



Arkansas Water Resources Center

ALGAL GROWTH POTENTIALS AND HEAVY METAL CONCENTRATIONS OF THE PRIMARY STREAMS TO UPPER BEAVER LAKE

By

Richard L. Meyer and W. Reed Green, Department of Botany &
Microbiology and Kenneth F. Steele and Diana Wickliff, Department of Geology,
University of Arkansas, Fayetteville, Arkansas 72701

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Richard L. Meyer and W. Reed Green
Department of Botany & Microbiology
and
Kenneth F. Steele and Diana Wickliff
Department of Geology
University of Arkansas
Fayetteville, AR 72701

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Arkansas Water Resources Research Center
University of Arkansas
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ABSTRACT

ALGAL GROWTH POTENTIALS AND HEAVY METAL CONCENTRATIONS OF THE PRIMARY STREAMS TO UPPER BEAVER LAKE

Meyer and Green (1984) demonstrated the probable inhibition of algal growth potential by heavy metals in upper Beaver Lake. Upper Beaver Lake receives water from three tributaries. One contains a small reservoir and the combined streams receive sewage input. Collections were made approximately monthly at eight sites for the Algal Assay Bottle Test (AABT) and heavy metal analysis.

In general, AABT results indicated that the collections above the sewage input were phosphorus limited while those below were nitrogen or combined nitrogen and phosphorus limited. Growth inhibition occurred during summer and early fall at various sites with greater inhibition at the confluence of the streams. No inhibitions occurred at the site below the sewage input.

Heavy metal concentrations had an overall tendency to increase downstream. Values within the small reservoir were 50-100% higher than in the feeder stream. Highest values of Pb were observed below the reservoir. SO_4 , Cl, Mg, Ca, Na and K had high values during low flow in August-October. The low values were independent of high flow. Pb followed an independent pattern. Storm event results showed that the Ca maximum was before the hydrographic peak while Fe, Mn, Pb, Zn, Co, Ni, Cu and Cd attained their maximum just after the peak. Maximum values were 4-10 times background values. Mn, Pb and Fe exceeded EPA recommended standards for drinking water.

Richard L. Meyer, W. Reed Green, Kenneth F. Steele and Diana Wickliff

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TABLE OF CONTENTS

	Page
Abstract	i
List of Figures	iii
List of Appendix Tables	v
Acknowledgements	vi
Introduction	1
A. Purpose and Objectives	4
B. Related Research or Activities.	5
Methods and Procedures	6
Principal Findings and Significance	11
Conclusions	54
Literature Cited	57
Appendix Tables	59

LIST OF FIGURES

		Page
Figure 1.	Location of Sampling Sites. All Samples were Collected Upstream of Bridges Except for DM which was Collected at the Dam on Lake Sequoyah.	7
Figure 2.	Downstream Variation in Manganese Concentration, August 21, 1985.	13
Figure 3.	Plot of Calcium Concentration, Specific Conductivity and Stream Flow versus Hours After Initiation of Rain for the First Rain Event.	16
Figure 4.	Plot of Sodium and Magnesium Concentrations, and Stream Flow versus Hours After Initiation of Rain for the First Rain Event.	18
Figure 5.	Plot of Nitrate, Ammonium and Orthophosphate Concentrations versus Hours After Initiation of Rain for the First Rain Event.	19
Figure 6.	Plot of Iron Concentration and Stream Flow versus Hours After Initiation of Rain for the First Rain Event.	21
Figure 7.	Plot of Manganese, Lead and Zinc Concentrations versus Hours After Initiation of Rain for the First Rain Event.	22
Figure 8.	Plot of Calcium Concentration, Specific Conductivity and Stream Flow versus Hours After Initiation of Rain for the Second Rain Event.	25
Figure 9.	Plot of Sulfate Concentration and Stream Flow versus Hours After Initiation of Rain for the First Rain Event.	26
Figure 10.	Plot of Sulfate Concentration and Stream Flow versus Hours After Initiation of Rain for the Second Rain Event.	27
Figure 11.	Plot of Nitrate, Ammonium and Orthophosphate Concentrations versus Hours After Initiation of Rain for the Second Rain Event.	28
Figure 12.	Plot of Manganese, Lead and Zinc Concentrations versus Hours After Initiation of Rain for the Second Rain Event.	30

LIST OF FIGURES (Cont.)

	Page
Figure 13. West Fork Baptist Ford Summer and Early Fall Maximum Standing Crop.	33
Figure 14. West Fork Baptist Ford Late Fall and Winter Maximum Standing Corp.	34
Figure 15. Middle Fork Highway 16 Summer and Early Fall Maximum Standing Crop.	35
Figure 16. Middle Fork Highway 16 Late Fall and Winter Maximum Standing Crop.	36
Figure 17. East Fork Highway 74 Summer and Early Fall Maximum Standing Crop.	37
Figure 18. East Fork Highway 74 Late Fall and Winter Maximum Standing Crop.	38
Figure 19. Lake Sequoyah Dam Summer and Early Fall Maximum Standing Crop.	39
Figure 20. Lake Sequoyah Dam Late Fall and Winter Maximum Standing Crop.	40
Figure 21. White River Iron Bridge Summer and Early Fall Maximum Standing Crop.	41
Figure 22. White River Iron Bridge Late Fall and Winter Maximum Standing Crop.	42
Figure 23. White River Wyman Bridge Summer and Early Fall Maximum Standing Crop.	43
Figure 24. White River Wyman Bridge Late Fall and Winter Maximum Standing Crop.	44
Figure 25. White River Highway 45 Bridge Summer and Early Fall Maximum Standing Crop.	45
Figure 26. White River Highway 45 Bridge Late Fall and Winter Maximum Standing Crop.	46
Figure 27. White River Highway 68 Bridge Summer and Early Fall Maximum Standing Crop.	47
Figure 28. White River Highway 68 Bridge Late Fall and Winter Maximum Standing Crop.	48

LIST OF APPENDIX TABLES

	Page
Table 1. Summary of Analytical Methods and Precision	60
Table 2. Field and Selected Laboratory Analysis for White River Samples	61
Table 3. Seasonal Heavy Metal Analysis for All Sites and Stream Flow Data for Site IB	66
Table 4. Stream Flow, Field Measurements and Cation Analysis for First Rain Event	70
Table 5. Anion and Ammonium-N Analysis for First Rain Event .	71
Table 6. Heavy Metal Analysis for First Rain Event	72
Table 7. Comparison of the Effect of Different Pore-Sized Membranes on the Heavy Metal Concentrations of Filtered Stream Samples	73
Table 8. Stream Flow, Field Measurements and Cation Analysis for Second Rain Event	74
Table 9. Anion, Ammonium-N and Silica Analyses for Second Rain Event.	75
Table 10. Heavy Metal Analyses for Second Rain Event	76
Table 11. Maximum Standing Crop	77
Table 12. Chemical Characteristics and Calculated Production Yields for Predicted Phosphorus Limited Samples . . .	81
Table 13. Chemical Characteristics and Calculated Production Yields for Predicted Nitrogen Limited Samples	84
Table 14. Chemical Characteristics and Calculated Production Yields for Predicted Nitrogen and Phosphorus Co-limited Samples	84
Table 15. Assay Derived Limiting Nutrient Influence	85
Table 16. Algal Growth Inhibition of Samples with Greater Than 50% Inhibition of NP vs. NPE and Corresponding Sample Test	86
Table 17. Bioavailable Nutrients With and Without the Influence of EDTA	87
Table 18. Percent Inhibition Indicated by the Test Treatments With and Without EDTA	91

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INTRODUCTION

The Selenastrum capricornutum Printz Algal Assay Bottle Test (AABT), (Miller et al., 1978a) has been developed: (1) to determine the nutrient status of a natural body of water and its sensitivity to changes in nitrogen and phosphorus loadings; (2) to evaluate the introduction of waste materials or products and determine their potential stimulatory or inhibitory effects on algal growth; and (3) to define the impact and the effects of introduced complex wastes originating from industrial, municipal, and agricultural point and non-point sources. It is intended to be used: (1) to identify algal growth-limiting nutrients; (2) to determine biologically the availability of algal growth-limiting constituents; and (3) to quantify the biological response to changes in concentrations of algal growth-limiting constituents.

The test procedure is based upon a modification of "Liebig's Law of the Minimum", which in theory states that the maximum growth yield produced by an organism is proportional to the amount of a nutrient or combination of nutrients which are present and biologically available in minimum quantity in respect to the growth requirements of the organism involved (Miller et al., 1978a).

The AABT is a familiar tool used by water management and related institutions for the assessment of multiple use bodies of water. Research involved with this test is primarily directed towards problematic and stressed aquatic ecosystems. Numerous laboratory and field studies have been conducted in association with the development

and application of this procedure and protocol. A detailed bibliography of this research up to 1978 is presented by Leischman et al. (1979).

Nutrient requirements for the algal test organism (S. capricornutum) has been conducted by Shiroyama et al. (1973). When essential nutrients are present at sufficient levels, the growth of S. capricornutum will define the amount of nitrogen and phosphorus biologically available within the test water.

In addition, the AABT procedure can define the biological reactive status and influence of heavy metals that might inhibit algal growth (Miller et al., 1978a, 1978b). Rai et al. (1981) discuss the function of heavy metals as essential trace elements necessary for algal growth and the influence of high concentrations of these chemicals upon growth inhibition and toxicity. High concentrations of heavy metals not only inhibit algal growth, but also reduces indigenous algal diversity. This reduction results in the economically and environmentally dominance of the most tolerant forms, most of which are undesirable greens and blue-greens.

However, the application of the AABT and the inhibited growth response of S. capricornutum may not necessarily reflect the growth potential of the indigenous algae which have adapted to these conditions through long-term exposure of such (Miller et al., 1978b). Greene et al. (1978) found strong correlations between the EDTA treatments with the combination of nitrogen and phosphorus, and that of the indigenous standing crop measured by chlorophyll-a. Eloranta

and Halttunen-Keyrilainen (1984) determined that the results of the AABT are more sensitive to heavy metal influence than assays conducted with inoculations from natural phytoplankton samples.

Quantitative determinations of heavy metal inhibitory effects upon the growth of S. capricornutum have been reported by Greene et al. (1975); Christensen and Scherfig (1979); and Michnowicz and Weaks (1984). Specific conductance and pH function in the regulation of biologically reactive heavy metal concentrations. Synergistic and antagonistic interactions can occur with the combination of high concentrations of these chemicals. The presence of high concentrations of heavy metals as determined by chemical analysis, may or may not influence cell growth. Only biological response analysis can determine the influence of heavy metal concentrations (Miller et al., 1978b).

Miller et al. (1974) used the AABT to determine the limiting nutrient in a number of waters. They found that phosphorus limitation decreased as the trophic status of the test water increased. As the phosphorus concentrations increased, the test water became more likely to be nitrogen limited. Davis and DeCosta (1980) found that all waters in their study were phosphorus limited and that toxic factors such as heavy metals were not important factors controlling algal important factors controlling algal growth. The AABT procedure was used by Ram and Plotkin (1983) to assess the influence of municipal and industrial waste discharges and the removal of phosphorus along a heavily used river system. These test waters were nitrogen

limited below the discharge sites. It was determined that the removal of phosphorus would not change the nutrient status of these waters.

A. Purpose and Objectives

The protocol of this study was designed to determine the source of the heavy metals causing the algal growth inhibition discovered by Meyer and Green (1984) in upper Beaver Lake. Specifically, the research focused upon the distinct differences in the three primary streams feeding into the upper lake. The eastern stream is bordered by forest and farm land. The middle stream includes an impoundment which may effect heavy metal concentrations. The western stream receives the urban runoff from the villages of West Fork and Greenland and the moderate-sized city of Fayetteville. All three streams drain areas with exposed shales with known concentrations of iron (and other heavy metals) and sulfide ions. The combined streams receive the effluent from the city. The industry located along the streams and the industry within the city may be sources of heavy metals.

The research protocol was structured to permit the determination of the background level of heavy metals from natural origins and the contribution by each tributary. The inclusion of Lake Sequoyah provides some insight into the influence of a small impoundment on heavy metal distribution. The post sewage outfall results indicate the influence of urban runoff and domestic/industrial wastes. Two reservoir sampling stations are used to estimate the total input influence

and assimilation within the lake.

B. Related Research or Activities

Meyer and Green (1984) conducted an AABT study within the body of water of the present research. It was found that nitrogen was the limiting nutrient directly below the municipal waste discharge site. The test water gradually became phosphorus limited further downstream. Storm events accelerated water flow which influenced nutrient limitation downstream. The presence of heavy metal inhibition of algal growth was determined in a number of samples during different seasons and associated with a storm event.

The results of the past study (Meyer and Green, 1984), led to the development and application of the present study. One of the objectives of the present study is to better resolve the influence of industrial and municipal wastes discharged from the City of Fayetteville's sewage treatment plant. This plant is located in the upper reaches of Beaver Lake Reservoir. Upstream from the treatment plant are the confluences of the three tributaries of the White River and a small impoundment (Lake Sequoyah). Objectives also include the determination of nutrient and heavy metal influence upon algal growth, contributed by these bodies of water.

The White River, along which the sewage treatment plant is located, and the three forks of the White River make up over 80% of the drainage basin of Beaver Lake. Beaver Lake is a multi-use reservoir and supplies the drinking water to the majority of the population and institutions in northwest Arkansas. Quantitative and quali-

tative determinations of nutrient limitation, growth potential and growth inhibition within this system will provide water management basic data to determine future strategies.

METHODS AND PROCEDURES

Physical and Chemical Procedures and Parameters

Samples were collected approximately monthly from May, 1985 through April, 1986 from eight sites on the White River at least three days after a major rain. The west, middle and main stream of the White River were sampled above Lake Sequoyah at the bridges at Baptist Ford (BF), Highway 16 (16) and Highway 74 (74), respectively. Samples also were collected at Lake Sequoyah Dam (DM) and Iron Bridge (IB) near Baldwin, Wymann Bridge (WB) near Wymann, the bridge on Highway 45 (45) near Goshen and at the bridge on Highway 68 (68) near Pleasant Valley on the White River (Figure 1). Samples also were collected at IB during two rain storm events in September and October, 1985. Temperature, pH, conductivity and total alkalinity were determined in the field on raw water samples (Table 1).

Collections were divided into "heavy metal" and "algal" subsets. Two 500 ml "heavy metal" samples were filtered through a 0.40 micrometer pore-size membrane using a freon-pressurized unit and stored in plastic bottles that had been prewashed with nitric acid. One sample was acidified with 1.5 ml of 1:1 nitric acid for cation analyses in the laboratory. The other 500 ml sample was refrigerated for anion, ammonia and silica analyses at the laboratory. The "algal" subset samples were placed on ice and filtered in the labora-

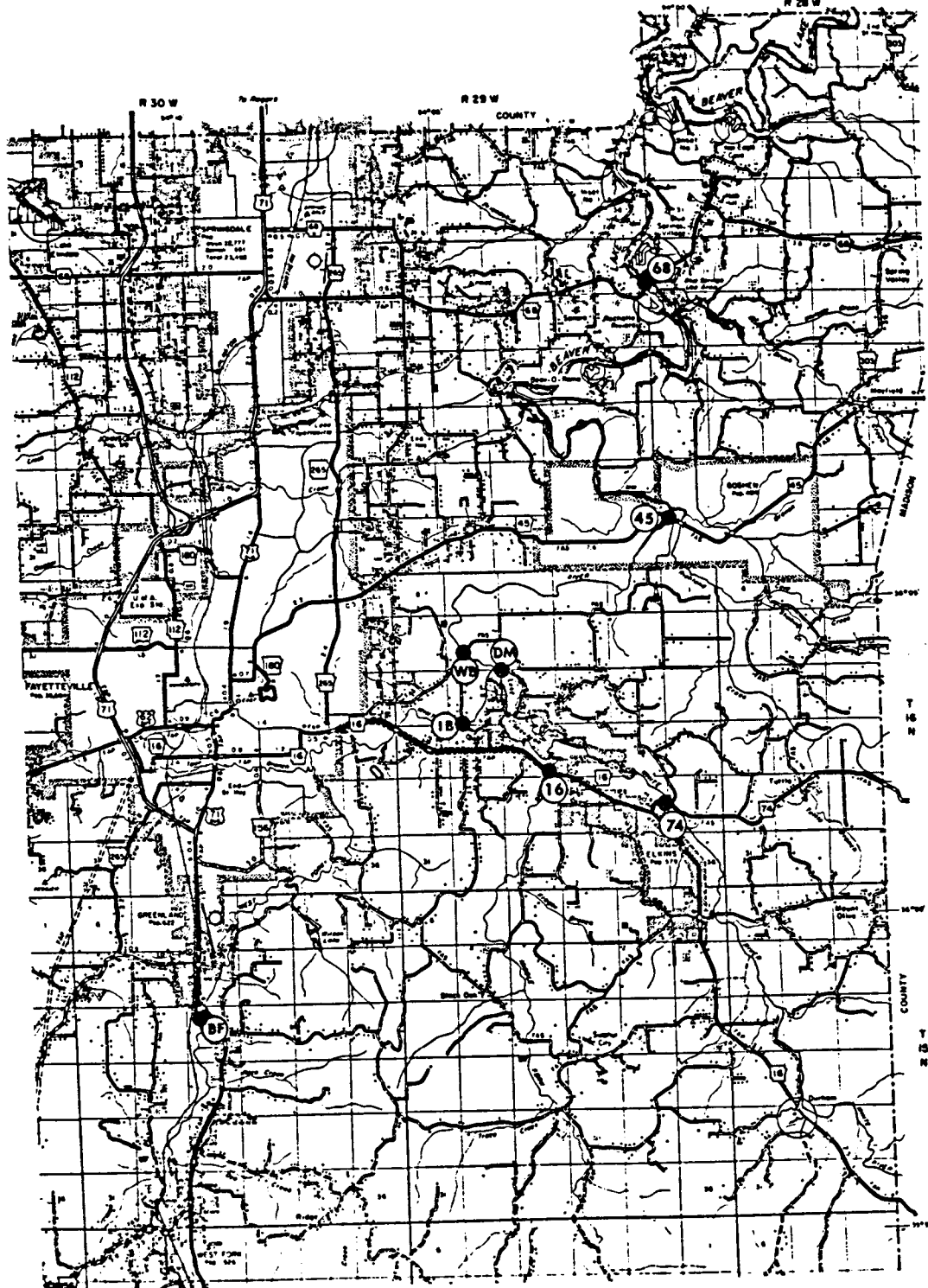


Figure 1. Location of sampling sites. All samples were collected upstream of bridges except for DM which was collected at the dam on Lake Sequoyah.

tory through Schleicher & Schuell #30 filters prior to nutrient analysis and inoculation.

U. S. Environmental Protection Agency (EPA, 1983), American Public Health Association (APHA, 1985) and Hach Chemical Company (1984) methods were used for analyses of the "heavy metal" subset samples. However, the chelation-extraction method of Nix and Goodwin (1974) was used for heavy metal analyses. See Table 2 for specific methods and precision for each analysis.

Chemical analysis for the "algal" subset included determinations of nitrate-nitrogen, nitrite-nitrogen, ammonia-nitrogen and orthophosphorus concentrations. Nitrate-nitrogen was determined by the UV method (Standard Methods, APHA, 1975) using a Perkin-Elmer model 202 spectrophotometer. Nitrite-nitrogen, ammonia-nitrogen and orthophosphorus were determined using a Bausch & Lomb Spectronic 70 spectrophotometer. Nitrite-nitrogen was determined by Method 354.1 (EPA, 1979). Ammonia-nitrogen was determined by the Chaney and Marboch method (Chaney and Marboch, 1962). Orthophosphorus was determined using the stannous chloride method (Standard Methods, APHA, 1975) using 10 cm cuvettes. Nutrient standards were prepared from stock solutions purchased from Hach Chemical Company, except for the nitrite-nitrogen standards which were prepared in the laboratory.

Nutrient analysis was conducted within 24-48 hours after collection.

Algal Assay Bottle Test Procedure

The experimental design and protocol used for this research project was that prepared by Miller et al. (1978) for the EPA entitled

"The Selenastrum capricornutum Printz Algal Assay Bottle Test."

The test water samples were initially filtered through Schleicher & Schuell (S&S) #30 glass fiber filters. Following filtration the samples were divided into 50 ml aliquots in 125 ml test flasks and then autoclaved. Control and nutrient additions were added to triplicate test flasks. Nutrient additions to the triplicate test flasks were as follows.

1. Control (C) (test water without nutrient additions)
2. Control + 1.00 mg Na₂EDTA/l (E)
3. Control + 1.00 mg N/l as NaNO₃ (N)
4. Control + 1.00 mg N/l + 1.00 mg EDTA/l (NE)
5. Control + 0.05 mg P/l as K₂HPO₄ (P)
6. Control + 0.05 mg P/l + 1.00 mg EDTA/l (PE)
7. Control + 1.00 mg N/l + 0.05 mg P/l (NP)
8. Control + 1.00 mg N/l + 0.05 mg P/l
+ 1.00 mg EDTA/l (NPE)

The test alga Selenastrum capricornutum Printz was obtained through the Carolina Biological Supply Co. (cat. #15-2520). The test organism was grown as stock cultures maintained in log growth using Synthetic Algal Nutrient Medium (Miller et al., 1978). Weekly transfers were made in order to maintain log growth. An inoculum equivalent to 1,000 cells per ml were added to each test flask.

The test flasks were maintained under constant temperature ($24 \pm 0.5^{\circ}$ C) and continuous 400 ft-c fluorescent light. The test flasks were shaken at least once daily for a period of fourteen days.

Cell growth production was determined by gravimetric biomass. The cells were harvested by filtration through S&S #30 glass fiber filters on day fourteen. The filters were dried using a Thelco vacuum oven and a vacuum desiccator. Weights were determined using a Mettler H-18 analytical balance. Triplicate tests were averaged together and factored by 20 to determine the maximum standing crop produced as mg dry-weight biomass per liter.

Data Analysis

Experimental results were determined using the maximum standing crop (MSC) weights of each test. The nitrogen yield coefficient (38) and the phosphorus yield coefficient (430) (Miller et al., 1978) were used to determine the expected yields produced by ambient nutrient concentrations and nutrient additions. Potential maximum standing crop production was calculated by multiplying the orthophosphorus concentration of a sample by 430 or by multiplying the TSIN concentration by 38. Biologically available phosphorus concentrations were calculated by dividing the MSC produced by nitrogen treatments by 430. Biologically available nitrogen concentrations were determined by dividing the MSC produced by the phosphorus treatments by 38. The percent algal growth inhibition after fourteen days (%I14) was determined using corresponding nutrient tests with and without the addition of EDTA. The control MSC was subtracted from the control + EDTA MSC and then divided by the EDTA MSC and multiplied by 100. Similar calculations were used with the N-NE, P-PE and the NP-NPE tests to determine percent inhibition associated with nutrient limitation.

PRINCIPAL FINDINGS AND SIGNIFICANCE

General Parameters and Heavy Metals

Seasonal Variation in Water Chemistry

Although there are some differences among sites, generally it can be stated that the period July through September had the highest values for specific conductivity, alkalinity, pH, sulfate, chloride, ammonia, magnesium, calcium, sodium and potassium (Tables 2 and 3). This observation is consistent with the higher amounts of evaporation and the lack of surface water recharge to the streams during this period. Although a few of the heavy metals exhibit high values during this period, the lack of a specific period of high heavy metal concentrations (Table 3) requires additional explanation. During periods of surface water recharge, higher loads of suspended sediments and/or colloids with absorbed heavy metals could affect heavy metal concentrations if some of these particles passed through the 0.40 micrometer pore-size filter. Thus, the conditions during the periods of low recharge which lead to sluggish, stagnant conditions could allow more of the suspended sediment to settle out of the water resulting in low heavy metal concentrations. The possibility of suspended sediments and/or colloids passing through the 0.40 micrometer pore-size will be discussed in more detail in the section on Variation in Water Chemistry During Storm Events/First Storm Event.

Chemistry During Storm Events

Because the IB site was used as the site for storm event sampling, it is important to note the seasonal variation in water chemis-

try at this site. Generally, August and September sampling dates give the highest values except for the heavy metals. The explanation for this period giving high values is the same as for the entire stream, i.e., higher evaporation rates and lack of surface water recharge. Variation in amount and type of suspended sediment load at IB could explain the lack of a period of consistently high heavy metal concentrations.

Variation of Water Chemistry Among Sites

The water chemistry of the White River generally shows a trend downstream toward Beaver Lake for the heavy metals. The upper stream sites (BF, 74 and 16) generally have the lowest heavy metal concentrations for any sampling date. There is an increase in concentration downstream to WB, which is located below Sequoyah Dam. It is somewhat surprising that the site at the dam on Lake Sequoyah follows this trend since the lake had been expected to effect the water chemistry. Apparently, the lake behaves much as a large pool on the river in terms of water chemistry, especially since the water overflows the top of the dam. The higher nutrient concentration at this site may be due to the outflow from Fayetteville waste water treatment plant and/or agricultural activities. Site 45 is either slightly higher or lower in concentration than WB. However, site 68 always has low concentration values (e.g., Figure 2). These differences in heavy metal concentrations at the sites are attributable to the geology and geohydrology of the areas in the vicinity of the stream. The rock type plays an important role in the water chemistry

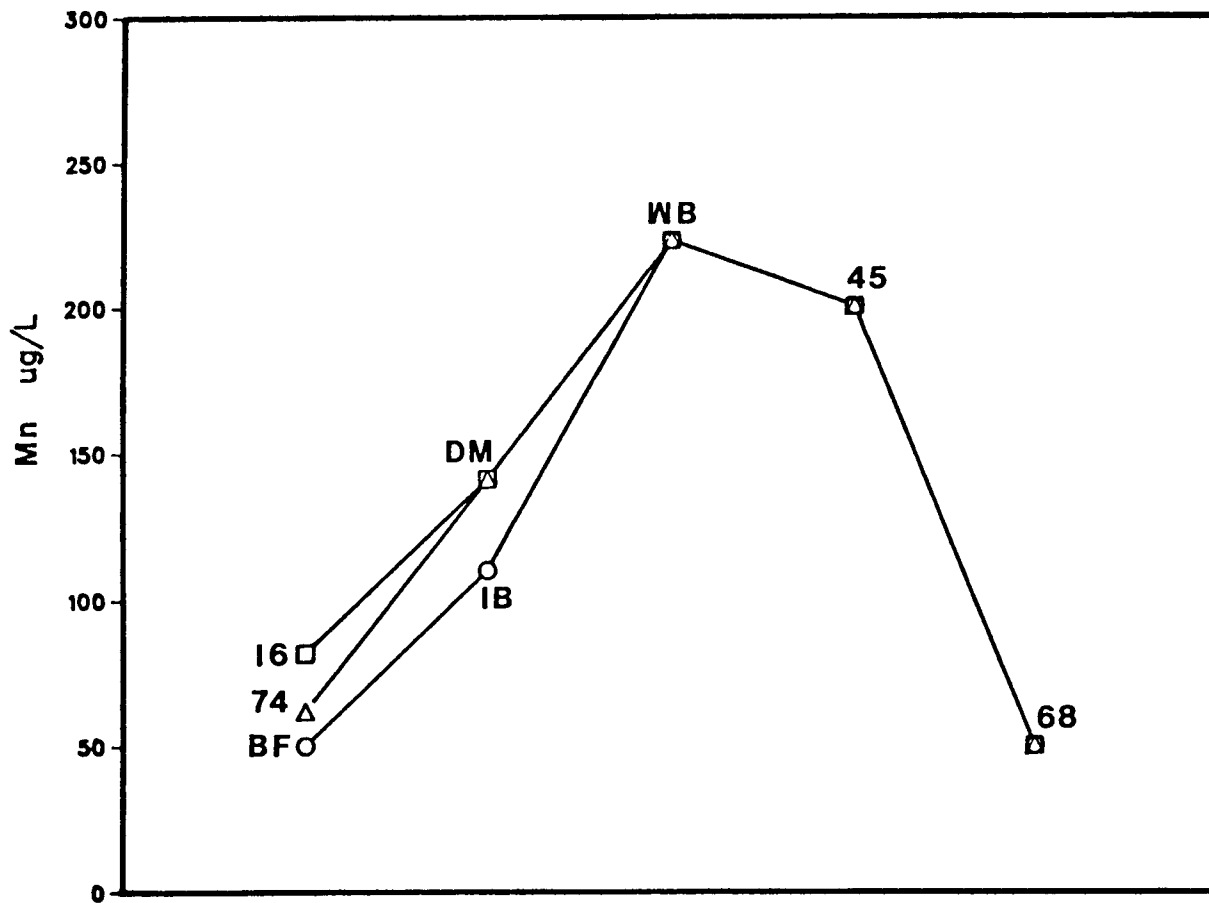


Figure 2. Downstream variation in manganese concentration, August 21, 1985.

due to both dissolved and suspended load. The Fayetteville Shale is exposed near all of the sites, except site 68. Thus, the shale could contribute heavy metals as suspended sediment directly to the river or via tributaries, and also could contribute dissolved ions by means of soil or ground water. The topography of the areas with shale present may be the controlling factor for most of the sites. High relief areas would probably contribute more suspended sediment due to erosion, and more soil and ground water due to better drainage than low relief areas. Thus, the upstream sites have low concentrations of heavy metals due to the low relief of the shale, and the concentration of the heavy metals increases downstream due to an increase in relief. The heavy metal concentrations decrease dramatically at site 68 due to lack of shale in the vicinity of this site and because of the "pool" nature of this site, which would allow suspended sediments to settle out. However, during storm events, this site might receive considerable suspended sediment from upstream and thus cause elevation of the heavy metal concentrations.

Variation of Water Chemistry During Storm Events

It is often thought that the critical period for pollution in streams is the period of lowest flow (as exemplified by the seasonal behavior of many of the White River parameters); however, this is not necessarily the situation. Nutrients have the potential to be washed into streams during storm runoff from surface sources, and because heavy metals are often adsorbed onto the suspended sediment it would be expected that a higher metal content would occur during high flow

conditions when suspended sediment load also would be high.

Thus, the purpose of this portion of the study was to determine the effects of storm events on the water chemistry of a portion of the White River. An effort was made to eliminate the effect of the suspended sediment load by filtering the samples through 0.40 micrometer pore-size membranes. The IB site on the West Fork of the White River was chosen for this part of the study. The monitoring site is located about four miles east of Fayetteville near Baldwin, Arkansas. The West Fork drains a basin of about 110 sq. mi., which is composed of limestone, shale and sandstone. The landuse in the area is predominantly pasture and forest. However, the river does flow nearby several small towns and along the outskirts of Fayetteville adjacent to an industrial park.

The river was sampled following a 1.5 inch rain in September and a 2.0 inch rain in October, 1985. Samples were collected approximately every hour or two immediately following the rain, with the sampling intervals becoming progressively longer after the peak of the stream hydrograph (Table 2).

First Rain Event

During the first storm event, the highest flow rate of 120 cfs (cubic feet per second) occurred approximately eight hours after initiation of rain. Some parameters increase in concentration as the stream hydrograph peaks; whereas, others decrease (Tables 4-6). Specific conductivity, calcium (Figure 3) and total alkalinity exhibited initial increases in concentration which peak about three hours after

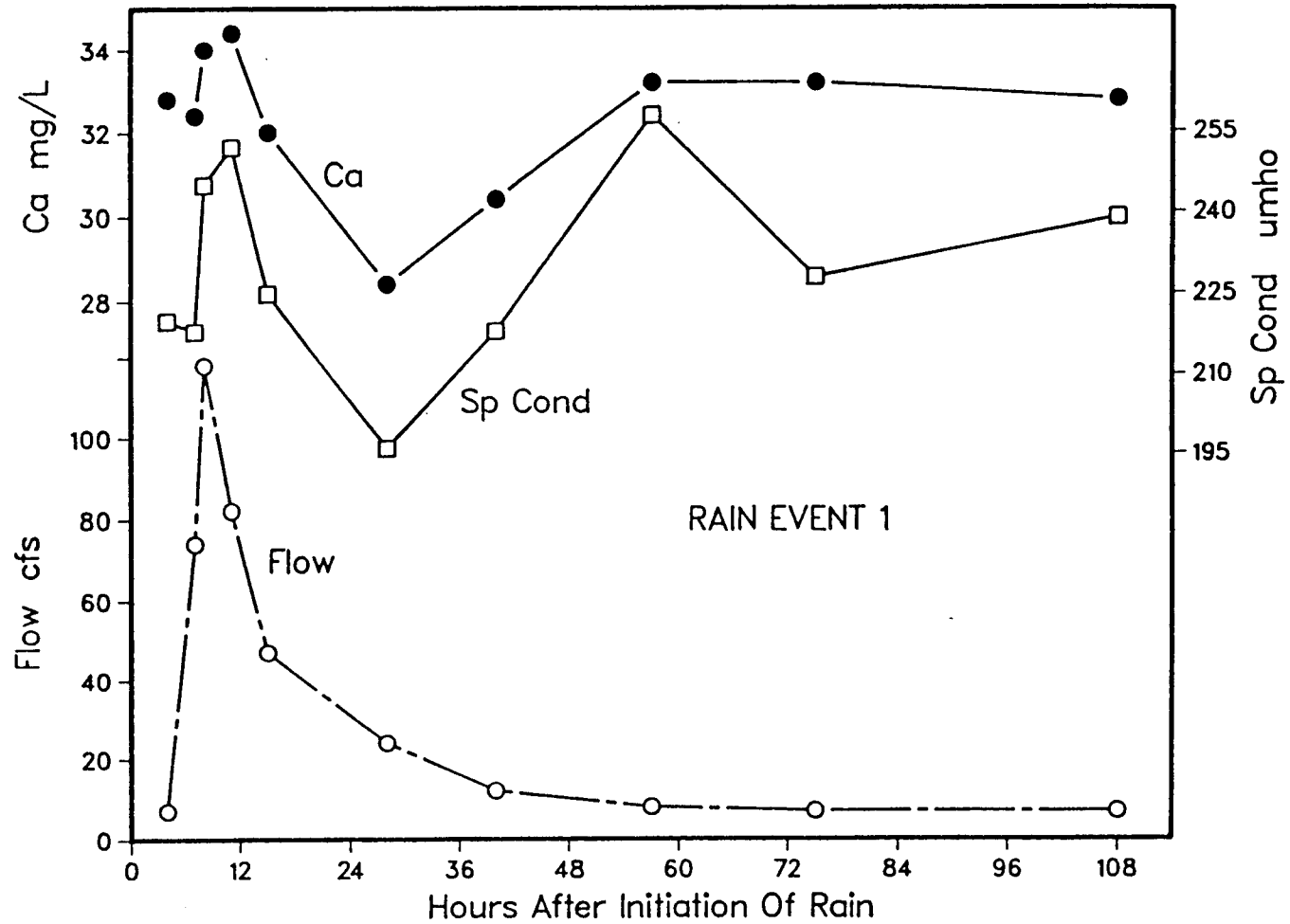


Figure 3. Plot of calcium concentration, specific conductivity and stream flow versus hours after initiation of rain for the first rain event.

the hydrograph peak and then exhibit decreases in concentration. These parameters reached a minimum 28 hours after the rain began and returned to background values as flow returned to base flow (Figure 3). The initial increase in values can be attributed to flushing of readily available surface sources which are rapidly depleted by the storm runoff. The later decrease in values represents a dilution effect caused by the influx of rain water as runoff.

Magnesium, sodium (Figure 4), potassium and chloride reached maximum concentrations slightly after the peak of the hydrograph. Although these cations reached maximum concentration values at the same time as specific conductivity, total alkalinity and calcium, these ions did not exhibit a dilution effect. Thus, there was a flushing effect of readily available material that increased the concentration of the ions slightly above background, and then a return to background values following the hydrograph, because the source of the ions was not depleted. The behavior of nitrate, ammonia and orthophosphate (Figure 5) is similar to the ions discussed above with the main difference being the lag time for these ions to reach maxima and the fact that the concentration peaks versus time are broader for these ions. Note that nitrate was still returning to background concentration at the end of the sampling period. There are two possible explanations for the behavior of these three nutrients. One is that the source for these nutrients was some distance from the sampling site, and the other is that the source material for these ions required a "wetting" time before the ions could

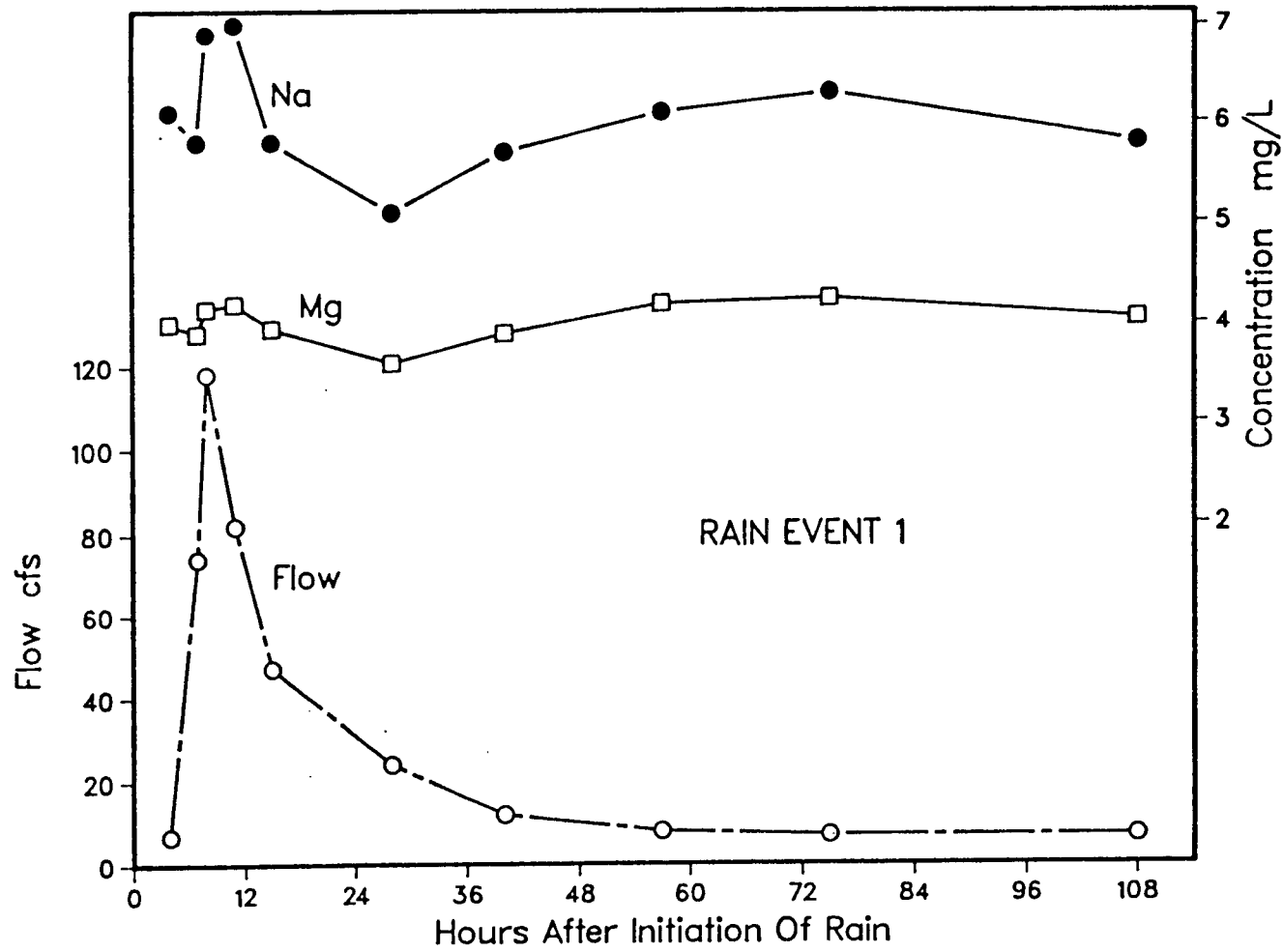


Figure 4. Plot of sodium and magnesium concentrations, and stream flow versus hours after initiation of rain for the first rain event.

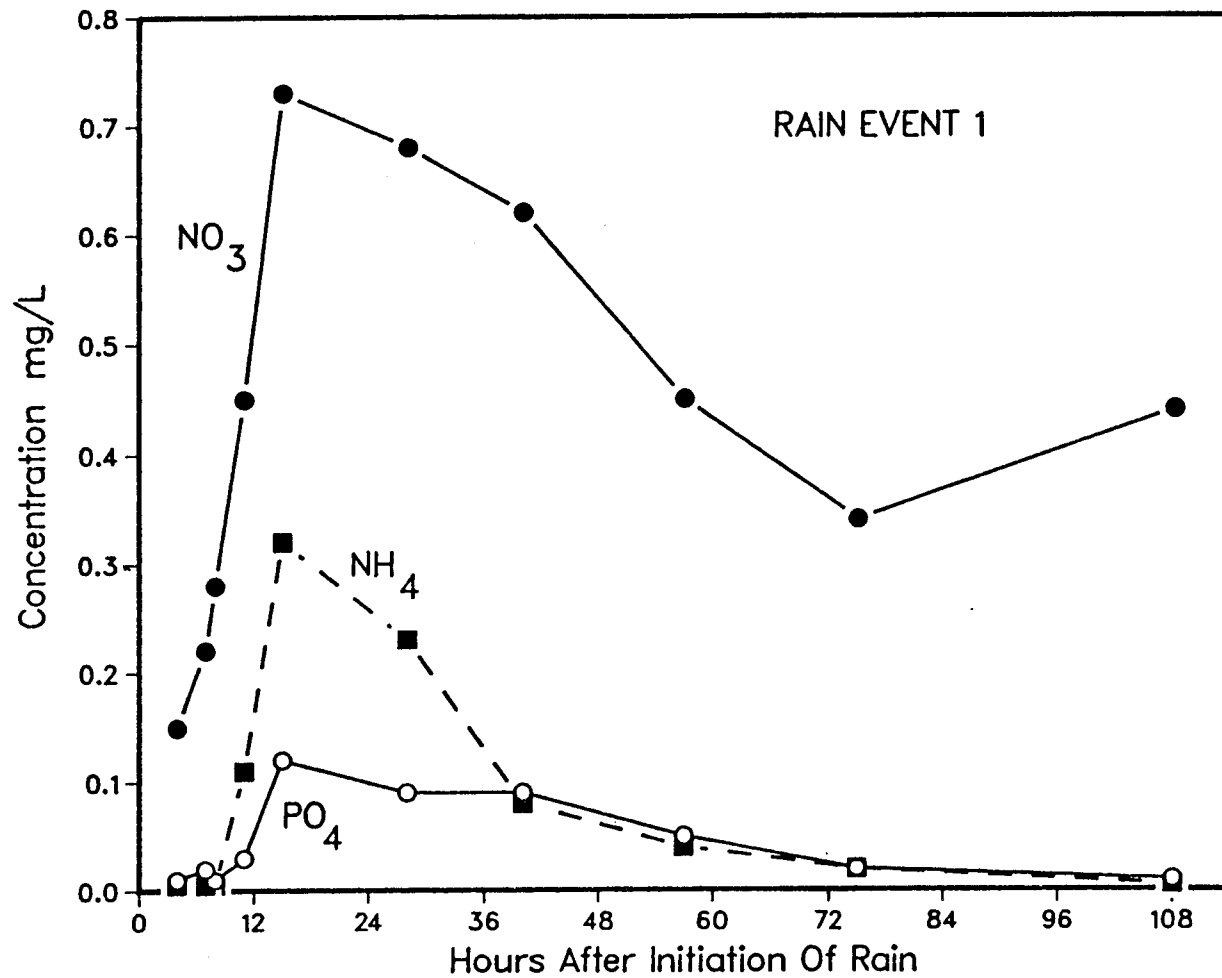


Figure 5. Plot of nitrate, ammonium and orthophosphate concentrations versus hours after initiation of rain for the first rain event.

be dissolved in significant concentrations. Sulfate concentration initially peaked with the hydrograph and also exhibited a second broad peak. The nature of the sulfate peaks may be related to sulfate being made available from shale by oxidation of pyrite in the form of sediments (i.e., first peak) and as dissolved ions from ground water (i.e., second peak). The explanations for the behavior of these parameters discussed above are similar to that used by Steele et al. (1985) to explain the variation in water chemistry in spring water following storm events and Wickliff and Steele (1986) in their investigation of heavy metals in stream water. Miller and Drever (1977) found similar trends (specific conductivity, bicarbonate [total alkalinity], calcium and potassium) for the North Fork of Shoshone River, Wyoming with the exception of a dilution trend for sodium.

Of the heavy metals, iron had the highest concentrations rising from a background of about 200 ug/l to a maximum of 1100 ug/l seven hours after the peak of the hydrograph (Figure 6). Manganese, lead and zinc (Figure 7) exhibited similar trends. Note that iron, manganese and lead (Table 6) concentrations all exceed the EPA (1976) drinking water standards of 300, 50 and 50 ug/l, respectively. Although much lower in concentrations, cobalt, nickel, copper and cadmium also reach maximum concentrations following the peak of the hydrograph. Whipple and Hunter (1977) found the highest concentrations of heavy metals in storm runoff from urban areas to occur within the first 30 minutes of storm runoff. Under natural stream

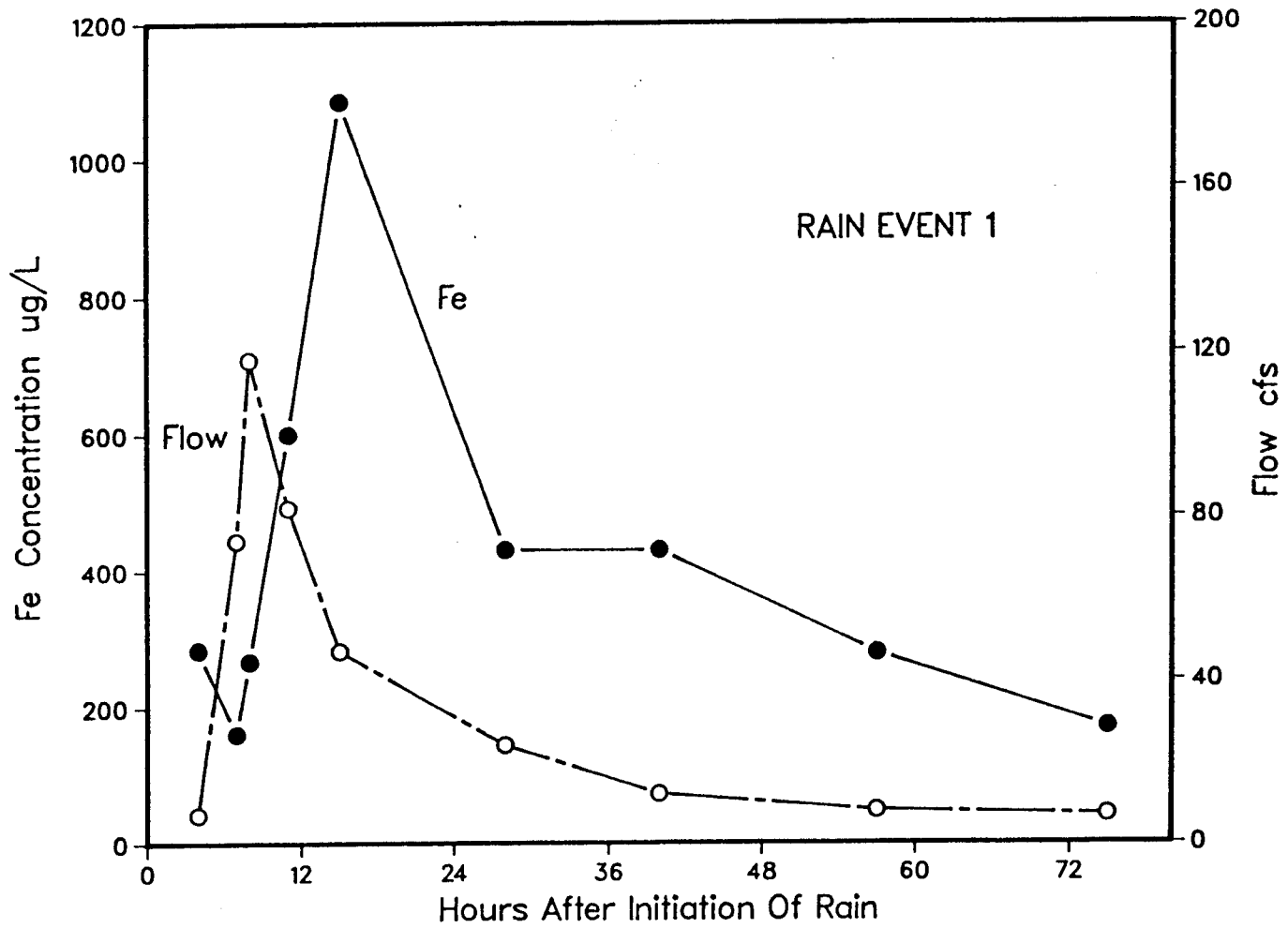


Figure 6. Plot of iron concentration and stream flow versus hours after initiation of rain for the first rain event.

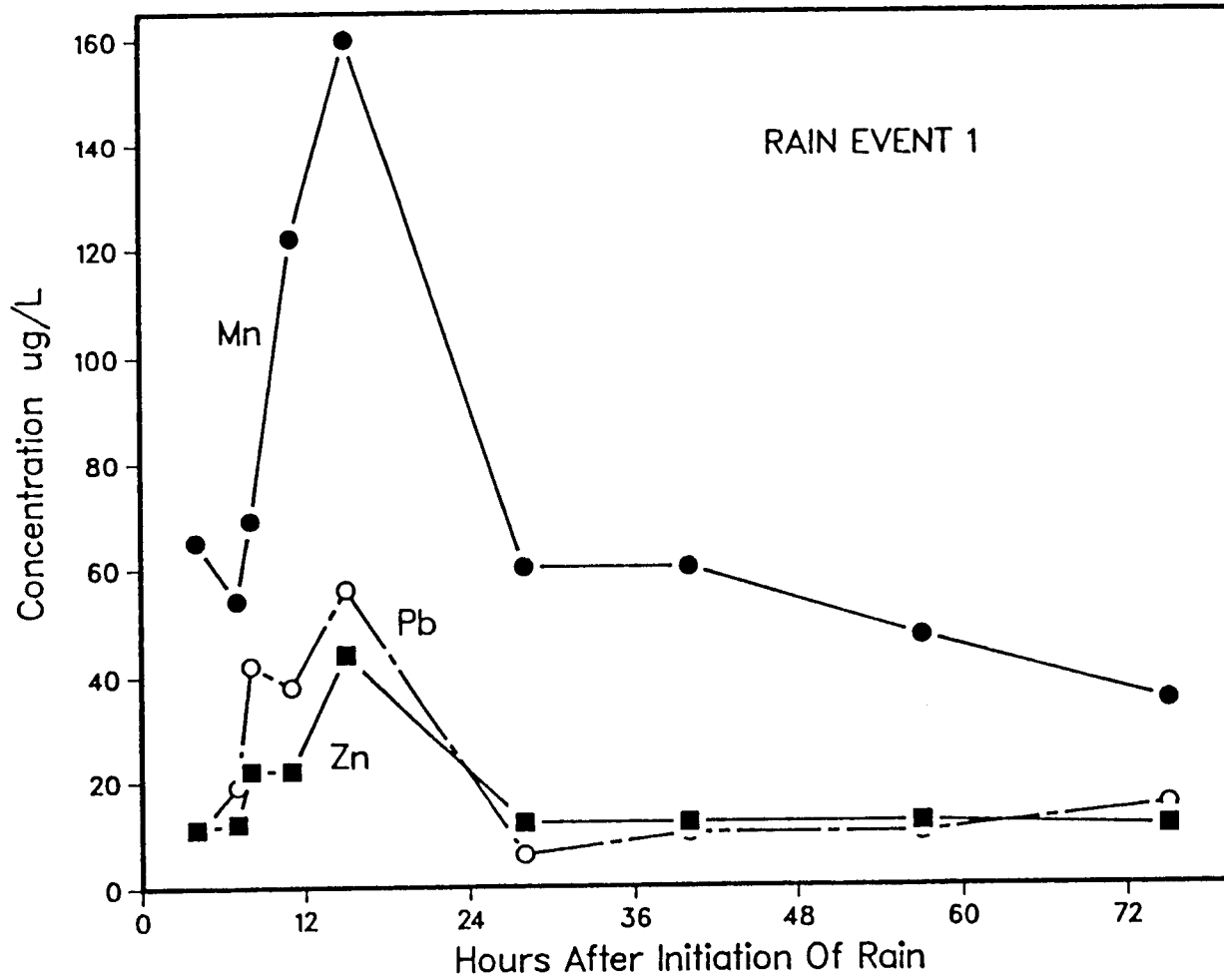


Figure 7. Plot of manganese, lead and zinc concentrations versus hours after initiation of rain for the first rain event.

conditions, manganese is precipitated from solution more readily than iron because of the autocatalytic effect on manganese precipitation. Thus, the dissolved concentration of these two metals should not correlate well. Figures 6 and 7 show a good correlation between these two elements indicating that the source for these two metals is nearby, or that particulate material is passing through the filter. Kennedy et al. (1974) found that fine-grained particulate material can pass through 0.45 micrometer pore-size membrane filters and cause large percentage errors in analyses of iron, manganese, aluminum and titanium that are enriched in the particulates relative to the water. In order to evaluate the possible importance of particulate material in this study, a water sample was collected at IB during a rain event in March, 1986. The results indicate that significant amounts of some heavy metals (especially iron) pass through 0.40 micrometer pores and that most are collected on 0.30 micrometer pores or smaller (Table 7). Thus, it appears that a significant amount of some heavy metals could have been leached from suspended material by the acid used to stabilize the White River water samples. Williams et al. (1973) found no correlation between stream flow and the soluble heavy metals in the Black Warrior River at Tuscaloosa, Alabama. However, they did find a strong positive correlation of heavy metals and the resuspended bottom sediments present in the water column following increased flow and scour from heavy rain runoff.

Comparison of the Two Rain Events

Sampling began just before the peak of the hydrograph during the

second rain storm event in October. The parameters exhibited trends similar to those of the first rain events (Tables 8-10). The flow rate was approximately five times greater in the second rain storm event than in the first; thus, it is not surprising that the dilution effects are greater (about 2x) than those for the first rain event, and that it required twice as long to return to background values (Tables 8 and 9 and Figure 8). Although the heavy metal concentrations, with the exception of iron, were higher in the second rain event, the ranges in concentrations were similar. Thus, iron, manganese and lead concentrations again exceeded the EPA (1976) standards for drinking water (Table 10). Some other differences between the two rain storm events are:

- (1) sulfate exhibits a dilution effect in the second rain event after exhibiting an increase that corresponds with the peak of the hydrograph (Figures 9 and 10)
- (2) ammonia and orthophosphate both reach a maximum that closely follows the peak of the hydrograph (rather than the later peak exhibited during the first rain event)
- (3) nitrate exhibits a second peak in concentration during the second rain event (Figure 11)
- (4) maximum values for the heavy metals occurred at the peak of the hydrograph during the second rain event rather than after the peak
- (5) Manganese, copper, lead, cobalt and nickel reached a second peak in concentration during the second rain

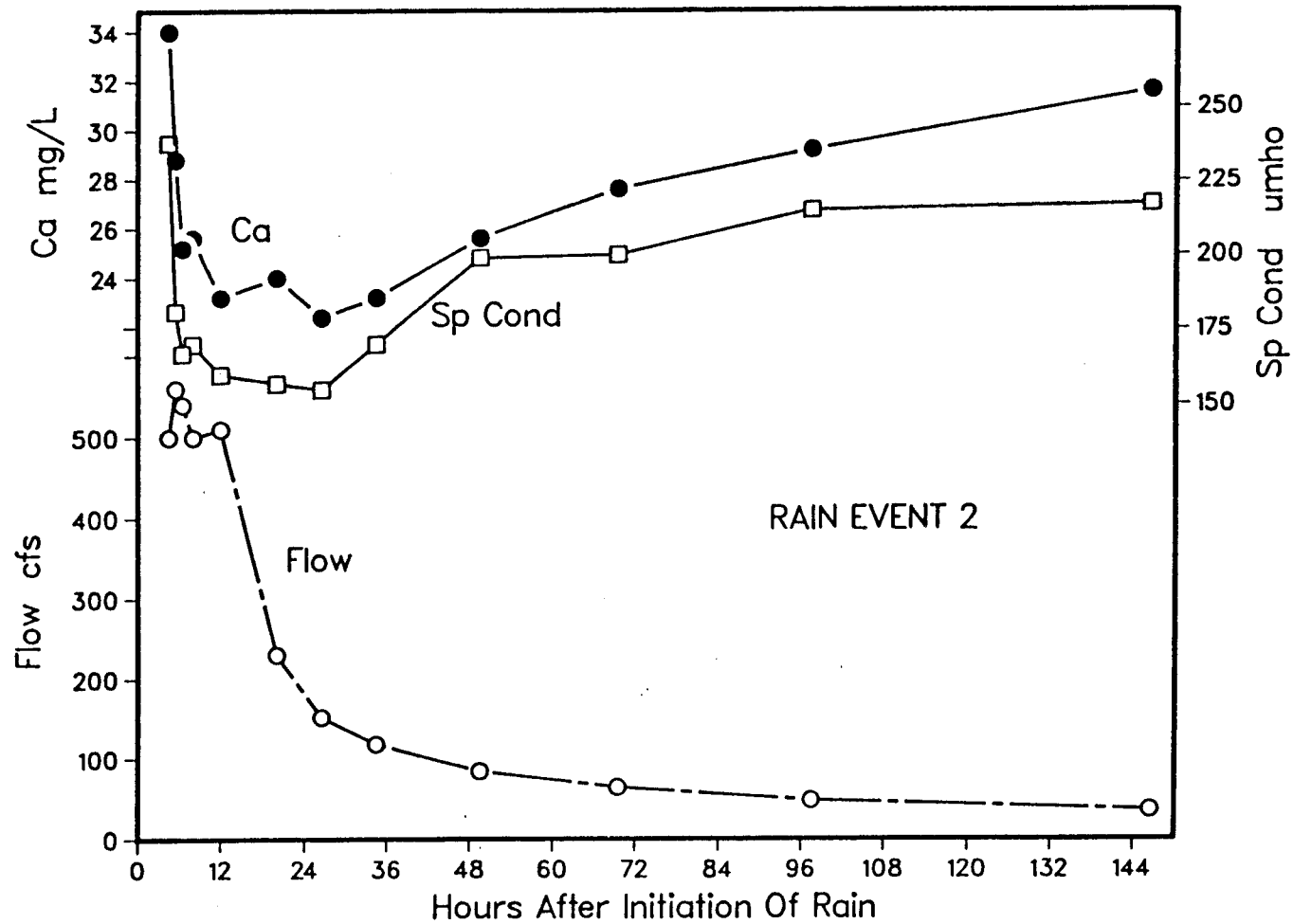


Figure 8. Plot of calcium concentration, specific conductivity and stream flow versus hours after initiation of rain for the second rain event.

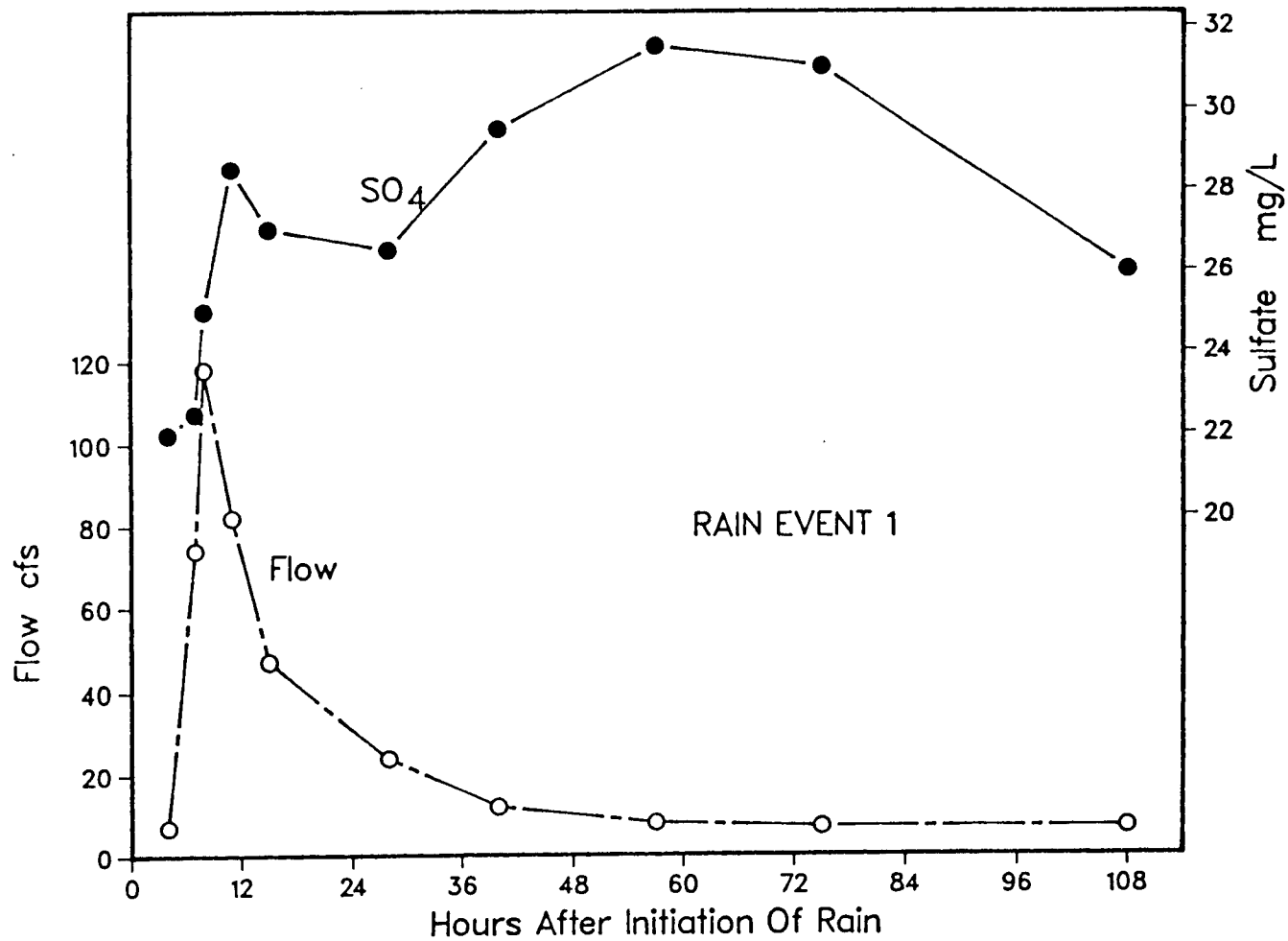


Figure 9. Plot of sulfate concentration and stream flow versus hours after initiation of rain for the first rain event.

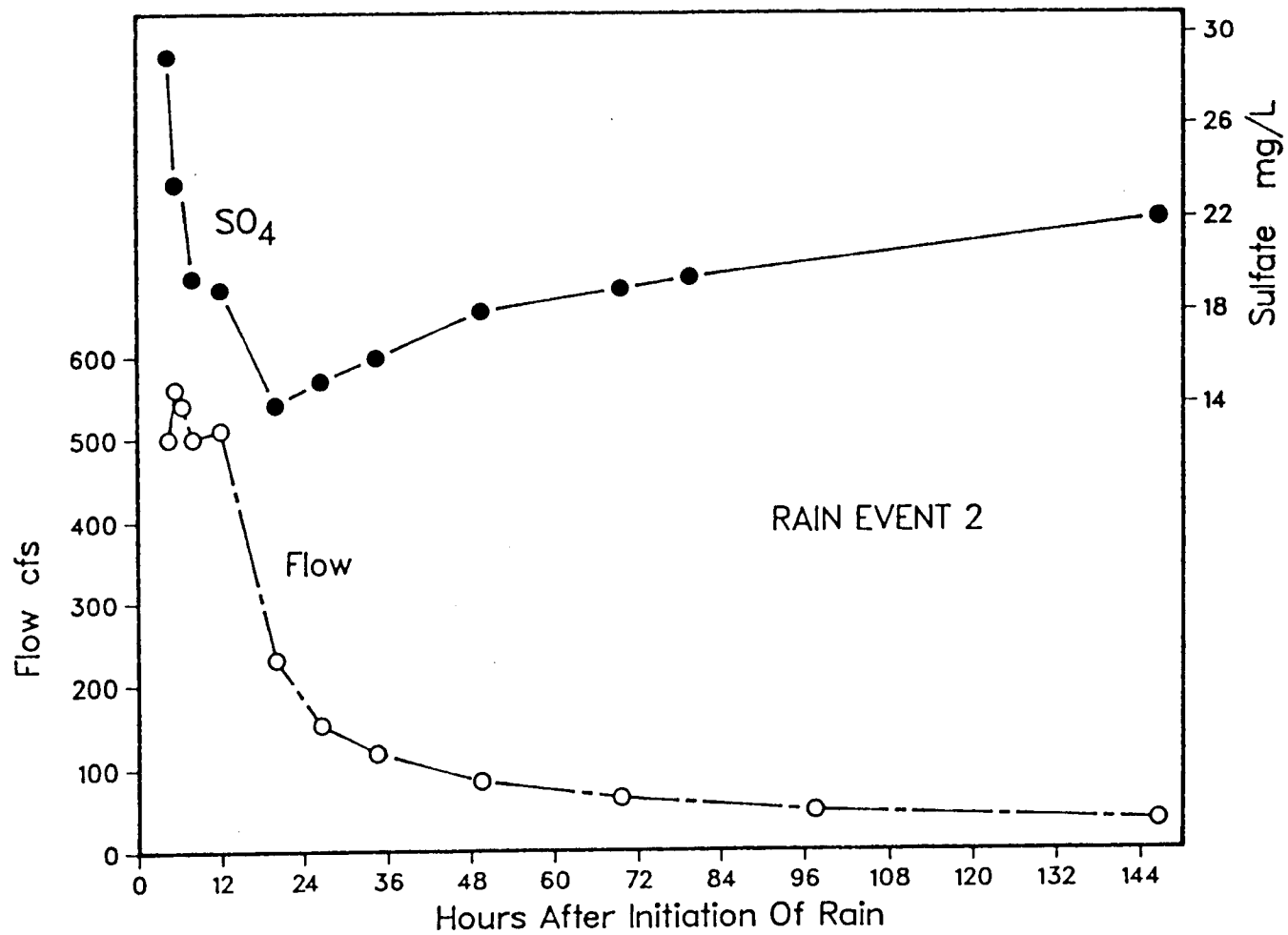


Figure 10. Plot of sulfate concentration and stream flow versus hours after initiation of rain for the second rain event.

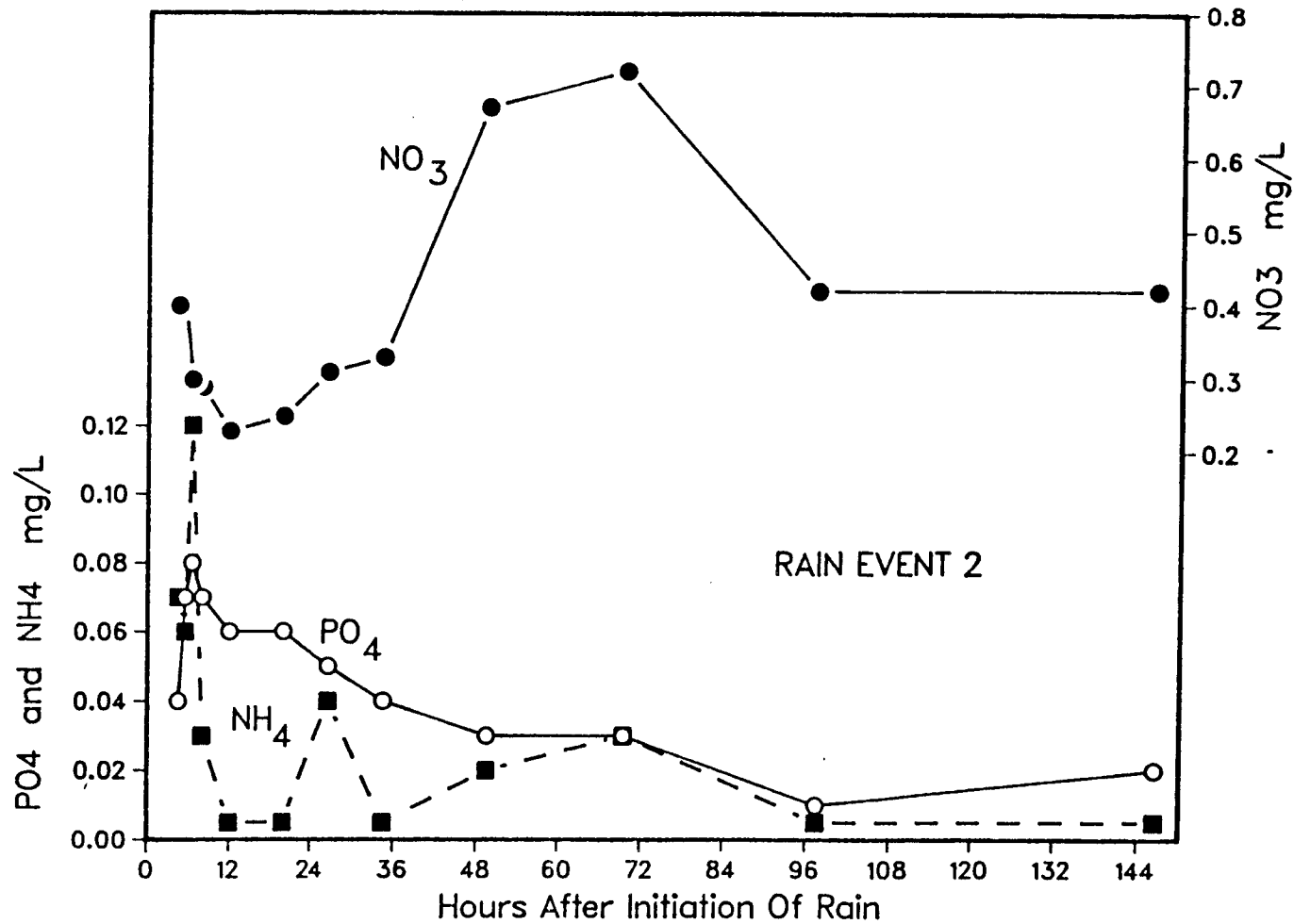


Figure 11. Plot of nitrate, ammonium and orthophosphate concentrations versus hours after initiation of rain for the second rain event.

event (e.g., Figure 12). Lead, cobalt, nickel and cadmium also exhibited this bimodal character during the first rain event.

The bimodal nature of the heavy metal peaks suggest that there are two sources of heavy metals, perhaps one at a greater distance from the monitoring site. The difference in behavior of the other ions between the two storm events probably is due to different amounts of readily available ions, variation in suspended sediment load, variation in soil moisture and variation in ground water chemistry. In turn, these variations can be attributed to time between rains, and amount and intensity of rain.

Algal Assay

Ambient nitrogen and phosphorus concentrations and the proportionality of these nutrients provides the basis for determining nutrient limitation. It has been determined (Miller et al., 1978) that the growth of Selenastrum capricornutum becomes phosphorus limited in waters containing N:P ratios greater than 11:1 and nitrogen limited in those less than 11:1. Background nutrient data can be used to place a sample in a limiting category; however, to do so without assay analysis is discouraged according to the previous author. Assay response can verify nutrient limitation with better resolution and determine the biological availability of these nutrients within the test water in question. Nutrient additions with and without the chelator (EDTA) addition can determine if growth inhibition occurs due to heavy metal toxicity and the extent of the

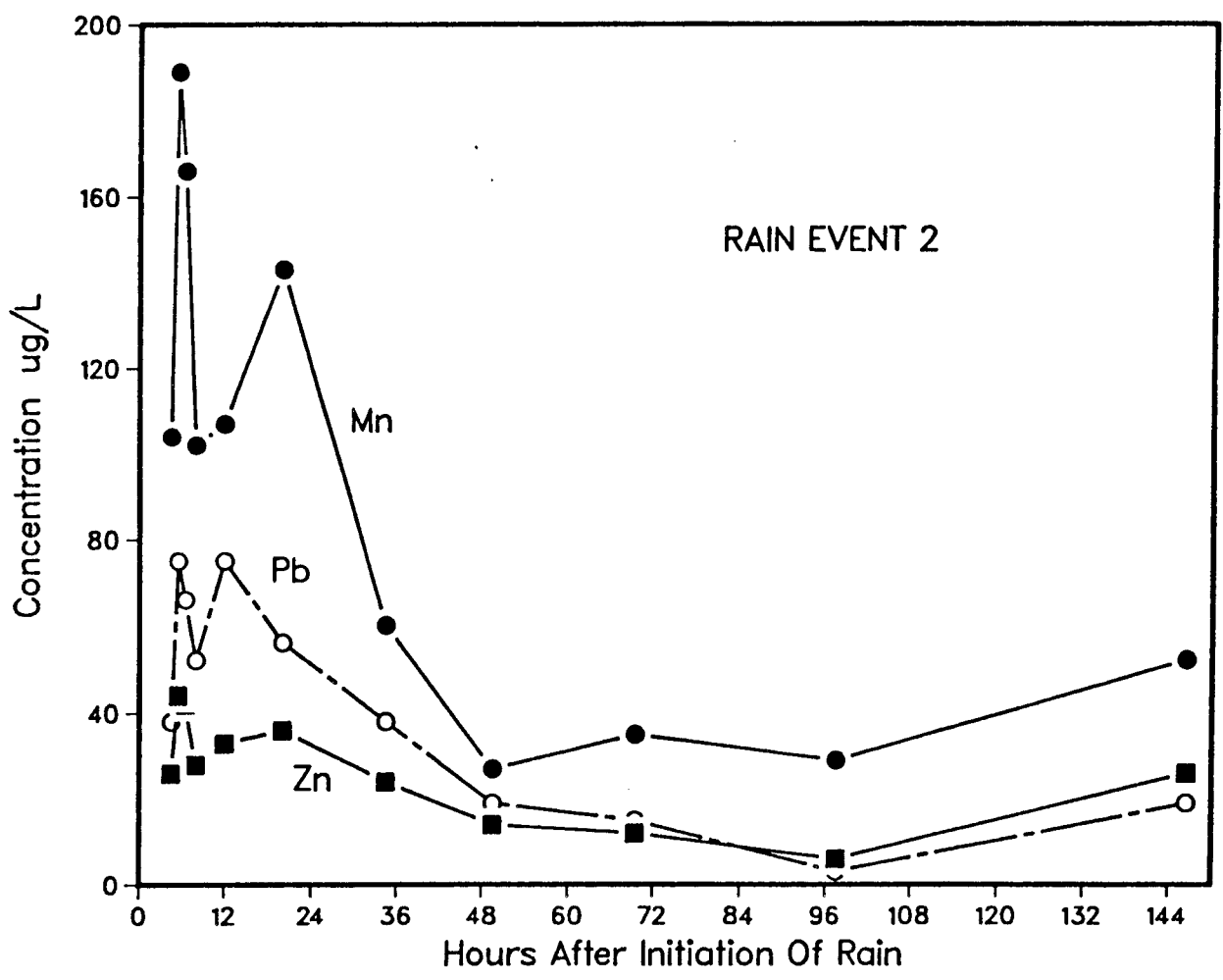


Figure 12. Plot of manganese, lead and zinc concentrations versus hours after initiation of rain for the second rain event.

inhibition if it does occur

Background Data

Nutrient ratios and calculated production (MSC) yields based on ambient nutrient concentrations of the test water were used to predict growth limiting nutrients. Based on these results, the test water samples can be separated into three categories of potential nutrient limitation: phosphorus, nitrogen and nitrogen-phosphorus co-limitation (Table 11).

Those samples which were expected to be phosphorus limited are presented in Table 12. In all cases, the N:P ratio is greater than 11:1, and the calculated MSC based on ambient phosphorus concentrations are less than those based on the ambient nitrogen concentrations. The calculated production yields further clarify the expected results based on the N:P ratios

The majority of the test water samples collected were predicted to be phosphorus limited (Table 12). In general, all three tributaries of the White River and the sites after the confluence of the tributaries upstream from the sewage discharge site were expected to be phosphorus limited throughout the sampling period.

Below the sewage discharge site, phosphorus levels were great enough to expect nitrogen limitation. All samples taken directly below the sewage discharge (45) were classified to be nitrogen limited (Table 13). During the late autumn and winter collections this nutrient influence continued downriver, as seen in the 68 site data. During the summer and early fall collection dates, phosphorus

levels declined between 45 and 68, enough to categorize 68 as being phosphorus limited. At one instance (68, 1/11/86), the N:P ratio and the calculated production yields were such that neither nitrogen or phosphorus could be expected to limit growth more than the other. This sample was placed into the category of nitrogen and phosphorus co-limitation (Table 14).

The effluent from the sewage discharge dramatically changed the expected growth limiting nutrient status and the calculated cell growth potential of this aquatic system. Upstream from the sewage discharge site, in the three tributaries and the post-confluent sites, phosphorus levels remain extremely low throughout the year. Associated with these low levels is the low potential for algal production. Under these conditions, the calculated growth yields never exceed the level of 10.0 mg/l. However, below the sewage discharge site where phosphorus levels are extreme enough to indicate nitrogen limitation, the potential algal growth yields are roughly an order of magnitude higher.

Maximum Standing Crop Production

The maximum standing crop produced by the test water assays are presented graphically in Figures 13-28, and the corresponding concentrations are found in Table 11. The test water collections above the sewer treatment plant generally produce low maximum standing crop values as expected. In many of the control treatments, ambient nutrient concentrations were at such levels that cell growth could not be detected using the present experimental technique. This also

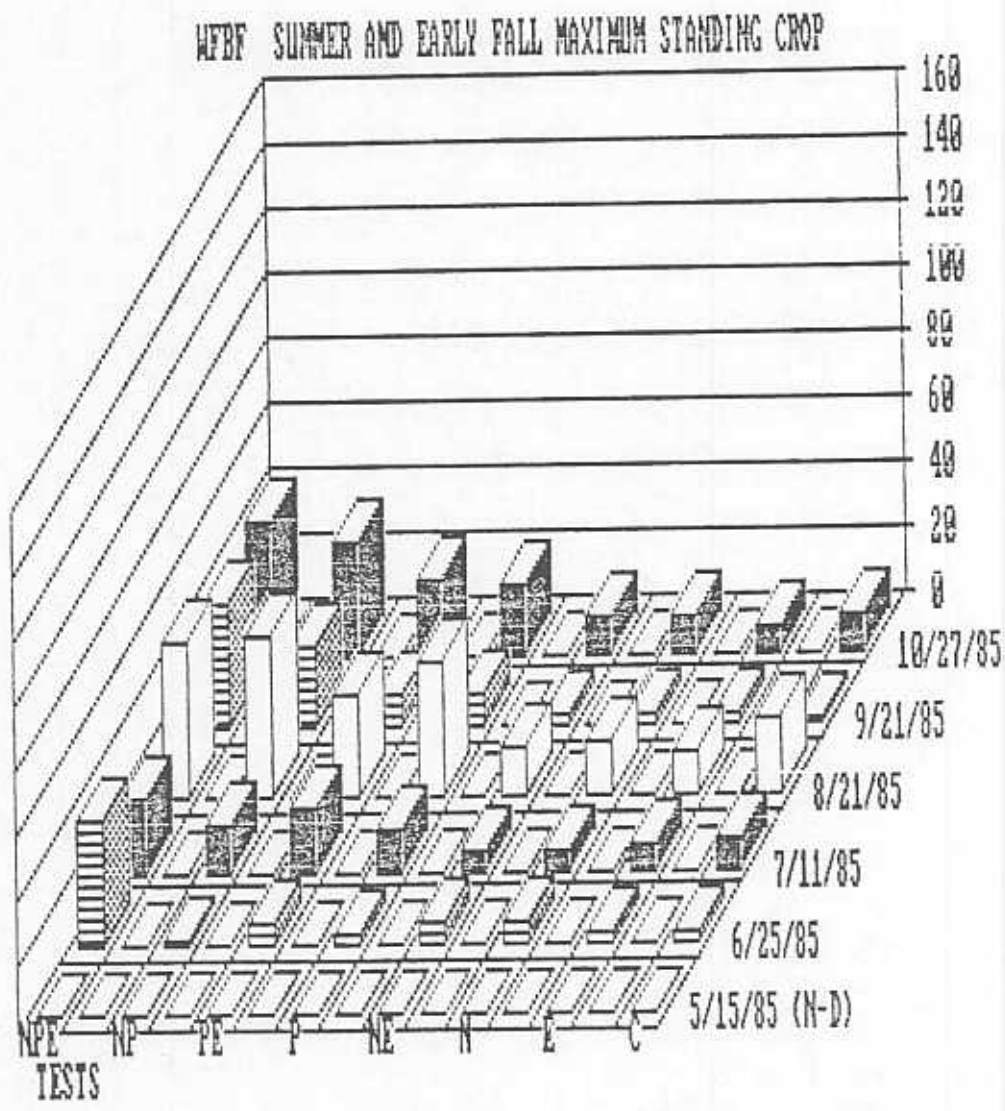


Figure 13. West Fork Baptist Ford Summer and Early Fall Maximum Standing Crop. (MSC mg/l)

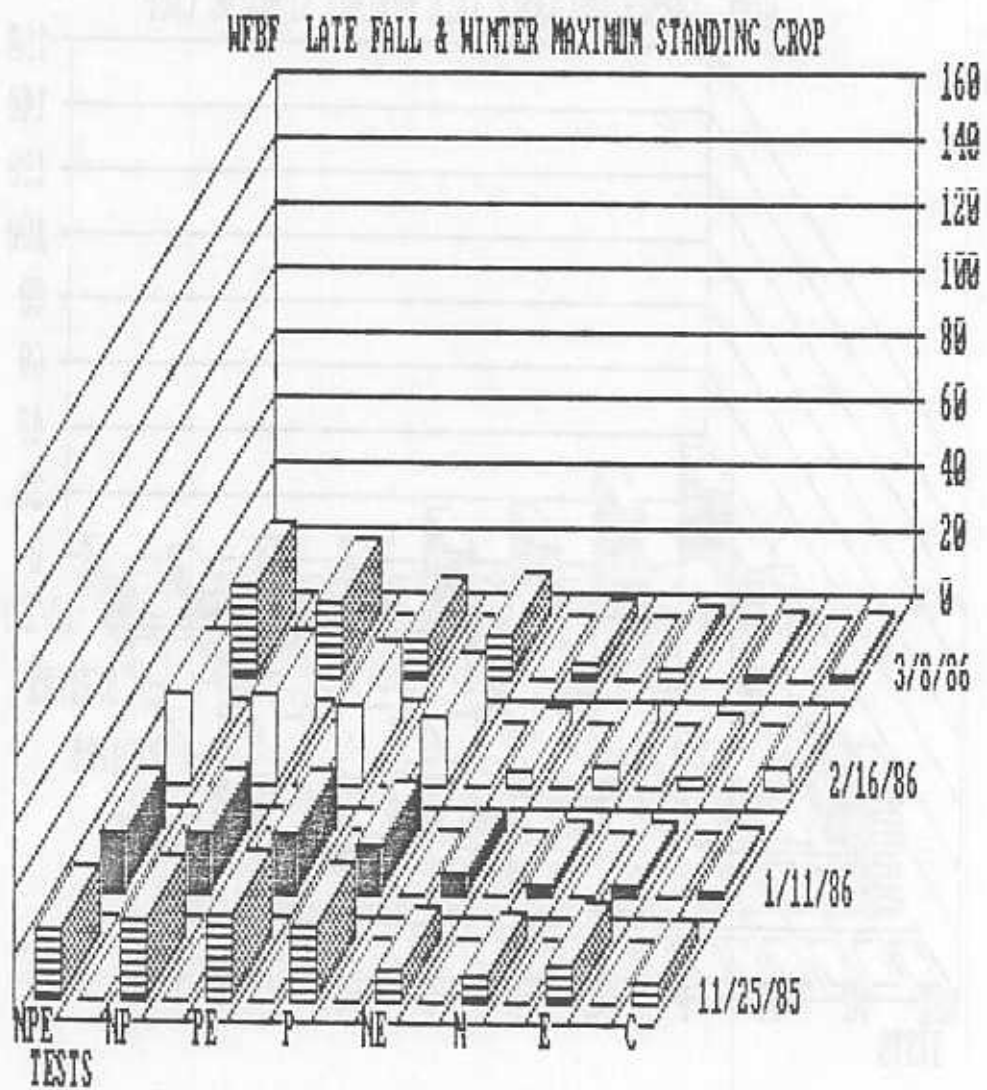


Figure 14. West Fork Baptist Ford Late Fall and Winter Maximum Standing Crop. (MSC mg/l)

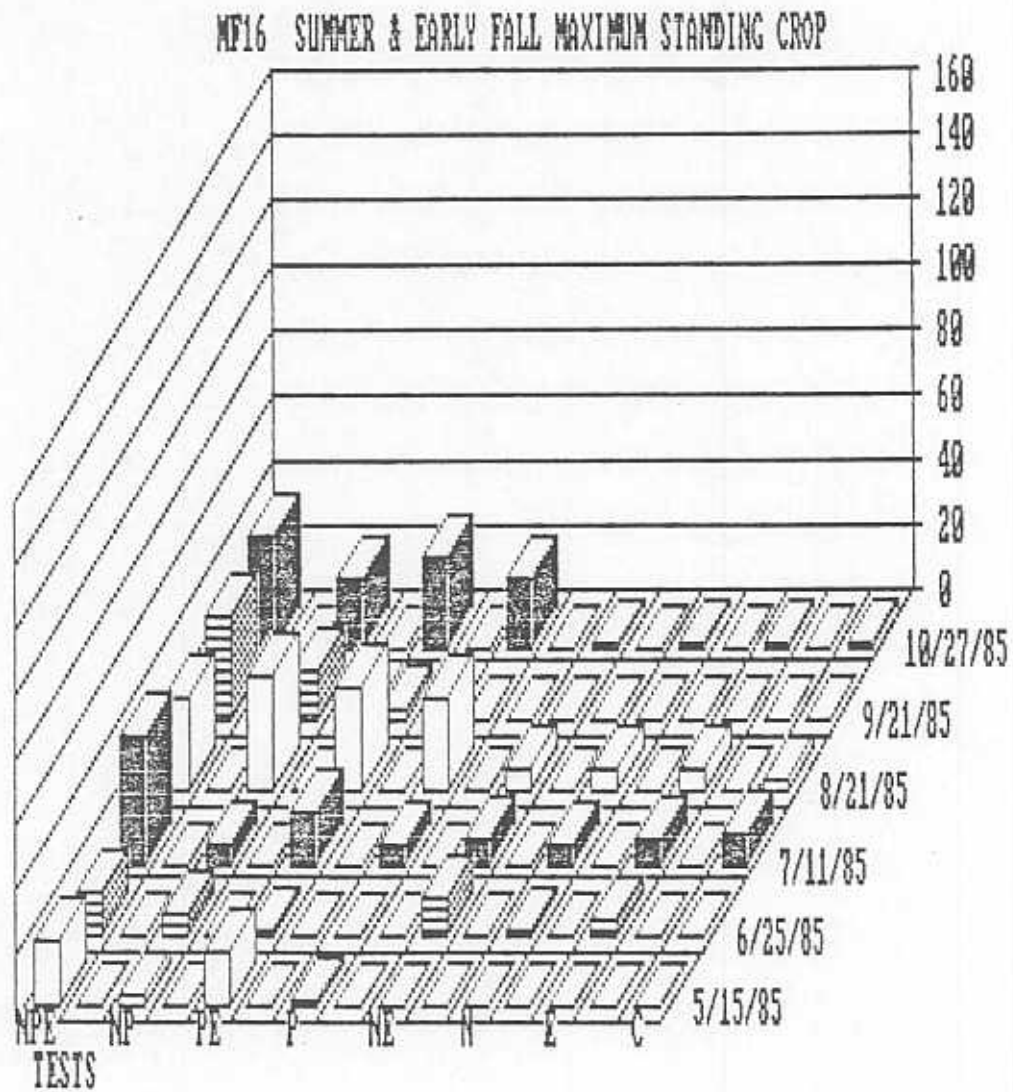


Figure 15. Middle Fork Highway 16 Summer and Early Fall Maximum Standing Crop. (MSC mg/l)

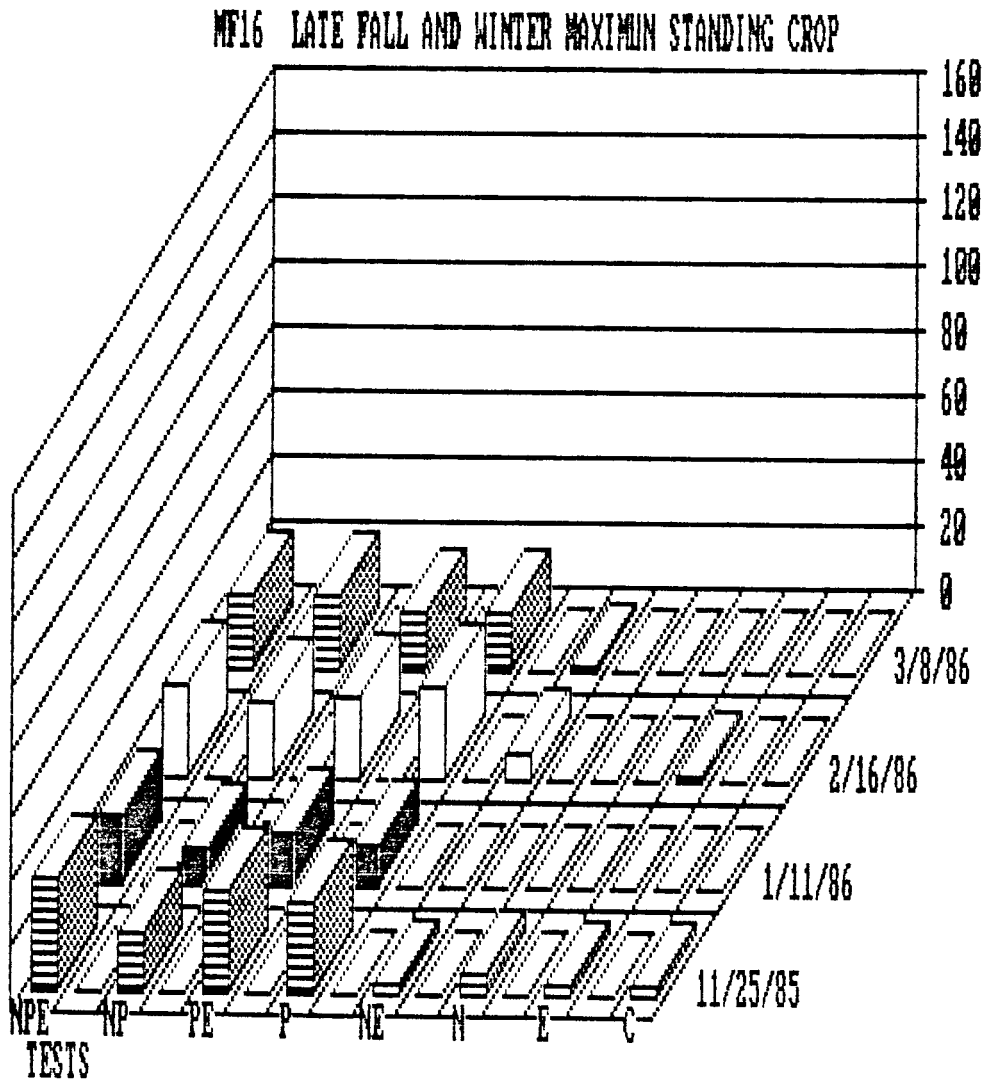


Figure 16. Middle Fork Highway 16 Late Fall and Winter Maximum Standing Crop. (MSC mg/l)

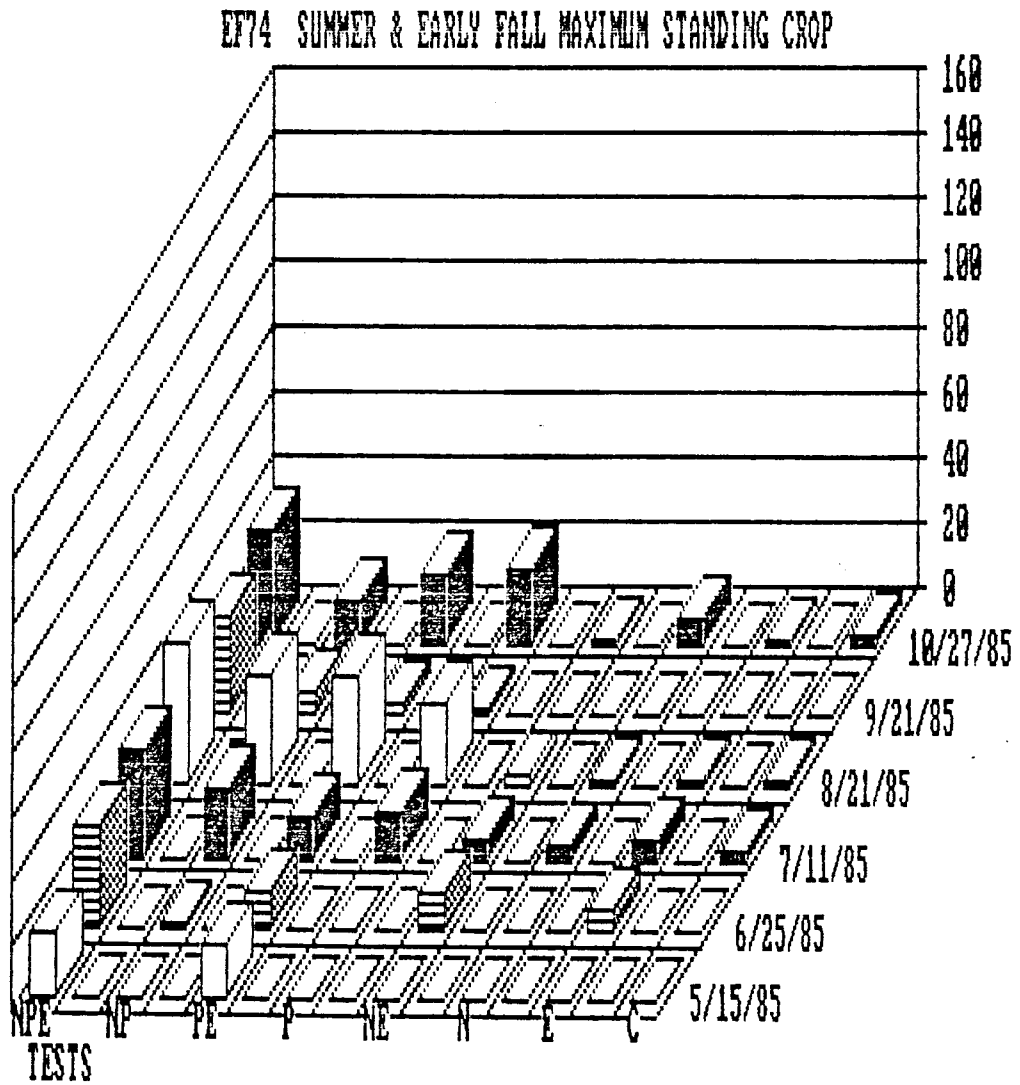


Figure 17. East Fork Highway 74 Summer and Early Fall Maximum Standing Crop. (MSC mg/l)

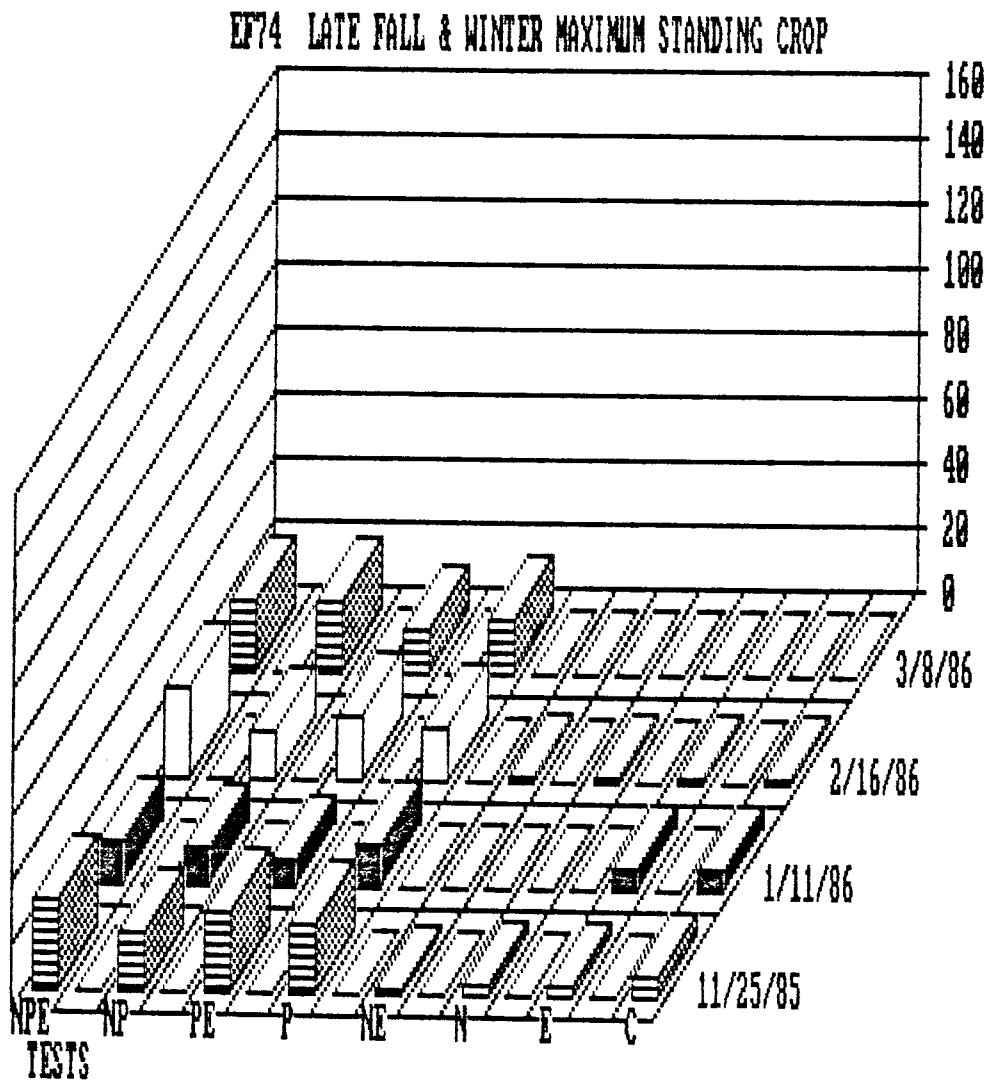


Figure 18. East Fork Highway 74 Late Fall and Winter Maximum Standing Crop. (MSC mg/l)

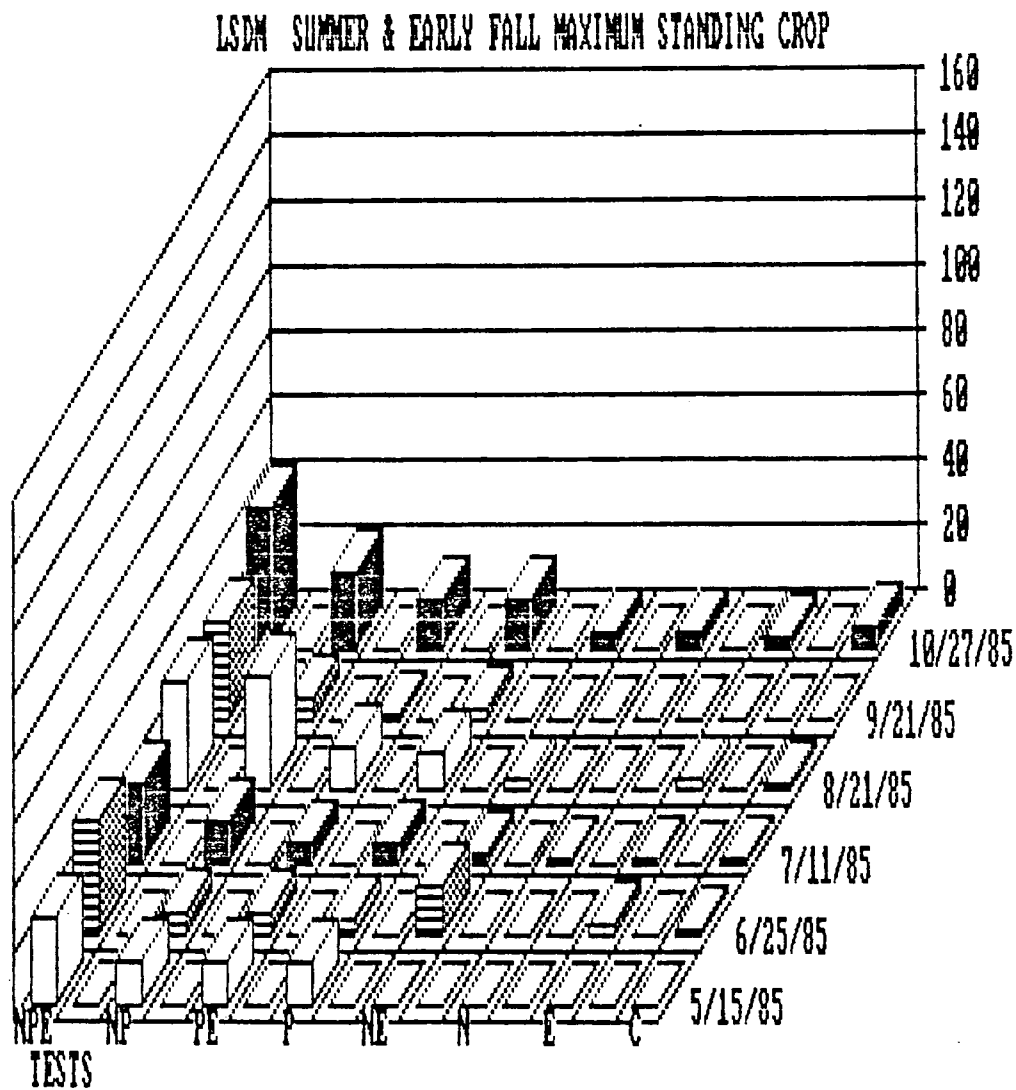


Figure 19. Lake Sequoyah Dam Summer and Early Fall Maximum Standing Crop. (MSC mg/l)

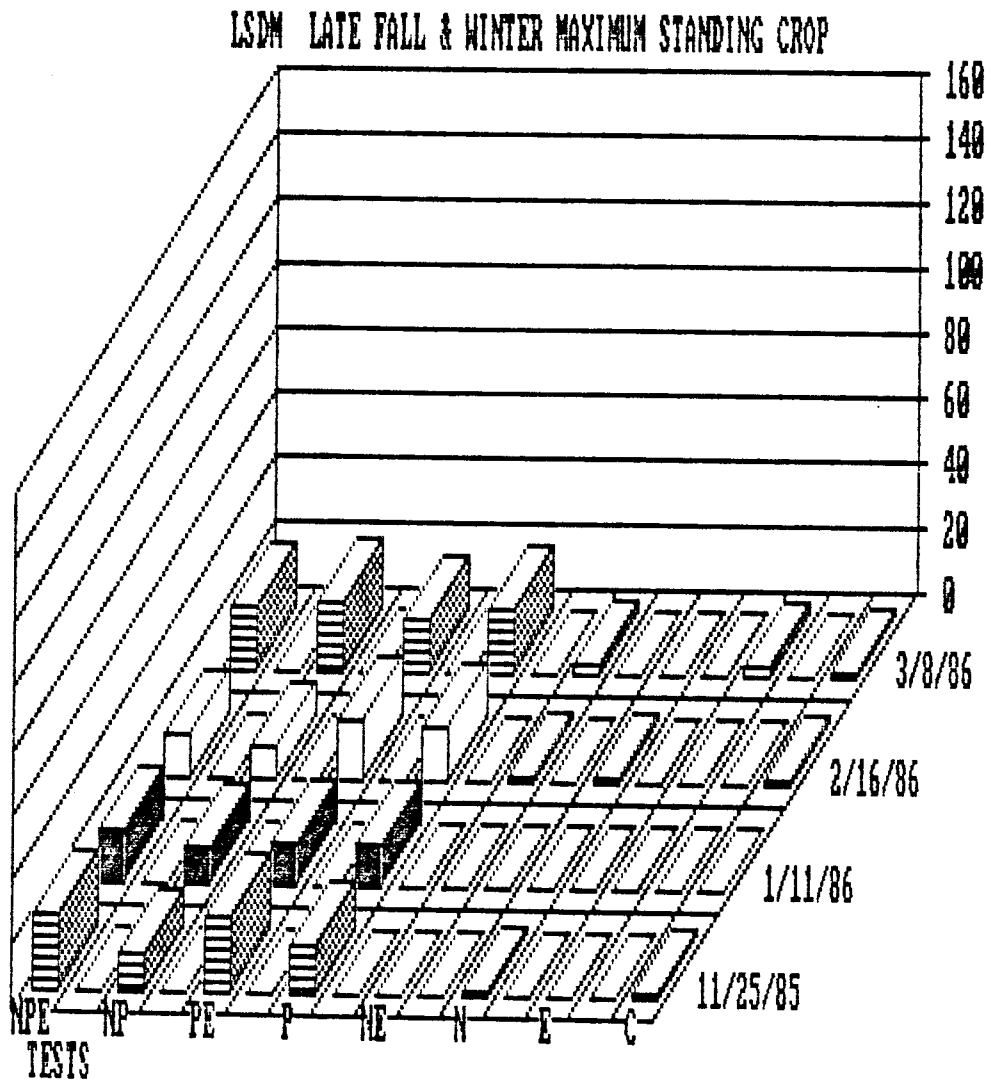


Figure 20. Lake Sequoyah Dam Late Fall and Winter Maximum Standing Crop. (MSC mg/l)

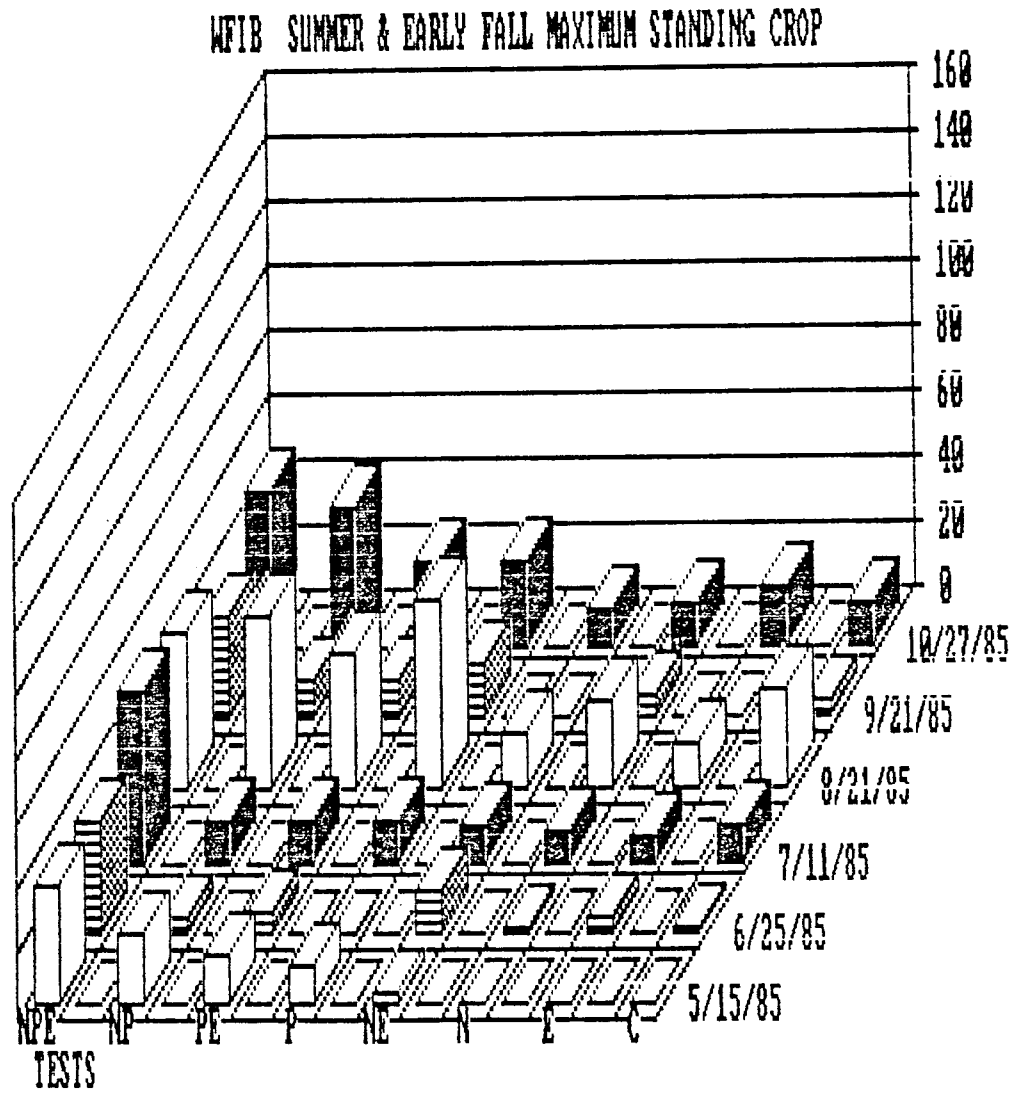


Figure 21. White River Iron Bridge Summer and Early Fall Maximum Standing Crop. (MSC mg/l)

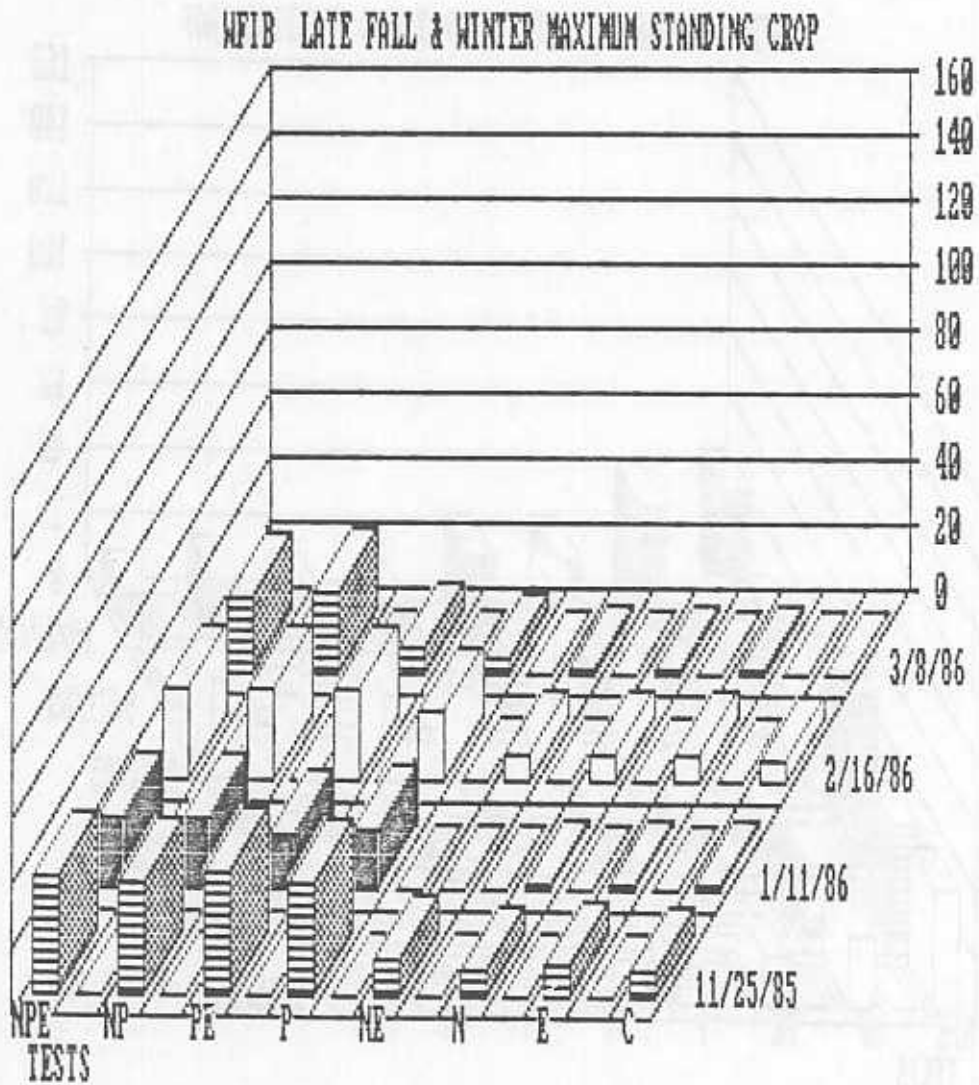


Figure 22. White River Iron Bridge Late Fall and Winter Maximum Standing Crop. (MSC mg/l)

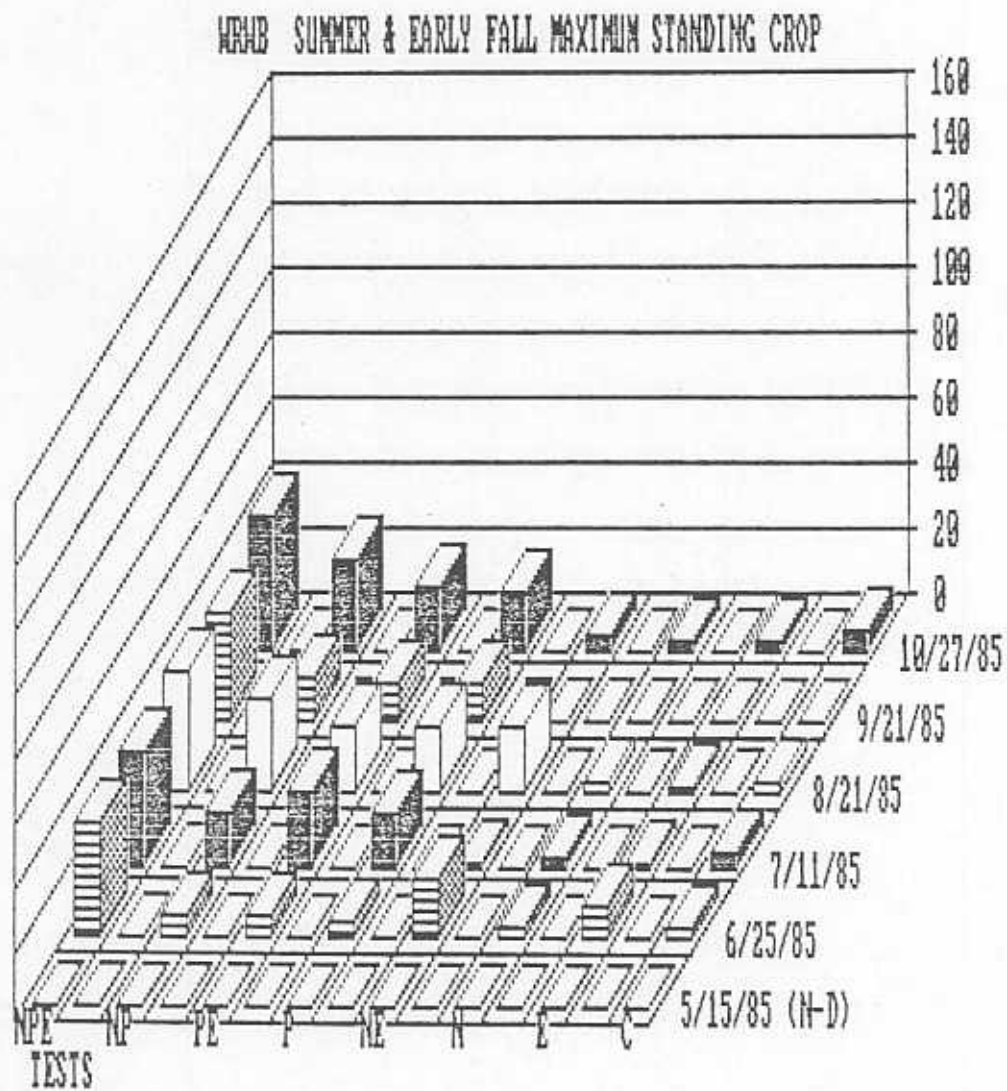


Figure 23. White River Wyman Bridge Summer and Early Fall Maximum Standing Crop. (MSC mg/l)

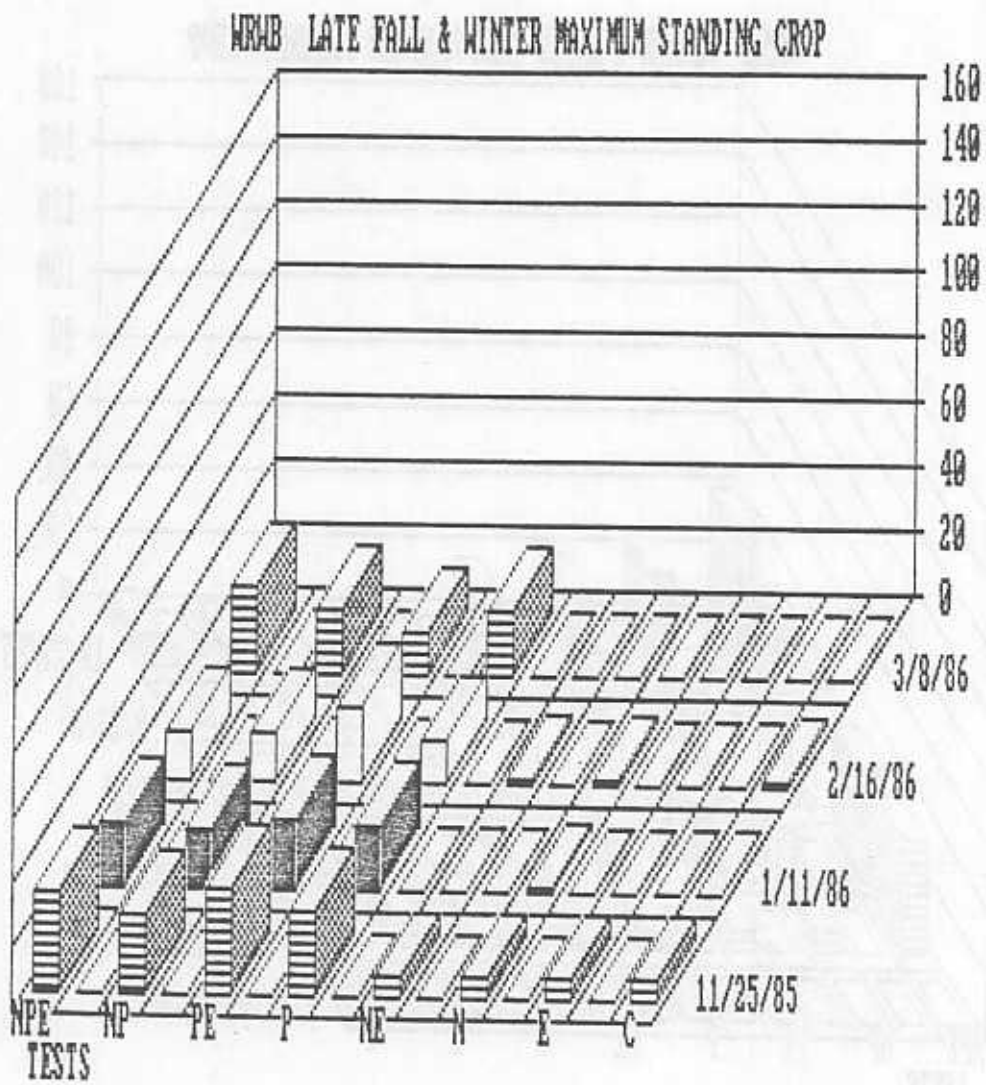


Figure 24. White River Wyman Bridge Late Fall and Winter Maximum Standing Crop. (MSC mg/l)

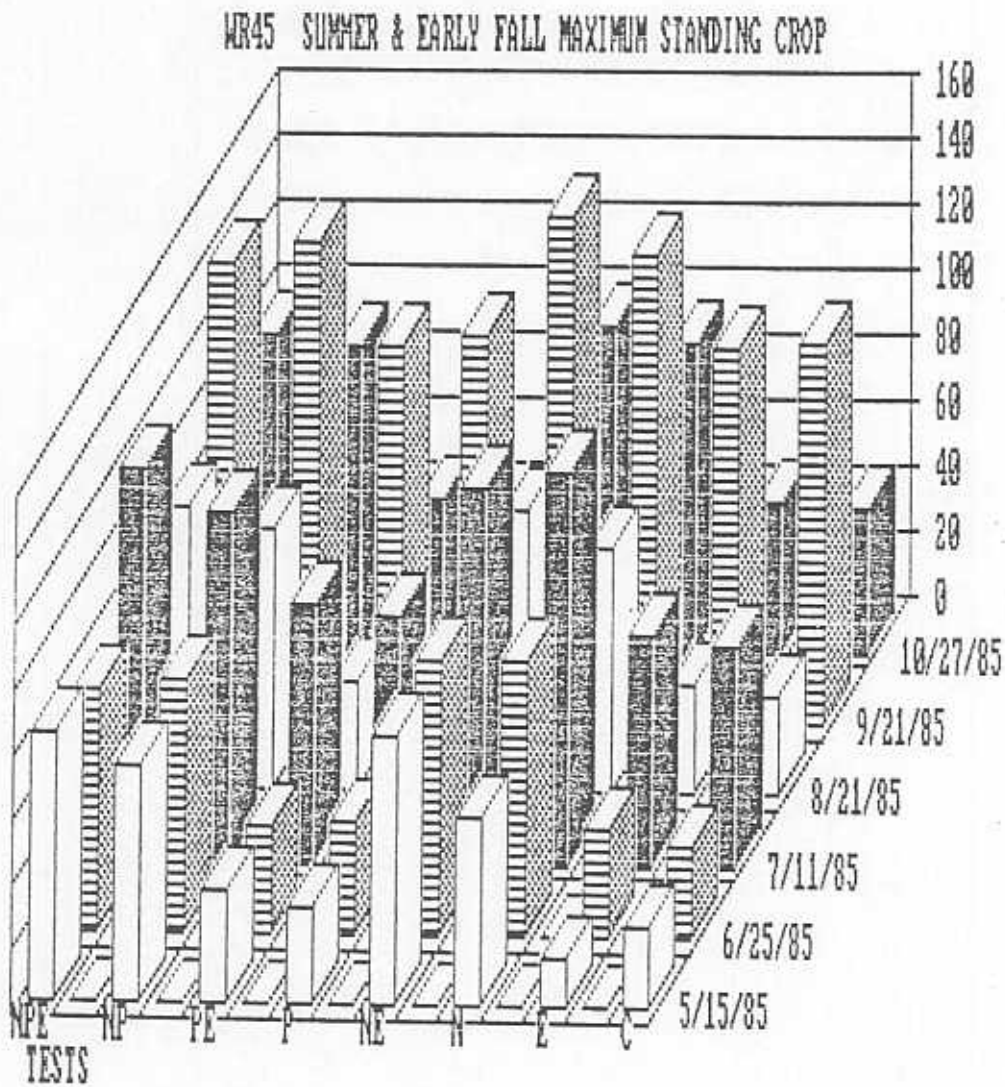


Figure 25. White River Highway 45 Bridge Summer and Early Fall Maximum Standing Crop. (MSC mg/l)

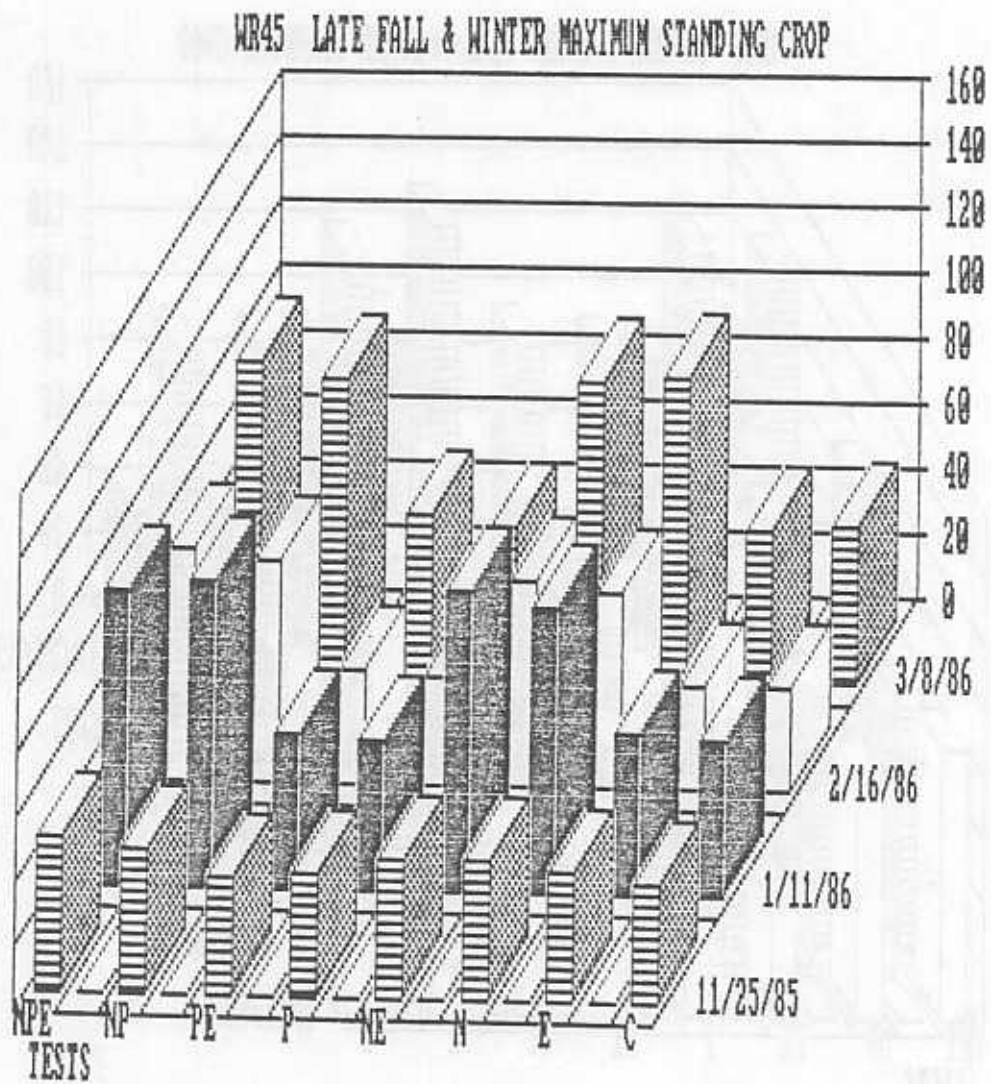


Figure 26. White River Highway 45 Bridge Late Fall and Winter Maximum Standing Crop. (MSC mg/l)

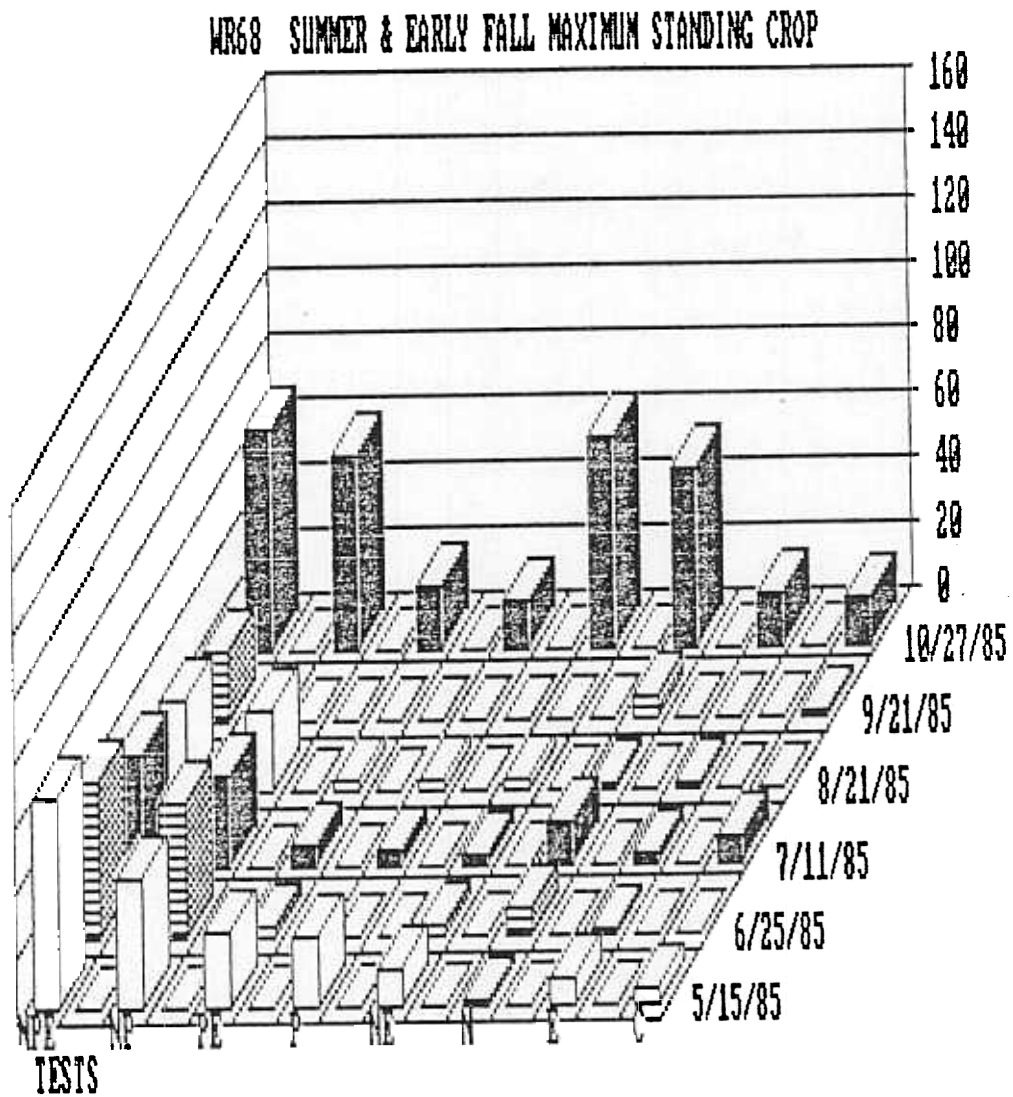


Figure 27. White River Highway 68 Bridge Summer and Early Fall Maximum Standing Crop. (MSC mg/l)

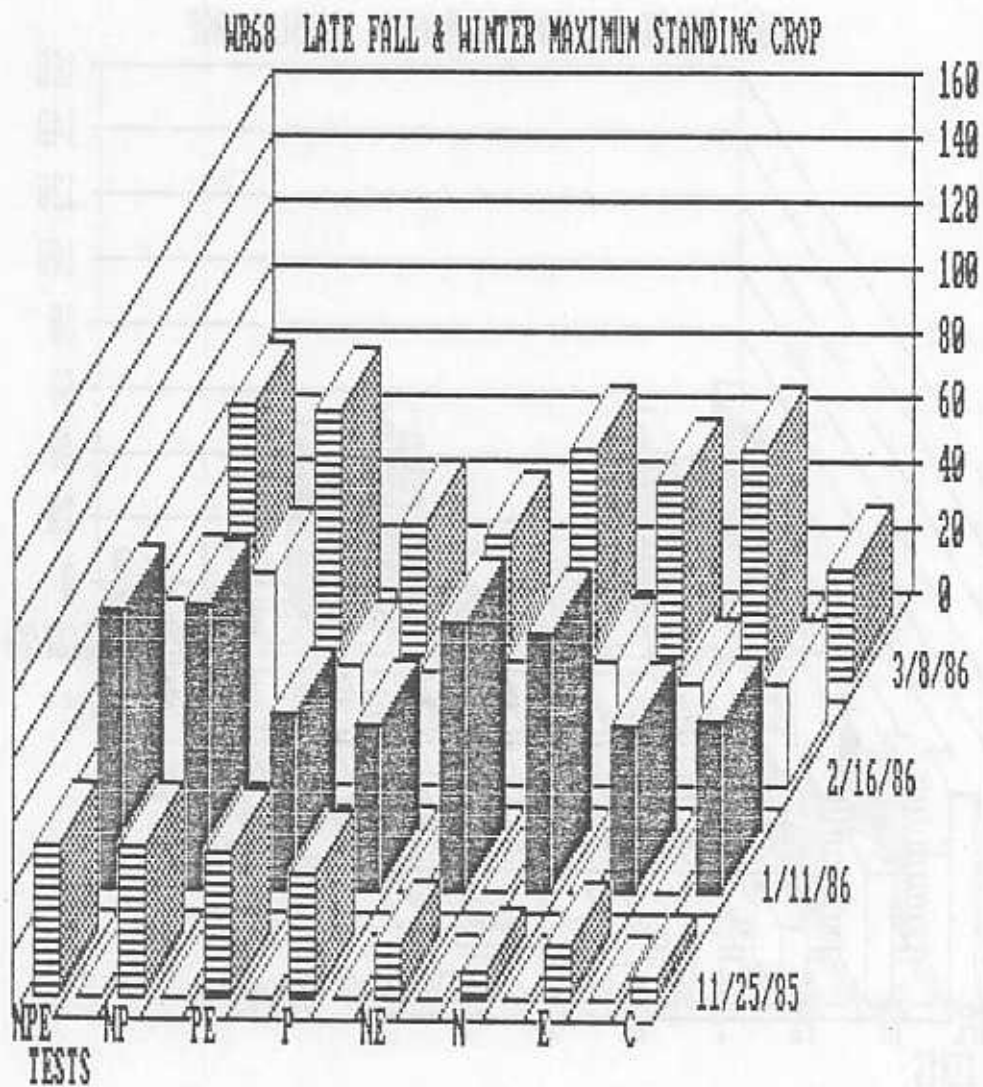


Figure 28. White River Highway 68 Bridge Late Fall and Winter Maximum Standing Crop. (MSC mg/l).

occurred in many of the nitrogen and phosphorus additions. With the addition of both nitrogen and phosphorus the maximum standing crops increased as was expected

The influence from the sewage effluent can be seen in those sites below the sewage treatment plant. The maximum standing crops of the control tests from 45 are much greater than those above the sewage plant. This nutrient influence continues downstream during the winter collections, as seen in the 68 data. During the summer and fall collections, the results from 68 resemble those of the upstream sample sites.

Nutrient Limitation

Nutrient limitation of the test water is better resolved through the analysis of assay results. From the results of this experiment, a number of nutrient limiting situations occur. If the test water was phosphorus limited, for example, the addition of phosphorus (0.05 mg/l) to the test water would increase the maximum standing crop. Similar results could occur under nitrogen limitation with the addition of nitrogen 1.00 mg/l. If the non-limiting nutrient (nitrogen in the case of phosphorus limitation) functions in a secondary way then the addition of both nitrogen and phosphorus would produce a MSC greater than that of the limiting nutrient added singly. This would be the case under phosphorus limitation if the addition of phosphorus changed the N:P ratio to a ratio below that of 11:1, resulting in nitrogen limitation. Under these conditions, the combined nutrient additions would produce a MSC similar to those calculated for the

ambient nitrogen yields with the addition of nitrogen

Conditions can occur in which neither nitrogen or phosphorus are strongly limiting growth over the other and resulting in co-limitation. Neither the addition of nitrogen or phosphorus produces increased growth, but the combination of both does. It can be determined which nutrient influences growth in a primary sense by comparing the assay produced maximum standing crops with those expected to occur. If the actual combined yield is more similar to the expected phosphorus addition yield, then phosphorus is the primarily nutrient influencing growth. The same would be true for nitrogen if the expected nitrogen addition yield was similar to the MSC produced by the combination of both nutrients.

Synergistic growth effects from the combination of both nutrients can be determined if the addition of both nitrogen and phosphorus produce a MSC greater than the single nutrient additions, as well as those expected to occur. Again, nitrogen or phosphorus may be the primary limiting nutrient, or they may be co-limiting.

Categories of nutrient limitation and influence can be classified based on the results of this research as follows: phosphorus limitation, nitrogen limitation, nitrogen and phosphorus co-limitation, nitrogen and phosphorus co-limitation with primary phosphorus influence, nitrogen and phosphorus co-limitation with primary nitrogen influence, nitrogen limitation with nitrogen and phosphorus synergistic influence, phosphorus limitation with nitrogen and phosphorus synergistic influence, and nitrogen and phosphorus co-limitation with

synergistic influence. Categorized assay results are found in Table 15

Relationships exist between the assay results and the seasonal and spatial test water collections. Spatial continuity exists with those sites above the sewage treatment plant and those below the plant. Temporal continuity exists between the summer and early fall (October) collections and the late fall and winter collections (November - March).

In general, the results from the sample sites above the sewage treatment plant during the late fall and winter collections indicate phosphorus limitation of growth production (Table 15a). These samples may also be phosphorus limited with nitrogen and phosphorus synergistic influence (Table 15g). The upstream sites during the summer and early fall collections have varied nutrient limiting influences. Many are phosphorus limited, with or without synergistic influence in combination with nitrogen additions. Others are nitrogen and phosphorus co-limited with synergistic influence (Table h).

Below the sewage treatment plant, assay results indicate nitrogen limitation. All collections from 45 are nitrogen limited except one collection occurring in February, which is nitrogen limited but with synergistic influence from the combination of both nitrogen and phosphorus (Tables 15b & f). Results from the collections at 68 vary in nutrient influence. Nitrogen plays a role in influencing growth production in all collections except on the November collection date,

which indicates strong phosphorus limitation. Three collections are nitrogen limited, and the other six are either co-limited by nitrogen and phosphorus or indicate synergistic influence with the addition of both nutrients

Biologically Available Nutrients

Another result of the Algal Assay Bottle Test is also used to determine biologically available concentrations of nitrogen and phosphorus. Nutrient concentrations are determined by the maximum standing crop produced by the additions of nitrogen or phosphorus with or without the addition of EDTA. This procedure can be used to verify chemical analysis and should theoretically correlate with such. However, according to Miller et al. (1978), failure of nutrient analysis to correlate with the biologically available nutrient determinations may be the result of the presence of biologically available organic nutrients, effects of other growth-limiting nutrients, the presence of inhibitory constituents, sediment and/or unreliable chemical analysis.

Calculated biologically available nutrients based on assay results are found in Table 16. These data are determined with both the presence and absence of EDTA. Correlations between nutrient analysis and biologically available nutrient determinations vary. Many measured and calculated biologically available nutrients correlate well; whereas, others indicate that the biologically available nutrients are much higher than measured and still others are much lower. There are no general trends among these data, and the signif-

icance of these findings is unknown. The lack of correlations between the measured nutrient levels and the biologically determined nutrient levels is probably due to a number of reasons, those mentioned above and those unknown. Since a number of test water samples suggest co-limitation, secondary limitation and synergistic influence, the biologically determined available nutrients would not be expected to correlate well with the analytically determined inorganic nutrient concentrations. Ambient phosphorus levels must be greater than 0.010 mg/l in order to accurately determine biologically available nutrient levels (Miller et al., 1978b). Chemical analysis shows that many samples are below this limit (Table 12).

Algal Growth Inhibition

Another purpose of the Algal Assay Bottle Test is to determine the extent of heavy metal toxicity and its interactions with nutrient regulation. If the presence of heavy metals inhibits the growth of the algae, it can be determined with the application of EDTA to the control and nutrient additions. EDTA combines with the heavy metals in solution, removing them from biological activity. Any increase in production, with the addition of EDTA over that of the treatment without EDTA, indicates that production may be inhibited by heavy metals.

Indications of growth inhibition during the summer and early fall can be seen graphically in Figures 13-28, and actual assay results are presented in Table 17. These data are expressed in percent inhibition (%I) in Table 18. To better resolve and analyze the greatest

cases of inhibition, those samples which had greater than 50% inhibition between the nitrogen and phosphorus combinations with and without EDTA were analyzed (Table 16). Analysis of variance between the two tests for each sample, along with the controls and the single nutrient additions with and without EDTA, was conducted to determine if the mean triplicate samples were significantly different. All reported data in Table 16 is significant at the $p < 0.01$ or greater than 99% significant.

Growth inhibition under these conditions occurs only during the summer and early fall collections, except on the August collection date. All three tributaries of the White River contain growth inhibition on one or more of these sample dates. The sample collections below the tributary confluences and above the sewage treatment plant also contain growth inhibition during June, July and September. No growth inhibition occurred at 45 any time during this study. This suggests that the heavy metals may already be complexed with the organics released in the sewage effluent, removing them from biological activity.

CONCLUSIONS

The concentrations of heavy metals in the White River vary significantly with location along the river, season and storm events. The local geology (especially presence of shale and relief, which will effect the suspended sediment load) and ground water hydrology (contribution of dissolved ions) probably are the major factors controlling the heavy metal concentrations for the sites. The sluggish

and stagnant conditions of the river during periods of low recharge cause increases in most parameters due to concentration by evaporation and the lack of dilution by storm runoff. These types of conditions can be used to explain the seasonal chemical variations of most parameters. However, the heavy metal seasonal and storm event variations appear to be controlled by the amount (and perhaps type) of fine suspended sediment load. For example, during the period of low recharge, the suspended sediment load would be low due to the lack of runoff and suspended sediments would tend to settle out of the water.

During storm events, parameter values exhibit variations that are significant and about the same magnitude as the seasonal variations. The heavy metals increase in concentration as flow increases, apparently because the suspended load also is increasing, and a portion of

suspended sediments and/or colloids are passing through the 0.40 micrometer pore-size membranes used for filtration of the water

The other parameters exhibit increases because of flushing effects (potassium) or dilution effects (e.g., calcium) due to rain runoff

Nutrient analysis of the collections predicts that most of the samples from the three tributaries and above the sewage treatment input are phosphorus limited. Below the sewage input the phosphorus concentration is great enough to cause nitrogen limitation to Highway 68. During low flow, phosphorus is processed between Highways 45 and 68 so that the 68 site may become phosphorus limited or nitrogen-phosphorus co-limited.

The MSC's are near detection limits above the sewage flow. In most instances, both nitrogen and phosphorus are necessary for significant growth. The MSC at the Highway 45 site tend to be greater than all other sites, including the Highway 68 site.

Inhibition of algal production by heavy metals was present at various times in all branches of the White River. The correlation of reduced production of biomass (MSC) with specific heavy metal toxicity was limited by the low MSC values. The lack of growth inhibition at the Highway 45 site may be associated with the organic input complexing with the metals and/or sedimentation, thereby removing them from biological activity. The variance between this study and that of Meyer and Green (1984) requires further investigation.

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APPENDIX TABLES

TABLE 1

SUMMARY OF ANALYTICAL METHODS AND PRECISION. THE METHOD USED IS INDICATED IN ().
IF NO (), THEN THE METHOD IS THE SAME AS OR SLIGHTLY MODIFIED EPA (1983) METHOD

Parameter	Method	Precision
Temperature	thermometer	± 0.5
pH	pH meter	± 0.1
Specific Conductivity $\mu\text{S}/\text{cm}$	conductivity meter	± 5
Total alkalinity as CaCO_3 mg/L	titration to methyl red end point with 0.02N sulfuric acid (APHA, 1985).	± 5
NO_3 as N mg/L	colorimetry cadmium reduction (Hach, 1984)	± 0.5
NH_4 as N mg/L	colorimetry phenate (APHA, 1985)	± 0.02
PO_4 (ortho, dissolved) as P mg/L	colorimetry ascorbic acid (Hach, 1984)	± 0.02
SO_4 mg/L	turbidimetric (Hach, 1984)	± 2.0
Cl mg/L	colorimetry Mercuric nitrate (Hach, 1984)	± 0.3
SiO_2 mg/L	colorimetry silicomolybdate (Hach, 1984)	± 2
Ca, Mg mg/L	AAS* $\text{C}_2\text{H}_2\text{-N}_2\text{O}$ flame, CsCl added	± 10%
Na, K mg/L	flame emission H_2 -air flame, CsCl added	± 10%
Zn, Pb, Cd, Fe, Cu, Ni, Co, Mn $\mu\text{g}/\text{L}$	C_2H_2 -air flame chelation - extraction method of Nix and Goodwin, 1974.	± 10%

*AAS - atomic absorption spectrometry.

TABLE 2

FIELD AND SELECTED LABORATORY ANALYSES FOR WHITE RIVER WATER SAMPLES
MAY, 1985 THROUGH APRIL, 1986

Site/ Date	Specific Conductivity µS/cm at 25° C	Total Alkalinity as mg/L CaCO ₃	pH	SO ₄ mg/L	Cl mg/L	Mg mg/L	Ca mg/L	Na mg/L	K mg/L	Silica mg/L
May 5/15/85										
BF	-	-	-	-	-	-	-	-	-	-
74	56	25	6.0	6.2	2.0	1.5	7	1.8	1.00	-
16	96	35	6.7	8.5	3.0	2.0	4	2.3	1.20	-
DM	69	35	7.0	7.5	2.0	1.6	9	1.8	1.10	-
IB	129	65	7.6	12.7	2.8	2.5	19	3.2	1.50	-
WB	-	-	-	-	-	-	-	-	-	-
45	119	50	6.9	10.2	5.3	2.2	16	4.3	1.85	-
68	102	45	7.3	9.8	2.3	2.3	14	2.7	1.45	-
June 6/25/85										
BF	167	80	7.4	13.0	3.0	3.1	26	4.5	1.75	-
74	118	55	7.4	5.5	3.0	2.4	18	3.1	1.50	-
16	141	70	7.5	6.5	2.5	2.6	22	3.2	1.60	-
DM	130	65	7.7	16.0	3.0	2.5	19	2.7	1.75	-
IB	206	85	7.7	5.0	4.5	3.5	32	5.3	2.00	-
WB	184	85	7.7	11.0	5.3	3.4	27	4.8	1.90	-
45	233	70	7.2	13.5	13.0	3.3	29	10.0	2.95	-
68	149	70	8.8	7.0	3.8	2.4	23	3.9	2.00	-
July 7/11/85										
BF	167	65	7.3	11.0	3.5	3.2	25	4.6	2.05	-
74	149	70	7.5	6.5	3.0	2.8	21	3.3	1.70	-

TABLE 2 (continued)

FIELD AND SELECTED LABORATORY ANALYSES FOR WHITE RIVER WATER SAMPLES
MAY, 1985 THROUGH APRIL, 1986

Site/ Date	Specific Conductivity $\mu\text{S}/\text{cm}$ at 25° C	Total Alkalinity as mg/L CaCO_3	pH	SO_4 mg/L	Cl mg/L	Mg mg/L	Ca mg/L	Na mg/L	K mg/L	Silica mg/L
16	145	65	7.3	5.0	3.0	2.9	23	3.4	1.65	-
DM	135	70	7.8	4.8	2.8	2.8	21	3.1	1.65	-
IB	213	85	7.6	13.0	4.3	3.8	33	4.9	1.80	-
WB	191	90	7.6	9.0	4.0	3.4	30	4.2	1.90	-
45	331	95	7.7	21.0	28.8	3.9	34	23.0	5.90	-
68	138	65	8.7	6.5	4.0	2.0	22	3.3	1.75	-
Aug 8/21/85										
BF	235	85	7.5	21.0	3.5	4.2	34	5.3	1.90	-
74	141	55	7.2	11.0	4.5	2.7	19	3.2	2.10	-
16	152	65	7.2	11.0	3.0	2.6	22	3.0	1.90	-
DM	138	60	7.1	5.0	3.0	2.8	21	2.9	2.15	-
IB	245	100	7.1	34.0	4.0	4.4	38	5.6	2.55	-
WB	178	80	7.2	12.0	4.0	3.4	26	3.8	2.25	-
45	190	80	7.0	18.0	6.5	3.0	26	6.4	2.90	-
68	156	70	8.1	6.0	4.5	2.0	24	3.7	1.95	-
Sept 9/21/85										
BF	210	85	6.4	17.5	3.5	3.7	31	5.2	1.65	-
74	130	50	6.9	6.5	3.0	2.4	17	3.0	1.70	-
16	154	65	6.3	7.0	3.0	2.8	21	3.4	2.10	-
DM	155	60	7.3	4.8	3.0	2.8	20	2.6	2.35	-
IB	249	90	7.2	21.0	4.0	4.0	34	5.7	2.55	-

TABLE 2 (continued)
 FIELD AND SELECTED LABORATORY ANALYSES FOR WHITE RIVER WATER SAMPLES
 MAY, 1985 THROUGH APRIL, 1986

Site/ Date	Specific Conductivity $\mu\text{S}/\text{cm}$ at 25° C	Total Alkalinity as mg/L CaCO_3	pH	SO_4 mg/L	Cl mg/L	Mg mg/L	Ca mg/L	Na mg/L	K mg/L	Silica mg/L	
Oct 10/27/85	WB	214	60	7.4	11.0	3.5	3.4	25	4.2	2.30	-
	45	357	90	7.3	26.5	28.0	4.1	36	22.0	5.90	-
	68	191	75	7.9	7.3	5.5	2.3	26	4.8	2.35	-
	BF	188	90	7.9	19.0	4.0	3.7	30	4.6	1.50	-
	74	69	30	7.5	4.5	3.0	1.7	8	2.1	1.35	-
	16	129	55	7.6	9.0	3.3	2.4	19	3.2	1.60	-
	DM	109	45	7.7	8.5	3.3	2.3	15	2.6	2.15	-
	IB	227	90	7.6	23.0	5.0	4.2	35	5.7	2.10	-
	WB	155	60	7.4	15.0	4.0	3.0	22	3.9	2.10	-
	45	195	65	6.9	16.5	8.5	3.2	26	7.5	2.85	-
68	204	85	8.6	14.5	8.5	2.8	30	6.9	2.90	-	
Nov 11/25/85	BF	118	55	7.5	10.0	3.0	2.4	17	2.7	1.25	7.1
	74	58	25	7.3	4.5	2.0	1.4	6	1.6	1.05	6.9
	16	95	35		6.0	3.5	1.9	12	2.4	1.35	7.5
	DM	63	25	7.0	5.0	2.5	1.5	6	1.6	1.20	7.1
	IB	149	55	7.0	16.0	3.0	2.8	21	3.4	1.55	7.5
	WB	84	30	6.6	7.0	3.0	1.9	10	2.0	1.35	7.3
	45	96	35	6.7	8.5	2.5	1.9	12	2.6	1.40	7.5
	68	91	40	6.7	6.5	3.0	1.7	14	1.8	2.10	6.9

TABLE 2 (continued)
FIELD AND SELECTED LABORATORY ANALYSES FOR WHITE RIVER WATER SAMPLES
MAY, 1985 THROUGH APRIL, 1986

Site/ Date	Specific Conductivity $\mu\text{S}/\text{cm}$ at 25° C	Total Alkalinity as mg/L CaCO_3	pH	SO_4 mg/L	Cl mg/L	Mg mg/L	Ca mg/L	Na mg/L	K mg/L	Silica mg/L
Jan 1/11/86										
BF	102	45	7.1	10.3	3.5	3.1	17	2.3	0.87	6.7
74	55	25	6.6	5.3	2.5	1.5	7	1.7	0.82	7.8
16	88	40	7.0	8.7	3.3	2.0	14	2.2	0.98	7.7
DM	66	30	6.9	6.1	3.0	1.8	9	2.0	1.15	6.7
IB	138	65	7.4	19.2	4.3	3.1	23	4.1	1.21	6.7
WB*	93	40	7.1	10.0	3.0	2.1	13	2.5	0.87	9.2
45*	114	50	7.1	13.5	6.8	2.5	17	5.8	1.60	10.5
68*	126	50	7.3	10.5	4.3	2.2	18	3.3	1.11	-
Feb 2/6/86										
BF	104	50	6.8	9.1	3.0	2.0	14	2.3	0.92	7.4
74	60	45	6.7	6.0	2.8	1.4	7	1.7	0.82	7.4
16	91	20	6.7	10.8	3.3	2.0	10	2.4	1.02	7.6
DM	54	25	6.7	5.8	2.3	1.4	7	1.6	0.82	7.0
IB	145	55	7.2	20.0	4.8	2.8	18	4.0	1.11	7.9
WB	94	35	6.9	10.8	3.0	1.9	12	2.4	0.92	7.6
45	102	40	7.0	14.0	4.0	2.1	12	3.4	1.02	7.6
68	105	45	7.2	12.0	4.3	2.0	15	3.0	1.15	8.3
Mar 3/8/86										
BF	106	50	7.1	10.0	3.3	2.1	15	2.5	0.92	4.9
74	51	25	7.0	4.7	2.0	1.8	6	1.5	0.72	5.4

TABLE 2 (continued)

FIELD AND SELECTED LABORATORY ANALYSES FOR WHITE RIVER WATER SAMPLES
MAY, 1985 THROUGH APRIL, 1986

Site/ Date	Specific Conductivity $\mu\text{S}/\text{cm}$ at 25° C	Total Alkalinity as mg/L CaCO_3	pH	SO_4 mg/L	Cl mg/L	Mg mg/L	Ca mg/L	Na mg/L	K mg/L	Silica mg/L
16	89	40	7.3	7.7	2.0	1.3	12	2.1	0.98	4.3
DM	60	25	7.5	4.1	2.3	1.4	8	1.7	0.82	4.8
IB	129	60	7.7	15.3	3.3	2.6	20	3.4	1.05	3.5
WB	67	40	7.6	7.5	2.5	1.2	10	2.1	0.87	4.6
45	131	55	7.4	10.7	5.0	2.1	16	5.3	0.56	5.7
68	121	55	7.5	9.0	3.8	2.0	20	3.6	1.40	7.0
Apr 4/11/86										
BF	97	50	7.6	6.6	2.5	1.8	12	1.9	1.02	8.5
74	50	25	6.8	3.1	2.3	1.3	6	1.3	0.92	9.4
16	84	45	7.6	5.6	2.3	1.7	11	1.8	1.11	8.7
DM	52	25	7.2	3.4	2.0	1.2	5	1.1	0.82	10.0
IB	115	50	7.5	10.0	3.0	2.1	15	2.2	1.02	10.1
WB	66	30	7.3	5.0	1.5	1.4	8	1.4	0.98	11.3
45	78	35	7.2	5.5	2.8	1.4	9	1.6	1.55	21.1
68	77	35	7.1	6.1	2.3	1.4	8	1.9	0.98	11.7

* No acid added in field

TABLE 3

SEASONAL HEAVY METAL ANALYSES FOR ALL SITES AND STREAM FLOW DATA FOR SITE IB

Site/Date	Flow cfs	Mn µg/L	Pb µg/L	Fe µg/L	Zn µg/L	Ni µg/L	Co µg/L	Cu µg/L	Cd µg/L
May 5/15/85									
BF	-	-	-	-	-	-	-	-	-
74	-	20	28	80	10	14	5	2	2
16	-	26	17	56	5	10	<5	<2	<1
DM	-	32	94	89	23	39	25	2	5
IB	-	16	88	169	23	43	25	2	7
WB	-	-	-	-	-	-	-	-	-
45	-	89	64	110	14	26	20	<2	3
68	-	91	46	110	12	31	15	2	3
June 6/25/85									
BF	-	55	12	80	18	6	<3	5	1
74	-	58	26	170	15	20	5	2	1
16	-	174	22	208	15	14	5	2	2
DM	-	251	29	166	17	14	7	2	5
IB	29	102	22	288	14	12	5	2	2
WB	-	223	47	285	24	17	9	<2	8
45	-	255	47	319	26	14	7	7	7
68	-	62	22	64	15	4	5	<2	4
July 7/11/85									
BF	-	104	29	36	18	9	9	<2	2
74	-	42	5	102	14	4	<3	<2	1
16	-	24	<5	59	10	<4	<3	<2	1
DM	-	60	12	74	13	6	3	<2	2
IB	29	121	26	293	26	14	7	2	6
WB	-	223	55	149	22	25	13	<2	8

TABLE 3 (continued)

SEASONAL HEAVY METAL ANALYSES FOR ALL SITES AND STREAM FLOW DATA FOR SITE IB

Site/Date	Flow cfs	Mn µg/L	Pb µg/L	Fe µg/L	Zn µg/L	Ni µg/L	Co µg/L	Cu µg/L	Cd µg/L	
August 8/21/85	45	-	207	26	230	15	25	7	2	2
	68	-	21	18	27	13	9	3	<2	1
	BF	-	50	5	60	22	4	<3	3	1
	74	-	62	18	223	21	9	5	3	2
	16	-	82	18	238	22	12	5	5	1
	DM	-	141	12	199	13	9	<3	<2	2
	IB	44	110	5	391	14	9	5	<2	1
	WB	-	223	33	285	17	17	9	<2	6
Sept 9/2/85	45	-	200	18	450	24	28	17	3	9
	68	-	50	8	80	15	4	3	<2	<1
	BF	-	53	12	24	6	9	2	1	3
	74	-	95	21	164	5	9	6	<1	4
	16	-	70	26	112	10	18	6	1	5
	DM	-	126	26	209	11	23	11	1	5
	IB	29	106	17	463	7	14	2	1	4
	WB	-	357	49	541	16	32	16	1	7
Oct 10/27/85	45	-	580	74	425	22	55	26	1	9
	68	-	110	31	146	12	23	11	1	6
	BF	-	11	<3	2	7	<5	<2	<1	1
	74	-	23	8	96	14	9	2	<1	3
	16	-	102	26	328	19	18	6	1	4
	DM	-	62	26	112	14	18	6	<1	4

TABLE 3 (continued)

SEASONAL HEAVY METAL ANALYSES FOR ALL SITES AND STREAM FLOW DATA FOR SITE IB

Site/Date	Flow cfs	Mn µg/L	Pb µg/L	Fe µg/L	Zn µg/L	Ni µg/L	Co µg/L	Cu µg/L	Cd µg/L	
Nov 11/25/85	IB	24	83	21	290	18	14	6	1	3
	WB	-	199	59	491	27	41	21	1	8
	45	-	439	64	747	33	41	21	1	7
	68	-	22	3	50	8	9	<2	1	2
	BF	-	11	3	46	14	5	<2	<1	8
	74	-	13	12	65	16	9	2	<1	3
	16	-	21	12	65	18	9	2	<1	3
	DM	-	44	35	205	24	23	11	1	7
	IB	90	57	21	200	24	14	2	1	5
	WB	-	50	26	248	22	18	2	1	5
Jan 1/11/86	45	-	56	21	312	24	14	2	1	5
	68	-	48	26	274	19	14	2	1	5
	BF	-	27	18	61	24	13	7	<2	<1
	74	-	32	13	253	19	8	4	<2	<1
	16	-	38	7	114	24	13	7	<2	3
	DM	-	58	7	231	14	13	4	<2	3
	IB	24	90	39	345	36	28	10	<2	5
	WB	-	7	<5	<4	<3	8	4	<2	<1
	45	-	4	<5	<4	<3	8	4	<2	<1
	68	-	6	7	<4	5	8	4	<2	<1
Feb 2/6/86	IB	-	15	13	160	26	18	4	<2	3
	BF	-	13	13	137	31	13	7	<2	<1
	74	-	13	13	137	31	13	7	<2	<1

TABLE 3 (continued)

SEASONAL HEAVY METAL ANALYSES FOR ALL SITES AND STREAM FLOW DATA FOR SITE IB

Site/Date	Flow cfs	Mn µg/L	Pb µg/L	Fe µg/L	Zn µg/L	Ni µg/L	Co µg/L	Cu µg/L	Cd µg/L
16	-	15	13	146	31	13	4	<2	3
DM	-	29	18	205	24	13	4	<2	3
IB	117	25	23	160	56	13	7	<2	3
WB	-	27	23	191	52	25	4	<2	<1
45	-	48	28	298	48	13	7	<2	3
68	-	60	13	247	17	8	4	<2	<1
March 3/8/86									
BF	-	31	45	56	35	10	6	<2	3
74	-	23	32	78	17	7	6	<2	2
16	-	23	29	53	22	4	3	<2	2
DM	-	82	35	212	27	7	9	2	2
IB	33	71	52	216	33	13	12	2	4
WB	-	106	42	209	25	10	6	<2	3
45	-	460	66	2343	51	26	18	3	9
68	-	332	59	3121	59	16	13	3	5
April 4/11/86									
BF	-	13	19	28	46	4	3	3	1
74	-	47	29	103	20	4	6	2	<1
16	-	24	19	61	13	<3	3	<2	5
DM	-	42	29	48	13	<3	3	<2	<1
IB	125	52	29	98	15	4	6	2	1
WB	-	61	32	112	15	4	6	<2	<1
45	-	71	39	147	20	7	9	<2	2
68	-	54	52	61	22	4	6	<2	2

TABLE 4

STREAM FLOW, FIELD MEASUREMENTS AND CATION ANALYSES FOR FIRST RAIN EVENT.
 SAMPLES WERE COLLECTED AT SITE IB. RAIN BEGAN AT 4:15 AM 9/25/85.

Date	Time	Flow cfs	Specific Conductivity $\mu\text{S}/\text{cm}$ 25°C	Total Alkalinity mg/L as CaCO_3	pH	Mg mg/L	Ca mg/L	Na mg/L	K mg/L
9/23/85	8:30a	11	228	85	6.9	3.9	32.8	5.7	2.60
9/25/85	8:15a	7	220	75	6.8	4.0	32.8	6.1	2.55
	11:15a	74	218	75	7.0	3.9	32.4	5.8	2.55
	2:30p	118	245	80	7.0	4.2	34.0	6.9	2.80
	3:00p	82	252	90	6.9	4.2	34.4	7.0	3.20
	7:00p	47	225	85	7.0	4.0	32.0	5.8	3.20
9/26/85	8:15a	24	196	75	6.9	3.6	28.4	5.1	3.10
	8:00p	12	218	70	6.9	3.9	30.4	5.7	3.20
9/27/85	1:00p	8	258	80	7.5	4.2	33.2	6.1	2.85
9/28/85	7:30a	7	228	80	7.4	4.3	33.2	6.3	2.90
9/29/85	3:45p	7	239	85	7.6	4.1	32.8	5.8	2.55

TABLE 5
 ANION AND AMMONIUM-N ANALYSES FOR FIRST RAIN EVENT.
 SAMPLES WERE COLLECTED AT SITE IB.
 RAIN BEGAN AT 4:15 AM 9/25/85.

Date	Time	SO ₄ mg/L	Cl mg/L	NO ₃ -N mg/L	Ortho- PO ₄ mg/L	NH ₄ -N mg/L
9/23/85	8:30a	-	-	-	-	-
9/25/85	8:15a	22.0	5.0	0.15	0.01	<0.01
	11:15a	22.5	5.0	0.22	0.02	<0.01
	2:30p	25.0	6.0	0.28	0.01	<0.01
	3:00p	28.5	6.5	0.45	0.03	0.11
	7:00p	27.0	5.5	0.73	0.12	0.32
9/26/85	8:15a	26.5	4.5	0.68	0.09	0.23
	8:00p	29.5	4.8	0.62	0.09	0.08
9/27/85	1:00p	31.5	4.8	0.45	0.05	0.04
9/28/85	7:30a	31.0	4.8	0.34	0.02	0.02
9/29/85	3:45p	26.0	4.5	0.44	0.01	<0.01

71

TABLE 6
 HEAVY METAL ANALYSES FOR FIRST RAIN EVENT.
 SAMPLES WERE COLLECTED AT SITE IB. RAIN BEGAN AT 4:15 AM 9/25/85.

Date	Time	Mn μg/L	Pb μg/L	Fe μg/L	Zn μg/L	Ni μg/L	Co μg/L	Cu μg/L	Cd μg/L
9/23/85	8:30a	56	10	95	9	8	7	4	<1
9/25/85	8:15a	65	10	284	11	4	7	2	<1
	11:15a	54	19	161	12	8	7	2	1
	2:30p	69	42	267	22	20	20	2	4
	3:00p	122	38	600	22	16	15	4	3
	7:00p	160	56	1085	44	24	24	7	4
	8:15a	60	6	430	12	4	7	<2	<1
9/26/85	8:00p	60	10	430	12	<4	7	2	<1
	1:00p	47	10	279	12	4	7	<2	1
9/27/85	7:30a	35	15	171	11	<4	7	<2	<1
9/28/85	3:45p	30	13	91	12	<4	7	<2	<1

TABLE 7
 COMPARISON OF THE EFFECT OF DIFFERENT PORE-SIZED MEMBRANES ON THE HEAVY
 METAL CONCENTRATIONS OF FILTERED STREAM SAMPLES.
 SAMPLES WERE COLLECTED AT SITE IB IN MARCH, 1986.

Pore size microns	Mn μg/L	Pb μg/L	Fe μg/L	Zn μg/L	Co μg/L	Ni μg/L	Cu μg/L	Cd μg/L
no filter	180	<5	1599	19	7	<5	<2	<1
0.40	48	<5	398	41	4	<5	<2	<1
0.30	7	<5	12	14	<4	<5	<2	<1
0.22	3	13	8	17	<4	8	<2	4
0.10	6	<5	12	8	4	<5	<2	<1

TABLE 8

STREAM FLOW, FIELD MEASUREMENTS AND CATION ANALYSES FOR SECOND RAIN EVENT.

SAMPLES WERE COLLECTED AT SITE 1B. RAIN BEGAN AT 11:30 AM 10/18/85.

Date	Time	Flow cfs	Specific Conductivity $\mu\text{S}/\text{cm}$ 25°C	Total Alkalinity mg/L as CaCO_3	pH	Mg mg/L	Ca mg/L	Na mg/L	K mg/L
10/18/85	3:30p	500	238	90	7.2	4.5	34.0	6.7	3.50
	4:30p	560	181	70	7.1	3.8	28.8	4.7	4.10
	5:30p	540	167	65	6.9	3.7	25.2	4.6	4.20
	7:00p	500	170	65	6.9	3.7	25.6	4.4	3.70
	11:00p	510	160	65	7.2	3.5	23.2	4.2	3.55
10/19/85	7:00a	230	157	70	7.2	3.2	24.0	3.2	3.00
	1:30p	152	155	65	7.5	3.1	22.4	3.4	2.90
	9:30p	118	170	65	7.4	3.3	23.2	3.8	2.65
10/20/85	12:30p	84	199	75	7.7	3.5	25.6	4.2	2.30
10/21/85	8:30p	64	200	75	7.3	3.7	27.6	4.4	2.25
10/22/85	12:30p	48	215	80	7.6	3.9	29.2	4.6	2.20
10/24/85	1:30p	36	217	85	7.6	4.0	31.6	5.0	2.20

TABLE 9

ANION, AMMONIUM-N AND SILICA ANALYSES FOR SECOND RAIN EVENT.

SAMPLES WERE COLLECTED AT SITE IB.

RAIN BEGAN AT 11:30 AM 10/18/85.

Date	Time	SO ₄ mg/L	Cl mg/L	NO ₃ -N mg/L	Ortho- PO ₄ mg/L	NH ₄ -N mg/L	Silica mg/L
10/18/85	3:30p	29	7.3	.40	.04	.07	9.0
	4:30p	23.5	4.5	.40	.07	.06	6.4
	5:30p	23.5	4.5	.30	.08	.12	7.0
	7:00p	19.5	4.5	.29	.07	.03	8.2
	11:00p	19	3.8	.23	.06	<.01	8.6
10/19/85	7:00a	14	3.5	.25	.06	<.01	9.8
	1:30p	15	3.3	.31	.05	.04	11.6
	9:30p	16	3.5	.33	.04	<.01	10.4
10/20/85	12:30p	18	3.8	.67	.03	.02	11.8
10/21/85	8:30p	19	4.0	.72	.03	.03	11.2
10/22/85	12:30p	19.5	4.0	.42	.01	<.01	10.4
10/24/85	1:30p	22	4.5	.42	.02	<.01	-

TABLE 10

HEAVY METAL ANALYSES FOR SECOND RAIN EVENT.

SAMPLES WERE COLLECTED AT SITE 18. RAIN BEGAN AT 11:30 AM 10/18/85.

Date	Time	Mn µg/L	Pb µg/L	Fe µg/L	Zn µg/L	Ni µg/L	Co µg/L	Cu µg/L	Cd µg/L
10/18/85	3:30p	104	38	416	26	12	15	2	4
	4:30p	189	75	773	44	32	32	4	7
	5:30p	166	66	795	42	41	32	4	7
	7:00p	102	52	363	28	29	24	2	4
	11:00p	107	75	314	33	39	32	2	7
10/19/85	7:00p	143	56	76	36	24	24	2	7
	1:30p	116	54	126	30	24	20	<2	7
	9:30p	60	38	279	24	24	20	2	18
10/20/85	12:30p	27	19	81	14	8	15	<2	1
10/21/85	8:30p	35	15	127	12	4	7	2	1
10/22/85	12:30p	29	<6	50	6	<4	7	<2	<1
10/24/85	1:30p	52	19	68	26	8	15	2	1

TABLE 11
 MAXIMUM STANDING CROP (MSC). DRY WEIGHT BIOMASS (mg/l).

SITE	DATE	C	E	N	NE	P	PE	NP	NPE
WFBF	05/15/85	ND	ND	ND	ND	ND	ND	ND	ND
WFBF	06/25/85	4.0	3.3	6.7	12.0	4.0	6.7	2.0	38.0
WFBF	07/11/85	10.0	8.7	6.7	7.3	12.7	19.3	14.7	22.7
WFBF	08/21/85	22.7	12.7	16.0	14.7	41.3	31.3	50.0	49.3
WFBF	09/21/85	1.3	2.7	2.7	3.3	10.0	9.3	24.7	39.3
WFBF	10/27/85	11.3	8.7	12.0	10.7	20.7	22.7	34.7	42.0
WFBF	11/25/85	7.3	10.7	9.3	10.0	24.0	27.3	25.3	20.7
WFBF	01/11/86	1.3	3.3	4.0	6.0	15.3	18.0	18.0	19.3
WFBF	02/16/86	6.0	3.3	6.7	5.3	20.7	24.7	28.0	28.0
WFBF	03/08/86	2.0	1.1	4.0	4.7	14.0	11.3	23.1	28.7
WFIB	05/15/85	0.0	0.0	0.0	3.3	12.0	15.3	21.3	36.0
WFIB	06/25/85	1.3	5.3	2.0	13.3	0.0	6.0	4.7	35.3
WFIB	07/11/85	12.0	9.3	10.0	13.7	12.7	14.0	13.3	53.3
WFIB	08/21/85	29.3	14.0	27.3	16.7	58.0	40.7	54.0	48.7
WFIB	09/21/85	5.3	0.0	6.7	0.0	16.0	10.7	11.3	30.7
WFIB	10/27/85	12.7	18.0	13.3	11.3	27.3	26.0	44.0	48.7
WFIB	11/25/85	8.7	10.0	8.7	11.3	35.3	38.7	35.3	36.7
WFIB	01/11/86	2.0	0.7	0.7	0.0	19.3	16.0	22.0	22.0
WFIB	02/16/86	7.3	8.7	8.0	8.7	22.0	28.0	28.0	28.0
WFIB	03/08/86	0.7	1.3	1.3	2.0	5.3	8.7	24.7	22.7
MF16	05/15/85	0.0	0.0	0.0	0.0	2.0	17.3	3.3	20.0
MF16	06/25/85	0.0	5.3	0.7	11.3	0.0	2.0	6.7	13.3

TABLE 11 (continued)
 MAXIMUM STANDING CROP (MSC). DRY WEIGHT BIOMASS (mg/l).

SITE	DATE	C	E	N	NE	P	PE	NP	NPE
MF16	07/11/85	10.0	8.7	7.3	9.3	6.0	16.7	6.7	40.0
MF16	08/21/85	4.0	6.7	7.3	7.3	28.7	31.3	35.3	29.3
MF16	09/21/85	0.0	0.0	0.0	0.0	0.0	3.3	14.7	32.0
MF16	10/27/85	2.0	2.0	2.0	1.3	23.7	28.0	22.0	34.7
MF16	11/25/85	3.3	4.0	6.0	4.0	29.3	31.3	19.3	35.3
MF16	01/11/86	0.0	0.0	0.0	0.0	14.0	16.0	11.3	21.3
MF16	02/16/86	0.0	0.7	0.0	9.3	28.7	24.7	22.7	29.3
MF16	03/08/86	0.0	0.0	0.0	1.3	18.7	18.0	23.3	22.7
EF74	05/15/85	0.0	0.0	0.0	0.0	0.0	16.7	0.0	20.0
EF74	06/25/85	0.0	7.3	0.0	12.0	0.0	10.7	0.7	30.7
EF74	07/11/85	4.0	6.7	5.3	6.7	15.3	12.7	20.7	32.7
EF74	08/21/85	0.7	0.7	2.0	2.7	24.7	32.7	32.7	44.0
EF74	09/21/85	0.0	0.0	0.0	0.0	1.3	2.7	6.7	30.0
EF74	10/27/85	4.0	1.3	8.0	0.7	22.7	21.3	14.0	34.7
EF74	11/25/85	6.0	4.0	4.0	1.3	21.3	24.7	18.7	28.7
EF74	01/11/86	6.0	6.0	0.0	0.0	13.3	9.3	11.3	14.0
EF74	02/16/86	2.0	2.0	2.0	2.0	16.0	20.0	14.7	28.0
EF74	03/08/86	0.0	0.0	0.0	0.0	16.0	14.0	22.0	22.0
LSDM	05/15/85	0.0	0.0	0.0	0.0	14.0	14.0	13.3	26.0
LSDM	06/25/85	1.3	2.7	0.0	14.7	0.0	1.3	0.0	20.7
LSDM	07/11/85	2.0	2.0	0.7	2.7	6.7	6.7	12.7	24.7
LSDM	08/21/85	0.7	4.0	0.0	2.7	12.0	14.0	35.3	32.7
LSDM	09/21/85	0.0	0.0	0.0	0.0	2.7	2.0	7.3	30.0

TABLE 11 (continued)
 MAXIMUM STANDING CROP (MSC). DRY WEIGHT BIOMASS (mg/l).

SITE	DATE	C	E	N	NE	P	PE	NP	NPE
LSDM	10/27/85	6.7	3.3	4.7	5.3	15.3	14.7	23.3	42.7
LSDM	11/25/85	2.0	0.0	1.3	0.0	14.7	22.7	12.0	22.7
LSDM	01/11/86	0.0	0.0	0.0	0.0	13.3	13.3	10.7	16.7
LSDM	02/16/86	1.3	0.0	0.7	0.7	17.3	19.3	10.0	12.7
LSDM	03/08/86	1.3	2.7	0.7	3.3	19.3	17.3	22.0	20.7
WRWB	05/15/85	ND	ND	ND	ND	ND	ND	ND	ND
WRWB	06/25/85	2.7	10.0	2.7	18.0	4.7	7.3	6.0	34.7
WRWB	07/11/85	4.7	2.0	4.0	0.7	16.0	22.7	16.7	34.7
WRWB	08/21/85	2.7	1.3	3.3	3.3	20.0	20.0	29.3	36.7
WRWB	09/21/85	0.0	0.0	0.0	0.0	12.0	10.7	14.0	34.0
WRWB	10/27/85	6.0	4.0	2.7	4.7	18.7	20.0	28.7	42.0
WRWB	11/25/85	6.0	6.0	6.7	6.7	27.3	32.7	24.7	32.0
WRWB	01/11/86	0.0	0.0	1.3	0.0	19.3	20.7	18.7	20.0
WRWB	02/16/86	1.3	0.0	1.3	2.0	13.3	24.0	15.3	15.3
WRWB	03/08/86	0.0	0.0	0.0	0.0	20.0	12.7	19.3	26.7
WR45	05/15/85	24.7	15.3	59.3	82.7	30.0	34.7	73.3	83.3
WR45	06/25/85	28.7	34.0	84.7	85.3	35.3	32.7	78.7	75.3
WR45	07/11/85	68.7	71.3	121.3	116.0	76.0	80.0	108.7	120.7
WR45	08/21/85	30.0	32.7	75.3	86.0	32.0	32.7	80.0	86.0
WR45	09/21/85	116.0	115.3	144.0	155.3	118.7	114.7	147.3	140.0
WR45	10/27/85	45.3	47.3	94.7	100.0	45.3	47.3	93.3	96.7
WR45	11/25/85	26.0	40.0	42.7	44.0	38.7	37.3	45.3	48.0
WR45	01/11/86	48.7	50.0	88.7	92.7	46.7	48.0	95.3	91.3

TABLE 11 (continued)
 MAXIMUM STANDING CROP (MSC). DRY WEIGHT BIOMASS (mg/l).

SITE	DATE	C	E	N	NE	P	PE	NP	NPE
WR45	02/16/86	32.0	30.7	60.0	63.3	34.0	34.7	68.7	70.7
WR45	03/08/86	48.7	46.7	94.0	91.3	47.3	50.0	91.3	97.3
WR68	05/15/85	4.7	9.3	1.3	12.0	22.0	22.7	40.0	64.7
WR68	06/25/85	0.0	0.7	8.0	3.3	0.0	2.7	41.3	49.3
WR68	07/11/85	8.7	3.3	13.3	4.0	4.7	6.0	28.0	35.3
WR68	08/21/85	0.0	2.0	2.0	2.7	3.3	4.0	24.7	29.3
WR68	09/21/85	2.0	0.0	6.0	0.0	0.0	0.0	0.0	21.3
WR68	10/27/85	15.3	16.7	54.7	64.7	14.7	20.0	60.0	69.3
WR68	11/25/85	6.0	17.3	9.3	16.7	39.3	44.7	47.3	47.3
WR68	01/11/86	53.3	50.7	80.0	82.7	50.7	54.7	89.3	87.3
WR68	02/16/86	32.0	31.3	39.3	39.3	35.3	36.0	64.7	56.7
WR68	03/08/86	33.3	69.3	59.3	69.3	42.7	46.0	82.0	84.0

TABLE 12

CHEMICAL CHARACTERISTICS AND CALCULATED PRODUCTION
YIELDS FOR PREDICTED PHOSPHORUS LIMITED SAMPLES.

SITE	DATE	TSIN*	O-P*	N:P*	APY*	APY+P*
WFBF	06/25/85	0.340	0.003	113.3	1.3	22.8
WFBF	07/11/85	0.184	0.002	92.0	0.9	22.4
WFBF	08/21/85	0.536	0.009	59.6	3.9	25.4
WFBF	09/21/85	0.081	0.002	40.5	0.9	22.4
WFBF	10/27/85	0.311	0.009	34.6	3.9	25.4
WFBF	11/25/85	0.649	0.020	32.5	8.6	30.1
WFBF	01/11/86	0.399	0.012	33.3	5.2	26.7
WFBF	02/16/86	0.323	0.013	24.8	5.6	27.1
WFBF	03/08/86	0.213	0.004	53.3	1.7	23.2
WFIB	05/15/85	0.359	0.004	89.8	1.7	23.2
WFIB	06/25/85	0.254	0.003	84.7	1.3	22.8
WFIB	07/11/85	0.094	0.005	18.8	2.2	23.7
WFIB	08/21/85	0.661	0.018	36.7	7.7	29.2
WFIB	09/21/85	0.225	0.006	37.5	2.6	24.1
WFIB	10/27/85	0.394	0.018	21.9	7.7	29.2
WFIB	11/25/85	0.693	0.023	30.1	9.9	31.4
WFIB	01/11/86	0.408	0.004	102.0	1.7	23.2
WFIB	03/08/86	0.133	0.005	26.6	2.2	23.7
MF16	05/15/85	0.424	0.007	60.6	3.0	24.5
MF16	06/25/85	0.233	0.005	46.6	2.2	23.7
MF16	07/11/85	0.080	0.002	40.0	0.9	22.4
MF16	08/21/85	0.853	0.015	56.9	6.5	28.0

TABLE 12 (continued)
 CHEMICAL CHARACTERISTICS AND CALCULATED PRODUCTION
 YIELDS FOR PREDICTED PHOSPHORUS LIMITED SAMPLES.

SITE	DATE	TSIN*	O-P*	N:P*	APY*	APY+P*
MF16	09/21/85	0.092	0.005	18.4	2.2	23.7
MF16	10/27/85	0.497	0.008	62.1	3.4	24.9
MF16	11/25/85	1.240	0.014	88.6	6.0	27.5
MF16	01/11/86	0.708	0.003	236.0	1.3	22.8
MF16	02/16/86	0.390	0.015	26.0	6.5	28.0
MF16	03/08/86	0.433	0.006	72.2	2.6	24.1
EF74	05/15/85	0.445	0.004	111.3	1.7	23.2
EF74	06/25/85	0.291	0.006	48.5	2.6	24.1
EF74	07/11/85	0.092	0.004	23.0	1.7	23.2
EF74	08/21/85	0.259	0.013	19.9	5.6	27.1
EF74	09/21/85	0.104	0.005	20.8	2.2	23.7
EF74	10/27/85	0.377	0.005	75.4	2.2	23.7
EF74	11/25/85	0.760	0.014	54.3	6.0	27.5
EF74	01/11/86	0.630	0.005	126.0	2.2	23.7
EF74	02/16/86	0.356	0.012	29.7	5.2	26.7
EF74	03/08/86	0.310	0.005	62.0	2.2	23.7
LSDM	05/15/85	0.370	0.006	61.7	2.6	24.1
LSDM	06/25/85	0.271	0.004	67.8	1.7	23.2
LSDM	07/11/85	0.090	0.003	30.0	1.3	22.8
LSDM	08/21/85	0.462	0.008	57.8	3.4	24.9
LSDM	09/21/85	0.108	0.003	36.0	1.3	22.8
LSDM	10/27/85	0.291	0.019	15.3	8.2	29.7
LSDM	11/25/85	1.197	0.020	59.9	8.6	30.1

TABLE 12 (continued)
 CHEMICAL CHARACTERISTICS AND CALCULATED PRODUCTION
 YIELDS FOR PREDICTED PHOSPHORUS LIMITED SAMPLES.

SITE	DATE	TSIN*	O-P*	N:P*	APY*	APY+P*
LSDM	01/11/86	0.592	0.007	84.6	3.0	24.5
LSDM	02/16/86	0.346	0.007	49.4	3.0	24.5
LSDM	03/08/86	0.285	0.005	57.0	2.2	23.7
WRBW	06/25/85	0.482	0.005	96.4	2.2	23.7
WRBW	07/11/85	0.260	0.005	52.0	2.2	23.7
WRBW	08/21/85	0.600	0.009	66.7	3.9	25.4
WRBW	09/21/85	0.311	0.006	51.8	2.6	24.1
WRBW	10/27/85	0.344	0.005	68.8	2.2	23.7
WRBW	11/25/85	0.817	0.018	45.4	7.7	29.2
WRBW	01/11/86	0.551	0.006	91.8	2.6	24.1
WRBW	02/16/86	0.291	0.009	32.3	3.9	25.4
WRBW	03/08/86	0.287	0.007	41.0	3.0	24.5
WR68	05/15/85	0.428	0.011	38.9	4.7	26.2
WR68	06/25/85	0.107	0.004	26.8	1.7	23.2
WR68	08/21/85	0.339	0.004	84.8	1.7	23.2
WR68	10/27/85	0.345	0.006	57.5	2.6	24.1
*TSIN = total soluble inorganic nitrogen ($\text{NH}_4 + \text{NO}_2 + \text{NO}_3$)(mg/l) O-P = ortho-phosphorus (mg/l) N:P = TSIN/O-P APY = ambient phosphorus yield (msc) APY+P = APY plus phosphorus spike yield (msc)						

TABLE 13
 CHEMICAL CHARACTERISTICS AND CALCULATED PRODUCTION
 YIELDS FOR PREDICTED NITROGEN LIMITED SAMPLES.

SITE	DATE	TSIN	O-P	N:P	ANY*	ANY+N*
WF1B	02/16/86	0.144	0.015	9.6	5.5	43.5
WR45	05/15/85	0.472	0.112	4.2	17.9	55.9
WR45	06/25/85	0.677	0.749	0.9	25.7	63.7
WR45	07/11/85	1.232	1.370	0.9	46.8	84.8
WR45	08/21/85	0.693	0.319	2.2	26.3	64.3
WR45	09/21/85	2.619	2.395	1.1	99.5	137.5
WR45	10/27/85	0.823	0.479	1.7	31.3	69.3
WR45	11/25/85	0.776	0.131	5.9	29.5	67.5
WR45	01/11/86	1.000	0.372	2.7	38.0	76.0
WR45	02/16/86	0.367	0.084	4.4	13.9	51.9
WR45	03/08/86	0.993	0.600	1.7	37.7	75.7
WR68	07/11/85	0.027	0.010	2.7	1.0	39.0
WR68	09/21/85	0.082	0.011	7.5	3.1	41.1
WR68	11/25/85	0.670	0.467	1.4	25.5	63.5
WR68	02/16/86	0.506	0.057	8.9	19.2	57.2
WR68	03/08/86	0.845	0.318	2.7	32.1	70.1

*ANY = ambient nitrogen yield (msc) *ANY+N = plus nitrogen spike yield

TABLE 14
 CHEMICAL CHARACTERISTICS AND CALCULATED PRODUCTION
 YIELDS FOR NITROGEN AND PHOSPHORUS CO-LIMITED SAMPLES.

SITE	DATE	TSIN	O-P	N:P	ANY	ANY+N	APY	APY+P
WR68	01/11/86	1.208	0.102	11.8	45.9	83.9	43.9	65.4

TABLE 15

ASSAY DERIVED LIMITING NUTRIENT INFLUENCE.

a. Phosphorus Limitation		b. Nitrogen Limitation		f. Primary Nitrogen, N+P Synergy		h. (continued)	
SITE	DATE	SITE	DATE	SITE	DATE	SITE	DATE
WFBF	07/11/85	MF16	06/25/85			MF16	07/11/85
WFBF	11/25/85	WR45	05/15/85	WR45	02/16/86	MF16	09/21/85
WFBF	01/11/86	WR45	06/25/85			EF74	07/11/85
WFBF	02/16/86	WR45	07/11/85	g. Primary Phosphorus, N+P Synergy		EF74	09/21/85
WFBF	03/08/86	WR45	08/21/85	SITE	DATE	LSDM	07/11/85
WFIB	08/21/85	WR45	09/21/85	WFBF	06/25/85	LSDM	09/21/85
WFIB	11/25/85	WR45	10/27/85	WFBF	08/21/85	WRWB	06/25/85
WFIB	01/11/86	WR45	11/25/85	WFBF	10/27/85	WR68	06/25/85
WFIB	02/16/86	WR45	01/11/86	WFIB	05/15/85	WR68	08/21/85
WFIB	03/08/86	WR45	03/08/86	WFIB	10/27/85		
MF16	05/15/85	WR68	10/27/85	MF16	10/27/85		
MF16	08/21/85	WR68	01/11/86	EF74	06/25/85		
MF16	11/25/85	WR68	03/08/86	EF74	08/21/85		
MF16	01/11/86	c. Nitrogen and Phosphorus Co-limitation		EF74	10/27/85		
MF16	02/16/86	SITE	DATE	LSDM	08/21/85		
MF16	03/08/86	LSDM	06/25/85	LSDM	10/27/85		
EF74	05/15/85	WR68	07/11/85	WRWB	07/11/85		
EF74	11/25/85	WR68	09/21/85	WRWB	08/21/85		
EF74	01/11/86	d. Primary Phosphorus, N+P Co-limitation		WRWB	09/21/85		
EF74	02/16/86	SITE	DATE	WRWB	10/27/85		
EF74	03/08/86	LSDM	05/15/85	WR68	05/15/85		
LSDM	11/25/85	e. Primary Nitrogen, N+P Co-limitation		h. Nitrogen and Phosphorus Synergy			
LSDM	01/11/86	SITE	DATE	SITE	DATE		
LSDM	02/16/86	WR68	02/16/86	WFBF	09/21/85		
LSDM	03/08/86			WFIB	06/25/85		
WRWB	11/25/85			WFIB	07/11/85		
WRWB	01/11/86			WFIB	09/21/85		
WRWB	02/16/86						
WRWB	03/08/86						
WR68	11/25/85						

TABLE 16
ALGAL GROWTH INHIBITION OF SAMPLES WITH GREATER THAN 50% INHIBITION
OF NP VS. NPE AND CORRESPONDING SAMPLE TESTS.*

DATE	SITE	%I14C**	%I14N	%I14P	%I14NP
05/15/85	MF16	0.0	0.0	88.4	83.5
05/15/85	EF74	0.0	0.0	100.0	100.0
06/25/85	WFBF	0.0	44.2	0.0	94.7
06/25/85	WFIB	0.0	85.0	100.0	86.7
06/25/85	EF74	100.0	100.0	100.0	97.7
06/25/85	LSDM	0.0	100.0	0.0	100.0
06/25/85	WRWB	73.0	85.0	0.0	82.7
07/11/85	WFIB	0.0	0.0	0.0	75.0
07/11/85	MF16	0.0	0.0	64.1	83.3
07/11/85	WRWB	0.0	0.0	29.5	51.9
09/21/85	WFIB	0.0	0.0	0.0	63.2
09/21/85	MF16	0.0	0.0	100.0	54.1
09/21/85	EF74	0.0	0.0	0.0	77.7
09/21/85	LSDM	0.0	0.0	0.0	75.7
09/21/85	WRWB	0.0	0.0	0.0	58.8
09/21/85	WR68	0.0	0.0	0.0	100.0
10/27/85	EF74	0.0	0.0	0.0	59.7

* Analysis of Variance 1-P > .99
** %I14 = percent inhibition at day 14

TABLE 17

BIOAVAILABLE NUTRIENTS WITH AND WITHOUT THE INFLUENCE OF EDTA. (mg/l)

SITE	DATE	BION	BIOP	BION/E	BIOP/E
WFBF	06/25/85	0.105	0.016	0.176	0.028
WFBF	07/11/85	0.334	0.016	0.508	0.017
WFBF	08/21/85	1.087	0.037	0.824	0.034
WFBF	09/21/85	0.263	0.006	0.245	0.008
WFBF	10/27/85	0.545	0.028	0.597	0.025
WFBF	11/25/85	0.632	0.022	0.718	0.023
WFBF	01/11/86	0.403	0.009	0.474	0.014
WFBF	02/16/86	0.545	0.016	0.650	0.012
WFBF	03/08/86	0.368	0.009	0.297	0.011
WFIB	05/15/85	0.316	0.000	0.403	0.008
WFIB	06/25/85	0.000	0.005	0.158	0.031
WFIB	07/11/85	0.334	0.023	0.368	0.032
WFIB	08/21/85	1.526	0.063	1.071	0.039
WFIB	09/21/85	0.421	0.016	0.282	0.000
WFIB	10/27/85	0.718	0.031	0.684	0.026
WFIB	11/25/85	0.929	0.020	1.018	0.026
WFIB	01/11/86	0.508	0.002	0.421	0.000
WFIB	02/16/86	0.579	0.019	0.737	0.020
WFIB	03/08/86	0.139	0.003	0.229	0.005
MF16	05/15/85	0.053	0.000	0.455	0.000
MF16	06/25/85	0.000	0.002	0.053	0.026
MF16	07/11/85	0.158	0.017	0.439	0.022
MF16	08/21/85	0.755	0.017	0.824	0.017

TABLE 17 (continued)

BIOAVAILABLE NUTRIENTS WITH AND WITHOUT THE INFLUENCE OF EDTA. (mg/l)

SITE	DATE	BION	BIOP	BION/E	BIOP/E
MF16	09/21/85	0.000	0.000	0.087	0.000
MF16	10/27/85	0.624	0.005	0.737	0.003
MF16	11/25/85	0.771	0.014	0.824	0.009
MF16	01/11/86	0.368	0.000	0.421	0.000
MF16	02/16/86	0.755	0.000	0.650	0.022
MF16	03/08/86	0.492	0.000	0.474	0.003
EF74	05/15/85	0.000	0.000	0.439	0.000
EF74	06/25/85	0.000	0.000	0.282	0.028
EF74	07/11/85	0.403	0.012	0.334	0.016
EF74	08/21/85	0.650	0.005	0.861	0.006
EF74	09/21/85	0.034	0.000	0.071	0.000
EF74	10/27/85	0.597	0.019	0.561	0.002
EF74	11/25/85	0.561	0.009	0.650	0.003
EF74	01/11/86	0.350	0.000	0.245	0.000
EF74	02/16/86	0.421	0.005	0.526	0.005
EF74	03/08/86	0.421	0.000	0.368	0.000
LSDM	05/15/85	0.368	0.000	0.368	0.000
LSDM	06/25/85	0.000	0.000	0.034	0.034
LSDM	07/11/85	0.176	0.002	0.176	0.006
LSDM	08/21/85	0.316	0.000	0.368	0.006
LSDM	09/21/85	0.071	0.000	0.053	0.000
LSDM	10/27/85	0.403	0.011	0.387	0.012
LSDM	11/25/85	0.387	0.003	0.597	0.000

TABLE 17 (continued)
 BIOAVAILABLE NUTRIENTS WITH AND WITHOUT THE INFLUENCE OF EDTA. (mg/l)

SITE	DATE	BION	BIOP	BION/E	BIOP/E
LSDM	01/11/86	0.350	0.000	0.350	0.000
LSDM	02/16/86	0.455	0.002	0.508	0.002
LSDM	03/08/86	0.508	0.002	0.455	0.008
WRWB	06/25/85	0.124	0.006	0.192	0.042
WRWB	07/11/85	0.421	0.009	0.597	0.002
WRWB	08/21/85	0.526	0.008	0.526	0.008
WRWB	09/21/85	0.316	0.000	0.282	0.000
WRWB	10/27/85	0.492	0.006	0.526	0.011
WRWB	11/25/85	0.718	0.016	0.861	0.016
WRWB	01/11/86	0.508	0.003	0.545	0.000
WRWB	02/16/86	0.350	0.003	0.632	0.005
WRWB	03/08/86	0.526	0.000	0.334	0.000
WR45	05/15/85	0.789	0.138	0.913	0.192
WR45	06/25/85	0.929	0.197	0.861	0.198
WR45	07/11/85	2.000	0.282	2.105	0.270
WR45	08/21/85	0.842	0.175	0.861	0.200
WR45	09/21/85	3.124	0.335	3.018	0.361
WR45	10/27/85	1.192	0.220	1.245	0.233
WR45	11/25/85	1.018	0.099	0.982	0.102
WR45	01/11/86	1.229	0.206	1.263	0.216
WR45	02/16/86	0.895	0.140	0.913	0.147
WR45	03/08/86	1.245	0.219	1.316	0.212

TABLE 17 (continued)

BIOAVAILABLE NUTRIENTS WITH AND WITHOUT THE INFLUENCE OF EDTA. (mg/l)

SITE	DATE	BION	BIOP	BION/E	BIOP/E
WR68	05/15/85	0.579	0.003	0.597	0.028
WR68	06/25/85	0.000	0.019	0.071	0.008
WR68	07/11/85	0.124	0.031	0.158	0.009
WR68	08/21/85	0.087	0.005	0.105	0.006
WR68	09/21/85	0.000	0.014	0.000	0.000
WR68	10/27/85	0.387	0.127	0.526	0.150
WR68	11/25/85	1.034	0.022	1.176	0.039
WR68	01/11/86	1.334	0.186	1.439	0.192
WR68	02/16/86	0.929	0.091	0.947	0.091
WR68	03/08/86	1.124	0.138	1.211	0.161

TABLE 18

PERCENT INHIBITION INDICATED BY THE TEST TREATMENTS WITH AND WITHOUT EDTA

DATE	SITE	%I14C**	%I14N	%I14P	%I14NP
05/15/85	WFIB	0.0	100.0	21.6	40.8
05/15/85	MF16	0.0	0.0	88.4	83.5
05/15/85	EF74	0.0	0.0	100.0	100.0
05/15/85	LSDM	0.0	0.0	0.0	48.8
05/15/85	WR45	0.0	28.3	13.5	12.0
05/15/85	WR68	49.5	89.2	3.1	38.2
06/25/85	WFBF	0.0	44.2	40.3	94.7
06/25/85	WFIB	75.5	85.0	100.0	86.7
06/25/85	MF16	100.0	93.8	100.0	49.6
06/25/85	EF74	100.0	100.0	100.0	97.7
06/25/85	LSDM	51.9	100.0	100.0	100.0
06/25/85	WRWB	73.0	85.0	35.6	82.7
06/25/85	WR45	15.6	0.7	0.0	0.0
06/25/85	WR68	100.0	0.0	100.0	16.2
07/11/85	WFBF	0.0	8.2	34.2	35.2
07/11/85	WFIB	0.0	27.0	9.3	75.0
07/11/85	MF16	0.0	21.5	64.1	83.3
07/11/85	EF74	40.3	20.9	0.0	36.7
07/11/85	LSDM	0.0	74.1	0.0	48.6
07/11/85	WRWB	0.0	0.0	29.5	51.9
07/11/85	WR45	3.6	0.0	5.0	9.9
07/11/85	WR68	0.0	0.0	21.7	20.7
08/21/85	WFBF	0.0	0.0	0.0	0.0

TABLE 18 (continued)

PERCENT INHIBITION INDICATED BY THE TEST TREATMENTS WITH AND WITHOUT EDTA

DATE	SITE	%I14C**	%I14N	%I14P	%I14NP
08/21/85	WFIB	0.0	0.0	0.0	0.0
08/21/85	MF16	40.3	0.0	8.3	0.0
08/21/85	EF74	0.0	25.9	24.5	25.7
08/21/85	LSDM	82.5	100.0	14.3	0.0
08/21/85	WRWB	0.0	0.0	0.0	20.2
08/21/85	WR45	8.3	12.4	2.1	7.0
08/21/85	WR68	100.0	25.9	17.5	15.7
09/21/85	WFBF	51.9	18.2	0.0	37.2
09/21/85	WFIB	0.0	0.0	0.0	63.2
09/21/85	MF16	0.0	0.0	100.0	54.1
09/21/85	EF74	0.0	0.0	51.9	77.7
09/21/85	LSDM	0.0	0.0	0.0	75.7
09/21/85	WRWB	0.0	0.0	0.0	58.8
09/21/85	WR45	0.0	7.3	0.0	0.0
09/21/85	WR68	0.0	0.0	0.0	100.0
10/27/85	WFBF	0.0	0.0	8.8	17.4
10/27/85	WFIB	29.4	0.0	0.0	9.7
10/27/85	MF16	0.0	0.0	15.4	36.6
10/27/85	EF74	0.0	0.0	0.0	59.7
10/27/85	LSDM	0.0	11.3	0.0	45.4
10/27/85	WRWB	0.0	42.6	6.5	31.7
10/27/85	WR45	4.2	5.3	4.2	3.5
10/27/85	WR68	8.4	15.5	26.5	13.4

TABLE 18 (continued)

PERCENT INHIBITION INDICATED BY THE TEST TREATMENTS WITH AND WITHOUT EDTA

DATE	SITE	%I14C**	%I14N	%I14P	%I14NP
11/25/85	WFBF	31.8	7.0	12.1	0.0
11/25/85	WFIB	13.0	23.0	8.8	3.8
11/25/85	MF16	17.5	0.0	6.4	45.3
11/25/85	EF74	0.0	0.0	13.8	34.8
11/25/85	LSDM	0.0	0.0	35.2	47.1
11/25/85	WRWB	0.0	0.0	16.5	22.8
11/25/85	WR45	35.0	3.0	0.0	5.6
11/25/85	WR68	65.3	44.3	12.1	0.0
01/11/86	WFBF	60.6	33.3	15.0	6.7
01/11/86	WFIB	0.0	0.0	0.0	0.0
01/11/86	MF16	0.0	0.0	12.5	46.9
01/11/86	EF74	0.0	0.0	0.0	19.3
01/11/86	LSDM	0.0	0.0	0.0	35.9
01/11/86	WRWB	0.0	0.0	6.8	6.5
01/11/86	WR45	2.6	4.3	2.7	0.0
01/11/86	WR68	0.0	3.3	7.3	0.0
02/16/86	WFBF	0.0	0.0	16.2	0.0
02/16/86	WFIB	16.1	8.0	21.4	0.0
02/16/86	MF16	100.0	100.0	0.0	22.5
02/16/86	EF74	0.0	0.0	20.0	47.5
02/16/86	LSDM	0.0	0.0	10.4	21.3
02/16/86	WRWB	0.0	35.0	44.6	0.0
02/16/86	WR45	0.0	5.2	2.0	2.8
02/16/86	WR68	0.0	0.0	1.9	0.0

TABLE 18 (continued)

PERCENT INHIBITION INDICATED BY THE TEST TREATMENTS WITH AND WITHOUT EDTA

DATE	SITE	%I14C**	%I14N	%I14P	%I14NP
03/08/86	WFBF	0.0	14.9	0.0	19.5
03/08/86	WFIB	46.2	35.0	39.1	0.0
03/08/86	MF16	0.0	100.0	0.0	0.0
03/08/86	EF74	0.0	0.0	0.0	0.0
03/08/86	LSDM	51.9	78.8	0.0	0.0
03/08/86	WRWB	0.0	0.0	0.0	27.7
03/08/86	WR45	0.0	0.0	5.4	6.2
03/08/86	WR68	51.9	14.4	7.2	2.4