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Evaluation of the Effect of Benthic Barrier Placement on Sediment Physical and Chemical Conditions

by *Harry L. Eakin, John W. Barko*



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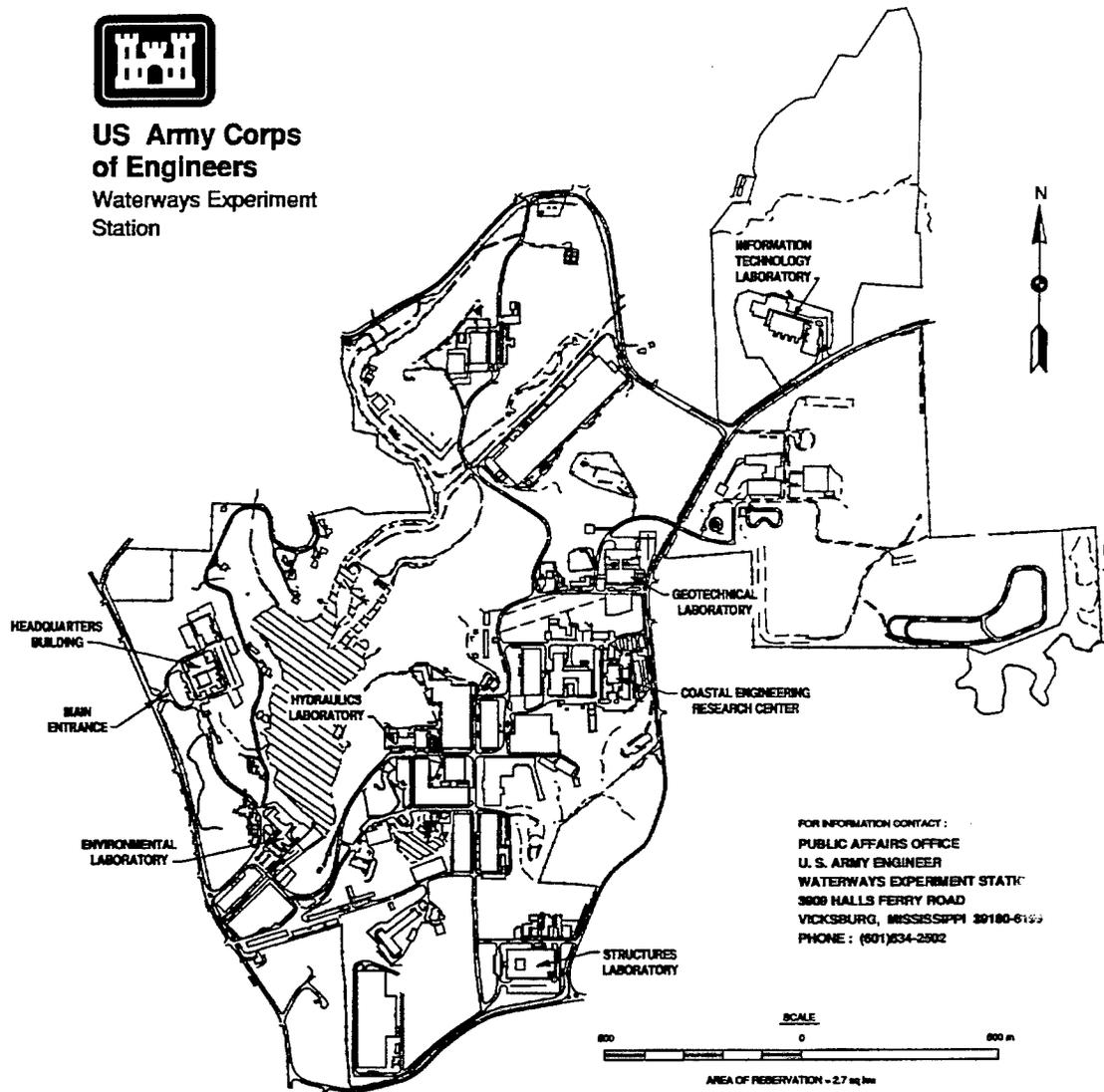
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Preface

The study reported herein was conducted as part of the Joint Agency Guntersville Project sponsored by the Tennessee Valley Authority (TVA) and the Headquarters, U.S. Army Corps of Engineers (HQUSACE), Directorate of Civil Works (DAEN-CW), through the Aquatic Plant Control Research Program (APCRP). The APCRP is sponsored by HQUSACE and is assigned to the U.S. Army Engineer Waterways Experiment Station (WES) under the purview of the Environmental Laboratory (EL). Funding was provided by DAEN-CW under Department of the Army Appropriation No. 96X3122, Construction General. The APCRP is managed under the Environmental Resources Research and Assistance Programs (ERRAP), Mr. J. L. Decell, Manager. Mr. Robert C. Gunkel was Assistant Manager, ERRAP, for the APCRP. Program Monitor for HQUSACE was Ms. Denise White.

This investigation was conducted under the general supervision of Dr. John W. Keeley, Director, EL, and Mr. Donald L. Robey, Chief, Environmental Processes and Effects Division (EPED), EL, and under the direct supervision of Dr. Richard E. Price, Acting Chief, Ecosystem Processes and Effects Branch, EPED.

Logistical and sampling assistance was provided by Messrs. D. Murphy, D. Brewster, and L. Mangum of the TVA and Mr. K. Pigott of ASci Corporation at Lake Guntersville. Sampling and logistical assistance at Eau Galle Reservoir was given by Mr. W. James and Mr. E. Zimmer of the WES Eau Galle Aquatic Ecosystem Research Facility and Mr. D. Dressel of ASci Corporation. Assistance in the conduct of the plant regrowth experiment was provided by Meses. D. McFarland and W. Dee. Analytical assistance was provided by Messrs. S. Fox and K. Pigott of ASci Corporation. The report was reviewed by Drs. Douglas Gunnison and Craig S. Smith, EPED.

Principal Investigator for this study was Dr. John W. Barko, EL. The report was prepared by Mr. Harry L. Eakin and Dr. John W. Barko.

Director of WES during publication of this report was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

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1 Introduction

Increasingly, high demands for recreational, industrial, and domestic uses of clean, fresh surface water are being placed on limited supplies (Wetzel 1983). Excessive additions of plant nutrients, organic matter, and silt that combine to support increased populations of algae and rooted macrophytes have resulted in increased eutrophication and decreased volume of many lakes and reservoirs (Likens 1972). Maintaining and/or restoring the quality of these limited supplies is a primary responsibility of water resource managers.

Among the many varied management and restorative techniques (Cooke et al. 1986) available to managers for improving water resources, benthic barriers have been used since the late 1960s for control of nuisance growths of rooted macrophytes (Born et al. 1973; Nichols 1974). Benthic barriers cover and isolate the sediment as a substrate and primary source of nutrients for aquatic macrophytes and limit plant access to the overlying water column and sunlight, all essential for sustained growth of rooted macrophytes (cf. reviews by Sculthorpe 1967; Hutchinson 1975).

Previous investigations of benthic barrier effectiveness in controlling rooted submersed macrophyte growth have delineated positive and negative attributes of barrier use (Born et al. 1973; Mayer 1978; Cooke and Gorman 1980). Recent investigations by Gunnison and Barko (1991, 1992) and Payne, Miller, and Ussery (1993) have examined gas evolution beneath barriers and the effects of barriers on macroinvertebrate communities, respectively. Among limited investigations that have examined environmental effects of benthic barriers (e.g., Perkins, Boston, and Curren 1980; Lewis, Wile, and Painter 1983), emphasis has been placed only on the quality of the overlying water. Little or no information exists on the effects of benthic barriers on physical and chemical conditions of the sediment beneath them.

Before widespread use of benthic barriers can be advocated, a comprehensive understanding of their long-term effects on the environment must be realized. The purpose of this report is (a) to describe changes in selected physical and chemical conditions of sediment; interstitial water (i.e., water filling the space between sediment particles); and surficial water (i.e., water between the benthic barrier and sediment surface) under experimentally placed benthic barriers and (b) to assess submersed aquatic macrophyte regrowth on affected sediments.

2 Study Sites and Methods

Study Sites and Barrier Placements

Eau Galle Reservoir, Wisconsin

Eau Galle Reservoir is a small (0.62-km²) U.S. Army Corps of Engineers impoundment on the Eau Galle River in Pierce and St. Croix counties in west-central Wisconsin (Figure 1). A single 6.1- by 12.2-m Bottom-Line benthic barrier fabric (Dow Corning Corporation, Midland, MI) was deployed in late August 1988 to examine the effects of benthic barriers on sediment characteristics. The barrier was located near the mouth of Lousy Creek in a plant bed dominated by *Ceratophyllum demersum* L., but also containing *Potamogeton crispus* L., at a depth of about 1 m.

Lake Guntersville, Alabama

Lake Guntersville is a large (about 274-km²) Tennessee Valley Authority reservoir located in Jackson and Marshall counties, Alabama, and in Marion County, Tennessee. Five benthic barriers, 6.1- by 12.2-m, were deployed on May 22, 1990, at sites within the Town Creek Embayment on Lake Guntersville (Figure 2). Locations of barrier placements were chosen based on historical information indicating past dominance at selected sites by *Hydrilla*.¹ Little, if any, plant biomass was present at the time of barrier placement. Soon after deployment, a dramatic and almost total decline of submersed macrophytes within the study area occurred and persisted throughout the study period.

Aquatic Macrophyte Regrowth Experiment

An experiment was conducted during February and March 1992 at the U.S. Army Engineer Waterways Experiment Station (WES) to examine the

¹ Personal Communication, April 1990, Earl Burns and David Webb, Aquatic Biology Department, Tennessee Valley Authority, Muscle Shoals, AL.

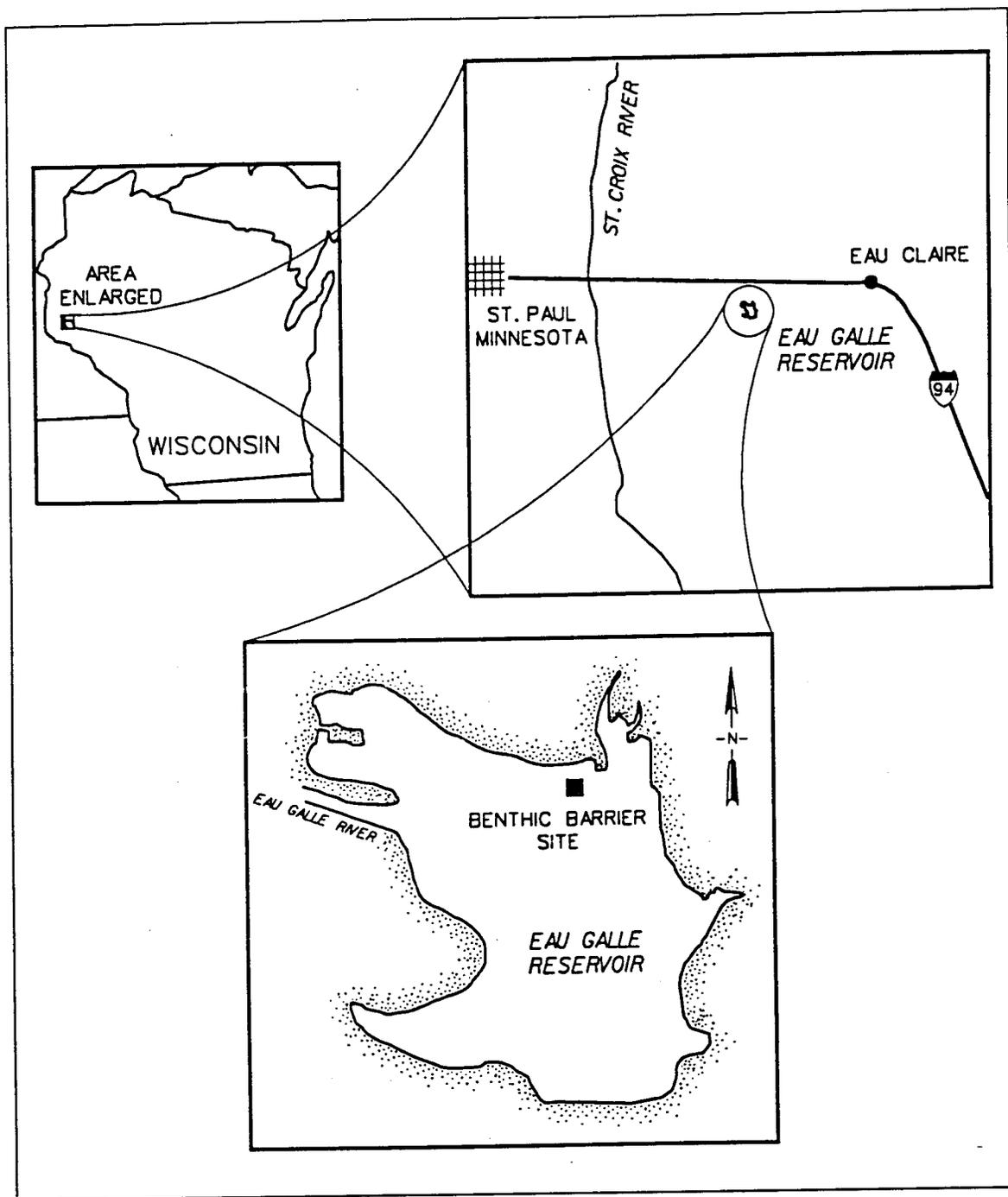


Figure 1. Location of benthic barrier in Eau Galle Reservoir, Wisconsin

effects of long-term barrier placement on submersed aquatic macrophyte regrowth. The premise for conducting the experiment was to assess whether changes in the physical and chemical conditions of sediments beneath the barriers were sufficient enough to influence the regrowth of submersed macrophyte following barrier removal.

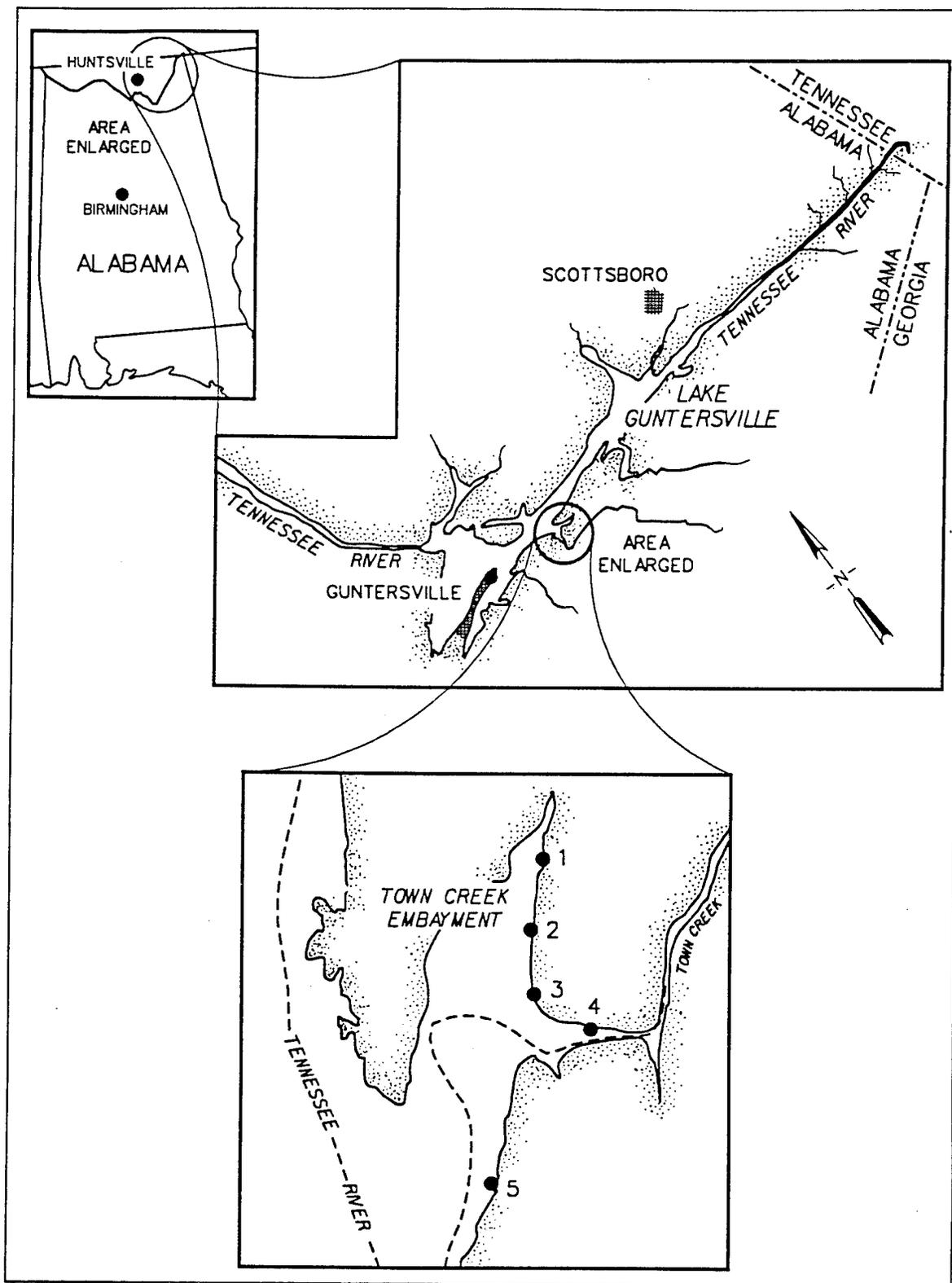


Figure 2. Location of benthic barriers in Lake Guntersville, Alabama

Methods

Benthic barrier placements

A three-technique sampling approach was used to assess environmental effects of benthic barriers on sediment over which they were placed. Core samples of sediment were collected from beneath and adjacent to each barrier and examined for alterations in the physical and/or chemical conditions of the sediment and interstitial water. Interstitial water samples were also collected in situ using dialyzer sampling devices. Surficial waters were similarly collected in situ using dialyzer sampling devices.

Collection of interstitial water by in situ sampling devices was done to preclude problems associated with collection techniques on sediment removed from the benthic environment. It has long been recognized that changes in concentrations of dissolved species are possible because of sediment manipulations (Simon, Kennedy, and Massoni 1985) or oxidation of reduced species during these sample manipulations.

Sediment physical and chemical composition studies

Core samples of sediment were collected during June and September 1991 at Eau Galle and May and October 1991 at Lake Guntersville. Sampling times were selected to assess physical and/or chemical changes occurring within the sediment during the macrophyte growth season at each reservoir. Sample collection was performed with a Wildco hand core sampler (Wildlife Supply Company, Saginaw, MI) equipped with acrylic core liners (6.5-cm-ID and 50-cm-long) from beneath each barrier (i.e., treatment area) and immediately adjacent to each barrier (i.e., reference area). Only the upper 10 cm of each core sample was retained for analysis. Samples were maintained at 4 °C and returned to the laboratory in Vicksburg, MS, within 48 hr for processing. Under nitrogen atmosphere and within a glove box, sediment cores were homogenized by vigorous hand-mixing and subsampled for physical and chemical analysis. Sediment interstitial water was removed by high-speed centrifugation at 4 °C.

Physical measurement of moisture content, density, and organic matter content used methods described by Allen et al. (1974). Sediment texture, i.e., particle size, determinations employed a modification of a hydrometer method (Patrick 1958) first described by Day (1956). Total Kjeldahl nitrogen (TKN) and total phosphorus (TP), following digestion with H₂SO₄, K₂SO₄, and red HgO (Plumb 1981), were measured colorimetrically on an AutoAnalyzer II System (Technicon Corporation, Tarrytown, NY) using the salicylate-hypochlorite method (Technicon 1978) and ascorbic acid reduction method (American Public Health Association (APHA) 1985), respectively. Exchangeable ammonium-N ($\sum \text{NH}_4\text{-N}$), after treatment with 1 M NaCl (modification of Bremner 1965) and extractable phosphate-P ($\sum \text{PO}_4\text{-P}$), following dilute HCl extraction (Olsen and Sommers 1982), were likewise measured

colorimetrically. Exchangeable potassium (${}_{ex}K$) was measured by direct atomic absorption spectrophotometry (APHA 1985) after treatment as ${}_{ex}NH_4-N$ above. Sediment interstitial water ammonium-N (${}_{iw}NH_4-N$) and phosphate-P (${}_{iw}PO_4-P$) were measured colorimetrically using methods described previously for TKN and TP. Measurement of sediment interstitial water iron (${}_{iw}Fe$) and manganese (${}_{iw}Mn$) was by direct atomic absorption spectrophotometry. The accuracy of total sediment analyses (typically >95-percent) was verified by including National Institute of Standards and Technology reference material in experimental sample sets. Statistical analysis of physical and chemical data was performed using analysis of variance (ANOVA) and t-test procedures (SAS Institute, Inc. 1988). Results reported herein as statistically significant were examined at the 5-percent probability level.

In situ interstitial water studies

Dialyzer samplers, after a design of Hesslein (1976) and generally referred to as "peepers," were used to collect close-interval in situ interstitial (pore) water samples in Lake Gunterville and Eau Galle. Sampler operation is based on the principle that, given sufficient time, solutes in the surrounding pore water will diffuse through a dialysis membrane and establish an equilibrium in water contained in the sample chambers.

Dialyzer samplers were constructed from Plexiglas blocks (2.5- by 10.2- by 55.7-cm) that were beveled on one end to an angle of 20 deg to facilitate insertion into the sediment. Each sampler contained a total of 14 sample chambers (1- by 1- by 7.6-cm) machine-cut horizontally into the block at 1-cm intervals beginning 8.6 cm from the beveled end.

Sampler preparation followed the techniques of Carignan (1984). A dialysis membrane (this instance, 2.0 μm , Nucleopore Corporation) was placed over the open side of the sample chambers after filling with deoxygenated-distilled water. The membrane was held in place by a Plexiglas cover sheet (0.3- by 10.2- by 30-cm). The cover sheet with openings machine-cut to align with the openings of the sample chambers (i.e., 1- by 7.6-cm) was secured in place on the sampler body with either nylon or stainless steel screws. To prevent the introduction of oxygen to the chambers prior to deployment, each sampler was submerged in a container of distilled water continuously being deoxygenated by degassing with nitrogen.

During a 2-week period in July and August 1990, a pilot experiment was conducted in Lake Gunterville to examine spatial differences in interstitial water profiles beneath a barrier. Replicate samplers were placed near the center, along the inside edge of a barrier, and in the open sediment adjacent to the barrier at Site 4. Results from the pilot experiment (Figure 3) showed that concentration profiles (e.g., ${}_{isw}NH_4-N$) were consistently more pronounced beneath the center of the barrier. Therefore, during all subsequent in situ sampler deployments in Lake Gunterville and Eau Galle, a single sampler was positioned by SCUBA divers vertically in the sediment near the center of the

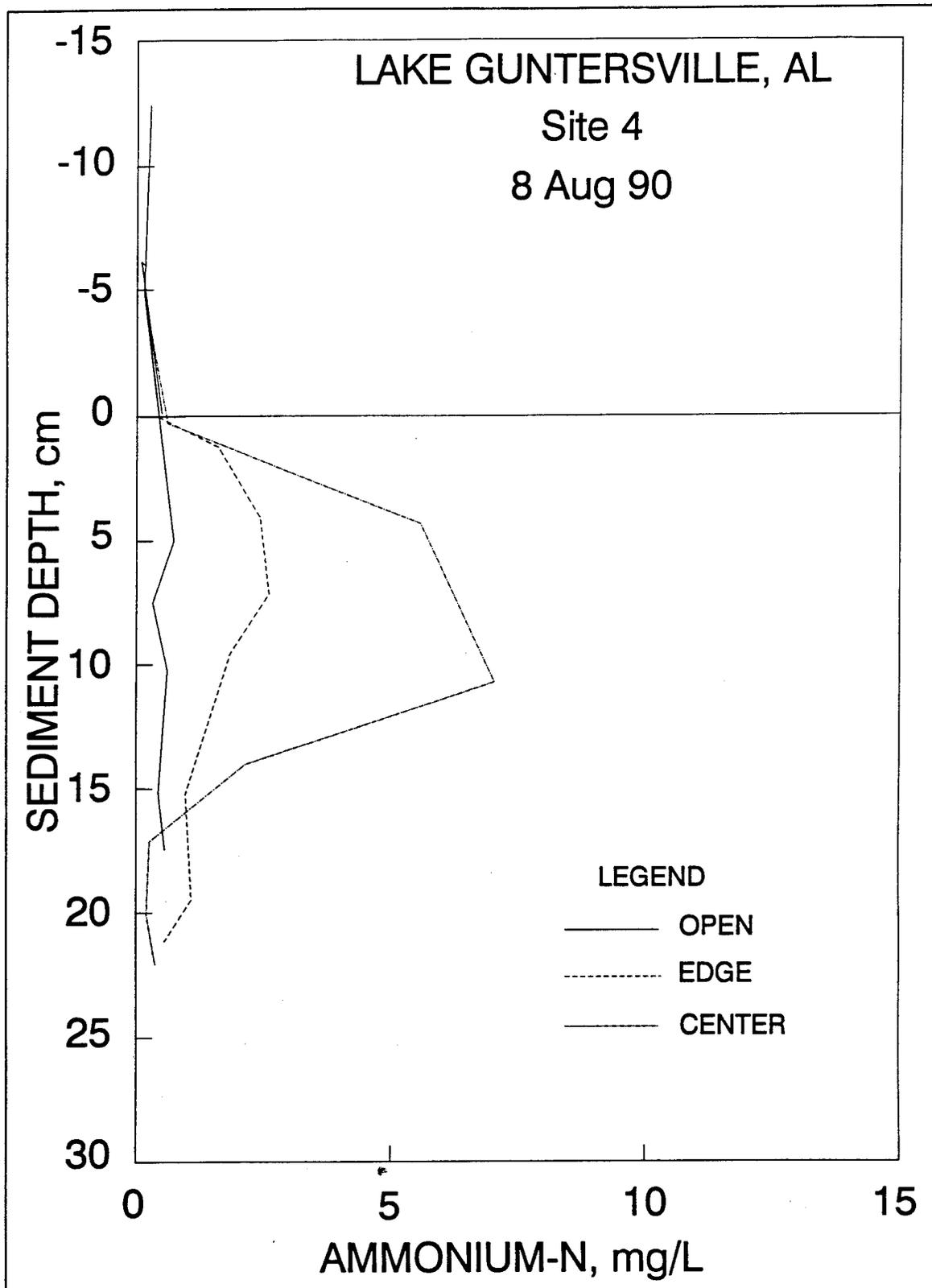


Figure 3. Profiles of interstitial $\text{NH}_4\text{-N}$ concentrations collected in situ near center, along edge, and in open sediment adjacent to benthic barrier at Site 4 in Lake Guntersville, Alabama

barrier (treatment), and a second sampler was positioned vertically approximately 1 m outside of the barrier in the open sediment (control) at each site. Placement of the peeper beneath each barrier was through a slit cut in the barrier material.

Samplers remained in place for periods of at least 14 days—sufficient time for equilibration (Carignan 1984). Upon retrieval, the contents of each close-interval chamber were removed, filtered (0.45- μm , Nalgene CA syringe filters), and preserved with H_2SO_4 to $\text{pH} < 2$. In situ interstitial water samples were analyzed colorimetrically for ammonium-N (${}_{\text{isiw}}\text{NH}_4\text{-N}$) and phosphate-P (${}_{\text{isiw}}\text{PO}_4\text{-P}$) using methods described above. In situ interstitial iron (${}_{\text{isiw}}\text{Fe}$) and manganese (${}_{\text{isiw}}\text{Mn}$) were determined using direct atomic absorption spectrophotometry (APHA 1985).

In situ interstitial water samplers were deployed for approximately 2-week periods in early and late summer to assess whether any changes in constituents occurred over the growing season. In 1991, samplers were deployed at Eau Galle during May-June and September and at Lake Guntersville during May-June and August-September.

Surficial water studies

Plexiglas chambers (5.1- by 7.6- by 10.2-cm), each containing about 400 ml of deoxygenated-distilled water, were deployed by SCUBA divers coincident with the deployment of the in situ interstitial samplers. Surficial water samplers were placed beneath the barrier fabric through slitted openings, and the openings were closed to prevent exchanges with water overlying the barriers. The contents of each chamber were allowed to equilibrate with the surficial water through a dialysis membrane (2.0- μm , Nucleopore Corporation) covering the open upper surface of the chamber. Upon retrieval, water contained in each chamber was transferred to a 300-ml BOD (biological oxygen demand) bottle and “fixed” for analysis of dissolved oxygen (DO) by the azide modified iodometric method (APHA 1985).

Plant regrowth experiment

Six replicate cores were collected from random locations beneath and adjacent to each benthic barrier at Lake Guntersville. Each replicate sediment core was extruded into individual 6.5-cm-ID by 10-cm acrylic core liners having a volume of 322 cm^3 , capped to prevent the introduction of air, stored at $4 \text{ }^\circ\text{C}$, and returned intact to WES within 48 hr. On February 5, 1992, each sediment core was planted with three *Hydrilla* apical shoots, 15 cm in length, placed in experimental growth columns (cf. Barko and Smart 1980), and allowed to grow over a 5-week period under controlled conditions in an environment chamber.

Plant growth estimates, for each sediment core, were determined by increases in total biomass, i.e., above ground plus below ground, over the initial apical shoots biomass. However, direct comparisons of plant growth between sediment cores and sampling locations, i.e., beneath the barriers and in adjacent sediments, were difficult because of considerable amounts of extraneous materials (e.g., mollusk shell fragments and stones) in some sediment cores. Therefore, following removal of all plant tissues at the end of the growth period, sediment from each core was sieved using a No. 10 (2-mm mesh opening) brass sieve. The volume of the extraneous material was determined by displacement and a corrected sediment volume by difference. Comparisons of plant growth were then made on a total biomass per unit of sediment basis.

3 Results

Effects of Barrier Placements on Sediment Physical and Chemical Conditions

Eau Galle Reservoir

Examination of moisture content, bulk density, and organic matter content of sediments collected at the beginning of the macrophyte growing season in June 1991, approximately 3 years after barrier placement, revealed no significant differences (Table 1) between the reference (i.e., adjacent open sediment) and the treatment (i.e., beneath the barrier) locations. However, in September 1991, near the end of the growing season, differences observed in the above parameters in the reference sediment were highly significant between the June and September sampling efforts. Whereas, differences in these parameters under the barrier were insignificant over the growing season.

Moisture content in the reference sediment declined from 78.2 percent in June to 53.9 percent in September, while remaining nearly constant at about 75 percent under the barrier. Bulk density of the reference sediment increased from 0.16 g/ml in June to 0.59 g/ml. A slight increase in the bulk density (0.20 g/ml in June and 0.27 g/ml in September) of sediment beneath the barrier was not statistically significant. Organic matter content of the reference sediment exhibited a significant decline, from 13.5 percent in June to 6.1 percent in September. The concurrent decrease in organic matter content of sediment collected under the barrier from 11.5 to 10.9 percent was not significant.

No significant differences in sediment texture were observed between the reference and barrier sediments in June (Table 1). Sediment in the reference area consisted of about 27-percent clay, 56-percent silt, and 17-percent sand. Meanwhile, sediment beneath the barrier consisted of about 22-percent clay, 51-percent silt, and 27-percent sand. In September, textural differences between the reference and barriers sediments, especially the silt and sand fractions, were highly significant. The reference and treatment sediments were composed of about 12- and 20-percent clay, 33- and 61-percent silt, and 55- and 19-percent sand, respectively. Over the growing season, highly significant changes in the texture of the reference sediment were noted for all sediment

Table 1
Mean (n = 3) Physical and Chemical Characteristics with
Associated Standard Errors (in parentheses) of Eau Galle
Reservoir, Wisconsin, Sediment Collected at Locations Beneath
the Benthic Barrier (barrier) and in the Adjacent Reference
Sediment (open) Near the Beginning and End of 1991 Plant
Growing Season

Characteristic	Location	June 6, 1991	September 19, 1991	
Total Sediment				
Texture, % ¹	Sand	Barrier	26.5	19.1
		Open	17.3	55.6
	Silt	Barrier	51.4	61.2
		Open	55.9	32.7
	Clay	Barrier	22.0	19.7
		Open	26.7	11.7
Density, g/ml ²	Barrier	0.20 (0.02)	0.27 (0.08)	
	Open	0.16 (0.02)	0.59 (0.12)	
Moisture, %	Barrier	73.6 (2.7)	74.9 (6.1)	
	Open	78.2 (2.4)	53.9 (7.7)	
Organic matter, %	Barrier	11.5 (0.8)	10.9 (1.6)	
	Open	13.5 (0.7)	6.1 (1.1)	
Total Kjeldahl nitrogen (TKN), mg/g ²	Barrier	4.32 (0.20)	3.64 (0.29)	
	Open	5.50 (0.23)	1.75 (0.33)	
Phosphorus, mg/g ²	Barrier	1.362 (0.045)	1.081 (0.047)	
	Open	1.738 (0.035)	0.518 (0.075)	
Extractable Nutrients				
Ammonium-N, mg/g ²	Barrier	0.17 (0.00)	0.25 (0.03)	
	Open	0.28 (0.03)	0.14 (0.03)	
Phosphate-P, mg/g ²	Barrier	0.005 (0.002)	0.032 (0.011)	
	Open	0.009 (0.004)	0.034 (0.007)	
Potassium, mg/g ²	Barrier	0.20 (0.01)	0.20 (0.03)	
	Open	0.26 (0.02)	0.13 (0.03)	
Interstitial Water				
Ammonium-N, mg/l	Barrier	16.37 (0.99)	22.60 (2.21)	
	Open	24.73 (1.47)	35.00 (2.33)	
Phosphate-P, mg/l	Barrier	0.610 (0.061)	0.065 (0.036)	
	Open	1.150 (0.511)	0.288 (0.179)	
Iron, mg/l	Barrier	13.6 (1.9)	13.8 (1.3)	
	Open	16.0 (3.1)	26.4 (6.0)	
Manganese, mg/l	Barrier	0.2 (0.0)	3.2 (0.1)	
	Open	0.3 (0.1)	4.2 (0.5)	
¹ Based on a composite of three replicate samples. ² Based on sediment dry mass.				

fractions, i.e., sand, silt, and clay. But, over the same time period, changes in the texture of the sediment beneath the barrier were only moderately significant and limited to the sand and silt fractions. Sediment under the barrier exhibited a decrease in the sand fraction from about 26 percent in June to about 19 percent in September, while the silt fraction increased to about 61 percent from about 51 percent.

These unexpected changes in sediment texture beneath the barrier are difficult to explain. Perhaps, variability of the sediment beneath the barrier was more than assumed. Three replicate core samples were taken within close proximity to each other in June and September. However, the sampling location under the barrier in June was about 4 m distant from the sampling location in September.

In June, TKN and TP concentrations at the reference location were significantly higher than those from beneath the barrier (Table 1). TKN, based on sediment dry weight, was about 5.5 mg/g in the reference sediment and about 4.3 mg/g under the barrier. By September, TKN had exhibited a substantial and highly significant decline to about 1.8 mg/g in the reference sediment. The slight decline in TKN from about 4.3 mg/g to about 3.6 mg/g observed in sediment from under the barrier was not significant. In September, declines of TP were also evident at both sampling locations. However, the decline of TP in the reference sediment from about 1.7 mg/g to about 0.5 mg/g was much greater than the decline observed under the barrier (1.4 mg/g TP to about 1.1 mg/g TP).

In June, results of the analysis of exchangeable and extractable nutrients ($_{ex}NH_4-N$, $_{ex}K$, and $_{ex}PO_4-P$) indicated $_{ex}NH_4-N$ as the only nutrient that was significantly different between the reference and barrier sediments. Within the reference sediment, $_{ex}NH_4-N$, at 0.28 mg/g, was significantly higher than beneath the barrier (0.17 mg/g) (Table 1). In September, no significant differences in exchangeable and extractable nutrients were observed between the reference and barrier locations. Comparing June and September data, declines in $_{ex}NH_4-N$ from 0.28 to 0.14 mg/g and $_{ex}K$ from 0.26 to 0.13 mg/g in the reference sediment were significant. Also, an increase in $_{ex}PO_4-P$ in the reference sediment from 0.009 to 0.035 mg/g was significant.

In June, sediment interstitial water ammonium-N ($_{iw}NH_4-N$) was nearly 25 mg/l, a concentration significantly greater than the approximately 16 mg/l observed in sediment under the barrier. However, sediment interstitial water phosphate-P ($_{iw}PO_4-P$) in the reference sediment (1.15 mg/l) was not significantly different from the 0.61 mg/l observed under the barrier. Differences observed in sediment interstitial water Fe ($_{iw}Fe$) between the reference area and under the barrier, 16.0 and 13.6 mg/l, respectively, were not significant. No significant differences in sediment interstitial water Mn ($_{iw}Mn$) were evident between the reference area (0.3 mg/l) and beneath the barrier (0.2 mg/l). From June to September, significant increases in $_{iw}NH_4-N$ and $_{iw}Mn$ were noted at both the reference and barrier locations (Table 1). However, only $_{iw}Fe$ did not change significantly. The decline in $_{iw}PO_4-P$ (1.15 to 0.29 mg/l) from June

to September in the reference area was proved not to be statistically significant; however, the decline observed under the barrier (0.61 to 0.07 mg/l) was significant.

Lake Guntersville

Soon after deployment, the benthic barrier at Site 1 was vandalized and destroyed. Thus, this report deals with only four of the original sites of barrier placement in Lake Guntersville. Since no significant difference was noted for any of the parameters measured in either the reference or barrier locations at Sites 2-4 during both May and October, data from Sites 2-4 are presented as grand means (Table 2).

At Sites 2-4, sediment moisture content, bulk density, and organic matter content were comparable and did not exhibit significant change from May to October 1991 in either the reference or treatment sediments (Table 2). However, significant differences were noted for these parameters at Site 5 between the reference and barrier locations in May and again in October (Table 2). In May, moisture content was about 62 and 48 percent, respectively, in the reference and treatment sediments at Site 5. Sediment bulk density was 0.43 g/ml in the reference sediment and 0.72 g/ml beneath the barrier. Organic matter comprised 9.2 percent of the reference sediment and 6.1 percent of the sediment under the barrier. From May to October, moisture content at Site 5 decreased significantly in both the reference and barrier sediments to about 53 and 40 percent, respectively. Sediment bulk density, meanwhile, increased significantly to 0.61 g/ml in the reference area and 0.87 g/ml under the barrier. At Site 5, organic matter content exhibited significant declines in both the reference sediment and under the barrier to 6.9 and 4.8 percent, respectively.

Sediment textures were not significantly different between the reference and barrier sampling locations at Sites 2-4 in May (Table 2). Likewise, significant textural differences were not observed between sampling locations at Site 5. However, significant textural differences were evident between Sites 2-4 and Site 5 in both May and October. In May, sediments at Sites 2-4 were comprised of about 64-percent sand, 22-percent silt, and 14-percent clay. Meanwhile, sediment at Site 5 contained about 21-percent sand, 55-percent silt, and 24-percent clay. As in May, no significant differences in sediment texture at Sites 2-4 were noted in October between the reference and barrier sampling locations (Table 2). However, significant differences were evident in October in all sediment fractions between sampling locations at Site 5. In the reference sediment, sand increased from 22.5 to 24.3 percent, silt decreased from 55.7 to 49.1 percent, and clay increased from 17.5 to 26.6 percent. Beneath the barrier, sand and clay fractions decreased from 20.0 to 15.0 percent and from 25.0 to 22.9 percent, respectively, while silt increased from 55.0 to 62.1 percent. Overall, significant differences in sediment textures were observed between Sites 2-4 and Site 5 during both May and October.

Table 2

Physical and Chemical Characteristics of Lake Guntersville, Alabama, Sediment Collected at Locations Beneath the Benthic Barrier (barrier) and in the Adjacent Reference Sediment (open) near the Beginning and End of the 1991 Plant Growing Season (Values are grand mean (n = 9) for Sites 2-4 and mean (n = 3) for Site 5 with associated standard errors in parentheses)

Characteristic	Location	May 7, 1991		October 10, 1991		
		Sites 2-4	Site 5	Sites 2-4	Site 5	
Total Sediment						
Texture, % ¹	Sand	Barrier	64.7 (3.5)	20.0 (1.3)	58.8 (3.6)	15.0 (3.4)
		Open	63.3 (3.2)	22.5 (1.5)	54.2 (3.9)	24.3 (1.7)
Silt	Barrier	21.0 (1.9)	55.0 (1.4)	22.0 (2.3)	62.1 (2.9)	
	Open	22.8 (1.8)	55.7 (1.4)	28.4 (3.6)	49.1 (2.2)	
Clay	Barrier	14.3 (2.5)	25.0 (1.4)	19.2 (1.4)	22.9 (0.6)	
	Open	13.9 (1.7)	21.8 (1.6)	17.5 (1.3)	26.6 (0.8)	
Density, g/ml ¹	Barrier	1.36 (0.02)	0.72 (0.10)	1.32 (0.02)	0.87 (0.04)	
	Open	1.29 (0.04)	0.43 (0.02)	1.31 (0.06)	0.61 (0.01)	
Moisture, %	Barrier	21.5 (0.5)	47.7 (4.1)	23.2 (0.6)	39.5 (2.2)	
	Open	22.2 (1.0)	62.0 (0.7)	22.4 (0.8)	53.0 (0.3)	
Organic matter, %	Barrier	2.7 (0.3)	6.1 (0.6)	2.5 (0.0)	4.8 (0.3)	
	Open	2.5 (0.2)	9.2 (0.2)	2.6 (0.0)	6.9 (0.1)	
Total Kjeldahl nitrogen (TKN), mg/g ¹	Barrier	0.42 (0.03)	1.60 (0.13)	0.37 (0.02)	1.03 (0.07)	
	Open	0.37 (0.02)	2.69 (0.09)	0.39 (0.01)	1.85 (0.04)	
Phosphorus, mg/g ¹	Barrier	0.399 (0.037)	0.782 (0.111)	0.220 (0.022)	0.461 (0.017)	
	Open	0.414 (0.037)	1.062 (0.027)	0.230 (0.011)	0.750 (0.042)	
Extractable Nutrients						
Ammonium-N, mg/g ¹	Barrier	0.01 (0.00)	0.06 (0.01)	0.01 (0.00)	0.06 (0.01)	
	Open	0.01 (0.00)	0.04 (0.00)	0.01 (0.00)	0.03 (0.00)	
Phosphate-P, mg/g ¹	Barrier	0.010 (0.002)	0.072 (0.009)	0.013 (0.001)	0.071 (0.005)	
	Open	0.012 (0.001)	0.100 (0.006)	0.017 (0.002)	0.130 (0.008)	
Potassium, mg/g ¹	Barrier	0.02 (0.00)	0.05 (0.00)	0.03 (0.01)	0.03 (0.00)	
	Open	0.03 (0.00)	0.07 (0.00)	0.02 (0.01)	0.06 (0.00)	
Interstitial Water						
Ammonium-N, mg/l	Barrier	1.49 (0.44)	6.87 (1.51)	1.44 (0.25)	6.80 (0.72)	
	Open	1.21 (0.38)	1.94 (0.30)	0.96 (0.22)	1.51 (0.11)	
Phosphate-P, mg/l	Barrier	0.067 (0.032)	0.380 (0.091)	0.009 (0.001)	0.148 (0.042)	
	Open	0.072 (0.043)	0.600 (0.077)	0.007 (0.001)	0.293 (0.025)	
Iron, mg/l	Barrier	5.5 (1.8)	25.9 (7.6)	4.1 (2.1)	19.0 (2.7)	
	Open	3.0 (1.7)	9.3 (0.6)	3.3 (1.4)	5.9 (0.7)	
Manganese, mg/l	Barrier	7.2 (1.7)	9.5 (2.2)	6.1 (1.2)	5.0 (0.8)	
	Open	5.4 (0.5)	8.9 (0.4)	3.1 (0.5)	4.0 (0.5)	
¹ Based on sediment dry mass.						

Comparison of total sediment nutrients, i.e., TKN and TP, at Sites 2-4 in May, near the beginning of the 1991 growing season, revealed no significant differences between the reference and barrier sampling locations (Table 2). TKN was 0.37 mg/g in the reference sediment (0.37 mg/g) and 0.42 mg/g under the barrier. TP was 0.414 mg/g in the reference sediment and 0.399 mg/g under the barrier. At Site 5, significant differences between TKN and TP were evident between sampling locations, as both exhibited higher concentrations in the reference sediment. TKN concentration was about 2.7 mg/g in the reference sediment and about 1.6 mg/g under the barrier. TP concentration was 0.072 mg/g in the reference sediment and 0.100 mg/g in sediment beneath the barrier. At Sites 2-4, no significant differences in TKN were observed either between the reference or barrier sediments in October or between the May and October sampling efforts. At Site 5, significant declines in TP between May and October were noted in both the reference and barrier locations. As in May, both TKN and TP concentrations were higher in the reference sediment than under the barrier (Table 2).

Examination of the exchangeable and extractable nutrients revealed no significant differences in $ex-NH_4-N$ or $ex-K$ between the reference and barrier locations at Sites 2-4 or at Site 5 during either the May or October sampling efforts (Table 2). Significantly higher $ex-PO_4-P$ concentrations were observed in the reference sediment than under the barrier at Site 5 during both the May and October sampling efforts. At Sites 2-4, however, no significant differences in $ex-PO_4-P$ were observed between sampling locations in either May or October.

In May, examination of $iw-NH_4-N$, $iw-PO_4-P$, $iw-Fe$, and $iw-Mn$ revealed insignificant differences between the reference and barrier locations for each of the parameters at Sites 2-4 (Table 2). At Site 5, significant differences were noted between the barrier and reference location for $iw-NH_4-N$, $iw-PO_4-P$, and $iw-Fe$. $iw-NH_4-N$ and $iw-Fe$ concentrations, 6.87 and 25.9 mg/l, respectively, were considerably higher under the barrier than in the reference sediment (1.94 and 9.3 mg/l, respectively). Conversely, $iw-PO_4-P$ concentration was less under the barrier (0.380 mg/l) than in the reference sediment (0.600 mg/l).

In October, as in May, no significant differences in $iw-NH_4-N$, $iw-PO_4-P$, $iw-Fe$, and $iw-Mn$ were observed between sampling locations at Sites 2-4 (Table 2). However, comparisons of concentrations measured in the May and October sampling efforts showed $iw-PO_4-P$ as the only parameter to exhibit significant differences over the growing season. $iw-PO_4-P$ under the barrier declined from 0.067 mg/l in May to 0.009 mg/l in October. While in the reference sediment, $iw-PO_4-P$ declined from 0.072 to 0.007 mg/l in May. At Site 5, $iw-PO_4-P$, $iw-Fe$, and $iw-Mn$ concentrations showed significant declines under the barrier as well as in the reference sediment from May to October. $iw-PO_4-P$ and $iw-Mn$ exhibited more than 50-percent reductions in concentrations in both reference and treatment sediments. $iw-Fe$ under the barrier declined from 25.9 mg/l in May to 19.0 mg/l in October. In the reference sediment, $iw-Fe$ declined from 9.3 mg/l beneath the barrier to 5.9 mg/l in the reference location.

Effects of Barrier Placements on Vertical Profiles of In Situ Interstitial Water Chemistry

Eau Galle Reservoir

Only minimal differences in profiles of in situ interstitial water ammonium-N (${}_{\text{isiw}}\text{NH}_4\text{-N}$), in situ interstitial water phosphate-P (${}_{\text{isiw}}\text{PO}_4\text{-P}$), in situ interstitial water iron (${}_{\text{isiw}}\text{Fe}$), and in situ interstitial water manganese (${}_{\text{isiw}}\text{Mn}$) were observed between the reference and barrier sediments during each sampling period. In May-June, ${}_{\text{isiw}}\text{NH}_4\text{-N}$ profiles exhibited nearly equal concentrations (about 23 mg/l) at the reference and barrier locations from the sediment-water interface to a depth of about 10 cm (Figure 4). In the reference sediment below 10-cm depth, ${}_{\text{isiw}}\text{NH}_4\text{-N}$ increased steadily to a maximum of about 38 mg/l at 25-cm depth. However, ${}_{\text{isiw}}\text{NH}_4\text{-N}$ beneath the barrier remained nearly constant at about 23 mg/l to 25-cm depth. Between May-June and September, ${}_{\text{isiw}}\text{NH}_4\text{-N}$ exhibited declines in both the reference and barrier sediments to about 2 mg/l near the sediment-water interface (Figure 5). An almost linear increase in ${}_{\text{isiw}}\text{NH}_4\text{-N}$ from about 2 mg/l at the sediment-water interface to about 45 mg/l at 20-cm depth was observed in the reference sediment. Under the barrier, ${}_{\text{isiw}}\text{NH}_4\text{-N}$ increased to about 25 mg/l at 10-cm depth, then remained about the same to a depth near 20 cm.

In May-June, ${}_{\text{isiw}}\text{PO}_4\text{-P}$ concentrations (Figure 4) under the barrier were about 45 percent less than in the open sediment (mean = 2.28 and 4.16 mg/l, respectively, $n = 12$). Generally, highest ${}_{\text{isiw}}\text{PO}_4\text{-P}$ concentrations (about 4 mg/l in the reference sediment and about 2 mg/l in the barrier sediment) were observed in the upper 10 cm of sediment. During September, ${}_{\text{isiw}}\text{PO}_4\text{-P}$ profiles in the reference and barrier sediments exhibited almost equal concentrations from the sediment-water interface (about 0.1 mg/l) to a depth of 23 cm (about 3 mg/l) (Figure 5).

In May-June, ${}_{\text{isiw}}\text{Fe}$ concentrations at the sediment-water interface were about 26 mg/l at each sampling location (Figure 4). Beneath the barrier, ${}_{\text{isiw}}\text{Fe}$ exhibited about the same concentration down to about 25-cm depth; but in the reference sediment, ${}_{\text{isiw}}\text{Fe}$ declined to about 15 mg/l at about 5-cm depth, then increased to a maximum of about 33 mg/l at 22-cm depth. In September, ${}_{\text{isiw}}\text{Fe}$ profiles (Figure 5) were almost identical at both the treatment and open locations and ranged from 1 to 3 mg/l at the sediment-water interface to about 35 mg/l at 20-cm depth.

Profiles of ${}_{\text{isiw}}\text{Mn}$ in May-June were quite similar in the reference and barrier sediment locations (Figure 4). However, ${}_{\text{isiw}}\text{Mn}$ concentrations in the reference sediment (about 5.5 mg/l) were consistently higher than under the barrier (about 4 mg/l). In September, reference sediment ${}_{\text{isiw}}\text{Mn}$ concentrations ranged from about 1.5 mg/l at the sediment-water interface to about 8 mg/l at about the 23-cm depth in the open sediment. Under the barrier, however, ${}_{\text{isiw}}\text{Mn}$ ranged from about 5 mg/l near the sediment-water interface to a nearly constant about 4 mg/l from the sediment surface to near the 25-cm depth.

EAU GALLE RESERVOIR -- BENTHIC BARRIERS

Interstitial water data for 31 May - 14 June, 1991

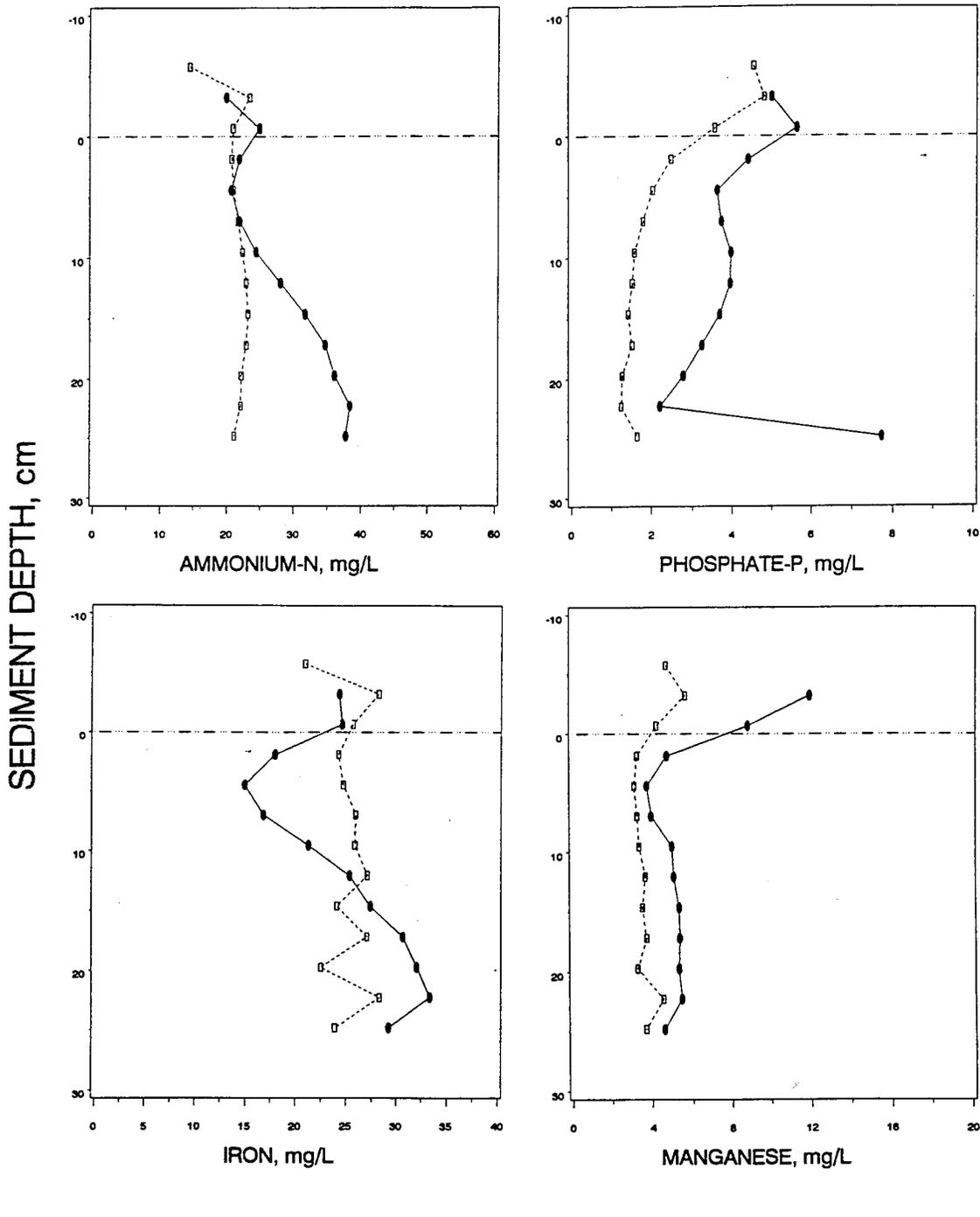


Figure 4. Profiles of interstitial $\text{NH}_4\text{-N}$, $\text{PO}_4\text{-P}$, Fe, and Mn concentrations collected in situ near center of barrier (dashed line) and in open sediment adjacent to benthic barrier (solid line) in early summer (May-June) 1991 in Eau Galle Reservoir, Wisconsin

EAU GALLE RESERVOIR -- BENTHIC BARRIERS

Interstitial water data for 5 -17 September, 1991

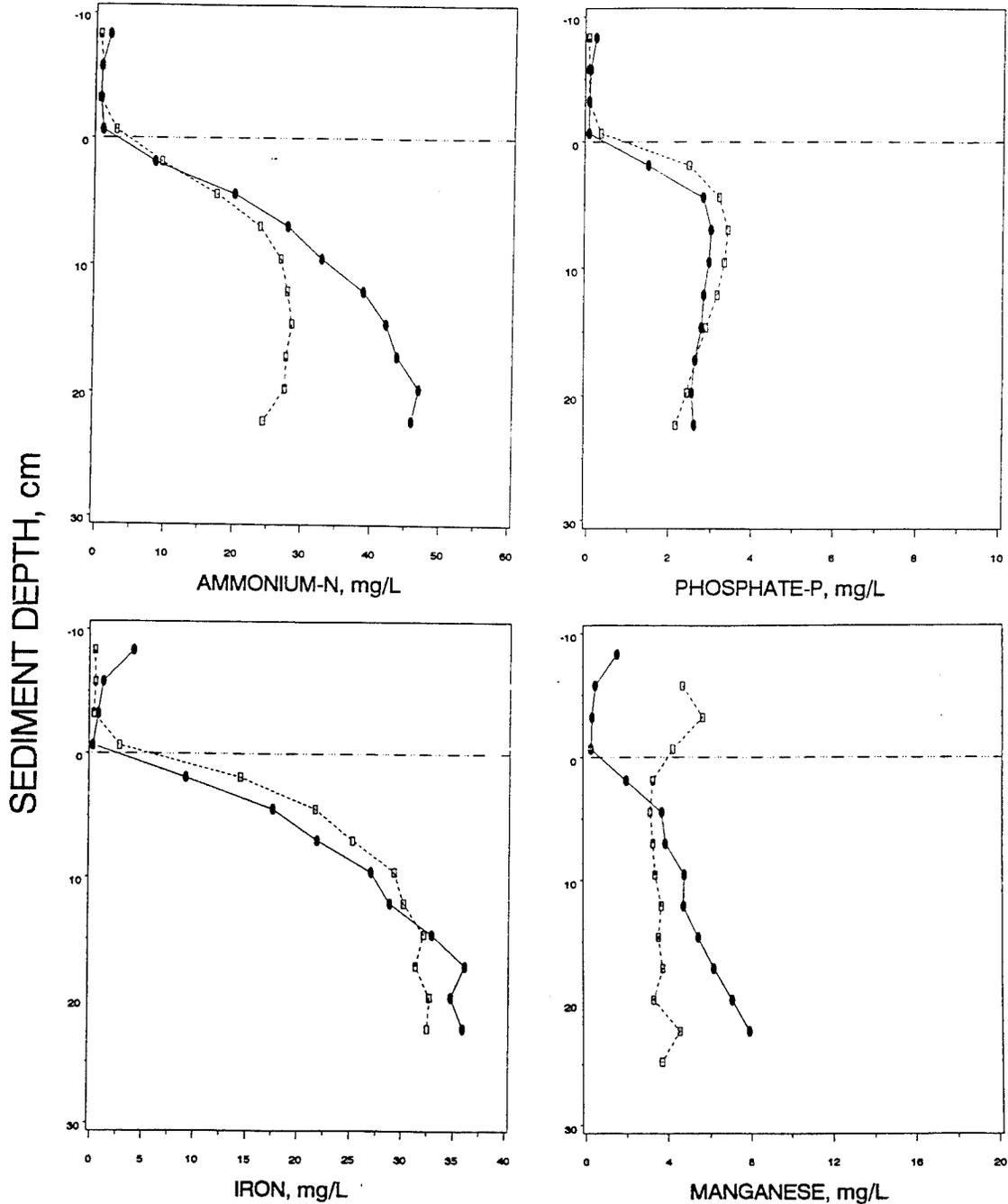


Figure 5. Profiles of interstitial $\text{NH}_4\text{-N}$, $\text{PO}_4\text{-P}$, Fe, and Mn concentrations collected in situ near center of barrier (dashed line) and in open sediment adjacent to benthic barrier (solid line) in late summer (September) 1991 in Eau Galle Reservoir, Wisconsin

Lake Guntersville

In early summer, during May-June, ${}_{\text{isiw}}\text{NH}_4\text{-N}$ profiles at Sites 2-4 (Figure 6) exhibited similarities between sites and sampling locations. Generally, ${}_{\text{isiw}}\text{NH}_4\text{-N}$ concentrations were low (about 0.1 mg/l) near the sediment-water interface and increased with sediment depth. At Sites 2 and 3, maximum ${}_{\text{isiw}}\text{NH}_4\text{-N}$ concentrations (about 2.5 and 4 mg/l, respectively) were observed beneath the barriers near the 5-cm depth. At Site 4, however, highest ${}_{\text{isiw}}\text{NH}_4\text{-N}$ values (about 2 mg/l) were observed in the open sediment at depths between 2 and 5 cm. Comparison of ${}_{\text{isiw}}\text{NH}_4\text{-N}$ profiles at the Site 5 barrier and open sediment locations was not possible because of the loss of the open sediment sampler. The ${}_{\text{isiw}}\text{NH}_4\text{-N}$ profile at the Site 5 barrier location, however, was quite unlike the ${}_{\text{isiw}}\text{NH}_4\text{-N}$ profiles at the barrier locations at Sites 2-4. ${}_{\text{isiw}}\text{NH}_4\text{-N}$ concentrations exhibited an almost linear increase from near 0.3 mg/l at the sediment surface to a maximum concentration of about 7 mg/l near the 27-cm depth. In August-September 1991, significant differences were observed in ${}_{\text{isiw}}\text{NH}_4\text{-N}$ profiles at study Sites 2, 4, and 5 (Figure 7). Maximum ${}_{\text{isiw}}\text{NH}_4\text{-N}$ concentrations under the Site 2 barrier (about 12 mg/l) were about twice those in the open sediment (about 6 mg/l). At both sampling locations, maximum concentrations occurred near the 7-cm depth. At Site 5, the maximum ${}_{\text{isiw}}\text{NH}_4\text{-N}$ concentration (about 11 mg/l) beneath the barrier was almost twice that observed in the open sediment (about 6 mg/l). The maximum concentration at the Site 5 barrier location was found between 10- and 15-cm depth. At Sites 3 and 4, ${}_{\text{isiw}}\text{NH}_4\text{-N}$ exhibited only slightly higher concentration under the barriers with maximums of about 7 mg/l.

In May-June, profiles of ${}_{\text{isiw}}\text{PO}_4\text{-P}$ at Sites 2-4 were remarkably similar (Figure 8). ${}_{\text{isiw}}\text{PO}_4\text{-P}$ concentrations did not differ greatly (from about 0.01 to about 0.13 mg/l) throughout the upper 20 cm of sediment. However, at Site 5, the ${}_{\text{isiw}}\text{PO}_4\text{-P}$ profile under the barrier was considerably different than at Sites 2-4. At the sediment-water interface, ${}_{\text{isiw}}\text{PO}_4\text{-P}$ concentrations were about the same (0.02 mg/l), but exhibited a quick and dramatic increase to a maximum of 1.68 mg/l at about 7-cm depth, followed by a steady decline to about 0.3 mg/l at a depth of 28 cm. At both Site 2 sampling locations, ${}_{\text{isiw}}\text{PO}_4\text{-P}$ profiles exhibited higher concentrations during August-September (Figure 9). Also, a substantial increase in ${}_{\text{isiw}}\text{PO}_4\text{-P}$ (to about 0.8 mg/l) under the barrier was evident from about 5- to 10-cm depth. At Sites 3 and 4, notable differences in ${}_{\text{isiw}}\text{PO}_4\text{-P}$ were not evidenced at either the barrier or adjacent sediment locations. At Site 5, ${}_{\text{isiw}}\text{PO}_4\text{-P}$ concentration maximums were about 1.5 mg/l under the barrier and about 2.6 mg/l in the open sediment.

At Sites 2 and 3 in May-June, ${}_{\text{isiw}}\text{Fe}$ profiles were comparable beneath the barriers and in the adjacent sediments (Figure 10). Concentrations of ${}_{\text{isiw}}\text{Fe}$ increased substantially (from about 1 to about 10 mg/l) under the barriers at a depth of about 7 cm. In the open sediment at Site 2, ${}_{\text{isiw}}\text{Fe}$ concentrations reached a similar maximum, but at a greater sediment depth (about 12 cm). At Site 3, ${}_{\text{isiw}}\text{Fe}$ concentrations in the open sediment reached a maximum of about 5 mg/l at a depth of 10 cm. ${}_{\text{isiw}}\text{Fe}$ concentrations in the open sediment, at Site 4, increased to about 17 mg/l below 10-cm depth. At the Site 5 barrier

LAKE GUNTERSVILLE -- BENTHIC BARRIERS

Interstitial water data for 9 May - 5 June, 1991

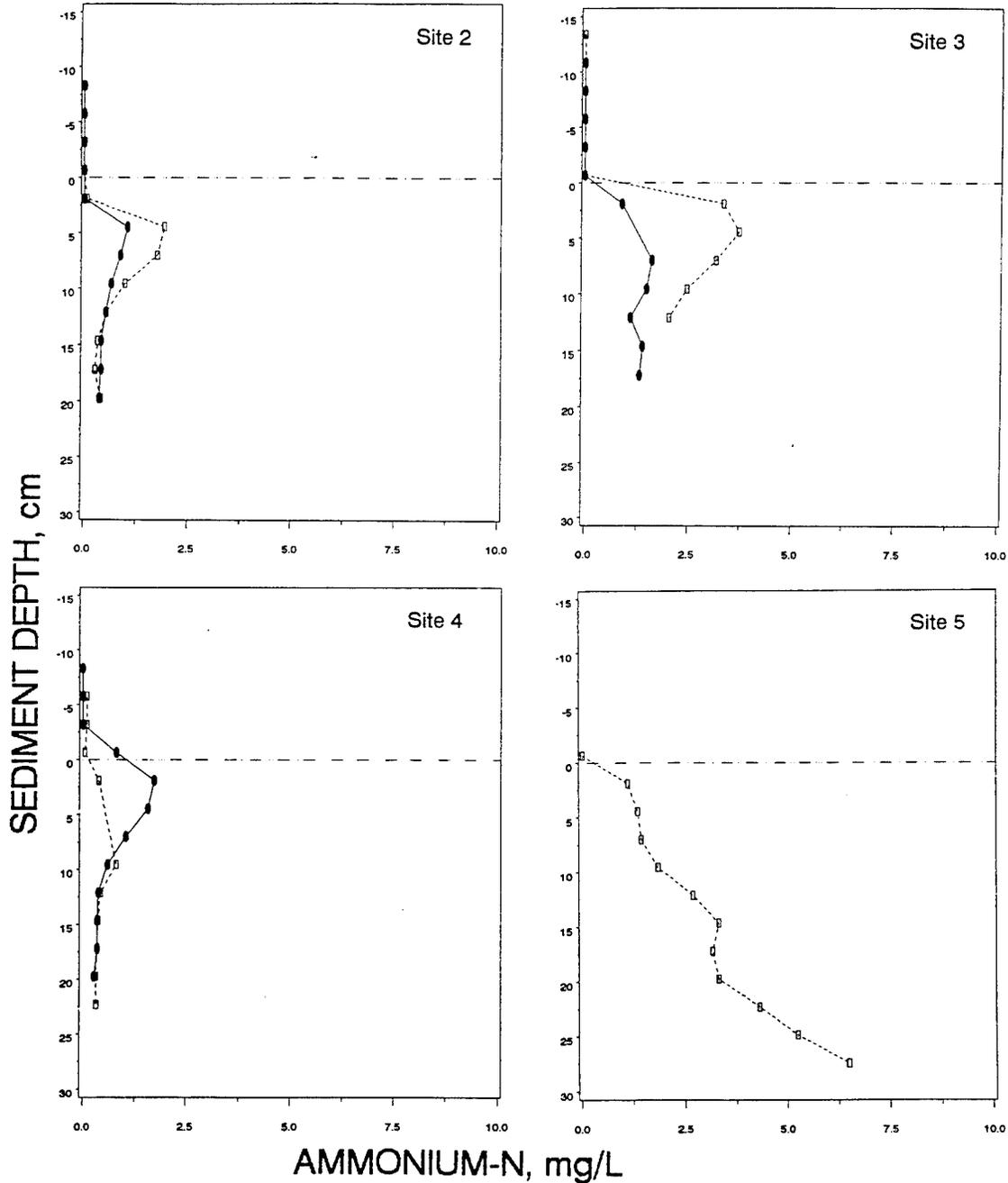


Figure 6. Profiles of interstitial NH₄-N concentrations collected in situ near center of barriers (dashed lines) and in open sediment adjacent to benthic barriers (solid lines) in early summer (May-June) 1991 in Lake Guntersville, Alabama

LAKE GUNTERSVILLE -- BENTHIC BARRIERS

Interstitial water data for 30 August - 16 September, 1991

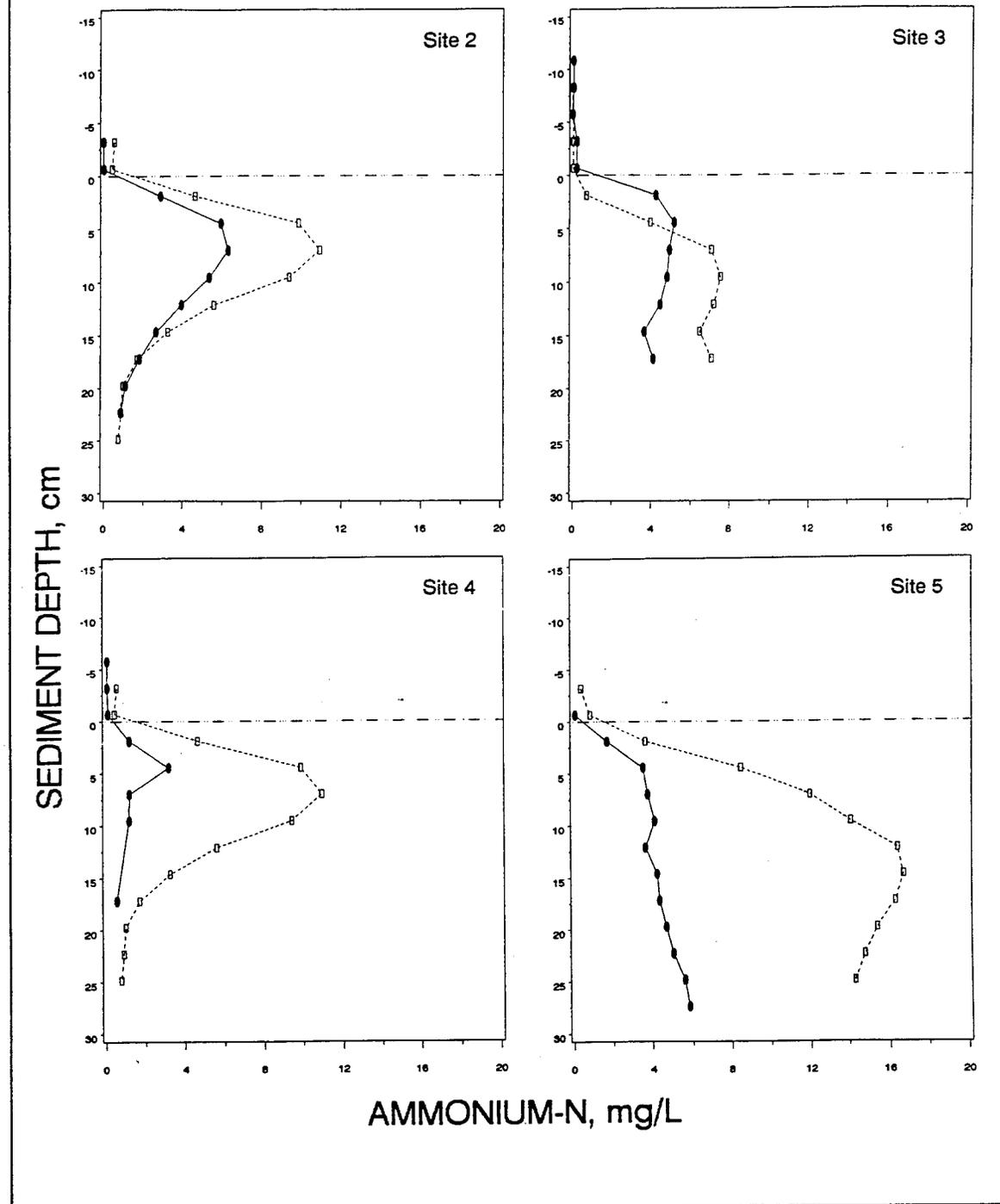


Figure 7. Profiles of interstitial $\text{NH}_4\text{-N}$ concentrations collected in situ near center of barriers (dashed lines) and in open sediment adjacent to benthic barriers (solid lines) in late summer (August-September) 1991 in Lake Guntersville, Alabama

LAKE GUNTERSVILLE -- BENTHIC BARRIERS

Interstitial water data for 9 May - 5 June, 1991

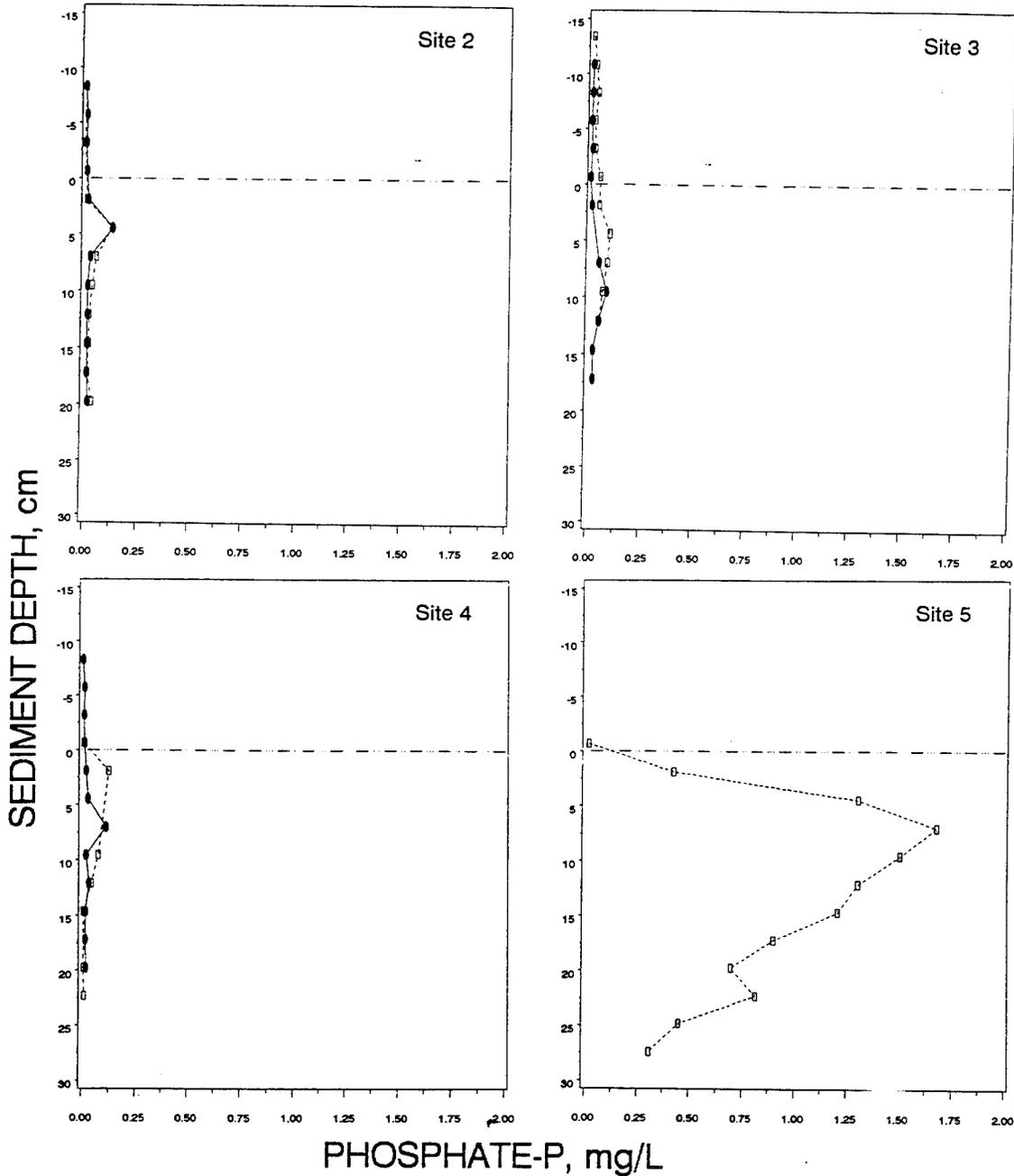


Figure 8. Profiles of interstitial $\text{PO}_4\text{-P}$ concentrations collected in situ near center of barriers (dashed lines) and in open sediment adjacent to benthic barriers (solid lines) in early summer (May-June) 1991 in Lake Guntersville, Alabama

LAKE GUNTERSVILLE -- BENTHIC BARRIERS

Interstitial water data for 30 August - 16 September, 1991

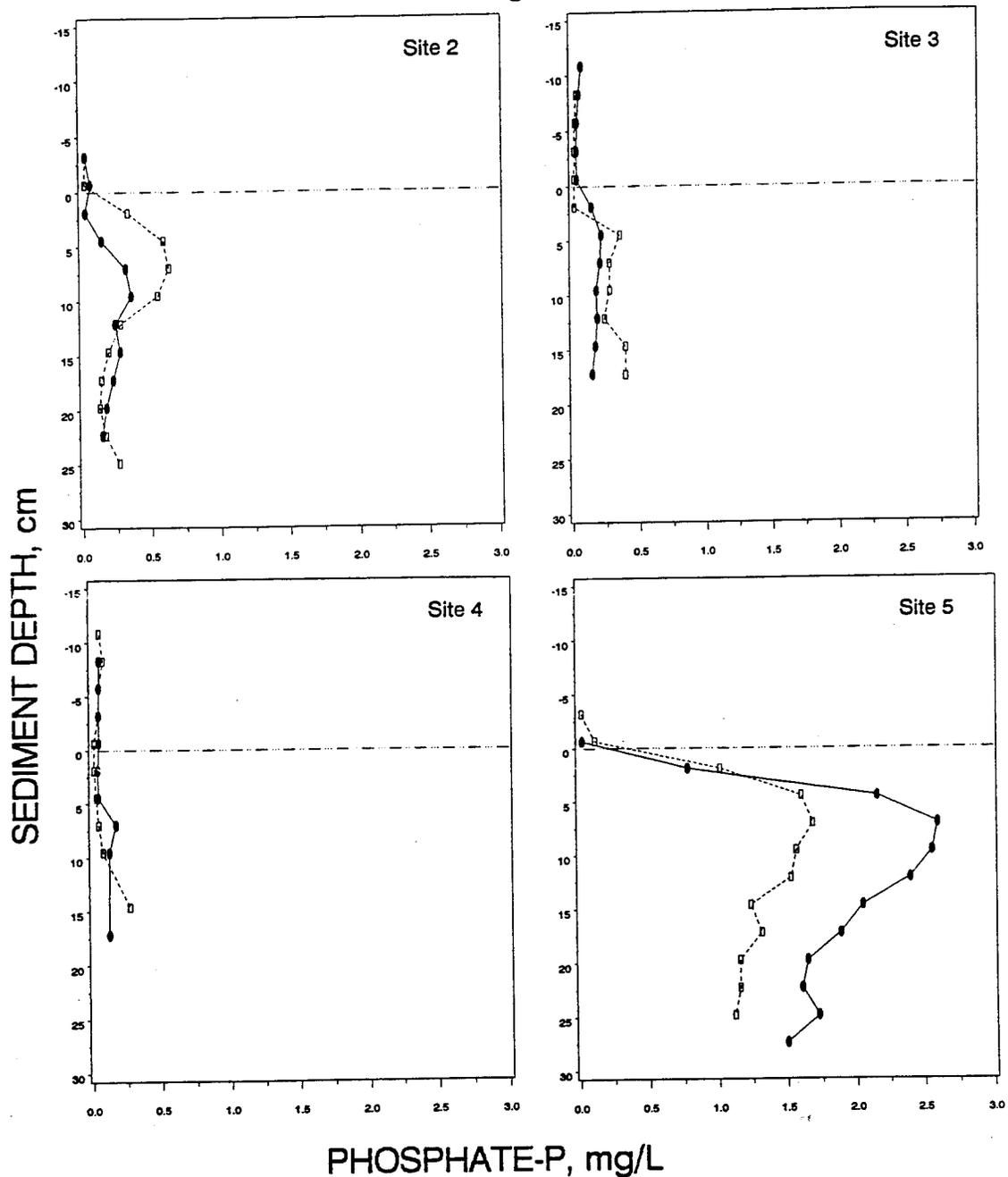


Figure 9. Profiles of interstitial $\text{PO}_4\text{-P}$ concentrations collected in situ near center of barriers (dashed lines) and in open sediment adjacent to benthic barriers (solid lines) in late summer (August-September) 1991 in Lake Guntersville, Alabama

LAKE GUNTERSVILLE -- BENTHIC BARRIERS

Interstitial water data for 9 May - 5 June, 1991

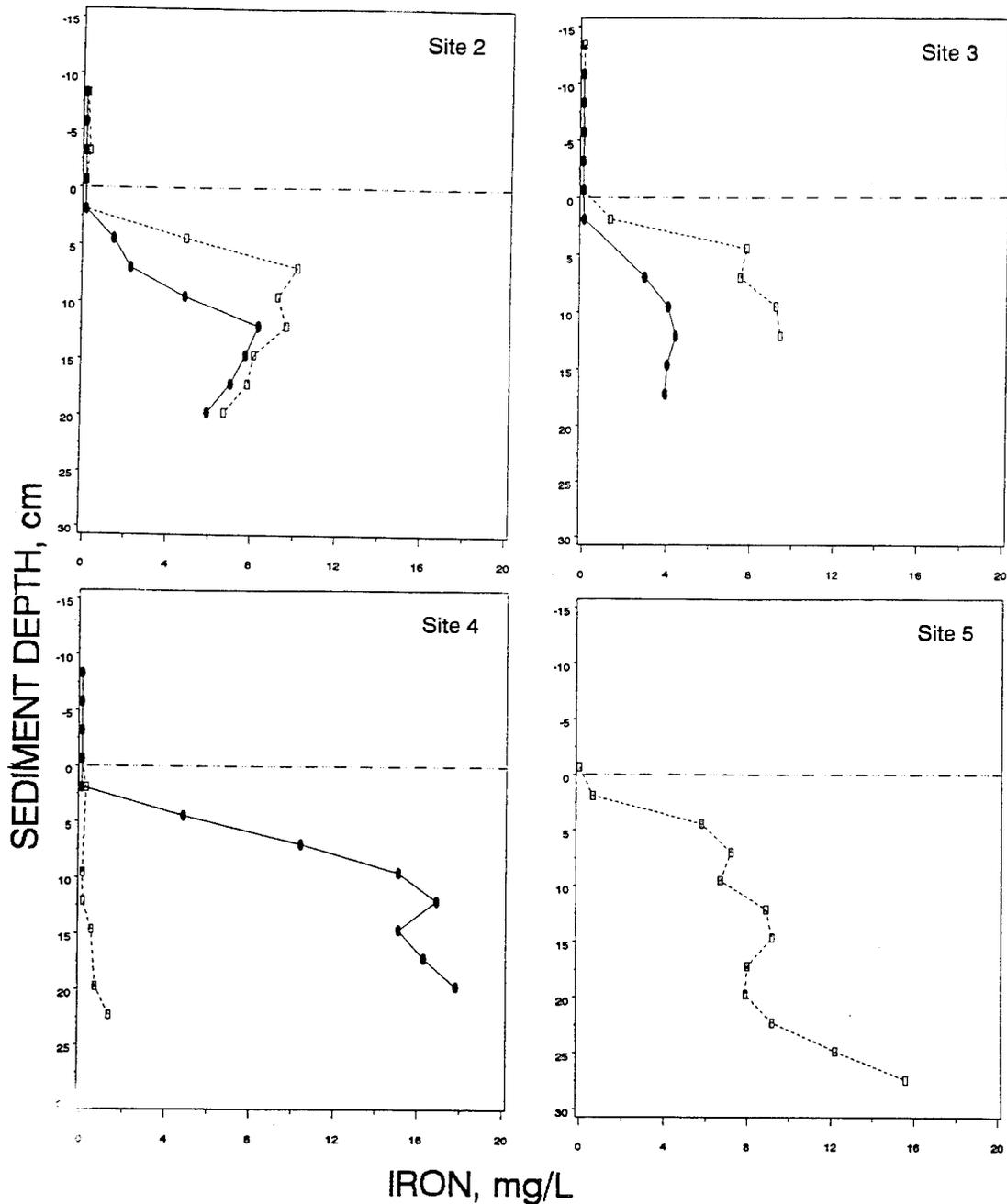


Figure 10. Profiles of interstitial Fe concentrations collected in situ near center of barriers (dashed lines) and in open sediment adjacent to benthic barriers (solid lines) in early summer (May-June) 1991 in Lake Gunterville, Alabama

location, the $_{\text{isiw}}\text{Fe}$ profile was similar to $_{\text{isiw}}\text{Fe}$ profiles observed at Sites 2 and 3. In August-September, $_{\text{isiw}}\text{Fe}$ profiles at Sites 2 and 5 showed substantial increases over those observed in June (Figure 11). At Site 2, the maximum $_{\text{isiw}}\text{Fe}$ concentration, under the barrier, was about 24 mg/l as compared with about 11 mg/l in June. At Site 5 under the barrier, the maximum $_{\text{isiw}}\text{Fe}$ concentration was about 16 mg/l in May-June and 36 mg/l in August-September. At Sites 3 and 4, $_{\text{isiw}}\text{Fe}$ profiles were not significantly different from profiles in May-June.

During May-June, $_{\text{isiw}}\text{Mn}$ profiles were similar beneath the barriers and in the open sediment at each of Sites 2-4 (Figure 12). Although a comparison of $_{\text{isiw}}\text{Mn}$ profiles was not possible at Site 5, concentrations under the barrier exhibited a pattern of increasing concentration from about 1 mg/l at the sediment-water interface to a maximum concentration of about 10 mg/l near the 5-cm depth, then declining to about 4 mg/l near the 17-cm depth, and again increasing to about 7 mg/l near the 28-cm depth. In August-September, $_{\text{isiw}}\text{Mn}$ profiles from under the barriers and open sediment locations exhibited considerable uniformity at each study site (Figure 13). Highest $_{\text{isiw}}\text{Mn}$ concentration (about 15 mg/l) was observed near the 12-cm depth under the barrier at Site 5 in August-September. At Sites 2-4, $_{\text{isiw}}\text{Mn}$ profiles did not differ significantly between the barrier and open sediment locations in either May-June or August-September.

Effects of Barrier Placements on Surficial Water

An absence of DO (0.0 mg/l) in the surficial water beneath the barrier was evident in both the May-June and September 1991 sampling efforts at Eau Galle.

At Lake Gunterville, DO concentrations varied between barrier sites in May-June, but generally were greatly reduced or absent. DO concentrations were 0.5 mg/l at Site 2, 0.9 mg/l at Site 3, 1.8 mg/l at Site 4, and 0.0 mg/l at Site 5. In August-September, DO concentrations were 0.0 mg/l beneath all barriers.

Plant Regrowth on Affected Sediments

No significant differences were noted in the growth of *Hydrilla* on sediments taken from beneath the barrier or the adjacent sediment at each sampling site. At Sites 2-4, a trend of slightly reduced, but insignificant, plant growth was observed beneath the barriers (Figure 14). At Site 5, plant growth on sediments from under the barrier was greater, although not significantly different from on sediments from the adjacent area.

LAKE GUNTERSVILLE -- BENTHIC BARRIERS

Interstitial water data for 30 August - 16 September, 1991

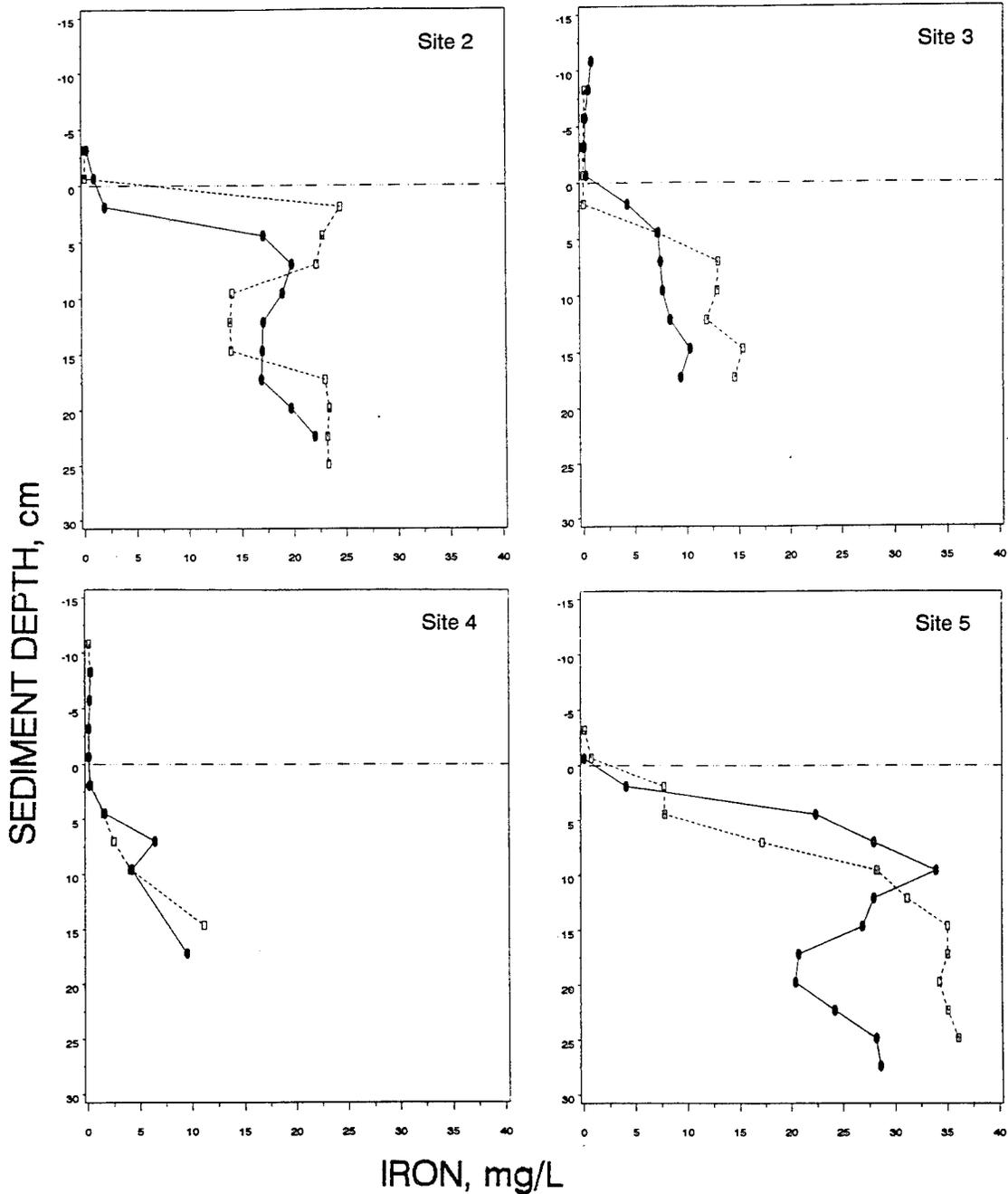


Figure 11. Profiles of interstitial Fe concentrations collected in situ near center of barriers (dashed lines) and in open sediment adjacent to benthic barriers (solid lines) in late summer (August-September) 1991 in Lake Guntersville, Alabama

LAKE GUNTERSVILLE -- BENTHIC BARRIERS

Interstitial water data for 9 May - 5 June, 1991

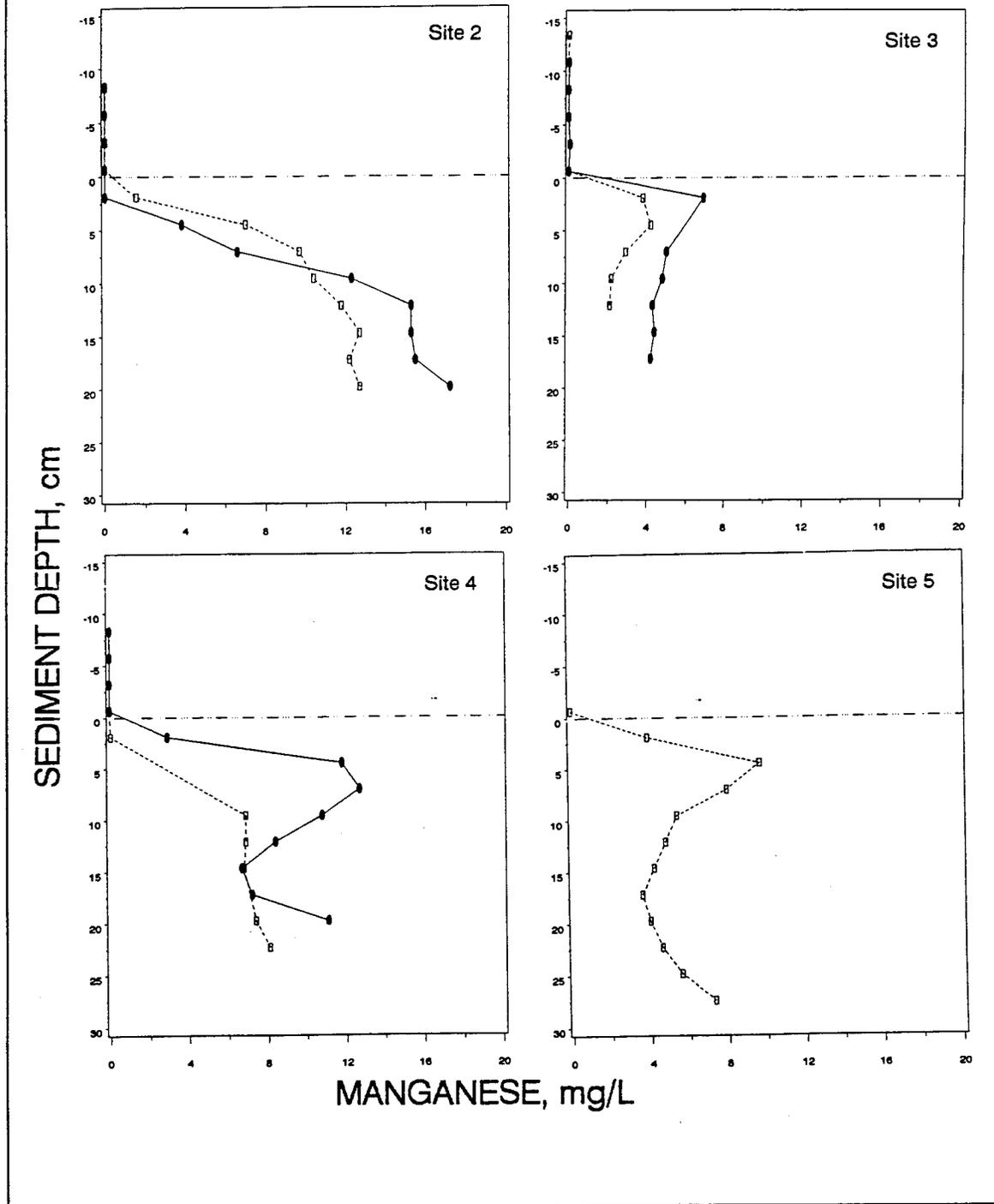


Figure 12. Profiles of interstitial Mn concentrations collected in situ near center of barriers (dashed lines) and in open sediment adjacent to benthic barriers (solid lines) in early summer (May-June) 1991 in Lake Guntersville, Alabama

LAKE GUNTERSVILLE -- BENTHIC BARRIERS

Interstitial water data for 30 August - 10 September, 1991

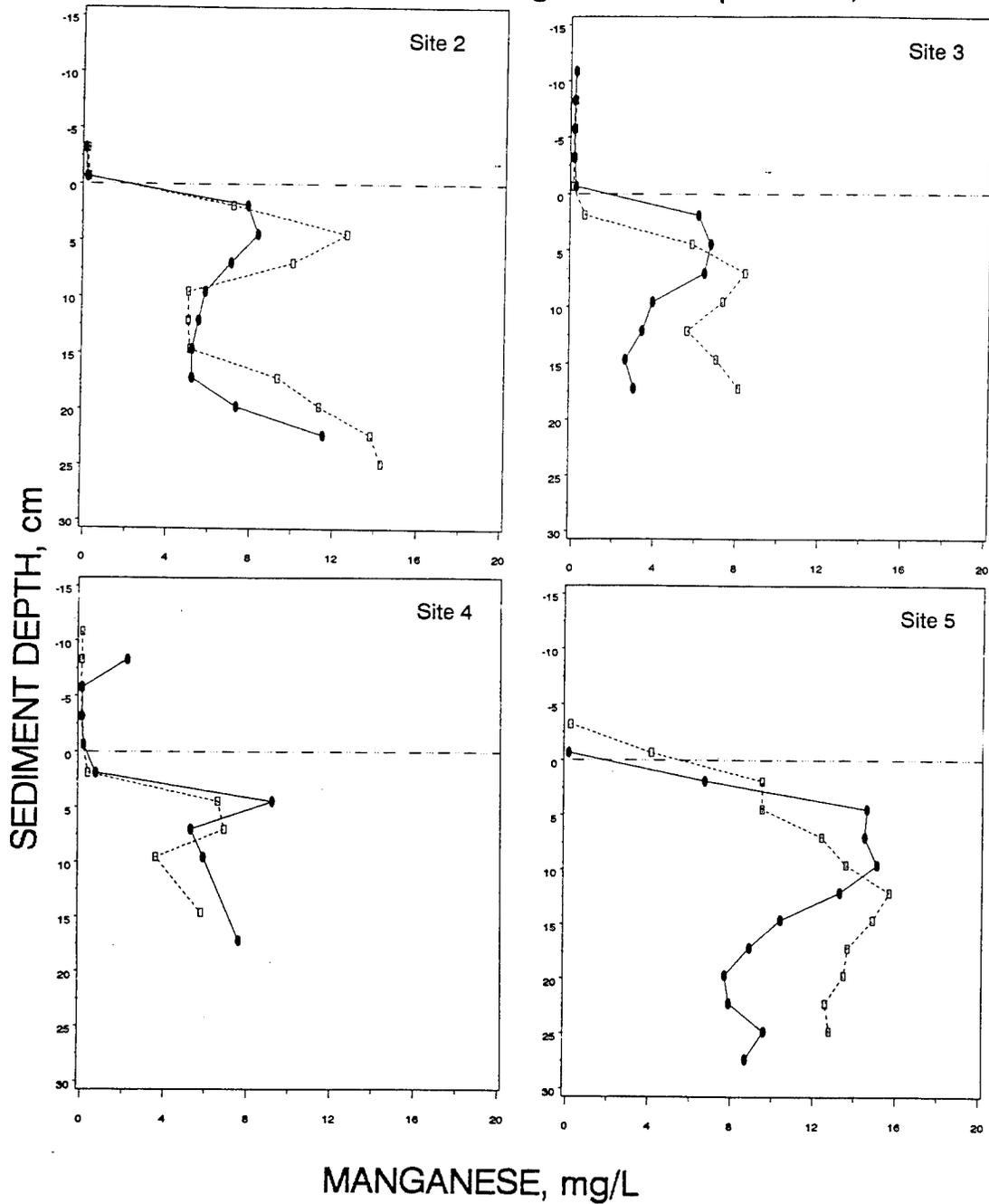


Figure 13. Profiles of interstitial Mn concentrations collected in situ near center of barriers (dashed lines) and in open sediment adjacent to benthic barriers (solid lines) in late summer (August-September) 1991 in Lake Guntersville, Alabama

LAKE GUNTERSVILLE -- BENTHIC BARRIERS

HYDRILLA REGROWTH EXPERIMENT
FEBRUARY 5 - MARCH 11, 1992

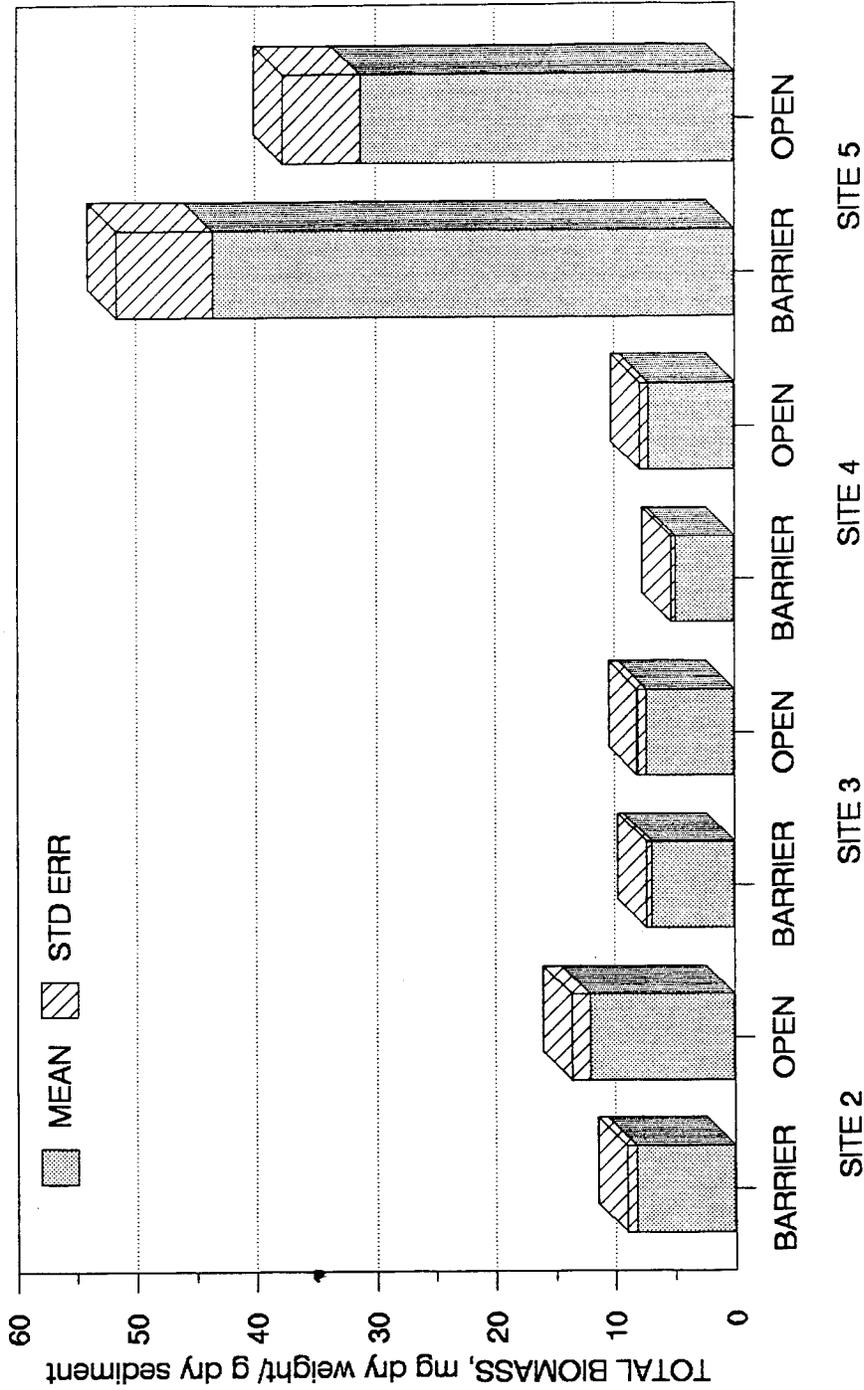


Figure 14. Mean (n = 6) total biomass production of *Hydrilla* with associated standard errors on Lake Gunter'sville sediments collected near center of barriers and in open sediment adjacent to barriers

4 Discussion

The benthic barrier used in this study appeared to affect the physical (e.g., moisture, density, and organic matter content) conditions of the sediment over which it was placed differently, depending on the sediment's texture. On relatively fine-textured sediments (e.g., >50-percent silt and clay), such as found at the barrier site in Eau Galle Reservoir and at Site 5 in Lake Gunterville, changes in physical conditions were more pronounced than on the relatively coarse-textured sediments (e.g., >50-percent sand) found at Sites 2-4 in Lake Gunterville.

Clearly, the physical conditions of sediments beneath the barriers and the open sediments at Sites 2-4 in Lake Gunterville were similar in both May and October. Likewise, similarities between the physical conditions of the treatment and reference sediments were evident in June at Eau Galle Reservoir. These observations suggest minimal influence by the barriers. However, significant differences in physical conditions were observed at Site 5 in Lake Gunterville in both May and October and at Eau Galle in September. Contrary to the above assessment, these observations suggest substantial influence by the barriers. In Lake Gunterville, the differences in physical conditions observed may be in response to increased microbial and decompositional processes. However, at Eau Galle the differences in physical conditions are more likely to have resulted from erosional and/or depositional processes altering the reference sediment. The location of the barrier site near the mouth of Lousy Creek may have allowed high flows and suspended material loads associated with storm runoff to alter or even replace the reference sediment during the study period. In this instance, the barrier at Eau Galle appears to have ameliorated the effect of these processes on the sediment over which it was placed.

Within the sediments of most aquatic macrophyte habitats, microbial respiration and decompositional (i.e., the oxidation of organic matter) processes tend to support the development of anoxic conditions, most often only millimeters below the sediment-water interface. In turn, this anoxia in the sediment promotes low oxidation-reduction potentials, thereby causing increases in the reduced counterparts of NO_3^- , SO_4^{2-} , Mn^{4+} , Fe^{3+} , and CO_2 : NH_4^+ , H_2S , Mn^{2+} , Fe^{2+} , and CH_4 (Ponnamperna 1972) in the interstitial water. Normally, increased concentrations of reduced species are lessened by diffusion and/or volatilization out of the sediment into the overlying water column. However, if a barrier constructed of material impermeable to exchanges of water and

gases were placed upon the sediment, then significant increases in reduced species in the sediment interstitial and surficial waters would be expected. Gunnison and Barko (1991) and Bartodziej (1992) described limited permeability of gases through a barrier of material used in this study. Consequently, the increases in reduced species observed in the interstitial and surficial waters beneath the barriers were expected.

At Eau Galle, in contrast to the scenario described above, each interstitial water chemistry parameter exhibited lower concentrations beneath the barrier in both June and September. Possible explanations for these unexpected lower concentrations are (a) blocking of deposition to the sediment beneath the barrier by the barrier, thereby diminishing the amount of oxidized material available for reduction and (b) greater cumulative losses of reduced species by diffusion and/or volatilization because of an absence of an oxic layer overlying the sediment-water interface under the barrier. Both arguments appear credible when the length of time the barrier was in place prior to the study (approximately 3 years) is considered.

In Lake Guntersville, interstitial water concentrations were most often only slightly elevated under the barriers at Sites 2-4. Whereas at Site 5, concentrations were as much as four times higher beneath the barrier than in the reference sediment. The significant increases observed under the barrier at Site 5 tend to support the argument that the type of sediment (i.e., low density, high moisture content, and high organic matter content) is of more importance to accumulations of reduced species within the interstitial water than the effective permeability of the barrier material.

Extractable nutrient concentrations were slightly higher in the sediment under the barrier at Eau Galle near the end of the growing season. Decreases in $\alpha\text{-NH}_4\text{-N}$ and $\alpha\text{-K}$ in the open sediment may have resulted from uptake by plants. At Lake Guntersville, almost no differences in extractable nutrient concentrations were evident between the barrier and reference sediments in May or October. Uptake of extractable nutrients was not expected because of an absence of plants at Lake Guntersville.

At Eau Galle, TKN and TP concentrations were less under the barrier in June than in the reference sediment. Also, a decrease in both TKN and TP concentrations under the barrier was observed over the growing season. These findings are, conceivably, indicative of increased microbial and decompositional conversions found in more organic sediments during periods of increased temperatures. However, the very significant decreases in TKN and TP that were observed in the reference sediment seem to contradict the above assessment. Perhaps these decreases were the result of assaying a different sediment than in June (see above).

Examination of DO concentrations, within the surficial water beneath the benthic barriers, revealed complete loss of oxygen during the study period. Loss of oxygen and increased concentrations of $\text{NH}_4^+\text{-N}$ and undissociated NH_4OH , a substance toxic to aquatic macroinvertebrates, in the surficial water

are thought to be responsible for the considerable reduction in viable macroinvertebrate populations beneath the barriers during the study. Payne, Miller, and Ussery (1993) suggested that a loss of oxygen and increased concentrations of NH_4OH and $\text{NH}_4^+\text{-N}$ were responsible for the almost total elimination of aquatic macroinvertebrates beneath barriers of the type used in this study.

5 Conclusions and Recommendations

Overall, the physical conditions, i.e., moisture content, density, organic matter content, and texture, of sediment were minimally affected by the benthic barriers. Some consolidation of sediment beneath barriers of this type appears to occur, as exhibited by slight increases in density and slight decreases in moisture content. This consolidation effect may occur because the barrier limits exchanges with the overlying water column. Also, the barriers appear to be able to physically restrict erosional and/or depositional processes from affecting the sediments over which they were placed.

The limited permeability of the barrier material inhibited exchanges of water and gases between the sediment and the overlying water column. As a result, microbial and decompositional processes occurring under the barriers brought about a complete loss of DO in the surficial water beneath the barrier. Anoxia in the surficial water, in turn, caused increases in reduced chemical species, particularly $\text{NH}_4^+\text{-N}$ and NH_4OH . Subsequently, anoxia and increased $\text{NH}_4^+\text{-N}$ and NH_4OH concentrations resulted in the elimination of aquatic macroinvertebrates from under the barriers.

Changes in sediment physical and chemical conditions because of barrier placement apparently had no detrimental effects that might limit the growth of aquatic macrophytes on the affected sediments. This was evidenced by acceptable regrowth of the aquatic macrophyte *Hydrilla* on the affected sediments following barrier removal.

Therefore, use of this particular benthic barrier may be considered as a viable method of aquatic macrophyte control. However, further examinations of the permeability of barrier materials should be undertaken. Increased permeability of the barrier material could further enhance the quality of the surficial water and prevent the elimination of macroinvertebrates.

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