1981) has shown that the total biomass of fish in north Florida rivers increases in response to increasing fertility as measured by conductivity and major nutrients. Winger (1981) discussed the general trend of fish populations in rivers to increase in a downstream direction due to a change from small, limited habitat conditions in upper river reaches to larger habitats with a greater number of niches in lower reaches. The increasing trend in fish biomass moving downstream in the Suwannee is undoubtedly a function of increasingly more productive waters and improving habitat conditions. The increased biomass of fish downstream of Swift Creek is almost certainly a function of changes in water quality since habitat conditions downstream of Swift Creek are comparable to those existing upstream. The total biomass of fish in the Suwannee is average when compared with other north Florida streams (see Appendix B).

To determine whether or not any trends existed with respect to trophic levels, the ratio of predatory fishes to all other fishes was calculated and plotted by station (Figure 75). Above Hunter Creek, the ratio was relative high; however, the ratio declines from that point to a low just below Swift Creek. The mean ratio of 1.61 pounds of predatory fishes per pound of all other fishes was significantly ($p < 0.05$) greater than the mean of 1.03 observed below Swift Creek. This result indicates that trophic relationships in the fish community have been altered by phosphate mine and chemical plant discharges, but whether or not this is a negative impact remains uncertain. Downstream from Swift Creek, the ratio gradually recovers to values in the range observed above the influence of phosphate mining.

Shannon-Weaver estimates of fish species diversity at each station are plotted in Figure 76. Species diversity declined somewhat downstream of both Hunter and Swift Creeks compared with upstream stations. These curves are similar to the changes observed in benthic macroinvertebrate and diatom diversities. Downstream of Swift Creek, species diversity recovers rapidly to values comparable to those observed above Hunter Creek and the influence of phosphate mining. The difference in species diversity above and below Swift Creek was not significant ($p >$

0.05) when all data collected since October, 1980, were tested.

In summary, 63 species of fish have been collected from the Suwannee River by Florida Game and Fresh Water Fish Commission Biologists since 1969. The most abundant fishes in the river were bowfin, largemouth bass, redbreast sunfish, spotted sunfish, Florida gar, spotted sucker, striped mullet, and bluegill. Fish populations tended to increase as one moved downstream in the Suwannee River. This observation was in keeping with the results of previous Commission studies. This trend is thought to be due to the more stable flows, improved habitat conditions, and better quality waters that occur in the lower river compared to the upper river. The phosphate mine and chemical plant wastewaters that reached the Suwannee River via Swift Creek clearly impacted the fish populations of the Suwannee River. Sport fish biomass was significantly greater below Swift Creek than above, but it appears that the effects of the discharge on sport fishes have dissappeared by the time Luraville is reached. The production of macroinvertebrate-feeding fishes, particularly benthophagic fishes, was stimulated in the Suwannee downstream of Swift Creek. Predator-prey relationships were altered by a 36% reduction in the biomass of predatory fishes relative to all other fishes. Fish species diversity appeared to decline downstream of Hunter and Swift creeks.

Fluoride in Fish - The bones of several species of fish were tested for fluoride content during 1980. As shown in Table 19, the fluoride content of fish bones was highest in Altman Bay, which receives chemical plant wastewaters, and the fluoride content of fish bones from the Suwannee River was higher below Swift Creek than above. Since the data are the average of only two replicates, statistical testing was not possible. While the data suggest that fish in the Suwannee River are accumulating fluoride as a result of industrial operations, the impact on fish populations is unclear as very little toxicological data are available on the subject. Given the abundance of fish downstream of Swift Creek, it would appear that fluoride has had no adverse effect on fish populations. Catfish, which are generally bottom feeders, appear to have accumulated higher fluoride levels than centrarchids.

Radium-226 Levels in Fish - Uranium-238 is a naturally occurring radioisotope that replaces calcium in phosphate-bearing minerals. Radium-226 is a long-lived decay product of U-238, and Ra-226 occurs in higher-than-background concentrations in the wastewaters from Occidental chemical plants. Since Ra-226 is a bone-seeking alpha emitter known to produce cancer in humans, the bones and flesh of several species of fish were sampled for Ra-226 activity in 1980. The samples were obtained from Altman Bay (on Occidental property) and from the Suwannee River above and below Swift Creek.

As shown in Table 20, more Ra-226 was present in catfish bones than flesh, but the content of Ra-226 in centrarchid bones and flesh was roughly equal. It appeared that there was no difference in the radium burdens of catfish upstream and downstream of Swift Creek. However, centrarchid radium burdens

were higher below Swift Creek than above. Catfish bones from Altman Bay contained higher levels of radium than bones from the Suwannee River; however, centrarchid bones from Altman Bay exhibited the least amount of radioactivity. The radium burdens of centrarchid flesh were an order of magnitude greater than the burdens in catfish flesh. Unfortunately, the number of samples was too small for statistical testing so the results were not conclusive.

Drinking water standards for Ra-226 can be used to estimate the hazard to human health that would result from eating the flesh of bream caught below Swift Creek. Assuming that the average U.S. citizen consumes 15 liters of water per week and assuming that the water contained the maximum allowable amount of Ra-226 (i.e., 5 pCi/l), an individual could hypothetically consume 75 pCi of Ra-226 per week. One would have to consume 0.4 pounds of bream flesh per week from below Swift Creek to equal this amount. The values reported for the Suwannee River are low, and no health hazard is believed to be associated with eating fish caught below Swift Creek.

Given the apparent health and abundance of fish from the Suwannee River below Swift Creek, there would appear to be no observable impact on fish health due to increased burdens of Ra-226 in bones and flesh.

Fisherman Creel Surveys - As shown in Table 21, the lower Suwannee River yielded roughly 3.5 times as many fish and supported four times as much effort as the upper river. Redbreast sunfish dominated the catch in both areas. All species of bream combined accounted for 77% of the fish harvested in the upper river and 84% in the lower river. Most of the effort was directed at redbreast sunfish and other species of bream in both areas. These results reflect the abundance of bream in the fish populations of the Suwannee.

Table 22 is a comparison of effort, harvest, and success data for the Suwannee and other eastern rivers. Compared to other rivers in Florida, the Suwannee was relatively low in effort and total harvest but was comparable with or slightly higher than several Missouri rivers. On the other hand, fisherman success rates on the Suwannee were higher and on the middle and lower portions rates were twice as high as on other rivers including those from Florida. Thus, overall the Suwannee supported a productive and high-quality fishery that generally received less pressure than other Florida rivers. Additional data on Suwannee River creel surveys are found in Appendix B.

Conclusions

Fish populations in the Suwannee River followed an increasing trend moving downstream. The fish populations of the upper reaches of river are thought to be limited by poor habitat conditions, highly variable flows, and waters that are naturally low in pH, low in fertility, and highly colored. The greater biomass of fish in the lower reaches of river is thought to result from improved habitat conditions that include limestone

bottoms and more abundant shoreline vegetation, more stable river flows, and waters that are high in pH, high in fertility, and low in color.

Phosphate mine and chemical plant discharges to Swift Creek have clearly altered fish populations in the Suwannee River downstream of the creek. While there is no significant statistical difference in the total biomass of fish above and below Swift Creek, sport fish populations are significantly ($p < 0.05$) greater below Swift Creek than above. No one species of fish is responsible for the increase. From a trophic standpoint, the biomass of invertebrate- and filter-feeding fishes below Swift Creek is greater ($p < 0.05$) than that above the creek, and the data suggest that bottom-feeding fishes account for most of the increase. This would indicate that the wastewater discharges to Swift Creek stimulate the production of macroinvertebrates, particularly benthic macroinvertebrates, in the Suwannee River and that bottom-feeding fishes respond to increased food resources. Trophic relationships in the fish community have been significantly ($p < 0.05$) altered by wastewater discharges with a lower biomass of predatory fishes relative to other fishes occuring below Swift Creek than above. Rough fish biomass appears to increase below Swift Creek, but the increase is not statistically significant. The effects of Swift Creek on fish populations appear to have disappeared by the time one reaches Luraville, but the actual distance downstream that the effects can be observed remains unknown.

Based on data collected in 1980, the bones of ictalurid and centrarchid fishes appeared to have a higher fluoride content downstream of Swift Creek than upstream. Highest fluoride content was observed in fish bones from Altman Bay, the water body which receives phosphate mine and chemical plant wastewaters prior to discharge to Swift Creek. The data were insufficient for statistical testing. While fluoride is toxic in high concentrations and is known to damage the structural integrity of bones in livestock, no health effects on fish were observed.

Also based on data collected in 1980, Radium-226 burdens of centrarchid bones and flesh were higher below Swift Creek than above; however, there appeared to be no difference in ictalurid Radium-226 burdens above and below Swift Creek. The data collected were insufficient to be tested statistically. The levels of radium involved appear to present no health hazards to humans.

The Suwannee River supported a high quality sport fishery. Effort and harvest were lower in the upper reaches of river than in lower reaches, but fisherman success rates were comparable in all areas. Redbreast sunfish dominated the catch. Effort and harvest rates on the Suwannee River were lower than on other Florida rivers, but fisherman success rates were higher on the Suwannee than any other river (inside or outside of Florida) for which data are readily available.

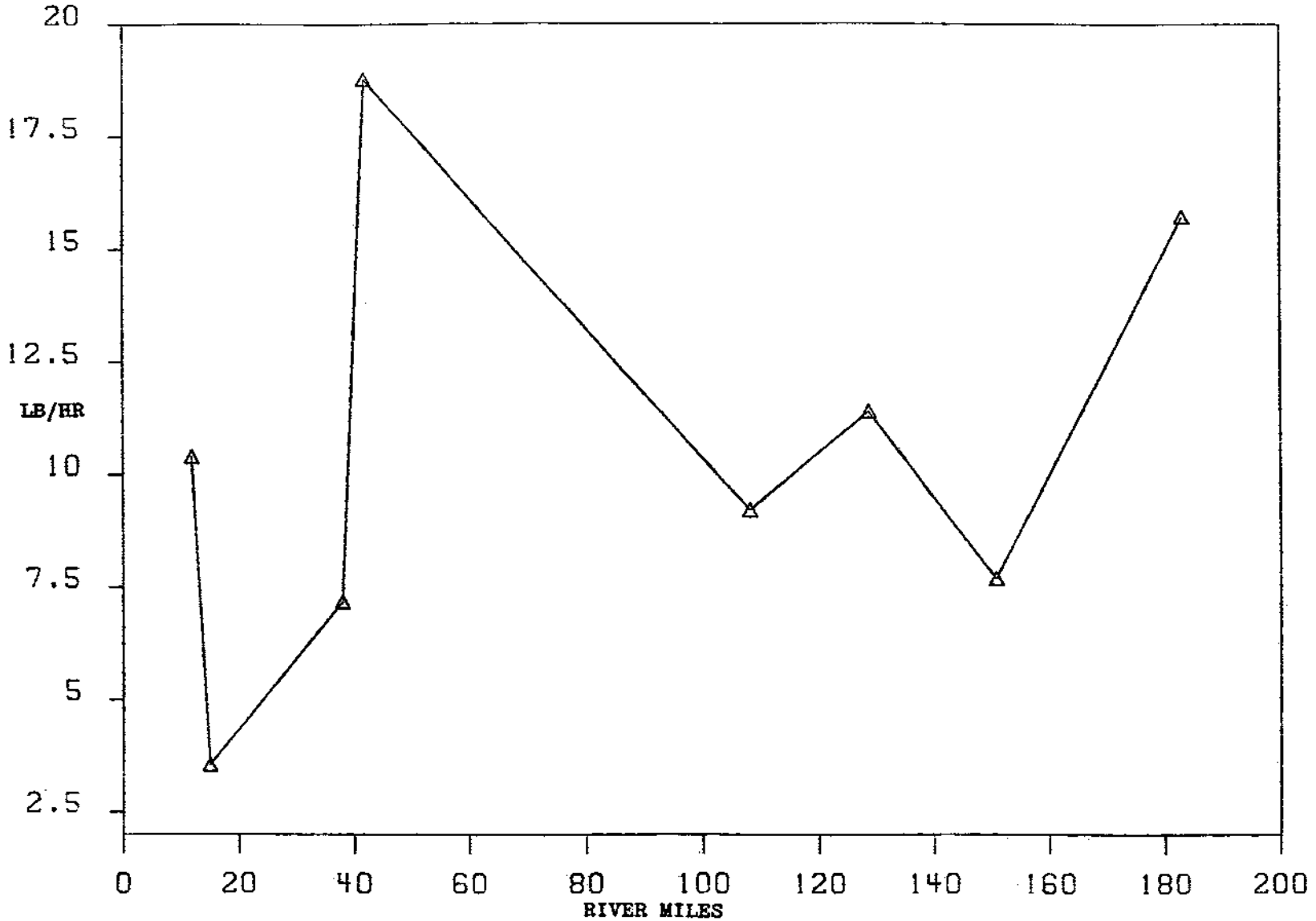


FIGURE 64. RELATIVE BIOMASS OF SPORT FISH

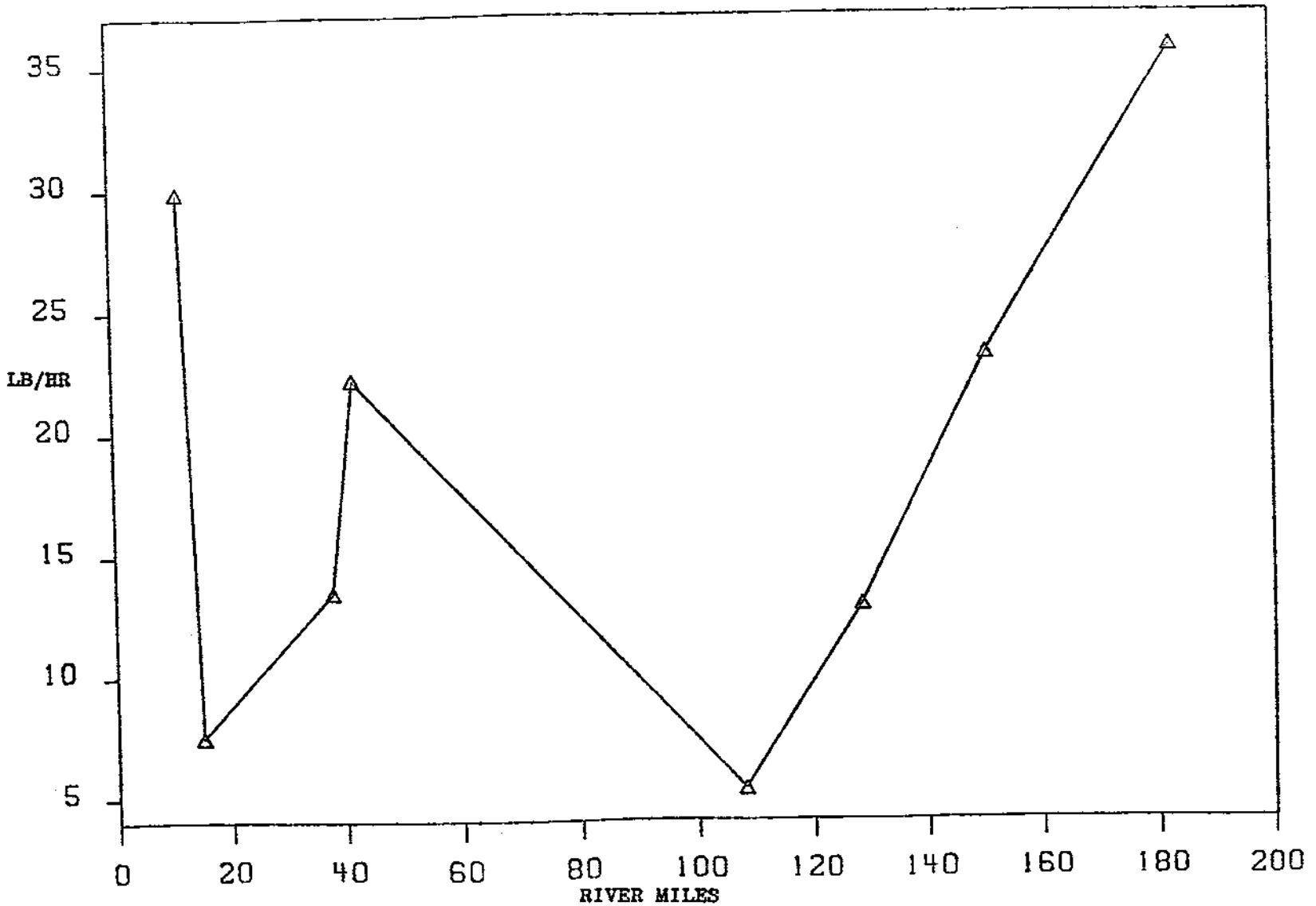


FIGURE 65. RELATIVE BIOMASS OF ROUGH-FISH

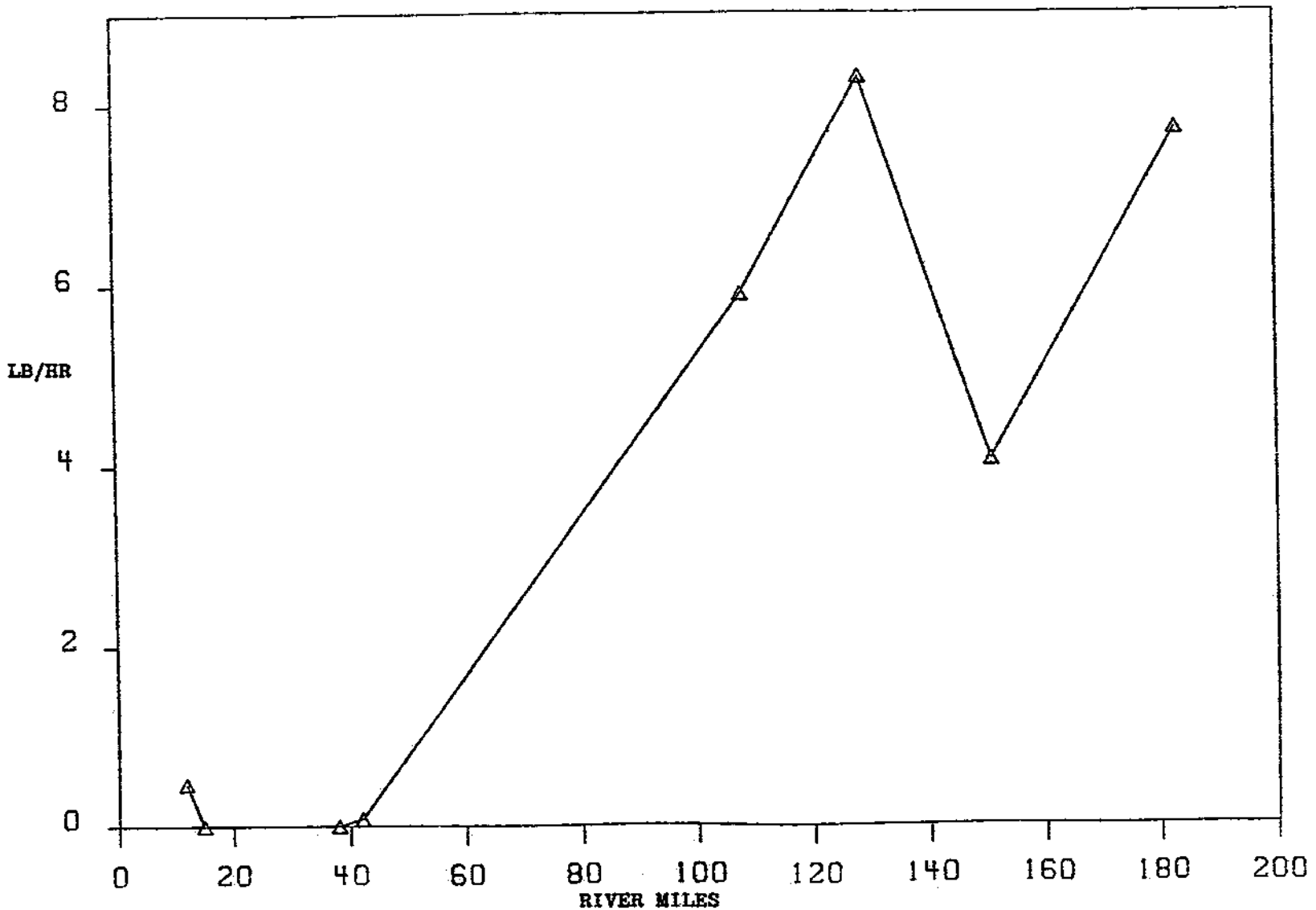


FIGURE 66. RELATIVE BIOMASS OF COMMERCIAL FISH

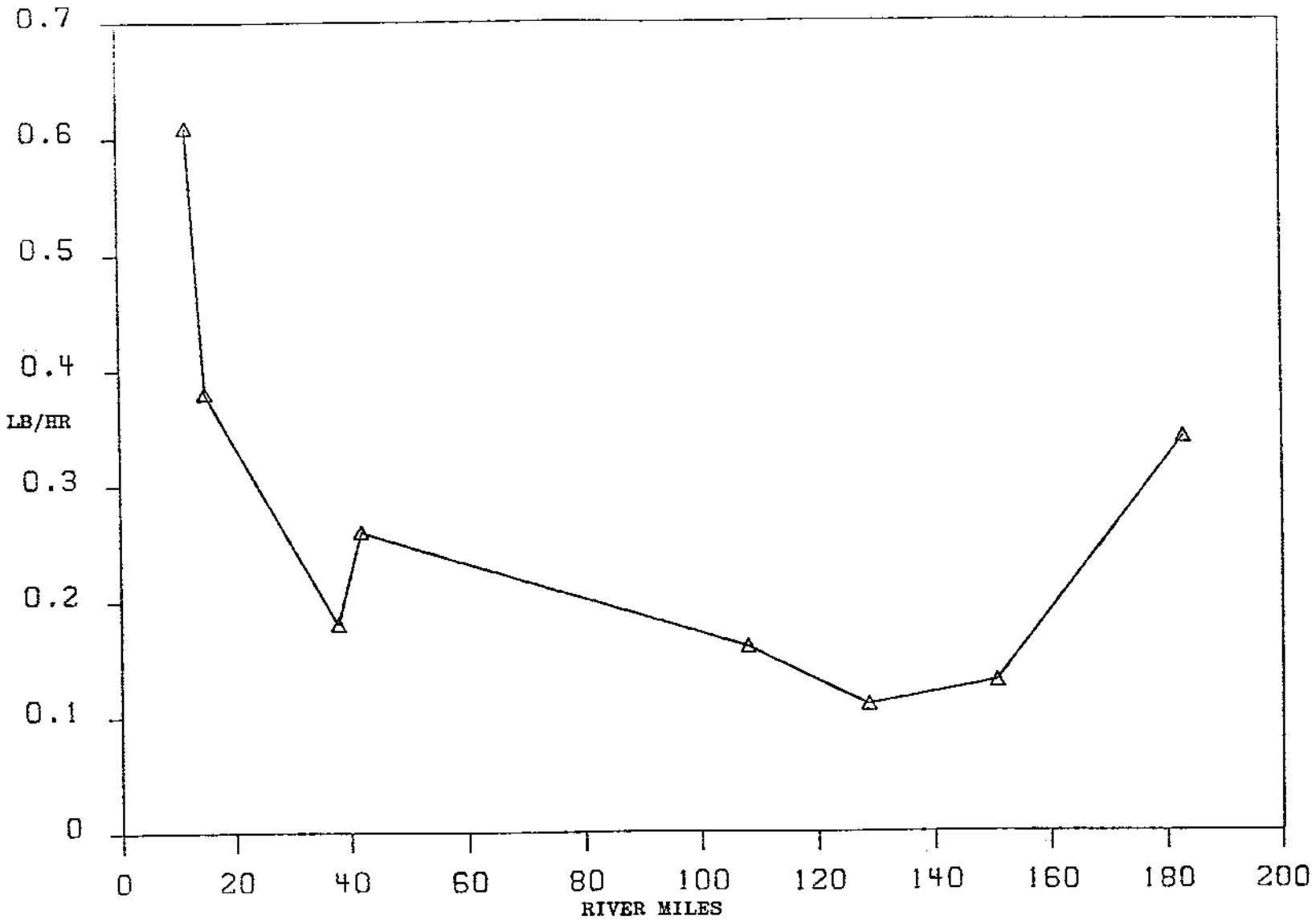


FIGURE 67. RELATIVE BIOMASS OF FORAGE FISH.

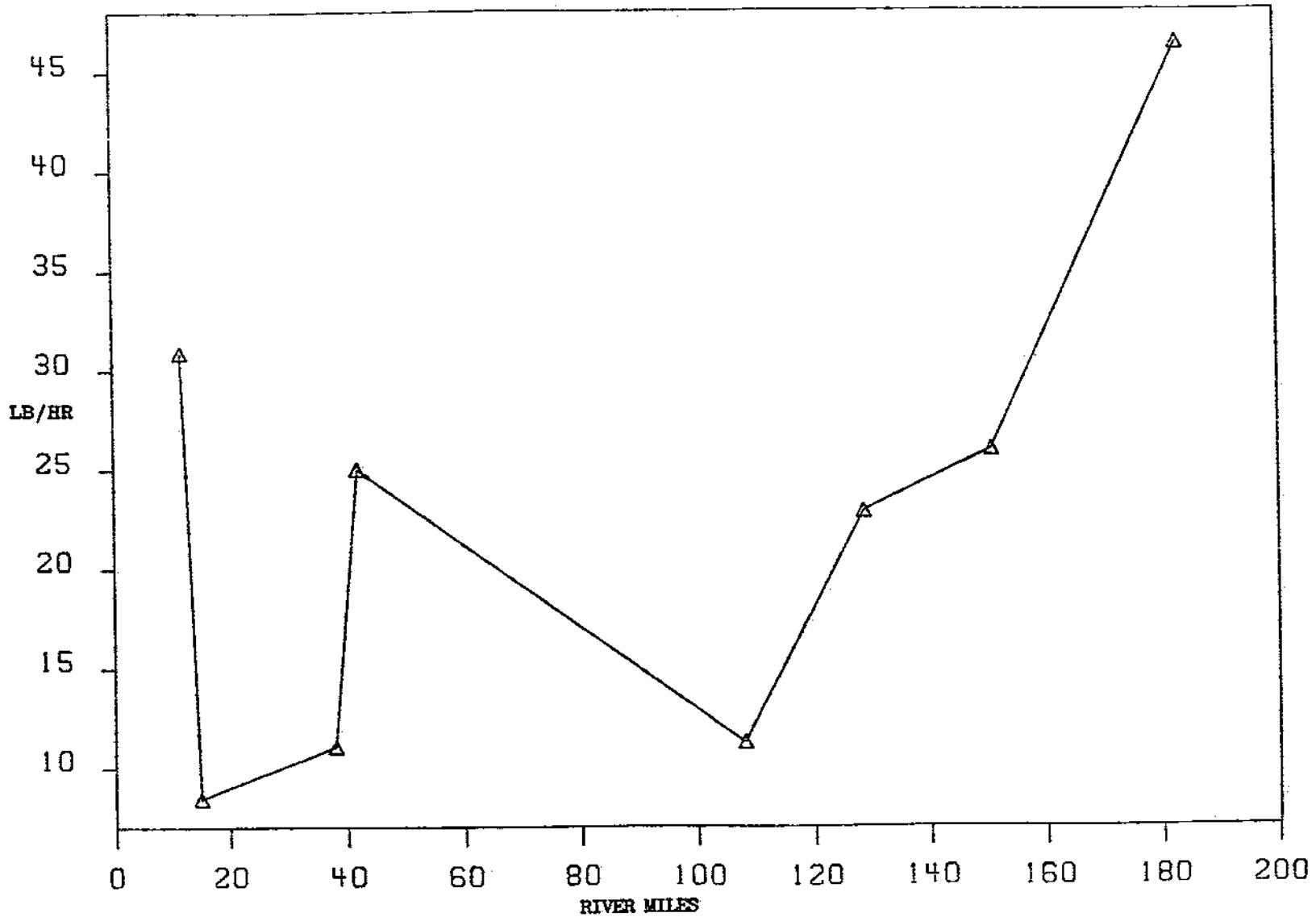


FIGURE 68. RELATIVE BIOMASS OF FISH THAT ARE PREDATORY ON OTHER FISH

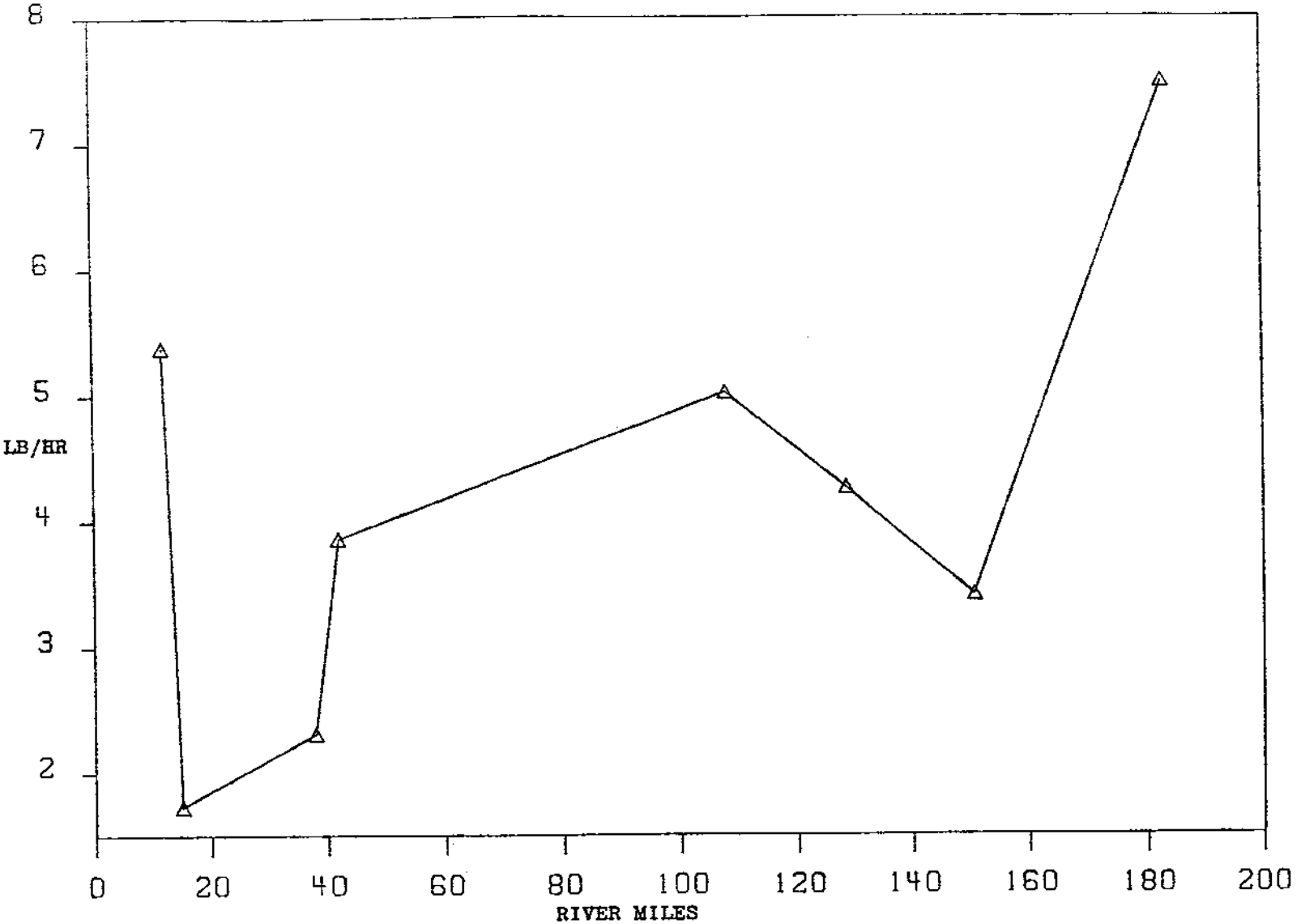


FIGURE 69. RELATIVE BIOMASS OF FISH THAT FEED PRIMARILY ON DRIFT MACROINVERTEBRATES

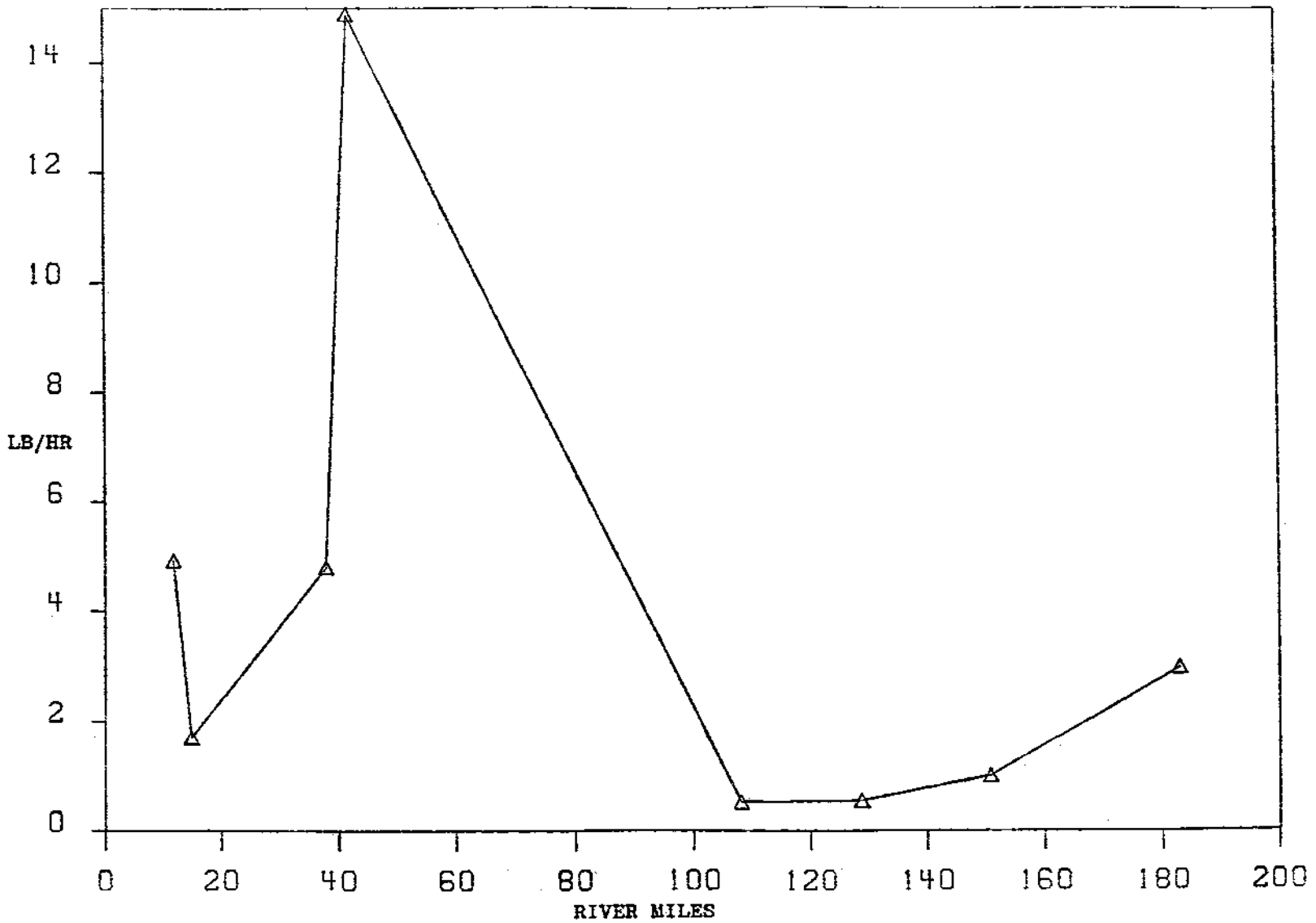


FIGURE 70. RELATIVE BIOMASS OF FISH THAT FEED PRIMARILY ON BENTHIC MACROINVERTEBRATES

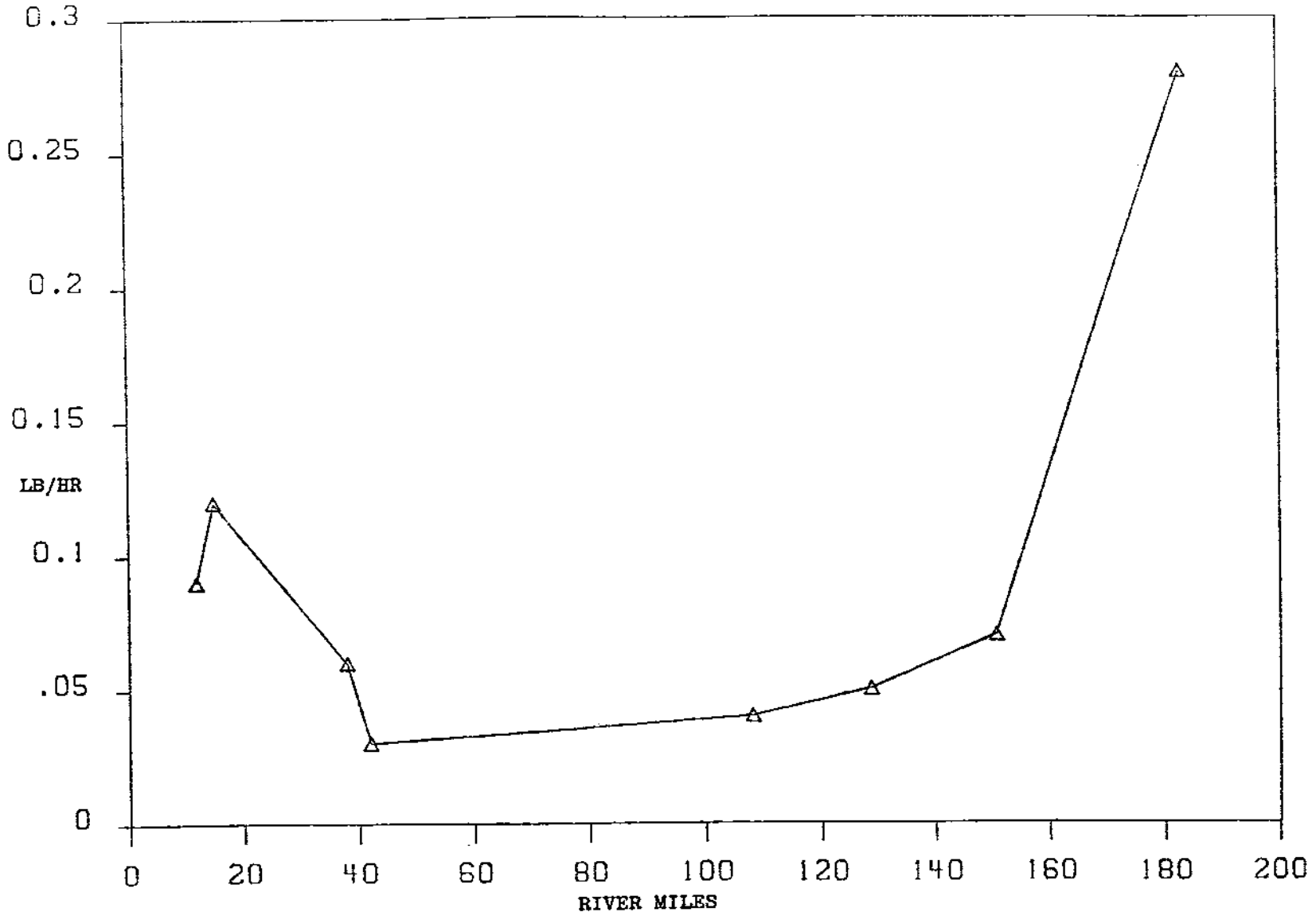


FIGURE 71. RELATIVE BIOMASS OF FISH THAT FEED PRIMARILY ON SMALL INVERTEBRATES AND ZOOPLANKTON

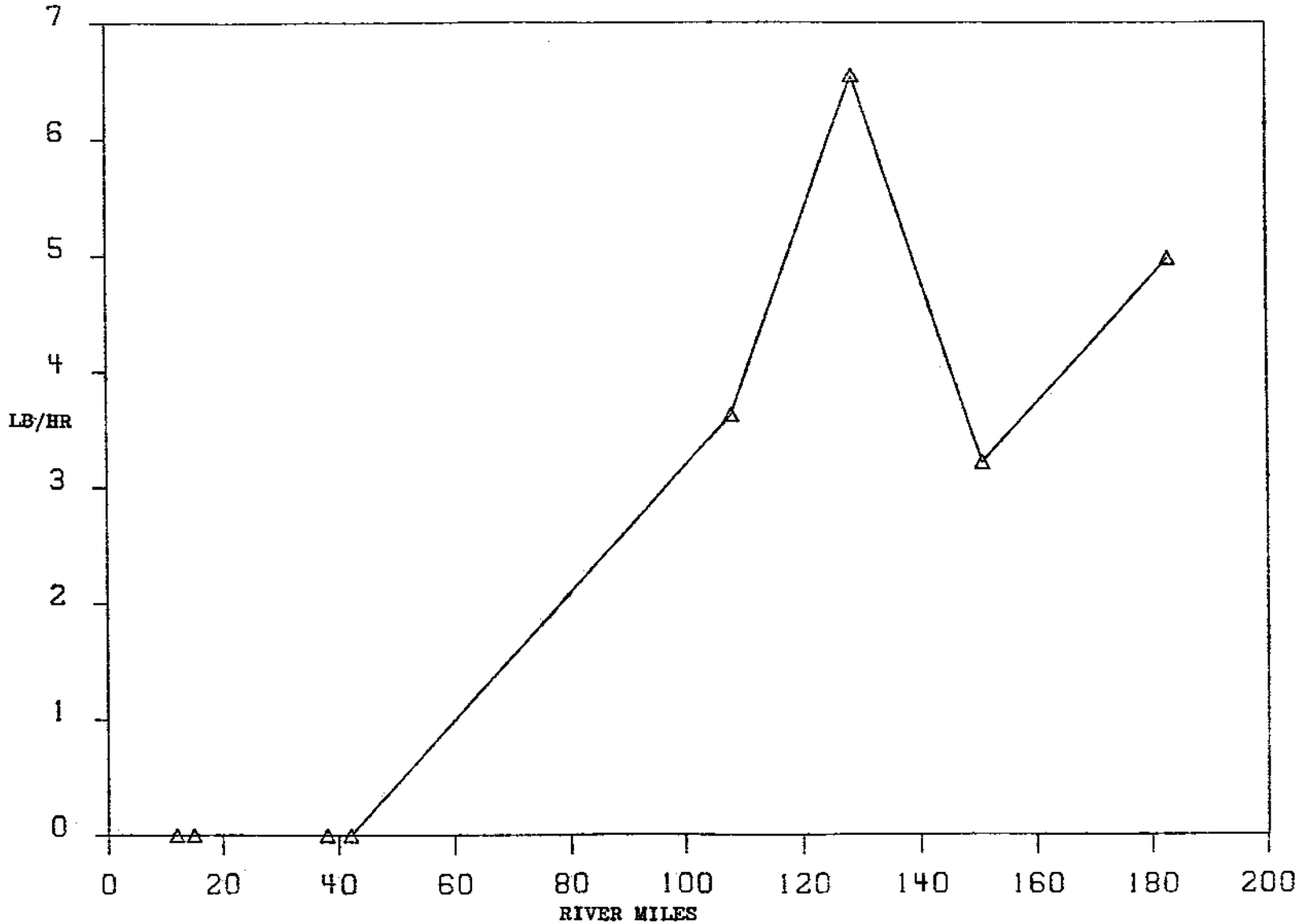


FIGURE 72. RELATIVE BIOMASS OF FISH THAT FILTER-FEED ON PHYTOPLANKTON AND ZOOPLANKTON

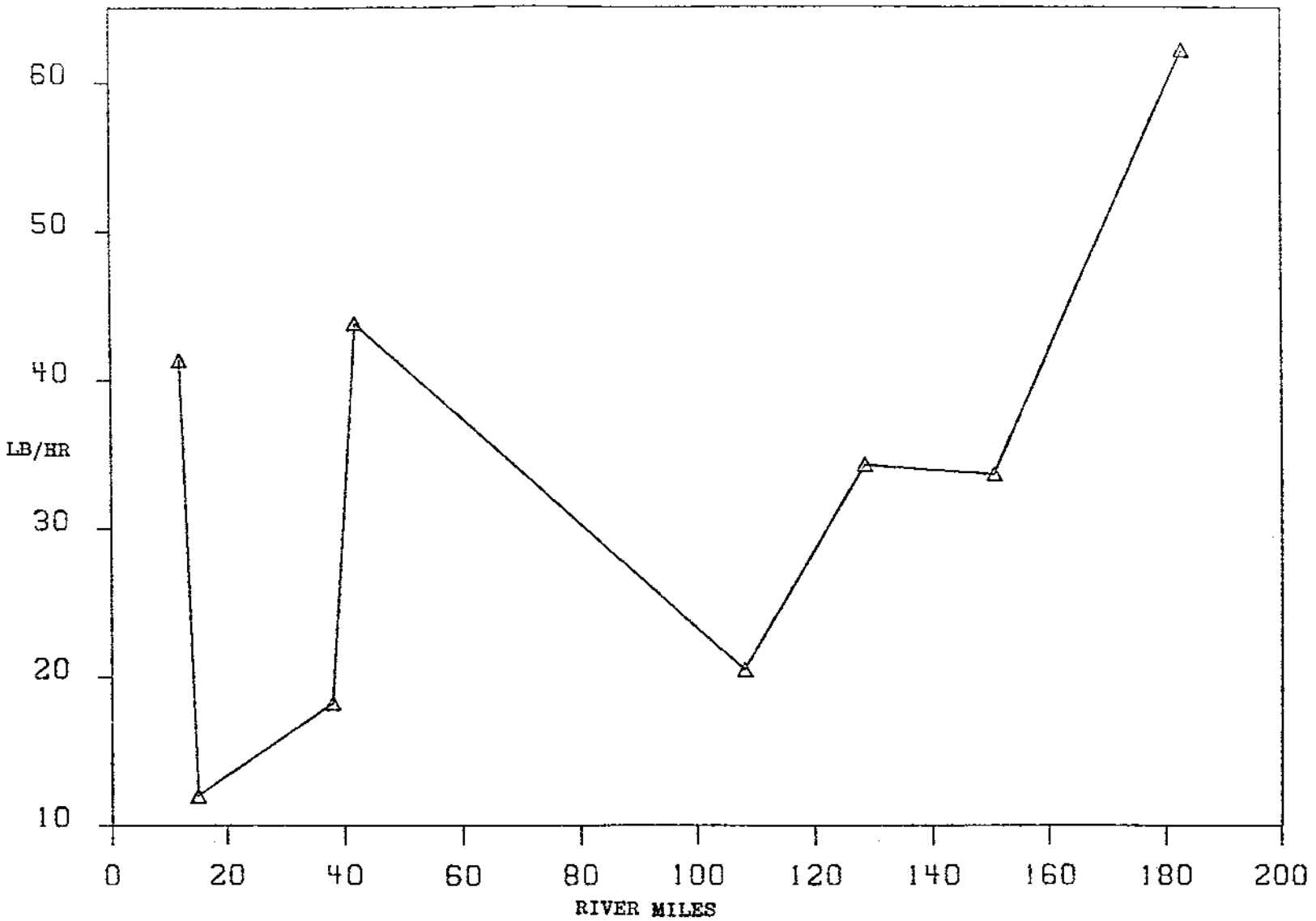


FIGURE 73. RELATIVE BIOMASS OF ALL FISH

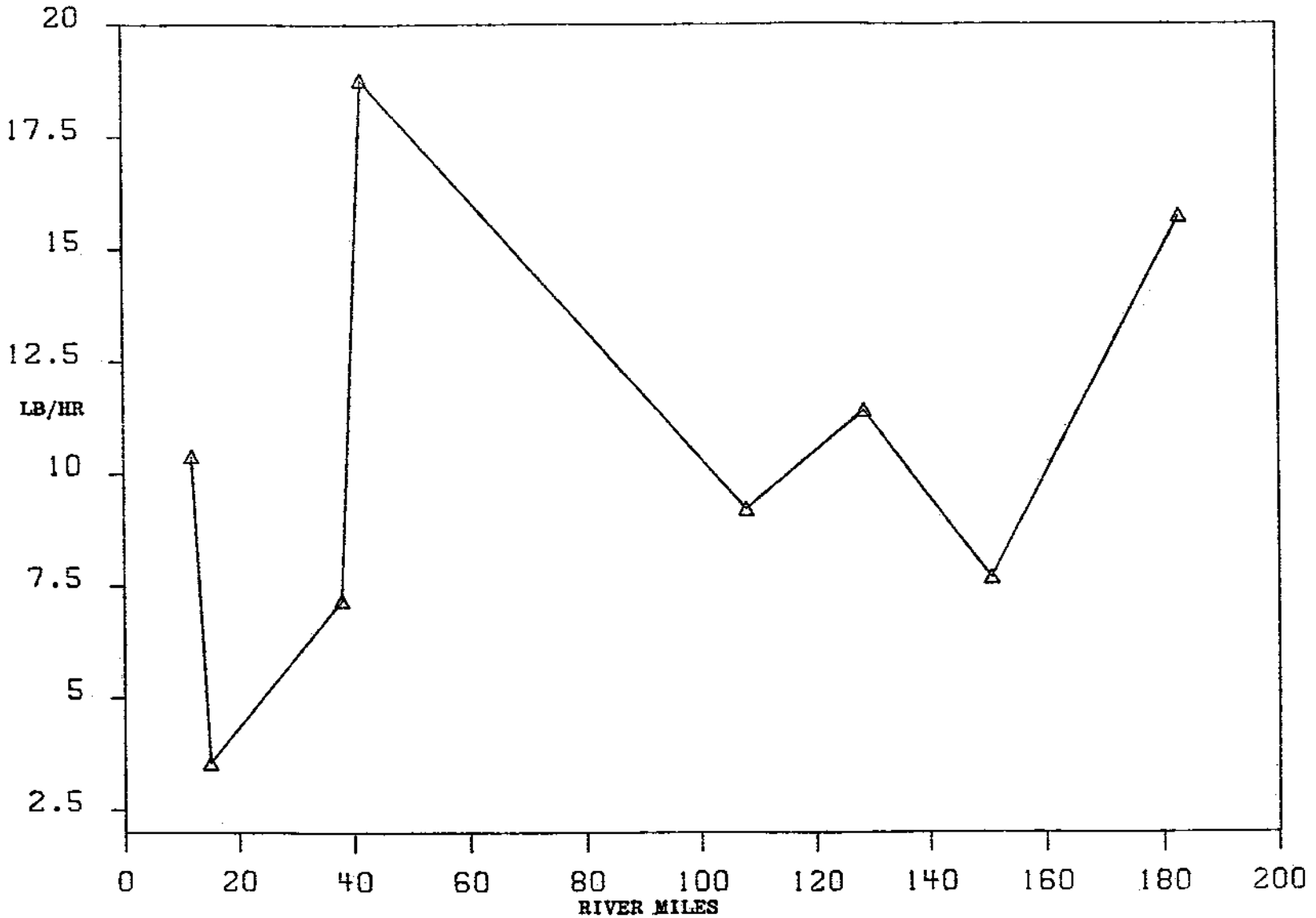


FIGURE 74. RELATIVE BIOMASS OF ALL FISH THAT FEED ON INVERTEBRATES OR THAT FILTER-FEED

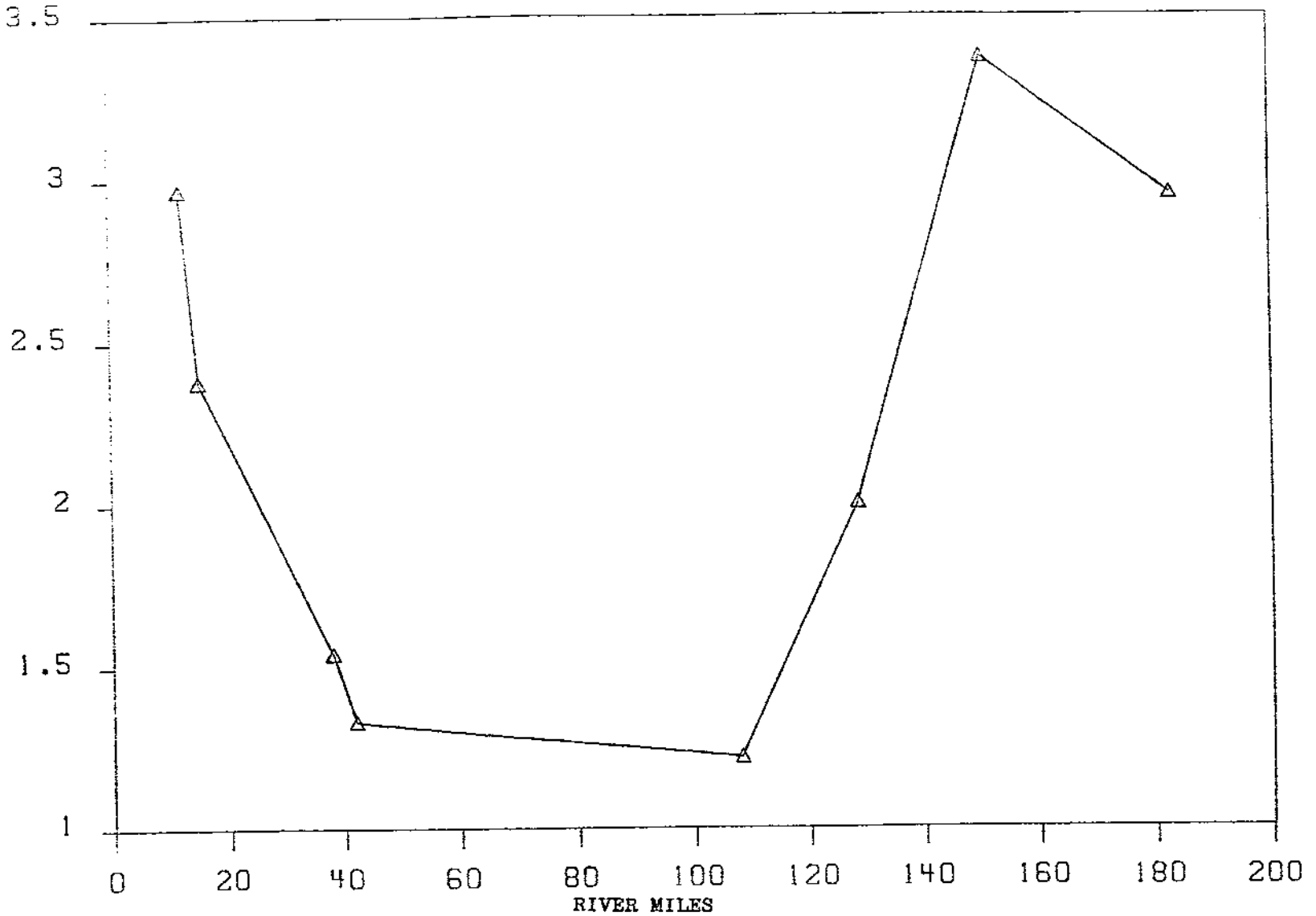


FIGURE 75. RATIO OF PREDATORY FISH TO ALL OTHER FISH

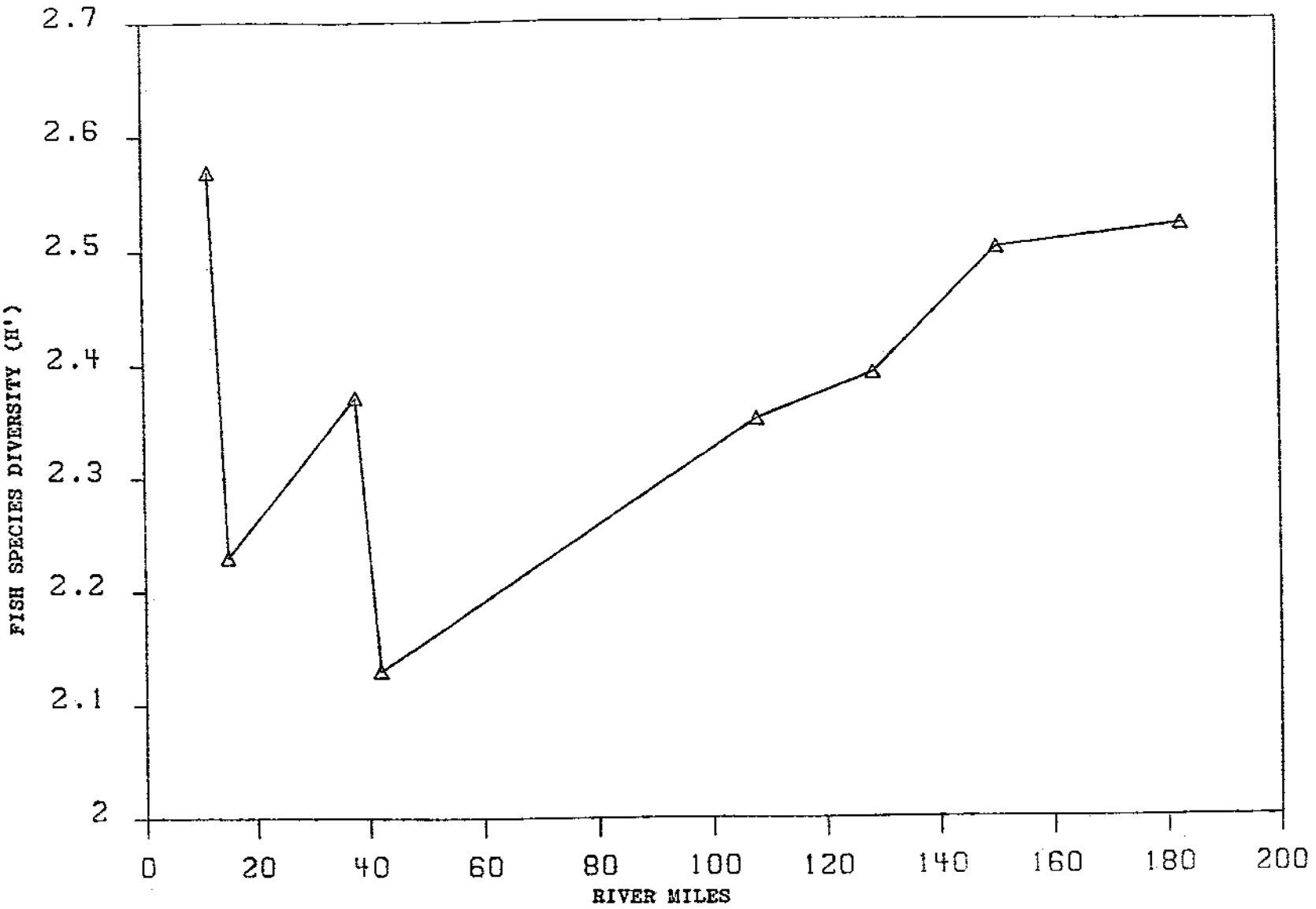


FIGURE 76. SHANNON-WEAVER SPECIES DIVERSITY OF THE FISH COMMUNITY

TABLE 17. Check List of fishes taken from or observed in the Suwannee River (Cox 1972; Bass and Hitt 1973; Krummrich et al. 1984).

Family	Scientific Name	Common Name
Amiidae	Amia calva	Bowfin
Acipenseridae	Acipenser oxyrhynchus	Atlantic sturgeon
Dasyatidae	Dasyatis sp.	Stingray
Lepisosteidae	Lepisosteus platyrhincus	Florida gar
	Lepisosteus osseus	Longnose gar
Anguillidae	Anguilla rostrata	American eel
Clupeidae	Alosa chrysochloris	Skipjack herring
	Alosa alabamae	Alabama shad
	Dorosoma cepedianum	Gizzard shad
	Dorosoma petenense	Threadfin shad
Esocidae	Esox americanus	Redfin pickerel
	Esox niger	Chain pickerel
Umbridae	Umbra pygmaea	Eastern mudminnow
Cyprinidae	Notemigonus crysoleucas	Golden shiner
	Notropis emiliae	Pugnose minnow
	Notropis leedsi	Ohoopee shiner
	Notropis petersoni	Coastal shiner
	Notropis venustus	Blacktail shiner
Catostomidae	Minytrema melanops	Spotted sucker
	Erimyzon sucetta	Lake chubsucker
Ictaluridae	Ictalurus serracanthus	Spotted bullhead
	Ictalurus natalis	Yellow bullhead
	Ictalurus punctatus	Channel catfish
	Ictalurus catus	White catfish
	Ictalurus nebulosus	Brown bullhead
	Noturus leptacanthus	Specked madtom
	Noturus gyrinus	Tadpole madtom
Aphredoderidae	Aphredoderus sayanus	Pirate perch
Belonidae	Strongylura marina	Atlantic needlefish
Cyprinodontidae	Fundulus lineolatus	Lined topminnow
	Jordanella floridae	Flagfish
	Lucania goodei	Bluefin killifish
	Fundulus seminolis	Seminole killifish
Poeciliidae	Gambusia affinis	Mosquitofish
	Heterandria formosa	Least killifish
	Poecilia latipinna	Sailfin molly
Atherinidae	Labidesthes sicculus	Brook silverside
Percichthyidae	Morone saxatilis	Striped bass
Centrarchidae	Micropterus salmoides	Largemouth bass
	Micropterus notius	Suwannee bass
	Enneacanthus gloriosus	Bluespotted sunfish
	Enneacanthus obesus	Banded sunfish
	Acantharchus pomotis	Mud sunfish
	Elassoma spp.	Pygmy sunfish
	Centrarchus macropterus	Flier

	Pomoxis nigromaculatus	Black crappie
	Lepomis gulosus	Warmouth
	Lepomis marginatus	Dollar sunfish
	Lepomis punctatus	Spotted sunfish
	Lepomis auritus	Redbreast sunfish
	Lepomis macrochirus	Bluegill
	Lepomis microlophus	Redear sunfish
Percidae	Etheostoma fusiforme	Swamp darter
	Etheostoma edwini	Brown darter
	Percina nigrofasciata	Blackbanded darter
Gerridae	Eucinostomus argenteus	Spotfin mojarra
Sparidae	Archosargus probatocephalus	Sheepshead
Sciaenidae	Leiostomous xanthurus	Spot
Gobiidae	Gobionellus shufeldti	Freshwater goby
Mugilidae	Mugil cephalus	Striped mullet
Bothidae	Paralichthys albigutta	Gulf flounder
	Paralichthys lethostigma	Southern flounder
Soleidae	Trinectes maculatus	Hogchoker

TABLE 18. Relative abundance, value class, and feeding class of fish in the Suwannee River. The values shown are the means of two-year averages collected at six stations along the river during 1982-83.

Species	Value Class[a]	Feeding Class[b]	Mean Biomass (lb/hr)	Mean Abundance (#/hr)
Bowfin	R	P	13.82	4.8
Florida gar	R	P	2.24	1.8
Longnose gar	R	P	0.05	0.3
American eel	C	M	1.33	1.8
Alabama shad	-	-	0.01	0.1
Gizzard shad	R	F	0.05	0.1
Chain pickerel	S	P	0.002	0.2
Golden shiner	F	Z	0.03	0.2
Notropis sp.	F	Z	0.01	3.6
Spotted sucker	R	B	2.56	2.5
Lake chubsucker	R	B	0.01	0.1
Spotted bullhead	F	B	0.01	0.4
Yellow bullhead	S	B	0.01	0.1
Channel catfish	S	B	0.35	0.1
White catfish	S	B	0.35	1.9
Brown bullhead	S	B	0.08	0.1
Tadpole madtom	F	B	0.01	0.3
Pirate perch	F	M	0.02	1.9
Lined topminnow	F	Z	0.002	0.1
Least killifish	F	Z	0.002	0.1
Flagfish	F	Z	0.002	0.1
Mosquitofish	F	Z	0.01	1.5
Sailfin molly	F	Z	0.002	0.1
Brook silverside	F	Z	0.01	0.3
Largemouth bass	S	P	6.29	9.4
Suwannee bass	S	P	0.72	2.5
Pygmy sunfish	F	Z	0.002	0.1
Flier	S	M	0.002	0.1
Black crappie	S	P	0.28	0.8
Warmouth	S	M	0.23	0.1
Dollar sunfish	F	Z	0.01	0.2
Spotted sunfish	S	M	0.51	7.7
Redbreast sunfish	S	M	1.56	30.7
Bluegill	S	M	0.37	4.8
Redear sunfish	S	M	0.39	2.7
Brown darter	F	Z	0.01	1.1
Blackbanded darter	F	Z	0.01	2.3
Striped mullet	C	F	3.01	1.8
Hogchoker	F	B	0.02	2.7

[a] Value Class: S=sport, R=rough, C=commercial, F=forage.
[b] Feeding Class: P=predatory on fish, M=drift macroinvertebrate feeder, B=benthic macroinvertebrate feeder, Z=small invertebrate feeder, F=filter feeder.

TABLE 19. Fluoride concentrations in fish bones from the upper Suwannee River and Occidental Chemical Company, 1980.

Fish Type	Site	% F in Bone Ash[a]
Catfish	Altman Bay	1.99
	Below Swift Creek	0.80
	Above Swift Creek	0.37
Centrarchids	Altman Bay	1.28
	Below Swift Creek	0.38
	Above Swift Creek	0.33

[a] Average of two replicates.

TABLE 20. Summary of results of Ra-226 analyses in fish flesh and bones in the Suwannee River, October 1980.

Species, Location	Ra-226, pCi/g (fresh weight)	
	Bones	Flesh
Catfish		
Above Swift Creek	0.4 ± 0.2[a,b]	0.05 ± 0.01[c]
Altman Bay	0.6 ± 0.05	0.04 ± 0.01[c]
Below Swift Creek	0.4 ± 0.1	0.04 ± 0.01
Centrarchid (Bream)		
Above Swift Creek	0.4 ± 0.1[c]	0.06 ± 0.04[c]
Retention Pond	0.3 ± 0.04	0.2 ± 0.1
Below Swift Creek	0.7 ± 0.2	0.4 ± 0.1

[a] ± values are one standard error of the mean of multiple counts of the same sample.

[b] Data as provided by University of Florida, Department of Environmental Engineering Sciences.

[c] Less than 50 pCi/sample.

TABLE 21. Results of spring creel studies of the upper (1982) and lower (1983) Suwannee River.

Species	Number of Fish Harvested		Hours of Effort	
	Upper River	Lower River	Upper River	Lower River
Largemouth bass	296	1,914	349	5,557
Redbreast sunfish	12,122	28,419	5,771	11,029
Other bream	2,787	31,061	561	20,635
Catfish	4,114	8,630	4,451	5,556
Other freshwater fish	0	81	0	9
Other saltwater fish	0	300	0	1,469
Total	19,319	70,405	11,132	44,255

TABLE 22. Comparison of effort, harvest and yield data from the Suwannee River with results from other eastern rivers.

River	Effort (Hr/mi)	Harvest (Fish/mi)	Success (Fish/hr)
Upper Suwannee (1982)	500	678	1.36
Lower Suwannee (1983)	1,256	2,164	1.72
Middle Suwannee (1971)	1,047	2,095	2.00
Lower Santa Fe, FL	1,555	2,156	1.38
Blackwater, FL	3,829	4,139	1.09
Escambia, FL	3,650	3,178	0.87
St. Johns, FL	3,788	3,651	0.97
Oklawaha, FL	3,384	2,508	0.74
Withlacoochee, South FL	2,677	2,012	0.75
Flint, GA	1,514	1,324	0.87
Northeast, MD	-	-	0.29
Magothy, MD	-	-	1.80
Potomac, MD	-	-	0.47
Susquehanna, MD	-	-	0.36
Huzzah Cr., MO	1,612	1,008	0.63
Courtois Cr., MO	1,144	915	0.80
Current, MO	486	185	0.38
Big Piney, MO	550	332	0.60
Cacapon, WV	--	-	1.00
New, VA	-	-	1.10
Shenandoah, WV	-	-	1.34

PILOT STUDY FOR MACROINVERTEBRATES AND PERIPHYTON

An important part of our overall investigation of the Suwannee River was the choice of samplers to be used in both the macroinvertebrate and periphyton portions of the study. For the macroinvertebrates, in addition to choosing the proper sampler, we also needed to know the number of replicates required to produce statistically valid results. To accomplish these tasks we conducted a brief pilot study where we employed a number of different sampler types and replicates at several stations on the river.

Due to the extremely diverse natural substrate types in the river we eliminated standard benthic samplers such as Ekman grabs in favor of artificial substrates. By so doing we hoped to eliminate substrate type as a variable responsible for the distribution and abundance of the organisms we collected.

Benthic Macroinvertebrates

Introduction

The selection of appropriate sampling devices for any study of macroinvertebrates in lotic environments is likely to be difficult. Available methodologies are numerous --all with fairly well documented drawbacks (Cairnes 1982). In studies emphasizing the interactions of water quality and benthos, some method involving the use of artificial substrates is often selected to avoid the confounding effects of substrate variation. Once a decision to use artificial substrates is reached, the selection process is still complex. Information regarding the number of samplers which will be needed at a given site to obtain a given degree of data reliability is needed, along with some measure of the adequacy of the chosen device for determining the parameters of interest in the investigation. Often, the ability of a sampler to detect variations in some parameter at different locations or dates is of paramount importance to an investigation. The best sampler will be one which is highly sensitive to this type of variation and is, simultaneously, highly precise -- that is, one which requires few subsamples to provide the desired information.

The majority of recent investigations of lotic benthic macroinvertebrates which have relied on artificial substrate samplers have used either some variation of the basket sampler, (Wene and Wickliff 1940; Mason et al. 1967) or a modification of the multiple-plate sampler of Hester and Dendy (1962). The sensitivity of rock baskets in detecting variations has been examined by Anderson and Mason (1968), Crowe (1971), Dickson et

al. (1971), Fullner (1971), Mason et al. (1973), Crossman and Cairns (1974), Newlon and Rabe (1977), and by Wise and Molles (1979), among others. Fullner (1971), Mason et al. (1973), and Newlon and Rabe (1977) include comparisons with multiple-plate samplers. Other studies of the sensitivities of multiplate-plate samplers were performed by Arthur and Horning (1969), Tsui and Breedlove (1978), and by Slack et al. (1982). Measurements of the precision of these samplers, however, have only rarely been reported, notably by Dickson et al. (1971) and Mason et al. (1973) for rock baskets.

Based on these studies, we conclude that: 1) the various types of rock baskets and multiple-plate samplers which have been tested all perform reasonably well in detecting variations in macroinvertebrate parameters, with, however, substantial differences in taxa collected; 2) rock basket samplers require four subsamples to estimate the mean number of taxa and of individuals within 25% at a 95% confidence interval (Dickson et al. 1971), or variously, three to twenty-three subsamples to estimate the mean number of taxa within 20% at a 95% confidence interval (Mason et al. 1973); and 3) the precision of multiple-plate samplers is not known quantitatively. This study was designed to compare the sampling efficiencies of four types of rock baskets and one of the most widely used types of multiple-plate samplers. We felt that one of these sampler types would fit not only our need for sensitivity and precision, but would also fit our time and manpower constraints.

Site and Methods

This study was performed at three stations along the length of the Suwannee River in Florida: Station 1, 2.5 mi. south of the Florida/Georgia border; Station 2, 1.5 mi. upstream of U.S. Highway 27, near Branford; and Station 3, immediately downstream of New Pine Landing, near Manatee Springs State Park. Sampling devices were placed in the river on October 12, 1981, and were retrieved on November 9, 1981, after a four week incubation period.

Five different types of sampling devices were used. Four of these were "rock baskets", constructed of plastic coated 1/2 inch (1.27cm) mesh galvanized hardware cloth, in the form of a cylinder 21.5cm long and 14.0cm in diameter. The four versions of rock baskets contained the following materials: 1) 2 1/4 inch (5.72cm) diameter unglazed procelain spheres, 2) 1 1/8 inch (2.86cm) diameter unglazed porcelain spheres, 3) a mixture of equal quantities by weight, of the two sizes of unglazed porcelain spheres, and 4) native limestone rocks that passed through a 7.5cm mesh screen and were retained by a 5.0cm mesh screen. (The procelain spheres were obtained from Ferro Corp., 1230 Railroad St., E. Liverpool, OH 43920.) The fifth type of sampler was a multiple-plate device of the design of the U.S. Environmental Protection Agency (Weber 1973), as modified from Hester and Dendy (1962), constructed from fourteen, 1/8 inch (0.3cm) thick, tempered Masonite® discs, 7.5cm in diameter, with twenty four spacers of the same material, 2.5cm in diameter.

These multiple-plate samplers were attached to concrete blocks with stainless steel rod, following the method of Parsons and Tatum (1974).

All samplers were placed in 1.0-1.5m of water, between the main channel of the river and the left bank as viewed from upstream. Samplers of each type were grouped together, and were spaced from 0.3 to 2.0m apart depending on local bottom configurations. Groups of like samplers were spaced from about 1.0 to 4.0m apart. Major emphasis was placed on sampling in equal depths of water, and this consideration was allowed to control sampler spacing. Spacing was such, however, as to preclude any significant interference between samplers in our opinion. Nine samplers of each type (a total of 45) were placed at Station 1, while three of each type were used at Stations 2 and 3 (a total of 15 at each).

Samplers were retrieved after 28 days. Retrieval was accomplished by hand with as little agitation of the samplers as possible. No special enclosures or nets were used around the samplers during retrieval based on the findings of Mason et al. (1973) that "loss of organisms during retrieval of shallow-placed samplers in large streams is insignificant". Little change in water depth was found to have occurred between placing the samplers and their retrieval.

After removal from the water, the entire samplers were placed in individual containers and preserved with 4% formaldehyde solution buffered with sodium bicarbonate. In the laboratory the substrates were carefully cleaned with a soft brush and water. Material removed was then sieved through a stainless steel sieve (.5mm mesh). Material retained by the sieve was then sorted under a 60X dissecting microscope and preserved in 70% ethanol. All organisms were identified to the lowest practical taxonomic level. If identification to the species level was not accomplished, arbitrary designations of what were believed to be species were used, and specimens were sorted and counted into such categories. This last procedure was fortunately necessary only for such difficult groups as oligochaetes and mites, which were minor constituents of the collected fauna.

Numerous statistical methods are available for comparing sampling methodologies. We chose two of them. To determine the sampler which required the least resources to obtain a given amount of information, and using the data from Station 1, the method of Elliott (1977, p. 130) was used in which:

$$n = \frac{t^2 s^2}{D^2 \bar{X}^2}, \text{ where}$$

n = number of samples required,

t = Student's t-distribution, two-tailed, with n-1 degrees of freedom, at a chosen confidence level,

s = standard deviation of the tested population,

$$D = \frac{t\ s}{\sqrt{n}\ \bar{x}}$$

D = tolerated error about the mean, and

$\bar{X}$ = mean of the tested population.

Since n must be an integer, for ease of computation we based our calculations on the equivalent formula:

This method assumes a normal distribution. We tested for normality by constructing normal probability plots, as described in Filliben (1975).

To test the relative sensitivities of the samplers to the parameters of interest, we first performed two-way analyses of variance (stations vs. samplers, with stations being considered a random treatment and samplers being considered fixed) to determine if there were significant differences between the samplers. Because of missing data at Station 3, the analyses were performed once using only the data from Stations 1 and 2, and again including Station 3 with missing data being derived by estimating a cell block total for the missing cell and then assuming equal observations in that cell (Yates 1933, fide Steel and Torrie 1960). Repetitions were unequal, but were proportional so that the orthogonality assumption was retained without additional bias. Samplers were then ranked using Duncan's Multiple Range Comparison Test.

Results and Discussion

Results of the analyses used to determine the required number of samples for a given degree of precision are presented in Table 23. The multiple-plate samplers are the most efficient in this sense, and the baskets containing the large (2 1/4") porcelain spheres are least efficient. Four multiple-plate samplers provide 90% certainty of being within 13.35% of the number of individuals and within 22.90% of the number of taxa of the sampled population mean. All of the basket type samplers require considerably more samplers to achieve this level of precision. It may also readily be seen that the multiple-plate samplers were also more efficient on an absolute basis, collecting considerably more taxa and many more organisms per sampler than any of the basket sampler types. This observation is contrary to what we had expected, since the basket samplers have greater surface areas than the multiple-plate samplers, and since they presumably more closely resemble the natural substrates of the river.

Analyses of sensitivity (Table 24) gave less clear-cut results, although certain conclusions may be reached. The basket samplers containing the large porcelain spheres appear to be the least sensitive in their ability to detect changes in numbers of taxa among stations. The multiple-plate samplers and the baskets

containing limestone rocks seem to be the most sensitive, although they are not significantly different (whether Station #3 is included in the analyses or not) from baskets containing the small (1 1/8" porcelain spheres).

Based on these results, the multiple-plate sampler (4 replicates of each) is the best choice for this situation. Not only is less effort (and cost) involved in the use of these samplers than for any of the basket type samplers, but fewer of them are required for a given degree of precision and they appear to be as sensitive to differences in numbers of taxa as the most sensitive basket type sampler.

Periphyton

Although artificial substrates (particularly glass microscope slides) have been used for many years in numerous studies of periphyton communities (e.g., Sladeckova 1962) we decided to investigate other substrate materials and sampler types. By so doing we hoped to find a substrate and sampler type that would not only provide good replication, but also would have certain advantages in the field (e.g., resistant to vandalism and breakage).

Methods

We experimented with the following substrate and sampler types in the pilot study:

1) Standard 75x25mm glass microscope slides that were placed in stainless steel slide racks and suspended 15cm below the water suface; 2) Lexan® strips that were cut into 75x25mm pieces that were placed in the same stainless steel slide racks as the microscope slides in #1 above; 3) Plastic strips (Mylar®) approximately 20cm long that were attached to foam floats and suspended approximately 15cm below the water surface; 4) A concrete block to which were attached glazed and unglazed tiles (150x150mm), glass plates (100x150mm), and a stainless steel slide rack which included both glass microscope slides (75x25mm) and Lexan® strips (75x25cm). The entire sampler was then placed in approximately 0.5m of water.

All sampler types were incubated for 28 days at the same stations used for the macroinvertebrate pilot study. At the end of the incubation period substrates that were to be analyzed for chlorophyll a were placed in tubes or bottles, filled with de-ionized water, placed on ice, and then returned to the lab for analysis. Laboratory analysis of the chlorophyll a was identical to that referenced in the chapter on periphyton.

Results and Discussion

All the various samples provided fairly good replication within substrate types, but where water clarity was reduced (i.e. Station 1) the surface samplers collected more periphyton biomass

(chlorophyll a) than the concrete block sampler placed on the bottom. Since stage height in the river could change radically during any time of the year and we could not control the depth at which the concrete block would be located during the 4 week incubation we thus decided to eliminate the block sampler from further consideration.

All the surface samplers appeared to be equally efficient at collecting periphyton, but the Lexan® and Mylar® strips had certain disadvantages that made them unacceptable for use in our study: 1) The Lexan® strips had to be cut by hand which was not only time consuming (since we would need a complete new set each month) but also imprecise. This last point was critical since calculations of periphyton chlorophyll a depended on an accurate measurement of substrate area; 2) The Mylar® strips suffered from the same imprecision as the Lexan® strips since they also needed to be cut by hand. An additional problem with the Mylar® strips became apparent in the field tests: Unless the current velocity of the river at the sampling point was relatively rapid the mylar strip would not maintain a constant depth (i.e., approximately 15cm). This might have allowed a differential colonization rate that would be only a function of light penetration. Since we were investigating parameters other than just light we felt this was a significant drawback.

The glass microscope slides, although less than ideal (i.e., breakage), were thus chosen as the artificial substrate for periphyton collection due to the uniformity of their construction, the ease of procuring them in quantity, and the fact that they had been used to good effect in many previous studies.

Sampler	Parameter	Sample $\bar{X}$	Sample S	n, if: D=.05	D=.15	D=.25
Basket: 2 1/4" porcelain spheres	no. individuals	23.77	15.83	480	56	22
	no. taxa	8.22	5.67	515	60	23
Basket: 1 1/8" porcelain spheres	no. individuals	37.33	13.36	140	18	8
	no. taxa	10.67	3.24	102	14	6
Basket: mixed porcelain spheres	no. individuals	29.11	10.90	153	19	9
	no. taxa	9.56	3.64	158	20	9
Basket: limestone	no. individuals	26.38	5.40	48	8	4
	no. taxa	12.11	4.51	152	19	8
Multiple-plate	no. individuals	104.22	11.83	16	4	3
	no. taxa	17.78	3.46	61	7	4

TABLE 23. Required numbers of samples (n) to be 90% certain of being within a given percent (D= .05 is ± 15%, and D = .25 is ± 25%) of the sampled population mean, in terms of numbers of individuals and of numbers of taxa per sampler.

All Stations:

1 3 2 5 4

Without Station #3:

1 3 2 4 5

1 = Basket: 2 1/4" balls

2 = Basket: 1 1/8" balls

3 = Basket: mixed balls

4 = Basket: limestone

5 = Multiplate

TABLE 24. Sampler sensitivity to differences in numbers of taxa among stations using ANOVA to determine significant differences (at the 5% confidence level), and ranking using Duncan's New Multiple Range Comparison Test. Sampler types connected by the lines are not significantly different. The ranking is from smallest to largest difference, from left to right.

BENTHIC MACROINVERTEBRATES

Introduction

A benthic macroinvertebrate is an animal that spends a portion of its life cycle within or upon available substrates in a body of water, and, for the purposes of this study, is retained by a 0.5mm mesh sieve. The major taxonomic groups of invertebrates found in freshwater include insects (predominantly larval forms of Diptera, Trichoptera, Ephemeroptera, Coleoptera, Megaloptera, Odonata, and Plecoptera), as well as annelids, crustaceans, and mollusks. Aquatic macroinvertebrate communities have been shown to be very sensitive to stress, and therefore can serve as useful indicators of environmental perturbations resulting from introduced contaminants (Gaufin and Tarzwell 1952; Beck 1954; Hynes 1959; Butcher 1959; U.S. EPA 1973; Bauer et al. 1980).

Benthic macroinvertebrates are an integral part of the food web, and the relative health of this community is reflected in the well-being of higher trophic levels such as fish populations (Tippets and Moyle 1978). Their sedentary nature, coupled with the phenomenon of "biological magnification", makes benthic organisms susceptible to contaminants (e.g., pesticides, radioactive materials, and metals) which may be present in undetectable concentrations, but which can be absorbed over time and produce adverse impacts in the benthic community (U.S. EPA 1973).

To adequately assess possible pollution sources, it is desirable to accentuate spatial differences in water quality (upstream and downstream of a discharge) while controlling for other factors which affect benthic community composition. Many authors state that the single most important factor influencing macroinvertebrate distribution and community structure is the substrate (Cummins and Lauff 1969; de March 1976; Ruggiero and Merchant 1979; Wise and Molles 1979). When spatial comparisons are desired in streams with hard or variable substrate quality or deep water, the use of artificial substrates for sampling benthic macroinvertebrates is a preferred method (Anderson and Manson 1968; Hilsenhoff 1969). By using artificial substrates, the major variable, sediment quantity and quality, is eliminated and differences in the benthos due to differences in water quality become more apparent.

The objectives of this part of the study were to quantitatively characterize the aquatic benthic macroinvertebrates of the Suwannee River in terms of taxonomic composition and abundance to: 1) determine ambient conditions; and 2) determine the biological effects of the major

discharges with regard to present and future regulatory concerns.

Methods And Materials

Field and Laboratory Methods

Based on the pilot study discussed earlier comparing macroinvertebrate sampling techniques, we selected a modification of the method of Parsons and Tatum (1974) which consisted of mounting 4 Hester-Dendy multiplate samplers (as modified by U.S. EPA 1973) on a concrete block. The concrete block was then placed at a depth of approximately 1 meter at each station. Each Hester-Dendy sampler had a total surface area of $0.11m^2$. The samplers were incubated for 28 days, which, according to previous studies (Rosenberg and Resh 1982), was adequate to allow macroinvertebrate colonization of the samplers to reach equilibrium. Upon retrieval, the incubated samplers were placed in separate polypropylene containers, filled with river water, and then stored on ice.

In the laboratory, the samplers were dismantled and the plates carefully brushed and washed with tap water over a 0.5mm mesh stainless steel sieve. The sieved material was then stored in 70% ethanol, and later, the organisms were separated from detritus under a 60x dissecting microscope and placed in fresh 70% ethanol. Organisms were then counted and identified, using either a dissecting or compound microscope, to the lowest possible taxonomic level using the taxonomic references listed in the Literature Cited.

Statistical Methods

Diversity Index - Diversity indices are useful statistical methods whereby large amounts of biological data can be condensed into numbers comprehensible and useful to people not immediately familiar with the specific biota (Godfrey 1978). The index we used (Shannon-Weaver diversity index ($\bar{d}$)) has been widely applied in stream pollution research (Cairns and Dickson 1971; Wilhm 1972; Cook 1976). Although species diversity indices have usually been calculated on species level identifications, Kaesler and Herricks (1979) suggest that when an index of diversity is to be used as a comparative tool in an environmental assessment, taxonomic identifications can be made to the generic level with little loss of information. In the study, when identifications could not be made to the species level due to inadequate taxonomic keys, identification to genera was therefore considered appropriate. As per U.S. EPA (1973) recommendations, $\bar{d}$ was not calculated for samples containing less than 100 individuals.

Numerical Classification - Following the methods of Green and Vascotto (1978) we performed normal and inverse classification (cluster analyses) on log transformed ($\log_{10}X+1$) macroinvertebrate and periphyton data. By so doing, we hoped to identify specific station and taxon groupings that could perhaps

be explained by discriminant analysis of selected physical-chemical data (Field et al. 1982).

To perform the classification analysis we used the ORDANA program of Bloom et al. (1977). We used Czekanowski's Quantitative Index of Similarity (also known as the Bray-Curtis Index) which has been found to reflect true similarity more accurately than other indices of this type (Bloom 1981). We used both the group average and flexible sorting strategies. We set the flexible sorting coefficient at B=-0.25, which produces moderately intensive clustering (Boesch 1977; Schaffner and Boesch 1982). To perform inverse analysis, it was necessary to standardize the data (Field et al. 1982). We selected simultaneous double standardization since this method reduces scale problems when comparing large and small numbers within the same transformed data set (Boesch 1977).

It was also necessary to reduce the number of species to be included in the cluster analysis. Clifford and Stephenson (1975), Boesch (1977), and Field et al. (1982) list several reasons why data reduction is desirable: 1) computer time increases with the square of the number of species being compared; 2) random co-occurrence of two rare species can result in their being grouped together, and 3) to permit the use of certain classification techniques which would not otherwise be available because of the volume of data. Since the method of data reduction is, to some extent, arbitrary, we initially included species that had >5% dominance of total species abundance at all stations. This reduced the number of species to analyze from 265 to 4. This obviously introduced an unacceptable bias toward the most dominant species. Therefore, for inverse analysis, we chose the maximum number of species we could conveniently include. These were the top 50 species, each of which constituted at least .15% dominance of total species abundance for all stations combined and accounted for 96% of all the organisms we collected. For normal analysis we included all taxa that were found at least twice during the study period. This reduced the number of taxa to analyze from 265 to 217.

Multiple discriminant analysis (Nie et al. 1975) was used to identify physical-chemical factors that were most directly associated with the station groupings that were derived from biological data. By this technique we hoped to relate species abundance and distribution patterns to abiotic parameters.

Results and Discussion

During the two year study period (including 24 sampling dates), a total of 188,401 individual benthic organisms were collected belonging to 265 taxa. A comprehensive taxonomic list is given in Table 25. Three insect orders, Diptera, Trichoptera, and Ephemeroptera, accounted for 96% of the total individuals and 57% of the taxa found. In terms of percent composition, Diptera (virtually all members of the family Chironomidae) was the dominant group at all stations, followed by Trichoptera and Ephemeroptera, respectively (Fig. 77).

The distribution of the dipteran population by station (Fig.

78), showed three fairly noticeable peaks, at Stations 2, 4, and 9. At Station 4 the dipteran population was the most abundant of the study (21,000 individuals), while at Station 11 dipteran abundance was lowest, with only 4000 individuals collected. Since Hester-Dendy samplers have a tendency to bias the collection in favor of chironomids (Meier et al. 1979), and since chironomids are also often the most numerous type of macroinvertebrates found in river systems (Boerger 1980; Seagle et al. 1982), it was not surprising that Diptera was the dominant order at all stations in the Suwannee.

Trichopterans were clearly the second most abundant organisms at Stations 1 and 2, accounting for about 40% of the total number of individuals of the top three orders at both stations (Fig. 77). For Stations 3 - 11, trichopterans accounted for only 10% to 25% composition of the top three orders (Fig. 77). Additionally, abundance was several times greater at Stations 1 and 2 than it was for Stations 3 - 11 (Fig. 78). Since current velocity has been shown to influence the size, distribution, and abundance of benthic organisms (Cummins 1964; Hynes 1970; Mackey 1976; Kovalak 1977; Rabeni and Gibbs 1980), higher current speeds in the upper river probably favored the occurrence of net spinning caddisfly larvae there. This relationship has been observed in other systems as well (Alstad 1980).

The third most abundant group, Ephemeroptera, displayed a noticeable peak at Station 5, where 4300 mayflies were collected over 2 years (Fig. 78). Even so, mayflies were only 20% of the total individuals for that station (Fig. 77). At Station 11, however, Ephemeroptera represented 30% of the top 3 orders, with only 2400 mayfiles collected.

Top Three Groups - Temporal Variation

Considerable seasonal variation in the percent composition was apparent, with dipterans exhibiting dominance on 17 of the 24 sampling dates (Fig. 79). On 6 dates, trichopteran taxa represented the majority, while mayflies were most numerous only once.

The dipteran annual abundance curve (logarithmic scale of the total individuals sampled) was bimodal, peaking in the winter and summer months (Fig. 80). This pattern suggests that a portion of the chironomid population was emerging during both the spring and fall. This seasonal periodicity was independent of stage height.

Although the caddisfly population generally seemed to increase during the summer and decrease in winter months (Fig. 80), no correlation with temperature was noted. The drift rate of Cheumatopsyche sp., the second most numerous trichopteran in this study, has, however, been found to correlate significantly with temperature in Florida (Cowell and Carew 1976). The caddisfly abundance may have been bimodal, considering the dips in the population in early fall both years, but the pattern remained unclear.

Stage height seemed to exert sightly more influence on the

number of trichopterans found on our Hester-Dendy samplers ($r=-0.502$, $P=.01$). Since caddisflies are generally considered rheophilic, an inverse correlation with stage height seems a paradox. However, because the dominant trichopteran taxa found do not construct retreats (i.e. cases), high stage conditions (= high flow velocity) may have reduced the population by catastrophic drift (Hynes 1970, Waters 1972).

The mayfly population was decidedly unimodal, exhibiting summer peaks and winter lows. Mayfly abundance correlated well with temperature ($r=0.733$, $P<0.01$) (Fig. 80). Distinctly seasonal trends in mayfly abundance in north Florida were noted by Townes (1981), even though he found no comparable temperature-synchronized invertebrate life cycles in New Zealand, where the climate and temperature range is quite similar. Ephemeropteran populations in the Suwannee River showed a strong inverse correlation with stage height ($r=-0.620$, $P<0.01$)

Although it is well documented that the temperature regime in a body of water is very important in determining the life cycle and emergence sequences in aquatic insects of temperate latitudes (Hynes 1970; Williams 1980; Minshall 1981; Ross and Wallace 1982), it has been postulated that temperature becomes less important in lower, subtropical latitudes (Townes 1981). Cowell and Carew (1976) concluded that seasonality is not a dominant factor in Florida streams, while Singh and Harrison (1982) suggested that endogenous rhythms established during larval life stages may be more important than temperature in influencing emergence patterns. Our data suggest, however, that the temporal periodicity exhibited by aquatic insects in the Suwannee River was more similar to that of temperate regions.

Overall Abundance - Spatial Variation

Macroinvertebrate populations at Stations 2 and 4 exhibited a 41% and 66% increase in number of individuals over Stations 1 and 3 respectively (Fig. 81); a trend that was consistent for both sampling years. Population abundance at Station 6 was only 50% of that of Station 5, which was also similar for both years. The notable increase in abundance between 8 and 9 was due primarily to 9,000 Rheotanytarsus sp. collected at Station 9 during a single sampling in May, 1983. The cause of this single dramatic occurrence of Rheotanytarsus sp. sampling is unknown.

The loss of samplers due to desiccation or vandalism occurred several times throughout the study, and had an effect on the number of organisms recovered (Fig. 82). To determine if any spatial differences in abundance were simply artifacts of sampler loss, we plotted the number of individuals per station using data only from occasions when all samplers were recovered (Fig. 82). The population increases observed downstream of Hunter and Swift Creeks and the population decreases downstream of the Withlacoochee River were still quite noticeable.

Overall Abundance - Temporal Variation

Not suprisingly, since chironomids were dominant, the temporal distribution of the total number of benthic

macroinvertebrate individuals resembles the same curve for dipterans (Figs. 80 and 83). Overall benthic abundance (standing crop) was not correlated with stage height ($r=-0.076$, P=NS). Unfortunately, missing data may obscure seasonal patterns since the total number of individuals was inversely correlated ($r=-.325$, $P<0.01$) with lost samplers (Fig. 83).

Taxa - Spatial Variation

The fewest taxa were found over the study period (Fig. 84) at Station 1 (95 taxa), while the total number of taxa was highest at Station 5 (165 taxa). There seemed to be a gradual increase in the number of taxa downstream, but with so much variability between stations, a clear relationship could not be established. Due to missing samples (Fig. 85), the number of taxa found, especially at Stations 1 and 3, was likely underestimated. The total taxa per station, using only months with no missing samplers (Fig. 86), suggests that the number of taxa at Station 3 should probably be about 20% higher, but that the relatively depauperate taxonomic composition at Station 1 was genuine.

A comparison of the mean number of taxa collected per station (Fig. 87) with Figure 86 indicates some notable differences, especially in the upper river. Although the average number of taxa collected at Stations 1 and 2 was the same (29 taxa), 23 more taxa were collected at Station 2 when considering only those months with no missing samplers. Though the average taxa collected at Stations 3 and 4 was also the same (34 taxa), 17 less taxa were collected at Station 4 during months in which there were no missing samplers. This suggests that although the same average number of taxa was found at the two station pairs (1 and 2; 3 and 4), recruitment from the benthic drift, or some other attribute of Hunter and Swift Creeks, may have contributed to the total taxa found at Stations 2 and 4. Invertebrate drift from Hunter Creek was probably responsible for increasing the number of taxa at Station 2 (see discussion of cluster analysis). Why a similar trend was not observed below Swift Creek is unknown.

The total number of taxa collected from the river per month (Fig. 88) was highest in the winter and lowest during September of both years. This may have been related to spring and fall insect emergence patterns (Boerger 1980; Thorp and Chesser 1983).

Diversity

The Shannon-Weaver diversity index ($\bar{d}$) was calculated for each station for each month and then the values averaged to emphasize longitudinal trends and seasonal differences. Although mean $\bar{d}$ values generally increased downstream (except for possible decreases between station pairs 1 and 2, 3 and 4, and 8 and 9) (Fig. 89) the actual data points plotted around the mean suggest

that this trend may be obscured by the inherent variablity associated with this measurement. Mean $\bar{d}$ calculated for sample dates (Fig. 90) did not exhibit any particular seasonal trends. The median and range of $\bar{d}$ per station (Fig. 91) show that the maximum and median curves are basically flat. However, the curve of minimum $\bar{d}$ values indicates that there were three stations where the diversity fell below 2.0: at Station 4 in December, 1982, and Station 9 in May, 1983, when large numbers of Rheotanytarsus sp. collected at these stations (approximately 8,000 and 9,000 individuals, respectively) drastically lowered the equitability and consequently $\bar{d}$; and at Station 10 in April, 1983, when Rheotanytarsus sp. again accounted for a depressed diversity by comprising over 90% of the individuals collected on that date.

The three abnormally low $\bar{d}$'s above are also evident in Figure 92, a plot of the median, maximum, and minimum diversities by month. The depressed values during April and May, 1983, at Stations 10 and 9, respectively, corresponded with the two highest mean stage heights recorded during the study. However, the low $\bar{d}$ noted at Station 4 in December, 1982, coincided with the lowest recorded water level, which suggests that these extreme increases of Rheotanytarsus sp. can occur regardless of season or stage height. Indeed, comparing Figure 92 with Figure 18 in the hydrological section, (stage height), indicates that macroinvertebrate diversity in the Suwannee River was independent of season or water level.

As an experimental approach to accentuate spatial differences, the total number of individuals and total taxa found for all samplings were pooled by station and then $\bar{d}$ calculated (Fig. 93). A general increase in this pooled $\bar{d}$ value between Station 1 and 11 is apparent, except for the two dramatic dips at Stations 4 and 9. As previously noted, two separate collections of abnormally high (8000 to 9000) numbers of Rheotanytarsus sp. were responsible for this. When these months of abnormally high collections of Rheotanytarsus sp. were omitted from the pooled $\bar{d}$ calculations, Stations 4 and 9 do not appear as divergent, although a decrease was still evident at Station 4 (Fig. 94). Figure 94 also shows a quite obvious increase of pooled diversity from the upper to lower river.

Numerical Analysis

Normal cluster analysis of species composition and abundance data indicated the presence of three distinct station groups at a level of 50% similarity (Fig. 95). Group A was a single station (#1) that was our most upstream station and also the "control" for the remaining stations. Group B consisted of Stations 2, 3, and 4 and were the stations that comprised the boundaries of Occidental Chemical Agricultural Products, (Oxy) discharges at Hunter Creek (#2) and Swift Creek (#4). Group C included the remaining stations, 5 - 11, which were the stations located well

downstream of the major Oxy discharge at Swift Creek as well as after the first major groundwater discharges from the springs between Stations 4 and 5.

A dendrogram of the results of an inverse cluster analysis of the top 50 taxa (Fig. 96) reveals five major groups. The invertebrates represented in Group I were found almost exclusively below Station 4 (Fig. 97) and reached their greatest abundance at Stations 9 - 11. The single animal that constituted Group II, the trichopteran Lype diversa, with few exceptions was most abundant at Stations 10 and particularly 11. The taxa in Groups III A and III B were found throughout the river. The organisms of Group III A, although found at all stations, were much less numerous than those of Group III B (Fig. 97). Additionally, the animals in Group III A were somewhat less abundant at Stations 1 - 4 whereas those of Group III B were more uniform in abundance throughout the river. The 4 most numerous organisms noted in our study (the dipterans Rheotanytarsus sp. and Tanytarsus sp., and the trichopterans Cheumatopsyche sp. and Chimarra sp.) were members of Group III B and accounted for nearly 50% of all the organisms collected. The organisms in Group IV were essentially restricted to Stations 1 and 2 and they were only infrequently observed below Station 4.

The results of a multiple discriminant analysis of temperature, dissolved oxygen, alkalinity, conductivity, pH, and turbidity (physical/chemical measurements we felt would most likely account for benthos distribution) indicated that 88.66% of among group variance could be explained by Discriminant Function I (DFI). The most important variables within DFI were alkalinity, conductivity, and pH. The addition of DFII increased the explained variance to 95.74%. Temperature and dissolved oxygen were the parameters that contributed most to among group separation in DFII.

The distribution of the station groups in discriminant space (Fig. 98) shows a fairly distinct separation of the four upstream stations from the remaining downstream stations. This separation corresponds fairly well with the station clusters based on benthic invertebrate data (Fig. 95). The notable exception was that Stations 2, 3, and 4 overlap Station 1 in the discriminant analysis of physical-chemical parameters while the classification analysis of invertebrate taxa indicated Station 1 was very much different from all other stations. Although other physical-chemical parameters not included in the discriminant analysis might account for the difference another factor may have been responsible.

Since a normal analysis of the top 50 taxa indicated the presence of 2 station groups: 1 - 4 and 5 - 11 (Fig. 99), the probable explanation for the disparity in the station clusters may lie with the distribution and abundance of rare species collected over the course of the study. For example a comparison of the taxa we collected at Station 2 but not at Stations 1, 3,

or 4 with those collected by Breedlove (unpublished data 1982) and EPA (unpublished data 1982) in Hunter Creek (Table 26) indicated the presence in Hunter Creek, either in the sediment or the drift, of animals found only at Station 2. These data suggest that macroinvertebrates from Hunter Creek as well as those normally present in the main channel of the Suwannee may have colonized our samplers. This then might account for the larger number of taxa found at Station 2 over those at Station 1. Vannote (personal communication) has noted similiar recruitment patterns from tributaries within 500m downstream of the confluence of two streams.

The total number of taxa we collected generally increased downstream throughout the river (particularly between Stations 1 and 2, and 4 and 5) (Fig. 84). This observation corresponded with the increased number of spring runs and other tributaries entering the Suwannee River downstream of Station 1. Between Stations 1 and 5, 32 creeks, 5 large springs, as well as the Alapaha River, enter the Suwannee. As has been shown earlier, the springs and groundwater inputs between Stations 4 and 5 also serve to raise the pH and alkalinity considerably over that observed at the four upstream stations (see Water Chemistry Section). From Stations 5 to 11, 9 major creeks, 32 major springs, and 18 minor springs, as well as the Withlacoochee and Santa Fe Rivers, enter the Suwannee. Despite the numerous spring inputs in this part of the river, however, the pH and alkalinity increase only slightly over the values recorded at Station 5. Below Station 5 then, the river water is apparently well buffered.

These data suggest that recruitment of invertebrates (at least the rarer species) from tributaries may play an important role in the colonization dynamics of the macroinvertebrate communities of the Suwannee River. However, the depressed pH and alkalinity of the river water at the four upstream stations most likely account for the observed station groupings based on species composition and abundance despite the effect that recruitment from tributaries may have had by increasing the number of taxa on a downstream gradient. It seems likely that even if large numbers of organisms were drifting into the Suwannee, from the tributaries and springs between Stations 1 and 4, that the pH and alkalinity regime there would have been inhospitable enough to reduce the number of taxa compared with that found below Station 4.

Benthos - Dischargers

To determine any effects major point source dischargers might have had on the macroinvertebrate communities that we collected, we examined some of the diversity and abundance measurements at three station pairs: Stations 1 and 2 (Oxy's discharge at Hunter Creek); Stations 3 and 4 (Oxy's discharge at Swift Creek); and Stations 5 and 6 (Withlacoochee River - numerous small sewage treatment plants and several major

discharges from Georgia). These data are summarized in the following table and are based on information discussed in more detail earlier in the text:

Macroinvertebrate Measurement	Stations		
abundance	1<2	3<4	5>6
total taxa	1<2	3>4	5>6
mean taxa	1=2	3=4	5>6
mean $\bar{d}$	1>2*	3>4	5<6*
median $\bar{d}$	1>2	3>4*	5>6*
pooled $\bar{d}$ (w/o Rheotanytarsus)	1<2	3>4	5<6*

*The difference between these two values was very slight.

These data suggest that any effect the discharge at Hunter Creek may have had on the invertebrate communities was slight. The parameters used in the preceding table show that the abundance of macroinvertebrates was greater at Station 2 than at Station 1 and show no clear diversity trend. As noted earlier, this was likely the result of additional organisms drifting into the Suwannee from Hunter Creek.

The data from Stations 3 and 4 would seem to suggest a decrease in diversity measurements between the stations. Macroinvertebrate abundance was higher at Station 4 than at Station 3. The dip in the mean $\bar{d}$ and pooled $\bar{d}$ noted at Station 4 (Figs. 89, 94) may be the result of the Swift Creek discharge. However, the difference between these values at Station 3 and Station 4 is small and the absolute values themselves are quite high. It should be noted though, that the pooled $\bar{d}$ at Station 4 was still a full unit lower than the value at Station 11, while it was only slightly higher than the value recorded for Station 1 (Fig. 94). These data plus the water chemistry data may suggest that effects we might have noted at Station 4 may have been masked by the substantial pH and alkalinity effects in that part of the river.

The data for Stations 5 and 6 indicate that the Withlacoochee River may have had a negative effect on the macroinvertebrate communities we sampled. Both species richness (number of taxa) and abundance were greater at Station 5 than Station 6. The various $\bar{d}$ measurements, however, were not vastly different between the two stations. Since the pH and alkalinity (particularly) have stabilized at relatively high values (i.e., high enough to no longer stress macroinvertebrate communities) at this point in the river, any stress evident in the benthos communities could be attributed to constituents in the discharge of the Withlacoochee River.

The cluster analyses of the benthos data identified only one station pair where an effect was noticeable. In an analyses of 217 species (Fig. 95), Station 1 was quite dissimilar to the remaining stations. Since an analysis of the top 50 species (Fig. 99) clustered Station 1 with Stations 2, 3, and 4 we have speculated that we collected organisms that drifted into the

Suwannee from Hunter Creek thus accounting for the difference between the two cluster analyses.

Historical Studies of Suwannee Macroinvertebrates

Five previous studies or collections of benthic macroinvertebrates have been performed in the Suwannee River between 1952 and the present. However, there are difficulties in attempting to make direct comparisons between these data due to sampling inconsistancies and changes in the taxonomic status of certain organisms. A comparative species list indicating the presence/absence of particular organisms collected by each study is presented in Appendix C. This list should provide a complete inventory of the macroinvertebrate taxa which have been found in the river (including some tributary species).

U.S. EPA

In August of 1972 and September of 1973, EPA collected macroinvertebrates in the Suwannee River at Manatee Springs (unpublished data, EPA sample numbers 72-1501 through 72-1516 and 73-0826 through 73-0829). This sampling was performed as an environmental surveillance project to detect subtle and long-term deterioration of aquatic ecosystems by studying biota at the mouths of major river systems. A minimum of eight Ponar grab samples were collected per year, along with those organisms colonizing four rock baskets containing limestone rocks. Additionally, qualitative sampling was performed utilizing dip nets. The number of taxa collected during this study was considerably lower than the number of taxa found by the DER District and by the Biology Section. This could be attributed to the low sampling frequency (twice in two years). Hoke Howard (who was involved in this study) concluded that the Suwannee River at Manatee Springs was a fairly productive area, with good macroinvertebrate diversity (personal communication).

Federal Water Pollution Control Administration

In 1966 and 1967, the Federal Water Pollution Control Administration surveyed 63 stations in the Suwannee River Basin, including qualitative collections of benthic organisms. The majority of stations sampled were located in Georgia and in tributaries of the Suwannee. Consequently, only data from 5 stations in the lower Suwannee are available for comparative purposes. Of these, 3 were considered "balanced" benthic communities by the investigators while 2 were deemed in "questionable" condition. This questionable rating was assigned mainly due to the sparse representation of pollution-sensitive organisms in the samples, but the authors noted that sampling these stations was difficult due to high flow and velocity conditions. Each station was sampled only once, so only a limited number of species was found (Appendix C).

Florida State Board of Health

The Florida State Board of Health routinely collected qualitative benthic macroinvertebrate data from the Suwannee River (unpublished records, Florida State Archives). We obtained species lists from 1952 and 1953 which are surprisingly similar to samples collected by the Biology Section 30 years later. Although sampling techniques are not directly comparable, it appears that the most common taxa found in 1952 are still present in 1982. This speaks well for the stability of the aquatic ecosystem in the Suwannee. J. R. Carver Jr. and W. M. Beck Jr. of the F.S.B.H. conducted a Chemical and Biological survey of the Suwannee River in 1965 (FSBH 1965). They note that the river was found to be healthy on the basis of the biotic index, a quantification technique developed earlier by Beck (1954).

Florida Department of Environmental Regulation

As part of the Permanent Network System of monitoring stations, DER District Biologists sampled four Suwannee River stations for macroinvertebrates from 1973 to 1978 (Ross and Jones 1979). Sampling techniques included the use of Hester-Dendy artificial substrate samplers, Eckman or Ponar dredges, and qualitative sampling with dip nets. There is generally good agreement between taxa found by the District and by the Biology Section. The differences that exist can be attributed to the fact that the Biology Section did not sample every available habitat with dip nets. Results from these sampling efforts are summarized in Ross and Jones (1979). Macroinvertebrates diversity was generally high and Florida index values (a variation of Beck's biotic index) were acceptable at the station near White Springs. The benthos at this station exhibited an unexplained but significant improvement in diversity during the sampling period. At the sampling stations near Branford and Old Town, macroinvertebrate diversities calculated for natural substrate samples were notably variable, primarily due to changing substrate conditions caused by variable flow and bottom scouring. Hester-Dendy samplers produced the most consistent results, and indicated that the diversity and Florida index values were excellent. Benthic diversities at the Luraville station, however, exhibited a significant downward trend. No explanation for this was given. The authors concluded that the Suwannee River appears to have very good water quality throughout its length in Florida as reflected by the biota.

Environmental Services and Permitting

As part of an environmental impact study prepared for the U.S. Army Corps of Engineers, Environmental Services and Permitting (ESP), a private Florida consultant, conducted

macroinvertebrate sampling of the upper Suwannee and selected tributaries during 1981-82 (ESP 1984). They utilized Hester-Dendy samplers and Ponar dredges for quantitative sampling and dip nets etc. for qualitative sampling. ESP also collected drift net samplers. They sampled each of their stations 2 to 3 times during the study. Comparing ESP's Hester-Dendy results with the Biology Section's indicates some consistent differences. ESP consistantly collected fewer taxa as well as fewer individuals than did the Biology Section, and their diversity values were generally lower. There were also major differences in the macroinvertebrate taxa dominating the samples. This was probably due to differences in sampler placement. ESP suspended their Hester-Dendys one foot below the surface, while the Biology Section mounted the Hester-Dendys on concrete blocks which were then placed approximately one to two meters deep (depending on water level fluctuations). It is reasonable to assume that different types and quantities of organisms would colonize these samplers due to their relative location in different microhabitats.

It is difficult to compare the species found by the two studies, since the data from ESP lumped all tributary, pond, and river species into one list. The Biology Section sampled only Suwannee River Stations. ESP also concludes that the water quality in the Suwannee was generally good, based on the macro-invertebrate community parameters (diversity and equitability).

Conclusions

1) Our data suggest that low pH and low alkalinity were the abiotic factors that limited the number of taxa we observed in the upper Suwannee.
2) Recruitment of macroinvertebrates from tributaries appears to play an important role in enriching the taxonomic composition of the Suwannee, especially in the upper river.
3) Discharges from springs beginning after Station 2 increase the pH and alkalinity, producing conditions more hospitable to a greater number of taxa.
4) Dipterans were the most abundant invertebrate group at all stations, followed by the Trichoptera and Ephemeroptera.
5) Seasonal variation of the benthic macroinvertebrate population was generally bi-modal with summer and winter peaks.
6) Diversity ($\bar{d}$) generally increased downstream.
7) The size of the benthic standing crop was independent of stage height.
8) Normal analysis indicated 3 distinct station groups consisting of Station 1; Stations 2 - 4; and Stations 5 - 11. Discriminant analysis of several physical-chemical parameters indicated that alkalinity, conductivity, and pH account for most of the among group variance.
9) Inverse analysis separated 4 species groups: those taxa found in the upper river, taxa restricted to the extreme lower

river, taxa that were very abundant and found throughout the entire river, and taxa that were found throughout the river but were much less numerous than those in the previous group.

10) Impacts on the Suwannee River due to tributary discharges are believed to have been partially masked by pH and alkalinity effects as well as by the introduction of organisms drifting out of tributaries to the Suwannee. The most notable effects which were observed which may have been due to point source discharges through tributary streams were: a) taxa and numbers of organisms increased downstream of Hunter Creek, b) taxa decreased below Swift Creek and macroinvertebrate abundance increased, whereas the various measures of diversity uniformly showed small decreases, and c) both taxa and numbers of organisms decreased below the Withlacoochee River.

11) A comparison of our macroinvertebrate data with that of other investigations of the river indicates no major differences in taxonomic composition that could not be accounted for by either sampling methodologies or taxonomic difficulties.

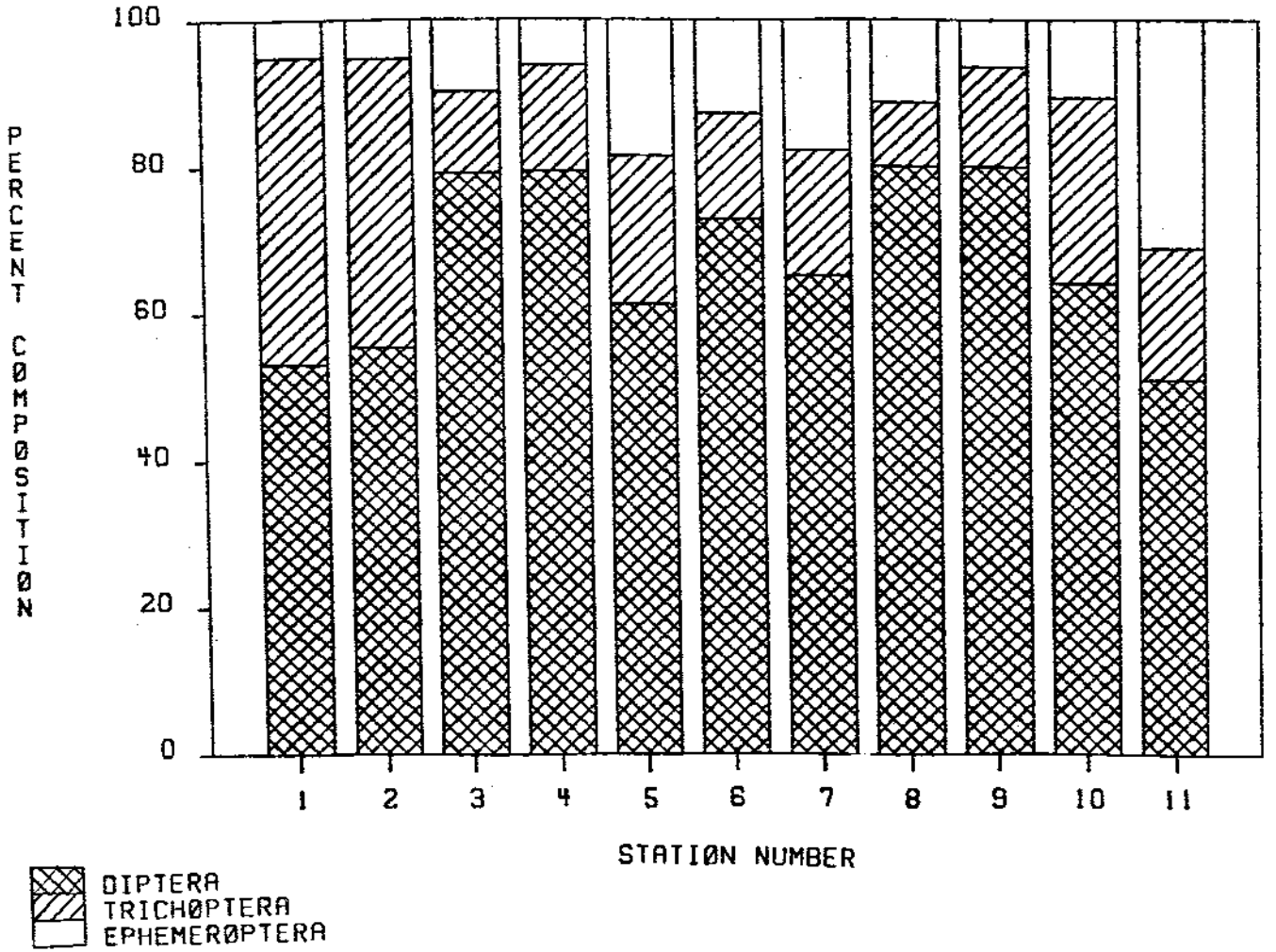


FIGURE 77. PERCENT COMPOSITION OF THE TOP THREE ORDERS BY STATION.

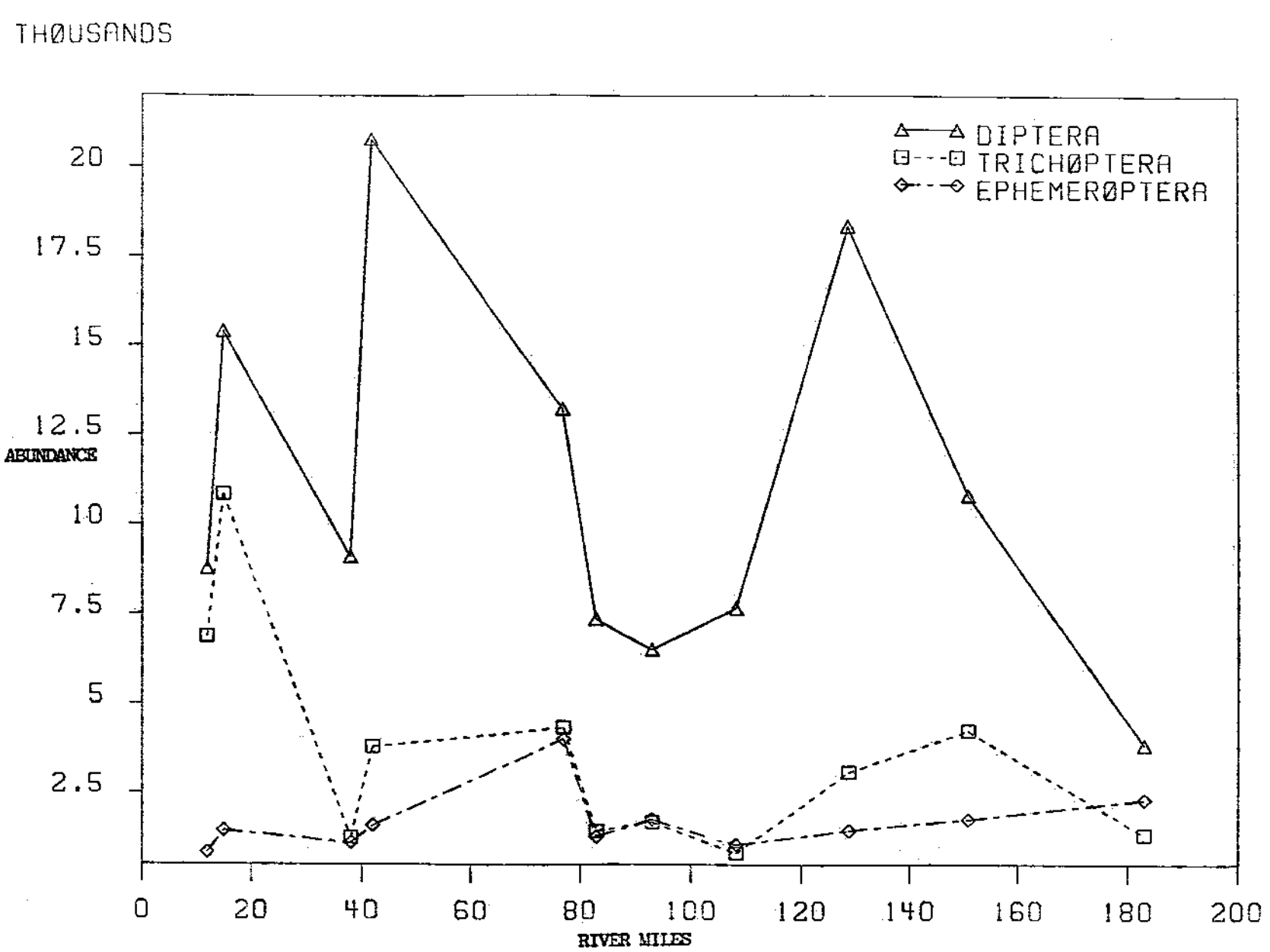


FIGURE 78. ABUNDANCE OF TOP THREE ORDERS BY STATION.

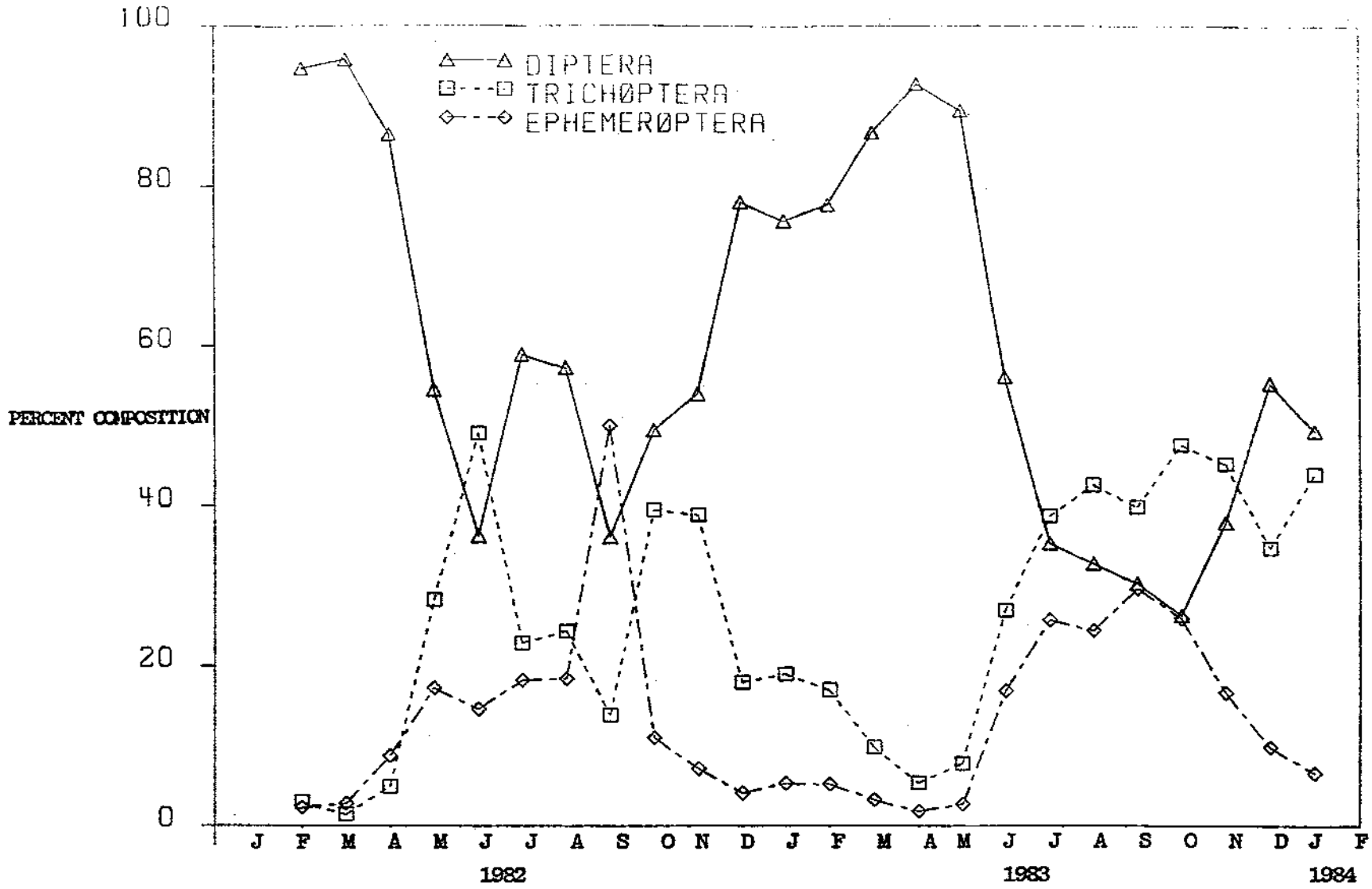


FIGURE 79. PERCENT COMPOSITION OF THE TOP THREE ORDERS BY DATE.

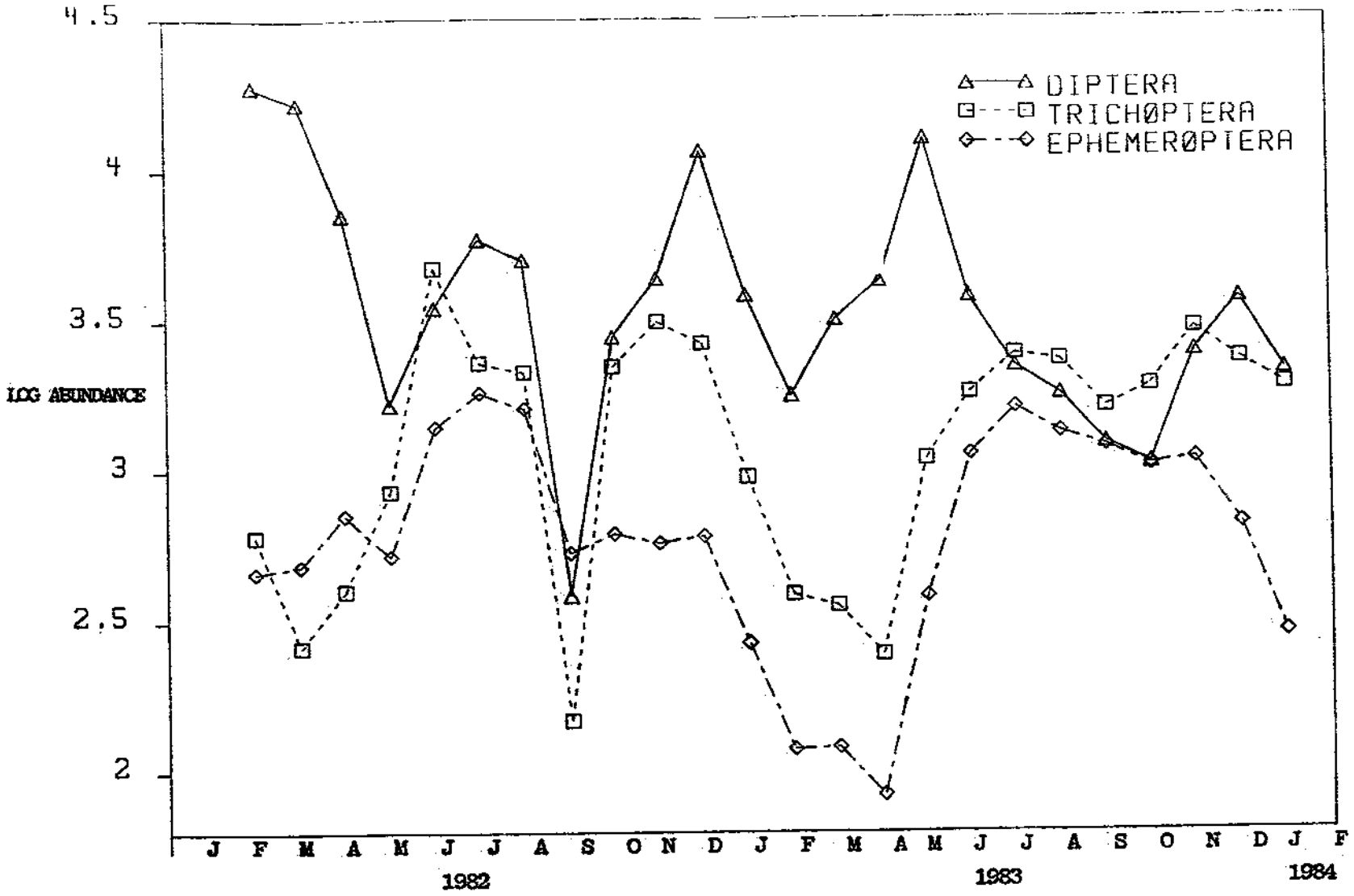


FIGURE 80. ABUNDANCE OF TOP THREE ORDERS BY DATE.

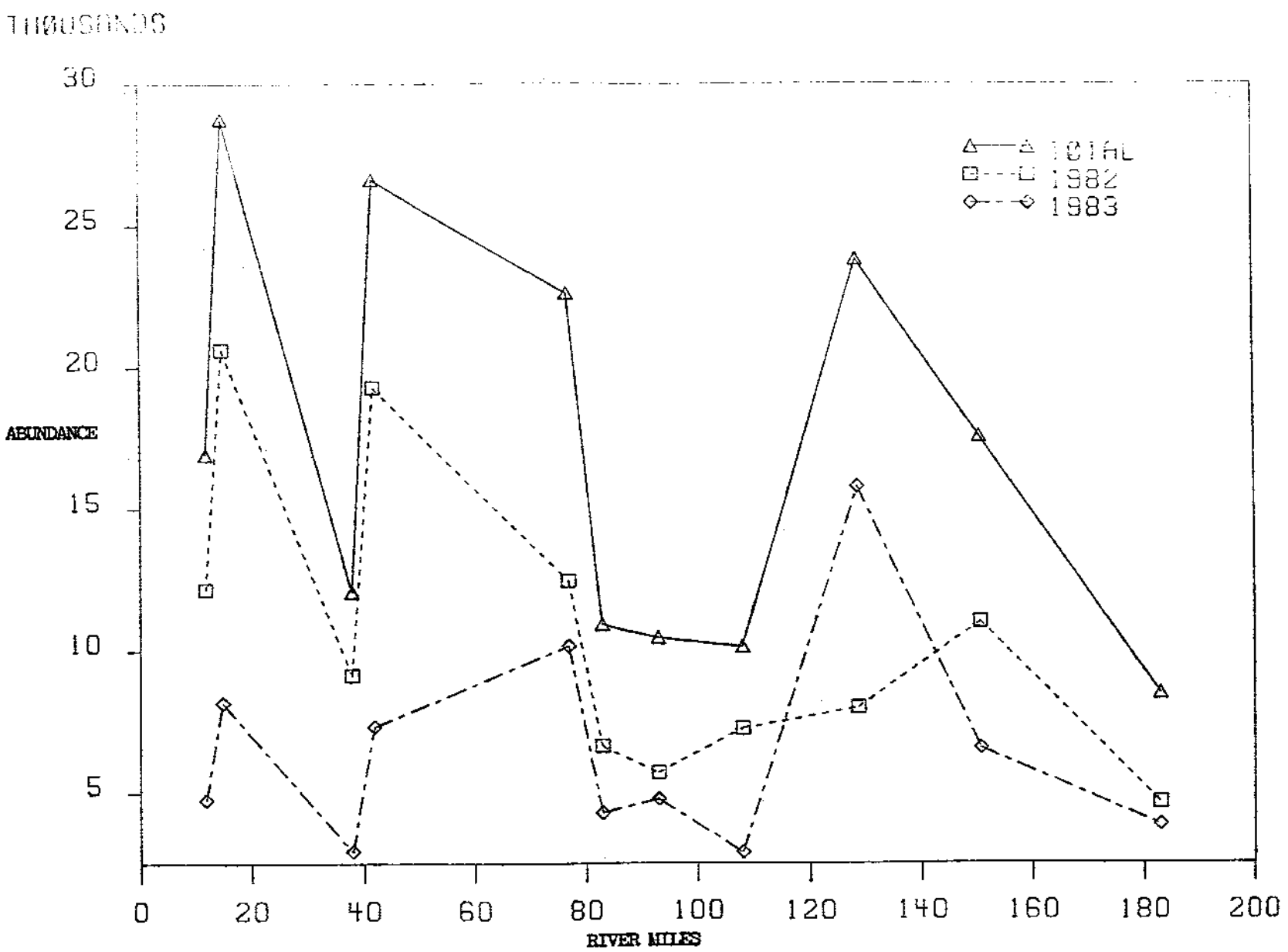


FIGURE 81. MACROINVERTEBRATE ABUNDANCE BY STATION.

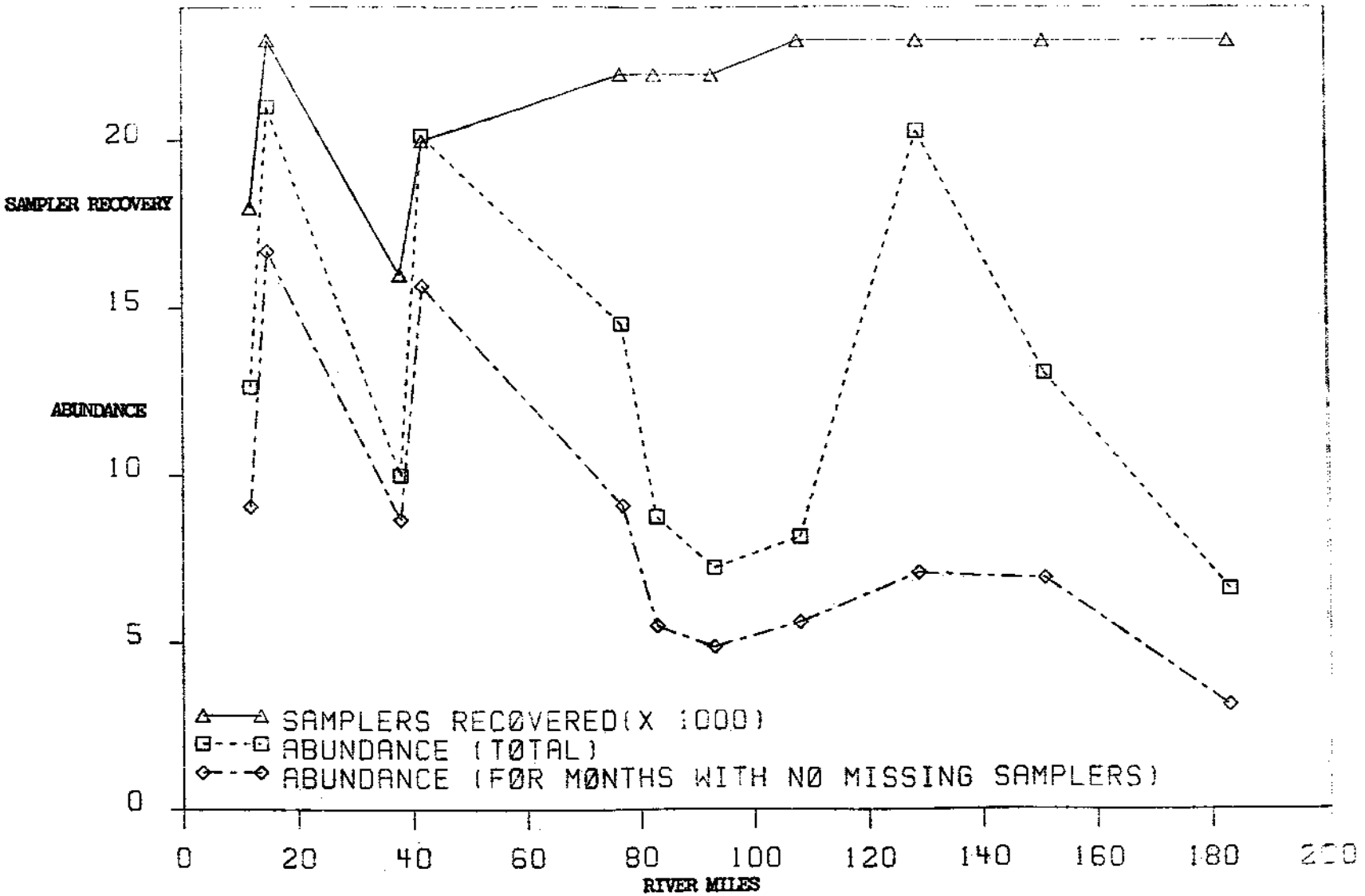


FIGURE 82. MACROINVERTEBRATE ABUNDANCE COMPARED TO SAMPLER RECOVERY BY STATION.

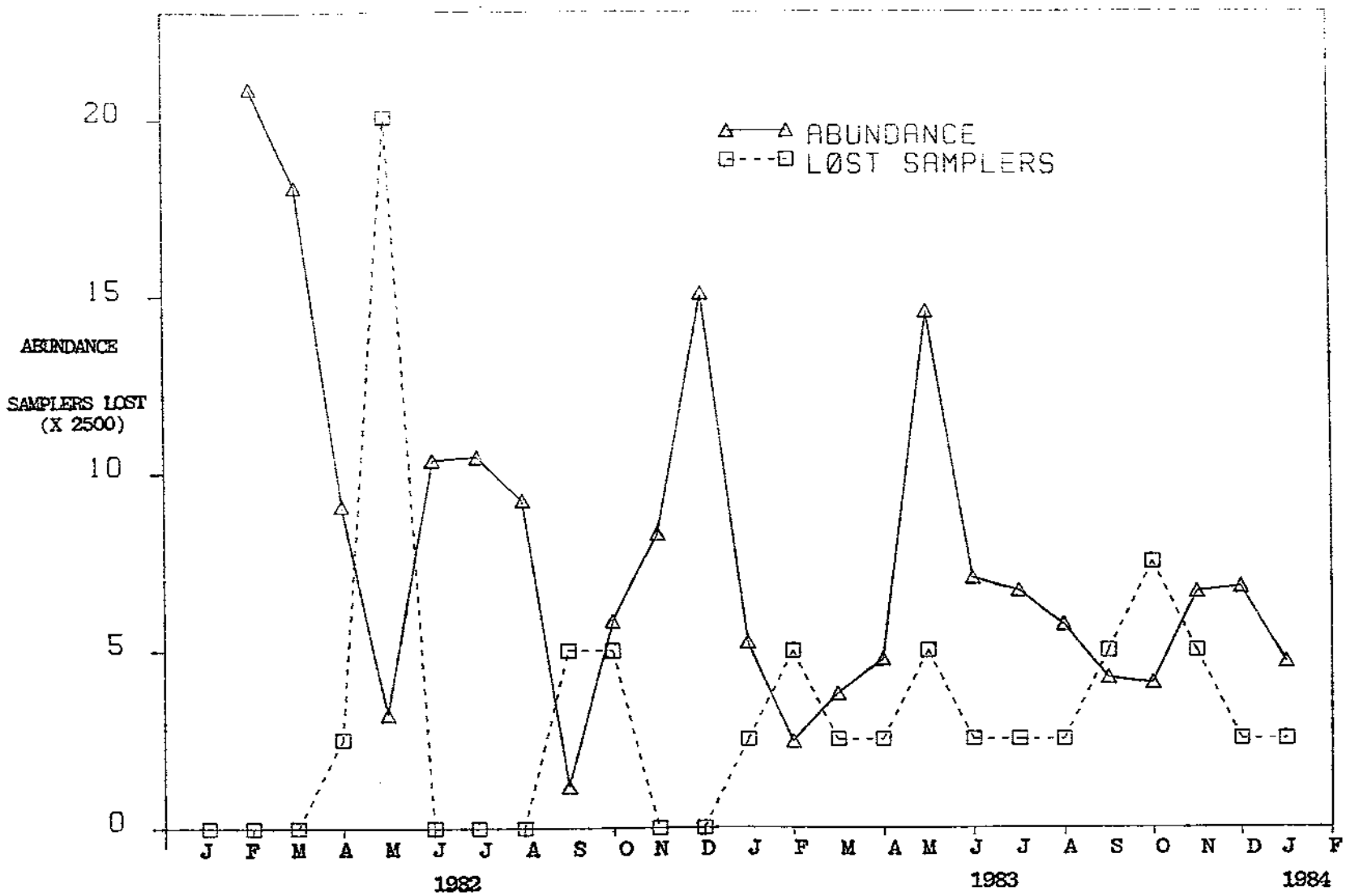


FIGURE 83. MACROINVERTEBRATE ABUNDANCE COMPARED TO SAMPLER RECOVERY BY DATE.

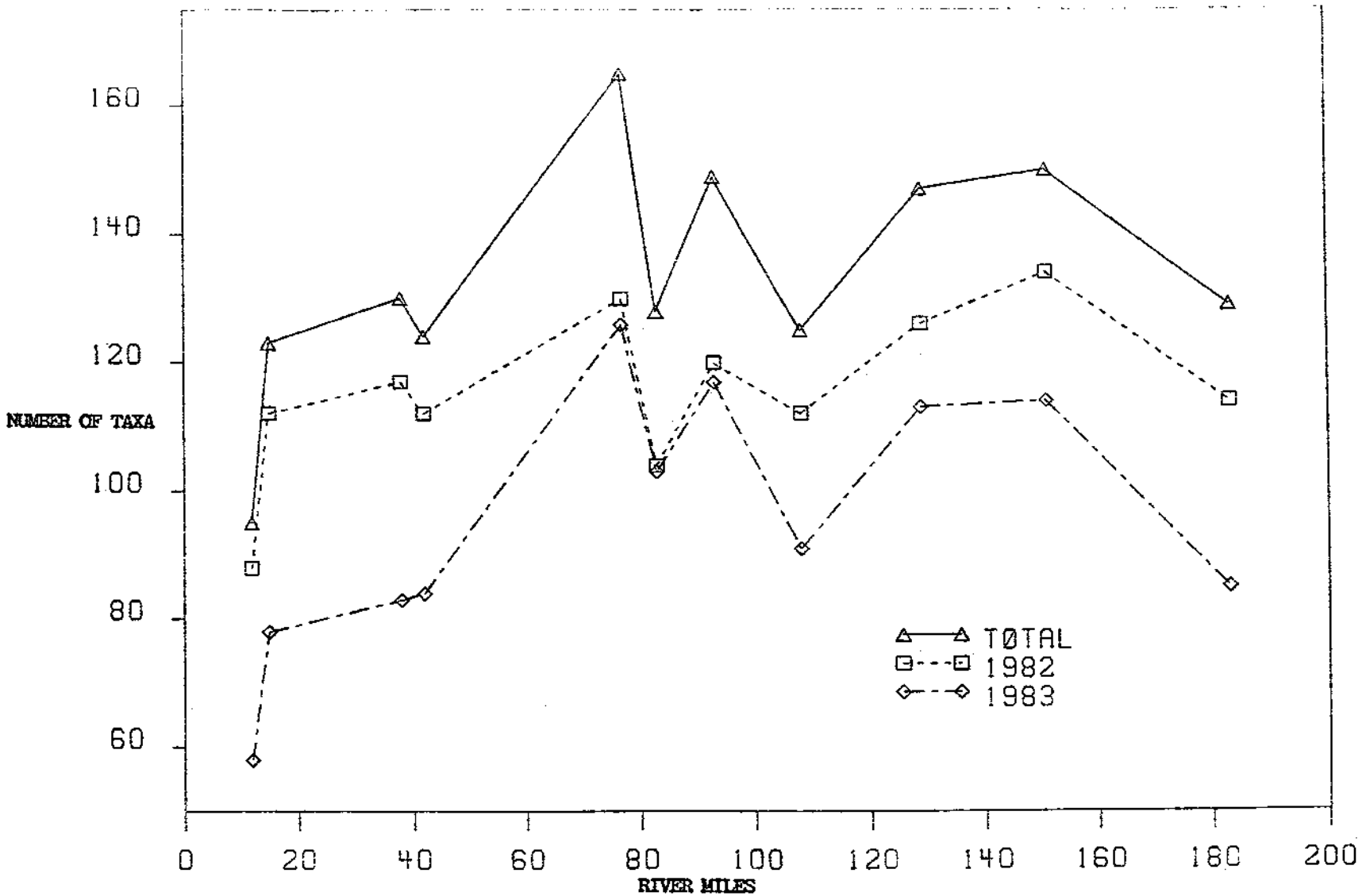


FIGURE 84. MACROINVERTEBRATE TAXA BY STATION.

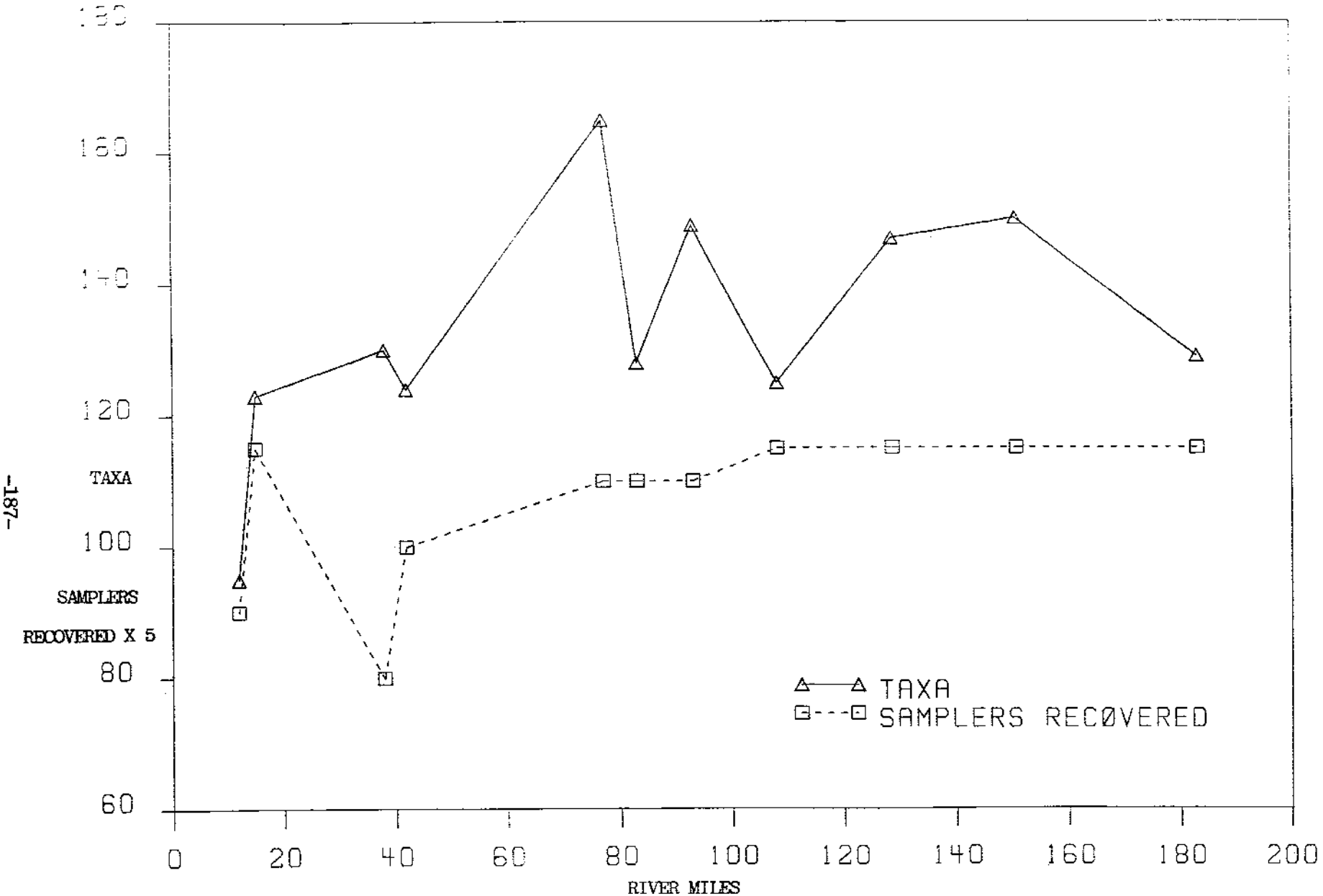


FIGURE 85. TOTAL MACROINVERTEBRATE TAXA COLLECTED COMPARED TO SAMPLER RECOVERY BY STATION.

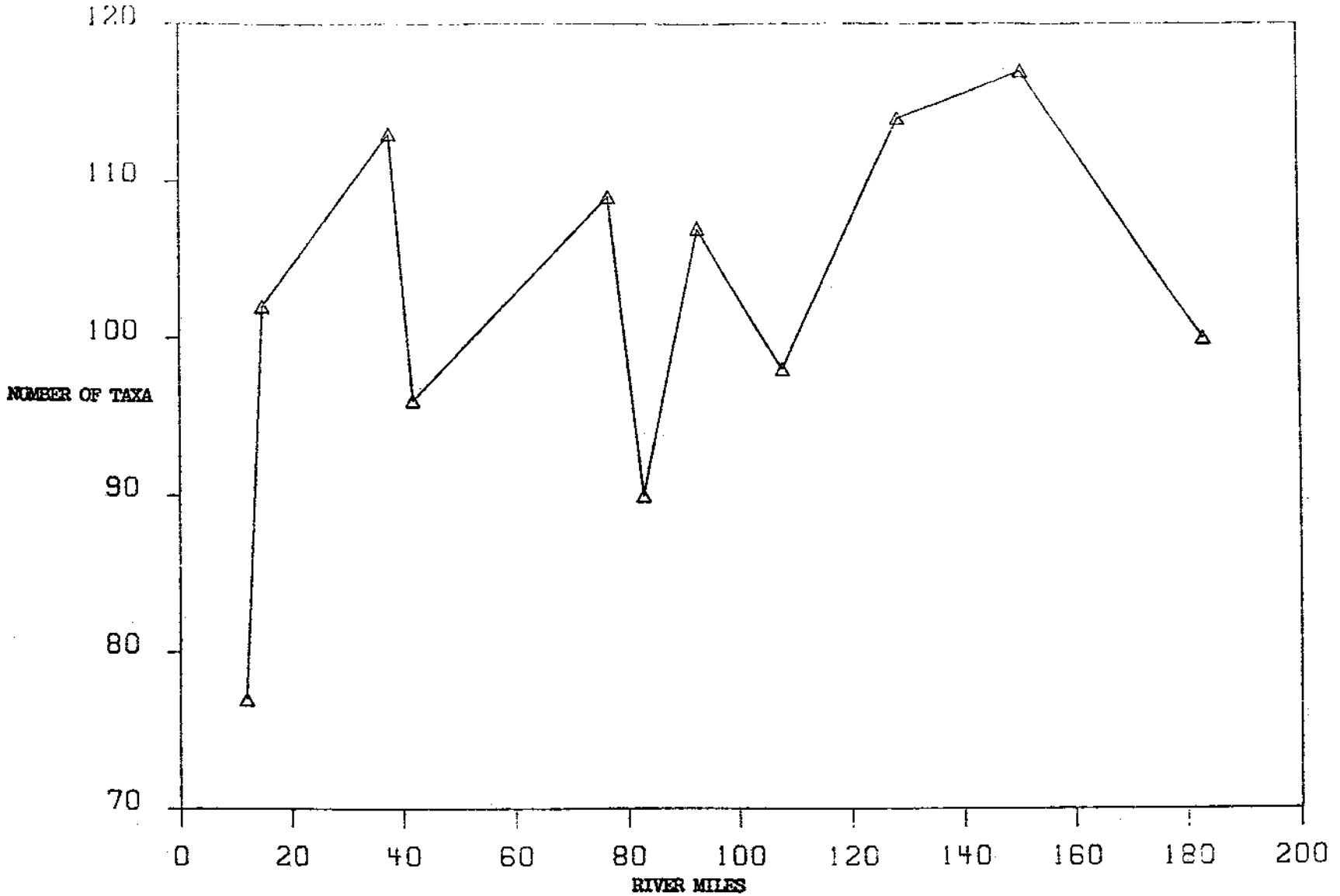


FIGURE 86. TOTAL MACROINVERTEBRATE TAXA COLLECTED BY STATION, SUMMING MONTHS WITH NO MISSING SAMPLERS.

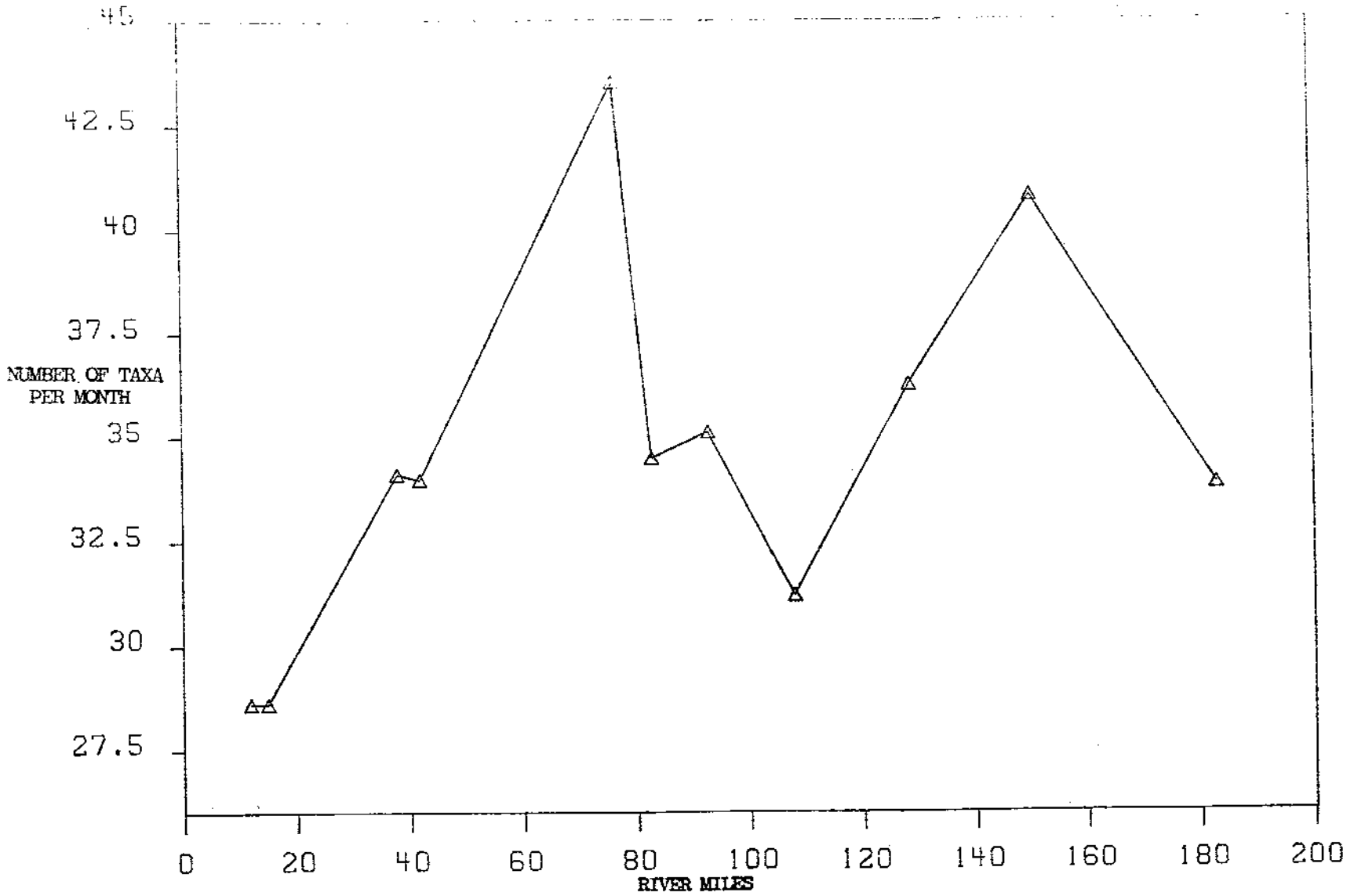


FIGURE 87. MEAN MACROINVERTEBRATE TAXA BY STATION.

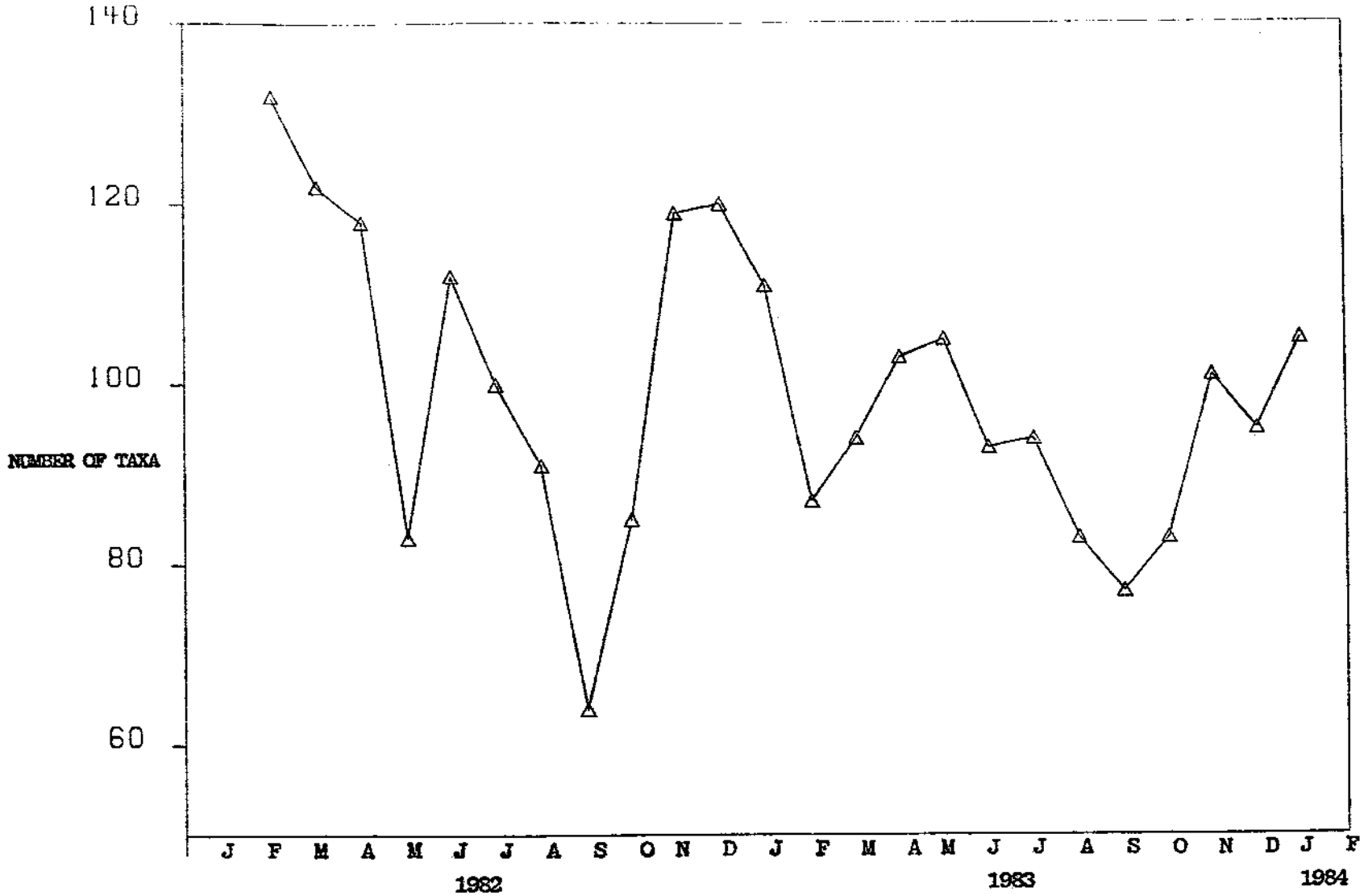


FIGURE 88. TOTAL MACROINVERTEBRATE TAXA COLLECTED BY DATE.

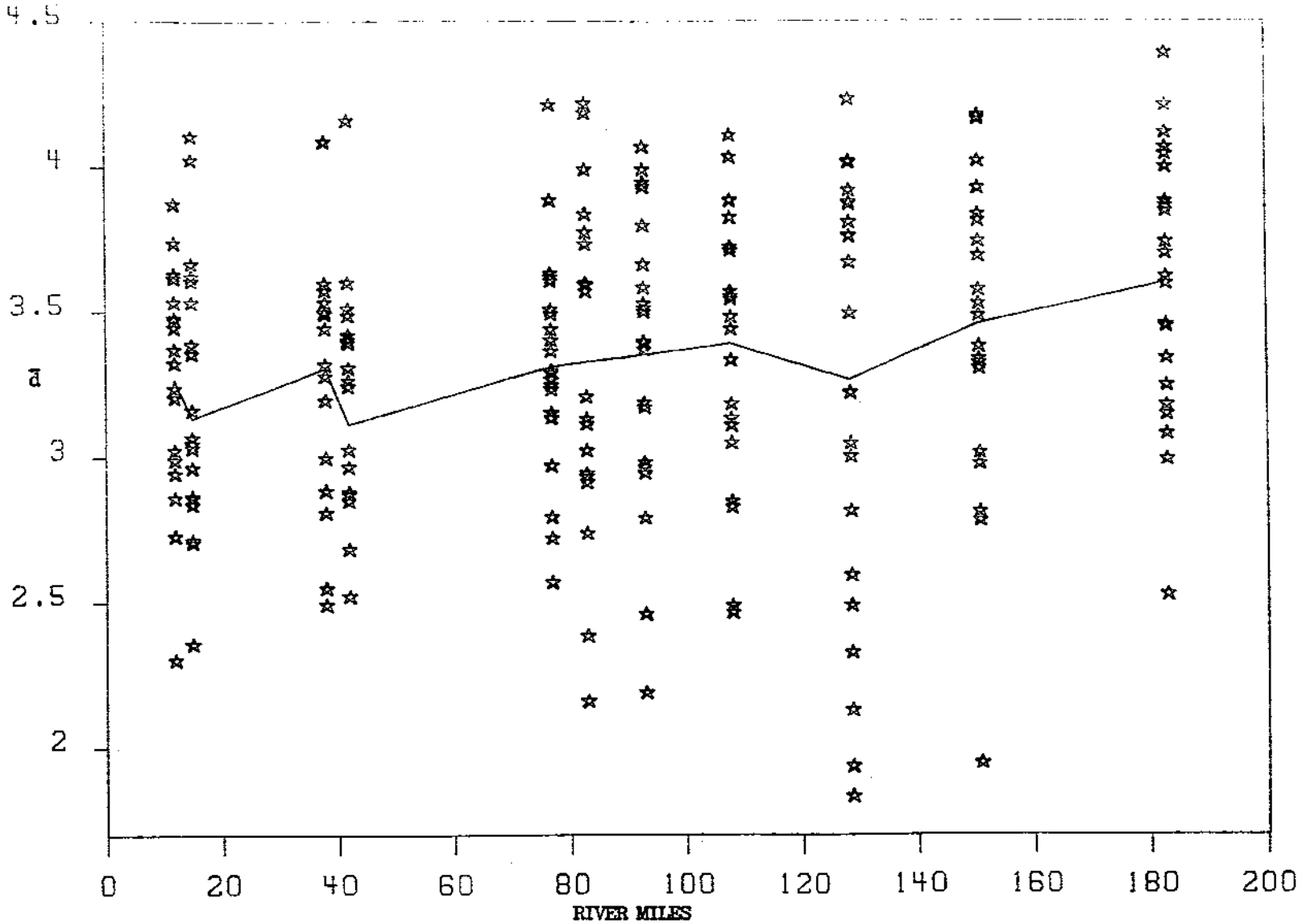


FIGURE 89. ACTUAL ā VALUES CALCULATED FOR EACH SAMPLE DATE AND STATION. LINE INDICATES MEAN ā.

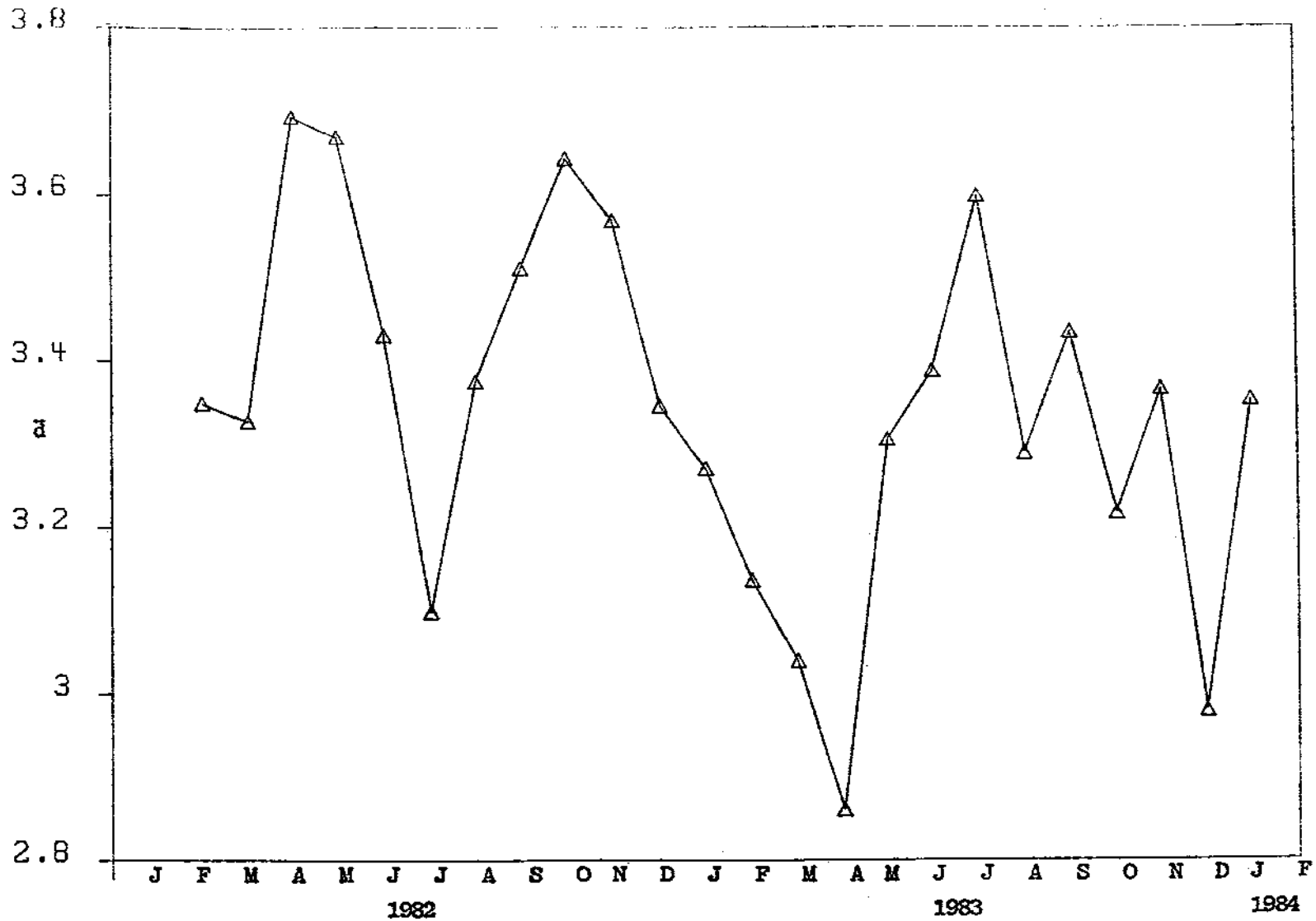


FIGURE 90. MEAN $\bar{d}$ BY DATE.

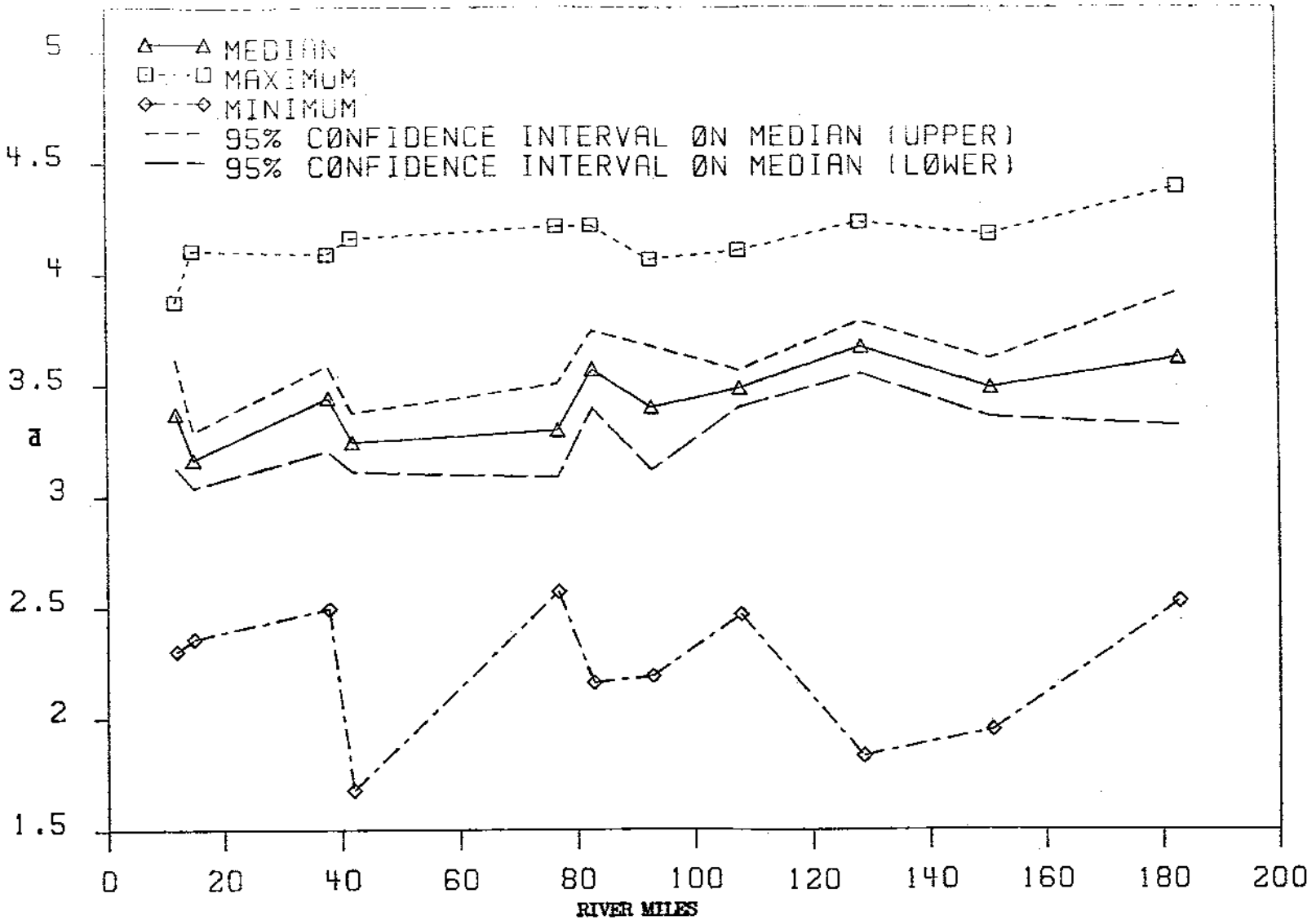


FIGURE 91. MEDIAN $\bar{d}$ WITH 95% CONFIDENCE INTERVALS, MAXIMUM $\bar{d}$, AND MINIMUM $\bar{d}$ BY STATION.

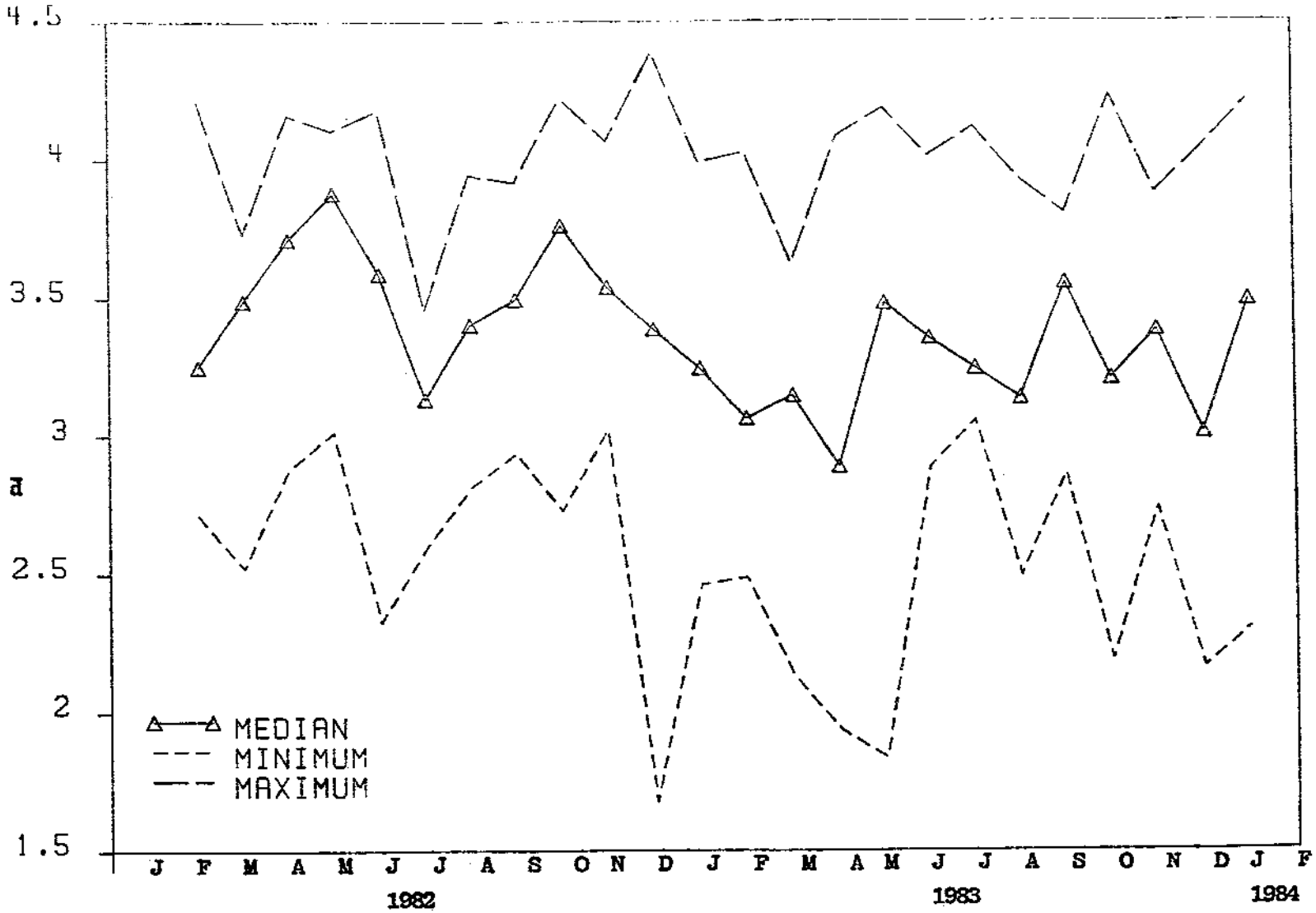


FIGURE 92. MEDIAN $\bar{d}$, MAXIMUM $\bar{d}$, AND MINIMUM $\bar{d}$ BY DATE.

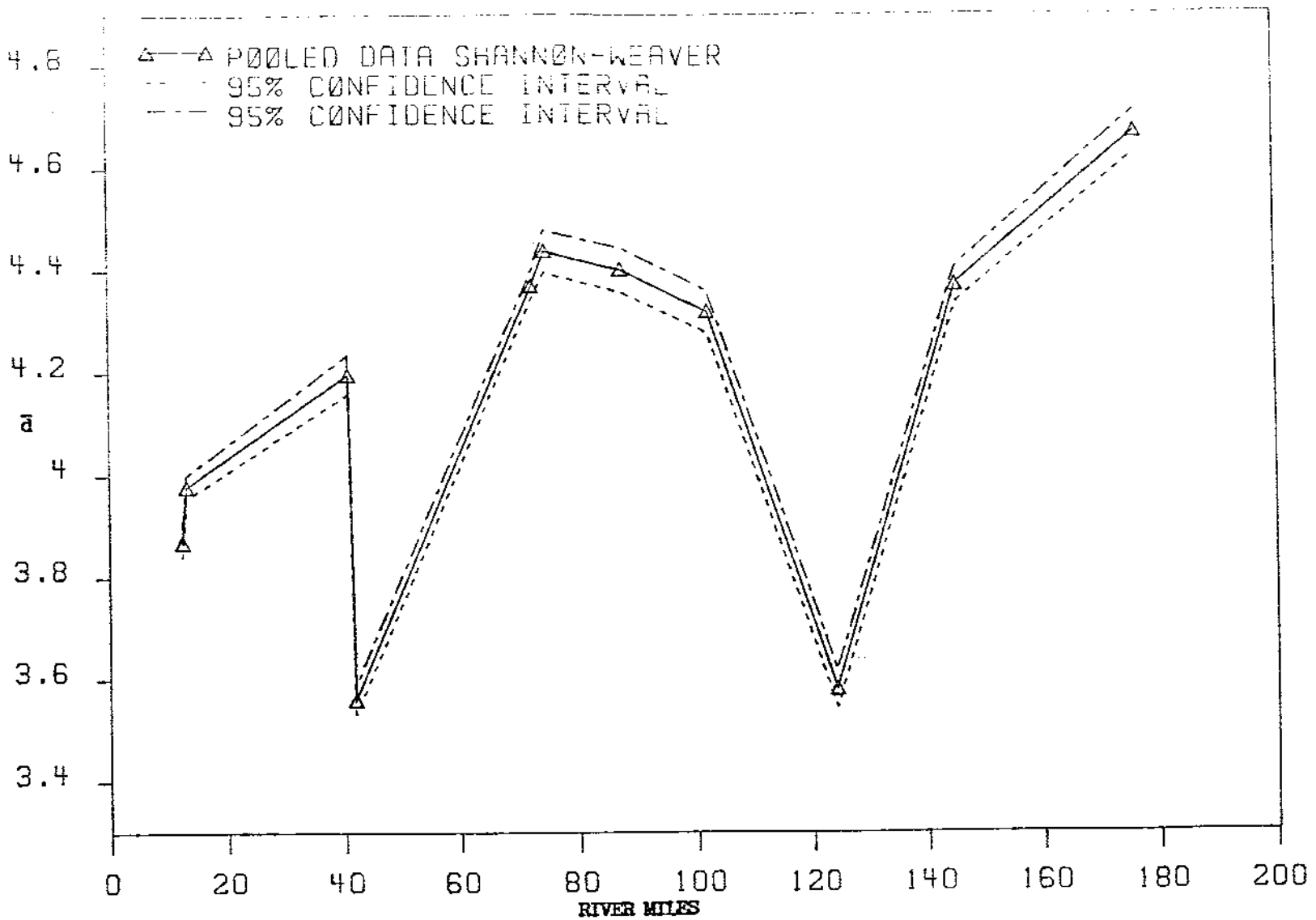


FIGURE 93. POOLED $\bar{d}$ WITH 95% CONFIDENCE INTERVALS BY STATION.

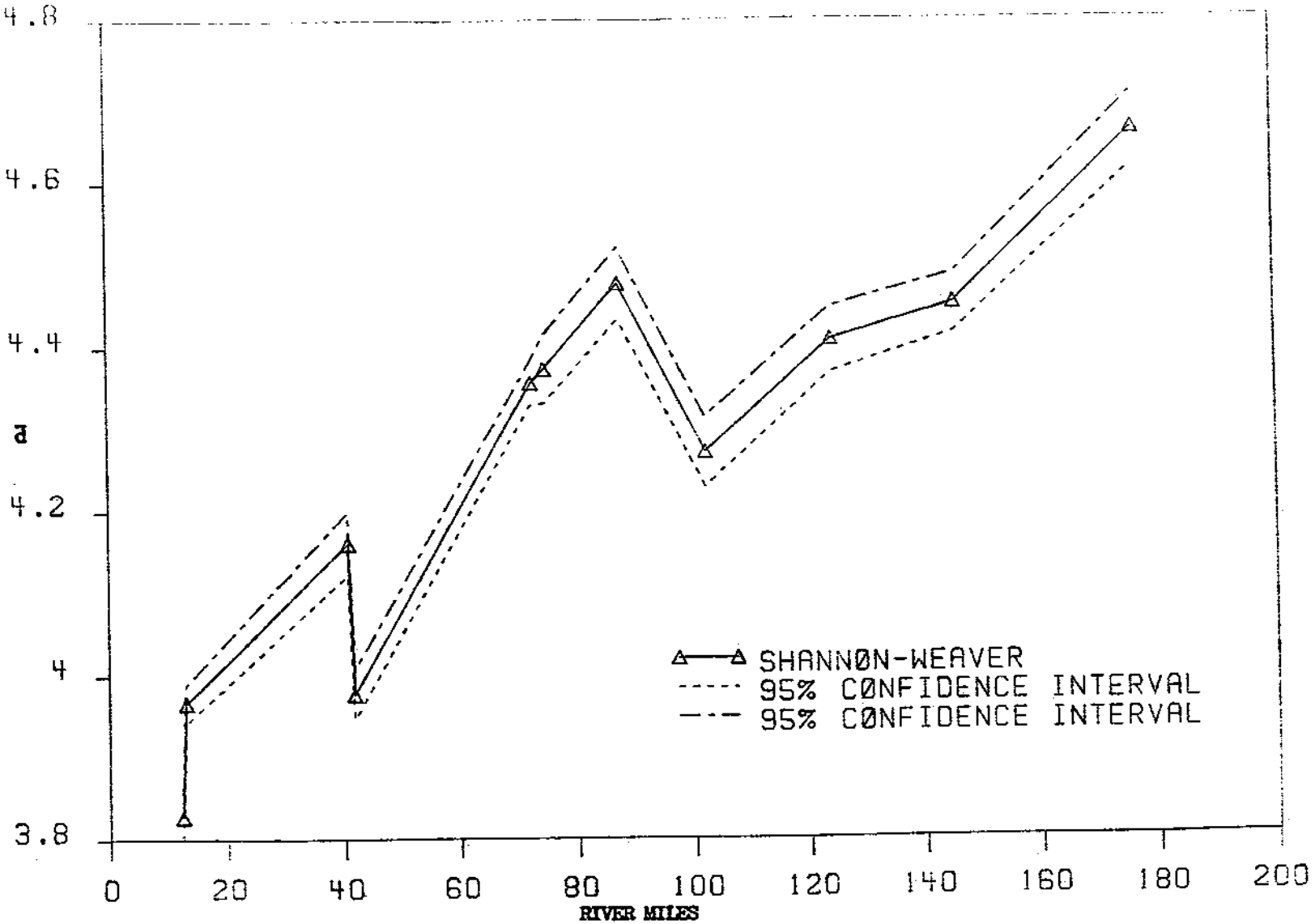


FIGURE 94. POOLED $\bar{d}$ WITH 95% CONFIDENCE INTERVALS BY STATION; DECEMBER, 1982 AND MAY, 1983 (HIGH OCCURRANCES OF Rheotanytarsus sp.) WERE OMITTED FROM CALCULATIONS.

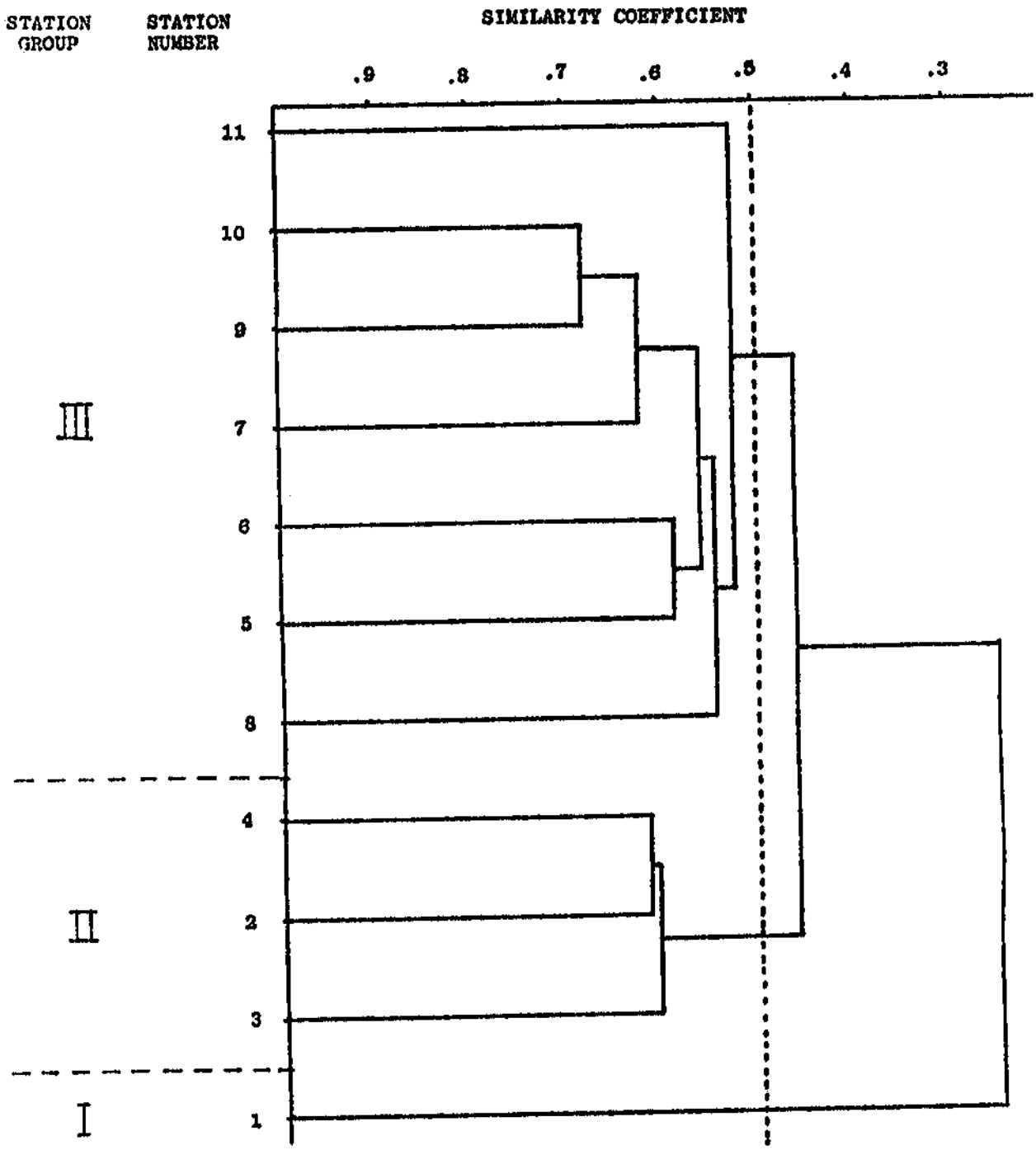


FIGURE 95. NORMAL ANALYSIS (STATION CLUSTERS) OF BENTHIC TAXA OCCURRING AT LEAST TWICE.

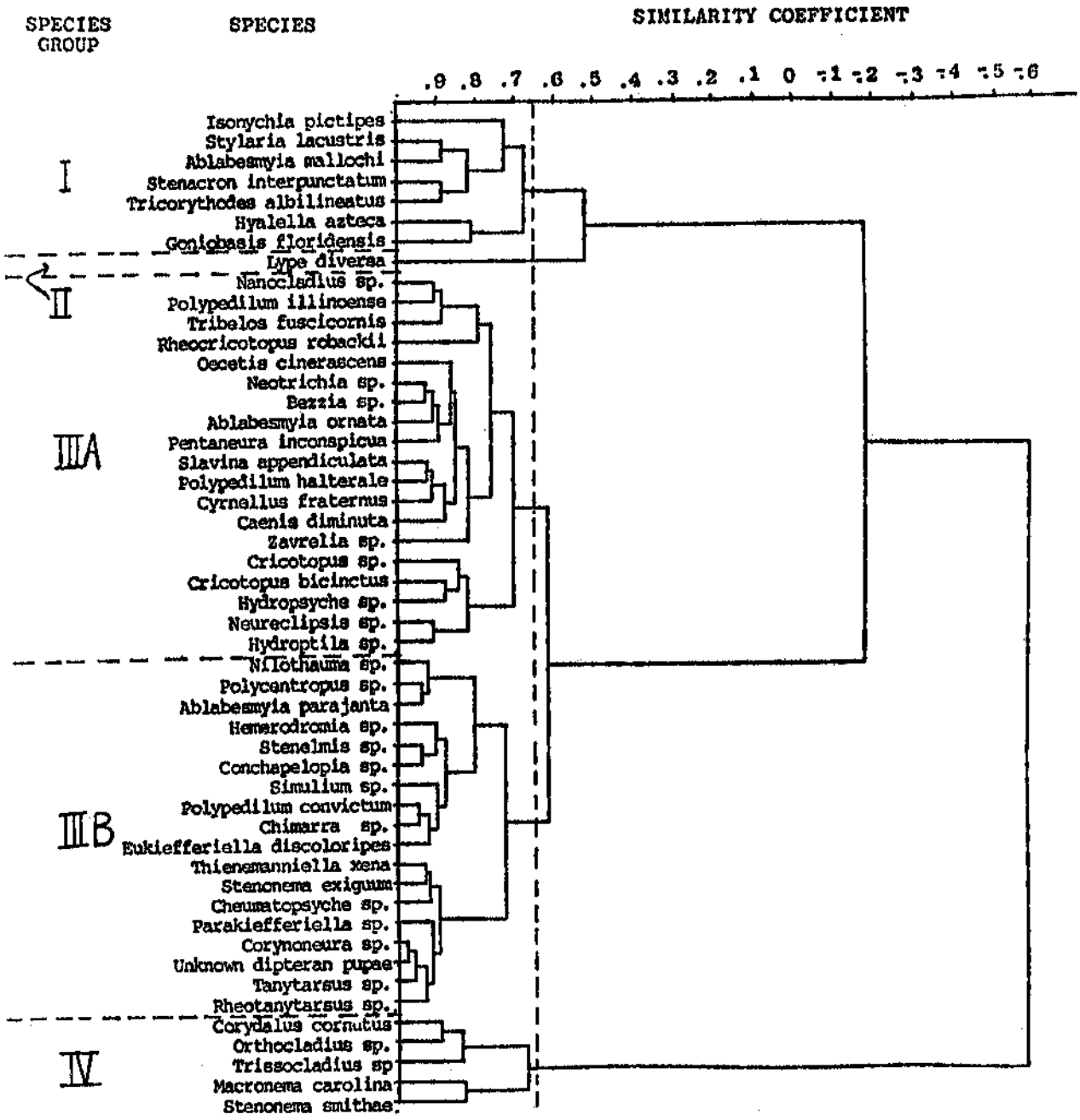


FIGURE 96. INVERSE ANALYSIS (SPECIES CLUSTERS) OF TOP 50 BENTHIC TAXA.

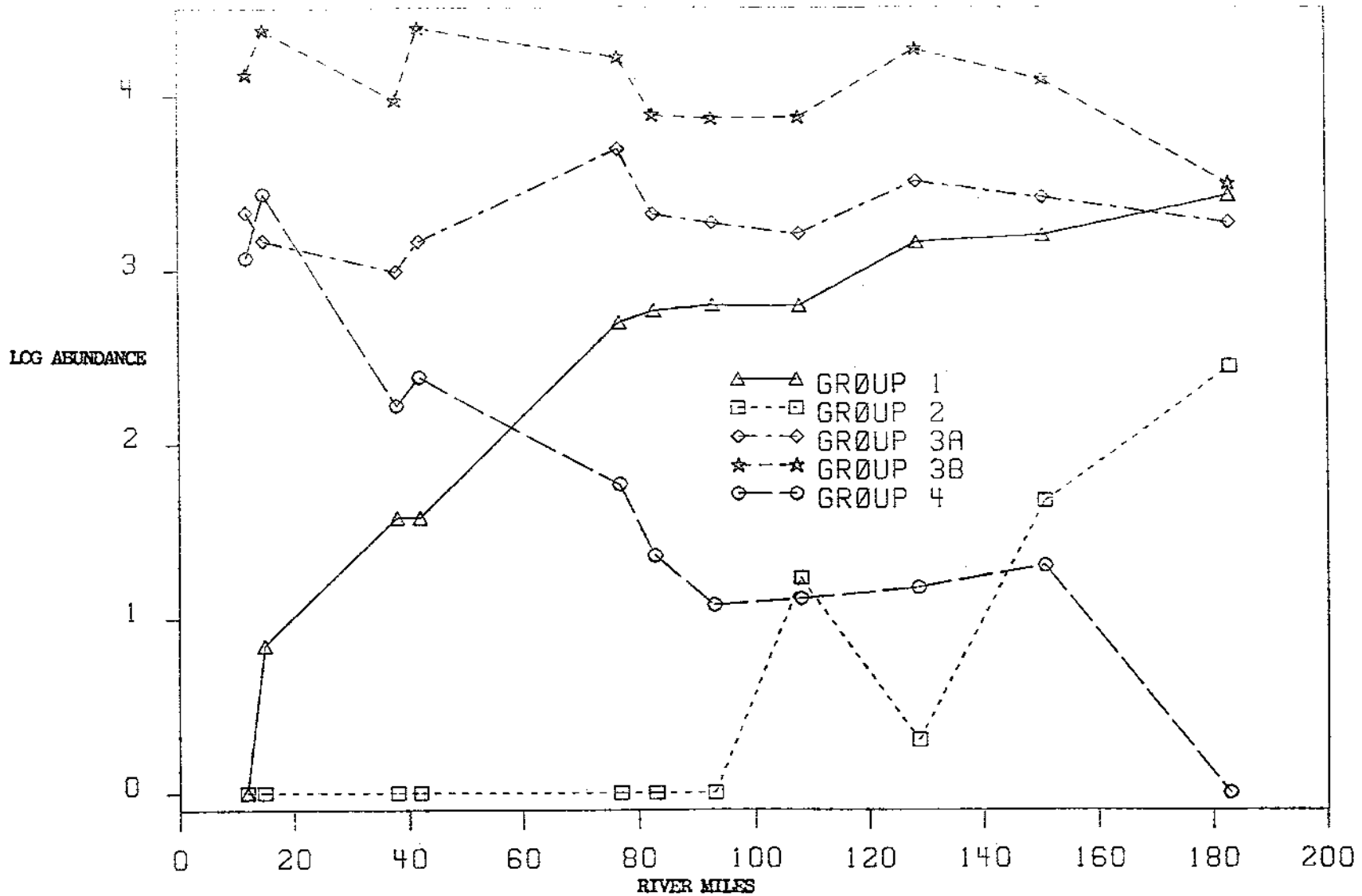


FIGURE 97. ABUNDANCE OF THE FIVE MACROINVERTEBRATE GROUPS DISCERNED BY CLUSTER ANALYSIS BY STATION.

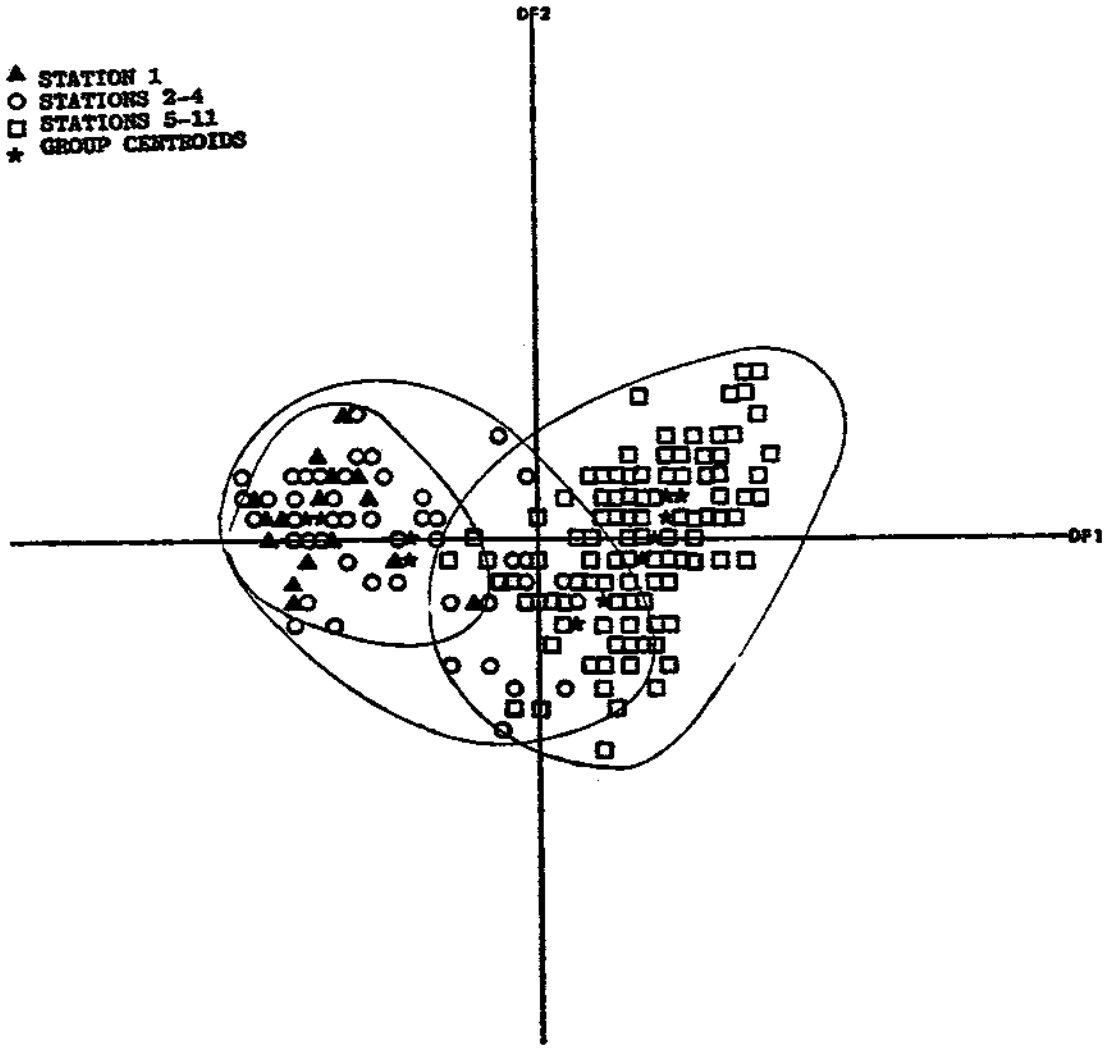


FIGURE 98. ORIENTATION OF STATION GROUPS IN DISCRIMINANT SPACE.

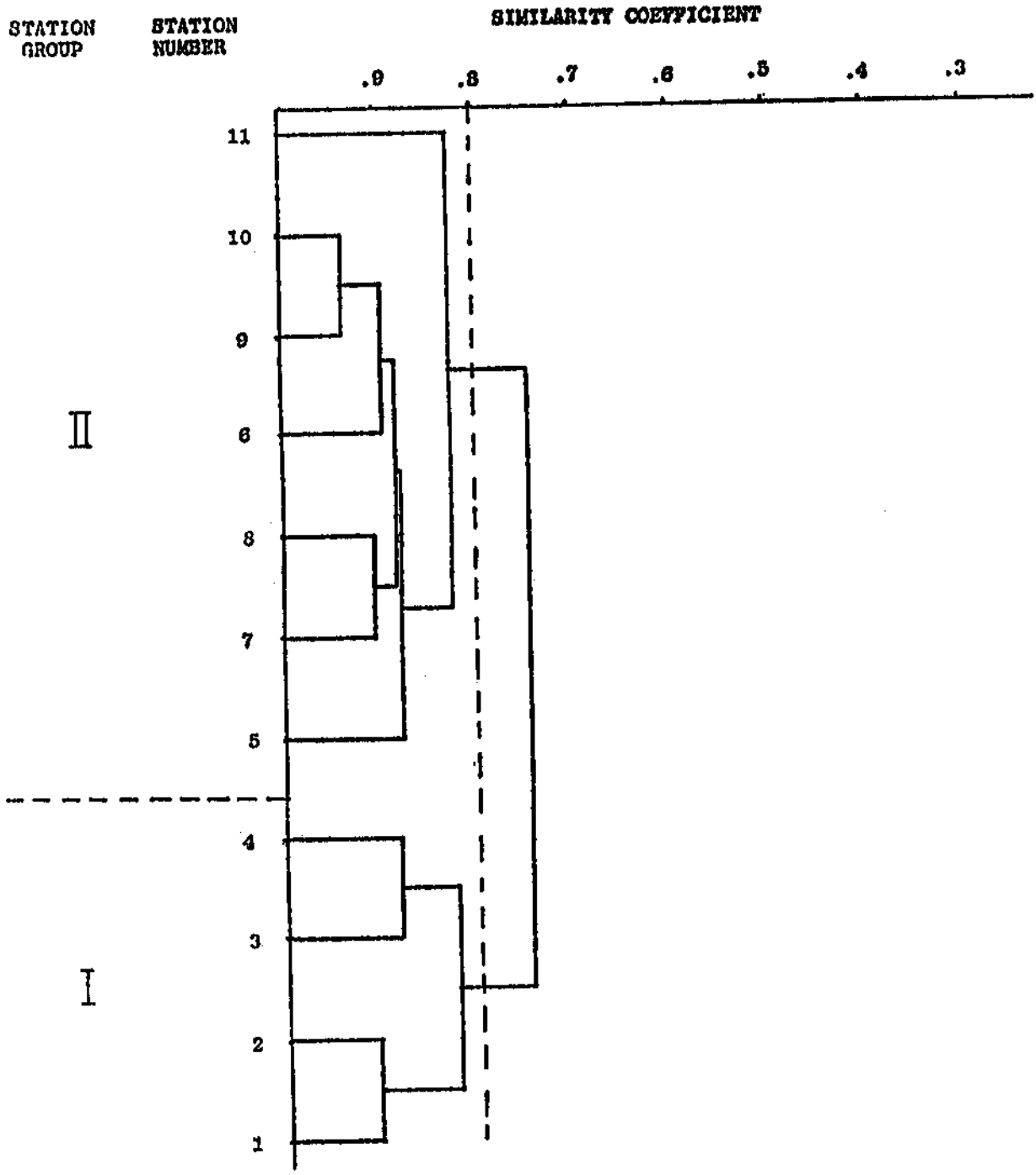


FIGURE 99. NORMAL ANALYSIS (STATION CLUSTERS) OF TOP 50 BENTHIC TAXA.

TABLE 25. SUWANNEE RIVER MACROINVERTEBRATE TAXONOMIC LIST.

Annelida
Hirudinea

Batracobdella phalera (Graf)
Helobdella elongata (Castle)
Placobdella papillifera (Verrill)
Placobdella parasitica (Say)

Annelida
Oligochaeta

Bratislava unidentata (Harman)
Chaetogaster sp.
Dero nivea Aiyer
Nais barbata Muller
Nais behningi (Michaelsen)
Nais communis Piguet
Nais pardalis Piguet
Nais elinguis Muller
Nais simplex Piguet
Nais sp.
Nais variablis Piguet
Pristina osborni Walton
Slavina appendiculata (d' Udekem)
Stylaria lacustrus (Linnaeus)

Arachnida
Acarina

Arrenurus sp.
Atractides sp.
Hydrodroma sp.
Hygrobates sp.
Koenikea sp.
Lebertia (Pilolebertia) sp. 4 (Pluchino)
Lebertia (Pilolebertia) sp.
Mideopsis sp.
Platynothrus sp.
Sperchonopsis echphyma Prasad and Cook
Sperchonopsis sp.
Torrenticola sp.
Unionicola sp.

Cnidaria
Hydrozoa

Hydra sp.

Crustacea
Malacostraca

Asellus sp.
Gammarus sp.
Hyalella aztecus (Saussure)
Procambarus sp.

Insecta
Coleoptera

Agabus johannis Fall
Ancyronyx variagata (Germar)
Berosus pugnax LeConte
Berosus sp.
Coptotomus interrogatus obscurus Sharp
Crenitulus suturalis (LeConte)
Dineutus angustus LeConte
Dineutus discolor Aube
Dineutus sp.
Dubiraphia quadrinotata (Say)
Hydroporus sp.
Hyperodes sp.
Microcylloepus pusillus (LeConte)
Microcylloepus sp.
Stenelmis convexula Sanderson
Stenelmis crenata (Say)
Stenelmis hungerfordi Sanderson
Stenelmis sinuata LeConte
Stenelmis sp.

Insecta
Collembola

Achorutes sp.
Isotomurus sp.
Sminthurides sp.

Insecta
Diptera

Ablabesmyia americana Fittkau
Ablabesmyia annulata (Say)
Ablabesmyia cinctipes (Johannsen)
Ablabesmyia mallochi (Walley)
Ablabesmyia ornata Beck
Ablabesmyia parajanta Roback
Ablabesmyia philosphagnos Beck
Ablabesmyia sp.
Ablabesmyia tarella Roback
Atrichopogon sp.
Bezzia sp.
Cardiocladius sp.
Chironomus crassicaudatus Malloch
Chironomus decorus Johannsen
Chironomus sp.
Chironomus stigmaterus Say
Cladotanytarsus sp.
Clinotanypus pinguis (Loew)
Clinotanypus sp.
Coelotanypus concinnus (Coquillett)
Coelotanypus tricolor (Loew)
Conchapelopia sp.
Corynoneura sp.
Corynoneura taris Roback
Cricotopus bicinctus (Meigen)
Cricotopus sp.
Cryptochironomus blarina Townes
Cryptochironomus fulvus (Johannsen) group
Cryptochironomus sp.
Culicoides sp.
Dicrotendipes leucoscelis (Townes)
Dicrotendipes lobus (Beck)
Dicrotendipes modestus (Say)
Dicrotendipes neomodestus (Malloch)
Dicrotendipes sp.
Djalmabatista pulcher (Johannsen)
Endochironomus nigricans (Johannsen)
Eukiefferiella discoloripes Goetghebuer
Eukiefferiella sp.
Goeldichironomus carus (Townes)
Harnischia curtilamellata (Malloch)
Harnischia sp.
Hemerodromia rogatoris Coquillett
Hemerodromia sp.
Labrundinia floridana Beck
Labrundinia johannseni Beck
Labrundinia sp.
Labrundinia virescens Beck

Diptera (cont.)

Limnophora sp.
Microcricotopus sp.
Microtendipes caelum Townes
Microtendipes sp.
Nanocladius sp.
Nilothauma sp.
Nilotanypus fimbriatus (Walker)
Nilotanypus sp.
Orthocladius sp.
Parachironomus monochromus (van der Wulp)
Parachironomus pectinatellae (Dendy and Sublette)
Parachironomus schneideri Beck and Beck
Parachironomus sp.
Parakiefferiella sp.
Paralauterborniella elachista (Townes)
Paralauterborniella nigrohalteralis (Malloch)
Parametriocnemus sp.
Paratanytarsus sp.
Parorthocladius sp.
Pentaneura inconspicua (Malloch)
Phaenopsectra obediens (Johannsen)
Polypedilum convictum (Walker)
Polypedilum fallax Johannsen
Polypedilum halterale (Coquillett)
Polypedilum illinoense (Malloch)
Polypedilum sp.
Procladius sp.
Pseudochironomus sp.
Psychoda sp.
Rheocricotopus robackii (Beck and Beck)
Rheocricotopus sp.
Rheotanytarsus sp.
Simulium sp.
Stenochironomus sp.
Stelechomyia sp.
Tanytarsus sp.
Thienemanniella xena Roback
Tribelos fuscicornis (Malloch)
Tribelos jucundus (Walker)
Tribelos sp.
Trissocladius sp.
Zavrelia sp.

Insecta
Ephemeroptera

Baetis intercalaris McDunnough
Baetis propinquus (Walsh)

Ephemeroptera (cont.)

Baetis sp.
Baetis spiethi Berner
Baetisca rogersi Berner
Brachycercus maculatus Berner
Brachycercus sp.
Caenis diminuta Walker
Caenis sp.
Centroptilum hobbsi Berner
Centroptilum viridocularis Berner
Choroterpes hubbeli Berner
Cloeon rubropictum McDunnough
Ephemerella sp. A (Berner)
Eurylophella trilineata (Berner)
Hexagenia munda Traver
Isonychia pictipes Traver
Isonychia sp.
Leptophlebia intermedia (Traver)
Neoephemera sp.
Paraleptophlebia bradleyi (Needham)
Paraleptophlebia volitans (McDunnough)
Pseudocloeon alachua Berner
Pseudocloeon parvulum McDunnough
Pseudocloeon sp.
Pseudiron sp.
Stenonema exiguum Traver
Stenonema smithae Traver
Stenacron interpunctatum (Say)
Tricorythodes albilineatus Berner

Insecta
Lepidoptera

Parapoynx sp.

Insecta
Megaloptera

Corydalus cornutus Linneaus

Insecta
Odonata

Argia apicalis (Say)
Argia fumipennis Burmeister

Odonata (cont.)

Argia moesta (Hagen)
Argia sedula (Hagen)
Argia sp.
Argia tibialis (Rambur)
Calyopteryx maculata (Beauvois)
Dromogomphus spinosus Selys
Arigomphus pallidus (Rambur)
Hetaerina titia (Drury)
Macromia georgiana (Selys)
Neurocordulia virginiensis Davis

Insecta
Plecoptera

Acroneuria arenosa (Pictet)
Acroneuria sp.
Attaneuria ruralis (Hagen)
Hydroperla phormidia Ray and Stark
Isoperla sp.
Neoperla clymene (Newman)
Neoperla sp.
Paragnetina fumosa (Banks)
Perlesta placida (Hagen)
Perlinella ephyre (Newman)
Perlinella sp.
Taeniopteryx leta Frison

Insecta
Trichoptera

Ceraclea sp.
Cheumatopsyche sp.
Chimarra sp.
Cyrnellus fraternus (Banks)
Hydropsyche sp.
Hydroptila sp.
Lype diversa (Banks)
Macronema carolina (Banks)
Mayatrichia sp.
Nectopsyche sp.
Neotrichia sp.
Neureclipsis sp.
Nyctiophalax sp.
Oecetis cinerascens (Hagen)
Oecetis sp.

Trichoptera (cont.)

Orthotrichia sp.
Oxyethira sp.
Polycentropus sp.
Trianodes sp.

Mollusca
Gastropoda

Campeloma sp.
Cincinnatia sp.
Ferrissia sp.
Fossaria sp.
Goniobasis floridensis Reeve
Gyraulus sp.
Helisoma duryi (Wetherby)
Laevapex sp.
Physa pumilia Conrad
Pomacea paludosa Say
Promenetus sp.
Pseudosuccinea sp.
Viviparus georgianus Lea

Mollusca
Pelecypoda

Corbicula manilensis (Philippi)
Musculium sp.

Nematoda

Unknown nematode sp.

Nemertea

Prostoma rubra (Leidy)

Platyhelminthes
Turbellaria

Dugesia polychroa (O. Schmidt)

Turbellaria (cont.)

Dugesia sp.
Dugesia tigrina (Girard)

TABLE 26. Macroinvertebrates collected at Station 2 but not Stations 1, 3 or 4. *= organisms found in Hunter Creek by Breedlove (1982) and/or U.S. EPA (1982).

Ephemeroptera
- Baetis spiethi
- *Ephemerella trilineata

Diptera
- Ablabesmyia annulata
- Clinotanypus pinguis
- *Cryptochironomus blarina
- *Paratanytarsus sp.
- Chironomus sp.
- *Nilotanypus sp.

Coleoptera
- *Dineutes angustus
- D. discolor

PERIPHYTON

Introduction

Periphyton refers to the community of microorganisms (predominantly algae) inhabiting surfaces of underwater vegetation, rocks, and other submerged substrates. This community is also commonly referred to as "Aufwuchs" and, sometimes, "epilithon" (Round 1964; U.S. EPA 1973; Swift 1981). Because of the ease of collection and standardization of samples, periphyton grown on artificial substrates has been used extensively in studies of aquatic systems (Yount 1956; Hohn 1961; Sladeckova 1962; Tilley and Haushild 1975). Furthermore, due to the sedentary nature of periphyton, its community composition, structure, and biomass are sensitive to changes in water quality and are often used as indicators of ambient conditions (Butcher 1947; Fjerdingstad 1964; Patrick 1964; Lowe 1974).

The goals of this portion of the project were to: 1) provide background measurements of Suwannee River periphyton biomass and generate a check list of taxa; 2) assess differences in community composition and structure associated with differences in water quality; and 3) provide a basis for comparison with future regulatory studies of Suwannee River water conditions.

Methods and Materials

Glass slides were chosen as the artificial substrate for this investigation because of their widespread use in similar studies (Hufford and Collins 1976; Swift 1981; Thompson et al. 1982). Furthermore, use of glass slides in a uniform sampling rack (periphytometers) reduces variables associated with substrate, water depth, and current (Patrick et al. 1954; Brown 1976; Pryfogle and Lowe, 1979). The pilot study conducted for this project offered further evidence for their suitability. Numerous studies have indicated that communities grown on artificial substrates, though not identical, are comparable to those grown on natural substrates (Flemer 1970; Hynes 1970; Tuchman 1979; Thompson et al. 1982).

Twelve standard 75 X 25 mm microscope slides were placed in stainless steel racks that were floated approximately 15cm below the surface. Duplicate racks were placed at each station to compensate for the possible loss of samplers. Despite this precaution, a number of samplers were not recovered (Table 27). Care was taken to float samplers in areas of similar flow and light at each station.

After 28 days incubation, slides were randomly placed in one of three tubes for analysis of phaeopigment corrected chlorophyll a, for ash-free dry weight (AFDW), and for taxonomic identification and enumeration. Slides were preserved in 5% formalin, except those for chlorophyll analysis which were placed in deionized water and stored on ice.

Pigment analysis was conducted within 24 hours of collection. Four slides were scraped into deionized water which was then filtered through a 0.45 um glass fiber filter (Whatman GFC®) and rinsed with magnesium carbonate solution. The filters were macerated with a fluted Teflon® tissue grinder and extracted in 90% aqueous acetone/magnesium carbonate mixture for 18 to 24 hours, then centrifuged. The optical density of the supernatant was measured with a Beckman Model 35 double beam spectrophotometer at 663 nm for chlorophyll a. The sample was acidified with 2 drops of 1.0 N HCl to degrade the chlorophyll a molecules into phaeopigment compounds. Optical density was then measured at 665 nm. The monochromatic equation of Strickland and Parsons (1972) was used to calculate phaeopigment corrected chlorophyll a.

To determine the AFDW's of the periphyton, the preserved slides were scraped and rinsed into a beaker. The algal slurry was then rinsed into a crucible that had previously been incinerated for one hour at 550°C. The crucible and algae were then dried in a oven at 105°C overnight, cooled in a dessicator for one hour, and weighed. The algae were ashed in a 550°C muffle furnace for one hour. After cooling, crucibles were filled to the previous level of liquid with deionized water. Crucibles were dried and reweighed according to the previously described procedure. At least two empty crucibles (blanks) were processed in the same manner to determine a correction factor for the AFDW calculations. Values are reported as g/m^2.

For algal identification, periphyton was scraped from the preserved slides and diluted to a known volume. This sample was split for two separate analyses: one for identification of the total algal community; and one for the diatom fraction which constituted the major portion of the algal community in the river. The algal mixture was diluted with deionized water in graduated cylinders until proper counting densities were achieved. Utermohl counting chambers and a Wild® inverted microscope were used for identification and enumeration. For a given sample, counting was halted after counting either 50 fields or 250 organisms. The taxonomic keys listed in Literature Cited were used for algal identification. Densities, in number of cells/mm^2, were determined from raw counts using the known volumes and dilutions.

Samples for diatom analysis were mixed with 20 ml of 50% hydrogen peroxide and heated for about 20 minutes on a warm laboratory hot plate. Potassium dichromate (1-2 g) was added to the mixture to complete the oxidation of the sample. After cooling, the sample was diluted with 500 ml of deionized water, allowed to settle for 24 hours, and decanted. This rinsing

process was repeated. The final residue was rinsed into a graduated centrifuge tube and diluted to a known volume. An aliquot of this mixture was dried onto a 0.17 um cover slip that was inverted and afixed onto a glass slide with Hyrax® mounting medium. For each sample, 250 frustules were identified to the lowest taxonomic level possible using the references in the Literature Cited. An oil immersion lens (Zeiss®) was used at 500X and 1250X. Raw counts were converted to number of cells/mm^2. Two different methods were used for calculating the total number of diatoms - one using cell counts from the total periphyton identification portion and one determined from the separate diatom fraction; however, the results of the two methods were similar ($r=.820$, $p=.01$). Most references to diatom density in this report were calculated from the diatom fraction enumeration technique.

Statistical analyses performed on the periphyton data included normal and inverse numerical classification (cluster analysis) and multiple discriminant analysis as described in the macroinvertebrate methods section. The normal cluster analysis of the total periphyton community used all genera identified. However, due to the large number of rare diatom species, only those with a cumulative abundance of at least 99 individuals (or .01% of the total diatoms counted) were used for the cluster analysis of the diatom community. Inverse numerical classification of periphyton and diatoms used taxa composing at least 0.02% and 0.1%, respectively, of the total number of individuals. These percentages account for the top 35 genera of periphyton and the top 50 taxa of diatoms.

Results and Discussion

A total of 356 separate taxa in 177 genera of 6 divisions were identified during the study. Diatoms were by far the most abundant group, composing 88% of the periphyton community by number. Cyanophytes and chlorophytes were the next most abundant groups, accounting for 10% and 2% of the community composition, respectively. These proportions were relatively constant throughout the river and during the entire sampling period (Fig. 100). Periphyton and diatom density generally increased downstream (Figs. 101 and 102). Complete lists of the periphyton and diatom taxa we collected are given in Tables 28 and 29.

Numerical classification (cluster analysis) of both the periphyton and diatom density data indicated the presence of two station groups: Stations 1 - 4 and Stations 5 - 11 (Figs. 103 and 104). This major division of upper and lower river stations corresponds with changes in periphyton community parameters and associated physical and chemical parameters. For example, the density of periphyton and diatoms distinctly increased between Stations 4 and 5 (Figs. 101 and 102), and appears to be associated with marked changes in water chemistry (notably pH, alkalinity, conductivity, and color) between these two stations (see Figs. 19, 21, 24, and 26).

Multiple discriminant analysis of temperature, alkalinity,

color, conductivity, fluorides, nitrate plus nitrite, orthophosphate, total phosphorus, and pH was used as a means to indicate some of the abiotic factors that might have contributed to the observed station groupings. These parameters were chosen on the basis of their possible growth regulating properties, either stimulatory (nutrient levels, light, temperature) or inhibitory (ionic balance, toxins, etc.). The position of groups in discriminant space (Fig. 105) indicates separation of the two major station groups. The first discriminant function (based primarily on pH, fluorides, and total phosphorus) explains 85% of the among-group variance and separates Stations 1 - 4 from 5 - 11. The second discriminant function (based primarily on fluorides and conductivity) accounts for an additional 10% of the variance, and further separates Station 4 from the rest. This analysis of abiotic factors thus separated three station groups (1-3; 4; and 5-11). Since cluster analysis of biological data did not distinguish Station 4 as a separate group, the data suggest that any effects fluorides and conductivity have on the periphyton community may be minimal compared with those of pH, the primary discriminator of the first function.

The effect of pH on diatom productivity and composition is well documented. Diatom species composition has been used to compute either a biotic index for water acidity (Watanabe and Yasuda 1982) or pH itself (Flower 1982). Van Dam et al. (1981) separated sampling sites based on the distribution of pH sensitive diatom species. Other authors have reported lower diatom productivity in acid waters as well as shifts in species composition (Butcher 1938; Stokes 1981; Hill and Webster 1982).

Station grouping can be further emphasized by species groupings. Inverse analysis performed on the top 50 diatom taxa distinguished four groups (Fig. 106). Table 30 lists the taxa by groups along with codes indicating their ecological preferences. The plots of group occurrence ($\log_{10}$ of # ind/mm^2) vs. river miles also show the variation, particularly between Stations 4 and 5 (Fig. 107).

Group I is composed of taxa that occurred in greatest densities in the upper river (96% above Station 5). All but one of the species belonged to the genus Eunotia which is commonly found in acidic waters (Butcher 1938; Williams and Scott 1962; Round 1964). Additionally, Frustulia rhomboides, also an acidophile and halophobe (Hynes 1970; Weaks 1982), defined the group.

Group II contained 25 species and varieties which were more abundant in the lower river (99% below Station 4). This group included four of the five varieties of Achnanthes lanceolata. These diatoms have been found in hard water where organic pollution was minimal (Lowe 1974). In contrast, Gomphonema parvulum, often an indicator of organic pollution (Butcher 1947), was also abundant. A species whose distribution conflicted with that expected from the literature was Achnanthes minutissima. Lowe (1974) and Evenson et al. (1981) noted this species as an indicator of soft and nutrient poor water; however, in our study,

it occurred only at Stations 6 - 11, and was most abundant at 11. Finally, Cocconeis placentula var. euglypta, a common alkaliphilic river diatom, was an abundant member of the group. Most Group II species are cosmopolitan and prefer neutral to alkaline water (see references, Table 30).

Group III was composed of species that occurred in relatively high numbers throughout the river. Though some species were more abundant upstream (e.g., Eunotia pectinalis var. minor) and others predominated downstream (e.g., Achnanthes exigua var. heterovalva), all were collected from the entire river. Many are cosmopolitan species known to be tolerant of wide ranges in pH as well as other parameters (eurytopic) (see references, Table 30).

Gomphonema affine, Gomphonema sp.10, and Cymbella minuta var. silesiaca, which composed Group IV, occurred largely at the mid-river stations (primarily Stations 5 and 6). Changes in water chemistry due to the influx of several springs may have substantially influenced the distribution of these species. Additionally, these mid-river stations are subject to wide ranges of pH (5 - 7.8) depending on the river stage height (see Water Chemistry Section). Our data suggest that the distribution of these particular species may be a function of their tolerance to such wide variations in pH and associated changes in water chemistry.

Several diatom taxa not listed in Table 30 were notable in their distribution. Evenson et al. (1981) found Cyclotella meneghiniana to be an indicator of high concentrations of F and SO_4, and of the nutrients, N and P. It was found almost exclusively at Stations 4 and 5 where the levels of these substances were highest (see Figs. 33, 35, 43, 50). Two genera, Nitzschia and Pinnularia, though common (with over 20 species each), were not represented in the top 50 taxa. Pinnularia spp., known acidophiles (Patrick and Reimer 1966), occurred almost entirely at the acidic upper river stations (see Appendix D). Nitzschia spp., though more abundant in the lower river, were not uncommon at upper river stations (see Appendix D).

The relationships of the non-diatom periphyton taxa clustered by inverse analysis are less well defined, probably because identification was made only to the generic level. The one relatively distinct group consisted of filamentous green algae and an encrusting blue-green alga, Chamaesiphon, which were nearly absent from the upper river (99% below stations 4). Except for this group, the other genera considered in the inverse analysis were generally ubiquitous in the river but were more abundant in the lower river. Finally, the euglenoid flagellates seemed to tolerate the wide range of pH encountered in the Suwannee, since they occurred as frequently at the acidic upper stations as they did at the non-acidic lower ones (see Appendix D). Ennis and Albright (1982) and Flower (1982) noted similar tolerances of euglenoids in Canada and Scotland, respectively.

Seasonal variation in algal growth, particularly diatoms, is well documented (Hynes 1970; Hufford and Collins 1976; Ennis and

Albright 1982). A plot of diatom density at the 24 sampling dates shows considerable variation through time (Fig. 108). Temporal changes of most physical and chemical parameters were associated primarily with increases in river stage height (dilution), or the degree of influence of the headwaters (pH, alkalinity, conductivity, color, etc.; see Chemistry section). Additionally, seasonal changes in water temperature might affect diatom growth.

Correlations of diatom density with mean water temperature, stage height, and pH were all significant ($p=0.05$; 23 d.f.) with r values of .417, -.434, and .402, respectively (Table 31). Furthermore, stage height correlated significantly with both temperature and pH (Table 31). The strong negative correlation between pH and stage height can be explained by the hydrology of the river. When rainfall is abundant, the river level rises, and the pH is lowered due to the increased drainage from the acidic waters of the Okefenokee Swamp (refer to Hydrology and Chemistry sections for a more detailed discussion). It is also possible that the rainfall itself can depress the pH in the lower river stations. Flooding is generally greater in the winter and spring when water temperatures are lower. This phenomenom may account for the weak stage height - water temperature correlation. The interrelationship of these variables, as well as the nearly equivalent r values using total diatom density, makes the analysis of their separate effects on diatom growth more difficult.

To help clarify the effects of these parameters on the diatoms, several of the more abundant species were examined more closely. They are listed in order of abundance along with r values for the above parameters in Table 31. It is apparent that different species are influenced by different variables. For example, Eunotia pectinalis var. minor and Achnanthes lanceolata var. 1 were more abundant in warmer temperatures. Achnanthes lanceotata and A. lanceolata var. dubia decreased in more acidic water. Other species were negatively correlated with stage height. The more encompassing aspect of stage height probably accounts for this stronger correlation. For example, when the water is high, pH is low; the water is often cooler (spring floods); flow and therefore abrasion is greater; and/or light may be somewhat attenuated; all combining to have a negative affect on diatom growth. Also stage height is calculated from a monthly mean rather than a single sample day as for pH and temperature. Finally, though pH undoubtedly had an effect temporally as well as spatially, it did not vary as profoundly at individual stations as did stage height.

Community diversity measurements are often used to help indicate water quality (Patrick et al. 1954; Hohn 1961; Pryfogle and Lowe 1979). In this study, the number of diatom taxa and Shannon-Weaver diversity indices were calculated for each sample. The Shannon-Weaver index ($\bar{d}$) is based on both the number of different taxa and the equitability of their distribution. The total number of taxa per station varied greatly during the study, particularly in the upper river. However, the average number of taxa per station remained fairly constant, ranging from a high of 25.8 at Station 6 to a low of 19.3 at Station 9 (Fig. 109).

Values for $\bar{d}$, likewise, showed monthly variability, though means were substantially lower in the upper river, and increased markedly at Station 5 (Fig. 110). Similarly, median, as well as mean $\bar{d}$ values, were lower at Stations 1 - 4 (lowest at 4) and higher at Stations 5 - 11 (highest at 11) (Fig. 111). The confidence intervals given for the median were calculated for the individual $\bar{d}$ value that was the median and therefore do not indicate seasonal variability. The lower $\bar{d}$ values in the upper river probably reflect the nearly constant dominance of Eunotia pectinalis var. minor, while the lower river had several dominating species (Achnanthes heterovalva var. exigua, A. lanceolata var. 1, Cocconeis placentula var. euglypta, and Gomphonema parvulum). Particularly abrupt decreases occurred in average number of taxa between Stations 1 and 2, and in median $\bar{d}$ between Stations 1 and 2 and Stations 3 and 4. Abrupt increases occurred between Stations 5 and 6 for mean and median $\bar{d}$ and for mean number of taxa (Figs. 109-111).

To better accentuate spatial rather than temporal variation, data for the separate stations were pooled over the entire sampling period. The number of taxa and $\bar{d}$ were then calculated for these pooled data (Fig. 112). The $\bar{d}$ values in Figure 112 were calculated from the sum of diatoms already converted to cells/mm^2 whereas the confidence intervals were calculated from actual counts. This technique was used to avoid the artificially narrow intervals which would result from the use of the artifically large converted counts. Therefore, the 95% confidence intervals from the population samples actually counted have been superimposed on the $\bar{d}$ values calculated from pooled, converted numbers. Figure 112 shows depressed values (<100) for the number of taxa at Stations 2, 5, 9 and 10 that are not reflected in their $\bar{d}$ values, suggesting that the equitability of the pooled data was higher at these stations. In contrast, Station 3 had a lower $\bar{d}$ value than might be expected by the number of taxa indicating a less equitable distribution of the pooled species here, most likely due to the dominance of Eunotia pectinalis var. minor. In comparing median $\bar{d}$ values of the unpooled data (Fig. 111) with the $\bar{d}$ values for pooled data (Fig. 112), the median values decreased fairly sharply between Station pair 1 and 2 and pair 3 and 4, whereas the pooled $\bar{d}$'s increased markedly at those same station pairs.

Correlation analyses were done on the four biomass estimates and were significant at the 0.01 level. Correlation values (r) were:

	r
Diatom density vs. periphyton density	.890
Diatom density vs. chlorophyll a	.761
Diatom density vs, AFDW	.511
AFDW vs. chlorophyll a	.654
Periphyton density vs. AFDW	.540
Periphyton density vs. chlorophyll a	.861

Excepting AFDW, these correlations indicate that measurements of any one of the parameters could be used to estimate the others

with a fair degree of certainty. The poorer correlations associated with AFDW are probably due to the inclusion of macroinvertebrates and detritus settling in the algal mat on the slides.

Since algal cells vary in size, cell counts may not give a totally accurate measure of biomass (Swift 1981). Chlorophyll a has been widely used as an indirect measure of biomass (Yount 1956; Sladeck and Sladeckova 1964; Odum 1971; Hooper-Reid and Robinson 1978). Though variation was high, mean chlorophyll a values increased threefold downstream (Fig. 113). In fact, with the exception of July 1983, mean values for chlorophyll a in the lower river were significantly higher than those in the upper river throughout the sampling period (Fig. 114). The high chlorophyll a value in the upper river in July 1983 was the result of a bloom of Eunotia pectinalis var. minor in this portion of the river. As expected, seasonal variation of chlorophyll a values paralleled those of density (Fig. 108). The range of chlorophyll a values in this study lies between those of Yount (1956) for a "high production area" and "a low production area" in Silver Springs, Florida.

To assess the influence of major point source dischargers on the Suwannee River, fluctuations in periphyton parameters between certain station pairs were examined. These station pairs are Stations 1 and 2 (Hunter Creek), Station 3 and 4 (Swift Creek), and Stations 5 and 6 (Withlacoochee River). Cluster analysis of periphyton and diatom data did not distinguish between stations in the specified pairs (Figs. 103 and 104). Diatom density values were lower at Station 1 than at Station 2; periphyton values were slightly lower at Station 6 compared with Station 5, and both diatom and periphyton densities were lower at Station 4 than at Station 3 (Figs. 101 and 102).

Figures 109-113 show relative values for station pairs for measures of diversity, number of taxa, and chlorophyll a, and are summarized in the following table:

Parameter	Station pair 1 and 2	Station pair 3 and 4	Station pair 5 and 6
Mean no. taxa	1>2	3<4*	5<6
No. taxa (pooled data)	1>2	3>4*	5<6
Mean $\bar{d}$	1>2*	3>4*	5<6
Median $\bar{d}$	1>2	3>4	5<6
$\bar{d}$ (pooled data)	1<2	3<4	5<6
Chlorophyll a	1<2*	3>4*	5>6

* The difference between these two values was very slight.

The most apparent trend in species richness and diversity indices was observed at Station 6 where all the values indicated better quality than at Station 5. Both chlorophyll a and density values were lower at Station 6. It was also noted that Stations 2 and 4 have lower median $\bar{d}$ values than their corresponding pair Stations 1 and 3 whereas the reverse was true for $\bar{d}$ on pooled

data, indicating greater biological variation over the 2 year sampling period. With the exception of $\bar{d}$ on pooled data, values for density, chlorophyll *a*, and diversity were 2-20% lower at Station 4 than at Station 3 indicating a possible negative effect from the discharge through Swift Creek.

Historical Studies of Suwannee River Periphyton

Algal community monitoring data from the Suwannee River are somewhat limited. In September, 1972, the Environmental Protection Agency performed periphyton analysis at Manatee Springs State Park. Sixty species were identified from glass slides incubated 2 weeks. The species were predominantly diatoms, dominated by *Gomphonema parvulum*, *Navicula graceloides*, and *Melosira varians* (Appendix D). These species were also common among the top 50 species identified in the D.E.R. study. Chlorophyll *a* values from these samples averaged 75 mg/m^2 which is 2-3 times higher than most of the D.E.R. values at this station.

EPA conducted an environmental impact study in the upper portion of the Suwannee River and its tributaries in 1977 (EPA 1978). Their river stations roughly corresponded to DER's Stations 3 and 4. They identified 19 taxa from these two stations all belonging to genera identified in the DER study (Appendix D). They also reported chlorophyll *a*, AFDW, and $\bar{d}$ values within the range of DER's findings at these stations.

Later in this same study area, Environmental Services and Permitting conducted an environmental impact study for the U.S. Army Corps of Engineers (ESP 1984). ESP studied both periphyton and phytoplankton. In addition to the actual report, DER received the species list generated by ESP during their study. The periphyton and phytoplankton had about 50% of the taxa in common with each other and about 70% in common with DER (Appendix D). This overlap of species can be explained by the phenomenon noted by Butcher (1940) and Pryfogle and Lowe (1979) that plankton in small rivers is often similar to the benthic-periphytic algal community. Though species were similar, ESP reports that the periphyton contained 29-83% diatoms whereas DER found 80-90% diatoms. The values they reported for density, number of taxa, and $\bar{d}$ are within the DER values for similar stations.

The Suwannee River Water Management District conducted a fairly comprehensive survey of the river during 1982 and 1983. They collected monthly samples for phytoplankton, chlorophyll *a*, and productivity along with other biological and chemical parameters not considered here. Though phytoplankton was identified rather than periphyton, over half of their species appeared in DER's species lists (Appendix D).

The chlorophyll *a* values determined in the SRWMD study, though not comparable to the DER Biology Section's periphyton chlorophyll *a* values, showed interesting trends along river stations. Values remained relatively constant between 0.5-2.0 mg/m^3 in river stations except at their stations 7 and 9 (approximately equivalent to DER Stations 4 and 5, respectively).

At Station 7, below Swift Creek, values were much higher (up to 16 mg/mm^3) and more variable. These higher values might be explained by the influence of Swift Creek, where values were as high as 88 mg/m^3. SRWMD's Station 9 at the Alapaha Rise was always quite low (below 0.6 mg/m^3) probably because of the large influence of the spring there. Seasonally, there was little apparent correlation with DER monitored periphyton biomass production. For example, in February, 1982, periphyton chlorophyll a values were extremely low whereas phytoplankton values were quite high. However, both periphyton and phytoplankton were low in April, 1983.

Direct comparisons of these studies with DER's study pose problems. The high natural variability demonstrated in this study makes it difficult to assess trends from the limited sampling of the other periphyton studies. Also the difference in sampling regime of other studies may account for additional discrepancies with DER data. However, despite the limited comparability of the other studies, the available data suggests no major differences or changes in the composition of the algal communities of the Suwannee for the period of record.

Summary

1) Periphyton collected on glass slides was composed predominantly of diatoms (88%), blue-green algae (10%), and green algae (2%).
2) Periphyton densities increased downstream.
3) Numerical classification (normal cluster analysis) by station clearly separated upper river stations (1 - 4) from lower river stations (5 - 11). Discriminant analysis of physical and chemical parameters that might affect periphyton growth separated Stations 1 - 4 from 5 - 11 primarily based on pH. Additionally, Station 4 was further separated on the basis of fluoride concentration.
4) Inverse cluster analysis indicated that several species groups had definite upper or lower river distributions. Likewise, most individual taxa were more abundant in either the upper or the lower river.
5) Temporal variation of total diatom density was associated with stage height, pH, and water temperature, though individual species were more distinctly influenced by only one of these variables.
6) Diversity indices were lower and more variable in the upper river (particularly Station 4) than in the lower river.
7) The number of species identified from the Suwannee is within the range recorded for "healthy" soft water rivers (Hohn 1961).
8) Periphyton biomass (chlorophyll a) was 2 - 3 times greater in the lower river than the upper river throughout the study.
9) Observed effects which may be attributable to tributary discharges were: a. decreased chlorphyll a and increased diversity and number of taxa downstream of the Withlacoochee River, b. a tendency for individual measurements of diversity to decrease downstream of Swift Creek, while pooled

measurements tend to increase, implying increased biological variation with time below Swift Creek, and c. variation in diversity below Hunter Creek of the same type as noted below Swift Creek as well as a decreased number of taxa below Hunter Creek.

10) Though periphyton data from other sources is limited and often not directly comparable, they show no major discrepancies when compared with DER's data.

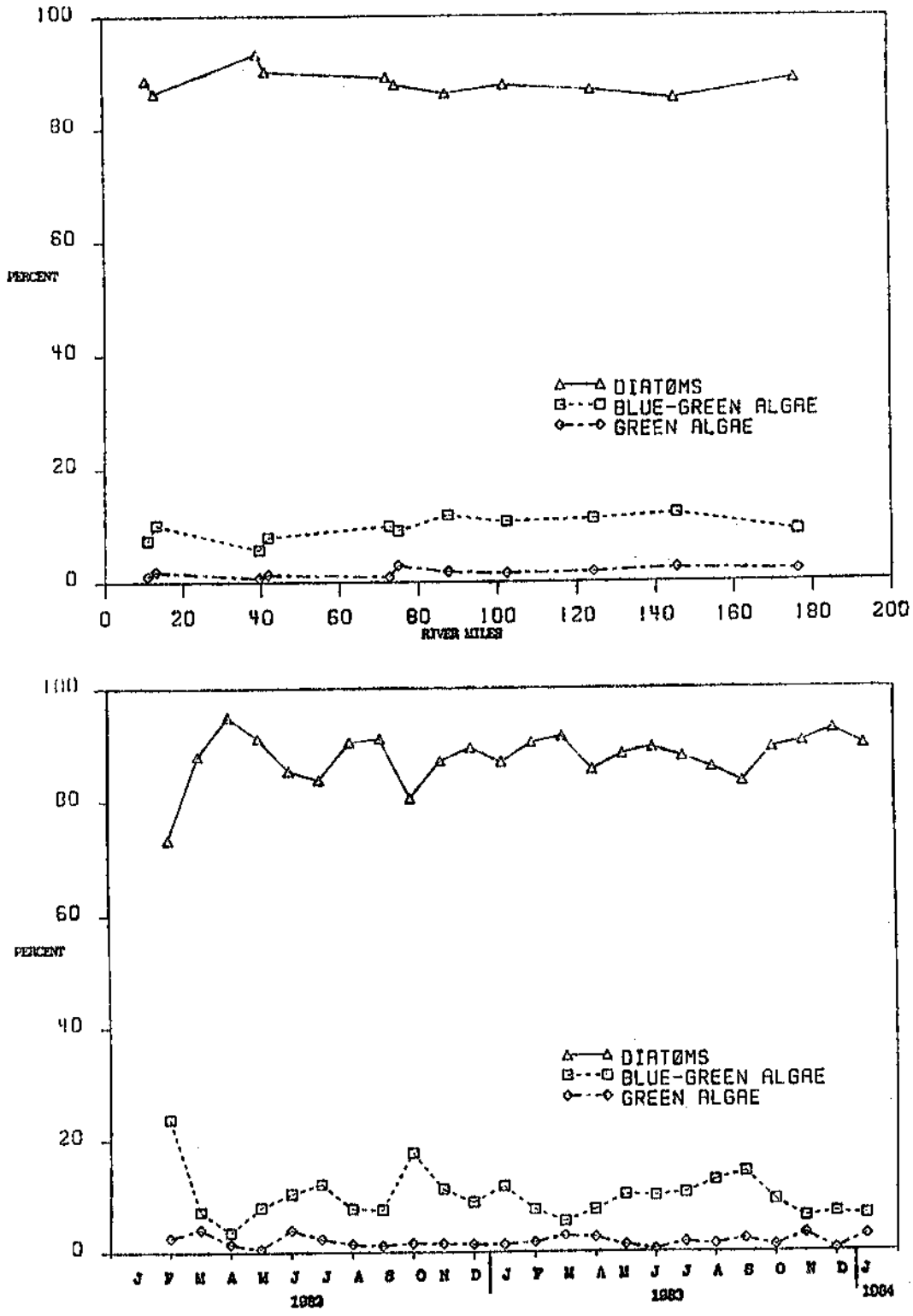


FIGURE 100. PERCENT COMPOSITION OF THE THREE MAJOR PERIPHYTON DIVISIONS BY RIVER MILES AND BY SAMPLING MONTH

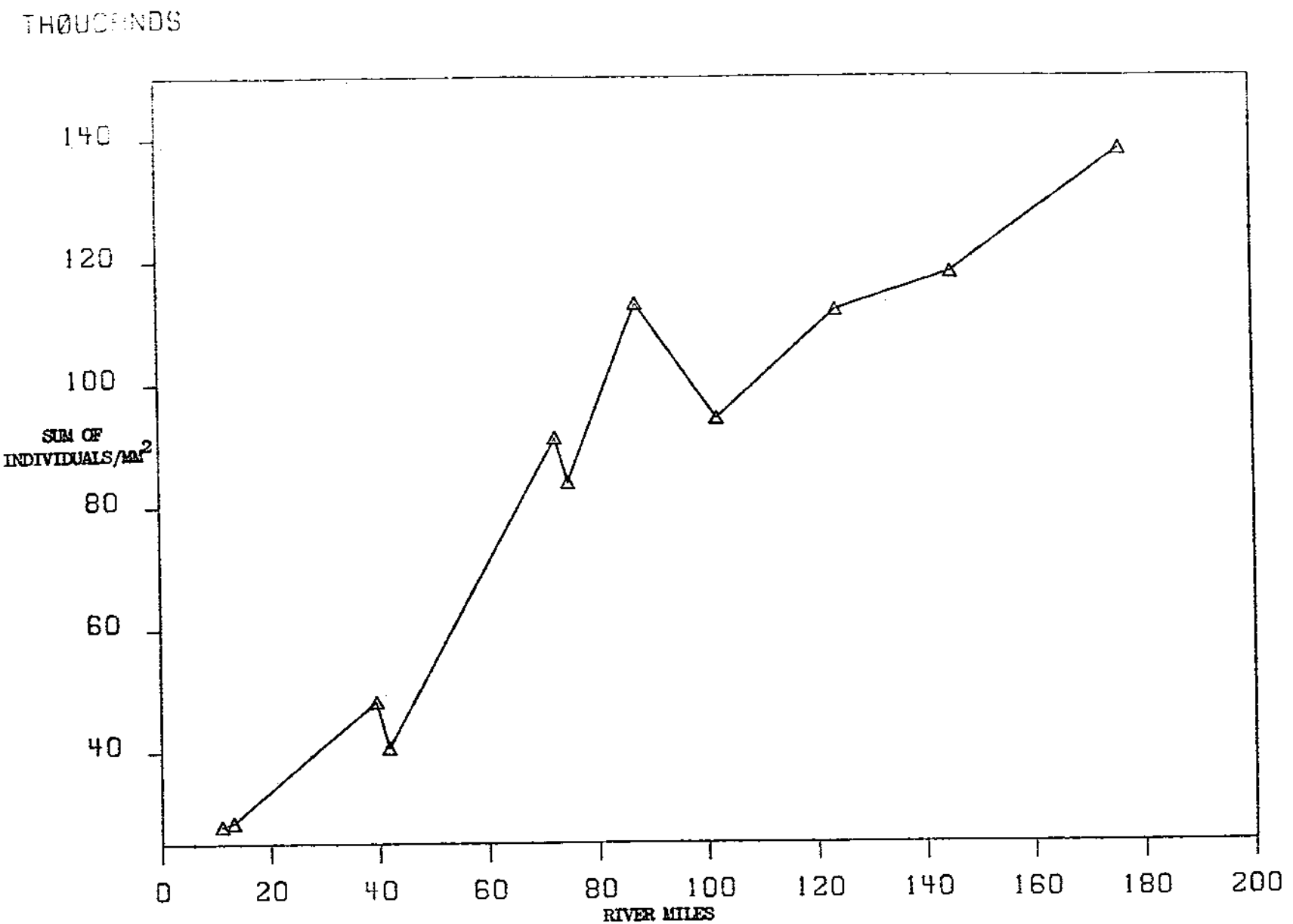


FIGURE 101. PERIPHYTON DENSITY BY RIVER MILES.

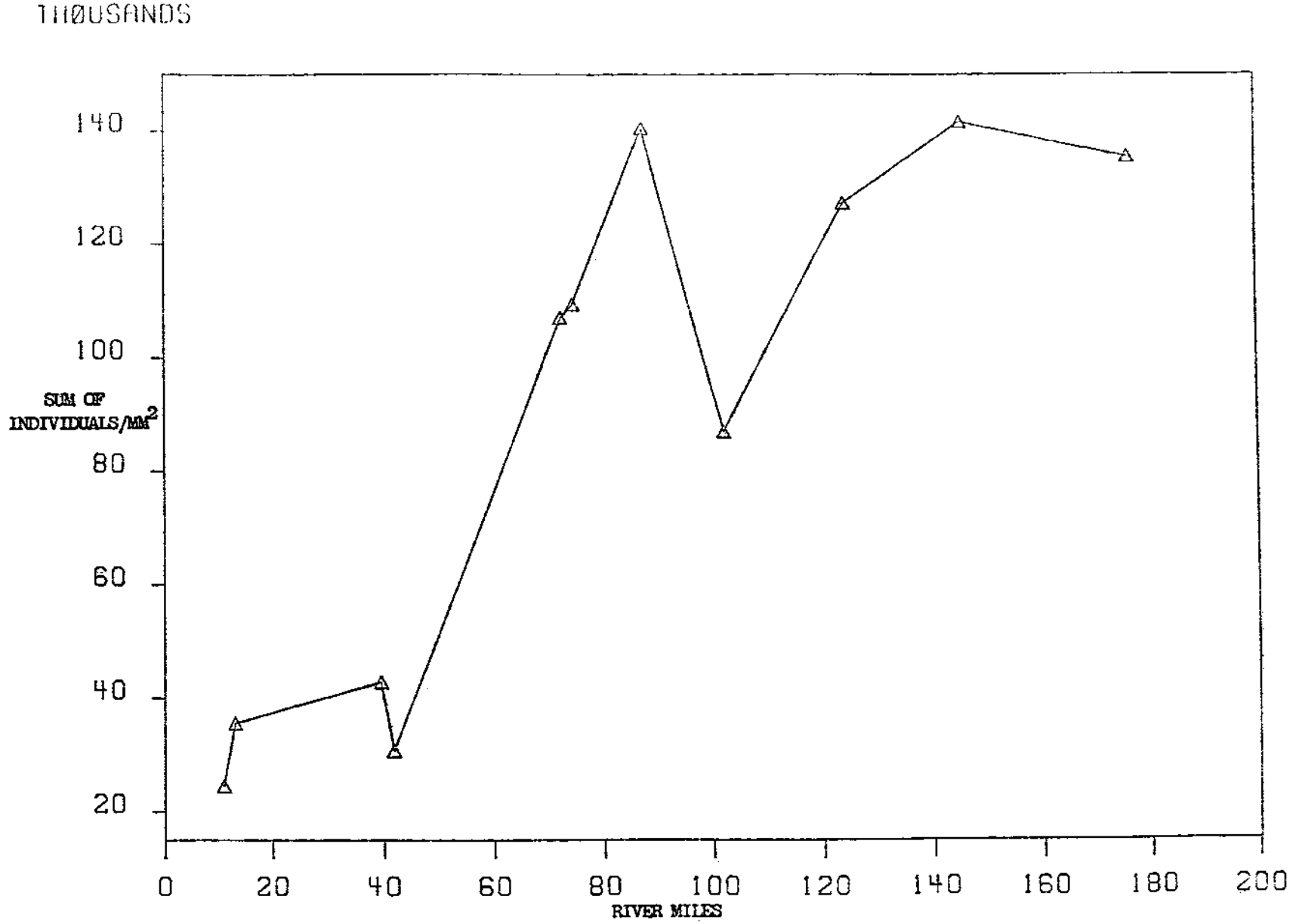


FIGURE 102. DIATOM DENSITY BY RIVER MILES.

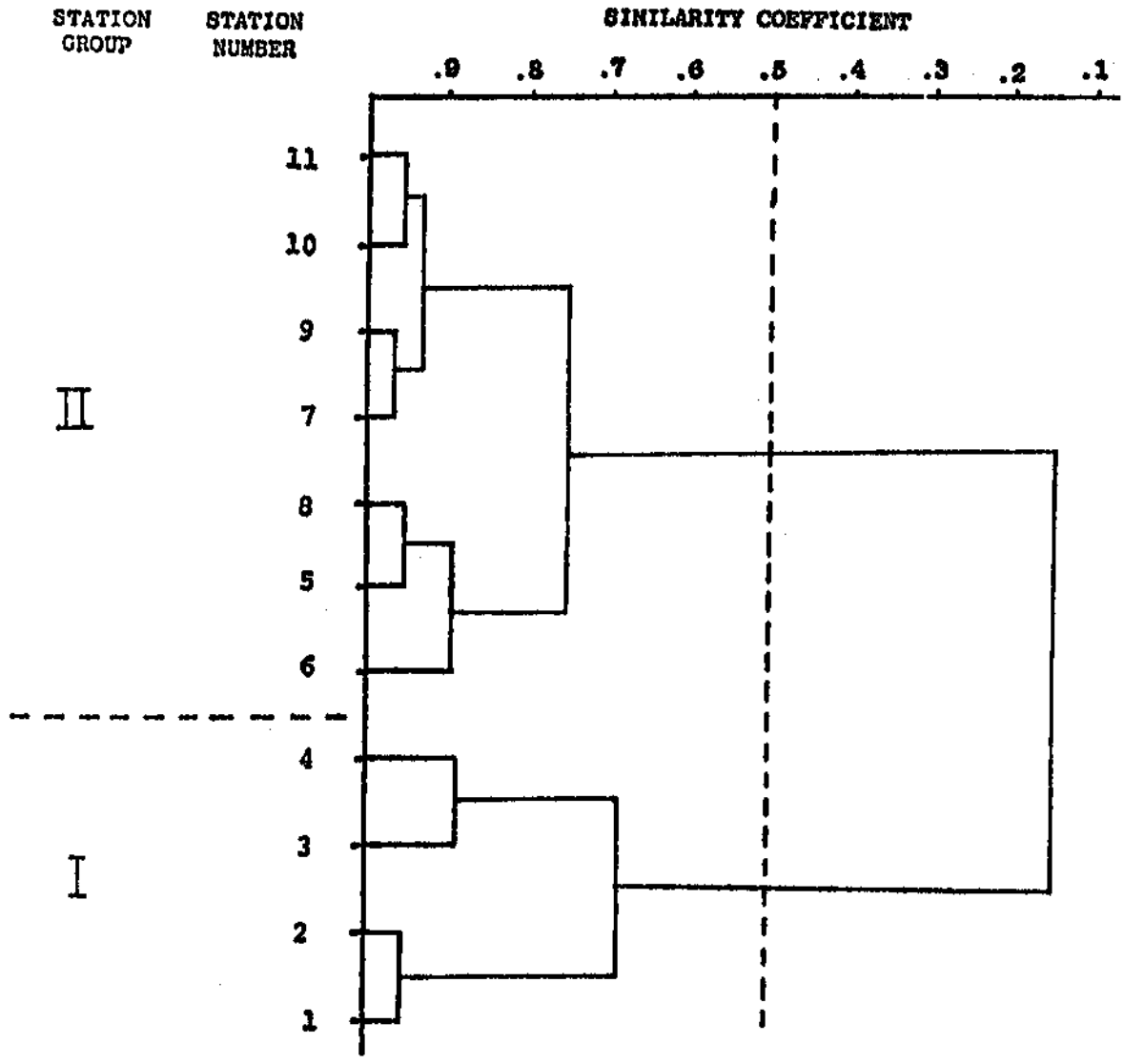


FIGURE 103. NORMAL ANALYSIS (STATION CLUSTER) OF PERIPHYTON GENERA.

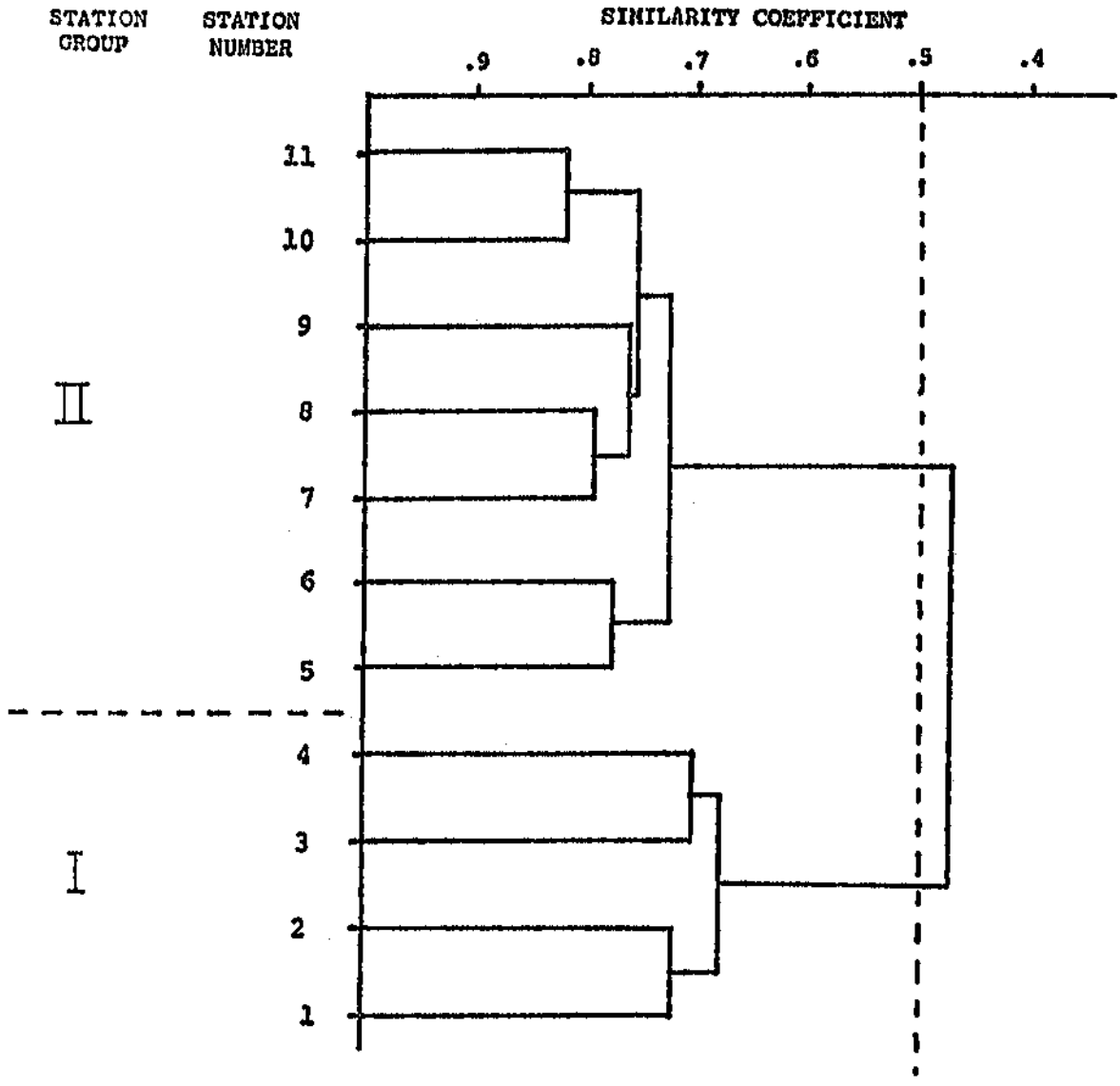


FIGURE 104. NORMAL ANALYSIS (STATION CLUSTER) OF DIATOM TAXA.

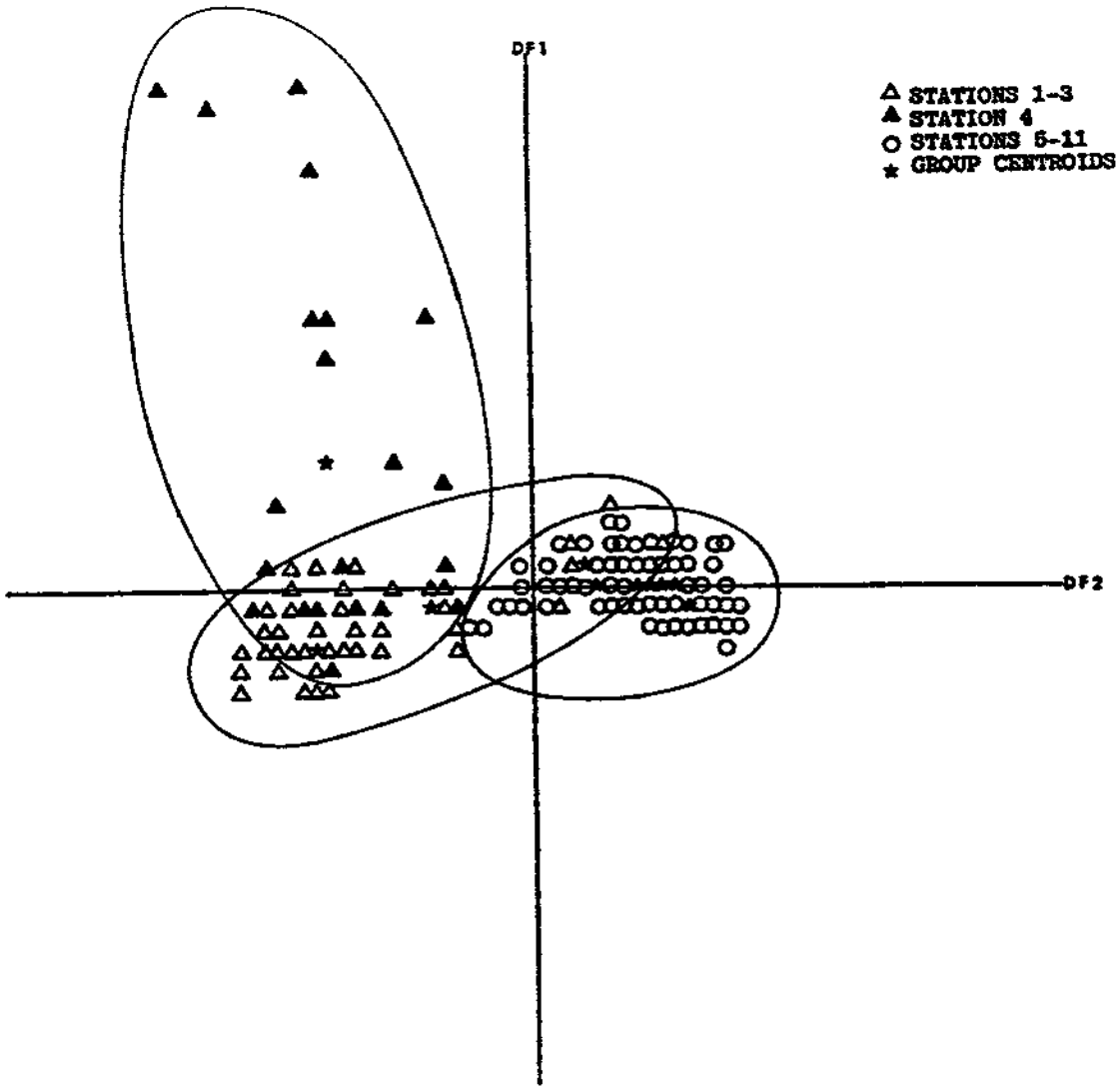


FIGURE 105. ORIENTATION OF STATION GROUPS IN DISCRIMINANT SPACE.

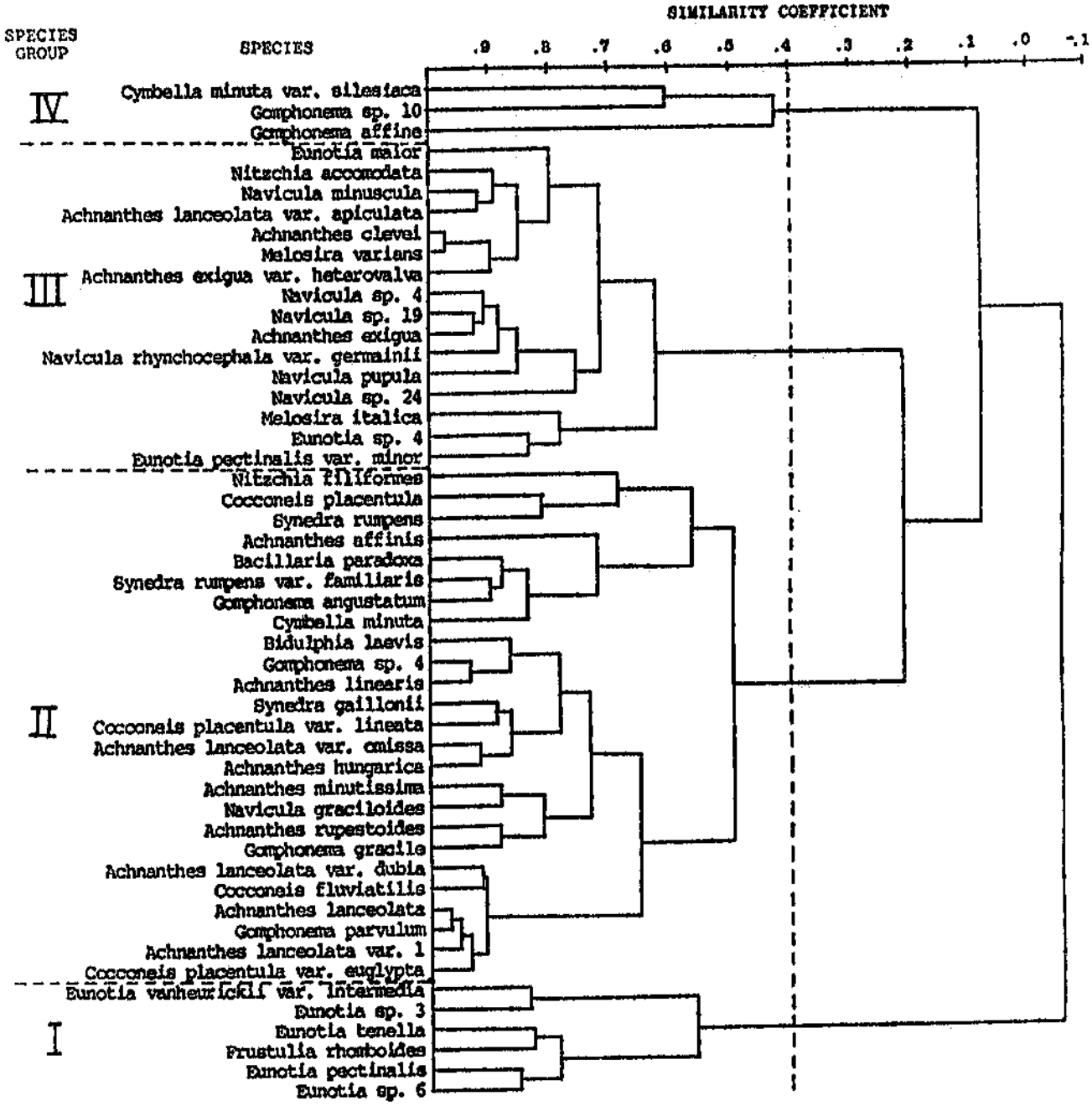


FIGURE 106. INVERSE ANALYSIS (SPECIES CLUSTER) OF TOP 50 DIATOM TAXA.

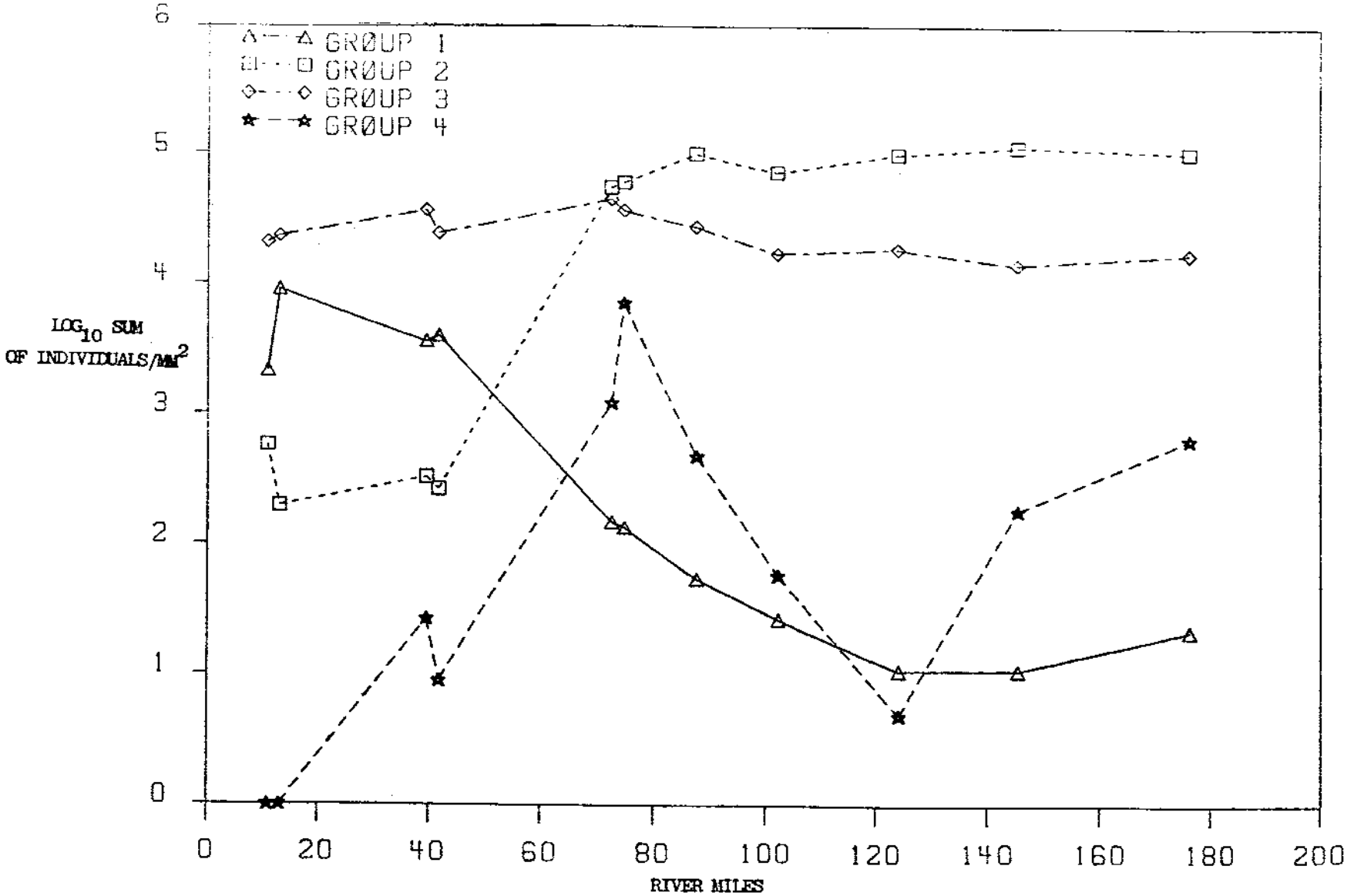


FIGURE 107. DIATOM SPECIES GROUPS DENSITY BY RIVER MILES.

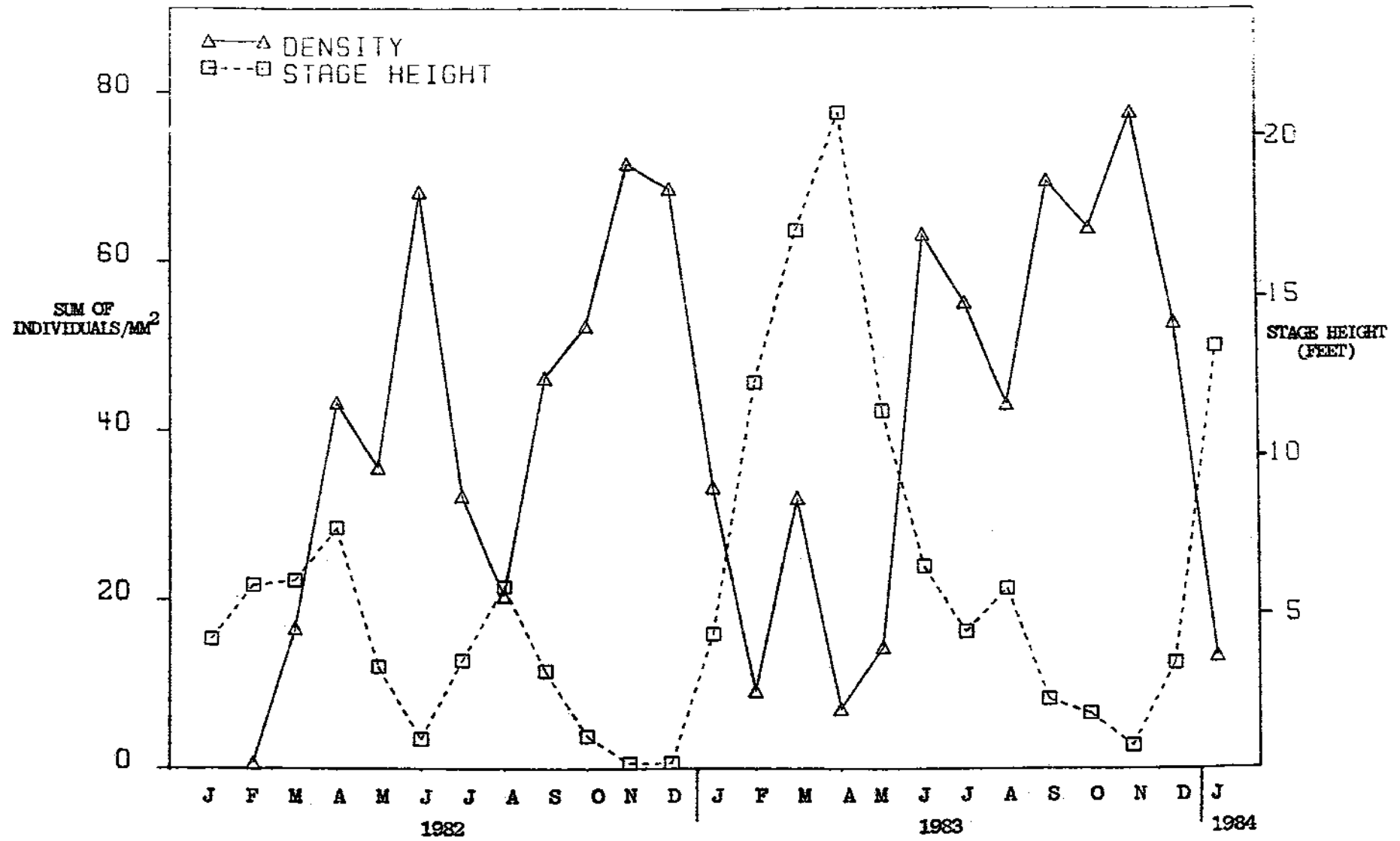


FIGURE 108. DIATOM DENSITY COMPARED WITH AVERAGE STAGE HEIGHT BY SAMPLING MONTH.

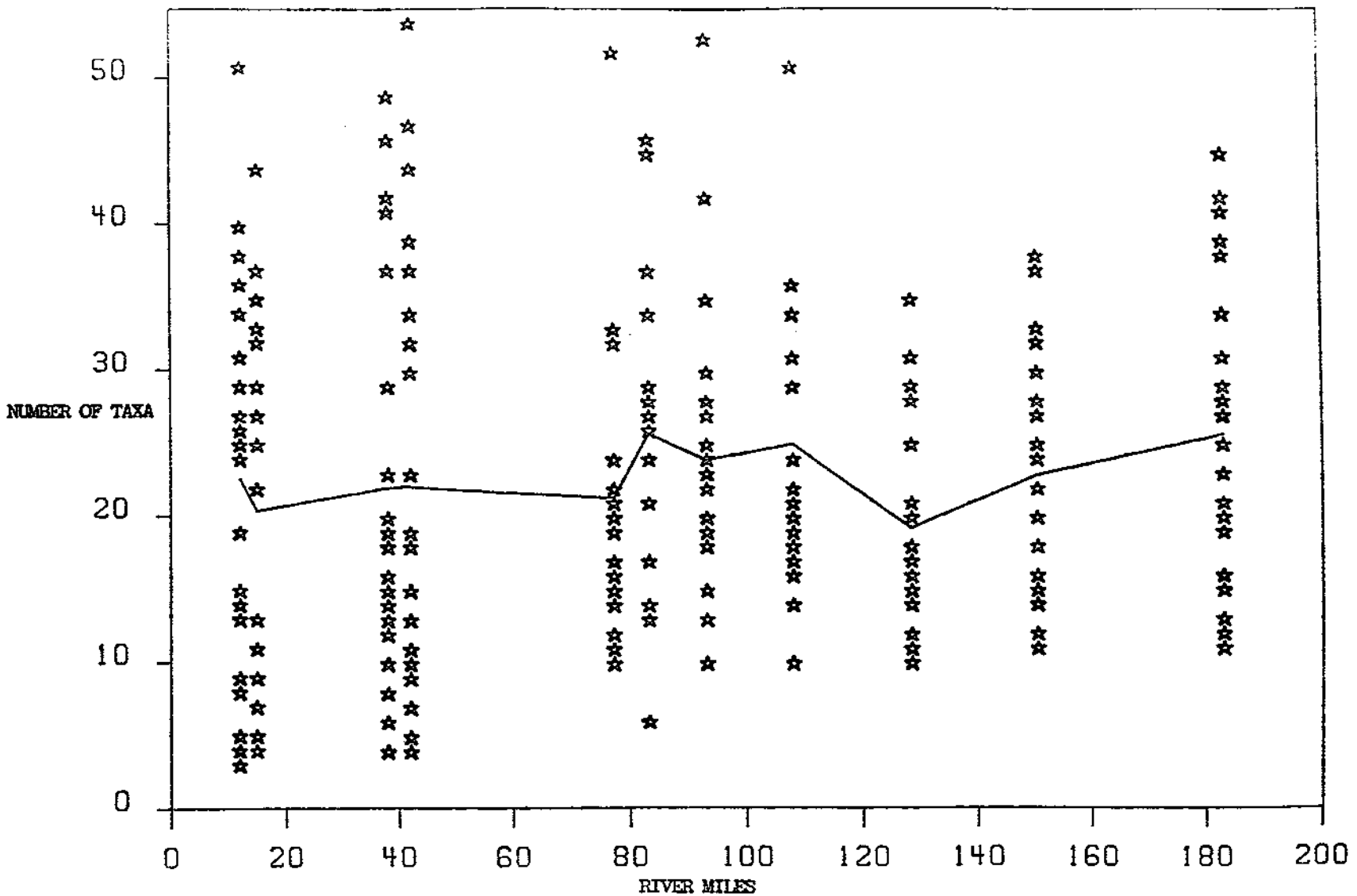


FIGURE 109. ACTUAL VALUES FOR THE NUMBER OF DIATOM TAXA CALCULATED EACH MONTH AND MEAN NUMBER OF TAXA BY RIVER MILES.

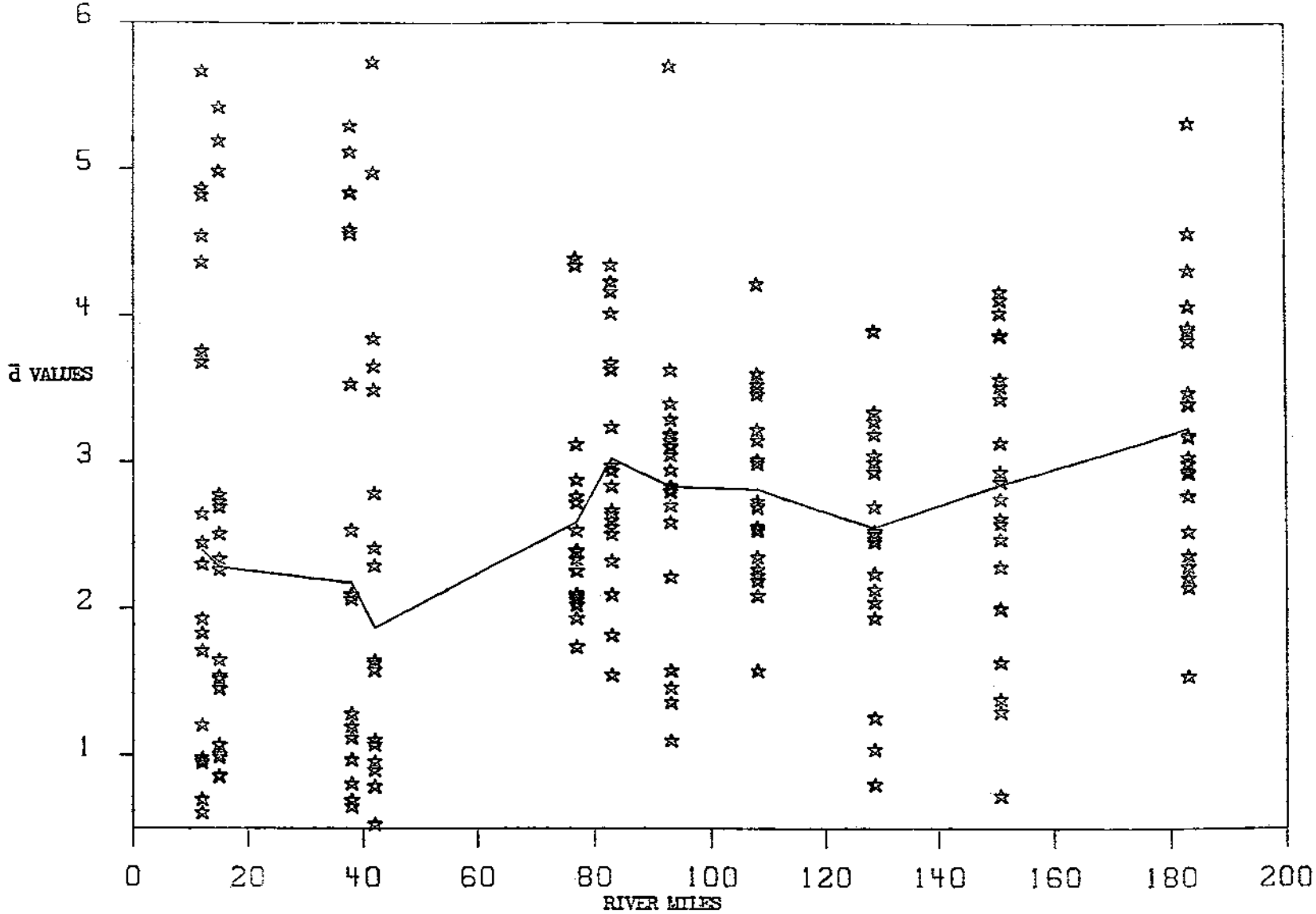


FIGURE 110. ACTUAL $\bar{d}$ VALUES CALCULATED EACH MONTH AND MEAN $\bar{d}$ BY RIVER MILES.

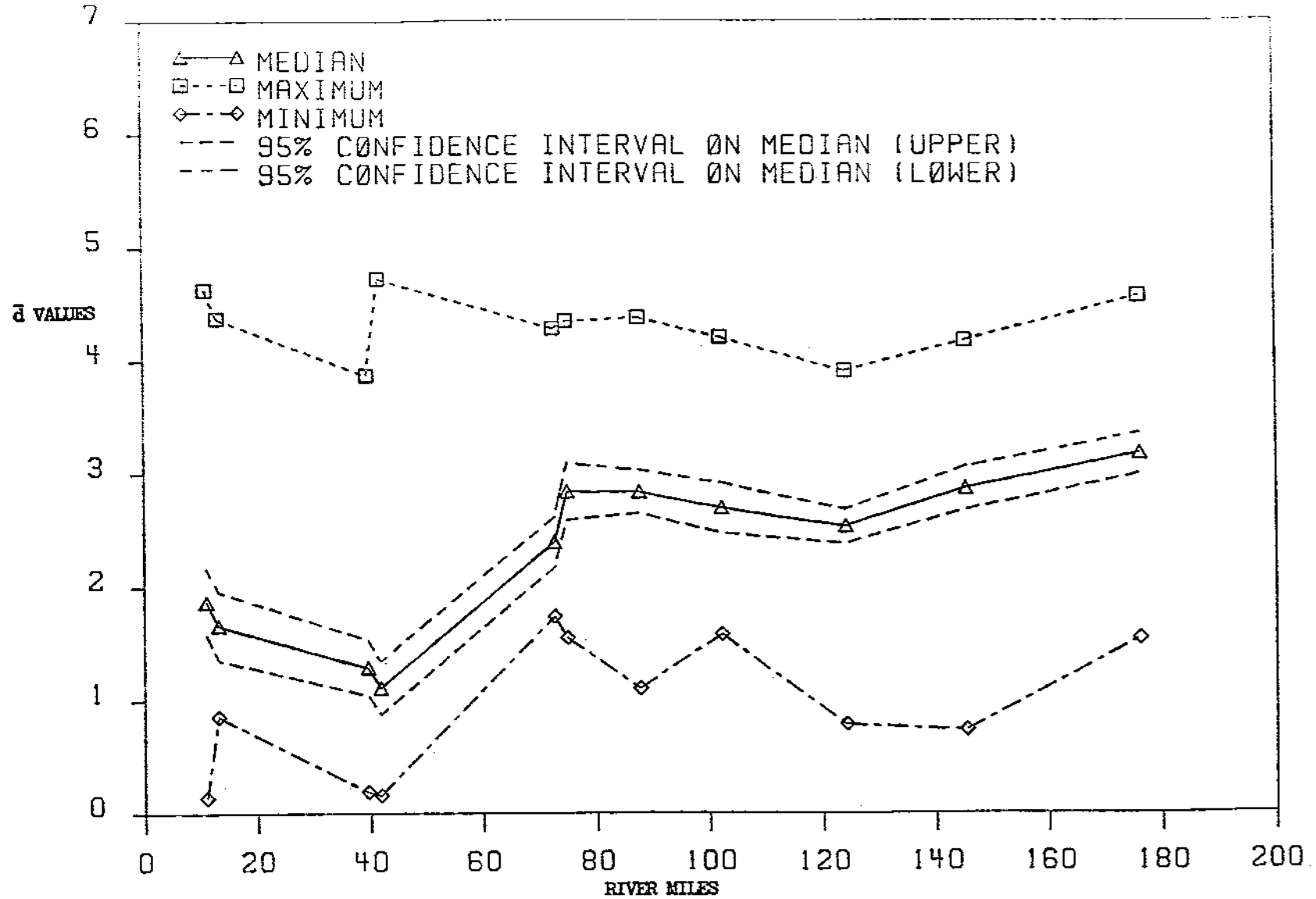


FIGURE 111. MEDIAN $\bar{d}$ VALUES WITH 95% CONFIDENCE INTERVALS, MAXIMUM $\bar{d}$ AND MINIMUM $\bar{d}$ BY RIVER MILES.

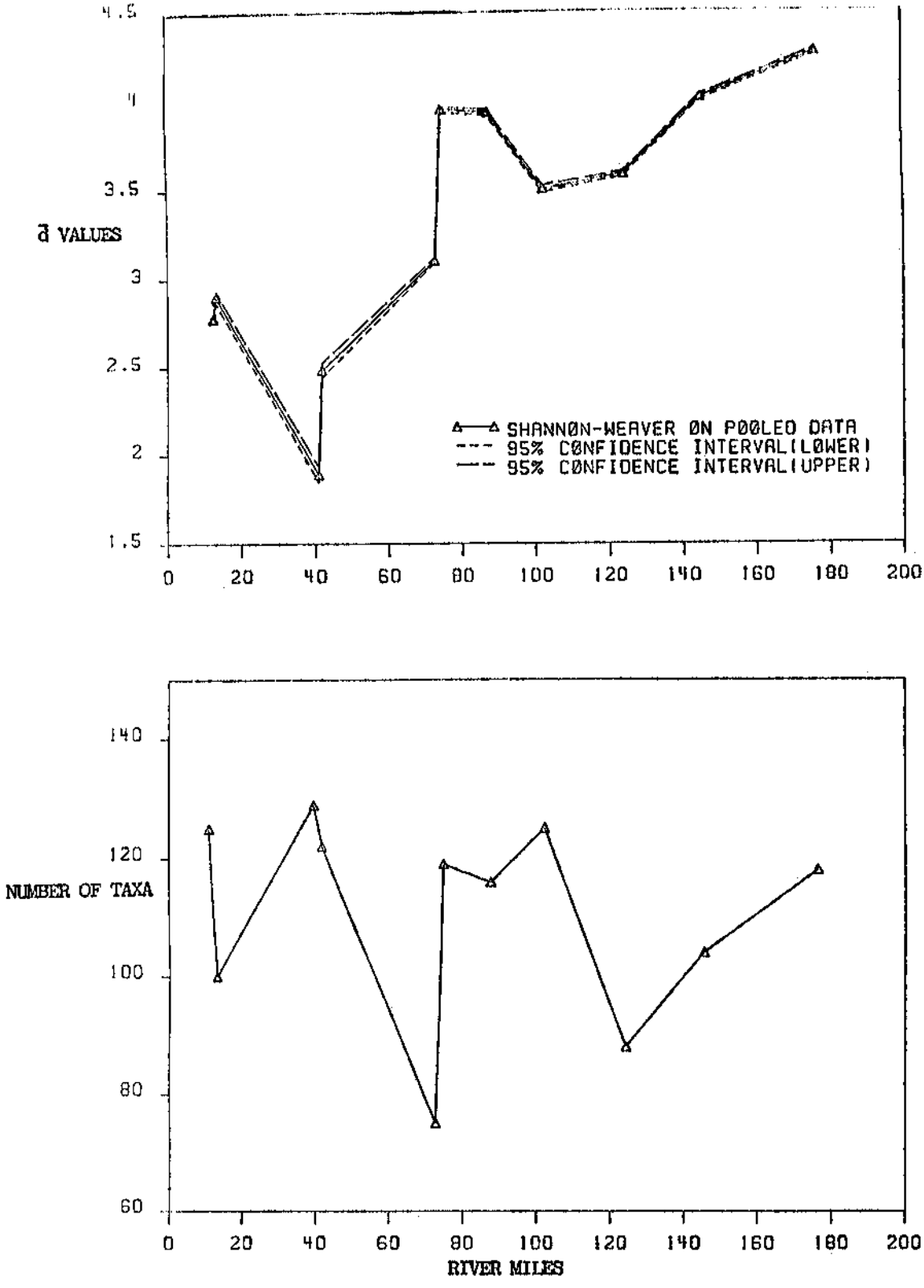


FIGURE 112. $\bar{d}$ VALUES WITH 95% CONFIDENCE INTERVALS AND NUMBER OF TAXA CALCULATED FROM POOLED DATA

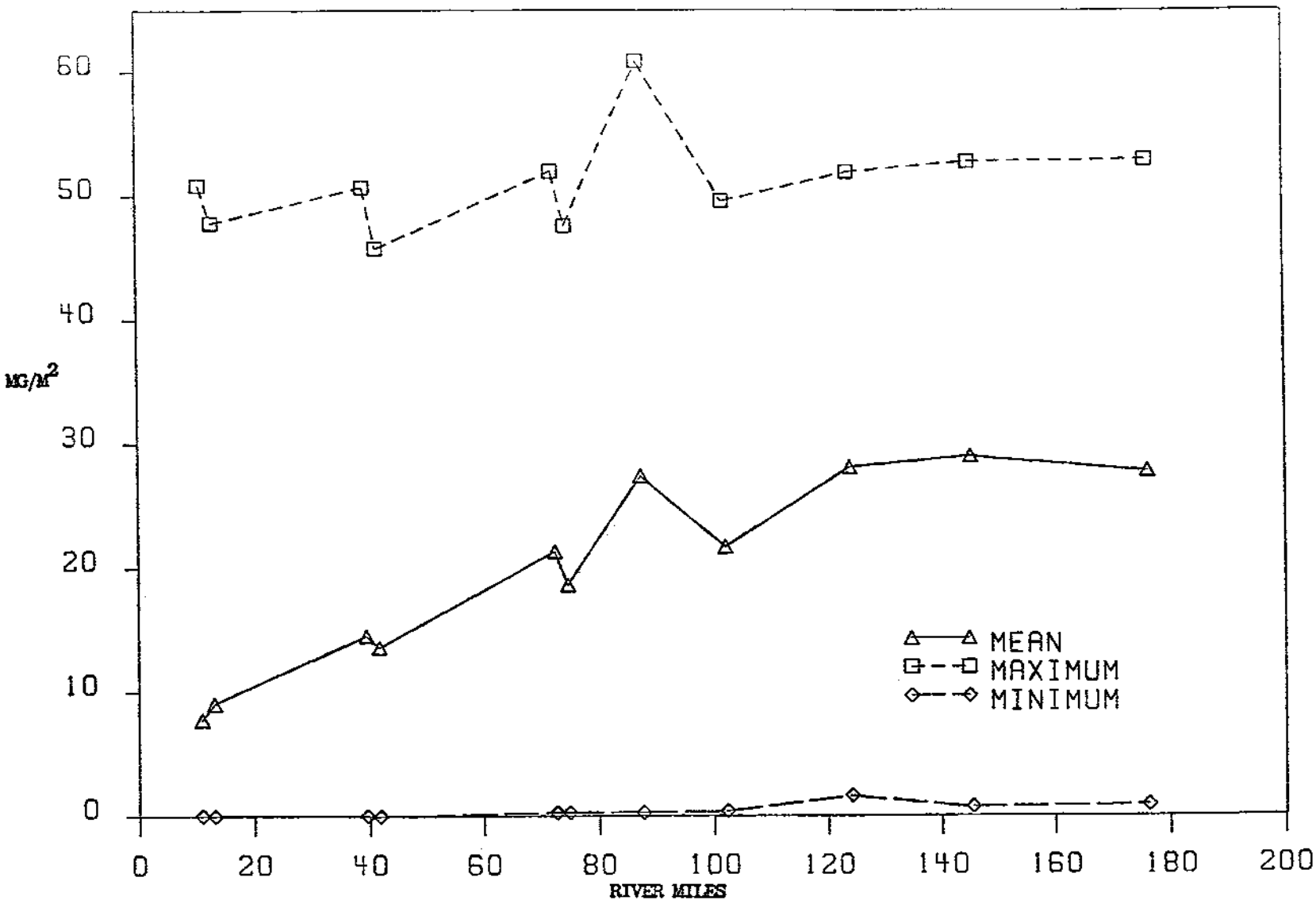


FIGURE 113. MEAN, MAXIMUM, AND MINIMUM VALUES FOR CHLOROPHYLL A BY RIVER MILES.

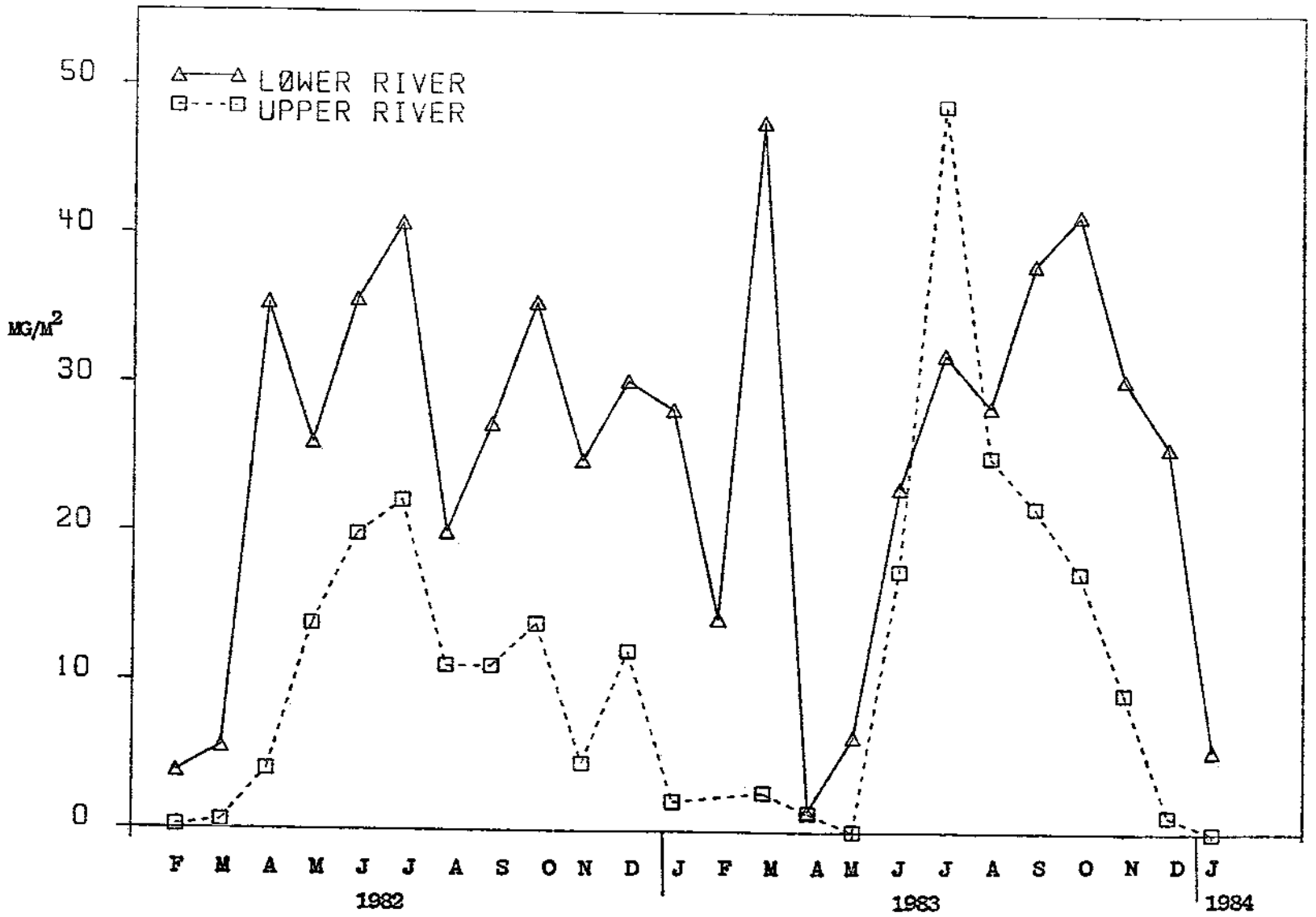


FIGURE 114. MEAN CHLOROPHYLL A VALUES FOR THE UPPER AND LOWER RIVER STATIONS.

TABLE 27. MISSING PERIPHYTON DATA

DATES MISSING

STATION #	1982	1983	1984
1	Sept., Dec.	Feb.	
2	May	Feb., June, Aug.	
3	Apr., Aug.	Feb.	
4		Feb., May	
5	Feb., May	Jan., Feb., Mar., May	
6	Feb., July	Feb., Mar.	
7		Mar., May	
8	Apr., May	Mar.	
9	May	Mar.	Jan.
10	Apr.		
11	Apr.		

TABLE 28. PERIPHYTON GENERA OF THE SUWANNEE RIVER

Chlorophyceae

Actinastrum sp.
Ankistrodesmus sp.
Aphanochaete sp.
Bambusina sp.
Basicaladia sp.
Botrycoccus sp.
Characium sp.
Chlorococcum sp.
Chlorella sp.
Cladophora sp.
Closterium sp.
Chlamydomonas sp.
Coelastrum sp.
Coleochaete sp.
Cosmarium sp.
Cylindrocapsa sp.
Desmidium sp.
Elakatothrix sp.
Gloeocystis sp.
Groenbladia sp.
Haematococcus sp.
Kirchneriella sp.
Microspora sp.
Micrasterias sp.
Mougeotia sp.
Netrium sp.
Oedogonium sp.
Oocystis sp.
Pediastrum sp.
Pithophora sp.
Pleurotaenium sp.
Protoderma sp.
Rhizocolonium sp.
Scenedesmus sp.
Sphaerocystis sp.
Staurastrum sp.
Stigeocolonium sp.
Tetraedron sp.
Trochiscia sp.
Ulothrix sp.
Uronema sp.
Zygnema sp.
Unk. Chlorophyta sp.

Chrysophyceae

Characiopsis sp.
Ophiocytium sp.
Peroniella sp.
Stipitococcus sp.
Unk. Chrysophyta sp.

Cryptophyceae

Cryptomonas sp.

Cyanophyceae

Anabaena sp.
Anabaenopsis sp.
Aphanocapsa sp.
Aphanothece sp.
Borzia sp.
Calothrix sp.
Chamaesiphon sp.
Chlorogloea sp.
Chroococcus sp.
Coelosphaerium sp.
Dactylococcopsis sp.
Gloeotrichia sp.
Gomphasphaeria sp.
Lyngbya sp.
Merismopedium sp.
Microcystis sp.
Nodularia sp.
Nostoc sp.
Oscillatoria sp.
Phormidium sp.
Pseudanabaena sp.
Rhaphidiopsis sp.
Rhabdoderma sp
Rivularia sp.
Spirulina sp.
Stigonema sp.
Unk. Cyanophyta sp.

Pyrrhophyceae

Gymnodinium sp.
Peridinium sp.

Euglenophyceae

Ascoglena sp.
Colacium sp.
Euglena sp.
Leplocinclis sp.
Phacus sp.
Trachelomonas sp.
Unk. Euglenophyta sp.

TABLE 29. DIATOM TAXA OF THE SUWANNEE RIVER

CENTRIC DIATOMS

Cyclotella atomus Hust.
C. meneghiniana Kütz.
Melosira italica (Ehr.) Kütz.
M. varians C. A. Ag.
Melosira sp. 1
Melosira sp. 2
Stephanodiscus invisitatus Hohn

PENNATE DIATOMS

Achnanthes affinis Grun.
A. clevei Grun.
A. clevei var. rostrata Hust.
A. clevei var. 1
A. curvirostrum Brun.
A. delicatula (Kütz.) Grun.
A. exigua Grun.
A. exigua var. constricta (Grun.) Hust.
A. exigua var. heterovalva Krasske
A. hauckiana Grun.
A. hauckiana var. rostrata Schulz
A. hungarica (Grun.) Grun.
A. lanceolata (Bréb.) Grun.
A. lanceolata var. apiculata Patr.
A. lanceolata var. dubia Grun.
A. lanceolata var. omissa Reim.
A. lanceolata var. 1
A. linearis (W. Sm.) Grun.
A. minutissima Kütz.
A. rupestoides Hohn
A. wellsiae Reim.
Achnanthes sp. 1
Amphora ovalis var. affinis (Kütz.) V.H. ex De T.
A. perpusilla (Grun.) Grun.
Amphora sp. 1
Amphora sp. 2
Amphipleura pellucida Kütz.
Asterionella formosa Hassell
Bacillaria paradoxa Gmelin
Biddulphia laevitalis (Ehr.)
Caloneis bacillum (Grun.) Cl.
C. hyalina Hust.
C. limosa (Kütz.) Patr.
Carpartogramma crucicula (Grun. ex Cl.) Ross
Cocconeis diminuta Pant.
C. fluviatilis Wallace
C. placentula Ehr.

C. placentula var. euglypta (Ehr.) Cl.
C. placentula var. lineata (Ehr.) V.H.
C. thumensis A. Meyer
Cocconeis sp. 1
Cocconeis sp. 2
Cocconeis sp. 3
Cymbella aspera (Ehr.) H. Perag.
C. lunata W. Sm.
C. minuta Hilse ex. Rabh.
C, minuta var. silesiaca (Bleisch ex Rabh.) Reim.
C. naviculiformis Auersw. ex Heib.
C. tumida (Bréb. ex Kütz.) V.H.
Cymbella sp. 1
Desmogonium rabenhorstianum var. elongatum Patr.
Diploneis sp. 1
Diploneis sp. 2
Diploneis sp. 3
Diploneis sp. 4
Epithemia adnata var. minor (Perag. & Herib.) Patr.
E. adnata var. proboscidea (Kütz.) Patr.
Eunotia elegans Østr.
E. faba (Ehr.) Grun.
E. fallax A. Cl.
E. fastigiata Hust.
E. flexuosa Bréb. ex Kütz.
E. incisa W. Sm. ex Greg.
E. levistrata Hust.
E. maior (W. Sm.) Rabh.
E. meisteri Hust.
E. monodon Ehr.
E. monodon var. constricta Cl.-Eul.
E. naegelii Migula
E. pectinalis (O. F. Mull.?) Rabh.
E. pectinalis var. minor (Kütz.) Rabh.
E. pectinalis var. undulata (Ralfs) Rabh.
E. pectinalis var. ventricosa Grun.
E. perpusilla Grun.
E. tautoniensis Hust. ex Patr.
E. tenella (Grun.) Cl.
E. trinacria Krasske
E. vanheurckii var. intermedia (Krasske ex Hust.) Patr.
E. veneris (Kütz.) O. Mull.
E. zygodon Ehr.
Eunotia sp. 1
Eunotia sp. 2
Eunotia sp. 3
Eunotia sp. 4
Eunotia sp. 5
Eunotia sp. 6
Eunotia sp. 7
Fragilaria construens (Ehr.) Grun.
F. construens var. venter (Ehr.) Grun.
F. leptostauron var. dubia (Grun.) Hust.

Frustulia rhomboides (Ehr.) De T.
F. rhomboides var. amphipleuroides (Grun.) Cl.
F. rhomboides var. capitata (A. Mayer) Patr.
F. rhomboides var. crassinervia (Bréb. ex W. Sm.) Ross
F. rhomboides var. saxonica (Rahb.) De T.
Frustulia sp. 1
Gomphonema affine Kütz.
G. angustatum (Kütz.) Rabh.
G. brasiliense Grun.
G. carolinense Hagelst.
G. clevei Fricke
G. gracile Ehr. emend. V.H.
G. parvulum (Kütz.) Grun.
Gomphonema sp. 1
Gomphonema sp. 2
Gomphonema sp. 3
Gomphonema sp. 4
Gomphonema sp. 5
Gomphonema sp. 6
Gomphonema sp. 7
Gomphonema sp. 8
Gomphonema sp. 9
Gomphonema sp. 10
Gomphonema sp. 11
Gomphonema sp. 12
Gyrosigma acuminatum (Kütz.) Rabh.
G. spencerii var. curvula (Grun.) Reim.
Gyrosigma sp. 1
Hantzchia amphioxys var. vivax (Hantzch) Grun.
H. virgata var. capitellata Hust.
Meridion circulare var. constrictum (Ralfs) V.H.
Navicula arvensis Hust.
N. capitata Ehr.
N. capitata var. hungarica (Grun.) Ross
N. cinta (Ehr.) Kütz.
N. cocconeiformis Greg. ex Grev.
N. contenta var. biceps (Arn.) V.H.
N. cuspidata (Kütz.) Kütz.
N. dystrophica Patr.
N. exigua Greg. ex Grun.
N. exigua var. capitata Patr.
N. gastrum (Ehr.) Kütz.
N. gottlandica Grun.
N. graciloides A. Mayer
N. gregaria Donk.
N. gysingensis Foged
N. lanceolata (Ag.) Kütz
N. minuscula Grun.
N. mutica var. cohnii (Hilse) Grun.
N. mutica var. stigma Patr.
N. mutica var. tropica Hust.
N. paucivisitata Patr.
N. pellicolosa (Bréb. ex Kütz.) Hilse
N. pupula Kütz.

N. pupula var. rectangularis (Greg.) Grun.
N. radiosa Kütz.
N. radiosa var. tenella (Bréb. ex Kütz.) Grun.
N. rhynchocephala Kütz.
N. rhynchocephala var. germainii (Wallace) Patr.
N. salinarum Grun.
N. schroeteri var. escambia Patr.
N. subtilissima Cl.
N. tripunctata (O. Mull.) Bory
N. viridula var. linearis Hust.
Navicula sp. 1
Navicula sp. 2
Navicula sp. 3
Navicula sp. 4
Navicula sp. 5
Navicula sp. 6
Navicula sp. 7
Navicula sp. 8
Navicula sp. 9
Navicula sp. 10
Navicula sp. 11
Navicula sp. 12
Navicula sp. 13
Navicula sp. 14
Navicula sp. 15
Navicula sp. 16
Navicula sp. 17
Navicula sp. 18
Navicula sp. 19
Navicula sp. 20
Navicula sp. 21
Navicula sp. 22
Navicula sp. 23
Navicula sp. 24
Navicula sp. 25
Navicula sp. 26
Neidium affine (Ehr.) Pfitz.
N. apiculatum Reim.
N. iridis (Ehr.) Cl.
N. iridis var. amphigomphus (Ehr.) A. Mayer
N. iridis var. 1
N. ladogense var. densestriatum (Østr.) Foged
Neidium sp. 1
Neidium sp. 2
Nitzchia accomodata Hust.
N. acicularis W. Sm.
N. amphiovoides Hust.
N. amphibia var. acutiuscula Grun.
N. filiformis (W. Sm.) Hust.
N. fonticola Grun
N. lorenziana var. densestriata Perag.
N. obtusa W. Sm.
N. palea var. debilis Grun.
N. parvula Lewis

N. sigma (Kutz.) W. Sm.
N. sigma var. rigidula Grun.
N. thermalis var. minor Hilse
Nitzchia sp. 1
Nitzchia sp. 2
Nitzchia sp. 3
Nitzchiz sp. 4
Nitzchia sp. 5
Opephora martyi Herib.
Pinnularia acrosphaeria W. Sm.
P. biceps Greg.
P. borealis var. brevicostata Hust.
P. braunii var. amphicephala (A. Mayer) Hust.
P. brebissonii (Kutz.) Cl.
P. divergens W. Sm.
P. divergens var. 1
P. mesolepta (Ehr.) W. Sm.
P. nodosa (Ehr.) W. Sm.
P. viridis (Nitz.) Ehr.
Pinnularia sp. 1
Pinnularia sp. 2
Pinnularia sp. 3
Pinnularia sp. 4
Pinnularia sp. 5
Pinnularia sp. 6
Pinnularia sp. 7
Pinnularia sp. 8
Pinnularia sp. 9
Pinnularia sp. 10
Pinnularia sp. 11
Pinnularia sp. 12
Rhopalodia gibba var. ventricosa (Kutz.) H. & M. Perag.
R. gibberula var. vanheurckii O. Mull.
R. musculus (Kutz.) O. Mull.
Stauroneis anceps Ehr.
S. livingstonii Reim.
S. smithii Grun.
Stauroneis sp. 1
Stauroneis sp. 2
Stauroneis sp. 3
Stauroneis sp. 4
Surirella angustata Kutz.
S. linearis W. Sm.
S. linearis var. constricta (Ehr.) Grun.
S. tenera var. nervosa A. Schmidt
Surirella sp. 1
Surirella sp. 2
Surirella sp. 3
Synedra acus Kutz.
S. fasciculata var. truncata (Grev.) Patr.
S. gaillonii (Bory) Ehr.
S. parasitica (W. Sm.) Hust.
S. pulchella Ralf ex Kutz.

S. rumpens Kütz.
S. rumpens var familiaris (Kütz.) Hust.
S. rumpens var fragilarioides Grun.
S. rumpens var. scotica Grun.
S. ulna (Nitz.) Ehr.
S. ulna var. amphirhynchus (Ehr.) Grun.
S. ulna var. danica (Kütz.) V.H.
S. ulna var. 1
Synedra sp. 1
Synedra sp. 2
Synedra sp. 3
Terpsinoe americana Ralfs

TABLE 30. SPECIES GROUPS AND THEIR ASSOCIATED PHYSICAL AND CHEMICAL PREFERENCES

GROUP I

1 Eunotia pectinalis - A,S
2 Eunotia sp. 3
3 Eunotia sp. 6
4 Eunotia tenella - A,S
5 Eunotia vanheurickii var. intermedia - O
6 Frustulia rhomboides - A,S

GROUP II

1 Achnanthes affinis - B, C
2 Achnanthes hungarica - B
3 Achnanthes lanceolata - B, H, L
4 Achnanthes lanceolata var. 1 - I, W, S, C
5 Achnanthes lanceolata var. dubia - B, H, L
6 Achnanthes lanceolata var. omissa - B
7 Achnanthes linearis - I
8 Achnanthes minutissima - I, S, O
9 Achnanthes rupestoides
10 Bacillaria paradoxa - I, O
11 Bidulphia laevis - B
12 Cocconeis fluviatilis
13 Cocconeis placentula - B, W, C
14 Cocconeis placentula var. euglypta - B, C
15 Cocconeis placentula var. lineata - B, C
16 Cymbella minuta - B, H, N
17 Gomphonema angustatum - B, E
18 Gomphonema gracile - I
19 Gomphonema parvulum - I, H, W, N, C
20 Gomphonema sp. 4
21 Navicula graciloides - I, H
22 Nitzchia filliformis
23 Synedra gaillonii
24 Synedra rumpens
25 Synedra rumpens var. familiaris

GROUP III

1 Achnanthes exigua - B, W, C
2 Achnanthes exigua var. heterovalva - B
3 Achnanthes clevei - B, W, C
4 Achnanthes lanceolata var. apiculata - I, S, W, C
5 Eunotia maior - A
6 Eunotia pectinalis var. minor - I, W, C
7 Eunotia sp. 4 - A
8 Melosira italica - I, W, C
9 Melosira varians
10 Navicula minuscula - C
11 Navicula pupula - I, W, C
12 Navicula rhynchocephala var. germainii - B, S
13 Navicula sp. 4
14 Navicula sp. 19
15 Navicula sp. 24
16 Nitzchia accomodata - B, W, E, C

GROUP IV

1 Cymbella minuta var. silesiaca - I, C
2 Gomphonema affine - W, C
3 Gomphonema sp. 10

KEY:

A = acidophilous
B = alkaliphilous
I = pH indifferent
S = soft water, low minerals
H = hard water, high minerals
C = cosmopolitan
W = eurytopic
O = oligotrophic
E = eutrophic
N = nitrogen heterotroph, possible pollution indicator
L = low organic pollution indicator

Based on: Hustedt 1930; Patrick and Reimer 1966, 1975; Lowe 1974; Evenson et al. 1981

TABLE 31. CORRELATIONS OF SELECTED PHYSICAL AND CHEMICAL PARAMETERS WITH DIATOM DENSITY.

Species/Group/Parameter	Average Temperature	Average Stage Height	Average pH
Diatoms	.417*	-.434*	.402*
Achnanthes exigua var. heterovalva	.555*	-.724*	.500*
A. lanceolata var. 1	.575*	-.385*	.257 NS
Cocconeis placentula var. euglypta	.349*	-.743*	.496*
Gomphonema parvulum	-.055 NS	.335 NS	-.303 NS
Eunotia pectinalis var. minor	.729*	-.325 NS	.330 NS
Cocconeis fluviatilis	.593*	-.677*	.476*
Achnanthes lanceolata	.313 NS	-.467*	.479*
A. lanceolata var. dubia	.208 NS	-.574*	.592*
Temperature		-.361*	-.045 NS
Stage Height			-.557*

* = Significant at the .05 level for 23 degrees of freedom

Method notes: Before correlating, densities were converted to a logarithmic scale.

Average stage heights for correlation with densities were calculated as average of daily readings at three stations (3, 9, 11) for each month.

Average stage heights for correlations with pH and temperature were calculated as an average of 3 stations (3, 9, 11) on the sampling day of each month.

Temperature and pH means are averages of the 11 stations on the sampling day of each month.

ALGAL GROWTH POTENTIAL AND LIMITING NUTRIENT ASSAYS

Introduction

Many studies of algal growth requirements have indicated that nitrogen and phosphorus play major roles in limiting algal growth (Miller et al. 1974; Miller et al. 1978). Other nutrients (e.g., Fe, Mn, Cu, Zn, Mo, V, B, Cl, Co, Si) are also necessary for algal growth (Clesceri 1973; Gerloff and Skoog 1957), but nitrogen and phosphorus are usually the primary nutrients limiting algal growth in natural waters (Gerhart et al. 1975; Miller et al. 1974; Shiroyama et al. 1975).

A method used to determine the limiting nutrient is the algal assay. The algal assay is based upon Liebig's Law of the Minimum which states that "maximum yield is proportional to the amount of a nutrient or combination of nutrients which are present and biologically available in minimal quantity in respect to the growth requirements of the organisms" (Miller et al. 1978)

The objectives of the algal assay portion of our study were to:

1) assess the current nutrient condition of the Suwannee River by measuring the algal growth potential,
2) determine the nutrient(s) that might be limiting algal growth in the river, and
3) determine if a major nutrient discharge on the Suwannee (Occidental Chemical Agricultural Products) had an effect on #1 and #2 above.

Methods and Materials

Algal assays, following methods described in "The Selenastrum capricornutum Printz Algal Assay Bottle Test" (Miller et al. 1978), were performed on water samples from 11 stations in the Suwannee River. Monthly water samples for the algal assays were collected in opaque two liter polyethylene jugs, placed on ice, and transported to the laboratory. In the laboratory, the samples were autoclaved to destroy any indigenous algae or bacteria. After cooling, the samples were filtered through prewashed Whatman glass fiber filters (GF/C) and 0.45 um membrane filters (Gelman GA/6). Prewashing the filters with distilled water was necessary to remove phosphate detergents used in manufacturing the filters (Cahn 1967). Sixty ml aliquots of the filtered samples were placed in 250ml Erlenmyer flasks and "spiked" with predetermined levels of nitrogen, phosphorus, and disodium (ethylenedinitrilo) tetraacetate (EDTA). EDTA is a synthetic organic ligand which is added to media or test waters

to assure that necessary trace elements are available to support algal growth (Miller et al. 1978).

Five nutrient spikes were used: Nitrogen (1.0mg/l); phosphorus (0.1mg/l); EDTA (1.0mg/l); nitrogen and phosphorus (1.0mg/l N plus 0.1mg/lP); and a combination of N, P, and EDTA (1.0mg/l N plus 0.1mg/l P plus 1.0mg/l EDTA). Unspiked water from each station was used as a control and to determine algal growth potential. The spiked samples were placed on shaker racks under constant lighting (400 ± 10% ft-C) and temperature (22 ± 2°C) to acclimate for 24 hours. After acclimation, the samples were innoculated with approximately 1,000 cells/ml of 7-10 day old test algae. The alga we selected was Selenastrum capricornutum Printz, a unicellular green alga, originally obtained from the E.P.A. Environmental Research Laboratory in Corvallis, Oregon, and cultured in the FDER laboratory (Roll 1981). A growth reference sample series was used to check the viability of the test algae and the nutrient spikes. The growth reference consisted of artificial growth media (PAAP) (Miller et al. 1978) as a control and PAAP media which had various nutrients omitted and added.

The growth reference series consisted of:

PAAP
PAAP - P
PAAP - P + P Spike
PAAP - N
PAAP - N + N Spike
PAAP - EDTA
PAAP - EDTA + EDTA Spike

The sample series consisted of:

Control
Control + N Spike
Control + N + P Spikes
Control + E Spike
Control + P Spike
Control + N + P + E Spikes

The growth response of the algae was monitored for 14 days by cell counts performed on days 1, 4, 7, 11, and 14 with an electronic particle counter (Coulter Model ZBI) equipped with a mean cell volume attachment. The cell counts and mean cell volume data were entered into a computer program, ALGASSY (Miller et al. 1978), which produced a summary of calculated dry weight yields. Algal growth curves (mean dry weights vs. time) were plotted and a graph produced for each spike and control over the 14 day period by the computer program ASSYPLOT (Miller et al. 1978).

The following definitions should be helpful in interpreting the results of the algal assays:

MSC: Maximum Standing Crop - Maximum dry weight in mg/l produced during the 14-day incubation period.

Inhibition: No significant increase of maximum standing crop (MSC) in any nutrient spiked sample over the control. (In many cases there were significant differences between actual assay results and predicted results, yet, the limiting nutrient could be determined by a significant increase in a particular spike.)

Co-limitation: When the MSC's of both the N and P spiked samples were significantly greater than control, but were not significantly different from each other; or when the only spike(s) significantly different from the control were the N + P spike and/or the N + P + E spikes.
P-limitation: Significant maximum standing crop responses are obtained only by addition of phosphorus, singly and/or in combination with nitrogen and EDTA.
N-limitation: Significant maximum standing crop responses are obtained only by addition of nitrogen, singly and/or in combination with phosphorus and EDTA.
AGP: Algal Growth Potential, expressed in mg/l. The assay results of an unspiked sample, based on nutrient availability.
Predicted AGP or MSC Yield: Calculation based on a growth factor of 430 ±86 mg algal dry weight per milligram of ortho-phosphate and 38 ±7.6 mg algal dry weight per mg of nitrogen for Selenastrum capricornutum (Miller et al. 1978). Other investigators have determined higher yield factors for phosphate. Claesson (1978), Toerien et al. (1971), Gerhold and Otto (1976), and Kotai et al. (1978) reported phosphate yield factors of 640mg/l, 805mg/l, 700mg/l, and 500mg/l dry weight, respectively. The nitrogen yield factor reported by these investigators is similar (38mg/l dry weight).
Bioavailability: The quantity of a nutrient(s) that is available for the algae to metabolize. Total soluble inorganic nitrogen (TSIN) and ortho-phosphate (oP) bioavailability for Selenastrum capricornutum are calculated as follows:

TSIN bioavailability: by dividing the phosphate spiked sample MSC by the nitrogen yield factor, (38 ±7.6 mg per mg algal dry weight of N).

oP bioavailability: by dividing the nitrogen spiked sample MSC by the phosphate yield factor (430 ±86 mg per mg algal dry weight of P).

Results And Discussion

The soft, acidic, and highly colored river water presented a problem in determing limiting nutrients, especially at the upper river stations. Algal growth in samples from Stations 1, 2, 3, and sometimes Station 4, was evidently inhibited by the low pH noted in this part of the river (see Fig. 115). Growth inhibition of Selenastrum capricornutum Printz at low pH has been noted (Miller et al. 1978), possibly by metabolic inhibition (Stewart 1974). Below pH 5 growth was severely inhibited. The optimal range of pH for Selenastrum has been reported as from pH 6 - pH 10 (Miller et al. 1978). However, the yield at pH 5.0 was only 13% less than the mean of the yields from pH 6 - pH 10. Since the mean pH for the upper 4 stations ranged from approximately 4.0 to 5.1, and was often < 4.0, growth inhibition due to low pH at these stations was suspected. Although pH inhibition in the upper river resulted in low algal growth; the data are being presented to characterize the entire portion of the Suwannee River we sampled. Algal assays for 24 of 25 dates, conducted on samples from 11 stations, were successfully completed

for March, 1982 was terminated because of growth inhibition caused by flask plugs which were evidently toxic to the test algae.

Limiting Nutrients

There were 264 individual samples assayed. Of these, 171 (64.8%) were nitrogen limited, 25 (9.5%) were phosphorus limited, 24 (9.1%) were co-limited, and 3 (1.1%) were limited by substances other than nitrogen and phosphorus (Table 32). Forty-one (15.9%) of the assayed samples did not respond to nutrient additions and so a limiting nutrient(s) could not be determined. A determination of limiting nutrients (N, P, and N plus P) based upon chemical analysis indicates that nitrogen should have been limiting 266 times (98.5%) phosphorus 3 times (1.1%) and one sample should have been co-limited (0.4%). The percentages are based on 270 complete chemical ratios rather than 275 as there were five missing chemical data.

The prediction of limiting nutrients from chemical analysis is based upon the TSIN:oP ratios from filtered water samples. A ratio of < 10:1 suggests nitrogen as the limiting nutrient, a ratio of > 11:1 suggests phosphorus limitation and a ratio of 10 - 11:1 suggests co-limitation (N and P) (Miller et al. 1974; Shiroyama et al. 1975; Miller et al. 1978). These ratios are approximations and nutrient limitation based on the chemical ratios do not always parallel the results of the algal assay.

The means of total soluble inorganic nitrogen (TSIN) and ortho-phosphate (oP) varied throughout the river (see Fig. 116, 117, and Table 33). Generally, both TSIN and oP increased from Station 1 through Station 4 at which point there was an abrupt increase in both parameters. The increase between Stations 1 and 2 for $\bar{x}$ TSIN was 18.8% and for $\bar{x}$ oP was 139%. The increase at Station 4 over Station 3 was 170.5% for $\bar{x}$ TSIN and 988.4% for $\bar{x}$ oP. Since Station 2 is located downstream of Hunter Creek and Station 4 is located downstream of Swift Creek these data indicate that very high levels of nitrogen and phosphorus enter the river from these sources (Oxy's phosphate mining and fertilizer production operations). Between Stations 4 and 5, $\bar{x}$ oP decreased by 249% and $\bar{x}$ TSIN decreased by 56%. After Station 5, the $\bar{x}$ TSIN began to increase steadily throughout the remainder of the river, while $\bar{x}$ oP continued to decrease (Fig. 118). These changes in nutrient concentrations are more fully discussed in the Water Chemistry section of this report.

Results of limiting nutrient assays (Fig. 119, Table 32) indicate that nitrogen was the primary limiting nutrient. The percentage of samples in which nitrogen was limiting increased from the upper river through the middle river and then decreased in the lower portion of the river.

Limiting nutrient determinations could only be made in approximately 30% of the samples from Stations 1 and 2, since pH inhibition of algal growth was most evident at those stations. Inhibition was less noticeable at Stations 3 and 4 and disappeared completely by Station 5. Although P was the limiting nutrient a few times (5) at Stations 1 - 4, it was limiting in up to 33% of

the samples from Stations 9, 10 and 11. This was likely the result of the decreased oP concentrations and increased TSIN at Stations 9, 10, and 11 (Table 33), although N:P ratios for the lower river remained sufficiently low as to suggest, on a chemical basis, that P-limitation should have been detected much less frequently.

The bioavailability (Table 34) of the TSIN of the test waters was less than 25.1% at Stations 1, 2, and 3. At Station 4, TSIN bioavailability increased to 75.7% and ranged from 58.2% to 131.8% for the remaining stations. TSIN bioavailability > 100% may indicate that other sources of nitrogen were being utilized by the test algae (Claesson 1980). The bioavailability (Table 34) of the oP increased from Station 1 (15.2%) through Station 3 (27.8%), dropped to 4.8% at Station 4, and then gradually increased from Station 5 (19.1%) through Station 11 (44.9%). The low bioavailability of nutrients at the upper stations is most probably because of inhibition of the test algae by low pH.

The predicted algal growth potential (Table 34), based on TSIN and oP concentrations of the test waters, is the MSC of the test algae that could be produced if all other nutrients were in excess and all of the TSIN and oP were bioavailable. The predicted yield based on TSIN closely parallels the actual AGP yield (at least at the stations uninhibited by low pH) (Table 34) and is further evidence for N being the primary limiting nutrient during our study.

Algal Growth Potential (AGP)

A general increase in AGP was noted from the upper river to the lower river (Fig. 120, Table 35) but the most significant increase in AGP was observed at Station 4. This was probably a reflection of the increased concentration and availability of nutrients at that station.

AGP correlated best with TSIN concentration (Fig. 121, Table 36). Since most samples were N-limited this was not unexpected. AGP was also highly correlated to the chlorophyll *a* and algal density of periphyton samples (Fig. 122). The AGP of our test algae paralleled the measurements of indigenous periphytic algae to a degree which indicated that *Selenastrum* growth in the lab was a reliable measurement of the bioavailability of nutrients and of conditions (excepting light penetration and current velocity) that might affect algal growth in the river.

River stage height was negatively correlated with AGP (Fig. 123). The maximum average AGP recorded for all eleven stations during a single sample month ($\bar{x}$=29.67 mg/l dry weight) occurred in November, 1982, which corresponded with the second lowest stage height. The minimum average AGP ($\bar{x}$=0.8427 mg/l dry weight) was observed in March, 1983, and corresponded with the period of maximum stage height.

These data suggest that increased flow may have reduced the nutrient concentrations through dilution while concurrently, the increased drainage from the Okefenokee Swamp decreased pH to levels which were inhibitory to the test algae. During periods

of low flow, reduced input of swamp water resulted in both a rise in pH to levels tolerable for the test organism, and an increased concentration of nutrients. These factors likely accounted for the higher AGP noted at those times.

The effect of pH on our test algae can be further demonstrated with the data in Table 37. Since Station 4 was where we generally first noted changes in pH and AGP in the upper river we decided to use pH differences at this station to indicate periods of inhibition. A pH of 5.0 was selected to divide the algal responses into inhibited (pH < 5.0) and non-inhibited (pH $\geq$ 5.0) sample groups.

At those times when pH at Station 4 was >5.0 (= little or no inhibition) not only was the average AGP higher but the utilization of the limiting nutrient was also greater. These periods coincided with periods of decreased stage height. The reverse was true when the pH at Station 4 was <5.0 (= inhibition). These periods coincided with periods of increased stage height. The exceptions to this occurred at the first three stations where the AGP, TSIN concentration, and percent utilization remained relatively constant and low regardless of the pH. Therefore, although it is obvious that the growth of our test algae was inhibited at all times of the year at Stations 1, 2 and 3, low pH effects at the remaining stations were noted principally during periods of increased stage height.

Conclusions

The algal growth potential of the Suwannee River generally increased from the upper river to the lower river; the exceptions being stations 1, 2, and 3 where AGP remained low and fairly constant. The largest single maximum standing crop (90.346 mg/l) was observed at Station 4 (below Swift Creek). The highest levels of nitrogen and phosphorus were also observed at Station 4.

The predominant limiting nutrient in the Suwannee River was nitrogen. Stations along the upper river although inhibited, were generally weakly nitrogen limited. The middle reach of the river was strongly nitrogen limited, in most cases, due almost certainly to sizeable phosphorus loading to the river. Both nitrogen and phosphorus limiting conditions were found in the lower river.

Low pH levels (pH < 5.0) generally inhibited algal growth at Stations 1, 2, and 3, sometimes at Station 4 and rarely at Station 5. When the pH at Station 4 was less than pH 5.0 nitrogen utilization at Station 4 was approximately 16.7%; however, when the pH at Station 4 was $\geq$ 5.0 the nitrogen utilization at Station 4 was approximately 87%.

AGP, nutrient levels, and pH were found to vary inversely with river stage height.

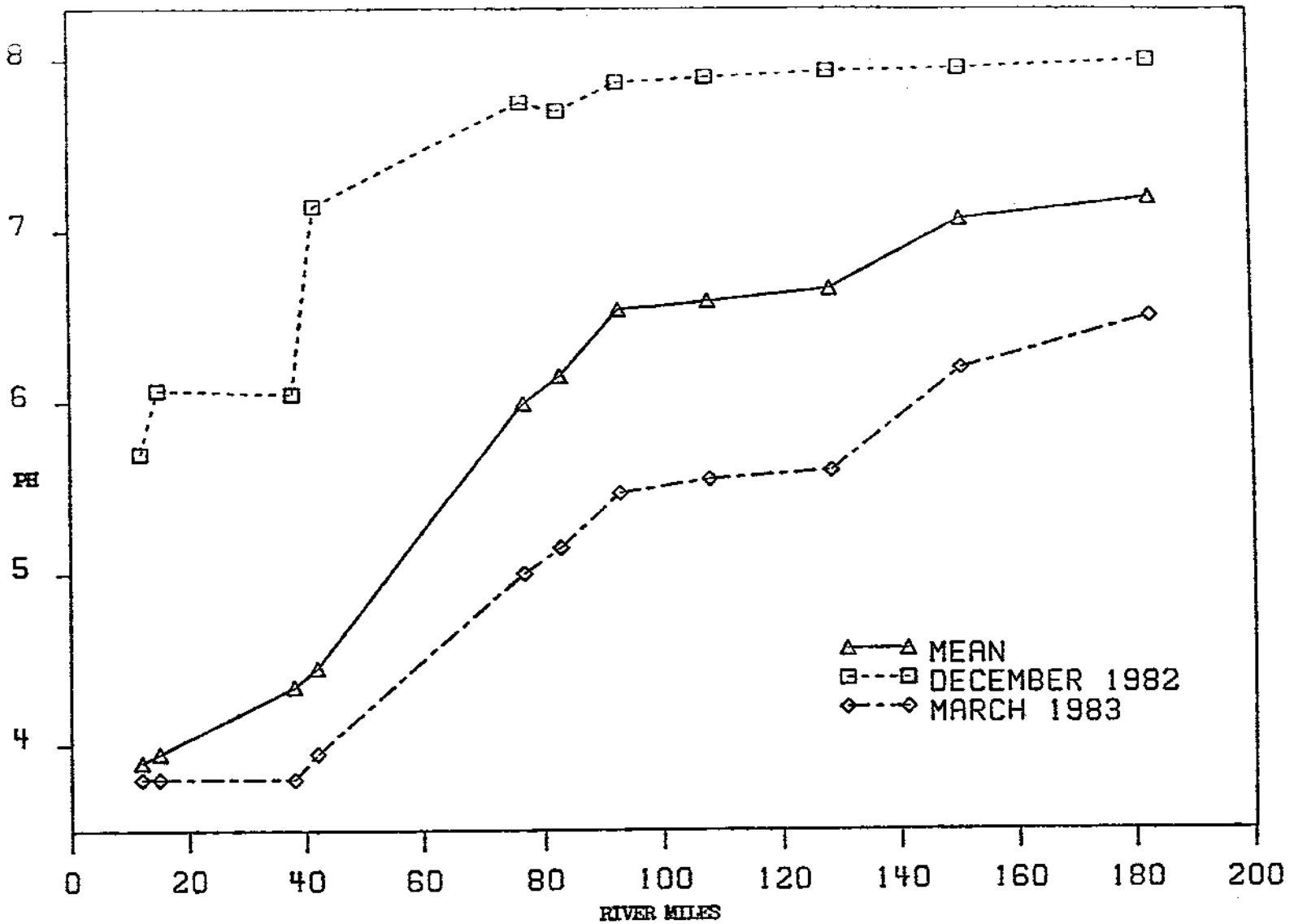


FIGURE 115. MEAN, MAXIMUM (BY MONTH) AND MINIMUM (BY MONTH) PH.

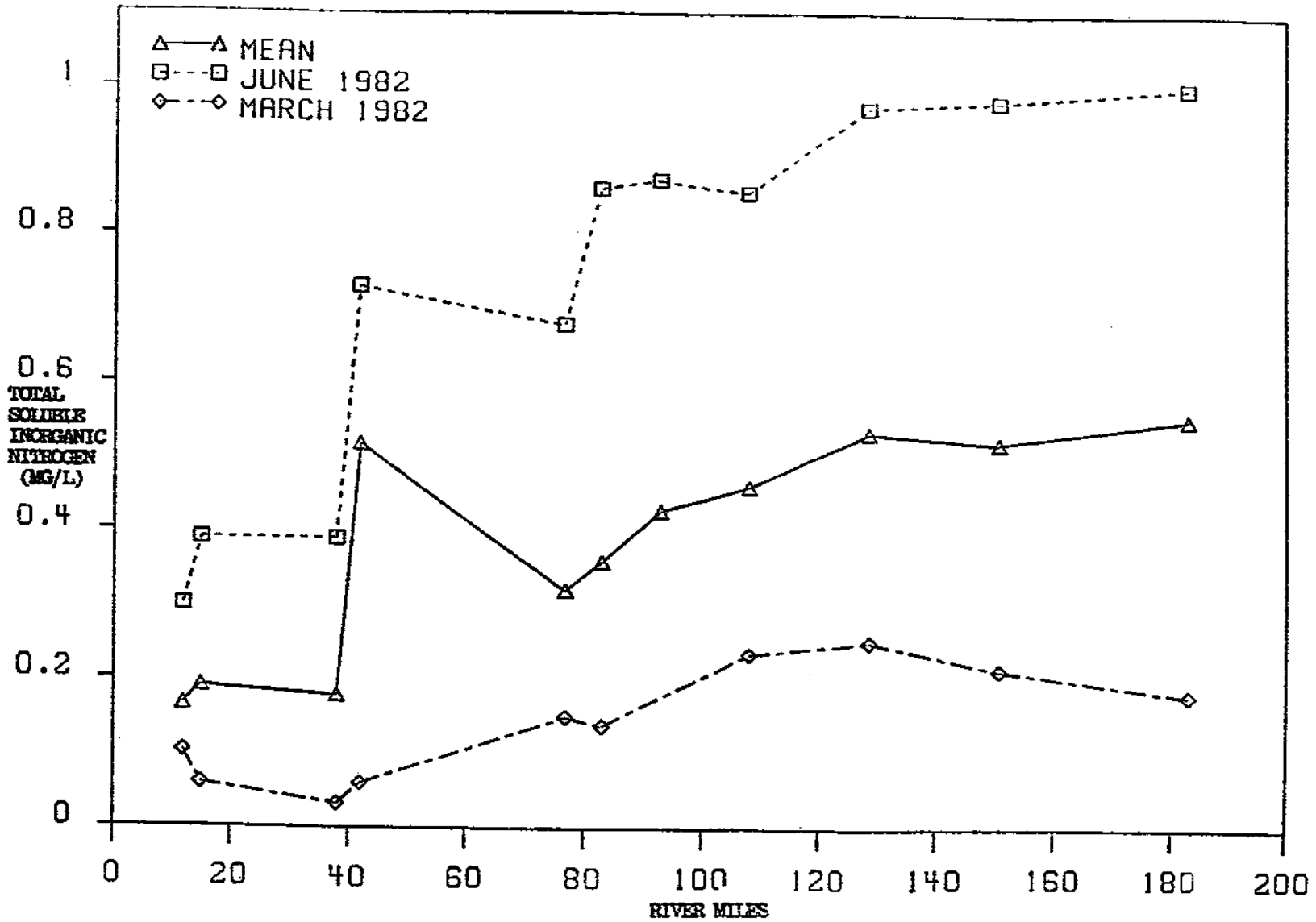


FIGURE 116. MEAN, MAXIMUM (BY MONTH) AND MINIMUM (BY MONTH) TOTAL SOLUBLE INORGANIC NITROGEN.

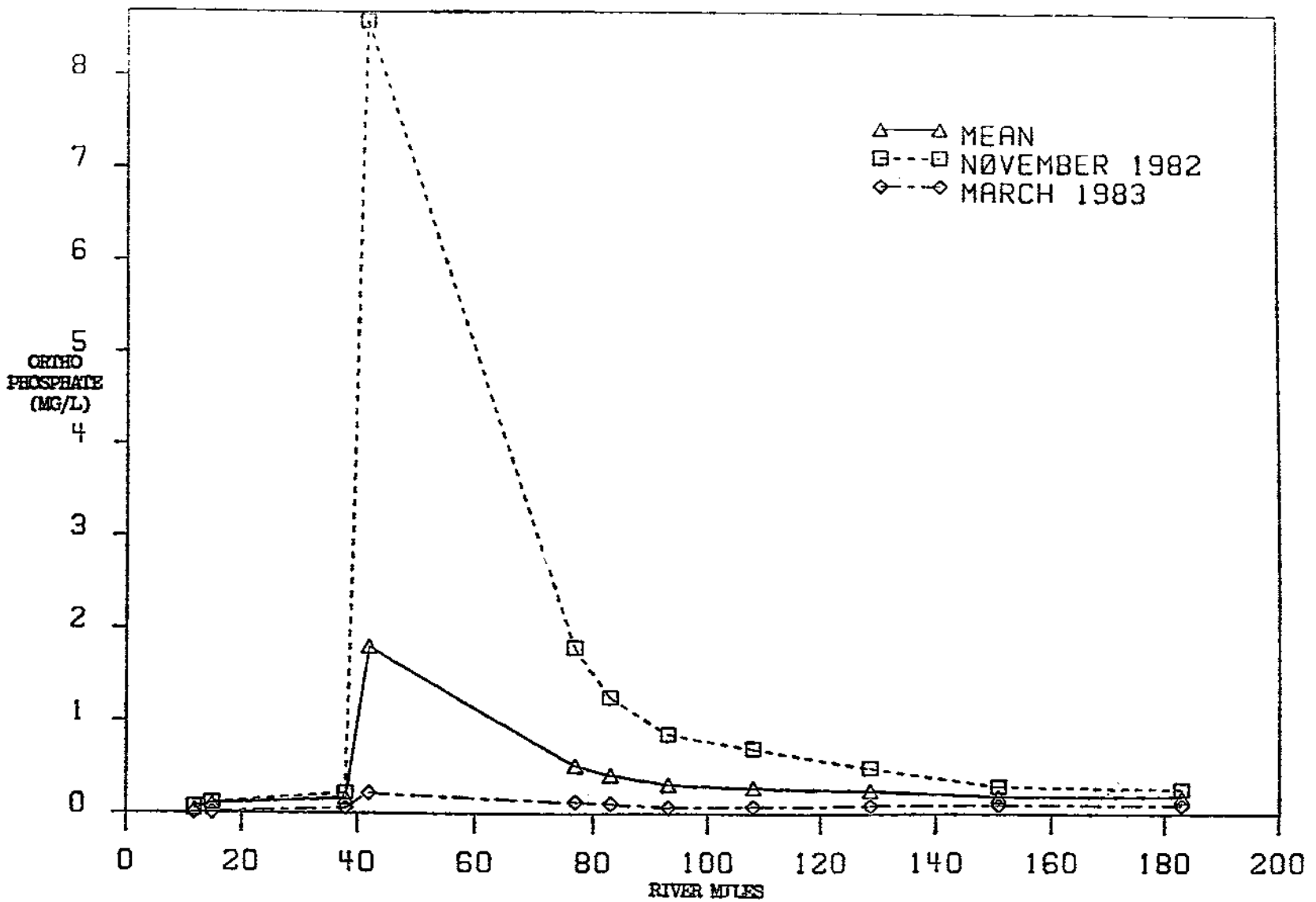


FIGURE 117. MEAN, MAXIMUM (BY MONTH) AND MINIMUM (BY MONTH) ORTHO-PHOSPHATE.

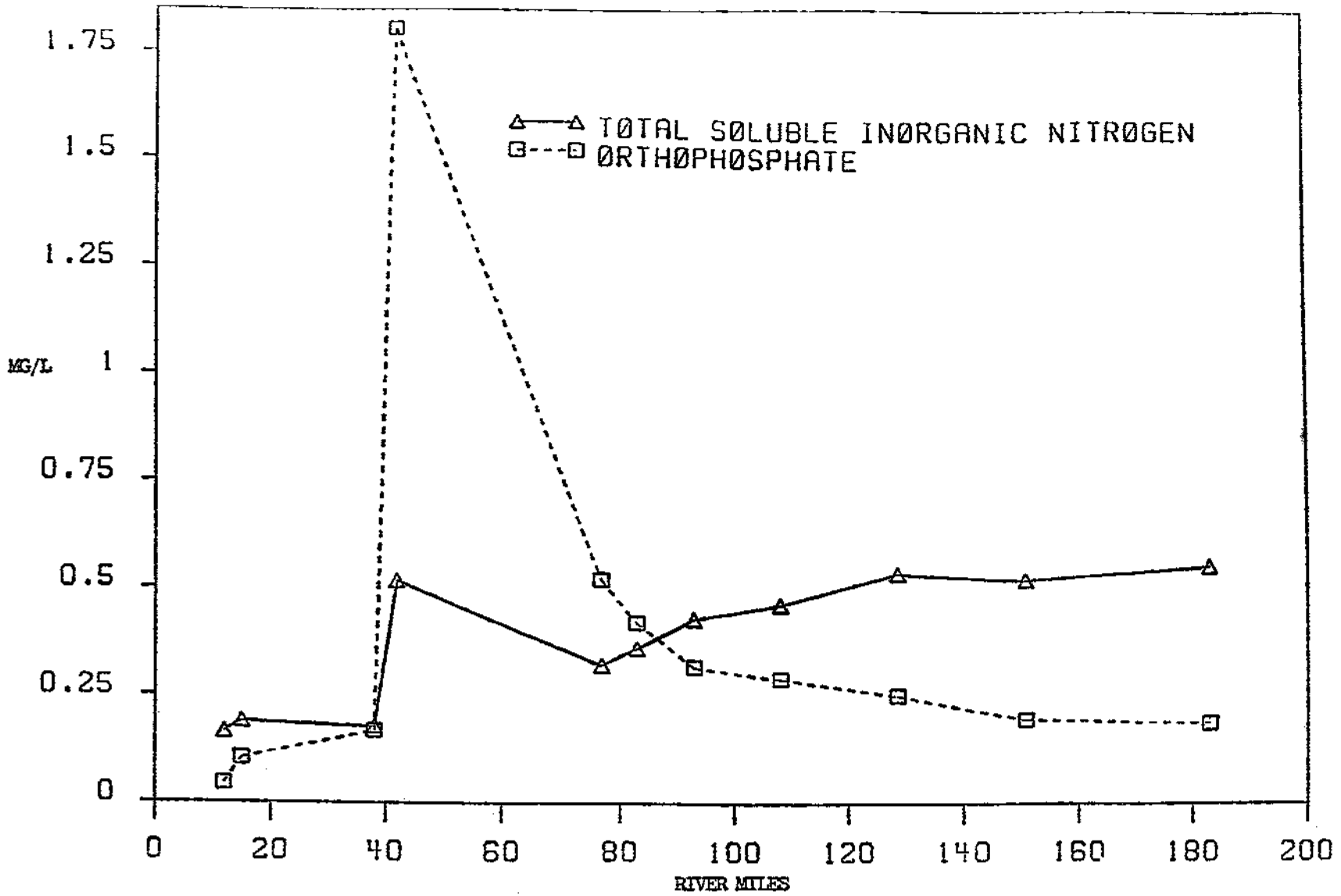


FIGURE 118. MEANS OF TOTAL SOLUBLE INORGANIC NITROGEN AND ORTHO-PHOSPHATE.

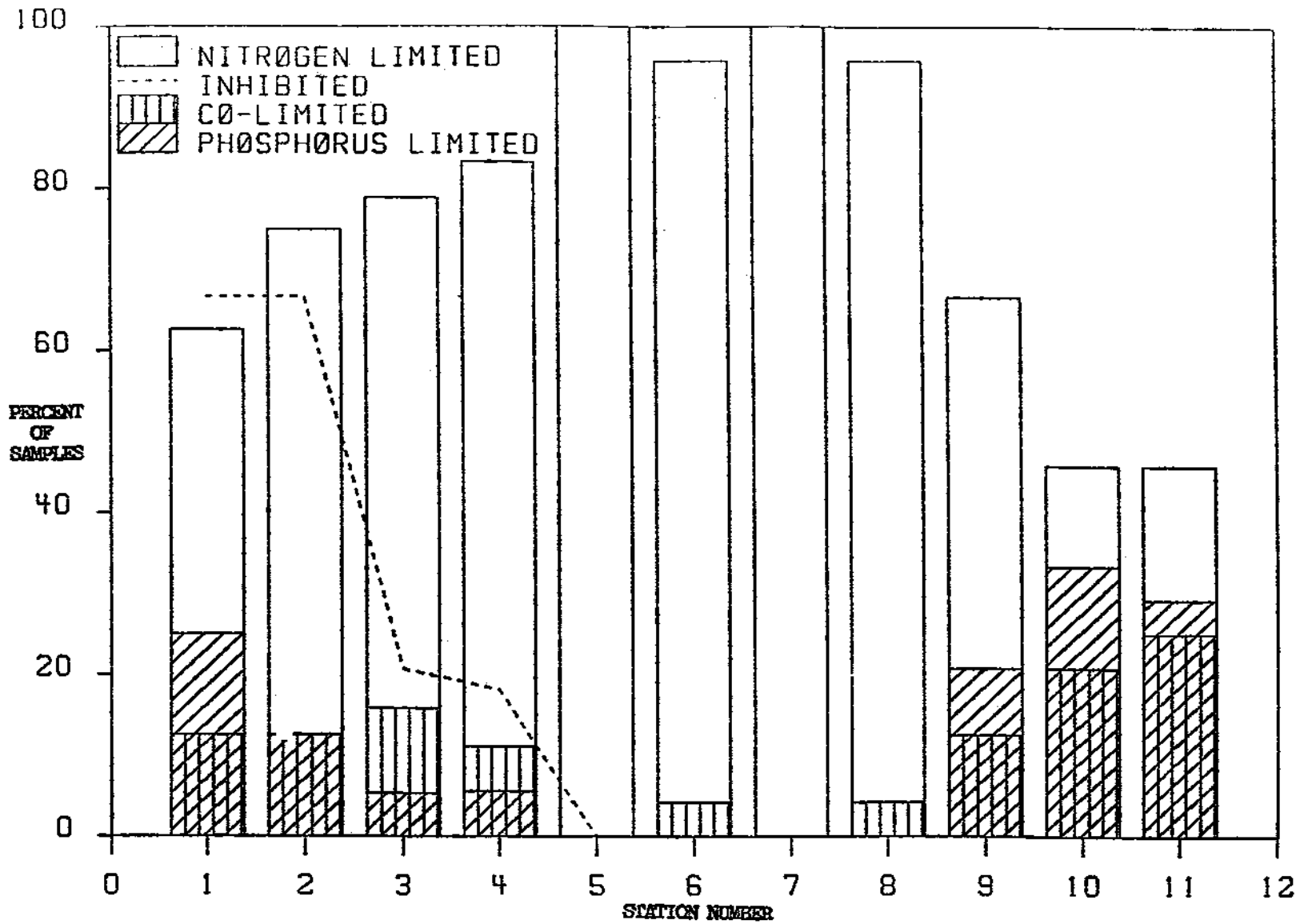


FIGURE 119. LIMITING NUTRIENTS BASED ON NUMBER OF SAMPLES PER STATION WHERE LIMITING NUTRIENT WAS DETERMINED. PERCENT INHIBITION IS BASED ON TOTAL NUMBER OF SAMPLES.

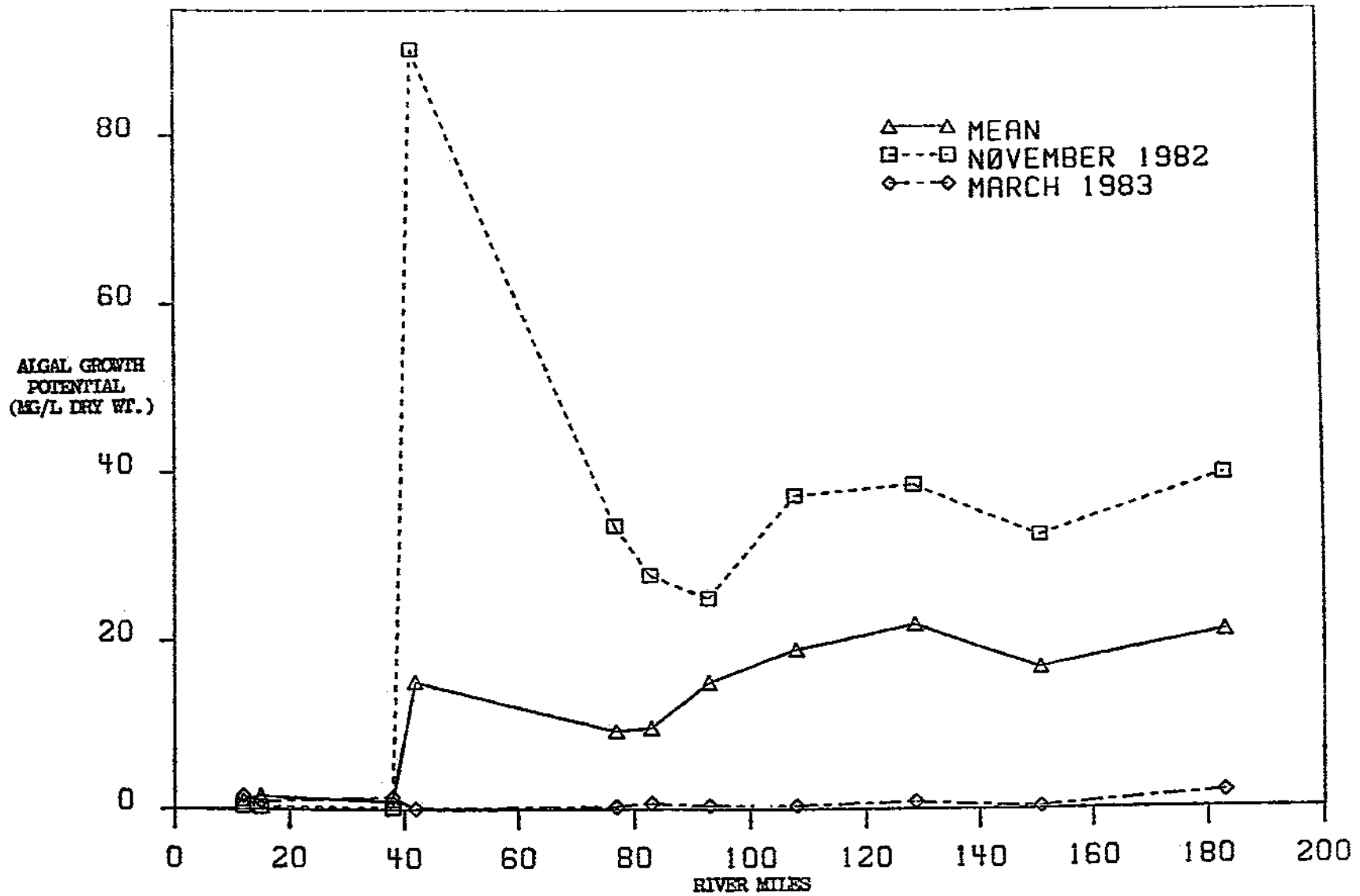


FIGURE 120. MEAN, MAXIMUM (BY MONTH) AND MINIMUM (BY MONTH) ALGAL GROWTH POTENTIAL.

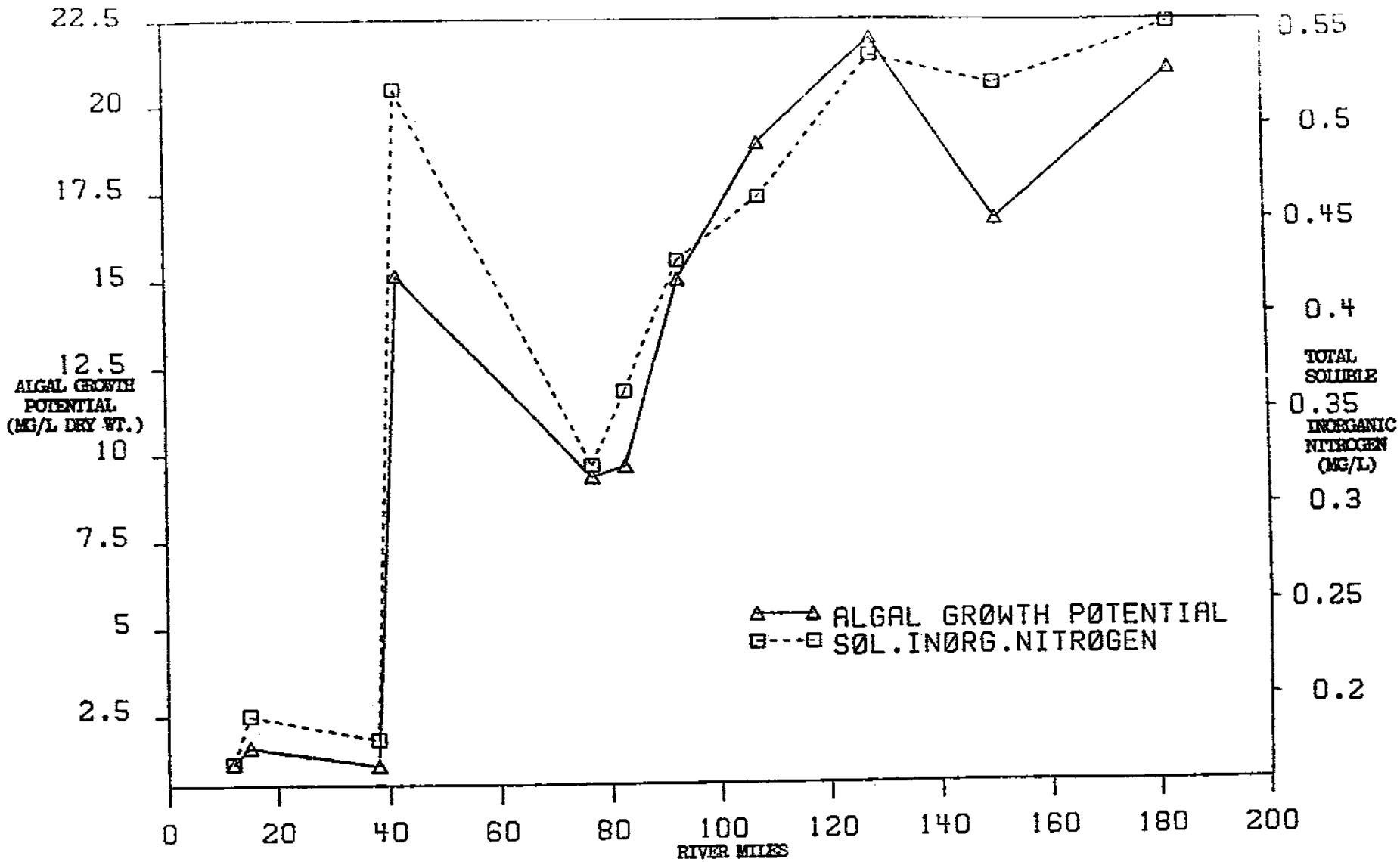


FIGURE 121. MEAN ALGAL GROWTH POTENTIAL AND MEAN TOTAL SOLUBLE INORGANIC NITROGEN.

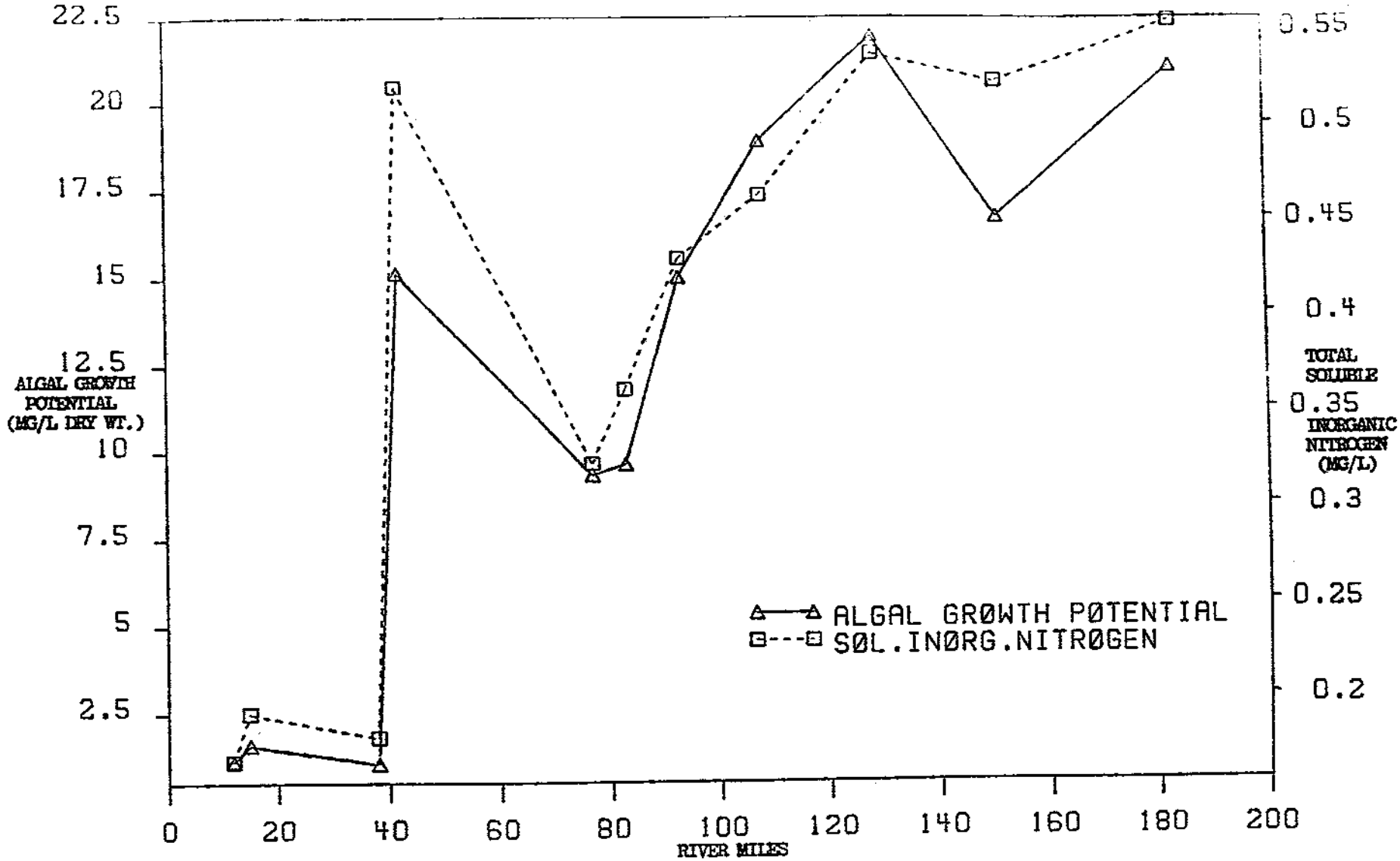


FIGURE 121. MEAN ALGAL GROWTH POTENTIAL AND MEAN TOTAL SOLUBLE INORGANIC NITROGEN.

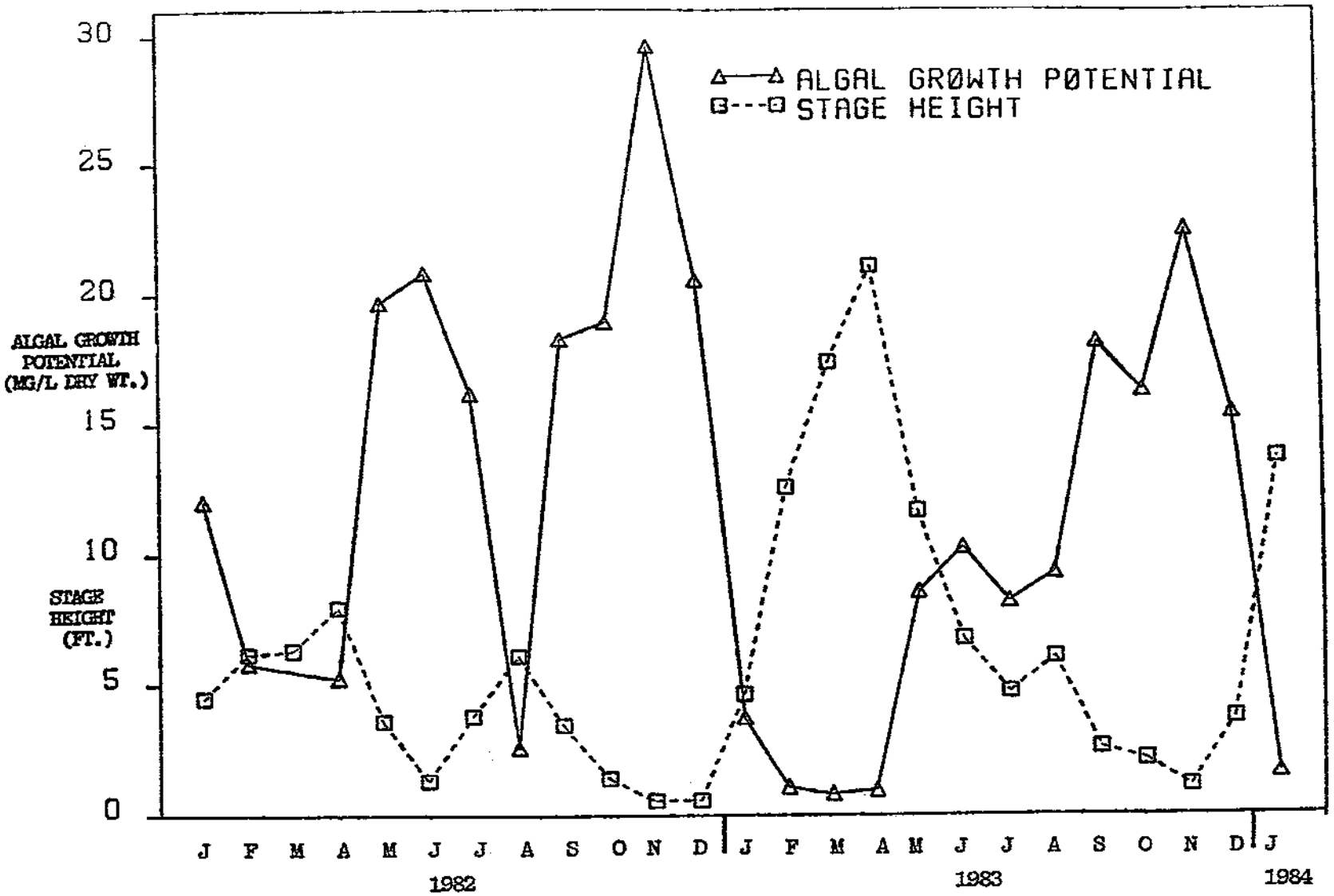


FIGURE 123. MEAN ALGAL GROWTH POTENTIAL AND MEAN RIVER STAGE HEIGHT.

Station	% N	% P	% C	% E	% INH
1	20.8	8.3	4.2	0.0	66.7
2	25.0	4.2	4.2	0.0	66.7
3	62.5	4.2	12.5	0.0	20.8
4	62.5	4.2	8.3	8.3	16.7
5	100.0	0.0	0.0	0.0	0.0
6	95.8	0.0	4.2	0.0	0.0
7	95.8	0.0	0.0	4.2	0.0
8	95.8	0.0	4.2	0.0	0.0
9	66.7	20.8	12.5	0.0	0.0
10	41.7	33.3	25.0	0.0	0.0
11	45.8	29.1	25.0	0.0	0.0

TABLE 32.

Percentage of Determined Nutrients and Inhibition Per Station

N = Nitrogen Limited
P = Phosphorus Limited
C = Co-Limited
E = EDTA Limited
INH = Inhibited

Station	$\bar{X}$ TSIN mg/l	$\bar{X}$ Ortho-P mg/l
1	0.15560	0.04140
2	0.18488	0.099
3	0.17600	0.16368
4	0.47616	1.7816
5	0.30548	0.5096
6	0.34072	0.41044
7	0.40696	0.30640
8	0.44108	0.28228
9	0.54037	0.23720
10	0.50667	0.18664
11	0.55068	0.18008

TABLE 33.

$\bar{x}$ TSIN and $\bar{x}$ Ortho-P Per Station

Station	$\bar{X}$ A.G.P. mg/L	$\bar{x}$ TSIN Predicted A.G.P. mg/L	$\bar{x}$ Ortho-P Predicted A.G.P. mg/L	Bioavailability of TSIN $\frac{\bar{x}}{\bar{X}}$ %	Bioavailability of Ortho-P $\frac{\bar{x}}{\bar{X}}$ %
1	1.0543	5.9128	17.802	12.8	15.2
2	1.4907	7.0252	42.57	25.02	16.6
3	.9813	6.6880	70.38	10.7	27.8
4	14.510	18.0940	760.88	75.7	4.8
5	8.9283	11.6080	217.0	58.7	19.1
6	9.2186	12.9470	176.48	86.9	28.4
7	14.3880	15.6460	131.75	96.2	34.1
8	18.1560	16.7610	121.4	124.8	41.2
9	21.0210	20.5340	101.99	131.8	42.8
10	16.0520	19.2530	80.25	118.8	44.7
11	20.2210	20.9360	77.43	127.9	44.9

TABLE 34.

Mean A.G.P., Predicted A.G.P., and

% Bioavailability of N & P

Station	Mean mg/l	Maximum mg/l	Minimum mg/l
1	1.0543	2.927	0.337
2	1.4907	11.753	0.129
3	.9813	7.205	0.090
4	14.5150	90.346	0.131
5	8.9283	41.635	0.144
6	9.2186	28.315	0.242
7	14.3880	34.216	0.220
8	18.1560	42.445	0.446
9	21.0210	43.128	0.875
10	16.0520	38.503	0.324
11	20.2210	41.964	1.493

TABLE 35.

Mean A.G.P. and ranges per station

Correlation	R	Significance
$\bar{x}$ AGP vs $\bar{x}$ TSIN by station	.972	<<.01
$\bar{x}$ AGP vs $\bar{x}$ Stage Height by date	-.791	<.01
$\bar{x}$ AGP vs $\bar{x}$ chlorophyll-a by station	.831	<.01
$\bar{x}$ AGP vs $\bar{x}$ Algal Density by station	.775	<.01
$\bar{x}$ AGP vs $\bar{x}$ Lab pH by station	.834	<.01
$\bar{x}$ AGP vs $\bar{x}$ Ortho P by station	.210	NS

TABLE 36.
Correlations of $\bar{x}$ A.G.P.

	pH of STA. 4 < 5.0 n=12			pH of STA 4 > 5.0 n=13		
	AGP mg/l (mean)	TSIN mg/l (mean)	Nitrogen Utilization %	AGP mg/l (mean)	TSIN mg/l (mean)	Nitrogen Utilization %
Station						
1	1.27	0.171	19.5	1.03	0.162	16.7
2	1.73	0.197	23.1	1.48	0.185	21.1
3	0.65	0.190	9.0	1.41	0.168	22.1
4	2.37	0.227	27.5	25.99	0.787	86.9
5	2.54	0.234	28.6	15.10	0.402	98.8
6	3.15	0.258	32.1	15.14	0.454	87.8
7	6.34	0.325	51.3	22.39	0.516	>100
8	7.63	0.355	56.6	28.54	0.561	>100
9	10.85	0.358	77.8	31.33	0.704	>100
10	9.23	0.367	66.2	23.15	0.662	100.0
11	10.43	0.394	69.7	30.14	0.700	>100

TABLE 37

Utilization of nitrogen by the algae in the station sample control water when pH of Station 4 is less than 5.0 and when pH of Station 4 is greater than or equal to 5.0.

CHRONIC BIOASSAYS

Introduction

Occidental Chemical Agricultural Products, Inc. (Oxy) discharges effluent from their mining and chemical operations into Swift Creek and from mining operations into Hunter Creek. The mixing of these two creeks with the poorly buffered Suwannee River, just above and below White Springs, results in a wide range of continually fluctuating chemical and physical conditions in the river downstream of their confluences. USGS records show that, from October, 1978, to September, 1979, water from Swift Creek provided from 2% to 50% of the river water volume below the confluence of Swift Creek and the Suwannee River. The variability of the Suwannee River water upstream of Hunter Creek is caused by changing proportions of groundwater and surface/swamp drainage. The variability of Swift Creek results from the changing proportions of runoff from previously mined areas, mine process water from the Suwannee River and Swift Creek mines, treated process water from the Suwannee River Chemical Plant, contaminated non-process water from the two chemical plants, and surface runoff from land in the drainage basin not affected by Oxy. Hunter Creek varies according to the proportions of mine process water from the Suwannee River mine, runoff from previously mined areas, and runoff from land unaffected by Oxy.

The conditions controlling the constituent proportions of each body of water are, to a large extent, independent of one another. The flow rates of Swift Creek, Hunter Creek, and of the Suwannee River are also largely independent of each other. The result is that, in the Suwannee River below these confluences, indigenous organisms can frequently be exposed to large, rapid changes in water quality.

The effects upon river fauna of such changes are impossible to determine solely using chemical analyses. Chronic bioassays performed upon indigenous animals provide a means to evaluate the effects of long term exposure to these mixtures. Early life stage (E.L.S.) chronic bioassays of fish examine the effects of effluents upon hatching, growth, and fry survival during the first twenty-eight days after egg fertilization. These tests have generally proven to be reliable indicators of effluents possessing toxic effects (Mount 1980). These tests, however, do not allow examination of effects upon maturation and reproduction up to and including egg fertilization. Still, their use was advantageous under the conditions of this study since the analysis of lengthier bioassays would be complicated by the fluctuating components of the effluent and diluent.

Methods and Materials

Test Organisms

Selection of Bioassay Organisms

The use of test animals endemic to the Suwannee River was desired to make the bioassays as pertinent as possible. In the late fall and winter of 1981, fish and invertebrates were seined from the Suwannee River at sites from Hunter Creek to a point approximately 7 miles upriver from the State Road #6 bridge. The difficulty of transporting water for bioassays, coupled with the need for year round availability of eggs and fry, dictated the use of fish and invertebrates that were small and that could be bred and reared in the laboratory. We collected species that might meet these requirements and attempted to rear them. Organisms we chose were: Percina nigrofasciata - the banded darter, Notropis leedsi - the bannerfin shiner, Labidesthes sicculus - the brook silverside, Fundulus lineolatus - the lined topminnow, Elassoma evergladei - the Everglades pygmy sunfish, Heterandria formosa - the least killifish, and an invertebrate, Palaemonetes paludosus - the grass shrimp.

N. leedsi, F. lineolatus, E. evergladei, and P. paludosus were successfully bred and the offspring raised in the laboratory. H. formosa was already being cultured. F. lineolatus, E. evergladei, and P. paludosus laid too few eggs (or, in the case of the shrimp, had too few young) at one spawning to be practical for use in the bioassays. H. formosa was not ideal for E.L.S. bioassays because, as a livebearing species, embryos are never directly exposed to the test water. Therefore, N. leedsi was selected as our primary test organism.

During the latter stages of our study, an unknown cladoceran species similar to Daphnia pulex was collected in the upper river. However, we decided to use our D. pulex stock culture to supply test organisms for an invertebrate assay since insufficient time remained to determine exact culture needs for the native organism.

Notropis leedsi (identification confirmed by Carter Gilbert of The Florida State Museum) proved to be an excellent test fish. Once reaching maturity (approximately four months), the females are capable of spawning large, frequent batches of eggs (80-200 eggs every 4 days with proper feeding) (Heins and Rabito in preparation). Their two year lifespan, however, appears to be considerably shortened if this spawning frequency is maintained. Egg predation by the adults is not a problem since the eggs are laid in crevices in spawning substrates, rendering them inaccessible. The adults, although small enough for laboratory culture (7 to 10 cm), were too large for lifecycle bioassays due to the difficulty of transporting the large volumes of effluent and diluent to which it would be necessary to expose them.

Acute toxicity bioassays using the EPA standard reference toxicant (sodium lauryl sulfate) were performed on all test organisms regularly throughout the testing period. The mean

LC_{50}'s (concentration of toxicant lethal to 50% of the organisms exposed) and standard deviations for each organism are given in Table 38, along with the results for the EPA standard test fish Pimephales promelas, the fathead minnow.

Heterandria formosa, with which we had previous acute bioassay experience, appeared to be a likely candidate for full life cycle tests. Though they are livebearing fish and, hence, never have eggs exposed directly to test waters, their small size and placid habits made them the only indigenous fish captured that was deemed likely to mature and reproduce in the 2 liter exposure chambers.

History and Maintenance of Bioassay Organisms

Notropis leedsi (bannerfin shiner) - Approximately 40 adult bannerfin shiners were obtained from the upper Suwannee River, near the S.R.#6 bridge, during October, 1981. The breeding stock was maintained in a 475 liter all-glass aquarium equipped with a flow-through water exchange system. Water for this system was unchlorinated and was pumped from the DER well near our laboratory. The bannerfin shiners were reared at 22°C ±2°C under a 16:8 hour light-dark cycle and were fed Aquarian® flake food and frozen adult Artemia (brine shrimp) twice daily. The eggs were laid between clay tiles spaced 3 mm apart.

Heterandria formosa (least killifish) - Approximately 100 adult least killifish were obtained from a wild population in the St. Marks Wildlife Refuge (Wakulla County, Florida) during August, 1980. The fish were maintained in 10 to 55 liter all-glass aquaria equipped with flow-through water exchange systems. Water for these systems was unchlorinated and was pumped from the same DER well as above. The least killifish were reared at 22°C ±2°C under a 16:8 hour light-dark cycle and were fed freshly hatched Artemia and Aquarian® flake food twice daily.

Daphnia pulex (water flea) - A breeding culture of D. pulex was obtained from the EPA laboratory in Athens, Georgia, in March, 1979. This culture has been maintained since its arrival in 10 liter all-glass aquaria, filled with unchlorinated DER well water, under a 16:8 hour light-dark cycle. The organisms were fed a liquified blend of Glencoe Trout Granules® and Cerophyl® twice daily, and were kept at a temperature of 22°C ±2°C. The aquaria were cleaned weekly by siphoning off half the water along with the detritus and excess Daphnia. They were then refilled with fresh well water.

Bioassay Facilities

The intensive monitoring necessary for the chronic bioassays required that they be conducted at the Florida Department of Environmental Regulation's Biology Section laboratory in Tallahassee, Florida. This location, away from the Suwannee River, required frequent transport of substantial quantities of

both effluent and diluent.

Effluent and Dilution Water Collection Sites

Dilution water was collected at a boat ramp off of Woodpecker Rd., 5 miles north of the S.R. #6 bridge over the Suwannee River. During high water, which flooded this site, diluent was collected from along the S.R. #6 bridge. The river at this location was within reach of our pumps once the river overflowed its banks. These sites, upriver from Hunter Creek and Swift Creek, allowed access for our transport vehicles while ensuring diluent unaffected by Oxy discharge.

Effluent was collected at the #001-1 NPDES sampling site approximately 6 miles up Swift Creek from the Suwannee River. Oxy influence upon the creek at this point consists primarily of drainage from their mining areas, overflow of their mine process water, and contaminated non-process water from their chemical plants. During 1983, Oxy also discharged treated process water regularly from their Suwannee River chemical plant holding ponds. For three bioassays, water directly from the mine process water system of the Swift Creek Mine was used as effluent. These effluent samples were collected from the mine process water pumping station at the Swift Creek Beneficiation Plant.

Effluent and Diluent Transport and Storage

Facilities for storing effluents initially consisted of 10 fifty liter Nalgene® polypropylene carboys. These permitted the effluent to be sealed to contain possible volatile compounds and minimize oxidation. The carboys were covered with opaque black plastic bags to prevent possible chemical changes due to algal growth. When a second diluter became operational, the increased demand for effluent required greater storage capacity. Two covered 210 liter polyethylene storage tanks, painted black on the exterior, were therefore added. These tanks also had polypropylene lids floating on the effluent to minimize exposed surface area and possible chemical changes from volatalization or oxidation.

Diluent was stored in a covered, black painted, 1890 liter polyethylene tank. Investigation showed that the pH buffering effect of the tannic acids in the Suwannee River water provided excellent pH stability in the stored diluent samples.

The diluent was transported in a black 1325 liter polyethylene tank. The effluents were transported in a black 755 liter polyethylene tank and/or the same carboys used for storage.

The water was pumped from its source into the tanks using a Prosser Industries Model 9-1311 submersible pump powered by a portable generator. The pump and tank were flushed before filling began. The pump intake was suspended in the water column to prevent contamination from benthic sediments or floating debris. The samples were then transported to our laboratory and

transferred, using a non-immersed pump possessing a polypropylene pumping chamber, through overhead PVC pipes to their respective storage tanks. The glue joints in the overhead pipes were isolated from the water with silicone sealer. The first 20 liters pumped through the overhead system during each transfer were discarded to avoid sample contamination.

The Bioassay Diluter System

The diluter system for use in the flow-though bioassays consists of the storage tanks mentioned above, which supplied effluent and diluent to two 19 liter head tanks. These head tanks in turn, supplied, two proportional diluters. The mixtures produced by these diluters flowed to temperature controlled exposure chambers containing the test organisms.

The proportional diluters (Fig. 124) were adaptations of the EPA mini-diluter (Benoit et al. 1981). This design minimized use of effluent and diluent and, therefore, the volume of water to be transported, while providing sufficient flow into maintain necessary water exchange rates in the exposure chambers.

All tubing used for water transport consisted of 316 stainless steel or, where necessary, Bev-a-line IV® polyethylene lined tubing. All chambers in the diluter system that came in contact with effluent or diluent were constructed of glass and bonded with minimal amounts of silicone sealer. Water level sensors in the head tanks were constructed of polypropylene and/or 316 stainless steel. Any stoppers used were made of silicone rubber and any fittings were glass, teflon, polypropylene, or 316 stainless steel.

Effluent and diluent were gravity fed to the diluters from their respective head tanks. When the head tank water levels dropped to preset levels, sensors triggered Iwaki MD-30T-G07 magnetic drive polypropylene pumps which filled the head tanks from the appropriate storage tank. The water was pumped through a filter of spun polyester to the head tanks. The same sensors turned the pumps off after filling.

The diluters used capillary tubing to meter the effluent and diluent. The rates of flow through the capillary tubes were governed by a combination of capillary diameter and depth of water above the tubes. The levels of effluent and diluent in the water cells were held constant by float valves. These liquids were then metered into and out of the dilution cell proportionally to maintain 1:1 dilution of the effluent at each metering point across the diluter cell. A modified design used in some of the later bioassays used a third water cell of DER well water which was metered in a similar manner into the dilution cell. This allowed individual pH adjustment of each treatment concentration.

The nominal treatment concentrations were 100% (straight effluent), 50%, 25%, 12.5%, 6.25% and control (straight diluent). These were chosen based on field conditions discussed in the introduction. Each concentration was collected in a flow

booster cell that delivered each treatment concentration, in approximately 50 ml slugs, to a splitter cell. The splitter cell divided the slug into two equal volumes, and delivered each portion to tubes leading to its respective exposure chamber replicate.

The diluters were initially calibrated using a flow-through fluorometer and an "effluent" of fluorescein-dyed water. The fluorometer reading was recorded on a strip chart recorder for 24 hours to establish the stability of the dilution concentrations. The concentrations were stable within 10% of the nominal value. The diluters were adjusted to the nominal concentrations at the beginning of each assay by temporarily replacing the effluent with fluorescein-dyed water. The dilutions were then checked with a fluorometer. These concentrations were monitored regularly during each assay.

The exposure tanks (Fig. 125) each consisted of six 2.5 liter exposure chambers with adjustable drain tubes allowing control of the depth of each chamber. Two exposure tanks were used for each bioassay, providing 2 replicates each of the 6 treatment concentrations. The "fresh" treatment water ran into one side of the top of each chamber and the "old" water drained from near the bottom of the opposite side, ensuring good exchange. Water flows were adjusted to deliver a minimum of 5 volumes of water per day to each chamber. Flow rates were maintained between chambers to ±15%. A heated water bath was constructed during the study to enable the bioassays to be run at 25°C, instead of the ambient 22°C provided in our laboratory. This bath retained water draining from the exposure chambers and was warmed by submersible heaters. To minimize temperature differences among chambers and tanks, the bath water was circulated by a small pump.

For early life stage bioassays, eggs were placed in baskets suspended in the exposure chambers. The baskets were constructed of 1043um 316 stainless steel bolting cloth attached, using silicone cement, to 47mm glass petri dish bottoms. The baskets were suspended in the exposure chambers from a gear-motor driven rack. This rack oscillated at approximately 7 cycles/minute to provide circulation of treatment water around the eggs.

Notropis leedsi Bioassay Procedures

N. leedsi was used in the early life stage bioassays. Test procedures were patterned after those of Schimmel (1982)*. Eggs <24 hours old were examined microscopically for viability and placed randomly into egg baskets containing some 25ml of DER well water. Each basket was then suspended from the shaker rack into a randomly selected exposure chamber. All exposure chambers

*The method referenced has appeared as a working, seventh draft document of ASTM Committee E47 on Biological Effects and Environmental Fate, and as a draft document does not represent a full consensus standard method of test. Reference of this document in no way represents an endorsement of its use by ASTM nor guarantees that the document cited will be published as an ASTM standard.

initally contained DER well water identical to that in which the eggs had been laid. After loading the chambers with eggs, the diluter began delivery of the treatment water dilutions into the exposure chambers. This technique gradually acclimated the eggs to the treatment waters over approximately 24 hours.

Each exposure tank held one replicate of each treatment concentration. The placement of the concentrations within an exposure tank was determined using a random sampling program in the Minitab Statistical Package (Ryan et al. 1981). This was done to minimize possible effects of the location within an exposure tank upon test data.

Tests were run under a 16:8 light-dark cycle. Assays #1-#4 took place at 22°C + 2°C. Assays #5-#15 took place at 25°C +1°C. The chemical/physical parameters of temperature, pH, dissolved oxygen, conductivity, alkalinity, and hardness of the treatment concentrations were monitored twice weekly. The egg cups were examined daily, using a dissecting microscope, and dead eggs and fry removed. During the first 48 hours of any bioassay, dead eggs were replaced by spare eggs, if available, that had been kept suspended in the exposure chambers. This assured that any mortality among the eggs was not a result of using non-viable eggs. These data, as well as any observations and comments, were recorded daily.

The mesh size of the egg baskets was sufficiently large to allow for the fry to swim out into the exposure chamber after hatching. The fry in each exposure chamber were fed equal volumes of concentrated freshly hatched Artemia nauplii twice daily. Upon completion of hatching, the water level in the exposure chambers was lowered to 2 cm and any detritus carefully pipetted off the bottom. This wastewater was examined before disposal for possible fry, and the number of young in each chamber then recorded.

If at least 20 fry had hatched in each treatment (both replicates combined), all exposure chambers were culled to 1/2 the population of the treatment with the lowest survival. If necessary, fry were transferred between the two replicates of a treatment to achieve this. If fewer than 20 fry survived hatching in any one treatment, the assay was abandoned. If the minimum number of fry were available, the assay continued to 28 days. The fry continued to be fed twice a day with concentrated Artemia nauplii (once per day on weekends). The volume of food was increased occasionally to allow for growth of the fry and was adjusted to correct for changes in population density between exposure chambers. Upon completion of the test, the standard lengths of the fry were measured to the nearest 0.5mm and recorded. The fish were then dried at 37°C overnight and the weight recorded to the nearest 5ug. The fry were not fed during the last 24 hours of the assay so that the weight of undigested food would not unduly affect the measured body weights.

The techniques used in these bioassays developed as the study progressed. The ways in which the assays varied are detailed in Table 39.

Heterandria formosa Bioassay Procedures

Flow-through chronic bioassays upon Heterandria formosa were performed to examine possible effluent effects upon survival, growth, and reproduction. Heterandria fry 1-14 days old were collected from the DER stock culture tanks. The same dilution system and exposure tanks used for the Notropis bioassays were employed. The dilution water consisted of Suwannee River water adjusted, using DER wellwater, to pH 5.5. The exposure chambers were assigned treatment concentrations in the same manner described for the Notropis tests. The concentrations chosen were 100% (Swift Creek), 50%, 25%, 12.5%, Suwannee River water control, and DER well water control. After randomly loading the fish into the exposure chambers, the acclimation procedure detailed for use with Notropis eggs was followed.

Twice daily (once daily on weekends), the fish in each chamber were fed equal amounts of concentrated, freshly hatched Artemia nauplii as well as an aqueous suspension of powdered Aquarian® flake food. As the fry matured, the feeding volumes were increased. Adjustments in feeding volumes were made to allow for changing populations between chambers if individuals died. Populations in each exposure chamber were counted and recorded daily. Physical-chemical parameters were measured and recorded as in the Notropis assays.

After 82 days the bioassay was terminated and the standard lengths of the fish were recorded using methods similar to those for Notropis. Each fish was weighed to the nearest 5ug while alive, after which the abdominal wall was punctured and the fish from each treatment replicate immediately placed in individual, labeled vials of Lavdowsky's AFA fixative (Lavdowsky 1895) for three days. The fish were subsequently transferred to 50% ethanol for two hours, then to 70% ethanol for holding.

Vials containing the fixed Heterandria were sent to the Florida Department of Natural Resources Marine Laboratory in St. Petersburg, Florida where they were mounted in paraffin, and sections including the liver, gut, gonads, and gills taken. The resulting slides were sent to Dr. John Couch, U.S. EPA, Gulf Breeze, Florida for pathological examination.

Daphnia pulex Bioassay Procedures

Controlled feeding of filter feeders such as Daphnia pulex is difficult using capillary flow-through diluter systems. To overcome this difficulty, bioassays of D. pulex were performed using renewal bioassay techniques (i.e., replacing the treatment water completely at regular intervals). We employed the techniques of Mount and Norberg (U.S. EPA 1983). Our methods differed slightly:

1) D. pulex were used as test organisms, instead of Ceriodaphnia reticulata.
2) The exposure vials contained 20 ml of test water to allow for

the larger size of D. pulex.
3) The individuals used in the assays were obtained by screening adults from the stock culture tanks using a 789um mesh sieve. These adults were placed in Carolina® culture dishes containing 50% filtered water from their culture tank and 50% filtered Suwannee River water. After 2 hours the adults were removed using a 583um mesh sieve, leaving the young of less than 2 hours. The young were left an additional hour to ensure their viability, then loaded singly via micropipette into each test vial.
4) Feeding techniques were changed as follows: Bioassays were performed to determine feeding rates that would minimize the effects of the differing amounts of natural foods in the effluent and diluent. The amount of food available to the adult affects the reproductive rate (Mount and Norberg 1983). We tried to overcome this by determining the feeding level at which the reproductive rate stabilized in the absence of natural food. As a results of these assays, the D. pulex were fed 1.6 mg. (dry weight) per day of a mixture of 5% (by weight) Cerophyll® and 95% Glencoe Trout Chow®. These ingredients were mixed with deionized water in a high speed blender for 15 minutes, allowed to settle overnight, and the supernatant removed. This supernatant was mixed thoroughly, then a sample dried and weighed. The supernatant was then adjusted with deionized water to the required density for feeding. Part of this food was frozen. The rest was refrigerated and enough removed each day for daily feeding. Each days food was "aged" in a covered container for 48 hours at 25°C to promote bacterial growth, before being used. The food was mixed thoroughly before the twice daily feedings (once daily on weekends), as well as before being removed from the refrigerated stock, to ensure constant feeding amounts. Refrigerated food stocks were replaced weekly from the frozen reserves.

Results and Discussion

Interpretation of data from the chronic bioassays is, at best, complicated. It is important when viewing the results to keep in mind that each assay was a unique test in itself due to the changing effluent and diluent characteristics. Each assay was a controlled, replicated test and differing results among the assays do not imply that the tests are invalid.

Notropis leedsi

Data from the flow-through E.L.S. chronic bioassays are contained in Appendix E. The tests were analyzed for three factors: 1) hatching success of the eggs; 2) growth of the fry; and 3) survival of the fry. Additionally, any deformities were noted.

Hatching

A number of assays were invalidated with regard to hatching. Assays #1 and #10 were not completed: #1 because of initial control mortality and #10 because of a laboratory accident. Assays

„2 - #5 were invalidated because pH corrected diluent control survival was less than 80%. (See below for a discussion of pH correction method.) These early assays alerted us to the inherently harsh pH and alkalinity regimes of the upper Suwannee River. They also demonstrated the need to maintain pH 6 or above in the treatments to allow normal egg development. To overcome this problem the Suwannee River diluent was buffered with small amounts (<10% by volume) of DER well water to permit good hatching. This buffering is analogous to that provided by the groundwater springs along the Suwannee River. In fact, the DER well draws water from the same aquifer that supplies many of those springs.

	White Springs (3 Dec 1982)	DER well water (7 Dec 1982)
pH	7.8	7.7
total alkalinity	126 mg/l	113 mg/l
total hardness	120 mg/l	116 mg/l

Plots of hatch rate vs. treatment are presented in Figs. 126, 128, 130, 132, 134, 136, 138, 140, and 142. The results of these assays indicated that hatching was reduced in the middle and/or lower concentration treatments. This trend was unclear, however, because of the reduced hatching we attributed to low pH. Because of the substantial effect of pH on the results of the Notropis leedsi assays, a correction technique was developed to allow the estimation of mortality caused by factors other than pH. This correction was determined by fitting a curve to the hatch rate vs. pH obtained from the controls of all assays (replicates combined)(Fig. 144). Use of these data, of course, requires the assumption that the only factor causing differential mortality between Suwannee River controls and well water controls is pH, an assumption we feel to be justified on theoretical grounds and on the basis of the fit of the curve.

The pH correction curve fitting was accomplished with the help of the SIMPLEX algorithm program (Caceci and Cacheris 1984). Examination of the preliminary fitted curves revealed two data points (assay #5 - Suwannee River control, and assay #11 - well water control) substantially different from the curve predictions. Examination of laboratory notes showed a pH stability problem in assay #5. No explanation was found to account for the low (45%) hatch in the assay #11 well water control, but, since all other well water control had hatch rates between 78% and 93%, it obviously is an outlier. These two data points (encircled on Fig. 144) were eliminated. The remaining data points resulted in the following curve equation that gives expected hatch at any test pH:

$$y = \frac{1}{.011 + .006(26.65^{(1.56(5.95-X))})}$$

y = expected % hatch

x = test pH

Using this equation, the hatch rate values were corrected for pH effects using:

$$\text{pH Corrected Hatch Rate} = \frac{\text{Measured Hatch Rate}}{\text{Expected Hatch Rate}} \times 100$$

This procedure is analogous to the use of Abbot's formula (APHA 1980), except that it is based on a curve derived from numerous control data rather than on a single control value. Values of the pH corrected data are listed at the end of Appendix E. Since the correction curve was fitted to our control data, it is obvious that some of the control points were above, and some below the curve. Since: 1) this results in corrected hatch rates above 100% in those points above the curve; 2) the ANOVAs to be performed on the corrected data examine the relationship within and between treatment repetitions and are unaffected by adding a constant to all the treatments, and; 3) we wished to apply the arcsine square root transformation described below and, therefore, needed hatch rate/100 values between 0 and 1 (hatch rates between 0% and 100%), we adjusted the hatch rates in any assays containing pH corrected values over 100% (assays #8, and #12-15). This was accomplished by applying the following formula to each treatment of the assay.

Adjusted Hatch = pH Corrected Hatch - (Highest pH Corrected Hatch in Assay - 100)

The adjusted hatch rates are used in the hatch rate plots in Figs. 127, 129, 131, 133, 135, 137, 139, 141, and 143. To assure that the sample variance was homogeneous across treatments, ANOVAs were also performed on hatch data transformed using a Freeman and Tukey modified arcsine square root transformation (Freeman and Tukey 1950):

$$h' = 1/2 \left(\arcsin \frac{x}{n+1} + \arcsin \frac{x+1}{n+1}\right)$$

h' = transformed hatch rate

x = number eggs hatching

number eggs exposed

This transformation helps assure the ANOVA assumption of equal variance.

One-way analyses of variance were performed on each of the assays (omitting the questionable 25% replicate in Assay #8, see Fig. 130). Assay #11 had a p-value of .034 from the ANOVA using un-transformed data and, hence, exhibited a statistically significant effect. The remaining assays had p>.05 (Table 40). The p-values from the assays using Swift Creek water for effluent and Suwannee River water for diluent were used with Fisher's Combined Test (Fisher 1944):

$$X^2 = (.2) \times \ln(\text{product of ANOVA p-values})$$

X^2 = chi square value

This test determines the statistical significance of the combined assays (assays #6, #7, #8, and #15), i.e., the significance of the effect over all tests. For reasons discussed later in this section, results from assay #9 were not used to calculate effect significance. The resulting X^2 (7.03) from the remaining assays had a significance of $.05<p<.1$ for untransformed data. For the arcsine square root transformed data the X^2 value (6.2) had a p-value = .1. The two assays using mine process water for effluent and Suwannee River water for diluent (#11 and #12) were examined in similar fashion with the resulting X^2 (6.64 for untransformed data and 5.79 for transformed data) significant with a $p<.001$ and $.001<p<.01$, respectively. Both these p-values indicate highly significant effects in the bioassays using mine process water effluent. Assays #13 and #14, using well water for diluent (and, therefore, taking place at higher pH), showed no statistically significant effects with all p-values >.45.

During the first bioassays the cause of egg mortality in our controls was uncertain. The initial diagnosis was that fungus was the cause of the egg deaths. However, careful observation led us to the conclusion that the fungus was growing upon dead eggs, killed by some other factor. The likelihood that this factor was associated with the naturally low pH, alkalinity and hardness of the upper Suwannee River water being used as diluent was suprising since the indigenous adult N. leedsi live in water of similar chemistry. Later assays were pH adjusted as described in the methods section. The success of the control group hatching in these assays confirmed our hypothesis concerning the cause of the control egg mortality. A treatment using 100% DER well water was therefore added to some assays to provide a test group not subjected to water of low ionic strength yet also free of possible Oxy effects.

The water of the upper reaches of the Suwannee River (above White Springs) presents difficult conditions for the survival of most fish eggs (Lee and Gerking 1980). During much of this study, the pH of these waters was approximately 4.0. One of the primary effects of low pH is the disruption of osmoregulation and the ionic balance of the blood. In adult fish this occurs primarily due to the loss of blood Na^+ and Cl^- through the gills (McWilliams and Potts 1978; Leivestad et al. 1980). In eggs this loss occurs through the chorion (egg "shell") which functions as a gill for the developing embryo. One of the reasons adult fish are better able to survive in low pH conditions is that the ratio of body mass to gill surface area is higher, enabling them to better control the ion balance between their blood and the surrounding water. The eggs, however, have a very low ratio of body mass to chorion surface area and are, hence, less tolerant of low pH (Lee and Gerking 1980). A water of high ionic Na, Ca, and/or Mg content helps combat this blood ion loss (Leivestad et al. 1976; McWilliams and Potts 1978). We found that the alkalinity and hardness levels of the upper Suwannee were seldom as high as 10ppm and generally were at or near 0ppm. In contrast the alkalinity and hardness levels of the North Florida springwaters are generally each well over 100ppm and sometimes approach 200ppm (Rosenau et al. 1977).

The importance of ionic strength to aquatic organisms at low pH probably causes the pH correction technique used in the bioassays to over-correct (increase) hatch rates in some treatment concentrations. As pH approaches the limits at which survival is possible, the survival rate is greatly improved if ionic strength is increased (Leivestad et al. 1976; McWilliams and Potts 1978). The greater ionic strength in the surrounding water helps the organisms maintain their blood ion balance. The mechanisms by which pH and ionic strength affect the physiology of aquatic organsms are quite complex and will not be addressed here. Most of the ionic content of the well water controls and the pH adjusted Suwannee River controls is carbonate which, as a strong pH buffer, links pH and ionic strength. However, the Oxy discharges possess high ionic strengths and are composed of many ions other than carbonate. Among these are chloride, sulfate, fluoride, and phosphate, many of which have much less effect on pH than does carbonate. As noted previously, ionic Mg, Na, and Ca in surrounding waters have, in particular, been shown to aid in blood ion regulation at low pH. Calcium is a substantial component of the limestone matrix within which the phosphate ore is found and it's presence in Oxy discharges is indicated by total hardness readings in the range of 140-180 ppm (upper Suwannee River water = 0 ppm, well water = 120 ppm). Samples of water from Swift Creek at the NPDES sampling site 001-1 have had ionic strengths (measured as conductivity) ranging from 280 umhos at pH 6.6 to 625 umhos at a pH of 7.2. The effluent conductivity was poorly correlated with pH. In contrast, the well water conductivities ranged from 200 umhos at pH 8.1 to 252 umhos at pH 7.7. Diluent conductivity correlated strongly with pH. The conductivity of the unadjusted Suwannee River water during much of this study was <50umhos at pH's near 4. Since the correction equation is most accurate when applied to water of the same ionic strength, the obvious result is that, when applied to the Oxy treatments, the equation over-corrects due to the higher than expected ionic stength. The amount of over correction decreases with increasing pH since the eggs are under less ionic stress at higher pH. A good example is Assay #9. The conductivity of the Suwannee River water control (pH adjusted with well water) was 55 umhos at pH 6.0. The conductivity of the 25% treatment, (no pH adjustment with well water) was 159 umhos at pH 5.8. The normal result of this over-correction for pH effects is to reduce the statistical significance of the effect by raising the corrected hatch rates in the Oxy treatments nearer to the expected hatch rates. In assay #9 however, the lower pH/high ionic strength in the 25% concentration resulted in this treatment being corrected to a hatch rate 146% of the expected hatch rate, resulting in an increased statistical significance. For this reason this assay is not used in the significance calculations.

Growth Rate

Bioassays #2, #5 and #12-15 continued for 28 days (#14 for 42 days). Assay #2 was invalid due to lack of a control

treatment. The remaining assays had insufficient hatching in one or more treatments to meet the criteria given in the methods section and were discontinued. The fish in each assay were measured, then dried and weighed. The measurements of dry weight were more precise than those of standard length. Therefore, after plotting length vs. weight of the fishes in each assay to check for outliers, the weights were used to look for treatment effects. Figures 145-149 are plots of mean dry weight vs. treatment concentration for each assay. Assay #15 had no fish in the 100% treatment due to a laboratory accident 3 days prior to completion of the assay.

The large natural variation in growth rates (typical within treatment variation is $\pm$90% of the mean) has masked any but the most massive effluent-caused growth effects. ANOVA F-values using log-transformed data (Table 41) were too low to indicate significance (p-values > .25). Due to the small number of growth assays performed and the growth variability, it was not possible to determine the need for a pH correction factor similar to that in the hatching analyses. Bioassays using many more replicates and/or test fish would be necessary to ascertain any effluent effects upon growth.

Fry Mortality

Assay #2 was invalid due to lack of a control treatment. Figures 150-154 plot the percent of fry surviving after 28 days vs. treatment concentration for the remaining fry bioassays (#5,#12-#15). ANOVAs performed on Freeman and Tukey modified arcsine square root transformed fry survival resulted in p-values >.25 for all assays except #12 (Table 42). The p-value for assay #12 (.007) indicated a highly significant effect. However, data irregularities suggest that results from this mortality assay may not be reliable. In assay #15, survival in the 100% treatment was for 25 day old fish due to a laboratory accident three days before completion of the assay. Based on results from other assays, it is unlikely there would have been further losses. Conventional LC_{50} calculations assume a dose response curve where any effect increases with concentration and, hence, are not suitable for these data.

It must be noted that, though not statistically significant, the plots of the assays using Suwannee River water as diluent and either Swift Creek water or mine process water as effluent (#5,#12, and #15) tend to demonstrat the same trend as those exhibited in the hatching results, i.e., increased effect (lower survival) in the middle or lower concentration treatments. No survival reduction in any treatment is implied by the plots of assays using DER wellwater as diluent (#13 and #14) and which, therefore, took place at higher pH's. Since few fry survival assays were performed, we were unable to apply a pH correction factor similar to that used in the hatching analyses.

Deformities

Observations of deformities in these assays showed no clear pattern of treatment effects. Early hatching frequently resulted in fry that were initially deformed. In most instances this condition corrected itself within a few days. Permanent deformities were slightly more common in the DER wellwater controls and 100% treatments. We feel that these deformed fry probably represent fry that would have died in the Suwannee River water controls and middle concentration treatments (which apparently are harsher environments) and were, therefore, a natural background occurrence not induced by the test waters.

Heterandria formosa

A preliminary bioassay was performed to determine the pH tolerance of Heterandria fry. Two gravid Heterandria were exposed to Suwannee River water at each of 5 different pH's. The pH of straight river water was (at this time) 4.9 and was adjusted, using White Springs water, to pH's from 4.9 - 7.6. The fry born appeared normally developed and survived in all pH's.

An assay designed to measure Oxy's effect upon growth, survival, and reproduction was attempted. Fry between 1 and 2 weeks of age were used as test animals. The pH in the Suwannee River, during the interim, had fallen to 4.2 which proved lethal to the test fish in the control and 12% concentrations. After adjusting the diluent pH to 5.5, another test was started using similar fry. Data from the Heterandria chronic bioassay are given in Table 43. After 68 days the test fish exhibited sufficient secondary sexual characteristics to allow each treatment chamber to be culled to three females and two males. After 76 days, an attempt was made to magnify the apparent inverse pH/toxicity relationship by lowering the diluent pH to the ambient pH of the Suwannee River (4.6). This led to mortality among the Suwannee River water control fish and abandonment of the assay after 82 days.

The tests were analyzed for three factors - growth rates of the fish, survival of the fish, and pathological effects. Examination of reproductive rates was prevented by the premature abandonment of the assay.

Growth Rate

Analysis for effluent-caused growth effects is difficult due to the sexual dimorphism and natural variations in growth exhibited by Heterandria formosa. Standard length measurements were used to examine growth effects. A plot of length versus treatment concentration is presented in Fig. 155. We did not obtain dry weights of these fish because they were used for pathological examinations. Due to evaporation during weighing, the measurements of standard length were more accurate than those of live weight.

Any possible growth effects were not discernable in this assay. The ANOVA p-value (>.25) failed to indicate statistical significance. Assays employing many more replicates and/or test individuals would be necessary to ensure that possible effluent effects upon growth could be observed.

Fry Mortality

After 68 days, before culling the populations to provide proper sex ratios for assaying reproductive effects, the survival rate of the fish was lowest in the 12% concentration (Fig. 156). Conventional LC_{50} calculations were not suitable for these assays for the same reasons discussed in the section on Notropis fry survival. An ANOVA performed using Freeman and Tukey modified arcsine square root transformed data yielded a p = .112. There were insufficient data to correct for pH effects.

Pathology

Upon completion of the bioassay, the test fish were fixed, sent to the DNR Marine Research Laboratory for histological preparation, then examined for internal tissue abnormalities by Dr. John Couch, U.S. EPA, Gulfbreeze, Florida. These fish were chosen for pathological examination because they were exposed to Oxy effluent for a substantially longer period of time than any other organisms tested. Of special concern in his examinations were tissues of the liver, gut, gonads, and gills. Dr. Couch found that "All [fish tissue] sections reviewed appeared to be essentially normal showing no pathological changes in any of the tissues of any fish" (personal communication 1984).

Daphnia pulex

No cladocerans were captured from the upper Suwannee River until the latter part of this study. Unanswered questions raised by preliminary assays, concerning the effects of different types of food upon D. pulex fecundity, make these assay results unreliable. Data from these assays are given in Tables 44 and 45. The assay results were examined for test animal survival and for reproductive rate.

Survival was plotted against concentration (Figs. 157, 158). The plots demonstrated a small reduction in survival in the lower concentration treatments. The individual assays were not suitable for ANOVA analyses because there were no replicates of percent survival within a treatment. Once again, conventional LC_{50} calculations were not suited to data not showing effect increasing with concentration.

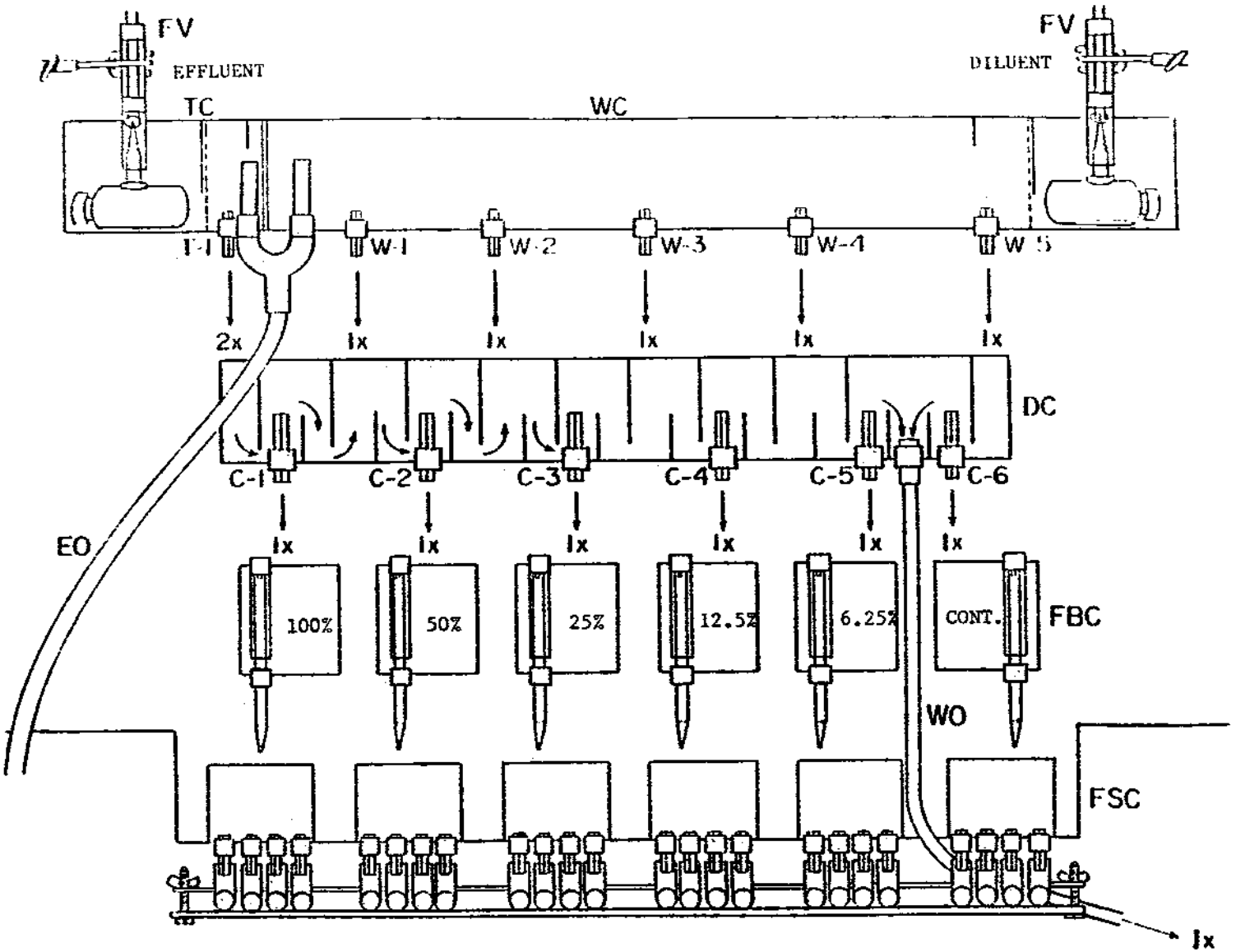
ANOVAs were performed using the total number of offspring from each test animal. Some test animals were mistakenly killed after day 12 in assay #1. Therefore, total fecundity to day 12 in assay #1 and to day 18 in assay #2 were used. The p-value for assay #1 (.08) is highly significant. For assay #2 (performed

with an improved feeding program), the p = .21 was not statistically significant. The fecundities were plotted against treatment concentration (Figs 159, 160). The data suggest increased fecundity in the middle and/or high concentration treatments. This may be linked to improved nutrition due to the natural foods available in the Swift Creek water, to the effect of low pH on the D. pulex, or to a pH/toxicity effect similar to that found in the Notropis assay.

Conclusions

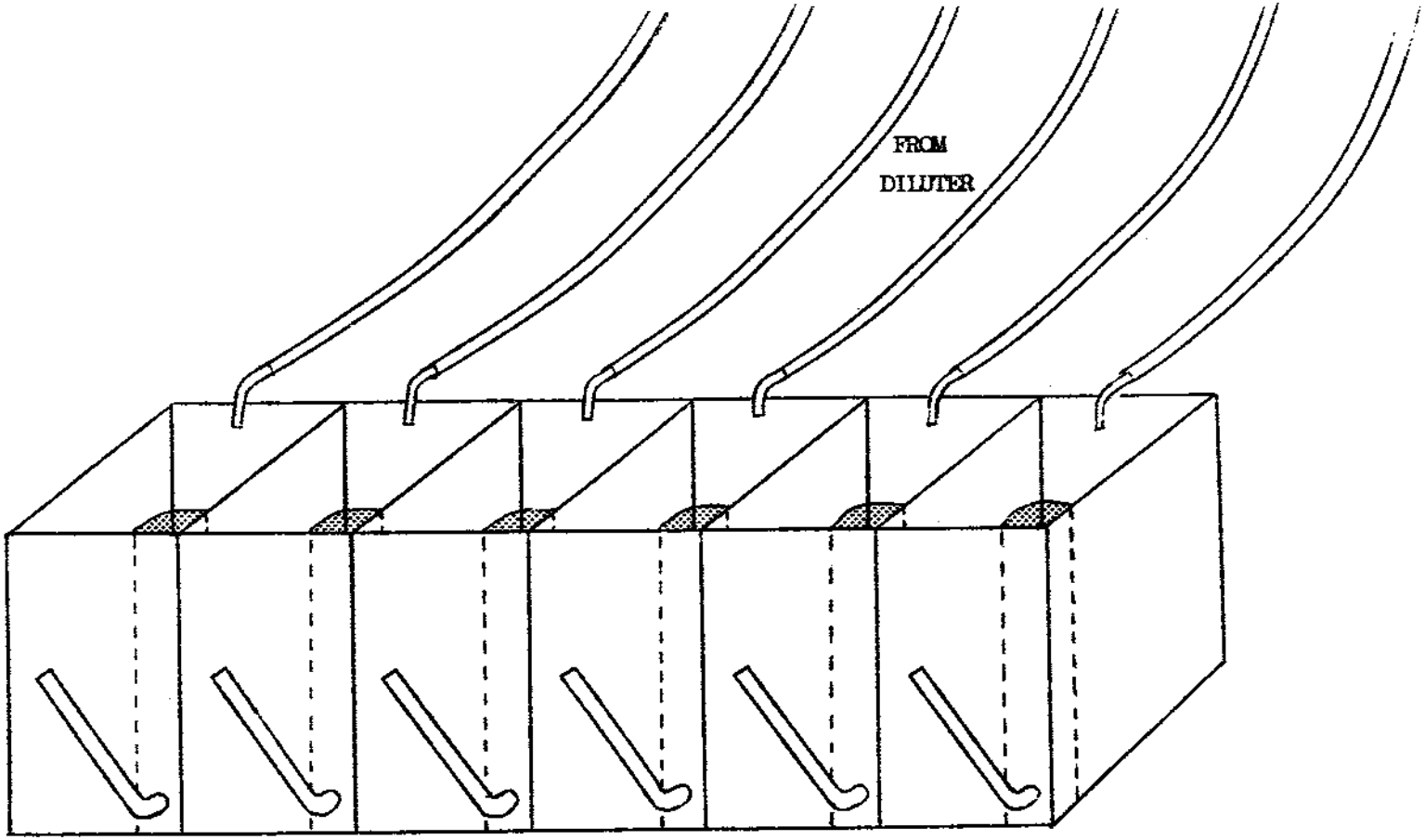
The chronic bioassays of Oxy's Swift Creek and mine process water discharges, using Suwannee River diluent, exhibited a characteristic effect upon the hatch rate, growth, and survival of Notropis leedsi. This effect was statistically significant for hatch rate using Swift Creek water and was highly significant for hatch rate using mine process water. Plots of the effect generally demonstrated a "saddle" shaped curve denoting an effect in the lower concentrations. The lack of this characteristic shape in assays using well water rather than Suwannee River water for diluent suggested that the toxicity of the effluent occurs at low pH and/or low ionic strength. This "saddle" curve is also evident in results from assays for Heterandria formosa survival and growth, though the effect is not statistically significant. Assays upon Daphnia pulex were inconclusive due to difficulties controlling nutritional variables. In most assays using Suwannee River water for diluent, rather than well water, there were pronounced pH effects which make analyses of plots and data difficult. These assays demonstrated no effluent related pathological effects or deformities. Assay treatments with a pH above approximately pH 6.5 - 7.0 showed no effects.

It is clear that Oxy's effluents had a detrimental effect upon the bioassay test animals in some lower concentration treatments. It is logical, in view of the bioassay data and the upper Suwannee River's chemistry, to conclude that the effects observed in the laboratory (reduced hatching and possible reduced survival and growth in the lower concentration treatments at low pH) are the result of some components of the effluents that are toxic at low pH and/or in low ionic strength water. This inverse relationship between pH and toxicity is well known (Fritz 1980). However, it is not possible, with present data, to extrapolate with any certainty the toxicity effects demonstrated in these bioassays to the existence of these effects in the Suwannee River.



C=dilution cell capillary tube, DC=dilution cell, EO=emergency overflow, FBC=flow booster cell FSC=flow splitter cell, FV=float valve, T=effluent capillary tube, TC=effluent cell, W=diluent capillary tube, WC=diluent cell, WO=water overflow, IX=one volume, 2X=two volumes

FIGURE 124. DIAGRAM OF CHRONIC BIOASSAY MINI-DILUTER



EXPOSURE TANK (SIX EXPOSURE CHAMBERS)

FIGURE 125. DIAGRAM OF CHRONIC BIOASSAY EXPOSURE TANK

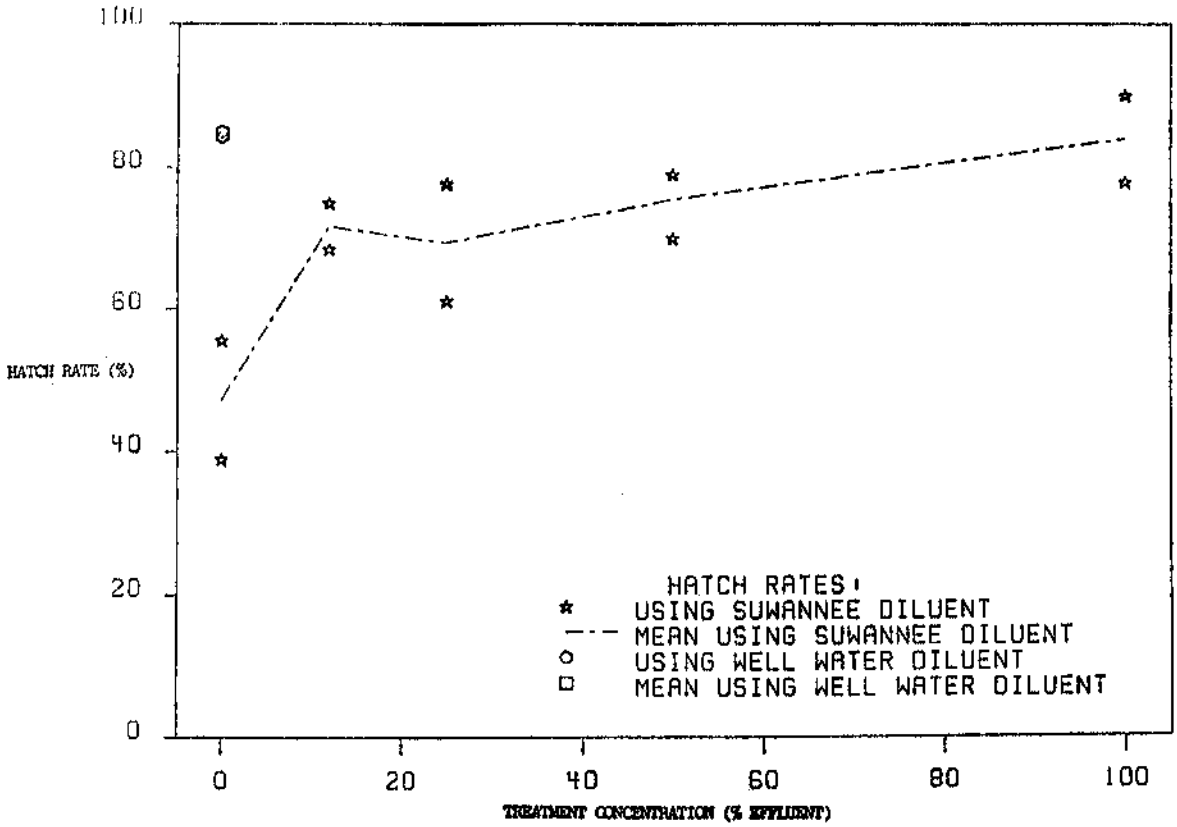


FIGURE 126. Notropis leedsi HATCH RATE - ASSAY #8 USING SWIFT CREEK EFFLUENT

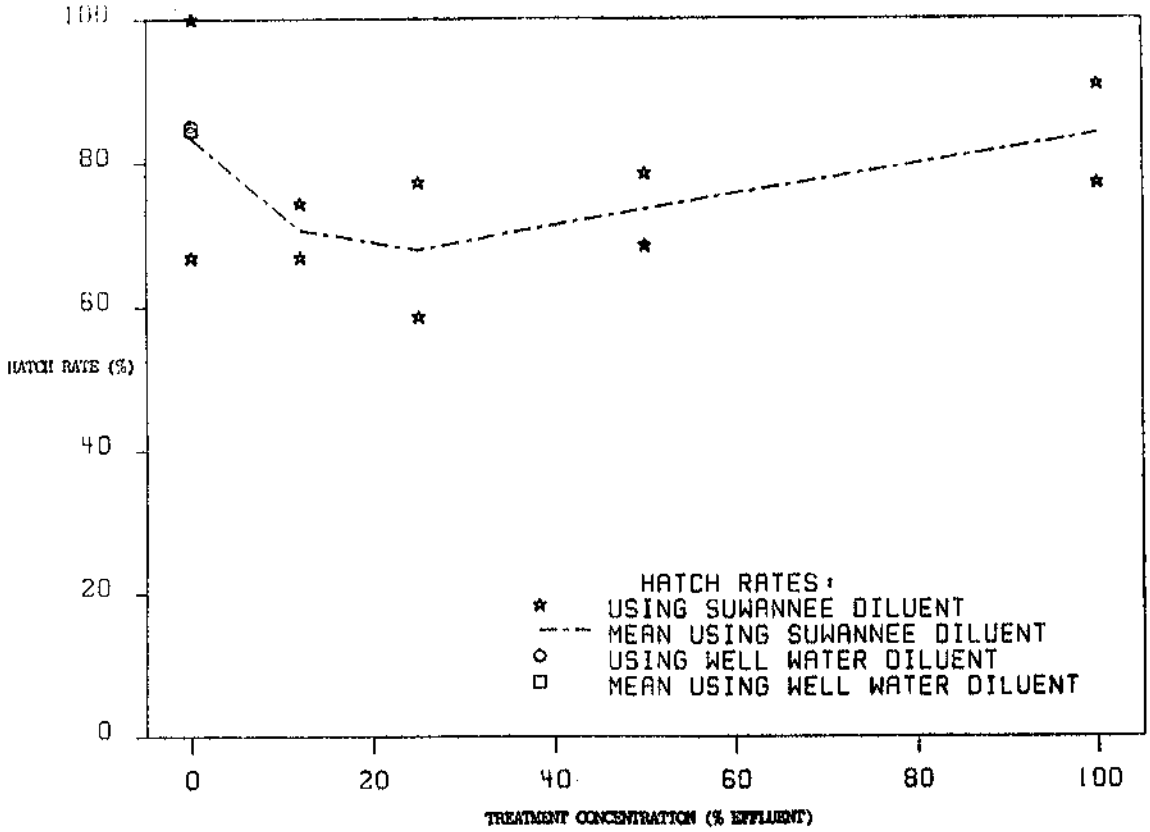


FIGURE 127. Notropis leedsi EXPECTED HATCH RATE (CORRECTED FOR PH) - ASSAY #8 USING SWIFT CREEK EFFLUENT

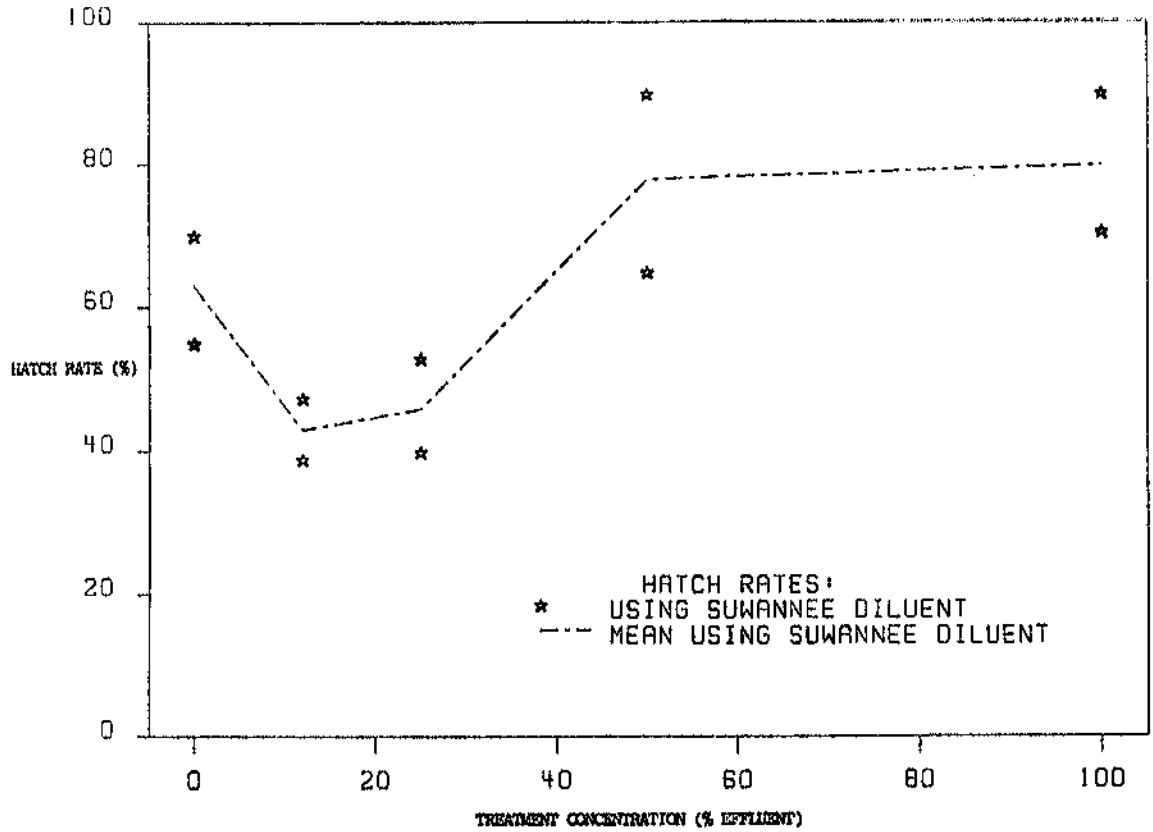


FIGURE 128. Notropis leedsi HATCH RATE - ASSAY #7 USING SWIFT CREEK EFFLUENT

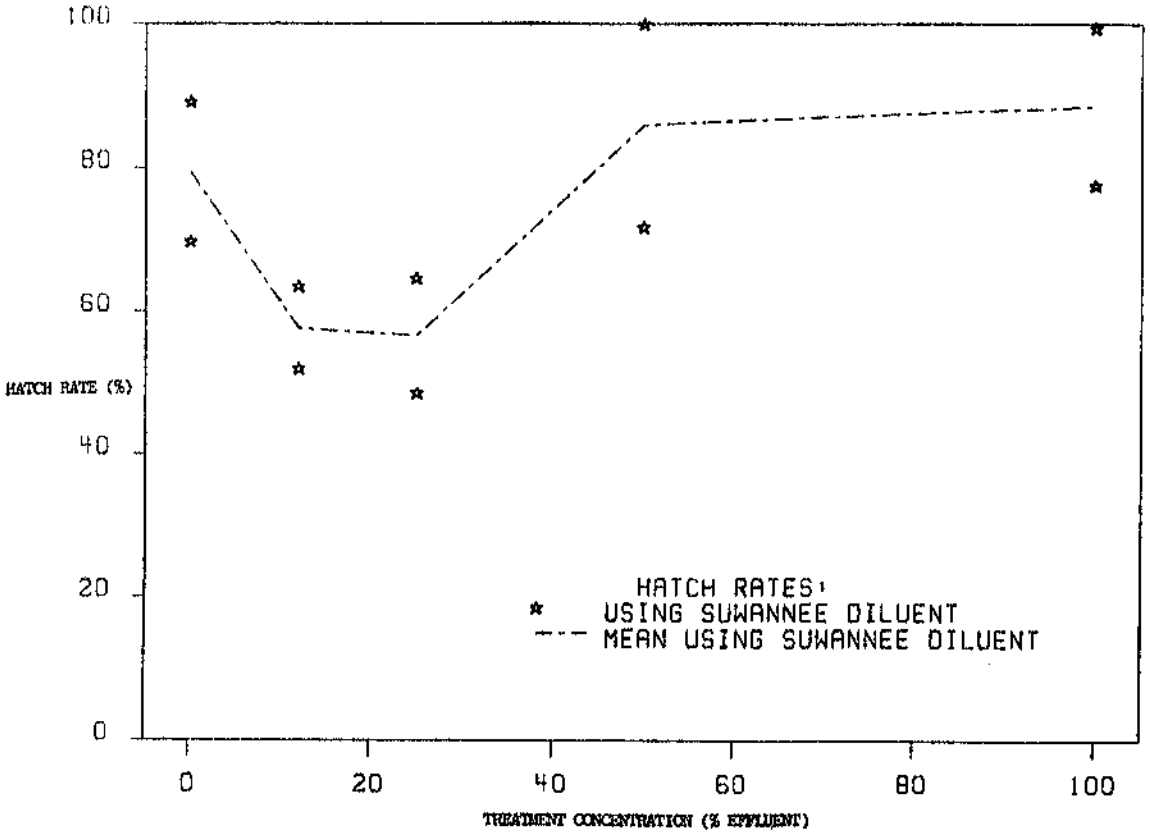


FIGURE 129. Notropis leedsi EXPECTED HATCH RATE (CORRECTED FOR PH) - ASSAY #7 USING SWIFT CREEK EFFLUENT

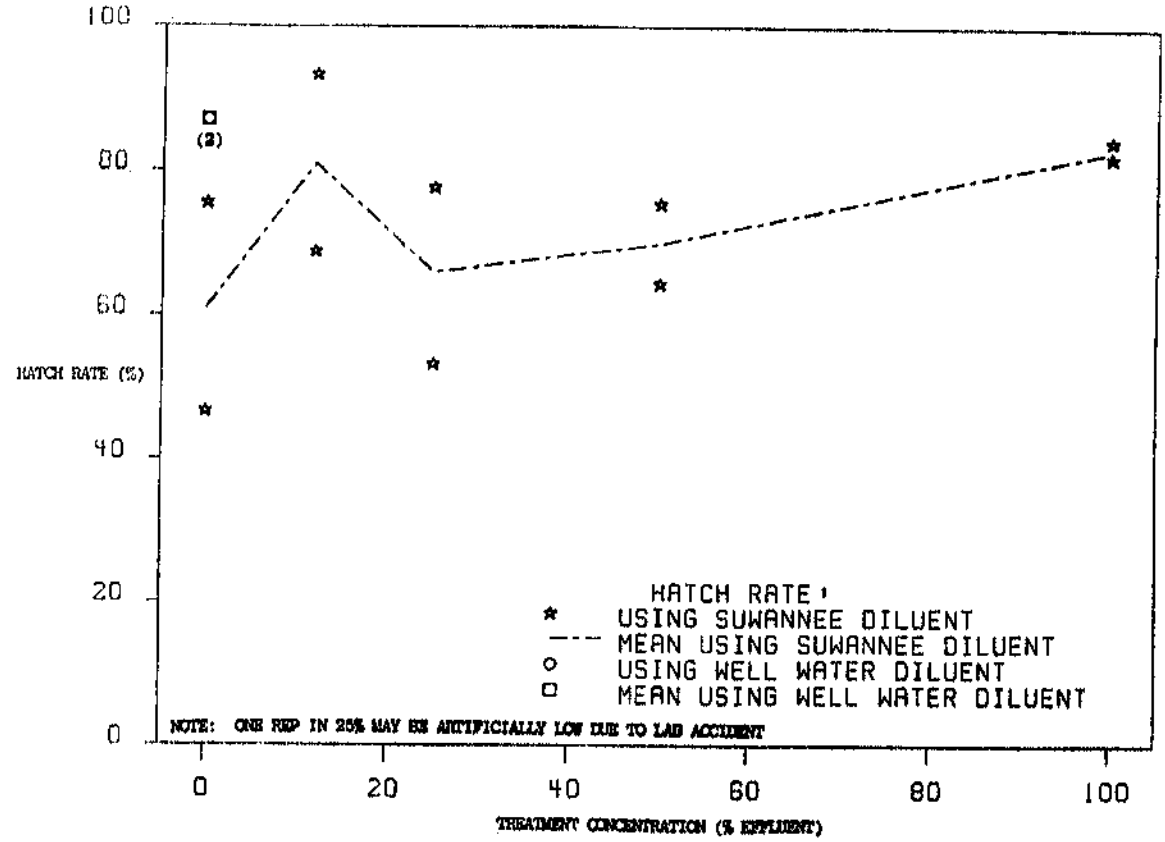


FIGURE 130. Notropis leedsi HATCH RATE - ASSAY #8 USING SWIFT CREEK EFFLUENT

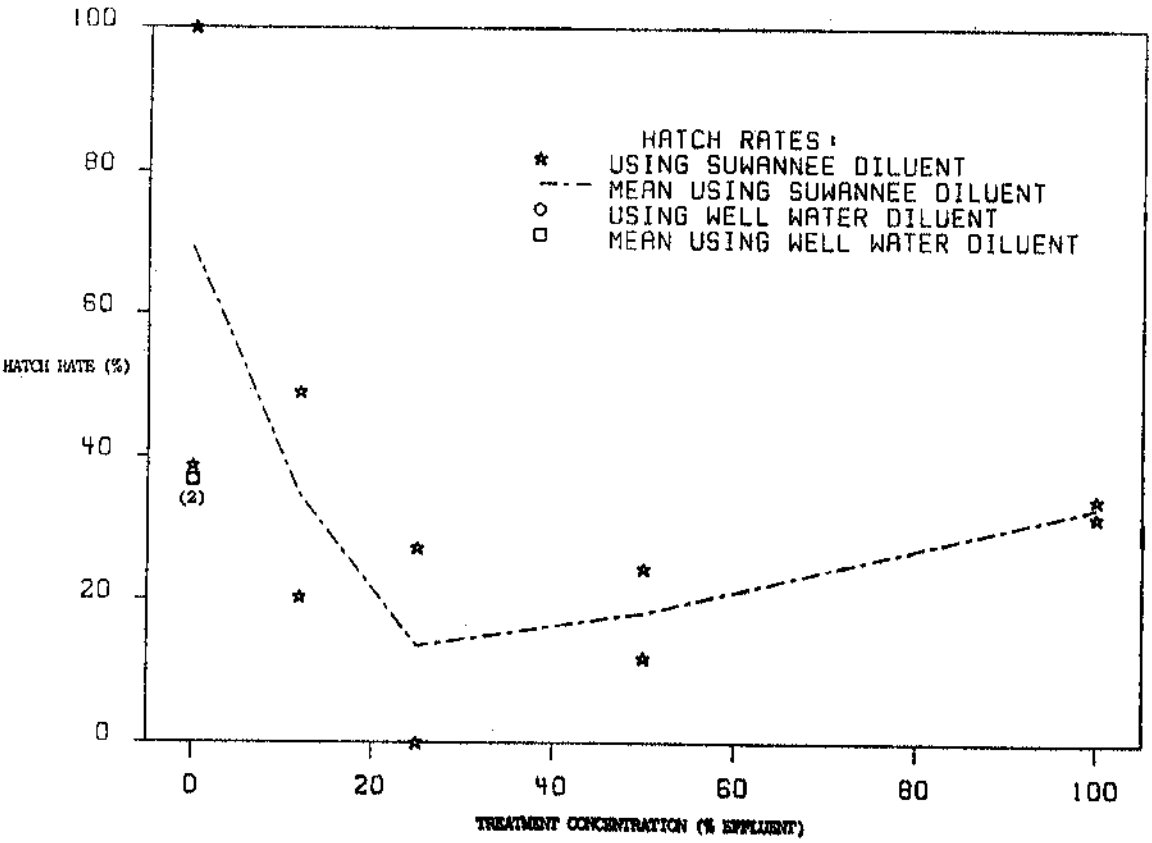


FIGURE 131. Notropis leedsi EXPECTED HATCH RATE (CORRECTED FOR PH) - ASSAY #8 USING SWIFT CREEK EFFLUENT

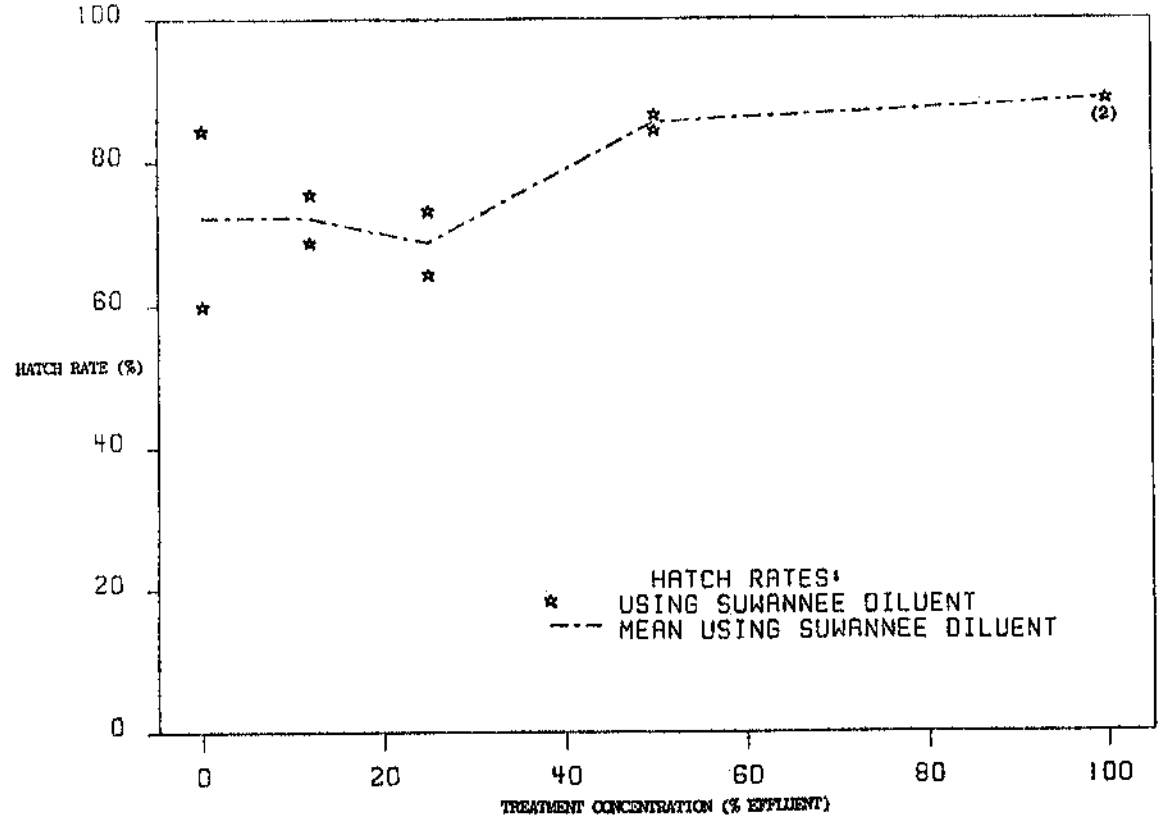


FIGURE 132. Notropis leedsi HATCH RATE - ASSAY #9 USING SWIFT CREEK EFFLUENT

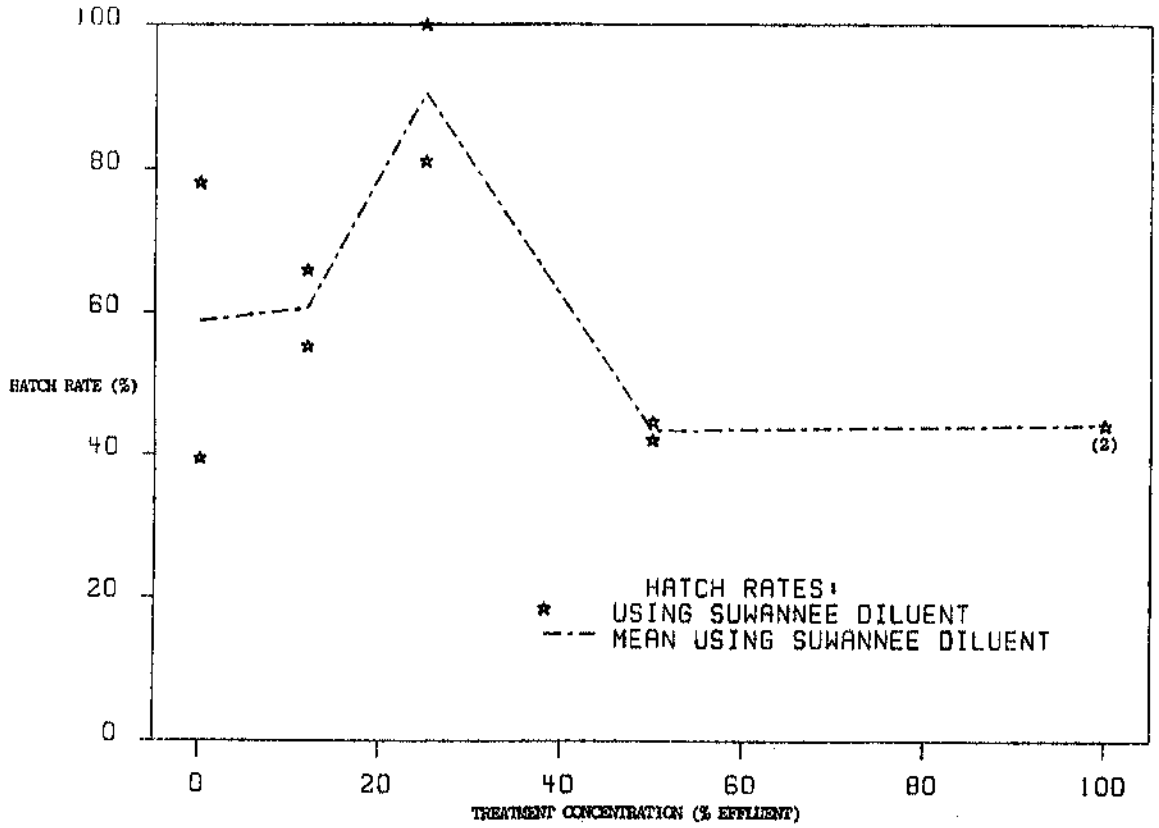


FIGURE 133. Notropis leedsi EXPECTED HATCH RATE (CORRECTED FOR PH) - ASSAY #9 USING SWIFT CREEK EFFLUENT

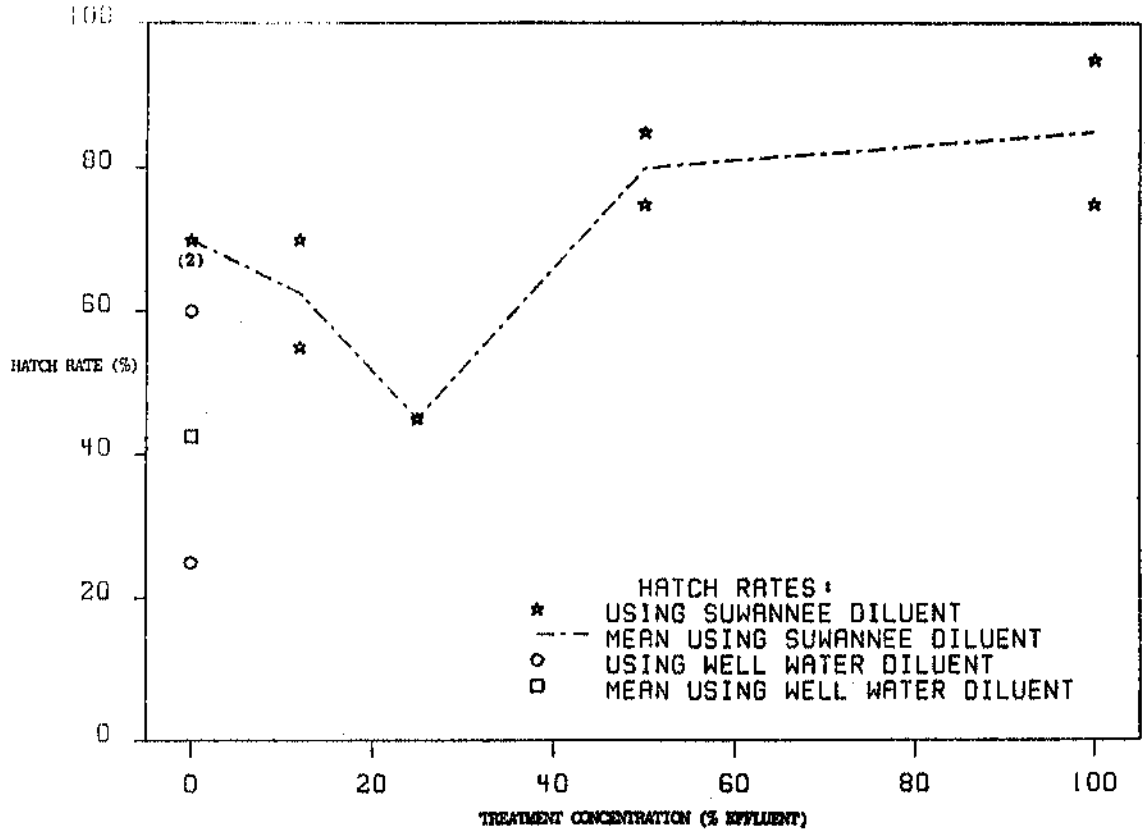


FIGURE 134. Notropis leedsi HATCH RATE - ASSAY #11 USING MINE PROCESS WATER EFFLUENT

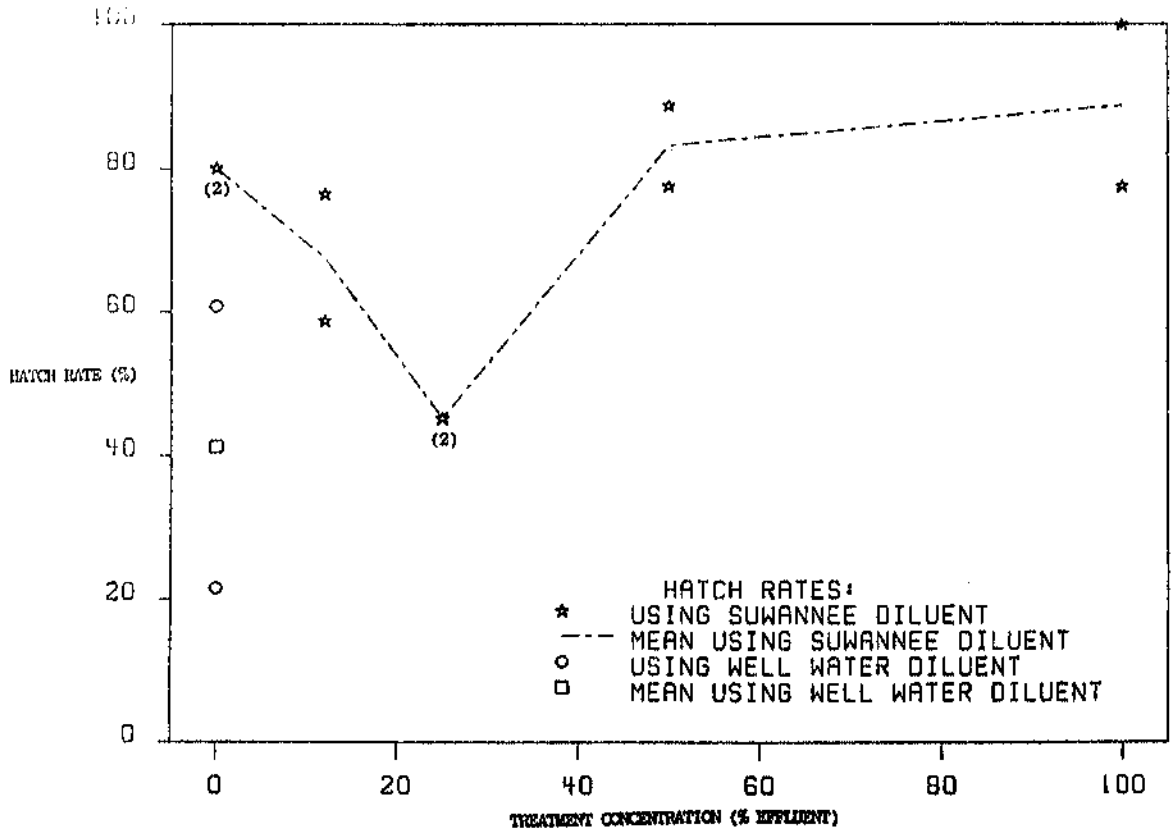


FIGURE 135. Notropis leedsi EXPECTED HATCH RATE (CORRECTED FOR PH) - ASSAY #11 USING MINE PROCESS WATER EFFLUENT

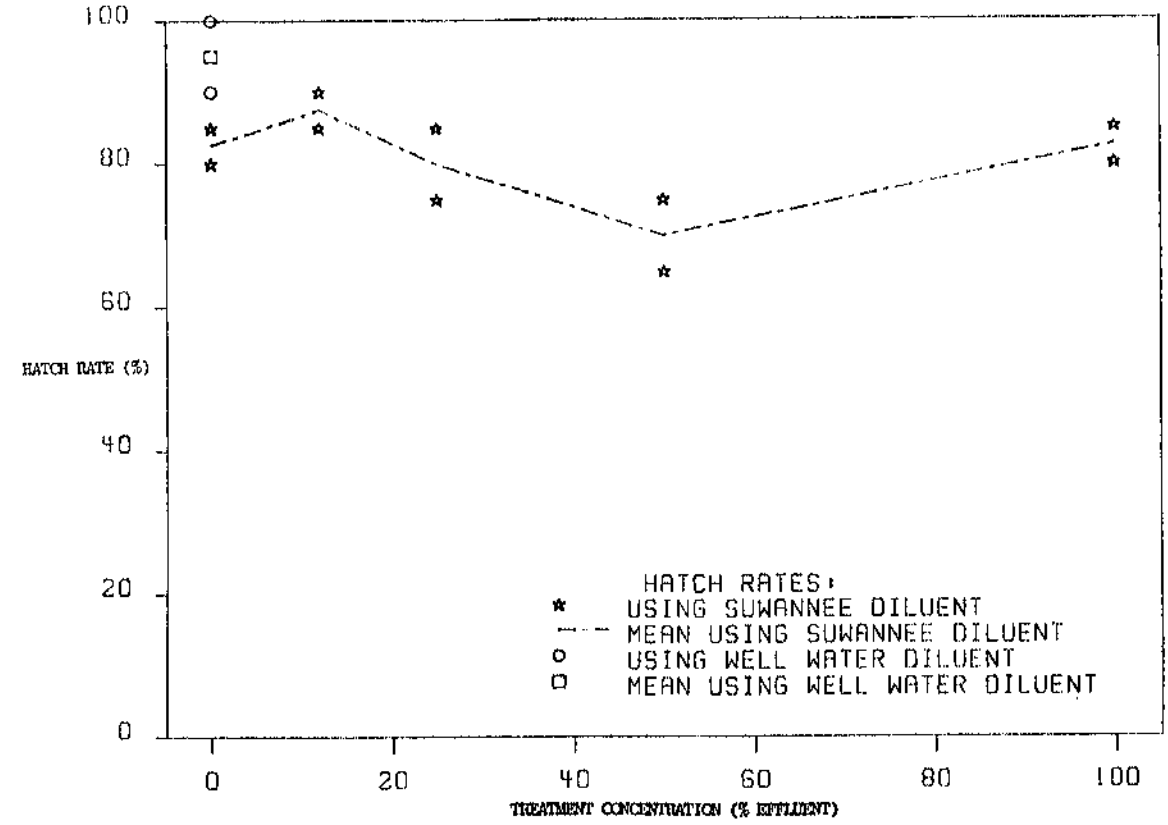


FIGURE 136. Notropis leedsi HATCH RATE - ASSAY #12 USING MINE PROCESS WATER EFFLUENT

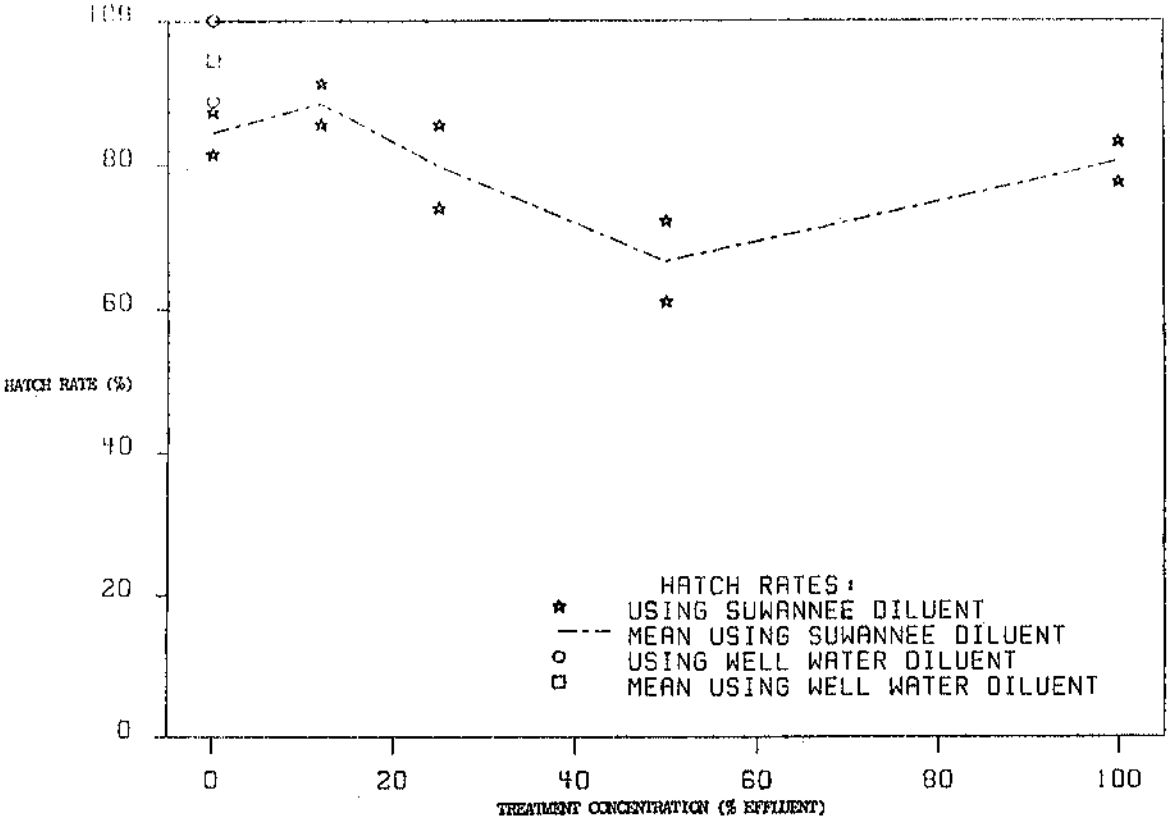


FIGURE 137. Notropis leedsi EXPECTED HATCH RATE (CORRECTED FOR PH) - ASSAY #12 USING MINE PROCESS WATER EFFLUENT

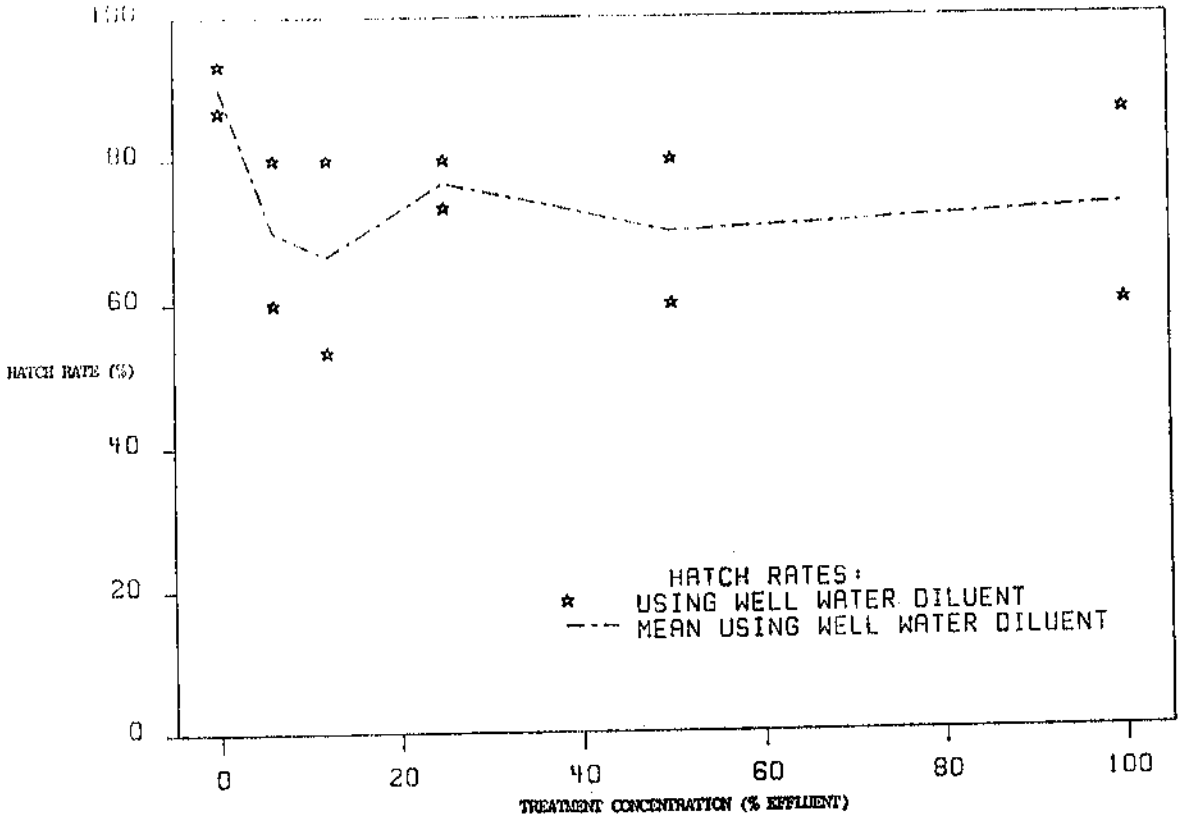


FIGURE 138. Notropis leedsi HATCH RATE - ASSAY #13 USING MINE PROCESS WATER EFFLUENT

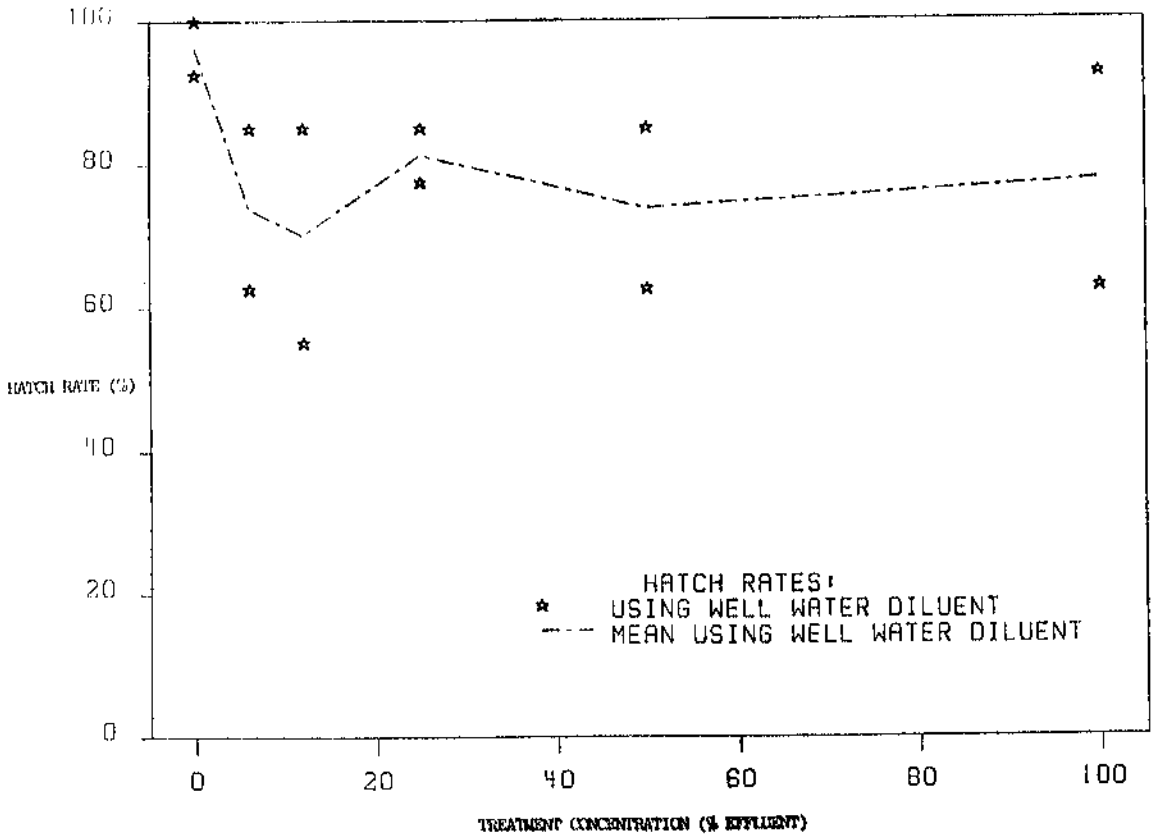


FIGURE 139. Notropis leedsi EXPECTED HATCH RATE (CORRECTED FOR PH) - ASSAY #13 USING MINE PROCESS WATER EFFLUENT

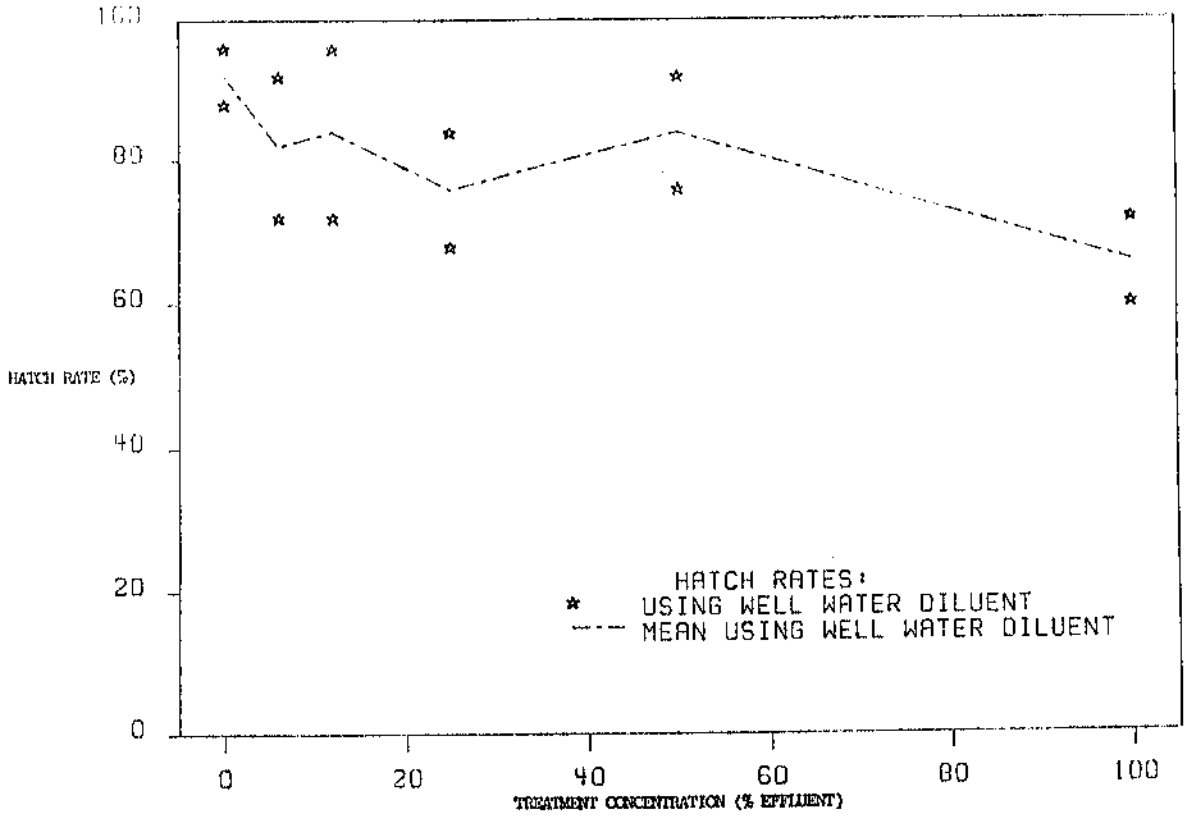


FIGURE 140. Notropis leedsi HATCH RATE - ASSAY #14 USING SWIFT CREEK EFFLUENT

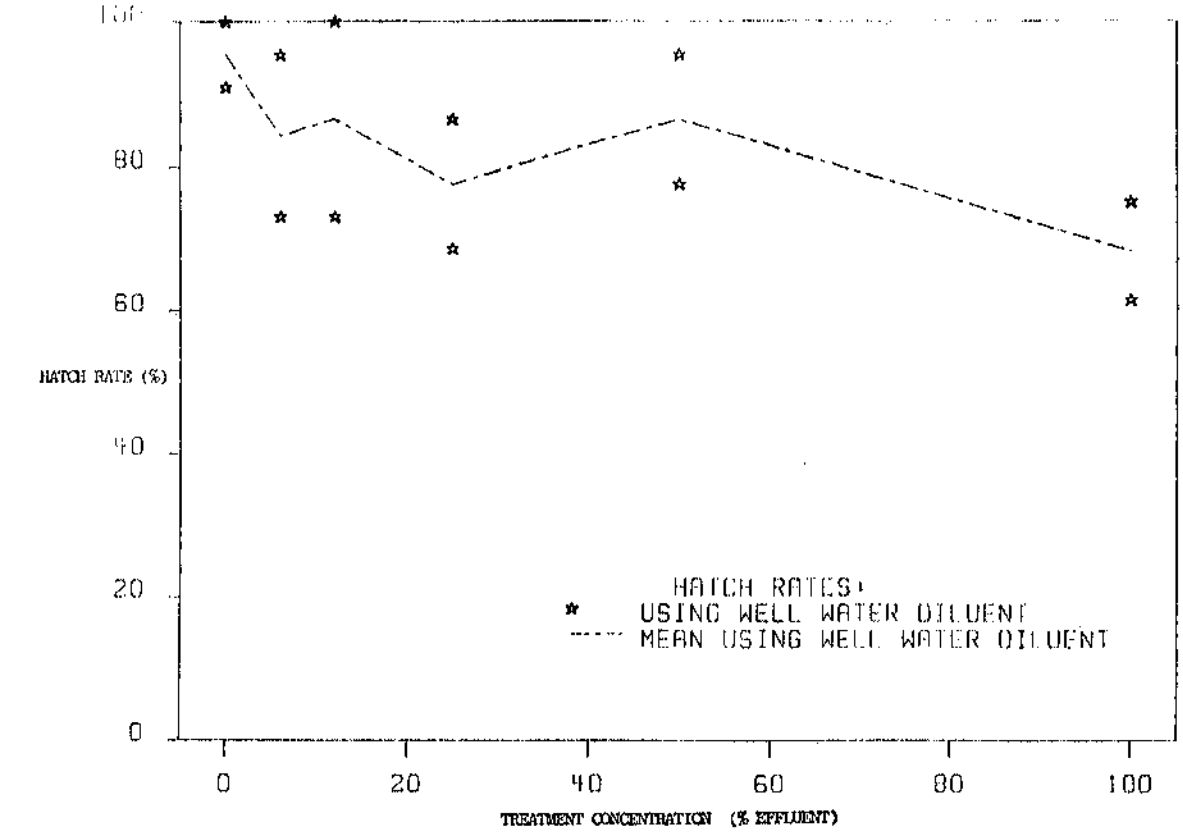


FIGURE 141. Notropis leedsi EXPECTED HATCH RATE (CORRECTED FOR PH) - ASSAY #14 USING SWIFT CREEK EFFLUENT

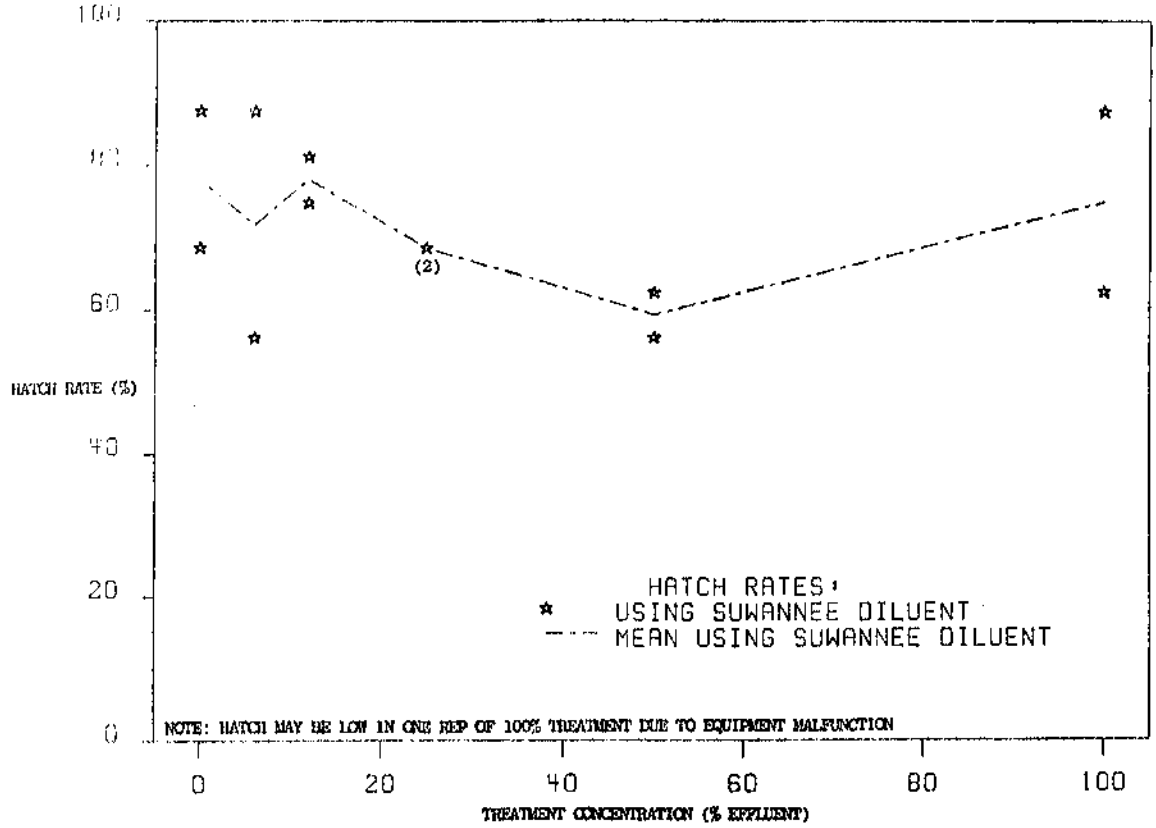


FIGURE 142. Notropis loedsi HATCH RATE - ASSAY #15 USING SWIFT CREEK EFFLUENT

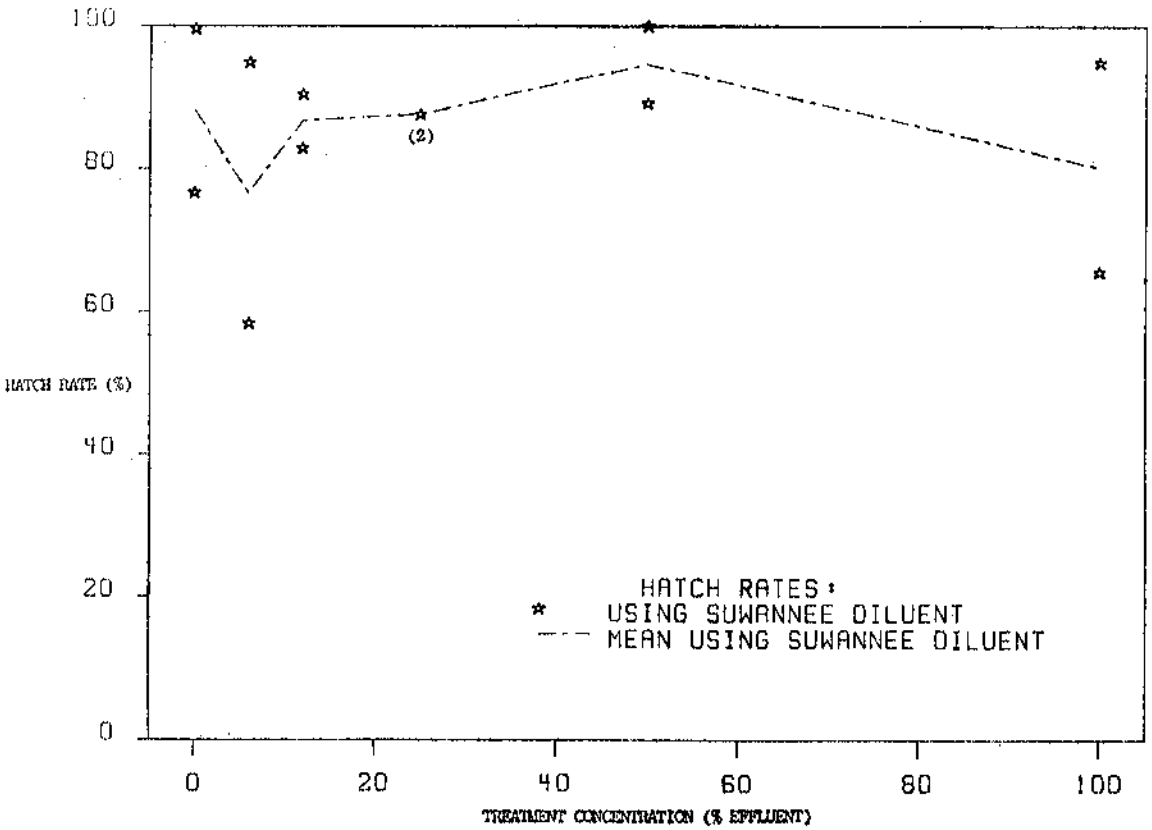


FIGURE 143. Notropis loedsi HATCH RATE CORRECTED FOR PH - ASSAY #15 USING SWIFT CREEK EFFLUENT

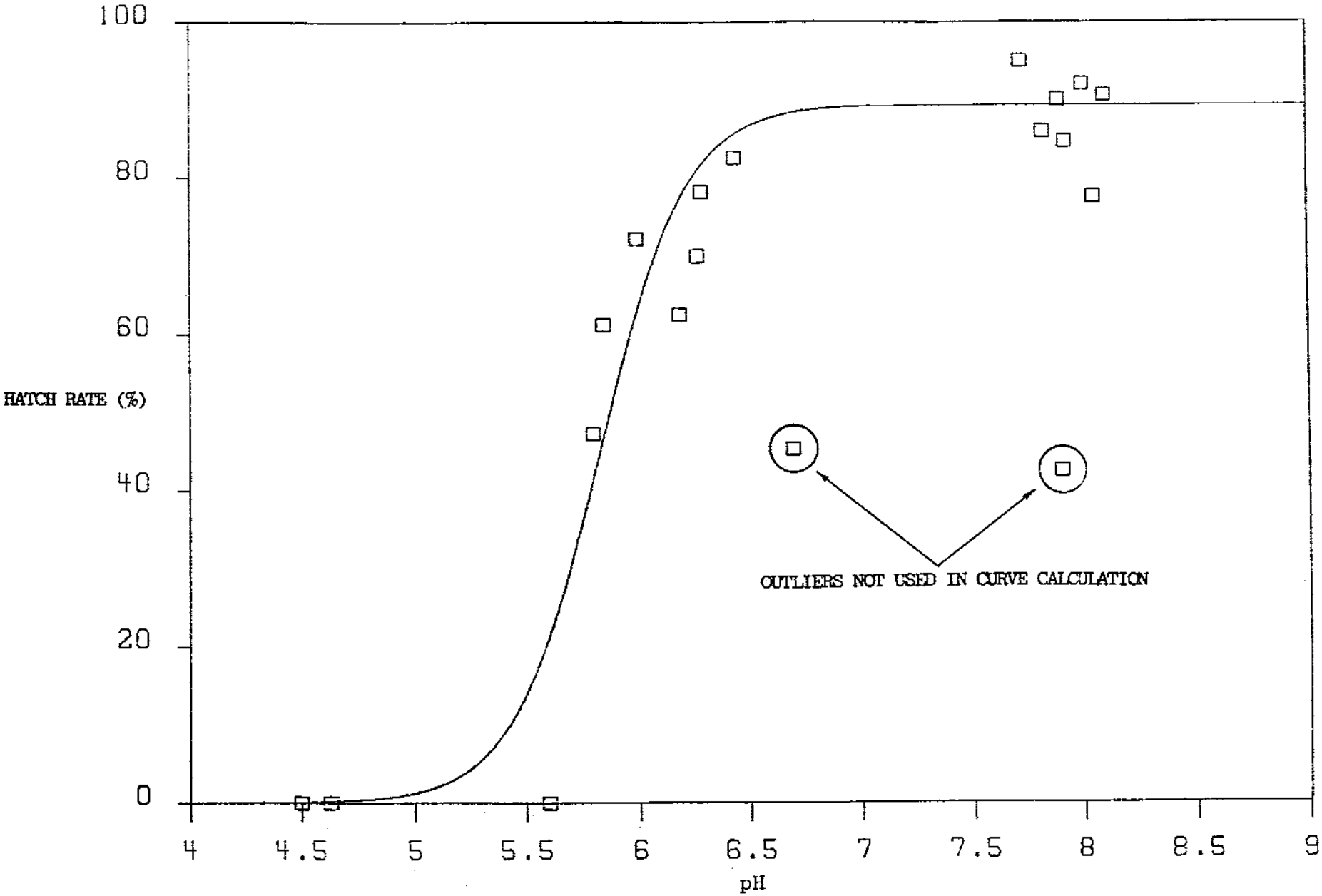


FIGURE 144. CONTROL HATCH RATES AND CALCULATED CURVE OF PREDICTED HATCH RATE

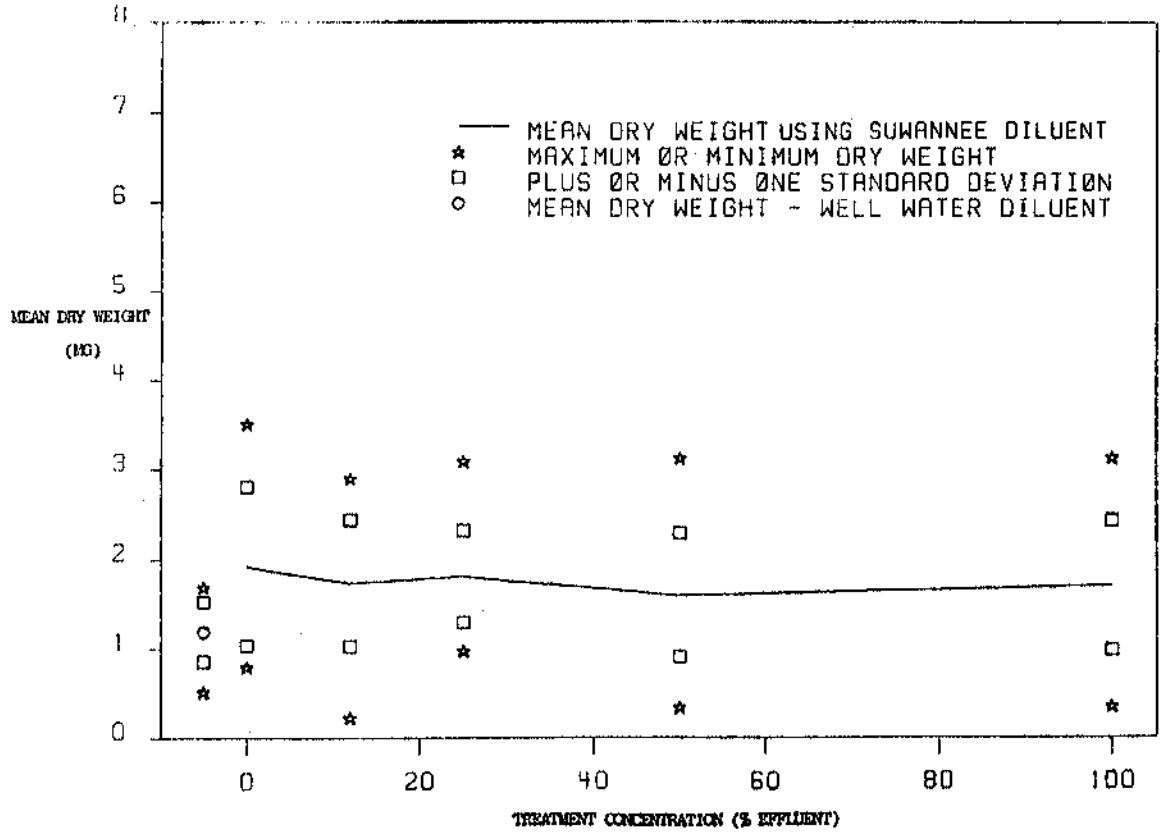


FIGURE 145. Notropis leedsi GROWTH AFTER 28 DAYS - ASSAY #5 USING SWIFT CREEK EFFLUENT

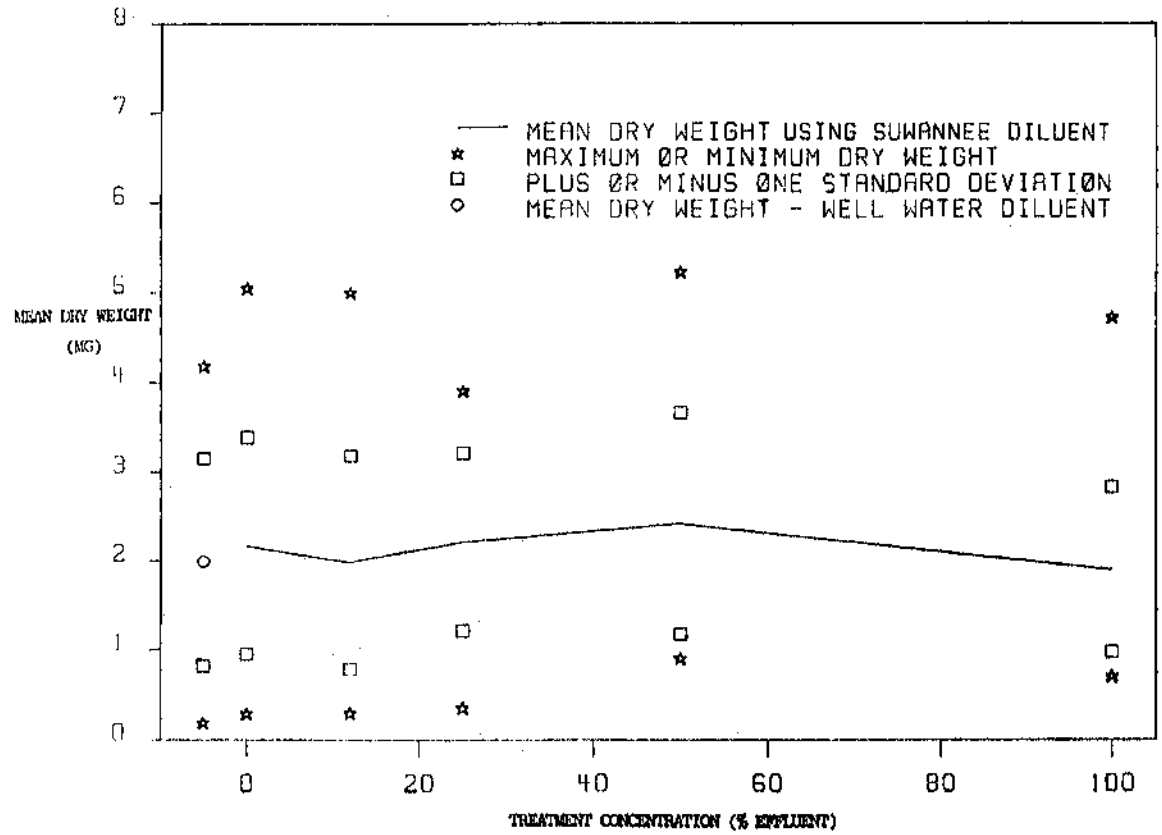


FIGURE 146. Notropis leedsi GROWTH AFTER 28 DAYS - ASSAY #12 USING MINE PROCESS WATER EFFLUENT

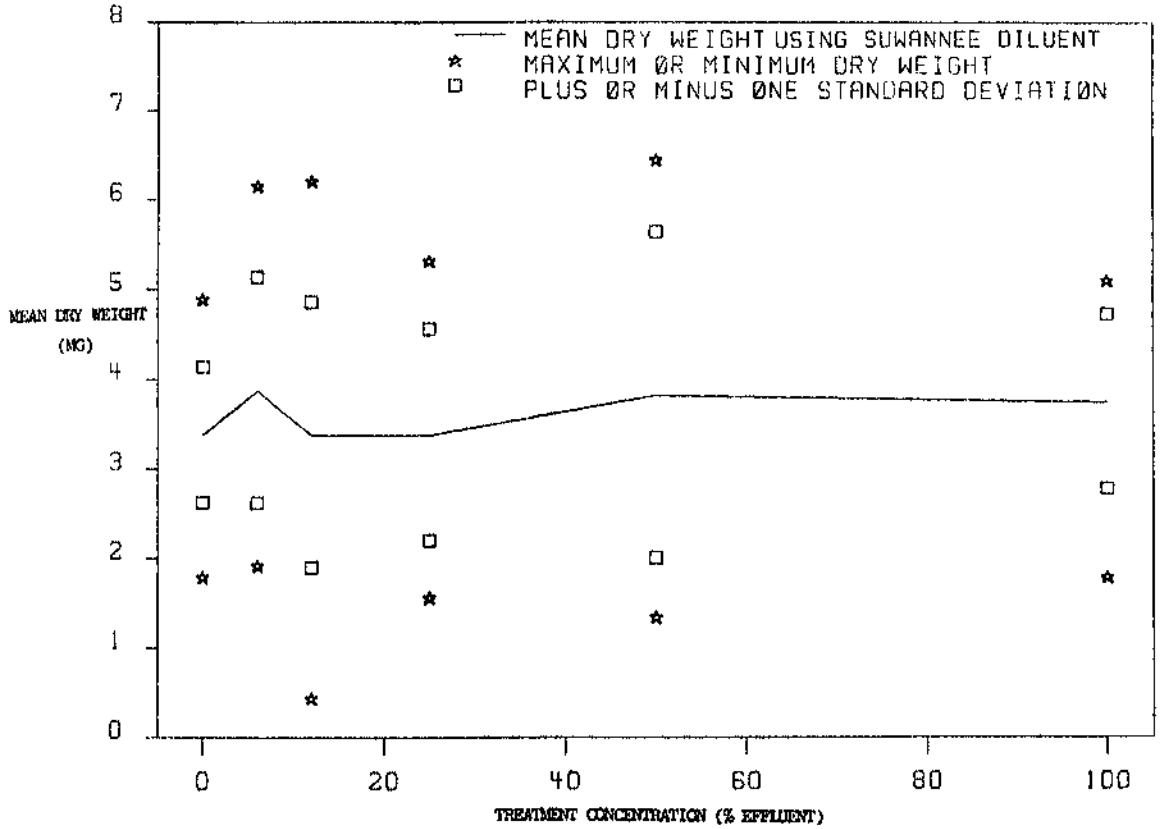


FIGURE 147. Notropis leedsi GROWTH AFTER 28 DAYS - ASSAY #13 USING MINE PROCESS WATER EFFLUENT

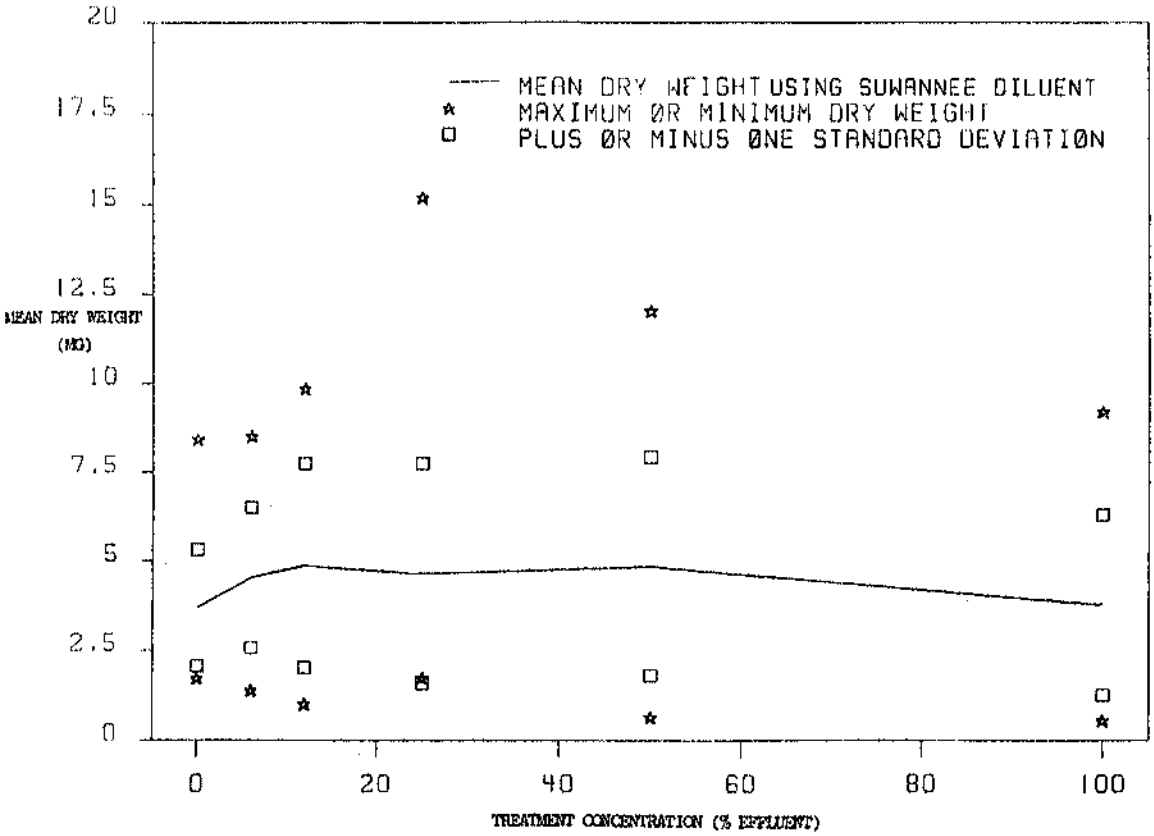


FIGURE 148. Notropis leedsi GROWTH AFTER 42 DAYS - ASSAY #14 USING SWIFT CREEK EFFLUENT

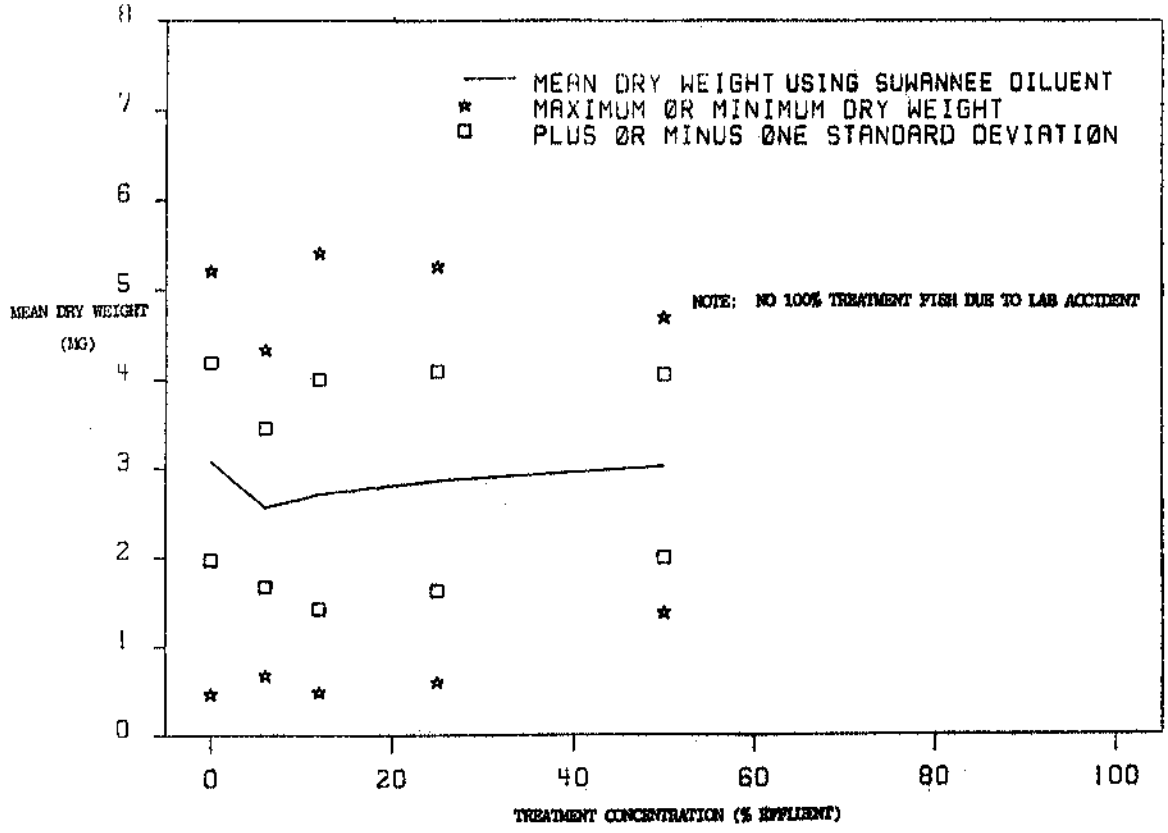


FIGURE 149. Notropis leedsi GROWTH AFTER 28 DAYS - ASSAY #15 USING SWIFT CREEK EFFLUENT

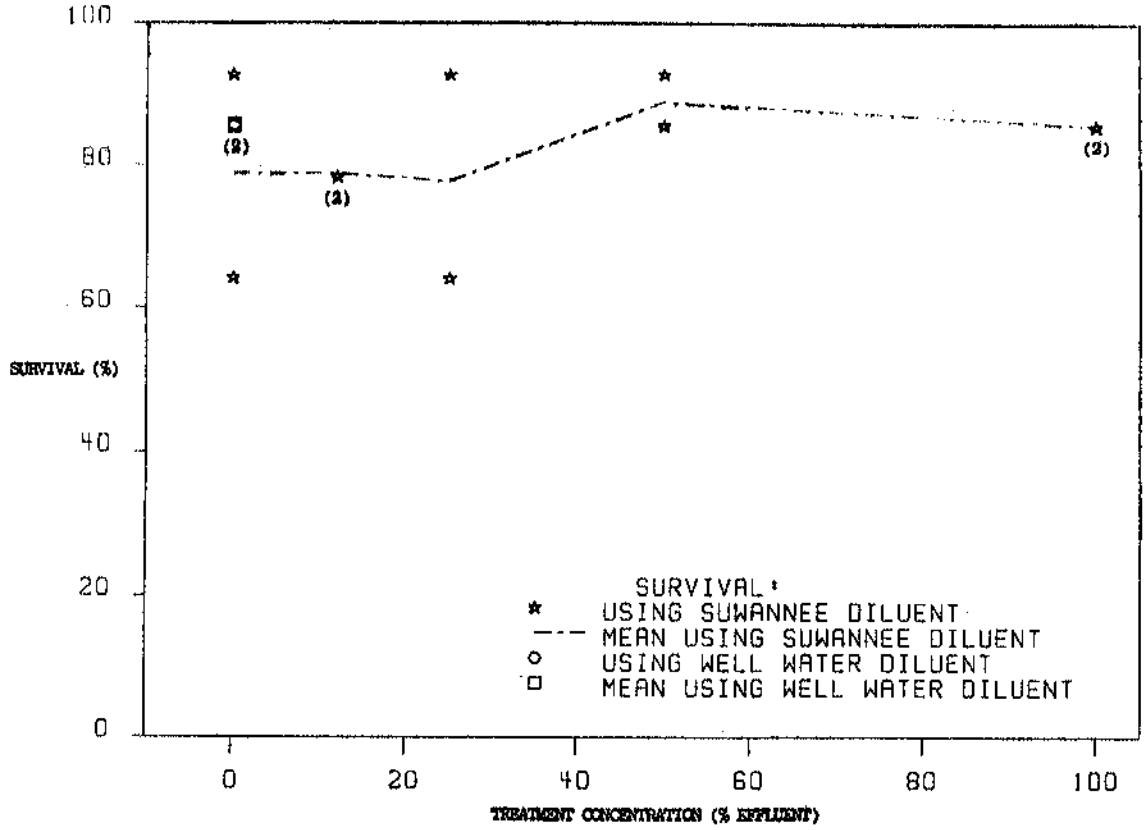


FIGURE 150. Notropis leedsi FRY SURVIVAL AFTER 28 DAYS - ASSAY #6 USING SWIFT CREEK EFFLUENT

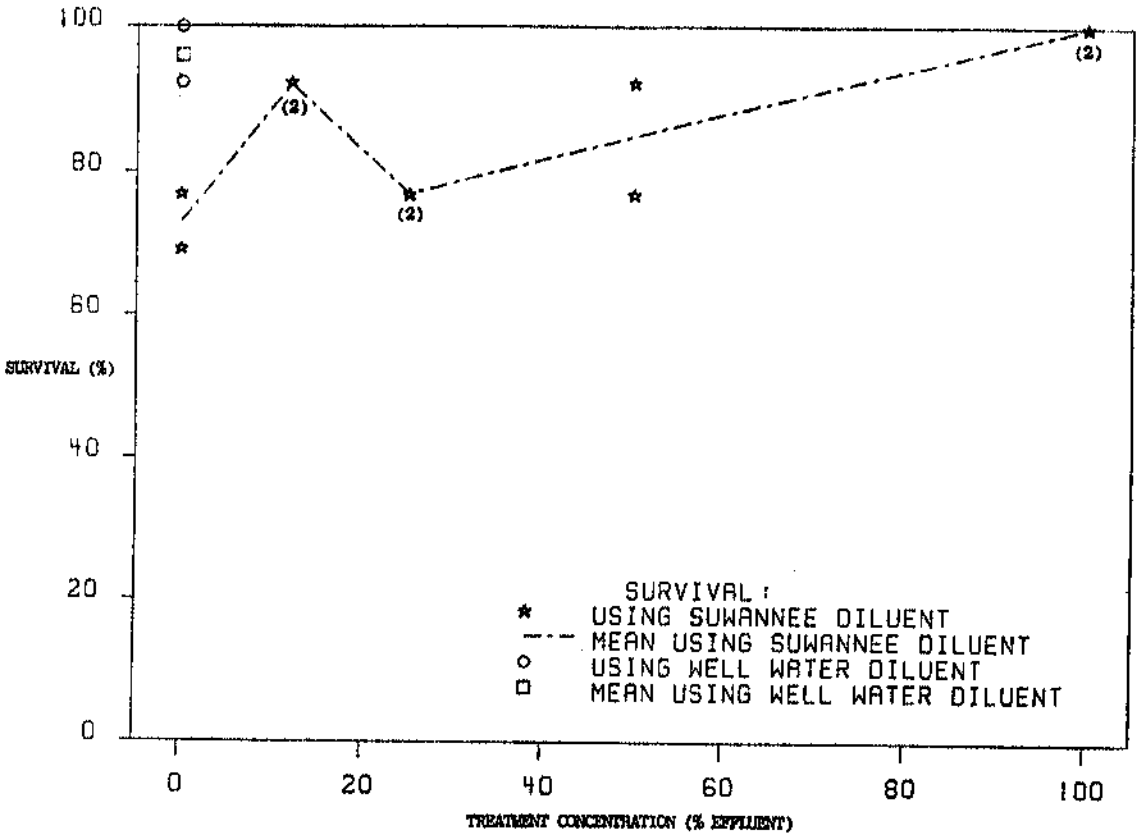


FIGURE 151. Notropis leedsi FRY SURVIVAL AFTER 28 DAYS - ASSAY #12 USING MINE PROCESS WATER EFFLUENT

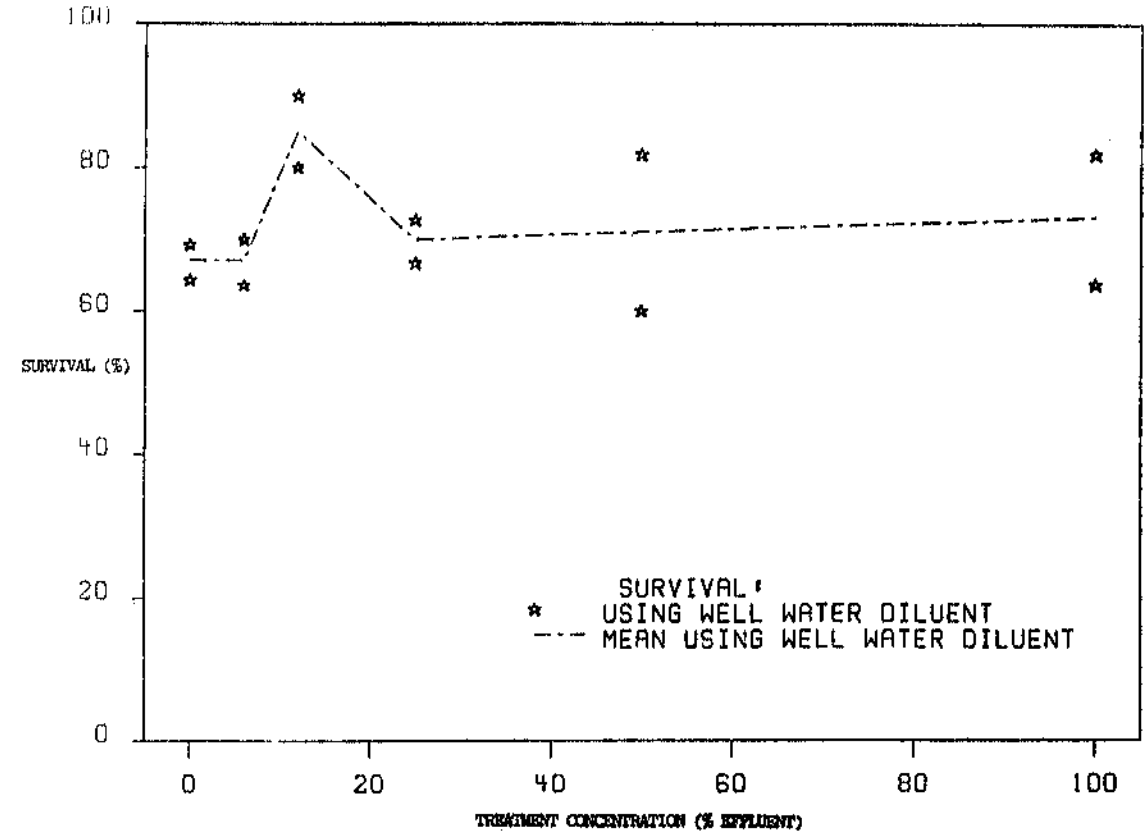


FIGURE 152. Notropis leedsi FRY SURVIVAL AFTER 28 DAYS - ASSAY #13 USING MINK PROCESS WATER EFFLUENT

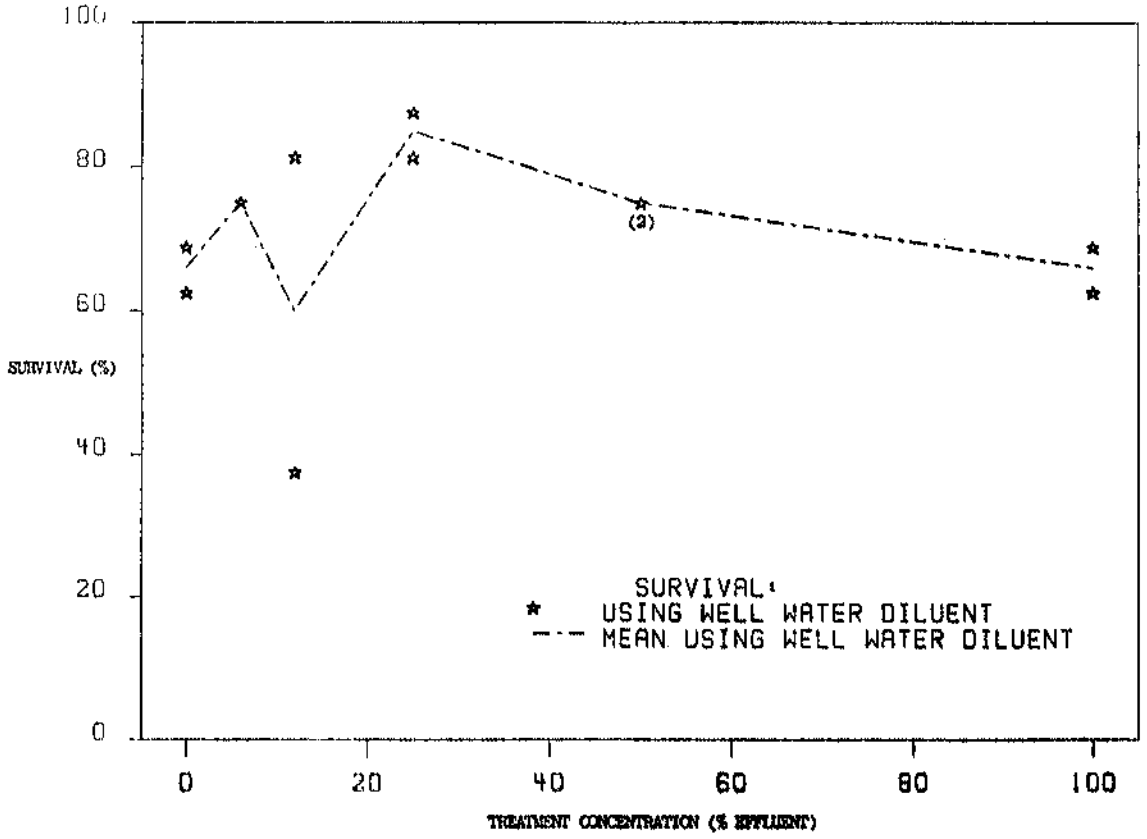


FIGURE 153. Notropis leedsi FRY SURVIVAL AFTER 28 DAYS - ASSAY #14 USING SWIFT CREEK EFFLUENT

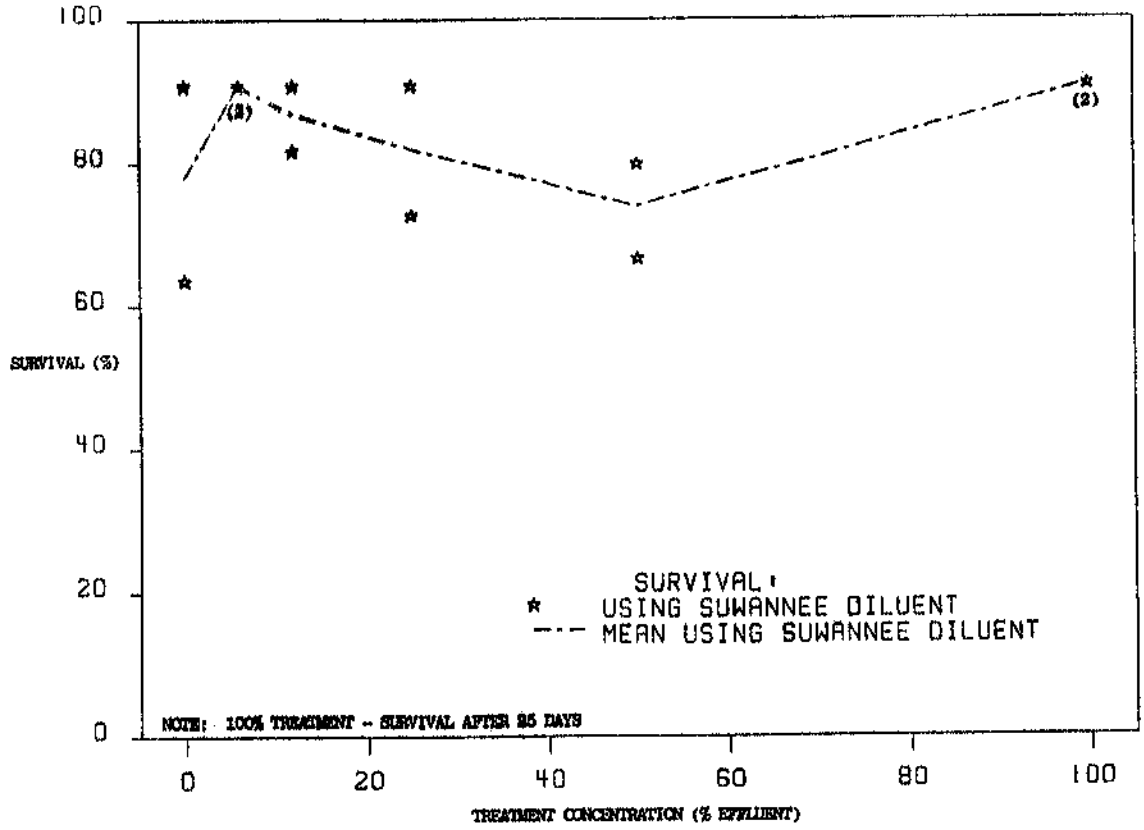


FIGURE 154. Notropis leedsi FRY SURVIVAL AFTER 28 DAYS - ASSAY #15 USING SWIFT CREEK EFFLUENT

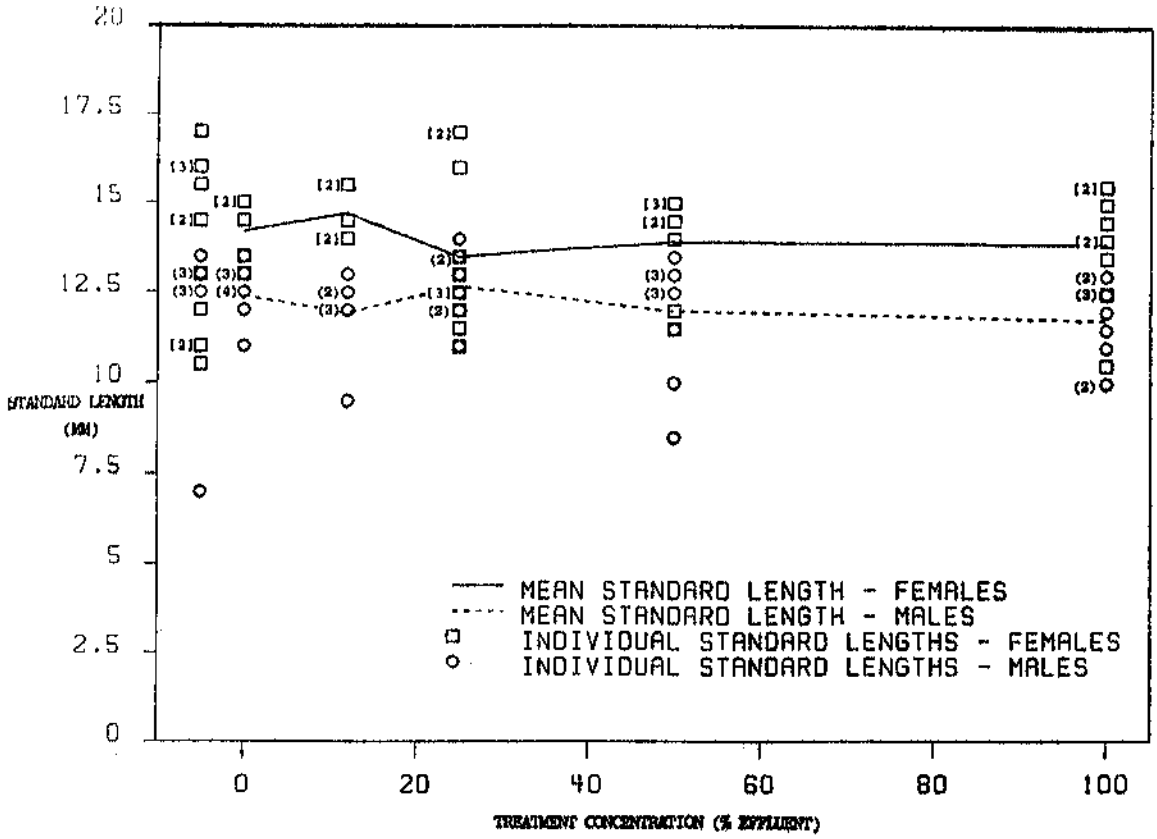


FIGURE 155. Heterandria formosa GROWTH RATE USING SWIFT CREEK EFFLUENT

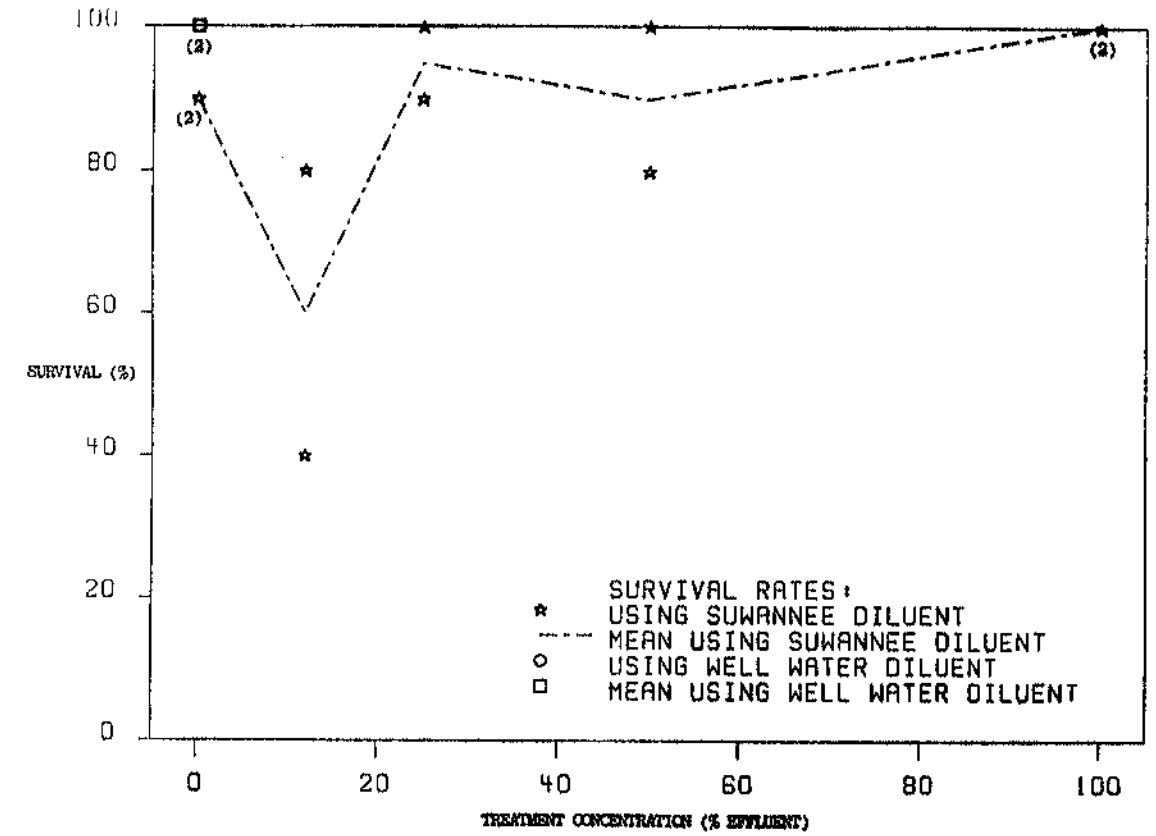


FIGURE 156. Heterandria formosa SURVIVAL RATE AFTER 60 DAYS USING SWIFT CREEK EFFLUENT

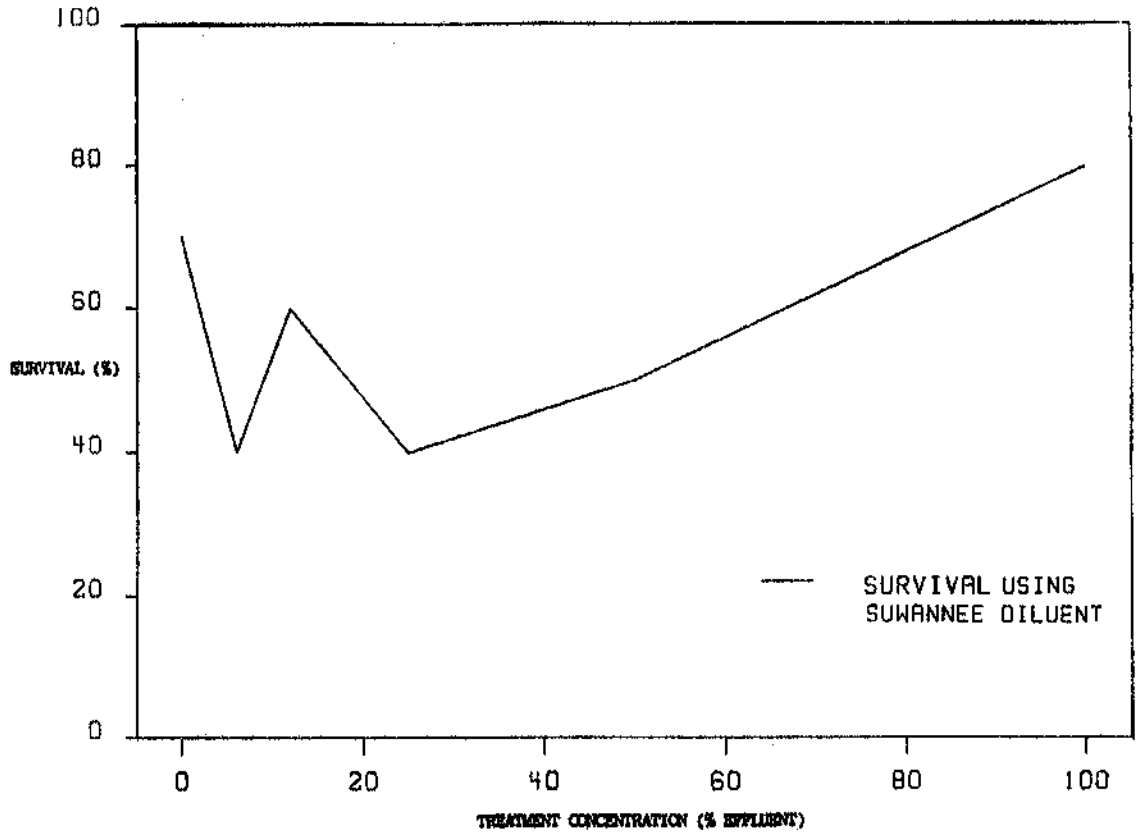


FIGURE 157. Daphnia pulex SURVIVAL RATE AFTER 12 DAYS - ASSAY #1 USING SWIFT CREEK EFFLUENT

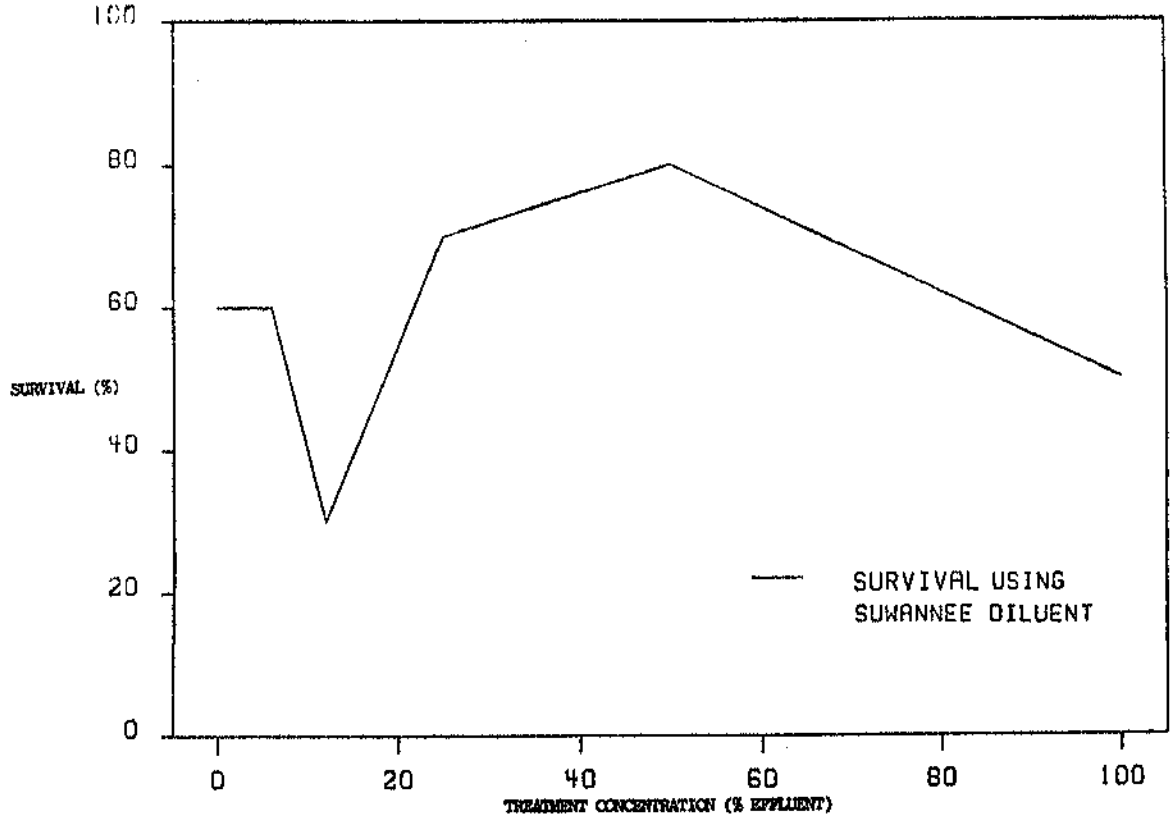


FIGURE 158. Daphnia pulex SURVIVAL RATE AFTER 16 DAYS - ASSAY #2 USING SWIFT CREEK EFFLUENT

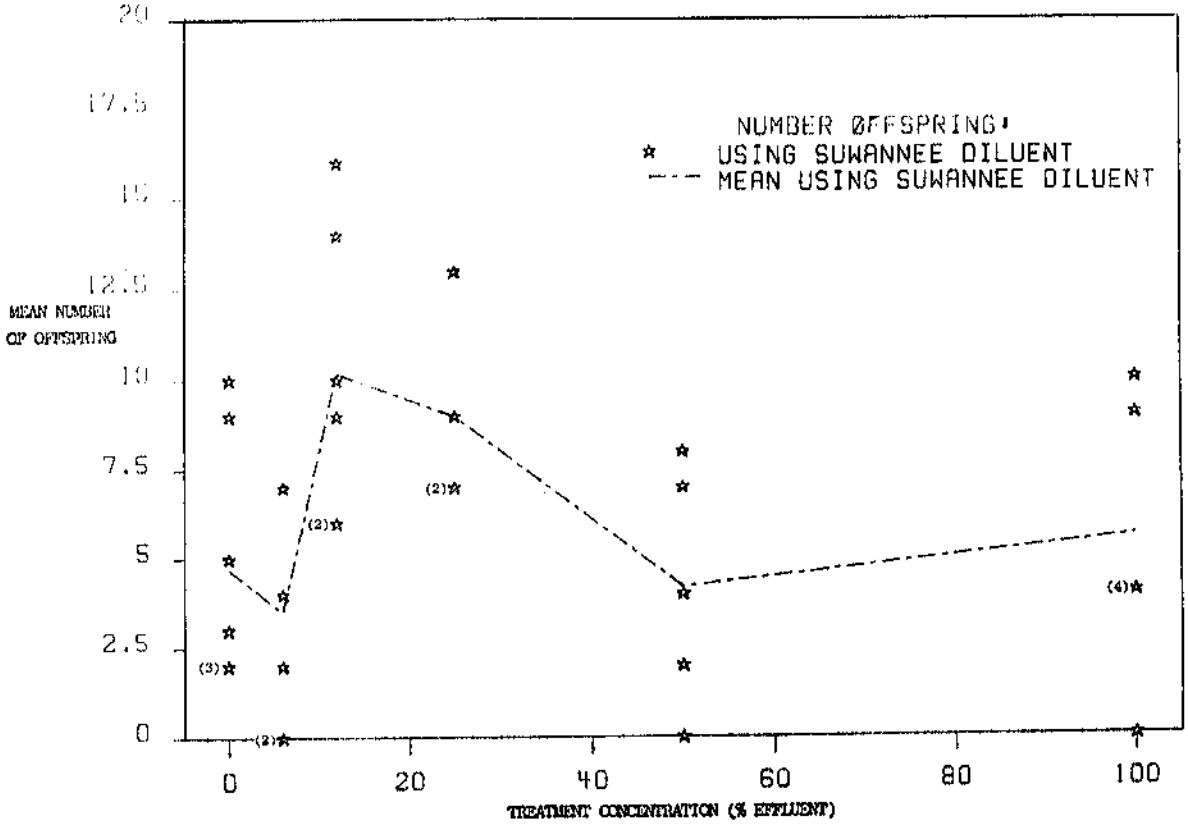


FIGURE 159. Daphnia pulex MEAN NUMBER OF OFFSPRING AFTER 12 DAYS - ASSAY #1 USING SWIFT CREEK EFFLUENT

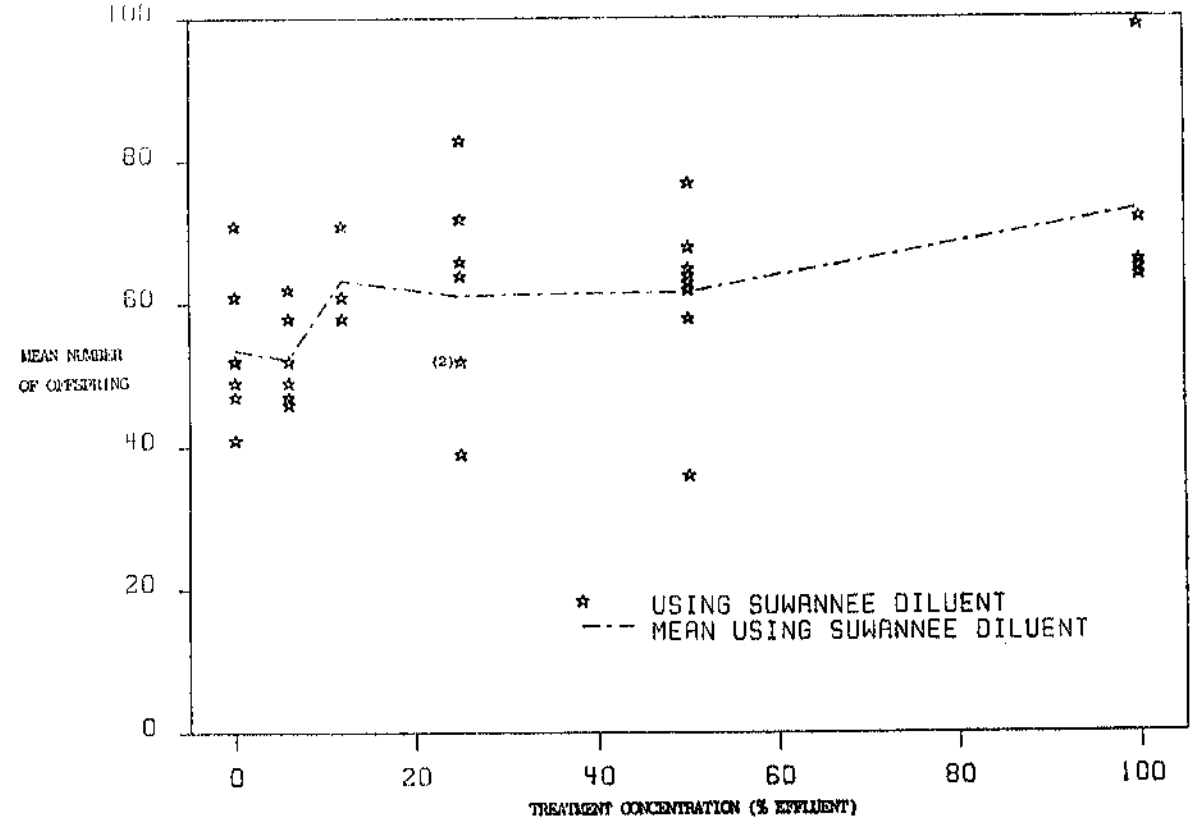


FIGURE 160. Daphnia pulex MEAN NUMBER OF OFFSPRING AFTER 18 DAYS - ASSAY #2 USING SWIFT CREEK EFFLUENT

TABLE 38. LC_{50}'s for monthly standard reference toxicant bioassays- 1983.

Test Animal

	LC_{50} - ppm											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
N. leedsi	-	-	-	5.6	-	-	5.2	5.7	6.6	6.2	-	4.2
H. formosa	6.4	8.4	-	5.7	-	4.0	5.0	6.7	9.6	4.7	6.6	6.0
D. pulex	4.5	6.0	4.0	0.2	6.4	3.6	4.0	5.2	7.2	2.5	-	-
P. promelas	7.2	5.7	-	5.6	4.9	5.8	3.6	5.0	4.2	6.6	-	-

TABLE 39. Variations in bioassay procedures.

Assay Number	Diluent pH Adjustment	Water Bath	Diluent	Mean Control pH	Effluent	Continued For Fry Assay	Remarks
1	None	No	S	4.5	S	No	-
2	None	No	S	4.63	S	No	-
3	None	No	S	4.5	S	No	Used control and 12% treatments only
4	Bulk	No	S	5.78	S	No	-
5	Bulk	Yes	S	6.66	S	Yes	Diluent pH over-adjusted
6	Bulk	Yes	S	5.88	S	No	Control pH Low For Part of Assay
7	Individual	Yes	S	6.19	S	No	
8	Bulk	Yes	S	5.85	S	No	Control pH Low For Part of Assay
9	Individual	Yes	S	6.00	S	No	Control pH Low For Part of Assay
10	Halted Due to Mercury Contamination From Broken Thermometer						
11	Individual	Yes	S	6.27	M	No	
12	Individual	Yes	S	6.44	M	Yes	
13	None	Yes	W	7.89	M	Yes	
14	None	Yes	W	8.00	S	Yes	At 28 Days, Fry Culled to 10/Rep and Assay Continued to 42 Days
15	Individual	Yes	S	6.29	S	Yes	Effluent pH Low Resulting in Low pH's in upper treatment concentrations.

1. None = No diluent pH adjustment.
   Bulk = All dilution water pH adjusted using DER well water.
   Individual = Each treatment concentration pH adjusted, if necessary, with DER well water to provide minimum pH

2. S = Suwannee River water.
   W = DER well water

3. S = Water from Swift Creek at 001-1 NPDES monitoring point.
   M = Mine process water from Swift Creek Mine.

TABLE 40. ANOVA values for Notropis leedsi hatching data.

Assay Number	pH corrected hatch		Freeman and Tukey arcsine square root transformed hatch	
	f	p	f	p
6	.62	.668	.64	.657
7	2.33	.195	1.72	.284
8	1.75	.278	1.66	.297
9	3.72	.092	3.59	.097
11	6.39	.034	3.72	.092
12	3.78	.090	3.69	.093
13	.72	.629	1.08	.458
14	.97	.503	.91	.531
15	.33	.822	.35	.812

TABLE 41. ANOVA values for Notropis leedsi log transformed growth data.

Assay Number	f	p
5	.73	.568
12	.80	.525
13	.58	.710
14	.83	.527
15	.46	.709

TABLE 42. ANOVA values for Notropis leedsi fry survival data.

Assay Number	Fry survival		Freeman and Tukey arcsine square root transformed fry survival	
	f	p	f	p
5	.28	.846	.30	.836
12*	13.37	.007	8.20	.021
13	1.16	.418	.30	.836
14	1.02	.469	.95	.512
15	.99	.481	.95	.512

* Data irregularities suggest results are inaccurate.

TABLE 43. Heterandria formosa fry data - 1/27/83 - 4/19/83.

Treatment Concentration %	Number Fry at Start	% Survival	Mean pH	Mean Alkalinity (mg/l)	Mean Hardness (mg/l)	Mean Conductivity (umho)
0	10	90	5.6	10	15	54
0	10	90	5.6	10	15	54
12	10	40	6.0	14	27	84
12	10	80	6.0	14	27	84
25	10	90	6.3	16	42	122
25	10	100	6.3	16	42	122
50	10	80	6.5	21	66	185
50	10	100	6.5	21	66	185
100	10	100	6.9	33	121	313
100	10	100	6.9	33	121	313
*	10	100	7.9	119	114	218
*	10	100	7.9	119	114	218

* = DER wellwater control

TABLE 44. Results of Daphnia pulex assay #1 - 2/17/84-3/2/84.

Treatment Concentration	% Survival after 12 days	Mean number offspring of survivors after 12 days
0	70	4.7
6	40	3.5
12	60	10.2
25	40	9.0
50	50	4.2
100	80	5.6

TABLE 45. Results of Daphnia pulex assay #2 - 4/21/84-5/7/84.

Treatment Concentration	% Survival after 18 days	Mean number offspring of survivors after 18 days
0	60	53.5
6	60	52.3
12	30	63.3
25	70	61.1
50	80	61.6
100	50	73.2

LITERATURE CITED

Alstad, D. N. 1980. Nearest-neighbor analysis of microhabitat partitioning in stream insect communities. Hydrobiol. 79: 137-140.

American Public Health Assoc., American Water Works Assoc., and Water Pollution Control Federation. 1980. Standard methods for the examination of water and wastewater, 15th ed. New York, N.Y. 1134p.

Anderson, J. B. and W. T. Mason. 1968. A comparison of benthic macroinvertebrates collected by dredge and basket sampler. J. Water Poll. Cont. Fed. 40(2): 252-259.

Arthur, J. W. and W. B. Horning, II. 1969. The use of artificial substrates in pollution surveys. Amer. Midland Naturalist 82(1): 83-89.

Bass, D. G., Jr. and V. G. Hitt. 1973. Sport fishery ecology of the Suwannee and Santa Fe rivers, Florida. Fla. Game Fresh Water Fish Comm. Tech. Rept., Tallahassee, Fla.

Bauer, G., E. Echimff, W. Thomas, and R. Herrmann. 1980. Relations between the decline of the freshwater pearl mussel (Margaritifera margaritifera) in the Fichtelgebirge and the water quality. Arch. Hydrobiol. 88(4): 505-513.

Beck, W. M., Jr. 1954. Studies in stream pollution biology. I. A simplified ecological classification of organisms. Quart. J. Fla. Acad. Sci. 17(4): 211-227.

Benoit, D. A., V. R. Mattson, and D. L. Olson. 1982. A continuous flow mini-diluter for toxicity testing. Wat. Res. 16: 457-464.

Berg, A. 1962. Expose des methodes d'analyse chimique et physico-chimique des eaux humiques. Mem. 1st Ital. Idrobiol. 15: 183-206.

Biggar, J. W. and R. B. Corey. 1969. Agricultural drainage and eutrophication, p. 405-445. In Eutrophication, causes, consequences and correctives. Proc. Symp. Nat. Acad. Sci., Wash., D.C.

Bloom, S. A. 1981. Similarity indices in community studies: potential pitfalls. Mar. Ecol. Prog. Ser. 5: 125-128.

Bloom, S. A., S. L. Santos, and J. G. Field. 1977. A package of computer programs for benthic community analyses. Bull. Mar. Sci. 27(3): 577-580.

Boerger, H. 1981. Species composition, abundance and emergence phenology of midges (Diptera: Chironomidae) in a brown-water stream of West-Central Alberta, Canada. Hydrobiol. 80: 7-30.

Boesch, D. F. 1977. Application of numerical classification in ecological investigations of water pollution. U.S. Envir. Prot. Agency, Ecol. Res. Ser., EPA-600/3-77-033. 114p.

Bouwer, H. 1978. Groundwater hydrology. McGraw-Hill., New York. 480p.

Bradley, J. T. 1972. Climate of Florida, 31p. In Climatography of the United States No. 60-8, Climates of the States. U.S. Dept. Commerce, N.O.A.A.

Brezonik, P. L. 1978. Effect of organic color and turbidity on Secchi disc transparency. J. Fish. Res. Bd. Can. 35: 1410-1416.

Brooks, H. K. 1981a. Geologic map of Florida. Inst. Food Agricultural Sci., Univ. Fla., Gainesville.

_____. 1981b. Physiographic divisions (map). Inst. Food Agricultural Sci., Univ. Fla., Gainesville.

_____. 1981c. Guide to the physiographic division of Florida. Inst. Food Agricultural Sci., Univ. Fla., Gainesville. 11p.

Brown, H. D. 1976. A comparison of the attached algal communities of a natural and an artificial substrate. J. Phycol. 12(3): 301-306.

Burnett, W. C. and S. Deetae. 1984. Radium in the Suwannee River. Draft report to Fla. Dept. Environ. Regulation, Contract no. LR-48. 48 pp. [Limited quantities available, upon request, from the Office of Special Projects, Fla. Dept. Environ. Reg., 2600 Blair Stone Rd., Tallahassee, Fla 32301.]

Butcher, R. W. 1938. The algae of the river. Rep. Avon. Biol. Res. 5: 47-52.

_____. 1940. Studies in the ecology of rivers. IV: Observations on the growth and distribution of the sessile algae in the River Hull, Yorkshire. J. Ecol. 28: 210-233.

_____. 1947. Studies in the ecology of rivers. VII: The algae of organically enriched waters. J. Ecol. 35(1,2): 186-191.

_____. 1959. Biological assessment of river pollution. Proc. Linn. Soc. London. 170(2): 159-165.

Cahn, R. D. 1967. Detergents in membrane filters. Sci. 155: 195-196.

Cairns, J., Jr. and K. L. Dickson. 1971. A simple method for the biological assessment of the effects of waste discharges on aquatic bottom dwelling organisms. J. Wat. Poll. Fed. 43: 755-772.

Ceryak, R. 1977. Hydrogeology of a river basin in a karst terrain Alapaha River Hamilton County, Florida. Suwannee River Water Management District, Information Circ. 5. 20p.

Ceryak, R., M. S. Knapp, and T. Burnson. 1983. The geology and water resources of the Upper Suwannee River Basin, Florida. Fla. Dept. Nat. Res., Bur. Geol. Rept. Invest. No. 87. 165 p.

Claesson, A. 1980. Variation in cell composition and utilization of N and P for growth of Selenastrum capricornutum. Physiol. Plant. 48: 59-64.

Clesceri, N. L. (with contributions by, G. C. McDonald, I. J. Kumar, and W. J. Green). 1973. Organic Nutrient Factors Effecting Algal Growth. U.S. Envir. Prot. Agency, EPA-660/3-78-018. p. 5-23.

Clifford, H. T. and W. Stephenson. 1975. An introduction to numerical classification. Academic Press, New York. 229p.

Coak, S. E. K. 1976. Quest for an index of community structure sensitive to water pollution. Envir. Pollut. 11: 269-288.

Coffin, J. E. 1982. Quality of surface water at selected sites in the Suwannee River basin, Florida, 1980. U.S. Geol. Surv. Open-File Rept. 82-103.

Cowell, B. C. and W. C. Carew. 1976. Seasonal and diel periodicity in the drift of aquatic insects in a subtropical Florida stream. Freshwat. Biol. 6: 587-594.

Cox, D. T. 1972. Annual progress report for investigation project: stream investigations. Fla. Game Fresh Water Fish Comm. Tech. Rept., Dingell-Johnson Project F-25-5 Tallahassee, Fla.

Crane, J. J. 1983. An investigation of the geology, hydrogeology, and hydrochemistry of the Lower Suwannee River Basin. Ph.D. dissertation, Fla. State Univ., Tallahassee. 378 p.

Crossman, J. S. and J. Cairns, Jr. 1974. A comparative study between two different artificial substrate samplers and regular sampling techniques. Hydrobiologia 44(4): 517-522.

Crowe, J.-A. M. E. 1971. The use of two types of artificial substrates to sample the macroinvertebrates of the Rat River, 1970. Midwest Benthological Soc., 19th annual meeting, abstracts: 2.

Cummins, K. W. 1964. A review of stream ecology with special emphasis of organism-substrate relationships, p. 2-51. In K. W. Cummins, C. A. Tyron, and R. T. Hartman (eds.), Organism substrate relationship in streams. Spec. Publ. No. 4, Pymatuning Lab. Ecol., Univ. Pittsburg.

Cummins, K. W. and G. H. Lauff. 1969. The influence of substrate particle size on the microdistribution of stream macrobenthos. Hydrobiol. 34: 145-154.

deMarch, B. G. E. 1976. Spatial and temporal patterns in macrobenthic stream diversity. J. Fish. Res. Bd. Can. 33: 1261-1270.

Devey, D. G. and H. Harknes. 1973. The significance of man-made sources of phosphorus: Detergents and sewage, p. 35-54. In S. H. Jenkins and K. J. Ives (eds.), Phosphorus in freshwater and the marine environment. Pergamon Press, Oxford.

Dickson, K. L., J. Cairns, Jr., and J. C. Arnold. 1971. An evaluation of the use of a basket-type artificial substrate for sampling macroinvertebrate organisms. Trans. Amer. Fisheries Soc. 100(3): 553-559.

Dye, C. W. and D. A. Jones. 1978. A review of eutrophication, nutrient regulation, and the impacts of nutrients on water quality. Fla. Dept. Envir. Reg. Tech. Ser. 4(1): 1-34.

Dye, C. W., D. A. Jones, L. T. Ross, and J. L. Gernert. 1980. Diel variations of selected physico-chemical parameters in Lake Kissimmee. Hydrobiol. 71: 51-60.

Elliott, J. M. 1977. Some methods for the statistical analysis of samples of benthic invertebrates, 2nd edition. Freshwater Biological Assoc. Scientific Pub. 25. 160 p.

Emiliani, C. 1970. Pleistocene paleotemperatures. Sci. 168: 822-825.

Englebrecht, R. S. and J. J. Morgan. 1959. Studies of the occurrence and degradation of condensed phosphate in surface waters. Sew. Ind. Wastes. 34(4): 458.

Ennis, G. L. and L. J. Albright. 1982. Distribution and abundance of periphyton and phytoplankton species in two subarctic Canadian rivers. Can. J. Bot. 60(3): 224-236.

Environmental Services and Permitting, Inc. 1984. Preliminary draft technical background document for wetlands mining, Occidental Chemical Agricultural Products, Inc., Hamilton County, Florida, Vol. III. Gainesville, Fla. 632p.

Evenson, W. E., S. R. Rushforth, J. D. Brotherson, and N. Fungladda. 1981. The effects of selected physical and chemical factors on attached diatoms in the Uintah Basin of Utah, U.S.A. Hydrobiol. 83: 325-330.

Field, J. G., K. R. Clarke, and R. M. Warwick. 1982. A practical strategy for analysing multispecies distribution patterns. Mar. Ecol. Prog. Ser. 8: 37-52.

Filliben, J. J. 1975. The probability plot correlation coefficient test for normality. Technometrics 17: 111.

Finn, J. T. and E. J. Rykiel, Jr. 1979. Effect of the Suwannee River sill on Okefenokee Swamp water level. Wat. Resources Res. 15: 313-320.

Fisher, R. A. 1944. Statistical methods for research workers, 9th ed. Oliver and Boyd, Edinburgh, Scotland.

Fjerdingstad, E. 1964. Pollution of streams estimated by benthal phytomicro-organisms I. A saprobic system based on communities of organisms and ecological factors. Int. Rev. Gesamt. Hydrobiol. 49(1): 63-131.

Flemer, D. A. 1970. Primary productivity in the north branch of the Raritan River, New Jersey. Hydrobiol. 35: 273-293.

Florida Department of Administration. 1977. A preliminary study of the Suwannee River by the Areas of Critical State Concern staff. Div. State Planning, Tallahassee.

Florida Department of Environmental Regulation. 1980. The proposed redesignation of the Suwannee River between State Road 6 (Hamilton and Columbia Counties) and Suwannee Springs (Hamilton and Suwannee Counties) as an "Outstanding Florida Water". Tallahassee. p. I1-I9, II1-II16, III1-III32, IV1-IV21, V1-V26, VI1-VI15, VII1-VII5, VIII1-VIII32, IX1-IX3.

_____. 1982. Interim report of the Suwannee River biological study. Biology Sect., Bur. Water Analysis, Tallahassee. 32p.

Florida State Board of Health. 1952-53. Biological survey reports. (Available through the Florida State Division of Archives).

_____. 1965. Survey of Suwannee River. June - August 1965. 17p.

Flower, R. J. 1982. A comparative limnological survey of Rathlem Island, Co. Antrim, with particular reference to diatoms. Proc. R. Ir. Acad. 828: 1-20.

Freeman, M. F. and J. W. Tukey. 1950. Transformations related to the angular and the square root. Ann. Math Stat. 21: 607-611.

Freeze, R. A. and J. A. Cherry. 1979. Groundwater. Prentice-Hall, Englewood Cliffs, N.J. 604p.

Fritz, E. S. 1980. Potential impacts of low pH on fish and fish populations. U.S. Fish Wildl. Serv., Biol. Serv. Prog., Power Plant Project, FWS/OBS-80/40.2. 14pp.

Gaufin, A. R. and C. M. Tarzwell. 1952. Aquatic invertebrates as indicators of stream pollution. Publ. Health Repts. 67(1): 57-64.

Gerhart, D. Z. and G. E. Likens. 1975. Enrichment experiments for determining nutrient limitation: Four methods compared. Limnol. Oceanog. 20(4): 649-653.

Gerhold, R. M. and R. G. Otto. 1976. Algal bioassays to evaluate a proposed cooling lake. J. Wat. Poll. Contr. Fed. 48: 2351-2366.

Gerloff, G. C. and F. Skoog. 1957. Nitrogen as a limiting factor for the growth of Microcystis aeruginosa in southern Wisconsin lakes. Ecol. 38(4): 556-561

Godfrey, P. J. 1978. Diversity as a measure of benthic macroinvertebrate community response to water pollution. Hydrobiol. 57(2): 111-122.

Gray, P. The Microtomist formulary and guide. 1954. Blakiston Co., N.Y. 191p.

Green, R. H. and G. L. Vascotto. 1978. A method for the analysis of environmental factors controlling patterns of species composition in aquatic communities. Wat. Res. 12: 583-590.

Harper, R. M. 1914. Geography and vegetation of northern Florida. Fla. Geol. Surv. 6th Ann. Rept.: 163-451.

Harvey, H. W. 1940. Nitrogen and phosphorus required for the growth of phytoplankton. J. Mar. Biol. Assoc. U.K. 241: 115-123.

Heins, D. C. and F. G. Rabito, Jr. [In preparation]. Direct evidence of the occurrence of multiple clutches in the genus Notropis.

Hem, J. D. 1959. Study and interpretation of the chemical characteristics of natural water. U.S. Geol. Surv. Water Supply Pap. 1473. 363p.

Henson, E. B. 1965. A cage sampler for collecting aquatic fauna. Turtox News 43: 298-99.

Herrick, S. M. and R. C. Vorhis. 1963. Subsurface geology of the Georgia coastal plain. Ga. Geol. Surv. Info. Circ. 25. 78p.

Hester, F. E. and J. S. Dendy. 1962. A multiple-plate sampler for aquatic macroinvertebrates. Trans. Amer. Fisheries Soc. 91: 430-421.

Hill, B. H. and J. R. Webster. 1982. Periphyton production in an Appalachian river. Hydrobiol. 97: 275-280.

Hilsenhoff, W. L. 1969. An artificial substrate device for sampling benthic stream invertebrates. Limnol. Oceanogr. 14(3): 465-471.

Hohn, M. H. 1961. The relationship between species diversity and population density in diatom populations from Silver Springs, Florida. Trans. Amer. Micro. Soc. 80(2): 140-165.

Holder, D. R. 1970. A study of fish movements from the Okefenokee Swamp into the Suwannee River. Ga. Game Fish Comm., Sport Fisheries Div., Tech. Rept., Atlanta, Ga.

Hooper-Reid, N. M. and G. G. Robinson. 1978. Seasonal dynamics of epiphytic algal growth in a marsh pond: composition, metabolism, and nutrient availability. Can. J. Bot. 56: 2441-2448.

Hufford, T. L. and G. B. Collins. 1976. Distribution patterns of diatoms in Cedar Run. Ohio J. Sci. 76(4): 172-183.

Hughes, G. H., E. R. Hampton, and D. F. Tucker. 1971. Annual and seasonal rainfall in Florida. Bur. Geol. Map Ser. No. 40, Fla. Dept. Nat. Res., Tallahassee.

Hull, R. W., J. E. Dysart, and W. B. Mann, IV. 1981. Quality of surface water in the Suwannee River Basin, Florida, August 1968 through December 1977. U.S. Geol. Surv. Wat. Res. Invest. 80-110. 97p.

Hustedt, F. 1930. Bacillariophyta (Diatomeae), p. 1-466. In A. Pascher (ed.), Die Süsswasser-flora Mitteleuropas. Bd. 10. Gustav Fischer, Jena.

Hutchinson, G. E. 1957. A treatise on limnology. Vol. 11. John Wiley and Sons, N.Y. 1015p.

Hynes, H. B. N. 1959. The use of invertebrates as indicators of river pollution. Proc. Linn. Soc. London 170(2): 165-169.

_____. 1970. The ecology of running waters. Univ. Toronto Press, Canada. 555p.

Kaesler, R. L. and E. E. Herricks. 1979. Hierarchical diversity of communities of aquatic insects and fishes. Wat. Res. Bull. 15: 1117-1125.

Kaufman, M. I. 1975. Color of water in Florida streams and canals. U.S. Geol. Surv. Map Series No. 35.

Kaufman, R. F. and D. J. Beiss. 1977. Effects of phosphate mineralization and the phosphate industry on radium-226 in groundwater of central Florida Pub. EPA/520-6-77-010. Environmental Protection Agency, Washington, D.C.

Kautz, R. S. 1981. Fish populations and water quality in north Florida rivers. Proc. Ann. Conf. SE Assoc. Fish Wildlife Agencies 35: 495-507.

Kenner, W. E. 1975. Seasonal variation of streamflow in Florida. Fla. Dept. Nat. Res., Bur. Geol. Map Ser. No. 31.

Kotai, J., T. Krogh, and O. M. Skulberg. 1978. The fertility of some Norwegian inland waters assayed by algal cultures. Mitt. Int. Ver. Theor. Angew. Limnol. 21: 413-436.

Kovalak, W. P. 1977. Relationships between size of stream insects and current velocity. Can. J. Zool. 56: 178-186.

Krummrich, J., D. Jones, G. Byerley, and P. Southall. 1984. Northeast Florida region, 1982-1983 fish management report. Fla. Game Fresh Water Fish Comm., Tech. Rept., Tallahassee, Fla.

Lawton, D. 1976. Geologic map of Georgia. Ga. Dept. Nat. Res., Ga. Geol. Surv., Atlanta.

eadon, C. 1980. The upper Suwannee River, an outstanding national water. Suwannee River Water Management District Staff Rept. 80-1. 25p.

Lee, R. M. and S. D. Gerking. 1980. Sensitivity of fish eggs to acid stress. Wat. Res. 14: 1679-1681.

Leivestad, H., G. Hendrey, I. P. Muniz, and E. Snekvik. 1976. Effects of acid precipitation on freshwater organisms. In: F. H. Braekke (ed.), Impact of acid precipitation on forest and freshwater ecosystems in Norway. Sur Nedbørs virkning på Skog og Fisk FR6/76, Oslo-Ås, Norway.

Leivestad, H., I. P. Muniz, and B. O. Rosseland. 1980. Acid stress in trout from a dilute mountain stream, p. 318-319. In D. Drabløs and A. Tollan (eds.), Ecological impact of acid precipitation. Proc. Int. Conf., Sandefjord, Norway. Sur Nedbørs virkning på Skog og Fisk, Oslo-Ås, Norway.

Lowe, R. L. 1974. Environmental requirements and pollution tolerance of freshwater diatoms. U.S. Envir. Prot. Agency, EPA-670/4-74-005. 333p.

MacIsaac, J. J. and R. C. Dugdale. 1972. Interactions of light and inorganic nitrogen in controlling nitrogen uptake in the sea. Deep Sea Res. 19: 209-232.

Mackey, A. P. 1976. Quantitative studies on the Chironomidae (Diptera) of the Rivers Thames and Kennet, II. The Thames flint zone. Arch. Hydrobiol. 78(3): 310-318.

Mason, W. T., Jr., J. G. Anderson, and G. E. Morrison. 1967. A limestone-filled, artificial substrate sampler-float unit for collecting macroinvertebrates in large streams. Progressive Fish Culturist 29: 74.

Mason, W. T. , Jr., C. I. Weber, P. A. Lewis, and E. C. Julian. 1973. Factors affecting the performance of basket and multiplate macroinvertebrate samplers. Freshwat. Biol. 3: 409-436.

McWilliams, P. G. and W. T. W. Potts. 1978. The effects of pH and calcium on gill potentials in brown trout Salmo trutta. J. Comp. Physiol. 126: 277-286.

Meier, P. G., D. L. Penrose, and L. Pollok. 1979. The rate of colonization by macroinvertebrates on artificial substrate samplers. Freshw. Biol. 9: 381-392.

Miller, W. E., T. E. Maloney, and J. C. Greene. 1974. Algal productivity in 49 lake waters as determined by algal assays. Wat. Res. 8: 667-679.

_____. 1978. The Selenastrum capricornutum Printz: algal assay bottle test. U.S. Envir. Prot. Agency, EPA-600/9-78-018. 126 p.

Minshall, G. W. 1981. Structure and temporal variations of the benthic macroinvertebrate community inhabiting Mink Creek, Idaho, USA: a third order Rocky Mountain stream. J. Freshw. Ecol. 1(1): 13-26.

Morris, I. 1974. Nitrogen assimilation and protein synthesis, p. 583-609. In W.D.P. Stewart (ed.), Algal physiology and biochemistry. Univ. Calif. Press, Berkley.

Mount, D. I. 1980. An evaluation of the ability of early life cycle tests to predict chronic toxicity as measured in life cycle tests. U.S. Envir. Prot. Agency (unpublished document). 25p.

Mount, D. I. and T. J. Norberg. 1983. A seven-day life-cycle cladoceran toxicity test. U.S. Envir. Prot. Agency (unpublished aquatic toxicity testing seminar manual).

Newlon, T. A. and F. W. Rabe. 1977. Comparison of macroinvertebrate samplers and the relationship of environmental factors to biomass and diversity variability in a small watershed. Research Technical Completion Report Project A-049-IDA. Idaho Water Resources Research Inst., Univ. Idaho, Moscow, Idaho. 26 p.

Odum, E. P. 1959. Fundamentals of ecology, second ed. W. B. Saunders Co., Philadelphia. 546 p.

_____. 1971. Fundamentals of ecology, third ed. W. B. Saunders Co., Philadelphia. 574 p.

Otsuki, A. and R. G. Wetzel. 1972. Coprecipitation of phosphate with carbonates in a marl lake. Limnol. Oceanogr. 17: 763-767.

Parrish, F. K. and E. J. Rykiel, Jr. 1979. Okefenokee Swamp origin: review and reconsideration. J. Elisha Mitchell Sci. Soc. 95: 17-31.

Parsons, D. S. and J. W. Tatum. 1974. A new shallow water multi-plate sampler. Prog. Fish. Cult. 36: 179-180.

Patrick, R., M. H. Hohn, and J. H. Wallace. 1954. A new method for determining the pattern of the diatom flora. Not. Nat. 259: 1-12.

Patrick, R. 1964. A discussion of natural and abnormal diatom communities, p. 185-204. In D. F. Jackson (ed.), Algae and man. Plenum Press, New York.

Patrick, R. and C. W. Reimer. 1966. The diatoms of the United States. Vol. 1. Acad. Nat. Sci. Philadelphia, Monog. No. 13. 688p.

_____. 1975. The diatoms of the United States. Vol. 2. Acad. Nat. Sci. Philadelphia, Monog. No. 13. 213 p.

Pirkle, E. C., W. A. Pirkle, and W. H. Yoho. 1977. The highland heavy-mineral sand deposit on Trail Ridge in northern peninsular Florida. Fla. Dept. Nat. Res., Bur. Geol. Rept. Invest. No. 84. 50p.

Pryfogle, P. A. and R. L. Lowe. 1979. Sampling and interpretation of epilithic lotic diatom communities, p. 77-89. In R. L. Weitzel (ed.), Methods and measurements of periphyton communities: A review. Amer. Soc. Test. Mat. STP 690, Philadelphia.

Rabeni, C. F. and K. E. Gibbs. 1980. Ordination of deep river invertebrate communities in relation to environmental variables. Hydrobiol. 74: 67-76.

Rai, H. and G. Hill. 1981. Physical and chemical studies of Lago Tupe: A central Amazonian blackwater river lake. Int. Rev. Gesamt. Hydrobiol. 66(1): 37-82.

Roll, M. L. 1981. Investigations of algal inhibition in Lake Okeechobee Florida, using algal assay techniques. Fla. Dept. Envir. Reg., Biol. Section. 58 p.

Rosenau, J. C., G. L. Faulkner, C. W. Hendry, Jr., and R. W. Hull. 1977. Springs of Florida. Fla. Dept. Nat. Res., Bur. Geol. Bull. No. 31 (Revised), Tallahassee. 461 p.

Rosenberg, D. M. and V. H. Resh. 1982. The use of artificial substrates in the study of freshwater benthic macroinvertebrates, p. 175-235. In John Cairns, Jr. (ed.), Artificial substrates. Ann Arbor Science, Ann Arbor, Mich. 279p.

Ross, D. H. and J. B. Wallace. 1982. Factors influencing the longitudinal distribution of larval Hydropsychidae (Trichoptera) in a southern Appalachian stream system (U.S.A.). Hydrobiol. 96(2): 185-199.

Ross, L. T. and D. A. Jones [eds]. 1979. Biological aspects of water quality in Florida. Part I: Escambia - Perdido, Choctawatchee, Apalachicola, Aucilla - Ochlockonee - St. Marks, and Suwannee Drainage Basins. Fla. Dept. Env. Reg. Tech. Ser. 4(3). 516p.

Round, F. E. 1964. The Ecology Of benthic algae, p. 138-181. In D. F. Jackson (ed.), Algae and man. Plenum Press, N.Y. 434p.

Ruggiero, M. A. and H. C. Merchant. 1979. Water quality, substrate and the distribution of macroinvertebrates in the Patuxent River, Maryland. Hydrobiol. 64: 183-189.

Ryan, T. A., B. L. Joiner, and B. F. Ryan. 1982. Minitab reference manual. Duxbury Press, Boston. 155 p.

Schaffner, L. C. and D. F. Boesch. 1982. Spatial and temporal resource use by dominant benthic Amphipoda (Ampeliscidae and Corophiidae) on the Middle Atlantic Bight Outer Continental Shelf. Mar. Ecol. Prog. Ser. 9: 231-243.

Schimmel, S. C. [chairman]. 1982. Proposed standard practice for conducting toxicity tests with the early life stages of fishes, draft No. 7. Amer. Soc. Test. Mat., Philadelphia (unpublished manuscript).

Scott, D. C. 1958. Biological balance in streams. Sewage and Industrial Wastes 30: 1169-1173.

Seagle, H. H., Jr., J. C. Hutton, and K. S. Lubinski. 1982. A comparison of the benthic invertebrate community composition in the Mississippi and Illinois Rivers, pool 26. J. Freshw. Ecol. 1(6): 637-650.

Shapiro, J. 1956. The coloring matter of natural waters. Unpublished thesis, Yale Univ. p 682-900.

Shiroyama, T., W. E. Miller, and J. C. Greene. 1975. Effect of nitrogen and phosphorus on the growth of Selenastrum capricornutum. U.S. Envir. Prot. Agency, EPA-660/3-75-034. 11 p.

Singh, M. P. and A. D. Harrison. 1982. Diel periodicities of emergence of midges (Diptera: Chrinonomidae) from a wooded stream on the Niagara Escarpment, Ontario. Aquat. Insects 4(1): 29-37.

Slack, K. V., L. T. Tilley, and S. S. Hahn. 1982. Detritus abundance and benthic invertebrate catch in artificial substrate samples from mountain streams. Water Resources Bull. 18(4): 687-698.

Slack, L. J. and M.I. Kaufman. 1975. Specific conductance of water in Florida streams and canals. U.S. Geol. Surv. Map Ser. No. 58.

Sládeček, V. and A. Sládečková. 1964. Determination of the periphyton production by means of the glass slide method. Hydrobiol. 23: 125-158.

Sládečková, A. 1962. Limnological investigation methods for the periphyton ("Aufwuchs") community. Bot. Rev. 28(2): 286-350.

Steel, R. G. D. and J. H. Torrie. 1960. Principles and procedures of statistics with special reference to the biological sciences. McGraw-Hill, N.Y. 481 p.

Stewart, W. D. P. 1974. Algal physiology and biochemistry. Bot. Monog. Vol. 10. Univ. Calif. Press, Berkeley. 989 p.

Stokes, P. M. 1981. Benthic algal communities in acidic lakes, p. 119-138. In R. Singer (ed.), Effects of acidic precipitation on benthos. Proc. Symp. Acidic Precipitation on Benthos. North Amer. Benthological Soc., Hamilton, N.Y.

Strickland, J. H. and T. R. Parsons. 1972. A practical handbook of seawater analysis, second ed. Fish Res. Bd. Can. 310 p.

Swift, D. R. 1981. Preliminary investigations of periphyton and water quality relationships in the Everglades Water Conservation Areas. Tech. Publ. #81-5, South Fla. Water Management Dist., West Palm Beach, Fla. 83 p.

Task Group 2610-P Report. 1966. Nutrient-associated problems in water quality and treatment. J. Am. Water Wks. Assoc. 585:1337-1355.

Thompson, A. R., R. B. Frydenborg, C. A. Biederman, C. W. Dye, and L. T. Ross. 1982. Phytoplankton and periphyton community dynamics in detention/retention wetlands, Kissimmee River Basin, Florida. Final Report to Coordinating Council on the Restoration of the Kissimmee River Valley and Taylor Creek-Nubbin Slough Basin. 50 p.

Thorp, J. H. and R. K. Chesser. 1983. Seasonal responses of benthic midge assemblages to environmental gradients. Holarc. Ecol. 6: 123-132.

Tilley, L. J. and W. L. Haushild. 1975. Use of productivity of periphyton to estimate water quality. J. Wat. Poll. Contr. Fed. 47(8): 2157-2171.

Tippets, W. E. and P. B. Moyle. 1978. Epibenthic feeding by rainbow trout (Salmo gairdneri) in the McCloud River, California. J. Anim. Ecol. 47: 549-559.

Toerien, D. F., C. H. Huang, J. Radimsky, E. A. Pearson, and J. Scherfig. 1971. Provisional algal assay procedures. Final Report. Univ. Calif. Sanitary Eng. Res. Lab. Rept. #71-6, Berkeley, Calif. 211 p.

Towns, D. R. 1981. Life histories of benthic invertebrates in a kauri forest stream in northern New Zealand. Aust. J. Mar. Freshw. Res. 32: 191-211.

Tsui, P. T. P. and B. W. Breedlove. 1978. Use of the multiple-plate sampler in biological monitoring of the aquatic environment. Fla. Scientist 41(2): 110-116.

Tuchman, M. 1979. Comparison of attached algal communities on natural and artificial substrata along a thermal gradient. Brit. Phyco. J. 14: 243-254.

United States Army Corps of Engineers. 1983. Reconnaissance report, Suwannee River, Georgia and Florida. Planning Division, Jacksonville, Florida. 39 p. plus appendices.

United States Environmental Protection Agency. 1973. Biological field and laboratory methods for measuring the quality of surface waters and effluents. EPA-670/4-73-001. Office of Research and Development, Cincinati, Ohio.

_____. 1978. Environmental Impact Statement - Occidental Chemical Co., Swift Creek Chemical Complex, Hamilton County, Florida. Resource Document, Vol. I, II. EPA-904/9-78-012 - A and B, Atlanta, Ga.

_____. 1979. Methods for chemical analysis of water and wastes. EPA-600/4-79-020. 298 p.

United States Geological Survey. 1982. Water resources data for Florida, Vol. 4., northwest Florida, water year 1981. U.S. Geol. Surv. Water-Data Report FL-81-4.

University of Florida. 1981. Florida population: a summary of 1980 census results. Bureau of Economic and Business Research, Gainesville. 47 p.

_____. 1983. Florida Statistical Abstracts. Bur. Economic Business Res. Univ. Presses of Fla., Gainesville. 700 p.

Van Dam, H., G. Suurmond, and C. J. F. Ter Braak. 1981. Impact of acidification on diatoms and chemistry of Dutch moorland pools. Hydrobiol. 83(3): 425-460.

Vaughn, T. L., E. J. Moyer, D. Weaver, and J. Chamberlain. 1978. 1977 fish management report for the northeast Florida region. Fla. Game Fresh Water Fish Comm., Tech. Rept., Tallahassee, Fla.

Watanabe, T. and I. Yasuda. 1982. Diatom assemblages in lacustrine sediments of Lake Shibu-ike, Lake Misumi-ike, Lake Naga-ike, Lake Kido-ike in Shiga Highland [Japan] and a new biotic index based on the diatom assemblage for the acidity of lake water. Jap. J. Limnol. 43(4): 237-245.

Waters, T. F. 1972. The drift of stream insects. Ann. Rev. Ent. 17: 253-272.

Weaks, T. E. 1982. A step-wise discriminant analysis of the effects of long term coal mine drainage and coal dredging on phytoplankton of the Guyandotte River. Hydrobiol. 97(2): 97-103.

Weber, C. I. (ed.). 1973. Biological field and laboratory methods measuring the quality of surface waters and effluents. U.S. Environmental Protection Agency, EPA-6701/4-73-001.

Wene, G. and E. L. Wickliff. 1940. Modification of a stream bottom and its effect on the insect fauna. Canadian Entomologist 72: 131-135.

Wetzel, R. G. 1975. Limnology. W. B. Saunders Co., Philadelphia. 743 p.

Wilhm, J. L. 1972. Graphic and mathematical analysis of biotic communities in polluted streams. Ann. Rev. Ent. 17: 223-252.

Williams, D. D. 1980. Temporal patterns in recolonization of stream benthos. Arch. Hydrobiol. 90(1): 56-74.

Williams, L. G. and C. Scott. 1962. Principal diatoms of major waterways of the United States. Limnol. Oceanogr. 7(3): 365-379.

Winger, P. V. 1981. Physical and chemical characteristics of warmwater streams: a review, p. 32-44. In L. A. Krumholz (ed.), The Warmwater Streams Symposium, Southern Division, American Fisheries Soc., Lawrence, Kans.

Wise, D. H. and C. Molles, Jr. 1979. Colonization of artificial substrates by stream insects: influence of substrate size and diversity. Hydrobiol. 65(1): 69-74.

Wood, C. M. and D. G. McDonald. 1982. Physiological mechanisms of acid toxicity to fish, p. 197-226. In T. A. Haines and R. E. Johnson (eds.), Acid Rain/Fisheries Proc. Int. Symp. on Acid Rain and Fishery Impacts on Northeastern North America. Amer. Fish. Soc., Bethesda, Md.

Yates, F. 1933. The analysis of replicated experiments when the field results are incomplete. Empire J. Exp. Agr. 1: 129-142.

Yount, J. L. 1956. Factors that control species numbers in Silver Springs, Florida. Limnol. Oceanogr. 1(4): 286-295.

Benthic Macroinvertebrate Identification References

Beck, W. M. 1979. Biology of the larval chironomids. Fla. Dept. Envir. Reg. Tech. Ser. 2(1): 1-58.

Berner, L. 1950. The mayfiles of Florida. Univ. Fla. Press, Gainesville. 267p.

Brinkhurst, R. O. and B. G. M. Jamieson. 1971. Aquatic Oligochaeta of the world. Univ. Toronto Press, Toronto. 860 p.

Brown, H. P. 1976. Aquatic dryopoid beetles (Coleoptera) of the United States. U.S. Envir. Prot. Agency Wat. Poll. Contr. Res. Ser. 18050 EZD/04/72. 82 p.

Burch, J. B. 1982. Freshwater snails (Mollusca: Gastropoda) of North America. EPA-600/3-82-026. 294 p.

Byers, C. F. 1930. A contribution to the knowledge of Florida Odonota. Univ. Fla. Biol. Sci. Ser. 1(1): 1-327.

Edmunds, G. F., Jr., S. L. Jensen, and L. Berner. 1979. The mayflies of north and central America. Univ. Minn. Press, Minneapolis. 330 p.

Heard, W. H. 1979. Identification manual of the freshwater clams of Florida. Fla. Dept. Envir. Reg. Tech. Ser. 4(2): 1-83.

Hiltunen, J. K. and D. J. Klemm. 1980. A guide to the Naididae (Annelida: Clitellata: Oligochaeta) of North America. EPA-600/4-80-031. 48p.

Johannsen, O. A. 1934. Aquatic diptera. Cornell Univ. Agric. Exp. Sta. Mem. (reprinted by Entomological Reprint Specialists, Los Angeles). 369p.

Kenk, R. 1976. Freshwater planarians (Turbellaria) of North America. U.S. Envir. Prot. Agency Wat. Poll. Contr. Res. Ser. 18050 EZD/02/72. 81p.

Klemm, D. J. 1982. Leeches (Annelida: Hirudinea) of North America. EPA-600/3-82-025. 177p.

Mason, W. T., Jr. 1973. An introduction to the identification of chironomid larvae. U.S. Envir. Prot. Agency. 90 p.

Merritt, R. W. and K. W. Cummins. 1978. An introduction to the aquatic insects of North America. Kendall/Hunt Publ., Dubuque. 441p.

Morihara, D. K. and W. P. McCafferty. 1980. The Baetis larvae of North America (Ephemaeroptera: Baetidae). Trans. Amer. Ent. Soc. 105: 139-221.

Oliver, D. R., D. McClymont, and M. E. Noussel. 1978. A key to some larvae of Chironomidae (Diptera) from the Mackenzie and Porcupine River watersheds. Can. Fish. Mar. Serv. Tech. Rept. No. 791. 72p.

Parrish, F. E. 1975. Keys to water quality indicative organisms of the Southeastern United States. U.S. Envir. Prot. Agency Off. Res. Dev., Envir. Mon. Supt. Lab., Cincinnati. 195p.

Pennak, R. W. 1978. Fresh-water invertebrates of the United States. John Wiley and Sons, New York. 803p.

Pluchino, E.S. 1984. Guide to the common water mite genera of Florida. Fla. Dept. Envir. Reg. Tech. Ser. 7(1): 1-45.

Ross, H. H. 1944. The caddis flies, or Trichoptera, of Illinois. Ill. Nat. Hist. Surv. Div. 23(1): 1-326.

Simpson, K. W. and R. W. Bode. 1980. Common larvae of Chironomidae (Diptera) from New York State streams and rivers. N.Y. St. Mus. Bull. No. 439. 103p.

Starke, B. P. and A. R. Gaufin. 1979. The stoneflies (Plecoptera) of Florida. Trans. Am. Ent. Soc. 104: 391-433.

Thompson, F. G. 1983. An identification manual of the freshwater snails of Florida. (Unpublished manuscript). 55 p.

Usinger, R. L. 1968. Aquatic insects of California. Univ. Calif. Press, Berkeley. 508p.

Ward, H. B. and G. C. Whipple (W.T. Edmonson, ed.). 1959. Fresh-water Biology, second ed. John Wiley and Sons, N.Y. 1248 p.

Wiggins, G. B. 1977. Larvae of the North American caddisfly genera (Trichoptera). Univ. Toronto Press, Toronto. 401p.

Young, F. N. 1954. The water beetles of Florida. Univ. Fla. Press, Gainesville. 238p.

Periphyton Identification Reference

Forest, H. S. 1954. Handbook of Algae. Univ. Tenn., Knoxville. 467 p.

Hanna, G. D. 1933. Diatoms of the Florida peat deposits. Florida Geol. Surv. 23rd-24th Ann. Repts.: 66-119.

Hustedt, F. 1930. Bacillariophyta (Diatomeae), p. 1-466. In A. Pascher (ed.), Die Süsswasser-flora Mitteleuropas. Bd. 10. Gustav Fisher, Jena.

Patrick, R. and C. W. Reimer. 1966. The diatoms of the United States. Vol. 1. Acad. Nat. Sci. Philadelphia, Monog. No. 13. 688 p.

_____. 1975. The diatoms of the United States. Vol. 2. Acad. Nat. Sci. Philadelphia, Monog. No. 13. 213 p.

Prescott, G. W. 1961. Algae of the western great lakes region. Brown Co. Publ., Dubuque. 977 p.

_____. 1970. The freshwater algae. Brown Co. Publ., Dubuque. 348 p.

Schmidt, A. 1885-1927. Atlas der Diatomaceen-kunde, Parts 1-92. O. R. Reisland, Leipzig.

Van Landingham, S. L. 1964. Miocene non-marine diatoms from the Yakima region in south central Washington. Nova Hedwigia, suppl. 14: 1-78.

_____. 1967. Paleoecology and microfloristics of Miocene diatomites from the Otis-basin - Juntura region of Harney and Malheur counties, Oregon. Nova Hedwigia, suppl. 26: 1-77.

_____. 1982. Guide to the identification, environmental requirements and pollution tolerance of freshwater blue-green algae (Cyanophyta). U.S. Envir. Prot. Agency, EPA 600/3-82-073. 341 p.

Weber, C. I. 1966. A guide to the common diatoms at water pollution surveillance system stations. U.S. Envir. Prot. Agency, Analytical Quality Control Lab., Cincinati, Ohio. 98 p.

APPENDIX A

HISTORICAL WATER CHEMISTRY DATA

APPENDIX A

		Fargo, Ga USGS (1931-82)	ESP (1979-82)	Near Benton USGS (1956-83)	Near Benton DER-JAX STUDY (1982-83)	Near Benton DER-TIH STUDY (1982-84)	Below Hunter Creek DER-JAX STUDY (1982-83)	Below Hunter Creek DER-TIH STUDY (1982-84)	@ SR 135 DER-JAX STUDY (1982-83)
Conductivity umhos/cm	Min.	0	36.0	33.0	38.0	38.0	43.0	42.0	43.0
	Mean	54.5	54.0	53.9	55.6	57.0	63.6	59.0	62.2
	Max.	255.0	78.0	90.0	84.0	86.0	150.0	86.0	122.0
Alkalinity mg/l as $CaCO_3$	Min.	0	0	0	0	0	.5	0	.5
	Mean	1.0	.7	2.0	1.0	.7	1.6	1.3	2.5
	Max.	14.0	9.8	8.0	4.0	3.0	10.0	6.0	10.0
pH SU	Min.	3.7	2.8	3.1	3.6	3.6	3.7	3.6	3.8
	Mean	4.1	3.4	4.3	4.0	4.0	4.2	4.1	4.4
	Max.	5.5	6.4	6.4	4.7	5.7	6.0	6.0	6.3
Fluoride mg/L	Min.	.10	.10	.10	.03	.02	.02	.03	.03
	Mean	.31	.05	.21	.06	.05	.13	.07	.12
	Max.	.60	.19	.60	.10	.09	.79	.23	.56
Sulfate mg/L	Min.	.5	0	0	2.0	0	2.0	1.0	2.0
	Mean	2.2	0	3.3	2.3	1.5	6.1	2.0	5.5
	Max.	7.2	0	11.0	5.0	6.0	35.0	17.0	24.0
Chloride mg/L	Min.	4.4	--	4.1	2.0	2.0	1.0	2.0	1.0
	Mean	7.0	--	6.8	5.5	5.6	5.6	5.9	6.0
	Max.	15.0	--	9.8	9.0	11.0	10.0	16.0	9.0
Turbidity NTU	Min.	.9	--	.0	1.5	1.0	.8	1.0	1.0
	Mean	5.7	--	1.3	2.6	2.7	2.5	3.1	3.0
	Max.	68.0	--	3.0	6.0	8.0	5.2	9.3	5.5
Color mg/L Pt	Min.	100.0	43.0	200.0	200.0	200.0	200.0	200.0	200.0
	Mean	235.9	219.0	305.7	335.8	334.0	335.5	332.0	330.8
	Max.	480.0	480.0	580.0	640.0	640.0	640.0	640.0	640.0
Dissolved Oxygen mg/L	Min.	3.3	6.0	4.8	3.7	5.3	3.6	5.3	3.7
	Mean	7.2	7.9	7.6	5.7	7.5	5.4	7.5	5.5
	Max.	13.0	13.9	12.0	8.0	12.6	8.2	12.6	8.3
Secchi Disc (M)	Min.	--	--	--	.30	.20	.30	.20	.32
	Mean	--	--	--	.54	.49	.53	.49	.56
	Max.	--	--	--	1.20	.80	.92	.80	.84
Temperature C°	Min.	4.0	--	5.4	8.8	7.0	8.8	7.0	8.8
	Mean	19.9	--	20.6	20.2	19.0	20.3	18.9	20.0
	Max.	31.0	--	32.0	30.7	29.5	30.6	29.5	30.1
Orthophosphate mg/L P	Min.	0	.01	.02	.04	.01	.02	.01	.03
	Mean	.03	.08	.06	.23	.04	.18	.10	.19
	Max.	.12	.19	.22	.72	.08	1.13	.86	.98
Phosphate mg/L P	Min.	.01	.01	.02	.01	.05	.10	.05	.10
	Mean	.03	.08	.07	.04	.19	.38	.27	.35
	Max.	.13	.24	.25	.13	.41	1.27	1.05	1.12
Total Kjeldahl Nitrogen mg/L N	Min.	.07	--	.40	.32	.10	.13	.10	.37
	Mean	.86	--	.91	1.42	1.04	1.40	1.14	1.52
	Max.	1.60	--	1.61	2.15	2.05	2.91	3.32	2.79
Total Ammonia mg/L N	Min.	.02	.01	0	.01	.01	.01	.01	.06
	Mean	.26	.03	.03	.12	.10	.14	.13	.13
	Max.	2.20	.15	.19	.60	.32	.70	.39	.59
Nitrite+Nitrate Nitrogen mg/L N	Min.	.02	0	0	.01	.01	.05	.03	.05
	Mean	.21	.02	.02	.05	.05	.05	.06	.06
	Max.	2.0	.06	.06	.07	.11	.11	.15	.20

		Below Roaring Crk.		@ White Springs (U.S. 41)				
		DER-JAX STUDY (1982-83)	DER-JAX PNS (1982-83)	ESP (1979-82)	USGS (1966-83)	EPA (1966)	DER-JAX STUDY (1982-83)	DER-JAX PNS (1982-83)
Conductivity umhos/cm	Min.	33.0	30.0	38.0	31.0	30.0	41.0	38.0
	Mean	60.1	64.3	69.0	60.5	34.2	59.5	66.0
	Max.	112.0	190.0	140.0	310.0	59.0	90.0	167.0
Alkalinity mg/l as $CaCO_3$	Min.	1.0	1.0	0	0	0	1.0	0
	Mean	2.1	4.3	5.6	6.7	.1	3.5	9.2
	Max.	12.0	12.0	35.0	29.0	1.0	19.0	40.0
pH SU	Min.	3.8	3.0	2.8	2.8	4.2	3.9	3.7
	Mean	4.4	4.0	3.7	4.8	4.4	4.6	4.7
	Max.	6.3	5.6	6.6	7.4	4.7	7.0	7.3
Fluoride mg/L	Min.	.04	.04	.02	0	0	.05	.05
	Mean	.11	.11	.13	.33	.25	.13	.35
	Max.	.54	.54	.52	2.6	.60	.28	7.4
Sulfate mg/L	Min.	1.0	2.0	0	0	---	0	1.0
	Mean	5.1	7.4	2.5	3.9	---	4.6	6.8
	Max.	24.0	24.0	26.2	11.0	---	20.0	20.0
Chloride mg/L	Min.	3.0	3.0	---	4.0	3.0	2.0	2.0
	Mean	6.29	6.28	---	6.36	4.14	6.08	6.26
	Max.	9.0	9.0	---	10.0	5.0	10.0	10.0
Turbidity NTU	Min.	1.2	1.2	---	0	---	1.1	.62
	Mean	2.8	2.8	---	1.4	---	2.6	2.6
	Max.	5.2	5.2	---	5.3	---	5.2	16.0
Color mg/L Pt	Min.	200.0	200.0	200.0	200.0	200.0	200.0	100.0
	Mean	334.0	336.0	316.0	248.0	228.0	325.0	291.0
	Max.	640.0	640.0	500.0	560.0	320.0	600.0	600.0
Dissolved Oxygen mg/L	Min.	3.9	3.9	5.5	4.3	5.0	3.8	3.8
	Mean	5.6	5.5	8.1	7.6	6.2	5.7	5.9
	Max.	8.1	8.2	12.2	11.8	7.3	8.2	9.4
Secchi Disc (M)	Min.	.35	.35	---	---	---	.35	.35
	Mean	.56	.56	---	---	---	.53	.57
	Max.	.84	.84	---	---	---	.90	.90
Temperature C°	Min.	8.7	8.7	---	6.4	12.0	9.0	9.4
	Mean	20.5	20.5	---	20.6	19.0	20.5	19.7
	Max.	30.0	30.0	---	31.0	24.0	31.4	32.0
Orthophosphate mg/L P	Min.	.03	.03	.04	.05	---	.06	.05
	Mean	.15	.18	.21	.21	---	.20	.20
	Max.	.72	.72	.52	4.4	---	.76	.76
Phosphate mg/L P	Min.	.09	.09	.02	.05	.19	.15	.08
	Mean	.35	.35	.18	.22	.38	.38	.93
	Max.	1.28	1.28	.56	4.50	.81	.90	22.0
Total Kjeldahl Nitrogen mg/L N	Min.	.42	.42	---	.22	---	.12	.12
	Mean	1.70	1.70	---	.90	---	1.37	1.30
	Max.	3.90	3.90	---	2.80	---	2.44	8.08
Ammonia mg/L N	Min.	.06	.06	.01	0	---	.06	.03
	Mean	.12	.19	.08	.07	---	.48	.55
	Max.	.60	.06	.93	1.70	---	.11	6.17
Nitrite+Nitrate Nitrogen mg/L N	Min.	.05	.05	.01	.01	---	.05	.01
	Mean	.06	.05	.06	.05	---	.07	.23
	Max.	.16	.05	.20	.52	---	.33	2.22

		Above Swift Creek				Below Swift Creek (I-75)			
		ESP (1979-82)	DER-JAX STUDY (1982-83)	DER-THL STUDY (1982-84)	DER-JAX PNS (1975-83)	DER-JAX STUDY (1982-83)	DER-THL STUDY (1982-84)	DER-JAX PNS (1972-83)	EPA (1966)
Conductivity umhos/cm	Min.	42.0	38.0	36.0	37.0	7.8	34.0	45.0	28.0
	Mean	68.0	64.0	59.0	67.0	94.6	92.0	111.0	37.7
	Max.	123.0	123.0	112.0	147.0	220.0	214.0	425.0	48.0
Alkalinity mg/l as $CaCO_3$	Min.	0	1.0	.5	2.0	0	.5	0	0
	Mean	1.0	8.4	9.4	12.8	11.6	11.3	14.37	.78
	Max.	2.6	37.0	45.0	37.0	40.0	45.0	51.0	2.0
pH SU	Min.	3.3	3.5	3.7	3.5	4.1	3.8	4.1	4.4
	Mean	5.6	5.2	5.1	5.2	5.5	5.2	5.6	4.9
	Max.	6.6	7.3	7.1	7.3	7.0	7.1	7.7	6.3
Fluoride mg/L	Min.	.02	.06	.04	.06	.09	.05	.09	---
	Mean	.05	.14	.10	.14	.47	.40	.60	---
	Max.	.15	.43	.22	.43	1.73	1.28	2.64	---
Sulfate mg/L	Min.	0	2.0	1.0	2.0	1.0	1.0	1.0	---
	Mean	0	4.7	2.9	8.3	20.7	12.3	22.0	---
	Max.	0	22.0	17.0	22.0	90.0	40.0	90.0	---
Chloride mg/L	Min.	---	2.0	2.0	2.0	2.0	3.0	2.0	3.0
	Mean	---	6.1	5.9	6.1	6.4	6.5	8.6	4.0
	Max.	---	13.0	6.0	13.0	13.0	15.0	29.0	5.0
Turbidity NTU	Min.	---	1.0	---	1.0	1.7	1.3	1.0	---
	Mean	---	3.0	2.9	3.0	5.7	3.9	4.4	---
	Max.	---	7.2	10.0	7.2	48.0	10.0	48.0	---
Color mg/L Pt	Min.	260.0	160.0	160.0	160.0	200.0	160.0	70.0	160.0
	Mean	342.0	324.0	332.0	324.0	319.0	317.0	272.0	210.0
	Max.	460.0	500.0	640.0	500.0	500.0	640.0	500.0	300.0
Dissolved Oxygen mg/L	Min.	5.3	3.9	5.0	3.9	3.0	4.8	3.0	5.8
	Mean	8.0	5.5	7.5	5.5	5.4	7.5	5.9	6.4
	Max.	11.0	8.1	12.0	8.3	8.1	11.9	10.9	7.6
Secchi Disc (M)	Min.	---	.25	.30	.25	.35	.40	.35	---
	Mean	---	.57	.53	.57	.53	.52	.61	---
	Max.	---	1.0	.80	1.0	.80	.80	1.72	---
Temperature C°	Min.	---	9.5	7.0	9.5	9.5	7.0	9.5	12.0
	Mean	---	20.7	19.5	19.9	20.3	19.5	19.8	18.4
	Max.	---	30.1	29.0	30.1	30.0	29.0	32.0	24.0
Orthophosphate mg/L P	Min.	.06	.11	.05	.01	.19	.10	.1	---
	Mean	.14	.23	.16	.22	3.0	1.80	2.38	---
	Max.	.26	.75	.55	.75	27.2	8.60	27.2	---
Phosphate mg/L P	Min.	.05	.210	.104	.07	.37	.163	.05	---
	Mean	.10	.444	.314	.49	3.32	2.00	2.79	---
	Max.	.24	1.018	.713	1.01	28.00	8.80	28.0	---
Total Kjeldahl Nitrogen mg/L N	Min.	---	.25	.10	.25	.43	.27	.43	---
	Mean	---	1.47	.914	1.47	1.91	1.44	2.11	---
	Max.	---	3.54	2.28	3.54	5.43	3.55	15.5	---
Ammonia mg/L N	Min.	.01	.06	.010	.06	.06	.01	0	---
	Mean	.06	.129	.123	.24	.36	.38	.88	---
	Max.	.07	.59	.340	.59	2.24	3.02	14.08	---
Nitrite+Nitrate Nitrogen mg/L N	Min.	.01	.05	.023	.05	.050	.05	.05	---
	Mean	.03	.077	.056	.103	.178	.131	.34	---
	Max.	.10	.24	.118	.24	.770	.390	1.32	---

		@ Suwannee Springs				Above Withlacoochee		At Ellaville		
		ESP (1979-82)	USGS (1956-83)	EPA (1966)	DER-JAX STUDY (1982-83)	DER-JAX STUDY (1982-83)	DER-THL STUDY (1982-84)	DER-JAX STUDY (1982-83)	DER-TLH STUDY (1982-84)	EPA (1966)
Conductivity umhos/cm	Min.	50.0	39.0	27.0	41.0	34.0	38.0	42.0	40.0	28.0
	Mean	202.0	114.0	31.9	125.0	153.8	140.0	152.0	152.0	43.0
	Max.	440.0	390.0	36.0	350.0	280.0	310.0	270.0	306.0	60.0
Alkalinity mg/l as $CaCO_3$	Min.	0	2.0	0	1.0	3.0	2.0	11.0	3.0	3.0
	Mean	31.9	34.8	.5	24.5	57.2	48.3	64.5	57.5	8.2
	Max.	68.0	78.0	2.0	86.0	146.0	114.0	123.0	125.0	18.0
pH SU	Min.	4.2	3.6	4.3	4.0	5.0	5.0	6.2	5.1	5.6
	Mean	5.0	5.8	4.6	6.1	7.0	6.7	7.2	6.8	6.0
	Max.	6.9	7.5	5.5	7.5	7.8	7.7	8.0	7.7	6.7
Fluoride mg/L	Min.	.16	0	.10	.07	.06	.07	.08	.07	--
	Mean	.97	.59	.20	.38	.20	.18	.15	.17	--
	Max.	1.70	2.0	.30	1.07	.39	.36	.26	.31	--
Sulfate mg/L	Min.	0	1.2	--	0	2.0	1.0	3.0	1.0	--
	Mean	39.0	12.4	--	15.4	14.7	14.5	10.5	13.2	--
	Max.	126.4	30.0	--	43.0	34.0	38.0	21.0	31.0	--
Chloride mg/L	Min.	--	4.8	3.0	1.0	2.0	3.0	3.0	3.0	--
	Mean	--	7.9	4.2	7.7	7.5	6.5	7.7	7.0	--
	Max.	--	11.0	5.0	11.0	15.0	14.0	12.0	14.0	--
Turbidity NTU	Min.	--	.4	--	1.0	1.5	1.0	1.8	1.0	--
	Mean	--	1.5	--	3.8	4.3	4.0	6.5	4.7	--
	Max.	--	3.0	--	10.0	11.0	9.5	20.0	10.0	--
Color mg/L Pt	Min.	185.0	70.0	175.0	90.0	30.0	40.0	10.0	30.0	120.0
	Mean	300.0	226.0	219.0	273.0	178.0	192.0	117.0	185.0	152.1
	Max.	450.0	400.0	300.0	380.0	480.0	400.0	240.0	400.0	180.0
Dissolved Oxygen mg/L	Min.	4.2	4.0	5.6	2.5	1.8	3.6	3.8	3.8	7.6
	Mean	7.2	7.1	6.3	5.1	4.1	5.7	5.4	5.9	8.1
	Max.	9.0	11.5	7.7	8.2	8.3	11.0	8.9	12.0	8.8
Secchi Disc (M)	Min.	--	--	--	.38	.60	.40	.40	.40	--
	Mean	--	--	--	.61	.88	.88	.86	.75	--
	Max.	--	--	--	.91	1.50	2.10	1.80	1.70	--
Temperature C°	Min.	--	7.0	12.0	12.2	10.5	8.0	10.3	7.3	12.0
	Mean	--	20.7	18.4	20.5	20.0	19.2	19.6	19.0	14.5
	Max.	--	29.0	25.0	28.4	26.5	26.0	25.7	25.8	16.5
Orthophosphate mg/L P	Min.	.51	.12	--	.09	.06	.13	.04	.11	--
	Mean	2.22	1.17	--	1.46	.54	.52	.21	.42	--
	Max.	4.20	6.89	--	5.86	1.86	1.80	.72	1.26	--
Phosphate mg/L P	Min.	.78	.12	.28	.13	.17	.25	.17	.30	--
	Mean	2.66	1.35	.42	1.73	.74	.65	.44	.58	--
	Max.	4.31	6.89	.75	6.23	2.07	1.86	1.22	1.30	--
Total Kjeldahl Nitrogen mg/L N	Min.	--	.45	--	.15	.18	.18	.10	.10	--
	Mean	--	1.04	--	1.51	.77	.83	.82	.69	--
	Max.	--	2.43	--	3.69	1.96	3.58	2.02	1.74	--
Ammonia mg/L N	Min.	.02	.01	.30	.06	.06	.06	.06	.04	--
	Mean	.56	.22	.50	.21	.10	.13	.10	.12	--
	Max.	1.40	1.80	.80	.62	.32	.47	.30	.43	--
Nitrite+Nitrate Nitrogen mg/L N	Min.	.15	.02	--	.05	.05	.05	.06	.05	--
	Mean	.71	.35	--	.20	.24	.18	.39	.23	--
	Max.	1.17	1.57	--	.91	.65	.56	1.43	.62	--

		At Dowling Park			At Luraville @ SR 51				
		DER-JAX STUDY (1982-83)	DER-TLH STUDY (1982-84)	DER-JAX PNS (1981-83)	EPA (1966)	USGS (1966-78)	DER-JAX STUDY (1982-83)	DER-TLH STUDY (1982-84)	DER-JAX PNS (1973-83)
Conductivity umhos/cm	Min.	37.0	42.0	37.0	24.0	40.0	40.0	43.0	19.5
	Mean	158.7	157.0	164.0	43.0	206.9	170.6	160.0	166.0
	Max.	295.0	308.0	319.0	62.0	317.0	338.0	315.0	328.0
Alkalinity mg/l as $CaCO_3$	Min.	5.0	4.0	5.0	4.0	85.0	4.0	5.0	4.0
	Mean	61.8	63.0	65.0	9.3	109.2	65.9	66.2	70.5
	Max.	124.0	130.0	143.0	20.0	131.0	127.0	135.0	127.0
pH SU	Min.	5.7	5.4	5.7	5.8	6.2	5.5	5.5	5.4
	Mean	7.2	7.0	7.2	6.2	7.1	7.2	7.1	7.1
	Max.	8.1	7.8	8.1	6.7	7.8	8.0	7.9	8.0
Fluoride mg/L	Min.	.07	.07	.07	--	.20	.07	.07	.07
	Mean	.17	.16	.17	--	.32	.16	.15	.18
	Max.	.25	.28	.26	--	.40	.24	.27	.40
Sulfate mg/L	Min.	2.0	1.0	2.0	--	11.0	0	1.0	0
	Mean	12.2	12.7	13.9	--	15.4	12.0	12.5	12.9
	Max.	30.0	27.0	30.0	--	21.0	27.0	24.0	27.0
Chloride mg/L	Min.	2.0	3.0	2.0	--	5.0	3.0	3.0	3.0
	Mean	7.0	7.0	7.0	--	7.2	7.7	6.9	8.0
	Max.	10.0	15.0	10.0	--	11.0	16.0	16.0	16.0
Turbidity NTU	Min.	2.0	1.0	1.6	--	4.7	2.0	1.0	1.2
	Mean	6.9	5.5	6.6	--	4.7	6.8	5.7	5.3
	Max.	14.0	14.0	14.0	--	4.7	14.0	15.0	14.0
Color mg/L Pt	Min.	40.0	20.0	40.0	120.0	20.0	30.0	15.0	20.0
	Mean	147.1	163.0	149.2	144.2	62.0	143.7	161.0	131.0
	Max.	320.0	320.0	320.0	180.0	100.0	320.0	320.0	320.0
Dissolved Oxygen mg/L	Min.	3.4	2.3	4.5	--	--	3.2	3.2	3.2
	Mean	5.3	6.7	5.1	--	--	5.4	6.9	5.7
	Max.	8.5	11.4	5.8	--	--	8.5	12.0	8.5
Secchi Disc (M)	Min.	.42	.40	.42	--	--	.50	.40	.43
	Mean	.89	.93	.89	--	--	.91	1.04	.91
	Max.	1.88	2.10	1.88	--	--	1.90	2.50	2.00
Temperature C°	Min.	10.4	7.8	10.4	12.0	9.0	10.7	7.8	10.7
	Mean	20.0	18.8	19.8	14.8	20.9	20.2	18.9	20.1
	Max.	26.4	25.5	26.4	19.0	27.0	27.1	26.0	27.1
Orthophosphate mg/L P	Min.	.09	.07	.09	--	.17	.10	.08	.07
	Mean	.32	.31	.32	--	.30	.31	.29	.28
	Max.	.87	.86	.87	--	.53	.77	.71	.77
Phosphate mg/L P	Min.	.26	.21	.26	.20	.31	.17	.24	.04
	Mean	.49	.47	.50	.23	.42	.47	.47	.43
	Max.	.90	.94	.90	.26	.53	.97	.99	1.20
Total Kjeldahl Nitrogen mg/L N	Min.	.05	.10	.05	--	--	.10	.05	.10
	Mean	.69	.73	.74	--	--	.84	.61	.90
	Max.	2.07	3.59	2.07	--	--	1.64	1.71	2.35
Ammonia mg/L N	Min.	.06	.06	.08	--	.06	.06	.06	0
	Mean	.10	.13	.14	--	.06	.07	.12	.18
	Max.	.30	.42	.30	--	.06	.15	.32	.46
Nitrite+Nitrate Nitrogen mg/L N	Min.	.05	.05	.07	--	.26	.05	.05	.07
	Mean	.33	.29	.35	--	2.08	.33	.34	.36
	Max.	.80	.68	.80	--	4.36	.84	.71	.84

		At Branford					At Rockbluff SR 340			
		EPA (1966)	USGS (1983)	DER-JAX PNS (1975-83)	DER-TLH STUDY (1982-84)	DER-JAX STUDY (1982-83)	EPA (1966)	DER-JAX PNS (1981-83)	DER-TLH STUDY (1982-84)	DER-JAX STUDY (1982-83)
Conductivity umhos/cm	Min.	35.0	37.0	55.0	46.0	47.0	32.0	70.0	54.0	54.0
	Mean	49.5	230.0	214.0	169.0	183.0	72.6	203.8	189.0	191.5
	Max.	72.0	625.0	595.0	322.0	337.0	104.0	320.0	331.0	313.0
Alkalinity mg/L as $CaCO_3$	Min.	4.0	5.0	11.0	5.0	--	4.0	18.0	9.0	18.0
	Mean	12.0	95.7	85.6	73.7	--	20.2	90.7	82.9	84.5
	Max.	23.0	157.0	165.0	140.0	--	36.0	152.0	143.0	145.0
pH SU	Min.	5.8	5.0	5.1	5.6	6.2	6.0	6.2	6.2	6.2
	Mean	6.3	7.3	7.2	7.2	7.3	6.6	7.4	7.3	7.4
	Max.	6.8	8.6	8.2	7.9	8.1	7.1	7.9	7.9	7.9
Fluoride mg/L	Min.	--	0	.07	.07	.08	--	.08	.07	.08
	Mean	--	.23	.19	.15	.15	--	.15	.14	.14
	Max.	--	.70	1.34	.23	.21	--	.29	.20	.18
Sulfate mg/L	Min.	--	0	1.0	1.0	2.0	--	4.0	3.0	2.0
	Mean	--	14.3	14.5	12.0	12.4	--	16.0	14.1	14.5
	Max.	--	26.0	31.0	22.0	26.0	--	26.0	25.0	26.0
Chloride mg/L	Min.	--	2.8	2.0	2.0	2.0	--	1.0	2.0	1.0
	Mean	--	6.4	7.6	6.8	6.6	--	7.0	7.1	7.0
	Max.	--	15.0	38.0	16.0	10.0	--	10.0	16.0	10.0
Turbidity NTU	Min.	--	.40	.40	1.00	1.00	--	.60	1.0	1.0
	Mean	--	2.24	3.70	5.50	6.00	--	5.18	5.20	5.64
	Max.	--	11.00	17.00	16.00	12.00	--	13.00	18.00	13.00
Color mg/L Pt	Min.	100.0	6.0	5.0	10.0	5.0	120.0	5.0	10.0	5.0
	Mean	138.0	81.9	116.3	150.0	127.0	133.0	111.1	142.0	121.2
	Max.	150.0	450.0	300.0	320.0	280.0	175.0	280.0	320.0	280.0
Dissolved Oxygen mg/L	Min.	7.7	3.5	3.6	4.0	3.6	7.5	3.6	4.4	3.6
	Mean	8.1	6.5	5.9	7.0	5.4	7.9	5.9	7.1	5.8
	Max.	8.7	10.2	10.1	12.0	9.1	8.3	8.8	11.0	8.6
Secchi Disc (M)	Min.	--	.66	.45	.40	.45	--	.45	.48	.45
	Mean	--	1.24	1.16	1.11	.86	--	1.14	1.19	1.03
	Max.	--	4.30	3.50	2.70	1.80	--	2.50	3.00	2.30
Temperature C°	Min.	12.0	7.4	7.0	7.5	9.0	12.5	10.5	8.0	10.5
	Mean	14.7	20.4	20.7	19.1	20.7	15.0	20.8	19.5	21.2
	Max.	16.5	28.0	30.0	25.5	26.6	16.5	26.9	25.5	26.9
Orthophosphate mg/L P	Min.	--	.05	.08	.09	.08	--	.07	.10	.07
	Mean	--	.21	.26	.25	.24	--	.21	.19	.19
	Max.	--	1.00	.70	.60	.54	--	.43	.32	.37
Phosphate mg/L P	Min.	--	.09	.01	.19	.25	--	.21	.22	.21
	Mean	--	.25	.36	.40	.42	--	.39	.40	.38
	Max.	--	1.30	.90	.63	.66	--	1.12	1.34	1.12
Total Kjeldahl Nitrogen mg/L N	Min.	--	.01	.04	.08	.09	--	.10	.08	.10
	Mean	--	.49	.94	.73	.88	--	1.04	.67	1.05
	Max.	--	2.60	8.73	1.91	1.70	--	2.78	2.03	2.78
Ammonia mg/L N	Min.	--	0	0	.06	.01	--	.03	.06	.03
	Mean	--	.05	.19	.12	.11	--	.18	.11	.10
	Max.	--	.86	.89	.36	.63	--	.67	.40	.67
Nitrite+Nitrate Nitrogen mg/L N	Min.	--	.03	.01	.04	.04	--	.05	.07	.05
	Mean	--	.48	.52	.41	.44	--	.46	.40	.42
	Max.	--	1.10	1.31	.99	1.31	--	1.32	.94	1.32

		At Fanning Springs			At Manatee Springs			At Fowlers Bluff	
		USGS (1963-83)	DER-JAX PNS (1970-83)	DER-JAX STUDY (1982-83)	DER-JAX STUDY (1982-83)	DER-TLH STUDY (1982-84)	DER-JAX PNS (1981-83)	DER-JAX STUDY (1982-83)	DER-JAX PNS (1981-83)
Conductivity umhos/cm	Min.	56.0	64.0	52.0	54.0	65.0	64.0	82.0	71.0
	Mean	225.0	214.5	198.3	200.2	197.0	216.0	217.3	216.0
	Max.	369.0	358.0	334.0	319.0	339.0	360.0	319.0	357.0
Alkalinity mg/L as $CaCO_3$	Min.	33.0	17.0	17.0	17.0	14.0	17.0	19.0	19.0
	Mean	116.0	89.0	86.8	87.9	86.6	93.7	89.2	95.0
	Max.	148.0	151.0	150.0	147.0	147.0	147.0	147.0	147.0
pH SU	Min.	5.0	5.1	6.3	6.5	6.5	6.5	6.5	6.5
	Mean	7.2	7.2	7.5	7.5	7.4	7.5	7.6	7.6
	Max.	8.3	8.1	8.0	7.9	8.0	7.9	8.3	8.3
Fluoride mg/L	Min.	0	.08	.08	.08	.08	.08	.09	.09
	Mean	.25	.18	.14	.14	.14	.14	.14	.14
	Max.	.99	.40	.20	.18	.18	.21	.18	.20
Sulfate mg/L	Min.	4.8	0	2.0	2.0	2.0	4.0	2.0	5.0
	Mean	15.7	14.4	14.4	14.3	14.3	15.8	15.15	16.6
	Max.	20.0	36.0	26.0	26.0	25.0	26.0	26.0	26.0
Chloride mg/L	Min.	5.0	0	4.0	1.0	2.0	1.0	2.0	2.0
	Mean	7.6	7.7	8.2	7.1	7.6	7.3	7.6	7.6
	Max.	15.0	26.0	25.0	11.0	19.0	11.0	13.0	13.0
Turbidity NTU	Min.	.7	.7	1.0	1.0	1.0	1.0	2.0	1.4
	Mean	2.4	3.8	5.9	5.4	5.4	5.1	5.8	5.5
	Max.	8.0	15.0	15.0	15.0	19.0	15.0	16.0	16.0
Color mg/L Pt	Min.	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
	Mean	84.0	111.0	118.8	115.0	134.0	105.0	112.5	102.0
	Max.	200.0	200.0	280.0	280.0	320.0	280.0	280.0	280.0
Dissolved Oxygen mg/L	Min.	3.9	3.3	3.3	3.7	4.7	2.5	3.5	3.5
	Mean	6.7	6.5	6.0	6.1	7.2	6.1	6.0	6.2
	Max.	10.4	9.8	8.2	8.5	10.6	8.6	8.2	8.6
Secchi Disc (M)	Min.	--	.50	.54	.47	.40	.47	.55	.55
	Mean	--	1.35	1.03	.98	1.20	1.08	1.20	1.26
	Max.	--	8.30	2.90	2.80	3.10	2.80	2.90	2.90
Temperature C°	Min.	7.9	10.0	11.5	14.0	8.0	14.0	12.5	12.5
	Mean	20.9	21.2	21.4	21.7	19.9	21.4	21.5	21.2
	Max.	28.0	29.5	27.4	27.9	26.8	27.9	27.9	27.9
Orthophosphate mg/L P	Min.	.15	.03	.08	.08	.10	.07	0	.07
	Mean	.33	.18	.18	.18	.18	.17	.16	.16
	Max.	.77	.53	.35	.34	.45	.34	.35	.33
Phosphate mg/L P	Min.	0	.02	.17	.18	.23	.18	.20	.20
	Mean	.33	.27	.34	.35	.35	.34	.35	.34
	Max.	.64	1.10	.63	.57	.57	.57	.60	.60
Total Kjeldahl Nitrogen mg/L N	Min.	.02	0	.15	.05	.06	.05	0	0
	Mean	.46	.76	.89	.85	.69	.88	1.29	1.24
	Max.	2.93	2.08	1.69	2.05	2.47	2.05	3.57	3.57
Ammonia mg/L N	Min.	0	0	.01	.06	.03	.01	.06	.06
	Mean	.03	.19	.11	.11	.12	.19	.14	.24
	Max.	.32	1.08	.62	.63	.52	.63	.65	.65
Nitrite+Nitrate Nitrogen mg/L N	Min.	0	.08	.05	.06	.07	.06	.05	.05
	Mean	.42	.49	.45	.45	.43	.49	.44	.45
	Max.	.86	1.27	1.27	1.21	.96	1.38	.98	.98

APPENDIX B

FISHERY RESOURCES DATA

APPENDIX B.

UPPER SUWANNEE RIVER FISH POPULATION - ELECTROSHOCKING INVESTIGATION**
POPULATION PARAMETERS

ABOVE SWIFT CREEK

	March 1969	October 1980	March 1981	November 1981	June 1982	October 1982	October 1983
1. Number fish per hour	68.00	79.00	140.00	288.00	137.70	45.00	50.00
2. Weight fish (pounds) per hour	28.84	19.50	26.00	6.72	28.70	12.70	22.90
3. Number species per sample	10.00	17.00	14.00	15.00	19.00	16.00	17.00
4. Number sportfish per hour	55.00	35.00	57.00	178.00	110.00	32.00	29.00
5. Number harvestable sportfish per hour	18.00	16.00	14.00	10.65	17.70	7.00	15.00
6. Weight sportfish per hour	4.03	14.90	7.40	6.40	12.70	7.40	4.40
7. Weight harvestable sportfish per hour	2.68	13.99	6.00	4.48	11.90	3.44	3.60
8. Number harvestable sportfish per 100#	62.00	79.00	53.00	158.40	62.00	55.00	66.00
9. % by number sportfish	81.00	44.00	41.00	62.30	79.80	71.10	57.00
10. % by weight sportfish	14.00	77.00	28.00	95.00	44.20	34.00	19.00
11. % by weight harvestable sportfish (A_T^H)	9.00	72.00	23.00	67.00	41.30	27.00	16.00
12. % by weight available size fish (A_T)	92.00	94.00	72.00	67.00	83.90	91.30	94.00
13. F/C	0.13	0.45	0.64	1.12	0.59	0.45	0.70
14. % by weight Bass	3.90	52.70	18.20	47.20	14.65	15.61	4.00
15. % by weight Bream Spp	9.96	13.78	10.30	46.98	19.58	9.56	14.00
16. PSD Bass	-----*	83.00	67.00	50.00	15.00	40.00	-----*
17. PSD Bream Spp	18.00	18.00	32.00	18.20	50.00	14.00	45.00

**Catch per unit effort based on actual elapsed (clock) time of total sampling effort.

* Sample size less than 8 stock sized fish

UPPER SUWANNEE RIVER FISH POPULATION - ELECTROSHOCKING INVESTIGATION*
POPULATION PARAMETERS

BELOW SWIFT CREEK

	March 1969	October 1980	March 1981	November 1981	June 1982	October 1982	October 1983
1. Number fish per hour	98.00	91.00	235.00	170.00	181.00	77.56	110.00
2. Weight fish (pounds) per hour	13.40	12.25	55.00	14.80	28.80	30.40	57.00
3. Number species per sample	11.00	19.00	16.00	16.00	28.00	16.00	16.00
4. Number sportfish per hour	80.00	40.00	57.00	127.70	123.90	59.30	81.00
5. Number harvestable sportfish per hour	13.00	22.00	21.00	28.20	27.10	16.10	50.00
6. Weight sportfish per hour	5.00	7.60	20.20	9.78	19.00	15.60	27.00
7. Weight harvestable sportfish per hour	2.07	6.70	19.30	8.17	15.70	13.80	25.00
8. Number harvestable sportfish per 100#	95.00	179.00	100.00	190.00	93.90	52.90	88.00
9. % by number sportfish	81.00	44.00	24.00	74.80	68.30	76.40	74.00
10. % by weight sportfish	37.00	62.00	36.70	83.46	65.80	51.30	47.00
11. % by weight harvestable sportfish (A_T^H)	15.00	55.00	35.00	67.30	54.30	45.40	44.00
12. % by weight available size fish (A_T)	87.00	87.00	93.00	79.50	80.90	92.90	95.00
13. F/C	0.60	1.96	0.91	3.86	0.84	0.91	0.90
14. % by weight Bass	4.90	8.50	24.00	17.68	32.27	20.60	16.00
15. % by weight Bream Spp	30.66	41.20	5.70	60.59	20.09	4.86	11.00
16. PSD Bass	-----	33.00	100.00	50.00	27.00	30.00	30.00
17. PSD Bream Spp	-----	51.00	54.00	32.00	23.00	12.00	28.00

*Catch per unit effort based on actual elapsed (clock) time of total sampling effort.

SUWANNEE RIVER FISH POPULATION ELECTROSHOCKING INVESTIGATIONS[1]
ABOVE AND BELOW SWIFT CREEK COMPARISONS

		Mean Fall Values[2]	
		Above	Below
1.	Number fish per hour	116.5	112.1
2.	Weight fish (pounds) per hour	15.4	28.6
3.	Number species per sample	16.2	17.0
4.	Number sportfish per hour	68.5	77.0
5.	Number harvestable sportfish per hour	9.5	29.1
6.	Weight sportfish per hour	7.2	15.0
7.	Weight harvestable sportfish per hour	5.5	13.4
8.	Number harvestable sportfish per 100#	73.1	127.4
9.	% by number sportfish	58.6	67.3
10.	% by weight sportfish	56.2	60.9
11.	% by weight harvestable sportfish (A_T^H)	45.5	52.9
12.	% by weight available size fish (A_T)	86.6	88.6
13.	F/C	0.68	1.91
14.	% by weight Bass	28.9	15.7
15.	% by weight Bream Spp	21.1	29.4
16.	PSD Bass	43.2	35.8
17.	PSD Bream Spp	23.8	28.0

[1]Catch per unit effort based on actual elapsed (clock) time of total sampling effort.

[2]Average of samples from October 1980, November 1981, October 1982, October 1983.

UPPER SUWANNEE RIVER FISH POPULATION ELECTROSHOCKING INVESTIGATION
NUMBERS AND POUNDS OF FISH PER HOUR (ACTUAL CLOCK TIME)
OCTOBER 1982

SPECIES	NUMBERS		POUNDS		PER CENT WEIGHT	
	Above Swift Creek	Below Swift Creek	Above Swift Creek	Below Swift Creek	Above Swift Creek	Below Swift Creek
Largemouth bass	4	9	1.99	5.78	15.60	19.00
Suwannee bass	0	2	----	0.49	----	1.64
Bluegill	2	4	0.19	0.23	1.46	0.77
Redbreast sunfish	23	34	0.95	0.98	7.47	3.22
Redear sunfish	-	1	----	0.22	----	0.79
Spotted sunfish	2	2	0.06	0.02	0.47	0.07
Warmouth	-	-	0.02	----	0.12	----
Flier	1	-	0.01	----	0.04	----
Black crappie	-	1	----	0.62	----	2.04
Channel catfish	1	3	1.07	2.57	8.42	8.78
White catfish	-	1	----	4.17	----	13.71
Spotted bullhead	1	1	0.06	0.39	0.43	1.27
Bowfin	2	2	6.78	9.02	53.28	29.65
Spotted sucker	2	4	1.58	5.76	12.39	18.92
Notropis	3	4	0.01	0.01	0.08	0.05
Black banded darter	-	6	----	0.01	----	0.05
Brown darter	2	-	0.01	----	0.04	----
Brook silversides	1	-	0.01	----	0.04	----
Pirate perch	4	1	0.01	0.01	0.08	0.02
Lined Topminnow	1	-	0.01	----	0.04	----
Gambusia	1	1	0.01	0.01	0.04	0.02

UPPER SUWANNEE RIVER FISH POPULATION ELECTROSHOCKING INVESTIGATION
NUMBER AND POUNDS OF FISH PER HOUR (ACTUAL CLOCK TIME)
OCTOBER 1983

	Numbers		Pounds		Per Cent by Weight	
	Swift Creek		Swift Creek		Swift Creek	
SPECIES	Above	Below	Above	Below	Above	Below
Largemouth bass	1	10	.89	8.10	3.90	14.00
Suwannee bass		1		1.20		2.10
Bluegill	1	2	1.10	.65	4.70	1.10
Redear	1	1	.15	.58	.66	1.00
Redbreast	17	41	1.60	4.40	7.10	7.80
Spotted sunfish	3	7	.29	.45	1.00	.79
Flier						
Warmouth	3		.18		.77	
Black crappie						
Chain pickerel						
Redfin pickerel						
Channel catfish	1	18	.66	12.00	2.90	20.00
Yellow bullhead	1		.08		.35	
Spotted bullhead	1		.14		.59	
Brown bullhead						
Mullet						
Bowfin	3	5	12.00	20.00	52.00	36.00
Florida gar	1	1	.47	.59	2.00	1.10
Long nose gar						
American eel		1		.15		.30
Spotted sucker	3	5	6.00	8.90	26.00	16.00
Alabama shad						
Golden shiner						
Notropis						
Black banded darter	5	10	.01	.01	.05	.02
Brown darter	1		.01		.03	
Hogchoker		1		.01		.01
Pirate perch	3	4	.01	.01	.05	.02
Brook silversides						
Madtom	1	1	.01	.01	.03	.01
Dollar sunfish						
Pygmy sunfish						
Banded sunfish						
Bluespot sunfish						
Mud sunfish						
Gambusia	5	1	.01	.01	.05	.01
Lined Topminnow						
Eastern mudminnow						

1982 SUWANNEE RIVER FISH POPULATIONS
ELECTROSHOCKING RESULTS
POPULATION PARAMETERS*

OCTOBER 1982

	Swift Creek Above	Swift Creek Below	Luraville	Branford Above Santa Fe River	Wannee	New Clay Landing
1. Number fish per hour*	45.00	77.56	66.50	93.53	84.86	105.00
2. Weight fish (pounds) per hour	12.72	30.43	12.18	24.21	38.26	24.04
3. Number species per sample	16.00	16.00	14.00	18.00	18.00	17.00
4. Number sportfish per hour	32.00	59.27	60.00	65.88	52.43	90.50
5. Number harvestable sportfish per hour	7.00	16.10	7.50	12.94	7.03	11.00
6. Weight sportfish per hour	4.33	15.61	10.66	14.93	10.71	15.43
7. Weight harvestable sportfish per hour	3.44	13.83	8.58	12.95	8.55	10.09
8. Number harvestable sportfish per 100#	55.05	52.90	61.58	53.46	18.36	45.76
9. % by number sportfish	71.11	76.42	90.23	70.44	61.80	86.19
10. % by weight sportfish	34.02	51.29	87.48	61.68	27.98	64.16
11. % by weight harvestable sportfish (A_T^H)	27.02	45.44	70.40	53.51	22.35	41.95
12. % by weight available size fish (A_T)	91.30	92.86	81.21	74.17	82.29	87.50
13. F/C	0.45	0.91	2.28	0.52	0.28	1.02
14. % by weight Bass	15.61	20.63	30.46	34.78	8.48	17.12
15. % by weight Bream Spp	9.56	4.86	9.15	10.04	3.32	10.17
16. PSD Bass	40.00	30.00	60.00	33.00	**----	29.00
17. PSD Bream Spp	14.00	12.00	15.00	14.00	3.00	1.00

*(Actual clock time sampling effort)
** Less than 8 stock size bass collected per sample

1983 SUWANNEE RIVER FISH POPULATIONS
ELECTROSHOCKING RESULTS
POPULATION PARAMETERS**

OCTOBER 1983

	Hunter Creek Above	Hunter Creek Below	Swift Creek Above	Swift Creek Below	Luraville	Branford above Santa Fe	Wannee below Santa Fe	New Clay
No. fish per hour	101.0	122.0	50.0	110.0	89.0	96.0	102.0	161.0
Wgt. fish (pounds) per hour	41.0	13.0	22.9	57.0	29.0	45.0	29.0	101.0
No. Species per sample	21.0	22.0	17.0	16.0	19.0	18.0	19.0	24.0
No. Sportfish per hour	54.0	54.0	29.0	81.0	69.0	80.0	75.0	107.0
No. Harv. Sportfish per hour	19.0	8.0	15.0	50.0	18.0	18.0	12.0	33.0
Wgt. Sportfish per hour	11.0	5.0	4.4	27.0	14.0	24.0	8.0	34.0
Lbs. Harv. Sportfish per hour	8.0	3.0	3.6	25.0	10.0	21.0	4.0	30.0
No. Harv. Sportfish per 100 lbs	46.0	59.0	66.0	88.0	62.0	40.0	42.0	33.0
% by No. Sportfish	53.0	44.0	57.0	74.0	77.0	83.0	74.0	66.0
% by wgt. Sportfish	26.0	39.0	19.0	47.0	50.0	54.0	29.0	34.0
% by wgt. Harv. Sportfish (A_T^H)	20.0	25.0	16.0	44.0	34.0	47.0	16.0	29.0
% by wgt available size fish (A_T)	86.0	84.0	94.0	95.0	82.0	92.0	86.0	93.0
F/C	0.3	0.5	0.7	0.9	0.6	0.5	0.3	0.2
% by wgt. Bass	4.0	6.0	4.0	16.0	32.0	27.0	14.0	21.0
% by wgt. Bream Spp	12.0	26.0	14.0	11.0	14.0	6.0	14.0	7.0
PSD Bass	100.0*	-0-*	-0-*	30.0	29.0	54.0	22.0	38.0
PSD Bream Spp	22.0	6.0	45.0	28.0	5.0	11.0	2.0	11.0

*Sample size less than 8 stock sized fish

**Actual clock time sampling effort

SUWANNEE RIVER FISH POPULATION - ELECTROSHOCKING RESULTS
OCTOBER 1982
NUMBER OF FISH PER HOUR (ACTUAL CLOCK TIME SAMPLING EFFORT)

SPECIES	Swift Creek Above	Swift Creek Below	Luraville	Branford Above Santa Fe River	Wannee	New Clay Landing
Largemouth bass	4	9	4	6	7	7
Suwannee bass	0	2	8	2	4	4
Bluegill	2	4	2	2	1	3
Redbreast sunfish	23	34	38	48	32	68
Redear sunfish	0	1	2	5	2	1
Spotted sunfish	2	2	3	2	3	2
Warmouth	1	0	0	0	0	0
Flier	1	0	0	0	0	0
Black crappie	0	1	0	0	1	0
Channel catfish	1	3	0	0	0	0
White catfish	0	1	0	0	0	0
Spotted bullhead	1	1	1	0	0	0
Bowfin	2	2	0	1	5	1
Florida gar	0	0	0	6	4	1
Spotted sucker	2	4	1	4	3	3
Lake chubsucker	0	0	0	0	1	0
American eel	0	0	2	1	1	1
Mullet	0	0	4	2	3	4
Gizzard shad	0	0	1	0	0	0
Notropis sp.	3	4	1	5	12	3
Blackbanded darter	0	6	0	0	0	0
Brown darter	2	0	1	3	3	2
Brook silversides	1	0	0	1	0	0
Hogchoker	0	0	2	4	0	0
Pirate perch	4	1	0	1	1	0
Lined topminnow	1	0	0	0	0	0
Gambusia	1	1	0	2	2	6
Flagfish	0	0	0	0	0	1
Sailfin mollie	0	0	0	0	0	1
Least killifish	0	0	0	0	0	1

SUWANNEE RIVER FISH POPULATION - ELECTROSHOCKING RESULTS
OCTOBER 1982
POUNDS OF FISH PER HOUR (ACTUAL CLOCK TIME SAMPLING EFFORT)

SPECIES	SWIFT CREEK ABOVE WT.	SWIFT CREEK ABOVE %	SWIFT CREEK BELOW WT.	SWIFT CREEK BELOW %	LURAVILLE WT.	LURAVILLE %	BRANFORD ABOVE SANTA FE RIVER WT.	BRANFORD ABOVE SANTA FE RIVER %	WANNEE WT.	WANNEE %	NEW CLAY LANDING WT.	NEW CLAY LANDING %
LARGEMOUTH BASS	1.99	15.61	5.78	19.00	2.63	21.63	7.57	31.28	2.41	6.30	3.35	13.91
SUWANNEE BASS	-	-	0.50	1.64	1.08	8.83	0.85	3.50	0.83	2.18	0.77	3.20
BLUEGILL	0.19	1.46	0.23	0.77	0.05	0.37	0.15	0.63	0.03	0.07	0.23	0.94
REDBREAST SUNFISH	0.95	7.47	0.98	3.22	0.75	6.12	1.21	4.98	0.75	1.96	2.09	8.67
REDEAR SUNFISH	-	-	0.22	0.79	0.22	1.77	0.99	4.11	0.09	0.24	0.04	0.17
SPOTTED SUNFISH	0.06	0.47	0.02	0.07	0.11	0.90	0.08	0.32	0.22	0.57	0.10	0.40
WARMOUTH	0.02	0.12	-	-	-	-	-	-	0.18	0.48	-	-
FLIER	0.01	0.04	-	-	-	-	-	-	-	-	-	-
BLACK CRAPPIE	-	-	0.62	2.04	-	-	-	-	-	-	-	-
CHANNEL CATFISH	1.07	8.42	2.67	8.78	-	-	-	-	-	-	-	-
WHITE CATFISH	-	-	4.17	13.71	-	-	-	-	-	-	-	-
SPOTTED BULLHEAD	0.06	0.43	0.39	1.27	0.08	0.62	-	-	-	-	-	-
BOWFIN	6.78	53.28	9.02	29.65	-	-	2.23	9.21	20.42	53.38	5.15	21.42
FLORIDA GAR	-	-	-	-	-	-	5.29	21.87	5.84	15.26	2.65	11.02
SPOTTED SUCKER	1.58	12.39	5.76	18.92	0.38	3.08	1.00	4.13	0.71	1.85	2.54	10.57
LAKE CHUBSUCKER	-	-	-	-	-	-	-	-	0.16	0.42	-	-
AMERICAN EEL	-	-	-	-	0.59	4.80	0.69	2.84	0.38	0.99	0.78	3.22
MULLET	-	-	-	-	5.76	47.25	4.08	16.87	5.84	15.27	6.33	26.31
GIZZARD SHAD	-	-	-	-	0.55	4.47						
NOTROPIS SP.	0.01	0.03	0.01	0.05	0.01	0.04	0.01	0.05	0.02	0.06	0.01	0.04
BLACKBANDED DARTER	-	-	0.01	0.05	-	-	-	-	-	-	-	-
BROWN DARTER	0.01	0.04	-	-	0.01	0.04	0.01	0.02	0.01	0.01	0.01	0.04
BROOK SILVERSIDES	0.01	0.04	-	-	-	-	0.01	0.02	-	-	-	-
HOGCHOKER	-	-	-	-	0.01	0.03	0.02	0.10	-	-	-	-
PIRATE PERCH	0.01	0.03	0.01	0.02	-	-	0.01	0.02	0.02	0.04	-	-
LINED TOPMINNOW	0.01	0.04	-	-	-	-	-	-	-	-	-	-
GAMBUSIA	0.01	0.04	0.01	0.02	-	-	0.01	0.02	0.01	0.01	0.01	0.02
FLAGFISH	-	-	-	-	-	-	-	-	-	-	0.01	0.02
SAILFIN MOLLIE	-	-	-	-	-	-	-	-	-	-	0.01	0.02
LEAST KILLIFISH	-	-	-	-	-	-	-	-	-	-	0.01	0.02

SUWANNEE RIVER FISH POPULATION - ELECTROSHOCKING RESULTS
OCTOBER 1983
NUMBER OF FISH PER HOUR[1] (ACTUAL CLOCK TIME SAMPLING EFFORT

	HUNTER CREEK					
SPECIES	ABOVE	BELOW	LURAVILLE	BRANFORD	WANNEE	NEW CLAY
LARGEMOUTH BASS	1	1	8	16	15	26
SUWANNEE BASS			3	1	4	1
BLUEGILL	1		6	20	1	14
REDEAR	-	-	3	-	2	5
REDBREAST	2	-	26	10	22	25
SPOTTED SUNFISH	16	24	16	16	20	16
FLIER	8	2	-	-	-	-
WARMOUTH	13	11	1	1	10	14
BLACK CRAPPIE	-	1	3	2	-	2
CHAIN PICKEREL	1	1	-	1	1	-
REDFIN PICKEREL	-	1	-	-	-	-
CHANNEL CATFISH	1	-	-	-	-	-
YELLOW BULLHEAD	8	4	-	-	-	-
SPOTTED BULLHEAD	2	-	1	-	-	-
BROWN BULLHEAD	-	-	-	-	-	1
MULLET	-	-	1	5	1	2
BOWFIN	7	2	1	3	5	14
FLORIDA GAR	4	-	2	-	-	7
LONG NOSE GAR	-	-	-	1	-	2
AMERICAN EEL	1	-	7	3	2	4
SPOTTED SUCKER	1	1	1	-	1	3
ALABAMA SHAD	-	-	-	-	-	1
GOLDEN SHINER	-	-	1	-	-	1
NOTROPIS	-	-	2	1	3	9
BLACKBANDED DARTER	7	9	2	1	2	2
BROWN DARTER	-	-	-	1	-	-
HOGCHOKER	-	-	4	6	9	6
PIRATE PERCH	16	33	1	1	3	4
BROOK SILVERSIDES	2	-	-	-	2	1
MADTOM	6	5	-	-	1	-
DOLLAR SUNFISH	-	-	-	-	1	1
PYGMY SUNFISH	1	1	-	-	-	1
BANDED SUNFISH	-	1	-	-	-	-
BLUESPOT SUNFISH	1	1	-	-	-	-
MUD SUNFISH	-	1	-	-	-	-
GAMBUSIA	1	14	-	-	-	-
LINED TOPMINNOW	-	2	-	-	-	-
EASTERN MUDMINNOW	-	1	-	-	-	-

(1)SAMPLE VALUES ROUNDED TO NEAREST WHOLE NUMBER

SUWANNEE RIVER FISH POPULATION - ELECTROSHOCKING RESULTS
OCTOBER 1983
POUNDS OF FISH PER HOUR (ACTUAL CLOCK TIME SAMPLING EFFORT)

HUNTER CREEK AREA

	ABOVE		BELOW		LURAVILLE		BRANFORD		WANNEE		NEW CLAY	
SPECIES	Lbs.	%	Lbs.	%	Wt.	%	Wt.	%	Wt.	%	Wt.	%
Largemouth bass	1.50	3.60	.82	6.50	7.70	27.00	11.50	26.00	3.50	12.00	20.00	20.00
Suwannee bass					1.30	4.70	.63	1.40	.48	1.70	1.00	1.00
Bluegill	.12	.55			.26	.92	.72	1.60	.10	.40	.67	.66
Redear					.43	1.50	.41	.90	.26	.90	1.20	1.20
Redbreast	.24	.60			1.60	5.70	.32	.70	1.50	5.40	2.50	2.50
Spotted sunfish	1.50	3.70	1.10	8.90	1.40	4.80	.97	2.20	1.20	4.10	1.20	1.20
Flier	.18	.43	.03	.23								
Warmouth	2.80	6.80	.42	3.20	.05	.18	.12	.30	.74	2.60	1.40	1.40
Black crappie			.97	7.60	.58	2.00	.49	1.10			1.30	1.30
Chain pickerel	1.40	3.30	.04	.30			.01	.02				
Redfin pickerel			.03	.20								
Channel catfish	.69	1.70							.03	.10		
Yellow bullhead	1.90	4.70	.75	6.00								
Spotted bullhead	.40	.98			.11	.40						
Brown bullhead											.95	.95
Mullet					.91	3.20	9.00	20.00	.57	2.00	3.60	3.60
Bowfin	24.00	58.00	6.60	51.00	7.20	25.00	17.00	39.00	18.00	62.00	48.00	48.00
Florida gar	4.00	9.80			2.00	6.90					10.00	10.00
Long nose gar							.08	.20			.45	.45
American eel	.47	1.20			4.50	16.00	2.80	6.30	1.30	4.50	4.70	4.70
Spotted sucker	1.90	4.50	.90	7.00	.46	1.60			1.00	3.60	2.40	2.40
Alabama shad											.12	.12
Golden shiner					.02	.06					.31	.31
Notropis					.01	.04	.01	.01	.01	.02	.02	.02
Blackbanded darter	.06	1.50	.03	.20	.01	.04	.01	.01	.01	.02	.01	.01
Brown darter							.01	.01				
Hogchoker					.01	.04	.05	.10	.06	.20	.06	.60
Pirate perch	.07	.17	.18	1.40	.01	.02	.01	.01	.02	.07	.06	.60
Brook silversides	.01	.03							.01	.02	.01	.01
Madtom	.04	.11	.05	.39					.01	.03		
Dollar sunfish									.02	.03	.03	.03
Pygmy sunfish	.01	.02	.01	.03							.01	.01
Banded sunfish			.01	.02								
Bluespot sunfish	.01	.02	.01	.02								
Mudsunfish			.01	.07								
Gambusia	.01	.02	.02	.10								
Lined topminnow			.01	.03								
Eastern mudminnow			.01	.10								

Upper Suwannee River and Lower Santa Fe River

Spring 1982 Creel Data

	Upper Suwannee River (22 miles)	Lower Santa Fe River (15 miles)
Total Harvest (fish)	14,909.00	32,346.00
Harvest per mile (fish)	678.00	2,156.00
Total Effort (Hours)	11,010.00	23,319.00
Effort per mile (Hours)	500.00	1,555.00
Overall Success (all species)	1.76	1.38
Overall Redbreast Success	1.10	0.83
Directed Redbreast Success	2.15	1.64
Directed Combined Bream Success*	2.35	1.53
Per Cent Harvest Redbreast	63.00	60.00
Per Cent Harvest Combined Bream*	77.00	87.00
Per Cent Harvest Catfish	21.00	10.00
Per Cent Harvest Bass	2.00	2.00
Per Cent Effort Redbreast	52.00	48.00
Per Cent Effort Combined Bream*	57.00	80.00
Per Cent Effort Catfish	40.00	14.00

* = Redbreast sunfish, spotted sunfish, bluegill, redear, warmouth

COMPARISON OF EFFORT, YIELD AND CATCH PER UNIT EFFORT
FOR FLORIDA RIVERS

River	Effort (Hours/Mile)	Harvest (Fish/Mile)	Overall Success (Fish/Hour)
Lower Suwannee - 1	1,256	2,164	1.72
Upper Suwannee - 2	500	678	1.76
Lower Santa Fe - 2	1,555	2,156	1.38
Blackwater - 3	3,829	4,139	1.09
Escambia - 3	3,650	3,178	0.87
Suwannee - 3	1.046	2,096	2.00
Santa Fe - 3	1,920	3,403	1.78
St. Johns - 3	3,788	3,651	0.97
Oklawaha - 3	3,384	2,508	0.74
Withlacoochee	2,677	2,012	0.75

1 - 16 week spring creel season

2 - 12 week spring creel season

3 - compiled by Bass 1980 - annual creel data

COMPARISON OF EFFORT, YIELD AND CATCH PER UNIT EFFORT FOR STREAMS OF THE SOUTHEASTERN UNITED STATES[1]

Water Body	Duration	Effort (Hours/Mile)	Harvest (Fish/Mile)	Overall Success (Fish/Hour)
Upper Suwannee 1982	12 weeks	500	678	1.76
Lower Santa Fe 1982	12 weeks	1,555	2,156	1.38
Middle Suwannee 1971	Annual	1,047	2,095	2.00
Lower Santa Fe 1973	Annual	1,908	3,382	1.77
Suwannee River, Georgia 1970	10 months	342	540	1.29
Suwannee River, Georgia 1970	10 months	594	1,204	2.63
Suwannee River, Georgia 1970	10 months	1,360	3,162	2.29
Flint River, Georgia	10 months	1,514	1,324	0.87
Satilla River, Georgia	Annual	668	460 (pounds)	0.78 (pound/hr)
Northeast River, Maryland				0.29
Magothy River, Maryland				1.80
Potomac River, Maryland				0.47
Susquehanna River, Maryland				0.36
Huzzah Creek, Missouri	9 months	1,612	1,008	0.63
Courtois Creek, Missouri	9 months	1,144	915	0.80
Current River, Missouri	9 months	486	185	0.38
Big Piney River, Missouri	9 months	550	332	0.60
Niangua River, Missouri	9.5 months			0.33 - 0.66
Cacapon River, West Virginia				1.00
New River, Virginia				1.10
Shenandoah River, West Virginia				1.34
Wheeling Creek, West Virginia				0.18 - 0.72

[1] Compiled by Bass 1974, Creel census data = Southeastern United States warm water sport fisheries, Florida GFC mimeo report.

COMPARISON OF SPECIES DIRECTED SUCCESS ESTIMATES FOR STREAMS OF THE SOUTHEASTERN UNITED STATES[1]

Water Body	Species	Success (Fish/hour)
Upper Suwannee 1982	Bass	0.85
	Combined Bream	2.35
	Redbreast Sunfish	2.15
Lower Santa Fe 1982	Redbreast Sunfish	1.64
	Combined Bream	1.53
St. Johns River / Dunns Creek	Largemouth Bass	0.30
	Combined Bream	2.00
	Crappie	0.80
Suwannee River, Georgia 1970	Largemouth Bass	0.15 - 0.47
	Combined Bream	0.79
	Warmouth	0.63
	Crappie	2.00
	Catfish	1.83 - 2.34
Flint River, Georgia	Bluegill	0.72
	Redear	0.42
	Largemouth Bass	0.49
	Redbreast Sunfish	0.72
	White Bass	1.25
Satilla River, Georgia	Largemouth Bass	0.40
	Redbreast Sunfish	0.90
	Channel Catfish	0.90
	Warmouth	0.30
	Bullheads	2.20
Escambia River, Florida 1979-80	Marine Species	1.42 - 1.67
	Largemouth bass	0.16 - 0.38
	Catfish	0.80 - 0.87
	Bream	0.86 - 1.20

[1]Compiled by Bass 1974, creel census data - southeastern United States warm water sport fisheries, Florida GFC mimeo report.

LOWER SUWANNEE RIVER - SPRING CREEL DATA
SUCCESS (FISH PER HOUR)
FEBRUARY 28 - JUNE 13, 1982

	Species Directed Success		Overall Success*
Bass	0.28		0.04
Redbreast sunfish	2.58		0.66
		1.88	
Other Bream	1.24		0.73
Catfish	0.55		0.20
		TOTAL	1.63

* = Number harvested per species divided by total effort.

LOWER SUWANNEE RIVER
SPRING CREEL DATA - HARVEST AND EFFORT
FEBRUARY 28, 1983 - JUNE 13, 1983

HARVEST (FISH)	NUMBER		PER CENT OF TOTAL	
Bass	1,914		2.7	
Redbreast sunfish	28,419		40.4	
		> 59,480		> 84.5
Other Bream	31,061		44.1	
Catfish	8,630		12.3	
Miscellaneous Freshwater Species(1)	81		0.1	
Miscellaneous Saltwater Species(2)	300		0.4	
TOTAL	70,405			
EFFORT (HOURS)				
Bass	5,557		12.6	
Redbreast sunfish	11,029		24.9	
		> 31,664		> 71.5
Other Bream	20,635		46.6	
Catfish	5,556		12.6	
Miscellaneous Freshwater Species	9		0.1	
Miscellaneous Saltwater Species	1,469		3.3	
TOTAL	44,255			
Weekdays	18,005		42	
Weekend Days	24,772		58	
Angler Days - Local	6,771		53	
Non Local Resident	4,445		35	
Non Resident	1,609		12	

(1) Miscellaneous Freshwater Species - Crappie, Mudfish, Eel
(2) Miscellaneous Saltwater Species = Channel bass, Spotted Seatrout, Sheepshead, Black Drum, Sea Bass

ELECTROSHOCKING DATA PER SPECIES GROUP

SUWANNEE RIVER (OCTOBER 1982)

CATCH PER ACTUAL HOUR SAMPLING

	NUMBER	PER CENT	POUNDS	PER CENT
ABOVE SWIFT CREEK				
Sport fish	32.00	(71)	4.33	(34)
Rough fish	4.00	(9)	8.35	(66)
Miscellaneous	9.00	(20)	0.04	(1)
TOTAL	45.00		12.72	
BELOW SWIFT CREEK				
Sport fish	59.26	(76)	15.61	(51)
Rough fish	6.59	(8)	14.78	(49)
Miscellaneous	11.71	(15)	0.04	(1)
TOTAL	77.56		30.43	
LURAVILLE				
Sport fish	60.00	(90)	10.66	(88)
Rough fish	2.00	(3)	0.92	(8)
Miscellaneous	4.50	(7)	0.61	(5)
TOTAL	66.50		12.19	
BRANFORD ABOVE SANTA FE RIVER				
Sport fish	65.88	(70)	14.93	(62)
Rough fish	10.59	(11)	8.52	(35)
Miscellaneous	17.06	(18)	0.75	(4)
TOTAL	93.53		24.20	
WANNEE				
Sport fish	52.43	(62)	10.71	(28)
Rough fish	12.43	(15)	27.13	(70)
Miscellaneous	20.00	(24)	0.43	(1)
TOTAL	84.86		38.27	
NEW CLAY LANDING				
Sport fish	88.00	(84)	12.88	(54)
Rough fish	4.50	(4)	10.34	(43)
Miscellaneous	12.50	(12)	0.82	(3)
TOTAL	105.00		24.04	

UPPER SUWANNEE RIVER - SPRING CREEL DATA
SUCCESS (FISH PER HOUR)
March 25 - June 15, 1982

	Species Directed Success		Overall Success*
Bass	0.85		0.03
Redbreast sunfish	2.15		1.10
Bluegill	1.31	2.35	0.03
Other Bream	7.40		0.23
Catfish	0.87		0.37
		TOTAL	1.78

* = Number harvested per species divided by total effort.

SUWANNEE RIVER CREEL DATA

	Middle Suwannee River (63 miles) (13 weeks) Spring 1971	Upper Suwannee River (22 miles) (12 weeks) Spring 1982	Lower Suwannee River (32 miles) (16 weeks) Spring 1983
Total Harvest (fish)	43,893.00	14,909.00	69,260.00
Harvest per mile (fish)	697.00	678.00	2,164.38
Total Effort (hours)	24,504.00	11,010.00	40,209.00
Effort per mile (hours)	388.00	500.00	1,256.53
Overall Success (all species)	1.78	1.76	1.72
Overall Redbreast Success	.67	1.10	7.58
Per Cent Harvest Redbreast	38.70	62.70	41.03
Per Cent Harvest Bluegill	16.60	1.50	-
Per Cent Harvest Catfish	20.80	21.30	11.92
Per Cent Harvest Bass	8.50	1.50	2.31

Upper Suwannee River - Spring Creel Data - Harvest and Effort
March 25 - June 15, 1982

HARVEST (Fish)			PER CENT OF TOTAL	
Bass	296		1.5%	
Redbreast Sunfish	12,122		62.7%	
Bluegill	297	14,909	1.5%	77.1%
Other Bream	2,490		12.9%	
Catfish	4,114		21.3%	
TOTAL	19,319			

EFFORT (Hours)				
Bass	349		3%	
Redbreast Sunfish	5,771		52%	
Bluegill	227	6,332	2%	57%
Other Bream	334		3%	
Catfish	4,451		40%	
TOTAL	11,132			

Bank Fishing Effort	4,734	43%
Boat Fishing Effort	6,276	57%
Total Weekend Effort	6,417	58%
Total Weekday Effort	4,593	42%

ELECTROSHOCKING DATA FOR STREAMS OF NORTHEAST FLORIDA (1980-1981)
NUMBER AND WEIGHTS PER HOUR[1] AND PER CENT COMPOSITION LENGTH AND WEIGHT

	Number Fish	Pounds Fish	Number Sportfish	[2]Number Harvestable Sportfish	Weight Sportfish	Weight Harvestable Sportfish	Species/ Sample	Number Harvestable Sportfish/ 100#	Per Cent By Number Sportfish	Per Cent By Weight Sportfish	A_T^H [2]	A_T	F/C	Per Cent By Weight Bass	Per Cent By Weight Bream	PSD Bass	PSD Bream
Steinhatchee	66.8	65.7	49.1	35.4	42.0	41.3	10.0	54.0	73.5	64.0	62.9	97.5	0.17	54.1	9.9	44.0	53.1
Econfina	154.5	131.6	53.1	16.1	9.6	7.0	13.0	12.0	34.4	7.3	5.3	94.9	0.21	2.9	3.4	[3]	2.0
Aucilla	161.4	46.8	90.4	24.8	8.9	6.2	15.0	53.0	56.0	19.1	13.2	90.9	2.42	3.8	4.0	[3]	15.0
Mills Creek	32.6	24.6	14.6	7.9	3.6	3.2	10.0	32.0	44.8	15.5	13.0	95.3	0.17	-0-	11.8	[3]	67.0
Upper Suwannee x of five samples	160.8	26.5	64.5	24.9	24.3	14.4	16.2	84.0	50.0	59.3	48.8	84.2	1.44	20.77	19.6	[3]	25.0
Boggy Creek	97.9	61.1	49.5	23.6	23.1	21.8	13.0	39.0	50.6	37.8	35.7	88.3	0.70	17.6	4.6	17.0	40.0
Santa Fe Route 129	1,092.7	278.3	786.1	189.8	110.3	79.2	25.0	68.0	72.0	40.0	28.0	79.0	2.24	16.0	19.0	13.0	.0
Santa Fe Hollingsworth Bluff	1,002.5	340.5	836.5	317.7	177.8	154.3	24.0	93.0	83.0	52.0	45.0	90.0	1.44	24.0	18.0	35.0	33.3
Santa Fe Above Olena	164.0	191.5	114.0	64.0	40.0	38.4	15.0	33.0	68.8	20.7	19.9	99.0	0.50	13.2	6.6	67.0	41.0
Black Creek Middleburg	86.3	14.7	64.7	18.5	14.4	12.9	13.0	126.2	21.4	98.2	88.2	88.2	1.69	16.4	37.6	[3]	23.0
Upper St. Marys River Macclenny/Baker County	218.0	82.8	127.2	31.8	24.2	20.7	13.0	38.4	58.3	9.2	25.1	88.0	0.26	15.9	11.9	29.0	25.0
Middle St. Marys Boulougne	203.8	17.2	139.7	12.6	8.6	6.0	16.0	73.1	68.5	50.1	34.7	77.7	1.16	-0-	27.3	[3]	6.0
Withlacoochee x of two samples	263.0	25.8	188.1	12.8	18.8	8.9	16.0	50.0	71.0	72.8	35.8	54.9	1.90	43.2	13.6	27.0	3.0
Middle Suwannee River Manree	219.7	99.1	135.7	18.2	27.7	22.1	13.0	18.4	28.0	61.8	22.4	82.3	0.28	8.5	3.3	[3]	3.0
Lower Suwannee River Manatee Springs	295.0	67.5	254.2	30.9	43.3	28.3	17.0	45.8	86.2	64.2	42.0	87.5	1.02	17.1	10.2	25.0	1.3
MEAN / N=15	281.3	98.2	197.8	55.3	38.4	31.0	16.3	54.6	57.8	46.1	34.7	86.5	1.04	19.5	13.4	35.9	23.2
RANGE	32.6 : 1,092.7	14.7 : 340.5	14.6 : 836.5	7.9 : 317.7	3.6 : 177.8	3.2 : 154.3	10.0 : 25.0	12.0 : 93.0	21.4 : 86.2	7.3 : 98.2	5.3 : 88.2	54.9 : 99.0	0.17 : 2.42	-0- : 54.1	3.3 : 37.6	[3] : 67.0	1.3 : 53.2

[1] Field data expanded from actual DC booster seconds to catch per 3600 seconds
[2] Mullet included as sportfish
[3] Sample less than 8 stock size bass

ELECTROSHOCKING DATA PER SPECIES GROUP
SUWANNEE RIVER-OCTOBER 1983
CATCH PER ACTUAL HOUR SAMPLING

	NUMBER	PER CENT	POUNDS	PER CENT
Above Hunter Creek				
Sportfish	54	53	10.80	26.000
Rough fish	13	12	30.00	73.000
Miscelaneous	34	34	0.21	.005
TOTAL	101		41.00	
Below Hunter Creek				
Sportfish	54	44	5.00	39.000
Rough fish	3	2	7.50	59.000
Miscellaneous	65	53	0.32	2.000
TOTAL	122		12.80	
Above Swift Creek				
Sportfish	29	58	4.00	19.000
Rough fish	7	14	18.40	80.000
Miscellaneous	14	28	.05	.002
TOTAL	50		22.90	
Below Swift Creek				
Sportfish	81	74	27.00	47.000
Rough fish	12	11	29.90	52.000
Miscellaneous	16	14	.05	.001
TOTAL	110		57.00	
Luraville				
Sportfish	69	78	14.40	51.000
Rough fish	11	12	14.10	49.000
Miscellaneous	9	10	.06	.210
TOTAL	89		28.50	
Branford - Above Santa Fe				
Sportfish	80	83	24.10	54.000
Rough fish	7	7	20.30	46.000
Miscellaneous	9	9	.07	.150
TOTAL	96		44.50	
Wannee				
Sportfish	75	73	8.38	29.000
Rough fish	7	7	20.10	70.000
Miscellaneous	20	20	.11	.380
TOTAL	102		28.56	
New Clay Landing				
Sportfish	107	66	34.10	34.000
Rough fish	30	19	66.10	65.000
Miscellaneous	24	15	.61	.600
TOTAL	161		101.00	

ELECTROSHOCKING DATA PER SPECIES GROUP
SUWANNEE RIVER (OCTOBER 1970, 1972; FROM BASS)
CATCH PER ACTUAL HOUR SAMPLING

	NUMBER	PER CENT	POUNDS	PER CENT
ABOVE SWIFT CREEK				
Sport fish	98	(72)	13.5	(59)
Rough fish	11	(8)	8.4	(37)
Miscellaneous	27	(20)	0.8	(4)
TOTAL	136		22.7	
BRANFORD ABOVE SANTA FE RIVER				
Sport fish	108	(74)	9.6	(71)
Rough fish	5	(3)	1.9	(14)
Miscellaneous	34	(23)	2.0	(15)
TOTAL	147		13.5	
WANNEE				
Sport fish	48	(69)	11.2	(48)
Rough fish	7	(10)	9.8	(42)
Miscellaneous	14	(20)	2.1	(9)
TOTAL	69		23.1	
NEW CLAY LANDING				
Sport fish	98	(64)	Raw Data Not Available	(32)
Rough fish	25	(16)		(68)
Miscellaneous	31	(20)		(.2)
TOTAL	154			

APPENDIX C

SUMMARY OF BENTHIC MACROINVERTEBRATE TAXA FOUND IN THE SUWANNEE RIVER FROM 1952 TO 1984

APPENDIX C. SUMMARY OF BENTHIC MACROINVERTEBRATE TAXA
FOUND IN THE SUWANNEE RIVER FROM 1952-1984.

TAXA	DER BIOLOGY 1982-84		DER DISTRICT 1973 - 78		EPA 1972-73	ESP 1981 - 82	FWPCA 1966 - 67	FSEH 1952 - 53	
	Upper	Lower	Upper	Lower	Manatee Springs	Upper	Lower	Upper	Lower
Annelida									
Hirudinea									
Batracobdella phalera		XX							
Helobdella elongata		XX							
H. fusca				XX					
H. stagnalis				XX					
Placobdella papillifera		XX							
P. parasitica		XX							
Annelida									
Oligochaeta									
Aeolosoma tenebrarum				XX					
Aulodrilus pigueti				XX					
A. vagus				XX					
Bratislava unidentata	XX	XX							
Chaetogaster sp.		XX							
Dero nivea			XX						
Eclipidrilus palustris			XX						
Ilyodrilus templetoni				XX					
Limnodrilus hoffmeisteri			XX	XX					
Lumbriculus variegatus					XX				
Nais barbata	XX	XX							
N. beimingi	XX	XX							
N. communis	XX	XX	XX	XX					
N. elinguis				XX					
N. pardalis	XX	XX							
N. simplex		XX							
N. sp.		XX	XX		XX				
N. variabilis		XX		XX					
Pristinella palustris			XX	XX					

TAXA	DER BIOLOGY 1982-84		DER DISTRICT 1973 - 78		EPA 1972-73	ESP 1981 - 82	FWPCA 1966 - 67	FSEH 1952 - 53	
	Upper	Lower	Upper	Lower	Manatee Springs	Upper	Lower	Upper	Lower
Pristina osborni		XX	XX	XX					
Slavina appendicula	XX	XX	XX	XX					
Stylaria lacustris	XX	XX							
Stylodrilus herringianus				XX					
Tubifex sp.				XX					
T. tubifex				XX					
Arachnida									
Acarina									
Acercus sp.			XX						
Arrenurus sp.	XX	XX	XX						
Atractides sp.	XX	XX	XX						
Hydrachna sp.				XX					
Hydrochoreutes ungulatus				XX					
Hydrodroma sp.	XX								
Hygrobates sp.	XX	XX	XX	XX					
Koenikea sp.	XX								
Krendowskia similix				XX					
Lebertia sp.	XX	XX		XX					
Limnesia sp.				XX					
Mideopsis sp.		XX		XX					
Piona sp.			XX	XX					
Platynothrus sp.	XX								
Sperchonopsis echphyma	XX	XX							
S. sp.		XX	XX						
S. verrucosa			XX	XX					
Torrenticola sp.	XX	XX	XX						
Tyrellia sp.				XX					
Unionicola sp.		XX	XX	XX					

TAXA	DER BIOLOGY 1982-84		DER DISTRICT 1973 - 78		EPA 1972-73	ESP 1981 - 82	FMPCA 1966 - 67	FSBE 1952 - 53	
	Upper	Lower	Upper	Lower	Manatee Springs	Upper	Lower	Upper	Lower
Cnidaria									
Hydrozoa									
Hydra sp.		XX		XX					
Crustacea									
Malacostraca									
Asellus sp.	XX	XX	XX	XX		XX			XX
A. communis				XX					
A. racovitizai australis				XX	XX				
Chlamydotheca sp.						XX			
Corophium sp.				XX					
Crangonyx sp.				XX	XX	XX			
C. serratus						XX			
Cyathura polita				XX	XX				
Gammarus sp.		XX							
G. tigrinis				XX	XX				
Hyalella azteca	XX	XX		XX	XX	XX			XX
Lirceus sp.						XX			
Palaemonetes kadiakensis				XX	XX				
P. sp.									XX
P. paludosus			XX	XX	XX			XX	XX
Procambarus sp.	XX	XX	XX	XX		XX			
P. fallax				XX		XX			
P. spiculifer					XX				
Taphromysis louisianae				XX					
Insecta									
Coleoptera									

TAXA	DER BIOLOGY 1982-84		DER DISTRICT 1973 - 78		EPA 1972-73	ESP 1981 - 82	FWPCA 1966 - 67	FSEH 1952 - 53	
	Upper	Lower	Upper	Lower	Manatee Springs	Upper	Lower	Upper	Lower
Agabus johannis	XX	XX							
Ancyronyx variagata	XX	XX	XX			XX			
Berosus exiguus						XX			
Berosus pugnax		XX							
B. sp.		XX	XX			XX			
Bidessus flavicollis						XX			
B. hobbsi						XX			
Bidessonatus longovalis						XX			
B. inconspicuus						XX			
Celina slossoni						XX			
Coptotomus interrogatus obscurus		XX	XX	XX		XX			
Crenitulus suturalis		XX							
Cybister fimbriolatus				XX					
Deronectes sp.			XX						
Dineutus angustus	XX			XX		XX			
D. analis						XX			
D. ciliatus					XX				
D. discolor	XX		XX	XX					
D. sp.	XX	XX	XX	XX	XX	XX			
Dubiraphia sp.	XX	XX	XX	XX					
D. quadrinotata	XX	XX			XX	XX			
D. vittata			XX						
Emplenota sp.			XX						
Gyrinus analis			XX	XX	XX				
G. floridensis				XX					
G. pachysomus						XX			
G. rockinghamensis			XX						
G. woodruffi						XX			
Haliplus sp.				XX					
H. punctatus			XX	XX		XX			
H. mutchleri				XX					

TAXA	DER BIOLOGY 1982-84		DER DISTRICT 1973 - 78		EPA 1972-73	ESP 1981 - 82	FWPCA 1966 - 67	FSBH 1952 - 53	
	Upper	Lower	Upper	Lower	Manatee Springs	Upper	Lower	Upper	Lower
Hellichus fastigiatus						XX			
Hydraena marginicollis						XX			
Hydrocanthus obloggus						XX			
Hydrochus scabratus						XX			
Hydroporus sp.	XX	XX	XX	XX	XX				
H. falli						XX			
H. pilatei						XX			
H. rufficeps						XX			
H. vittatipennis				XX		XX			
Hyperodes sp.	XX								
Laccophilus gentilis						XX			
Matus ovatus						XX			
Microcylloepus pusillus	XX	XX				XX			
M. sp.		XX				XX			
Oreodytes sp.			XX						
Peltodytes sp.			XX	XX		XX			
P. floridensis						XX			
P. oppositus						XX			
Stenelemis convexula	XX	XX	XX						
S. crenata		XX							
S. fuscata				XX					
S. humerosa				XX					
S. hungerfordi	XX	XX	XX	XX		XX			
S. sinuata	XX								
S. sp.	XX	XX	XX	XX	XX	XX			
Suphisellus gibbulus			XX			XX			
S. puncticolis						XX			
Insecta									
Collembola									

TAXA	DER BIOLOGY 1982-84		DER DISTRICT 1973 - 78		EPA 1972-73	ESP 1981 - 82	FWPCA 1966 - 67	FSBH 1952 - 53	
	Upper	Lower	Upper	Lower	Manatee Springs	Upper	Lower	Upper	Lower
Achorutes sp.	XX								
Isotomurus sp.	XX	XX							
Sminthurrides sp.		XX							
Insecta									
Diptera									
Ablabesmyia americana	XX	XX		XX					
A. annulata	XX	XX							
A. aspera				XX		XX			
A. auriensis						XX			
A. cinctipes	XX	XX							
A. janta						XX			
A. mallochi	XX	XX	XX	XX		XX			
A. ornata	XX	XX		XX		XX			
A. parajanta	XX	XX	XX	XX					
A. philosphagnos	XX	XX				XX			
A. rhamphe					XX				
A. sp.	XX	XX				XX			
A. tarella	XX	XX	XX	XX					
Anopheles sp.				XX					
Arctopelopia fittkaui						XX			
Atherix sp.			XX			XX			
Atrichopogon sp.	XX	XX				XX			
Bezzia-Probezzia sp.	XX	XX	XX	XX		XX			
Cardiocladius sp.	XX					XX			
Chironomini sp. A (Roback)			XX						
Chironomus attenuatus				XX					
C. crassicaudatus		XX							
C. decorus	XX	XX						XX	XX
C. sp.	XX	XX	XX	XX		XX			

TAXA	DER BIOLOGY 1982-84		DER DISTRICT 1973 - 78		EPA 1972-73	ESP 1981 - 82	FWPCA 1966 - 67	FSEH 1952 - 53	
	Upper	Lower	Upper	Lower	Manatee Springs	Upper	Lower	Upper	Lower
C. stigmaterus	XX			XX					
Chrysops sp.						XX			
Chaoborus sp.				XX					
Cladotanytarsus sp.	XX	XX	XX	XX		XX			
Clinotanypus pinguis	XX	XX							
C. sp.	XX	XX	XX	XX		XX			
Onephia sp.						XX			
Coelotanypus concinnis		XX		XX					
C. tricolor		XX		XX					
C. scapularis				XX					
C. sp.				XX					
Conchapelopia sp.	XX	XX	XX	XX		XX			
C. celeripes					XX			XX	
C. sp.	XX	XX			XX	XX			
C. taris	XX	XX	XX	XX					
C. xena									XX
Cricotopus bicinctus	XX	XX	XX		XX			XX	
C. sp.	XX	XX	XX	XX		XX	XX		
Cryptochironomus blarina	XX	XX	XX	XX		XX			XX
C. digitatus									XX
C. fulvus group	XX	XX		XX	XX	XX			XX
C. sp.	XX	XX	XX	XX		XX		XX	XX
Cryptotendipes sp.			XX	XX	XX				
Dulicoides sp.	XX	XX	XX						
Dasyhelea sp.				XX					
Dicrotendipes leucoscelis	XX	XX		XX		XX			
D. lobus	XX	XX	XX	XX					
D. modestus	XX	XX	XX	XX	XX	XX			
D. neomodestus	XX	XX	XX	XX					
D. nervosus				XX					
D. sp.	XX	XX		XX	XX	XX			

TAXA	DER BIOLOGY 1982-84		DER DISTRICT 1973 - 78		EPA 1972-73	ESP 1981 - 82	FWPCA 1966 - 67	FSBH 1952 - 53	
	Upper	Lower	Upper	Lower	Manatee Springs	Upper	Lower	Upper	Lower
Djalmabatista pulcher	XX	XX							
Einfeldia sp.						XX			
Endochironomus nigricans	XX	XX						XX	XX
E. sp.				XX	XX				
Enkiefferiella discoloripes	XX	XX							
E. sp.	XX	XX	XX	XX		XX		XX	
Euparyphus sp.				XX					
Forcipomyia sp.						XX			
Goeldichironomus carus		XX							
Gonomyia sp.						XX			
Glyptotendipes sp.				XX		XX			
G. paripes						XX			
Harnischia curtilamellata	XX	XX							
H. edwardsi			XX						
H. galeator				XX					
H. sp.	XX	XX	XX	XX		XX	XX	XX	
Hemerodromia rogatoris	XX	XX							
H. sp.	XX	XX				XX			
Heterotrissocladius sp.			XX						
H. oromosia						XX			
Hexatoma sp.						XX			
Kiefferulus dux						XX			
Labrundinia floridana	XX		XX		XX	XX			
L. johannseni		XX	XX						
L. neopilosella			XX	XX					
L. sp.	XX	XX				XX			
L. virescens	XX	XX		XX					
Larsia lurida				XX		XX			
L. sp.						XX			
Limonia sp.						XX			
Limnophora sp.		XX							
Limnophyes sp.						XX			

TAXA	DER BIOLOGY 1982-84		DER DISTRICT 1973 - 78		EPA 1972-73	ESP 1981 - 82	FWPCA 1966 - 67	FSBH 1952 - 53	
	Upper	Lower	Upper	Lower	Manatee Springs	Upper	Lower	Upper	Lower
Microcricotopus sp.		XX							
Micropsectra sp.						XX			
Microtendipes caelum	XX	XX							
M. sp.		XX	XX	XX		XX			
Nanocladius alternantherae						XX			
N. minimus					XX				
N. sp.	XX	XX		XX	XX	XX			
Natarsia sp.						XX			
Nilotanypus americanus						XX			
N. fimbriatus		XX							
N. sp.	XX	XX							
Nilotheuma bicornis			XX						
N. sp.	XX	XX	XX			XX			
Orthocladius annectens				XX					
O. sp.	XX	XX				XX			
Pagastiella sp.			XX	XX					
Palpomyia tibialis			XX	XX	XX				
Parachironomus alatus						XX			
P. carinatus					XX				
P. directus					XX				
P. pectinatellae	XX	XX	XX	XX					
P. schneideri	XX	XX							
P. sp.	XX	XX							
Paracladopelma denneijerei			XX	XX					
P. loganae				XX					
P. sp.			XX	XX					
P. undine				XX					
Parakiefferiella sp.	XX	XX							
Paralauterborniella elachista	XX			XX					
P. nigrohalteralis		XX	XX	XX					

TAXA	DER BIOLOGY 1982-84		DER DISTRICT 1973 - 78		EPA 1972-73	ESP 1981 - 82	FWPCA 1966 - 67	FSBH 1952 - 53	
	Upper	Lower	Upper	Lower	Manatee Springs	Upper	Lower	Upper	Lower
Paraorthocladius sp.	XX	XX							
Paramerina anomala						XX			
P. sp.						XX			
Parametriocnemus sp.		XX							
Paratanytarsus sp.	XX	XX							
Paratendipes sp.				XX					
Pedionomus beckae				XX					
Pedicia sp.						XX			
Pentaneura inconspicua	XX	XX		XX	XX	XX			
P. carnea									XX
P. monilis								XX	
P. pilosella								XX	
P. sp.						XX		XX	XX
Phaenopsectra obediens		XX							
P. sp.						XX			
Pilaria sp.						XX			
Polypedilum convictum	XX	XX	XX	XX		XX			
P. fallax	XX	XX		XX		XX			
P. halterale	XX	XX	XX	XX		XX			XX
P. illinoense	XX	XX	XX	XX	XX	XX		XX	
P. ontario						XX			
P. parascalaenum					XX				
P. scalaenum						XX			
P. sp.	XX	XX		XX		XX	XX	XX	XX
Potthastia sp.						XX			
Procladius sp.	XX	XX	XX	XX		XX			
Psectrocladius sp.			XX	XX		XX			
P. pilosus									XX
P. vernalis				XX					
Pseudochironomus sp.	XX	XX	XX			XX			
P. fulviventris					XX				

TAXA	DER BIOLOGY 1982-84		DER DISTRICT 1973 - 78		EPA 1972-73	ESP 1981 - 82	FWPCA 1966 - 67	PSBH 1952 - 53	
	Upper	Lower	Upper	Lower	Manatee Springs	Upper	Lower	Upper	Lower
Pseudorthocladius sp.						XX			
Psychoda sp.		XX							
Rheocricotopus robackii	XX	XX							
R. sp.	XX	XX				XX			
Rheotanytarsus exiguus				XX		XX	XX		
R. sp.	XX	XX				XX	XX	XX	XX
Robackia claviger						XX			
Simulium slossonae			XX	XX					
S. sp.	XX	XX				XX			
Stempellina sp.			XX			XX			
Stenochironomus hilaris			XX	XX	XX				
S. sp.	XX	XX	XX	XX		XX	XX		
Stelechomyia sp.	XX	XX							
Strictochironomus devinctus			XX	XX					
S. sp.						XX			
Stigopterna sp.						XX			
Tabanus sp.						XX			
Tanypus carinatus			XX			XX			
T. neopunctipennis						XX			
T. sp.						XX			
T. stellatus			XX						
Tanytarsus exiguus					XX				XX
T. guerlus					XX			XX	
T. sp.	XX	XX		XX	XX	XX	XX		
Thienemanniella xena	XX	XX		XX	XX	XX	XX		
T. sp.						XX			
Tipula sp.				XX		XX			
Tribelos fuscicornis	XX	XX				XX			
T. jucundus	XX	XX				XX			
T. quadripunctatus						XX			
T. sp.		XX		XX	XX	XX			

TAXA	DER BIOLOGY 1982-84		DER DISTRICT 1973 - 78		EPA 1972-73	ESP 1981 - 82	FWPCA 1966 - 67	FSBH 1952 - 53	
	Upper	Lower	Upper	Lower	Manatee Springs	Upper	Lower	Upper	Lower
Trissocladius sp.	XX	XX	XX	XX					
Xenochironomus sp.						XX			
Zavrelia sp.	XX	XX		XX		XX			
Insecta									
Ephemeroptera									
Baetis intercalaris		XX				XX			
B. obesa				XX					
B. propinquus	XX			XX					
B. sp.	XX	XX		XX	XX	XX			
B. spiethi	XX					XX			
Baetisca rogersi		XX							
Brachycercus maculatus		XX	XX	XX					
B. sp.		XX		XX					
Caenis diminuta	XX	XX	XX	XX	XX	XX			
C. sp.	XX			XX		XX			
Callibaetis floridanus				XX	XX				
C. pretiosus						XX			
C. sp.						XX			
Centroptilum hobbsi		XX				XX			
C. sp.					XX	XX			
C. viridocularis	XX	XX		XX		XX			
Choroterpes hubbeli	XX	XX		XX					
Cloeon rubropictum		XX				XX			
C. sp.						XX			
Dolania americana				XX					
Ephemerella sp.		XX				XX			
Eurylophella trilineata	XX	XX	XX	XX		XX			
Habrophlebiodes brunneipennis						XX			
H. sp.						XX			

TAXA	DER BIOLOGY 1982-84		DER DISTRICT 1973 - 78		EPA 1972-73	ESP 1981 - 82	FWPCA 1966 - 67	FSBH 1952 - 53	
	Upper	Lower	Upper	Lower	Manatee Springs	Upper	Lower	Upper	Lower
Hexagenia munda	XX			XX					
Isonychia pictipes	XX	XX			XX				
I. sp.				XX	XX				
Leptophlebia intermedia	XX	XX				XX			
Neoephemera sp.	XX	XX		XX					
Paraleptophlebia bradlei	XX		XX			XX			
P. volitans	XX		XX						
Pseudocloeon alachua		XX							
P. parvulum		XX							
P. sp.		XX							
Pseudiron sp.		XX							
Stenonema exiguum	XX	XX	XX	XX	XX	XX		XX	XX
S. smithae	XX	XX	XX	XX		XX		XX	XX
S. sp.	XX	XX	XX		XX	XX			
Stenacron annexum			XX						
S. floridense				XX					
S. integrum		XX							
S. interpunctatum	XX	XX	XX	XX		XX			
S. proximum					XX	XX			
S. pulchellum			XX						
Tricorythodes albilineatus	XX	XX	XX	XX	XX	XX			
Insecta									
Hemiptera									
Abedus immaculatus			XX	XX					
Belostoma sp.				XX					
Corisella edulis						XX			
Gerris sp.			XX		XX	XX			
Rebrus sp.				XX					
Mesovelia sp.				XX					

TAXA	DER BIOLOGY 1982-84		DER DISTRICT 1973 - 78		EPA 1972-73	ESP 1981 - 82	FWPCA 1966 - 67	FSEH 1952 - 53	
	Upper	Lower	Upper	Lower	Manatee Springs	Upper	Lower	Upper	Lower
Microvelia sp.						XX			
M. buenoi						XX			
Pelocoris sp.				XX					
Plea striola				XX					
Ranatra australis						XX			
R. sp.					XX				
Sigara hubbelli						XX			
Trichocorixa sp.			XX	XX	XX				
T. louisianae						XX			
Insecta									
Lepidoptera									
Parapoynx sp.		XX							
Synclita sp.						XX			
Insecta									
Megaloptera									
Corydalus cornutus	XX	XX	XX		XX	XX		XX	XX
Sialis sp.				XX		XX			
Insecta									
Neuroptera									
Climacia areolaris			XX						
C. sp.						XX			
Nigronis sp.					XX				
Sisyra sp.						XX			
Insecta									
Odonata									

TAXA	DER BIOLOGY 1982-84		DER DISTRICT 1973 - 78		EPA 1972-73	ESP 1981 - 82	FWPCA 1966 - 67	FSBH 1952 - 53	
	Upper	Lower	Upper	Lower	Manatee Springs	Upper	Lower	Upper	Lower
Anax junius						XX			
Argia apicalis		XX							
A. fumipennis	XX	XX							
A. moesta	XX	XX	XX	XX		XX			
A. sedula	XX	XX	XX			XX			
A. sp.	XX	XX	XX	XX		XX		XX	XX
A. tibialis	XX	XX		XX		XX			
Arigomphus pallidus		XX							
Arithemis simplisicolis						XX			
Boyeria binosa						XX			
Brachymesia gravida						XX			
Calyopteryx maculata	XX	XX							
C. sp.			XX			XX			
Didymops transversa						XX			
Dromogomphus armatus			XX	XX					
D. sp.				XX		XX			
D. spinosus		XX	XX	XX		XX			
Enallagma cardenium		XX							
E. sp.				XX		XX			
Epicordulia sp.					XX				
Epitheca sp.						XX			
Erythrodiplax sp.				XX					
E. minuscula						XX			
Erythemis sp.				XX					
E. simplicicollis						XX			
Gomphus dilatatus						XX			
G. ivae						XX			
G. minutus					XX	XX			
G. pallidus								XX	XX
G. plagiatus						XX			
G. sp.			XX	XX		XX	XX	XX	XX

TAXA	DER BIOLOGY 1982-84		DER DISTRICT 1973 - 78		EPA 1972-73	ESP 1981 - 82	FWPCA 1966 - 67	FSBH 1952 - 53	
	Upper	Lower	Upper	Lower	Manatee Springs	Upper	Lower	Upper	Lower
G. stylurus				XX					
Gomphoides sp.					XX				
Hetaerina titia		XX							
H. sp.					XX				
Ischnura sp.			XX						
Libellula incesta						XX			
Libellula librans						XX			
L. sp.						XX			
Macromia georgiana	XX	XX							
M. sp.			XX	XX		XX		XX	XX
M. taeniolata			XX			XX			
Nasiaeschna pentacantha				XX					
Nehallenia integricollus						XX			
N. sp.				XX	XX				
Neurocordulia virginiensis	XX	XX		XX		XX			
N. obsoleta				XX					
Pachydiplax longipennis						XX			
Perithemis tenera						XX			
P. sp.						XX			
Progomphus alachuensis			XX						
P. obscurus				XX		XX	XX		
P. sp.			XX						
Tetragoneuria semiaquea				XX					
T. sepia				XX					
T. sp.						XX			
Tramea sp.						XX			
Insecta									
Acroneuria abnormis									XX

TAXA	DER BIOLOGY 1982-84		DER DISTRICT 1973 - 78		EPA 1972-73	ESP 1981 - 82	FWPCA 1966 - 67	FSBH 1952 - 53	
	Upper	Lower	Upper	Lower	Manatee Springs	Upper	Lower	Upper	Lower
A. arenosa	XX	XX							
A. mela									XX
A. sp.	XX	XX	XX			XX			
Attaneuria ruralis		XX							
Hydroperla phormidia		XX							
Isoperla sp.		XX				XX			
Neoperla clymene		XX			XX				XX
N. sp.		XX							
Paragnetina fumosa		XX							
Perlesta placida	XX	XX	XX			XX			XX
Perlinella ephyre	XX								
P. cryno						XX			
P. sp.		XX				XX			
Taeniopteryx leta		XX							
Insecta									
Trichoptera									
Agarodes sp.				XX					
Agrayles sp.					XX				
Ceraclea sp.	XX	XX	XX	XX					
Cheumatopsyche sp.	XX	XX	XX	XX	XX	XX	XX	XX	XX
C. burksi					XX				
Chimarra aterrima			XX			XX			
C. perigua						XX			XX
C. socia			XX		XX				
C. sp.	XX	XX	XX	XX		XX	XX	XX	XX
Cernellus fraternus		XX	XX	XX	XX	XX			
Hydropsyche sp.	XX	XX	XX	XX	XX	XX	XX		XX
H. incommoda					XX			XX	XX
Hydroptila sp.	XX	XX	XX	XX		XX		XX	XX

TAXA	DER BIOLOGY 1982-84		DER DISTRICT 1973 - 78		EPA 1972-73	ESP 1981 - 82	FWPCA 1966 - 67	FSSH 1952 - 53	
	Upper	Lower	Upper	Lower	Manatee Springs	Upper	Lower	Upper	Lower
Leptocella sp.								XX	
Lype diversa	XX	XX		XX		XX			
Macronema carolina	XX	XX	XX	XX		XX	XX	XX	XX
Mayatrichia sp.	XX	XX							
M. ayama					XX				
Molanna sp.			XX	XX		XX			
Nectopsyche sp.	XX	XX		XX		XX			
N. candida				XX					
Neotrichia sp.	XX	XX							
Neureclipsis sp.	XX	XX		XX	XX				
N. crepuscularis					XX				
Nyctiophylax sp.	XX	XX	XX			XX			
N. celta						XX			
N. vestitus			XX						
Ochrotrichia sp.				XX					
Oecetis cinerascens	XX	XX			XX				
O. sp.	XX	XX	XX	XX		XX			
Orthotrichia sp.	XX	XX							
Oxyethira sp.	XX	XX		XX	XX	XX			
Phylocentropus sp.						XX			
Polycentropus sp.	XX	XX	XX	XX		XX		XX	XX
Psychomyia sp.				XX					
Ptilostomes sp.						XX			
Pycnopsyche sp.						XX			
Tianodes sp.	XX	XX				XX			
Mollusca									
Gastropoda									
Amnicola sp.				XX					

TAXA	DER BIOLOGY 1982-84		DER DISTRICT 1973 - 78		EPA 1972-73	ESP 1981 - 82	FWPCA 1966 - 67	FSBH 1952 - 53	
	Upper	Lower	Upper	Lower	Manatee Springs	Upper	Lower	Upper	Lower
Ancylus sp.									XX
Campeloma geniculum				XX					
C. sp.		XX			XX				
Cincinnatia sp.		XX							
Ferrissia sp.	XX	XX		XX	XX		XX	XX	
Fossaria sp.		XX							
Goniobasis floridensis		XX							
G. sp.				XX					XX
Gundlachia sp.				XX					
Gyraulus sp.		XX		XX		XX			
Helisoma duryi		XX							
H. sp.				XX					
Laevapex sp.		XX				XX			
Lioplax sp.				XX					
Lymnaea columella				XX					
Lyogyrus sp.				XX					
Notogillia sp.				XX					
Physa pumilia		XX	XX	XX		XX		XX	XX
Pomacea paludosa		XX		XX	XX				
Promenetus sp.		XX		XX					
Pseudosuccinea sp.		XX							
Rissoina cancellata					XX				
Viviparus georgianus		XX							
V. sp.				XX					
Mollusca									
Pelecypoda									
Corbicula manilensis	XX	XX	XX	XX	XX	XX			
C. sp.							XX		
Elliptio sp.						XX			

TAXA	DER BIOLOGY 1982-84		DER DISTRICT 1973 - 78		EPA 1972-73	ESP 1981 - 82	FWPCA 1966 - 67	FSBH 1952 - 53	
	Upper	Lower	Upper	Lower	Manatee Springs	Upper	Lower	Upper	Lower
E. jayensis						XX			
Fusconais sp.						XX			
Musculium sp.		XX							
Pisidium sp.			XX	XX					
Quincuncina sp.				XX					
Q. infucata						XX			
Sphaerium partumeium			XX	XX					
S. sp.						XX			
Nemertea									
Prostoma rubra		XX		XX					
Platyhelminthes									
Turbellaria									
Dugesia polychroa		XX							
D. sp.		XX							
D. tigrina		XX							
Procotyla fluviatilis			XX						
Porifera									
Spongilla sp.			XX						

APPENDIX D

SUMMARY OF PERIPHYTON AND PHYTOPLANKTON FOUND IN THE SUWANNEE RIVER FROM 1972 TO 1984

APPENDIX D. SUMMARY OF PERIPHYTON AND PHYTOPLANKTON FOUND IN THE SUWANNEE RIVER FROM 1972 TO 1984

TAXA	DER PERIPHYTON ONLY (1984) Upper	DER PERIPHYTON ONLY (1984) Lower	SRWMD (1982-1984) PHYTOPLANKTON Upper	SRWMD (1982-1984) PHYTOPLANKTON Lower	EPA EIS (1978) PERIPHYTON Upper Only	ESP (1984) PERIPHYTON Upper Only	ESP (1984) PHYTOPLANKTON Upper Only	EPA (1972) PERIPHYTON Lower Only
Chlorophyta								
Actinastrum hantzschii				XX			XX	
Actinastrum sp.	XX							
Ankistrodesmus braunii			XX	XX				
A. convolutus							XX	
A. falcatus				XX			XX	
A. nannoselene							XX	
Ankistrodesmus sp.	XX	XX			XX			
Aphanochaete sp.		XX						
Bambusina brebissonii								
Bambusina sp.	XX		XX					
Basicaladia sp.		XX						
Botrycoccus sp.	XX	XX						
Characium ambiguum			XX	XX				
Characium sp.		XX						
Chlamydomonas sp.	XX	XX			XX			
Chlorella sp.	XX	XX	XX	XX				
Chlorococcum sp.	XX	XX						
Cladophora sp.		XX					XX	
Closteriopsis longissima								
Closterium sp.		XX	XX	XX	XX			XX
Coelochaete sp.			XX					
Coelastrum microsporum						XX	XX	
Coelastrum sp.	XX	XX	XX	XX				
Cosmarium regnellii								
Cosmarium sp.	XX	XX		XX				XX
Crucigenia crucifera							XX	
C. irregularis							XX	
C. quadrata			XX				XX	
C. rectangularis				XX				
C. tetrapedia							XX	

TAXA	DER PERIPHYTON ONLY (1984) Upper	DER PERIPHYTON ONLY (1984) Lower	SRAMD (1982-1984) PHYTOPLANKTON Upper	SRAMD (1982-1984) PHYTOPLANKTON Lower	EPA ELS (1978) PERIPHYTON Upper Only	ESP (1984) PERIPHYTON Upper Only	ESP (1984) PHYTOPLANKTON Upper Only	EPA (1972) PERIPHYTON Lower Only
Crucigenia sp.					XX			
Cylindrocapsa sp.		XX					XX	
Desmidium aptogonum	XX					XX		
Desmidium sp.			XX	XX		XX	XX	
Dictyosphaerium pulchellum						XX		
Dimorphococcus lunatus	XX							
Elakatothrix sp.						XX		
Euastrum sp.						XX		
Eudorina elegans		XX						
Gloeocystis sp.				XX				
Golenkinia radiata		XX						
Groenbladia sp.		XX						
Haematococcus sp.							XX	
Honnotila muciglna							XX	
Kirchneriella obesa						XX	XX	
K. subsolitaria	XX	XX						
Kirchneriella sp.				XX				
Lagerheimia quadriseta			XX					
Mesotaenium sp.			XX	XX		XX	XX	
Micractinium pasillum		XX	XX					
Micrasterias sp.		XX						
Microspora sp.	XX	XX		XX	XX	XX		
Mougeotia sp.	XX							
Netrium sp.		XX				XX		
Oedogonium sp.						XX	XX	
Oocystis borgei						XX		
O. parva	XX	XX	XX	XX				
Oocystis sp.			XX				XX	
Pandorina morum				XX		XX		
Pediastrum duplex								
P. tetras	XX	XX						
Pediastrum sp.								

TAXA	DER PERIPHYTON ONLY (1984) Upper	DER PERIPHYTON ONLY (1984) Lower	SRWMD (1982-1984) PHYTOPLANKTON Upper	SRWMD (1982-1984) PHYTOPLANKTON Lower	EPA EIS (1978) PERIPHYTON Upper Only	ESP (1984) PERIPHYTON Upper Only	ESP (1984) PHYTOPLANKTON Upper Only	EPA (1972) PERIPHYTON Lower Only
Pithophora sp.		XX						
Planktosphaeria gelatinosa						XX		
Pleurotaenium sp.	XX							
Polyedriopsis spinulosa							XX	
Protoderma sp.		XX						
Quadriqula chordati						XX		
Rhizacolonium sp.	XX				XX			
Scenedesmus abundens				XX				
S. acuminatus			XX			XX	XX	
S. armatus				XX				
S. bicaudatus							XX	
S. bijua			XX	XX				
S. brasiliensis							XX	
S. denticulatus				XX		XX	XX	
S. quadricauda			XX	XX		XX	XX	
Scenedesmus sp.	XX	XX			XX			
Schroedaria setigera				XX				
Selenastrum minutum			XX	XX				
Sphaerocystis sp.		XX						
Spirogyra sp.								XX
Spondylosium sp.						XX		
Staurastrum orbiculare						XX		
S. punctatum						XX		
S. setigerum						XX		
Staurastrum sp.	XX		XX	XX				
Stigeoclonium sp.	XX							
Tetrahedron caudatum							XX	
T. minimum						XX		
T. plactonicum						XX		
T. trigonum						XX		
Tetrahedron sp.	XX	XX						
Tetrallantos lagerheimii						XX		

TAXA	DER PERIPHYTON ONLY (1984) Upper	DER PERIPHYTON ONLY (1984) Lower	SRSMD (1982-1984) PHYTOPLANKTON Upper	SRSMD (1982-1984) PHYTOPLANKTON Lower	EPA EIS (1978) PERIPHYTON Upper Only	ESP (1984) PERIPHYTON Upper Only	ESP (1984) PHYTOPLANKTON Upper Only	EPA (1972) PERIPHYTON Lower Only
Treubaria sp.				XX				
Trochiscia sp.	XX	XX						
Ulothrix sp.	XX	XX						
Uronema sp.		XX						
Zygnema sp.	XX							
Chrysophyta (non-diatom)								
Characiopsis sp.	XX	XX						
Dinobryon ehrenbergii							XX	
Lagynion reductum						XX		
Mallomonas majorensis							XX	
Mallomonas sp.						XX		
Ophiocytium sp.	XX							
Peroniella sp.	XX	XX						
Salpingoeca frequentissima						XX		
Stipitococcus vasiformis						XX		
Stipitococcus sp.	XX	XX						
Cryptophyta								
Chroomonas sp.						XX	XX	
Cryptomonas erosa				XX				
C. ovata			XX	XX				
Cryptomonas sp.	XX					XX	XX	
Cyanophyta								
Anabaena sp.	XX	XX	XX	XX		XX	XX	XX
Anabaenopsis sp.	XX							
Anacystis marina							XX	
Aphanocapsa sp.		XX						

TAXA	DER PERIPHYTON ONLY (1984) Upper	DER PERIPHYTON ONLY (1984) Lower	SRAMD (1982-1984) PHYTOPLANKTON Upper	SRAMD (1982-1984) PHYTOPLANKTON Lower	EPA ETS (1977) PERIPHYTON Upper Only	ESP 1984 PERIPHYTON Upper Only	ESP (1984) PHYTOPLANKTON Upper Only	EPA (1972) PERIPHYTON Lower Only
Aphanotheca sp.	XX							
Borzia sp.	XX							
Calothrix sp.	XX							
Chamaesiphon sp.	XX	XX						
Chlorogloea sp.		XX						
Chroococcus varius						XX	XX	
Chroococcus sp.	XX	XX						
Coeloshaerium sp.		XX						
Dactylococcopsis sp.	XX	XX						
Gloeotrichia sp.	XX	XX						
Gomphosphaeria sp.	XX					XX		
Lyngbya sp.	XX	XX					XX	
Merismopedium tenuissima				XX				
Merismopedium sp.		XX						
Microcystis incerta			XX	XX				
Microcystis sp.	XX	XX						
Nodularia sp.		XX						
Oscillatoria chlorina						XX		
O. geminata						XX	XX	
O. limnetica			XX	XX				
O. limosa							XX	
O. princeps							XX	
O. tenuis						XX	XX	
Oscillatoria sp.	XX	XX			XX	XX	XX	XX
Phormidium sp.	XX	XX						
Pseudanabaena sp.		XX						
Rhabdoderma sp.		XX						
Rhaphidiopsis curvata						XX		
Rhaphidiopsis sp.	XX	XX						
Rivularia sp.	XX							

TAXA	DER PERIPHYTON ONLY (1984) Upper	DER PERIPHYTON ONLY (1984) Lower	SFWMD (1982-1984) PHYTOPLANKTON Upper	SFWMD (1982-1984) PHYTOPLANKTON Lower	EPA ETS (1978) PERIPHYTON Upper Only	ESP (1984) PERIPHYTON Upper Only	ESP (1984) PHYTOPLANKTON Upper Only	EPA (1972) PERIPHYTON Lower Only
Spirulina genneri			XX	XX				
Spirulina sp.	XX	XX						
Stigonema sp.		XX						
Pyrrhophyta								
Gymnodinium sp.		XX						
Peridinium pusillum						XX		
Peridinium sp.	XX		XX	XX				
Euglenophyta								
Ascoglena sp.	XX	XX						
Colacium sp.	XX	XX						
Cryptomonas sp.	XX							
Euglena gracilis				XX			XX	
Euglena oxyurus			XX	XX				
Euglena sp.	XX	XX				XX	XX	XX
Lepocinclis sp.	XX			XX			XX	
Phacus curvicauda			XX	XX				
P. obicularis						XX	XX	
P. pleuronectes						XX	XX	
P. tortus						XX		
Phacus sp.	XX	XX			XX			
Trachelomonas glardiana			XX	XX				
T. hispida			XX	XX				
T. volvorina						XX		
Trachelomonas sp.	XX	XX						
Diatoms								
Centric								
Cyclotella atomus	XX							

TAXA	DER PERIPHYTON ONLY (1984) Upper	DER PERIPHYTON ONLY (1984) Lower	SFWMD (1982-1984) PHYTOPLANKTON Upper	SFWMD (1982-1984) PHYTOPLANKTON Lower	EPA EIS (1978) PERIPHYTON Upper Only	ESP (1984) PERIPHYTON Upper Only	ESP (1984) PHYTOPLANKTON Upper Only	EPA (1972) PERIPHYTON Lower Only
C. glomerata			XX	XX				
C. meneghiniana	XX	XX		XX	XX	XX		XX
C. stelligera					XX		XX	
Melosira distans						XX		
M. granulata						XX		
M. italica	XX	XX				XX	XX	
M. varians	XX	XX		XX	XX	XX		XX
Melosira sp.	XX	XX						
Stephanodiscus invisitatus	XX	XX						
Pennate								
Achnanthes affinis		XX						
A. clevei	XX	XX						XX
A. curvirostrum		XX						
A. delicatata		XX						
A. exigua		XX	XX	XX	XX			XX
A. hauckiana		XX				XX		
A. hungarica		XX						
A. hustedtii								XX
A. lanceolata		XX		XX		XX	XX	XX
A. linearis		XX						XX
A. marginulata								XX
A. minutissima		XX						XX
A. pinnata								XX
A. rupestoides		XX						
A. wellsiae		XX						
Achnanthes sp.		XX		XX		XX	XX	
Amphora ovalis	XX	XX						
A. perpusilla	XX							

TAXA	DER PERIPHYTON ONLY (1984)		SEMMD (1982-1984) PHYTOPLANKTON		EPA EIS (1978) PERIPHYTON	ESP (1984) PERIPHYTON	ESP (1984) PHYTOPLANKTON	EPA (1972) PERIPHYTON
	Upper	Lower	Upper	Lower	Upper Only	Upper Only	Upper Only	Lower Only
Amphora sp.		XX						XX
Amphipleura pellucida								XX
Asterionella formosa	XX		XX					
Asterionella sp.						XX		
Bacillaria paradoxa		XX						XX
Biddulphia laevitalis		XX						
Caloneis bacillum	XX	XX						
C. hyalina	XX							
C. limosa	XX							
Carpartogramma crucicula		XX	XX	XX	XX	XX	XX	
Cocconeis diminuta	XX	XX						
C. fluviatilis		XX	XX	XX				
C. placentula		XX				XX		XX
C. thumensis		XX						
Cocconeis sp.	XX	XX				XX	XX	
Cymbella aspera	XX	XX						
C. lunata	XX							
C. minuta		XX						
C. naviculiformis	XX							
C. tumida		XX						
C. turgida				XX				XX
Cymbella sp.		XX				XX		
Desmogonium rabenhorstanum	XX							
Diploneis interupta								XX
D. puella	XX		XX					
Diploneis sp.		XX					XX	
Epithemia adnata	XX							
E. argus						XX		
E. ocelata						XX		
E. proboscidea	XX							
E. turgida						XX		

TAXA	DER PERIPHYTON ONLY (1984)		SRAMD (1982-1984) PHYTOPLANKTON		EPA EIS (1978) PERIPHYTON	ESP (1984) PERIPHYTON	ESP (1984) PHYTOPLANKTON	EPA (1972) PERIPHYTON
	Upper	Lower	Upper	Lower	Upper Only	Upper Only	Upper Only	Lower Only
Eunotia elegans	XX							
E. faba	XX							
E. fallax	XX	XX						
E. fastigiata	XX							
E. flexuosa	XX					XX		
E. incisa	XX		XX					
E. levistrata	XX							
E. maior	XX	XX			XX		XX	
E. meisteri	XX	XX						
E. monodon	XX		XX					
E. naegellii	XX					XX		
E. pectinalis	XX	XX	XX			XX	XX	XX
E. perpusilla	XX							
E. parallelia	XX					XX		
E. sudetica						XX		
E. tautoniensis	XX							
E. tenella	XX							
E. trinacria	XX							
E. valida						XX		
E. vanheurckii	XX					XX	XX	
E. veneris	XX							
E. zasutensis						XX		
E. zygodon	XX							
Eunotia sp.	XX		XX	XX		XX		XX
Fragilaria construens	XX							XX
F. leptostauron	XX	XX						
F. virescens			XX					
Fragilaria sp.						XX	XX	
Frustulia rhomboides	XX		XX	XX		XX	XX	
Frustulia sp.	XX	XX			XX			
Gomphonema affine								

TAXA	DER PERIPHYTON ONLY (1984) Upper	DER PERIPHYTON ONLY (1984) Lower	SRMD (1982-1984) PHYTOPLANKTON Upper	SRMD (1982-1984) PHYTOPLANKTON Lower	EPA ELS (1978) PERIPHYTON Upper Only	ESP (1984) PERIPHYTON Upper Only	ESP (1984) PHYTOPLANKTON Upper Only	EPA (1972) PERIPHYTON Lower Only
G. angustatum		XX						
G. brasiliense		XX						
G. carolinese		XX						
G. clevei		XX						
G. gracile		XX						
G. parvulum		XX		XX				XX
Gomphonema sp.		XX		XX		XX		
Gyrosigma acuminatum		XX		XX				
G. spencerii		XX						
Gyrosigma sp.		XX			XX	XX		
Hantzchia amphioxys		XX						
H. virgata	XX	XX						
Meridion circulare		XX		XX				
Monoraphidium sp.							XX	
Navicula aikenensis								XX
N. arvensis		XX						
N. apiculatum				XX				
N. bacillus								XX
N. bicnica								XX
N. capitata		XX						
N. cinta		XX						
N. cryptocephala								XX
N. cocconeiformis		XX						
N. contenta		XX						
N. crucicula								XX
N. cuspidata		XX						
N. disputans				XX				
N. dystrophica		XX						
N. elginensis			XX	XX	XX	XX		
N. exigua	XX	XX						
N. fossalis								XX

TAXA	DER PERIPHYTON ONLY (1984) Upper	DER PERIPHYTON ONLY (1984) Lower	SRAMD (1982-1984) PHYTOPLANKTON Upper	SRAMD (1982-1984) PHYTOPLANKTON Lower	EPA EIS (1978) PERIPHYTON Upper Only	ESP (1984) PERIPHYTON Upper Only	ESP (1984) PHYTOPLANKTON Upper Only	EPA (1972) PERIPHYTON Lower Only
N. gastrum		XX						
N. gottlandica		XX						
N. graciloides		XX						XX
N. gregaria		XX						
N. gysingensis		XX						XX
N. hungarica								XX
N. lanceolata		XX			XX	XX		XX
N. minuscula	XX	XX						
N. mutica	XX	XX						
N. notha					XX	XX		XX
N. paucivisitata		XX						
N. pellicolosa		XX						
N. placentula				XX				
N. pupula		XX						XX
N. radiosa		XX						
N. rhychocephala		XX						XX
N. salinarum		XX						
N. schroeteri		XX						
N. subtilissima		XX						
N. tripunctata		XX						XX
N. viridula		XX				XX		XX
Navicula sp.	XX	XX						
Neidium affine		XX						
N. apiculatum	XX	XX	XX	XX				
N. iridis		XX						
N. ladogense		XX						
Neidium sp.	XX	XX						
Nitzchia accomodata	XX	XX						XX
N. acicularis		XX						
N. amphioxoides		XX						
N. amphibia		XX						XX

TAXA	DER PERIPHYTON ONLY (1984) Upper	DER PERIPHYTON ONLY (1984) Lower	SRWD (1982-1984) PHYTOPLANKTON Upper	SRWD (1982-1984) PHYTOPLANKTON Lower	EPA EIS (1978) PERIPHYTON Upper Only	ESP (1984) PERIPHYTON Upper Only	ESP (1984) PHYTOPLANKTON Upper Only	EPA (1972) PERIPHYTON Lower Only
N. bacata								XX
N. capitella								XX
N. confinis								XX
N. dissipata							XX	
N. filiformes		XX						
N. fonticola		XX					XX	
N. gracilis				XX				
N. ignorata		XX						
N. lorenziana	XX							
N. obtusa		XX	XX	XX	XX	XX	XX	XX
N. palea		XX						
N. parvula		XX						
N. sigma	XX							
N. thermalis	XX	XX				XX		
Nitzchia sp.		XX						
Opephora martyi	XX							
Pinnularia acrosphaeria	XX							
P. biceps		XX						
P. borealis	XX	XX						
P. brauni		XX				XX		
P. brebissonii	XX							
P. divergens	XX							
P. mesolepta	XX	XX						XX
P. nobosa	XX						XX	
P. parva	XX							
P. subcapitata	XX		XX		XX	XX	XX	
P. viridis	XX							
Pinnularia sp.	XX							
Rhopelodia gibba	XX							
R. gibberula	XX							
R. musculus								

TAXA	DER PERIPHYTON ONLY (1984)		SFWMD (1982-1984) PHYTOPLANKTON		EPA EIS (1978) PERIPHYTON	ESP (1984) PERIPHYTON	ESP (1984) PHYTOPLANKTON	EPA (197[illegible] PERIPHYTON
	Upper	Lower	Upper	Lower	Upper Only	Upper Only	Upper Only	Lower Only
Rhopalodia sp.						XX		
Stauroneis anceps		XX						
S. livingstonii	XX	XX						
S. smithii		XX						
Stauroneis sp.	XX	XX						
Surirella angustata	XX	XX		XX		XX		
S. atomus								XX
S. biseriata						XX		
S. linearis	XX	XX	XX					
S. patella						XX		
S. robusta			XX					
S. tenera		XX						
Surirella sp.	XX	XX		XX		XX		
Synedra acus		XX	XX					
S. fasciculata		XX						
S. gaillonii		XX						
S. goulardi			XX					
S. parasitica		XX	XX	XX				
S. pulchella		XX						
S. rumpens		XX						
S. ulna	XX	XX		XX	XX	XX		XX
Synedra sp.	XX	XX		XX		XX		
Tabellaria sp.			XX			XX		
Terpsinoe americana		XX						

APPENDIX E

CHRONIC BIOASSAY DATA

APPENDIX E.

Assay #2 - Notropis leedsi hatching data - 11/4/82-11/12/82.

Treatment Concentration %	Number Eggs at Start	% Hatch	Mean pH	Mean Alkalinity (mg/l)	Mean Hardness (mg/l)	Mean Conductivity (umho)
0	20	0	4.63	0	13	48
0	20	0	4.63	0	13	48
12	20	0	5.15	-	-	72
12	20	0	5.15	-	-	72
25	20	90	5.89	-	-	122
25	20	100	5.89	-	-	122
50	20	100	6.50	-	-	237
50	20	95	6.50	-	-	237
100	20	90	6.74	57	187	521
100	20	75	6.74	57	187	521

Assay #3 - Notropis leedsi hatching data - 11/18/82 - 11/29/82.

Treatment Concentration %	Number Eggs at Start	% Hatch	Mean pH	Mean Alkalinity (mg/l)	Mean Hardness (mg/l)	Mean Conductivity (umho)
0	40	0	4.50	5	13	-
0	40	0	4.50	5	13	-
12	40	0	5.00	-	-	-
12	40	0	5.00	-	-	-

Assay #4 - Notropis leedsi hatching data - 3/24/83 - 4/4/83.

Treatment Concentration %	Number Eggs at Start	% Hatch	Mean pH	Mean Alkalinity (mg/l)	Mean Hardness (mg/l)	Mean Conductivity (umho)
0	20	00	5.78	8	17	47
0	20	00	5.78	8	17	47
12	20	10	5.86	11	25	73
12	20	10	5.86	11	25	73
25	20	60	6.12	11	35	113
25	20	40	6.12	11	35	113
50	20	30	6.38	12	52	162
50	20	20	6.38	12	52	162
100	20	25	6.60	15	99	282
100	20	40	6.60	15	99	282
*	20	80	8.05	121	114	212
*	20	75	8.05	121	114	212

* = DER wellwater control

NOTE: Notropis leedsi Assay #1, 10/28/82 - 11/2/82, abandoned after 3 days due to control mortality.

TABLE . Assay #5 - Notropis leedsi hatching data - 5/24/83 - 6/3/83.

Treatment Concentration %	Number Eggs at Start	% Hatch	Mean pH	Mean Alkalinity (mg/l)	Mean Hardness (mg/l)	Mean Conductivity (umho)
0	32	40	6.66	11	20	48
0	32	50	6.66	11	20	48
12	32	68	6.73	12	30	89
12	32	56	6.73	12	30	89
25	32	62	6.76	18	39	128
25	32	78	6.76	18	39	128
50	32	71	6.93	22	63	192
50	32	87	6.93	22	63	192
100	32	93	6.64	32	118	335
100	32	75	6.64	32	118	335
*	32	90	8.10	116	115	212
*	32	-	8.10	-	-	-

* = DER wellwater control

Assay #6 - Notropis leedsi hatching data - 8/2/83 - 8/12/83.

Treatment Concentration %	Number Eggs at Start	% Hatch	Mean pH	Mean Alkalinity (mg/l)	Mean Hardness (mg/l)	Mean Conductivity (umho)
0	18	55	5.88	24	30	63
0	18	38	5.88	24	30	63
12	19	68	6.88	26	48	123
12	16	75	6.88	26	48	123
25	18	61	7.02	32	67	178
25	18	77	7.02	32	67	178
50	19	78	7.04	37	93	288
50	20	70	7.04	37	93	288
100	18	77	7.16	47	164	553
100	20	90	7.16	47	164	553
*	19	84	7.92	120	111	213
*	20	85	7.92	120	111	213

* = DER wellwater control

Assay #7 - Notropis leedsi hatching data - 8/2/83 - 8/12/83.

Treatment Concentration %	Number Eggs at Start	% Hatch	Mean pH	Mean Alkalinity (mg/l)	Mean Hardness (mg/l)	Mean Conductivity (umho)
0	20	70	6.19	15	18	50
0	20	55	6.19	15	18	50
12	18	38	6.12	11	31	117
12	19	47	6.12	11	31	117
25	17	52	6.25	16	52	208
25	20	40	6.25	16	52	208
50	20	90	6.80	26	83	300
50	20	65	6.80	26	83	300
100	17	70	7.20	46	163	550
100	20	90	7.20	46	163	550

Assay #8 - Notropis leedsi hatching data - 8/18/83 - 8/29/83.

Treatment Concentration %	Number Eggs at Start	% Hatch	Mean pH	Mean Alkalinity (mg/l)	Mean Hardness (mg/l)	Mean Conductivity (umho)
0	45	75	5.85	13	18	54
0	45	46	5.85	13	18	54
12	45	93	6.43	19	34	111
12	45	68	6.43	19	34	111
25	45	77	6.85	25	49	168
25	45	53	6.85	25	49	168
50	45	75	7.01	33	77	283
50	45	64	7.01	33	77	283
100	45	84	7.20	53	155	558
100	45	82	7.20	53	155	558
*	45	86	7.82	126	108	228
*	45	86	7.82	126	108	228

* = DER wellwater control

Assay #9 - Notropis leedsi hatching data - 8/18/83 - 8/29/83.

Treatment Concentration %	Number Eggs at Start	% Hatch	Mean pH	Mean Alkalinity (mg/l)	Mean Hardness (mg/l)	Mean Conductivity (umho)
0	45	60	6.00	11	16	51
0	45	84	6.00	11	16	51
12	45	75	5.99	12	25	103
12	45	68	5.99	12	25	103
25	45	64	5.85	11	44	165
25	45	73	5.85	11	44	165
50	45	84	6.50	29	78	292
50	45	86	6.50	29	78	292
100	45	88	7.24	48	152	562
100	45	88	7.24	48	152	562

NOTE: Notropis leedsi Assay #10, 10/10/83 - 10/13/83 abandoned due to mercury contamination from broken thermometer.

Assay #11 - Notropis leedsi hatching data - 10/13/83 - 10/24/83.

Treatment Concentration %	Number Eggs at Start	% Hatch	Mean pH	Mean Alkalinity (mg/l)	Mean Hardness (mg/l)	Mean Conductivity (umho)
0	20	70	6.27	14	16	56
0	20	70	6.27	14	16	56
12	20	70	6.38	15	27	96
12	20	55	6.38	15	27	96
25	20	45	6.55	20	47	133
25	20	45	6.55	20	47	133
50	20	85	7.05	39	78	232
50	20	75	7.05	39	78	232
100	20	75	7.46	75	164	411
100	20	95	7.46	75	164	411
*	20	25	7.85	126	113	227
*	20	60	7.85	126	113	227

* = DER wellwater control

Assay #12 - Notropis leedsi hatching data - 11/9/83 - 11/18/83.

Treatment Concentration %	Number Eggs at Start	% Hatch	Mean pH	Mean Alkalinity (mg/l)	Mean Hardness (mg/l)	Mean Conductivity (umho)
0	20	80	6.44	12	16	69
0	20	85	6.44	12	16	69
12	20	90	6.54	16	24	101
12	20	85	6.54	16	24	101
25	20	85	6.54	18	41	142
25	20	75	6.54	18	41	142
50	20	75	6.91	34	86	259
50	20	65	6.91	34	86	259
100	20	85	7.36	71	180	451
100	20	80	7.36	71	180	451
*	20	90	7.72	121	115	115
*	20	100	7.72	121	115	115

* = DER wellwater control

Assay # 13 - Notropis leedsi hatching data - 11/17/83 - 11/25/83.

Treatment Concentration %	Number Eggs at Start	% Hatch	Mean pH	Mean Alkalinity (mg/l)	Mean Hardness (mg/l)	Mean Conductivity (umho)
*	15	86	7.89	120	121	235
*	15	93	7.89	120	121	235
6	15	60	8.00	122	110	251
6	15	80	8.00	122	110	251
12	15	80	8.00	116	115	262
12	15	53	8.00	116	115	262
25	15	73	8.00	110	118	291
25	15	80	8.00	110	118	291
50	15	60	7.90	95	125	341
50	15	80	7.90	95	125	341
100	15	86	7.80	65	170	449
100	15	60	7.80	65	170	449

* = DER wellwater control

Assay #14 - Notropis leedsi hatching data - 1/3/84 - 1/15/84.

Treatment Concentration %	Number Eggs at Start	% Hatch	Mean pH	Mean Alkalinity (mg/l)	Mean Hardness (mg/l)	Mean Conductivity (umho)
*	25	88	8.00	134	120	224
*	25	96	8.00	134	120	224
6	25	92	7.93	114	115	230
6	25	72	7.93	114	115	230
12	25	96	7.75	106	119	238
12	25	72	7.75	106	119	238
25	25	68	7.68	99	121	250
25	25	84	7.68	99	121	250
50	25	92	7.40	69	126	278
50	25	76	7.40	69	126	278
100	25	72	6.55	20	137	385
100	25	60	6.55	20	137	385

* = DER wellwater control

Assay #15 -- Notropis leedsi hatching data - 1/17/84 - 1/27/84.

Treatment Concentration %	Number Eggs at Start	% Hatch	Mean pH	Mean Alkalinity (mg/l)	Mean Hardness (mg/l)	Mean Conductivity (umho)
0	16	87	6.29	12	14	54
0	16	68	6.29	12	14	54
6	16	56	6.43	15	19	89
6	16	87	6.43	15	19	89
12	16	81	6.33	15	26	120
12	16	75	6.33	15	26	120
25	16	68	6.11	16	46	180
25	16	68	6.11	16	46	180
50	16	62	5.95	16	79	285
50	16	56	5.95	16	79	285
100	16	62	6.43	26	144	488
100	16	87	6.43	26	144	488

Assay #2 - Notropis leedsi fry data - 11/13/82-11/29/82.

Treatment Concentration %	Number Fry at Start	% Survival	Mean pH	Mean Alkalinity (mg/l)	Mean Hardness (mg/l)	Mean Conductivity (umho)
0	-	-	-	-	-	-
0	-	-	-	-	-	-
12	-	-	-	-	-	-
12	-	-	-	-	-	-
25	18	94	5.3	-	-	122
25	20	80	5.3	-	-	122
50	20	90	5.8	-	-	237
50	19	100	5.8	-	-	237
100	18	88	6.7	66	173	521
100	15	100	6.7	66	173	521

Assay #5 - Notropis leedsi fry data - 6/4/83 - 6/22/84.

Treatment Concentration %	Number Fry at Start	% Survival	Mean pH	Mean Alkalinity (mg/l)	Mean Hardness (mg/l)	Mean Conductivity (umho)
0	14	92	6.3	13	23	51
0	14	64	6.3	13	23	51
12	14	78	6.5	15	31	87
12	14	78	6.5	15	31	87
25	14	64	6.5	18	40	121
25	14	92	6.5	18	40	121
50	14	85	6.7	24	64	198
50	14	85	6.7	24	64	198
100	14	85	6.9	37	121	356
100	14	85	6.9	37	121	356
*	14	85	8.4	112	116	234
*	-	-	-	-	-	-

* = DER wellwater control

Assay #12 - Notropis leedsi fry data - 11/19/83 - 12/7/83.

Treatment Concentration %	Number Fry at Start	% Survival	Mean pH	Mean Alkalinity (mg/l)	Mean Hardness (mg/l)	Mean Conductivity (umho)
0	13	76	6.7	17	11	78
0	13	59	6.7	17	11	78
12	13	92	6.6	18	24	120
12	13	92	6.6	18	24	120
25	13	76	6.6	18	41	160
25	13	76	6.6	18	41	160
50	13	76	6.9	31	84	268
50	13	92	6.9	31	84	268
100	13	100	7.3	62	160	449
100	13	100	7.3	62	160	449
*	13	100	7.9	121	106	242
*	13	92	7.9	121	106	242

* = DER wellwater control

Assay #13 - Notropis leedsi fry data - 11/26/83 - 12/15/83.

Treatment Concentration %	Number Fry at Start	% Survival	Mean pH	Mean Alkalinity (mg/l)	Mean Hardness (mg/l)	Mean Conductivity (umho)
*	13	69	8.0	125	105	242
*	14	64	8.0	125	105	242
6	10	70	8.0	115	107	254
6	11	63	8.0	115	107	254
12	10	80	8.0	111	111	269
12	10	90	8.0	111	111	269
25	11	72	7.9	108	118	296
25	12	66	7.9	108	118	296
50	10	60	7.8	89	130	341
50	11	81	7.8	89	130	341
100	11	81	7.4	56	161	439
100	11	63	7.4	56	161	439

* = DER wellwater control

Assay #14 - Notropis leedsi fry data - 1/16/84 - 2/14/84.

Treatment Concentration %	Number Fry at Start	% Survival	Mean pH	Mean Alkalinity (mg/l)	Mean Hardness (mg/l)	Mean Conductivity (umho)
*	16	68	8.0	124	101	216
*	16	62	8.0	124	101	216
6	16	75	8.0	115	101	230
6	16	75	8.0	115	101	230
12	16	37	7.8	109	103	246
12	16	81	7.8	109	103	246
25	16	81	7.6	93	109	275
25	16	87	7.6	93	109	275
50	16	75	7.2	67	122	335
50	16	75	7.2	67	122	335
100	16	62	6.3	19	141	454
100	16	68	6.3	19	141	454

* = DER wellwater control

Assay #15 - Notropis leedsi fry data - 1/28/84 - 2/14/84.

Treatment Concentration %	Number Fry at Start	% Survival	Mean pH	Mean Alkalinity (mg/l)	Mean Hardness (mg/l)	Mean Conductivity (umho)
0	11	63	6.2	14	6	52
0	11	90	6.2	14	6	52
6	11	90	6.3	16	18	72
6	11	90	6.3	16	18	72
12	11	90	6.1	14	22	97
12	11	81	6.1	14	22	97
25	11	72	5.8	11	31	148
25	11	90	5.8	11	31	148
50	10	80	5.6	9	64	258
50	9	66	5.6	9	64	258
100	11	90	6.2	19	123	450
100	11	90	6.2	19	123	450

Notropis leedsi % hatch data, pH corrected.
(Diluent control is indicated by *.)

Assay Number	Well Water Control	Suwannee Control	6%	12%	25%	50%	100%
2	---	0.0*	---	186.8	184.0	112.7	93.3
3	---	0.0*	---	0.0	---	---	---
4	86.8	0.0*	---	20.7	68.6	29.7	37.1
5	101.5	51.5*	---	70.7	79.4	89.6	96.0
6	94.8	93.5*	---	80.7	78.0	84.7	94.1
7	---	81.0*	---	59.1	58.0	87.4	90.0
8	97.1	129.7*	---	95.0	73.8	78.6	93.4
9	---	114.4*	---	116.2	146.2	98.9	99.6
11	47.6	86.6*	---	74.1	51.6	89.8	95.2
12	106.4	96.4*	---	100.6	91.9	78.7	92.4
13	100.8*	---	78.4	74.7	85.9	78.4	82.1
14	103.0*	---	91.8	94.1	85.1	94.1	75.7
15	---	95.7*	84.2	94.2	95.2	102.2	87.8