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Effects of Liming on Plankton and Young-of-the-Year Bluegill Growth in Flat Top Lake, West Virginia

by

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(ABSTRACT)

The responses at three trophic levels (phytoplankton, zooplankton, young-of-the-year bluegill) were compared between a limed and unlimed arm in a moderately fertile, circumneutral reservoir that was sensitive to acidification, but had not yet shown signs of damage. The east arm (25.5 ha) of Flat Top Lake was treated with 28.8 dry metric tonnes of calcite using slurry box technology between July 13-20, 1987. The design was confounded because calcite dissolution products diffused into the unlimed (west) arm after the treatment which made total alkalinity similar between the arms within 1 month. Phytoplankton gross productivity and chlorophyll *a* was similar between the arms for the pre- and post-treatment samples as well as for the period after the treatment when total alkalinity was relatively higher in the limed arm. Zooplankton biomass was higher in the unlimed than limed arm in the pre-treatment samples but was similar between the arms in the post-treatments samples; however, the changes in zooplankton biomass after treatment in the limed arm could not be attributed to the treatment. Phytoplankton community composition for the common netplankton and nannoplankton was similar between the limed and unlimed arms for the combined pre- and post-treatment samples; however, *Gemellicystis spp.*, *Gloeocystis spp.*, and *Dinobryon spp.* showed an order of magnitude higher density in the limed relative to the unlimed arm on the initial post-treatment sample. This difference, as well as the observed post-treatment differences in zooplankton community composition between the two arms could not be attributed to the treatment because there were minimal impacts on nutrient levels (e.g., CO_2, total phosphorus) and zooplankton-phytoplankton interactions. Lake transparency was significantly deeper in the limed arm relative to the unlimed arm for the post-treatment samples; however, a corresponding lower dissolved organic carbon concentration was not measured in the limed arm. Young-of-the-year bluegill (e.g., primarily those 15-20 d old) showed significantly higher growth rates in the unlimed arm during the period when total alkalinity was higher in the limed arm, apparently due to a higher density of suitable pelagic zooplankton in the unlimed arm during this period. In conclusion, no significant positive or negative responses to the treatment were detected because of trophic level interactions. The high pre-treatment pH (7.07), small change in post-treatment pH, low dissolution percentage (8-10%), the inability of the sediment dose to neutralize the acidic sediments and induce phosphorus release, and phosphorus rather than carbon dioxide limited primary productivity were the main factors why no significant post-treatment biological responses were detected.

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Introduction

Although the phenomenon of "acidic deposition[1]" has been known since the mid-19th century when Robert Angus Smith discovered high levels of sulphuric acid deposition in and around Manchester of England (Cowling 1982), its deleterious effects on susceptible lakes and their fisheries was largely ignored until the 1970's when declining and extinct fish populations were being discovered in ever-increasing amounts in Scandinavia, southern Ontario, Nova Scotia, and the Adirondack Mountains of New York (Beamish and Harvey 1972; Scholfield 1976; Overrein et al. 1980; Sevaldrud et al. 1980; Haines 1981). Acidic deposition, generally called acid rain, has been referred to as the "environmental crisis of the eighties" due largely to its severe consequences for recreational, commercial, and ecologically important fisheries resources (Simmons 1982).

The most severe declines in fish populations due to acidification and associated increases in toxic metals (e.g., inorganic monomeric aluminum) have been experienced in Sweden (i.e., primarily southwestern Sweden), where an estimated 16,000 lakes and 90,000 km of streams and rivers have been acidified (Dickson 1985; Bernes and Thornelof 1988) causing declines

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[1] Defined as the sum total of acidic precipitation (acid rain and/or acid snow) and acidic dry deposition, theoretically with a pH less than 5.6; however, evidence suggests that natural rainwater can have pH's near 5.0 (Schindler 1988).

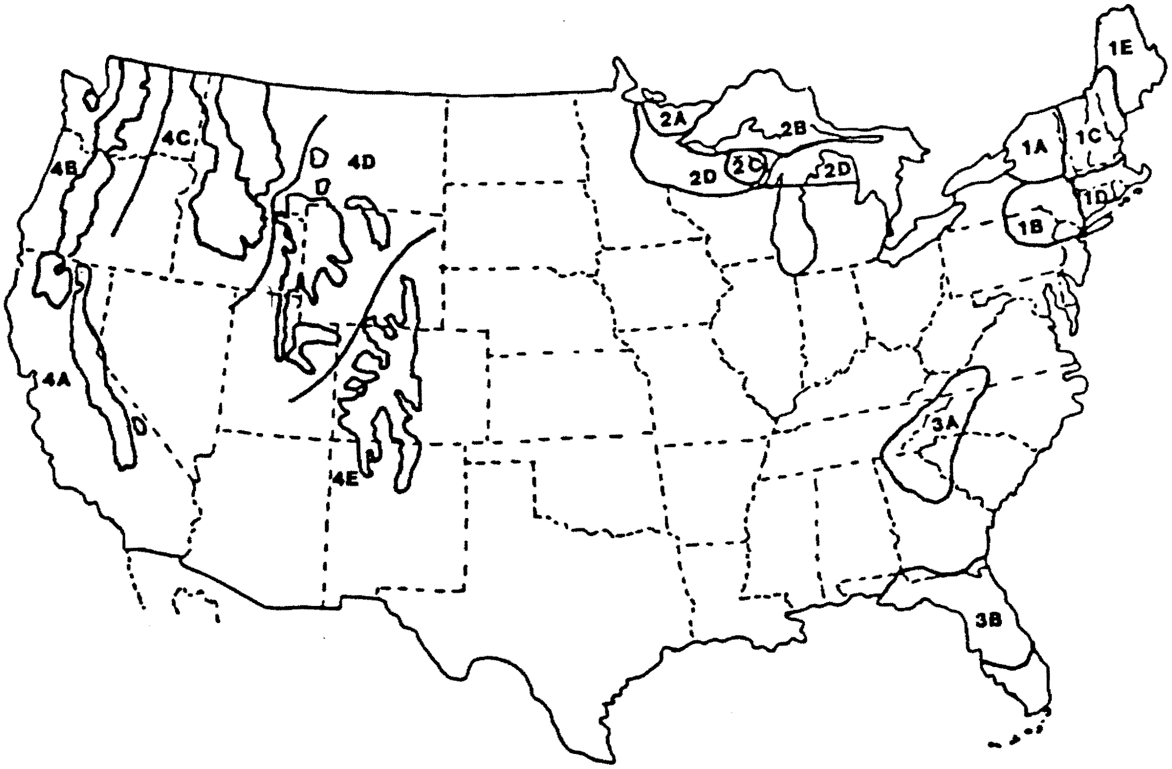
and extinctions in roach (*Rutilus rutilus*), brown trout (*Salmo trutta*), and Atlantic salmon (*Salmo salar*) populations (Rosseland et al. 1986b); and in Norway (i.e., primarily southern Norway), where an estimated 73% of the brown trout and 43% of the European perch (*Perca fluviatilis*) populations had been lost in the most susceptible counties by 1983 (Sevaldrud and Skogheim 1986). By 1978, Atlantic salmon became extinct in southern Norway (Rosseland et al. 1986b). Declining fisheries have also been reported in other parts of Norway and Sweden, as well as in Finland (Rosseland et al. 1986a, 1986b). Eastern Canada has also experienced significant losses in fish populations with the loss of Atlantic salmon in nine Novia Scotia streams and the loss of 54 fish populations in the LaCloche Mountain lakes of southern Ontario being the most significant reported (Harvey and Lee 1982). Harvey and Lee (1982) stated that the documented losses of fish populations represented only a small percentage of the total losses in eastern Canada because of the lack of historical fisheries survey data for many of the high altitude or otherwise remote lakes. An estimated 350,000 lakes in the six eastern provinces of Canada and south of 52^0N are considered extremely acid-sensitive with total alkalinities or acid neutralizing capacities (ANC) below 50 μeq/L (Kelso et al. 1986).

Losses of fish populations have also been documented in the United States, however, to a much smaller extent than in Scandinavia and eastern Canada. Scholfield (1976) reported that brook trout (*Salvelinus fontinalis*) had become extinct in 26 of 40 Adirondack Mountain lakes surveyed. Fraser and Britt (1982) reported that 219 lakes (3203.7 ha) and 58 streams had been affected by acidic deposition in the United States. The majority of lakes (206) were in the Adirondack Mountains and the majority of the streams were also in New York (25) and in Pennsylvania (24).

More distressing, perhaps, is recent evidence that fisheries in a much larger geographical area in the United States, other than the Adirondack Mountains, are vulnerable to acidic deposition and many have shown signs of acidification (Schindler 1988). The National Surface Water Survey (NSWS), conducted by the United States Environmental Protection Agency, documented the chemical and biological status of lakes and streams in regions of the United States that are potentially sensitive to acidic deposition and identified representative surface waters for continued long-term monitoring to assess aquatic resource changes (Schreiber 1988). The sensitivity of a water body to acidification is dependent on a variety of factors, however, total alkalinity is generally regarded as the best indicator with waters that have alkalinities less than 200 μeq/L (i.e., 10 mg/L) generally considered to be sensitive (Fraser and Britt 1982). In a survey of 226 headwater lakes and low order streams in six New England states, Haines and Akielaszek (1983) concluded that 59% were sensitive to acidification; furthermore, 6% had a pH of 5.5 or less with aluminum concentrations of 200 μg/L, a potentially toxic combination for sensitive species (Baker 1982), and in lakes where historical data were available, hydrogen-ion content increased five-fold and alkalinity decreased by 60% (i.e., an average decline of 100 μeq/L). A similar survey of 278 lakes and streams in nine mid-Atlantic states concluded that 49% were sensitive to acidification and an estimated 28% had been acidified (Arnold et al. 1985). The Rocky Mountain Acidification Study (Gibson et al. 1983) concluded that the high elevation lakes and streams in the Central Rocky Mountain Region are very sensitive to acidic deposition; however, little, if any, acidification has occurred except possibly in areas near large population centers (e.g., Denver, Colorado). Many other of the mountainous regions in the Western states contain large acid-sensitive areas (Schindler 1988) and some are currently receiving acidic precipitation (Tonnessen 1984). The upper Midwest states of Minnesota, Wisconsin, and upper Michigan have more acid-sensitive lakes than any other region in the United States with some lakes beginning to demonstrate symptoms of acid stress (Schreiber 1988). An estimated 2,000 lakes in Minnesota (Payer 1983) and 36% of 275 northern Wisconsin lakes surveyed in 1979 (Wiener 1983) were considered acid sensitive. Thornton et al. (1982) reported that 72% of the 254 Minnesota lakes historically sampled have shown a decline in alkalinity. Figure 1 displays the areas in the United States that are considered sensitive to acidic deposition (U.S. Environmental Protection Agency 1985). It is apparent that a growing number of aquatic resources and their associated fisheries, of a variety of types and locations, are currently at risk or will be in the future to the damaging consequences of acidic deposition.

Widespread concern about the seriousness of the acid rain problem has initiated large-scale government and corporate sponsored research efforts (e.g., in the United States, the 10-year National Acidic Precipitation Assessment Program, Malanchuk et al. 1986) to improve the understanding of the effects of acidic precipitation on the environment and to address "ways to remedy or otherwise ameliorate the harmful effects which may result from acidic precipitation" (Interagency Task Force on Acid Precipitation 1982; Schreiber 1988). "Liming", as it is generally called, or the addition of alkaline materials (e.g., usually limestone-$CaCO_3$) to surface waters has received the most attention as a interim mitigation tool to protect and restore sensitive and acidified aquatic resources (Fraser and Britt 1982). Although the practice of adding lime to acidic surface waters in the United States began approximately 30 years ago in Massachussetts (Bergin 1984) and New York (Kretser 1984), the first large scale evaluation of liming strategies and technologies for different aquatic ecosystems was conducted by the Swedish National Board of Fisheries from 1977 to 1982 when approximately 1,100 lakes were treated (Hasselrot and Hultberg 1984; Nyberg and Thornelof 1988). Favorable improvements in water quality (e.g., increased ANC, pH, and decreased aluminum concentrations) and positive biological responses (Hasselrot and Hultberg 1984) prompted other countries to consider expanding their liming operations and conduct extensive research on the ecological and long-term effects of liming (Schreiber 1988). The International Liming Workshop, held at the University of Washington in 1982, identified high priority research needs on liming effects (International Liming Workshop 1982) which served as an initial guideline for liming research projects in the United States (Porcella 1988; Schreiber 1988; Brocksen and Emler 1988). The major biological issues related to liming activities established by group consensus during the workshop were:

- impact of episodic events,



Region 1: Northeast

1A: Adirondacks
1B: Poconos/Catskills
1C: Central New England
1D: Southern New England
1E: Maine

Region 2: Upper Midwest

2A: Northeastern Minnesota
2B: Upper Peninsula of Michigan
2C: North-central Wisconsin
2D: Northern Plains

Region 3: Southeast

3A: Southern Blue Ridge Province
3B: Florida

Region 4: West

4A: Sierras/Klamath Mountains
4B: Cascades/Olympic Mountains
4C: Northern Rockies/Blue Mountains
4D: Central Rockies
4E: Southern Rockies

Figure 1. Areas in the United States containing surface waters susceptible to acidic deposition (U.S. Environmental Protection Agency 1985)

- impact of metal toxicity,
- time and placement of base additions,
- energy flow and nutrient cycling alterations,
- short- and long-term ecological effects,
- restocking strategies.

In the United States, studies such as the Acid Precipitation Mitigation Program (APMP), the Lake Acidification Mitigation Program (LAMP), and the Living Lakes, Inc. (LLI) Aquatic Liming and Fish Restoration Demonstration Program were designed to examine these and other liming related issues.

The APMP, managed by the United States Fish and Wildlife Service, is a 5-year cooperative research project (state cooperation) with the primary objective to analyze and evaluate the ecological responses of lime treatment to three streams and one lake (Schreiber 1988). The streams are located in the Northeastern (Whetstone Brook, MA), mid-Atlantic (Dogway Fork, WV), and Southeastern regions (Laurel Branch, TN), and the lake is located in northeast Minnesota (i.e., Thrush Lake). The focus of the projects are to re-establish or protect the fisheries resources; however, a comprehensive research effort designed to examine the physical, chemical, and biological conditions of the entire ecosystem (Schreiber and Rago 1984; Brown and Goodyear 1987) and the production of guidance documents for resource managers planning protective or restorative liming projects will also result (Schreiber 1988).

The LAMP, sponsored by the Electric Power Research Institute (EPRI), conducted detailed information on the chemical, physical, and biological effects of liming and subsequent reacidification of three Adirondack Mountain lakes (Porcella 1988). Cranberry Pond, a small, fishless lake with a short hydraulic residence time (63 days), was limed, stocked with brook trout, and allowed to reacidify. Woods Lake, a larger, fishless lake with a longer hydraulic residence time (214 days), was limed twice and the stocked brook trout fishery has been maintained. Little Simon Pond, a large lake (160 ha, hydraulic residence time of 450 days) which contained populations of brook trout, lake trout (*Salvelinus namaycush*), and other fishes was limed once with no negative effects on the fishery reported after liming. The effects of using different particle sizes of calcite on reacidification rate, calcite dissolution characteristics immediately after liming (Fordham and Driscoll 1989; Young et al. 1989), the fate of metals (Driscoll et al. 1989), the effects of stratification, factors influencing the reacidification rate (DePinto et al. 1989), phytoplankton dynamics (Bukaveckas 1989), zooplankton dynamics (Schaffner 1989), macroinvertebrate abundance (Evans 1989), growth, condition, survival, and reproduction of reintroduced brook trout (Gloss et al. 1989), and fish bioenergetics modelling (Scholfield et al. 1989) were all addressed in this study which looked at the entire ecosystem when determining responses to liming.

LLI, a not-for-profit organization, currently manages the most extensive liming program in the United States, with nearly 30 liming projects in the Northeast, mid-Atlantic, and upper-Midwest United States to date (Marcus 1988). The primary objective of LLI is to demonstrate the effectiveness of using lake and stream liming techniques to neutralize acidic waters with the ultimate goal being the restoration and protection of ecologically, recreationally, or economically important fisheries (Brocksen and Emler 1988). Mitigative, maintenance, and research liming projects have been conducted in order to restore lost fisheries, maintain existing but vulnerable fisheries, and enhance the effectiveness of future liming operations (Brocksen and Emler 1988). The Flat Top Lake liming project was included in LLI operations as a protective or maintenance research liming project. Flat Top Lake was a unique liming site for a variety of reasons.

- Although Flat Top Lake would be considered sensitive to acidification (i.e., total alkalinity less than 10 mg/L), no symptoms of biological stress or damage was apparent prior to liming.

- Flat Top Lake supports a sustainable warmwater fishery and is considered to be moderately fertile (i.e., mesotrophic); whereas, the majority of liming projects have been conducted in oligotrophic, coolwater lakes and ponds.
- Flat Top Lake is the highest altitude reservoir in West Virginia.
- Based on LLI sponsored water chemistry sampling, Flat Top Lake had the second highest pre-treatment pH (6.83) and acid neutralizing capacity (ANC, 114 μeq/L or 5.7 mg/L total alkalinity) of the 23 lakes treated under the LLI program in 1986 and 1987, and was the only reservoir and most southern water body included (Brocksen and Emler 1988).
- The shape of Flat Top Lake, which resembled a "V" with the outlet at the base (Figure 2), allowed for one arm to be limed, and the unlimed arm used as a control to test for liming responses.

The Flat Top Lake liming study was designed similarly to the APMP and LAMP liming projects in that physical, chemical, and biological responses were monitored with a pre- and post-treatment sampling program. The primary goal of the study was to assess the short-term biological responses to liming at several trophic levels. The specific objectives for the Flat Top Lake liming study were as follows:

1. Compare phytoplankton biomass and primary productivity between the limed and unlimed arms for the pre- and post-treatment samples and determine liming responses.

2. Compare phytoplankton community composition between the limed and unlimed arms for the pre- and post-treatment samples and determine liming responses.

3. Compare zooplankton biomass between the limed and unlimed arms for the pre- and post-treatment samples and determine liming responses.

4. Compare zooplankton community composition between the limed and unlimed arms for the pre- and post-treatment samples and determine liming responses.

Flat Top Lake

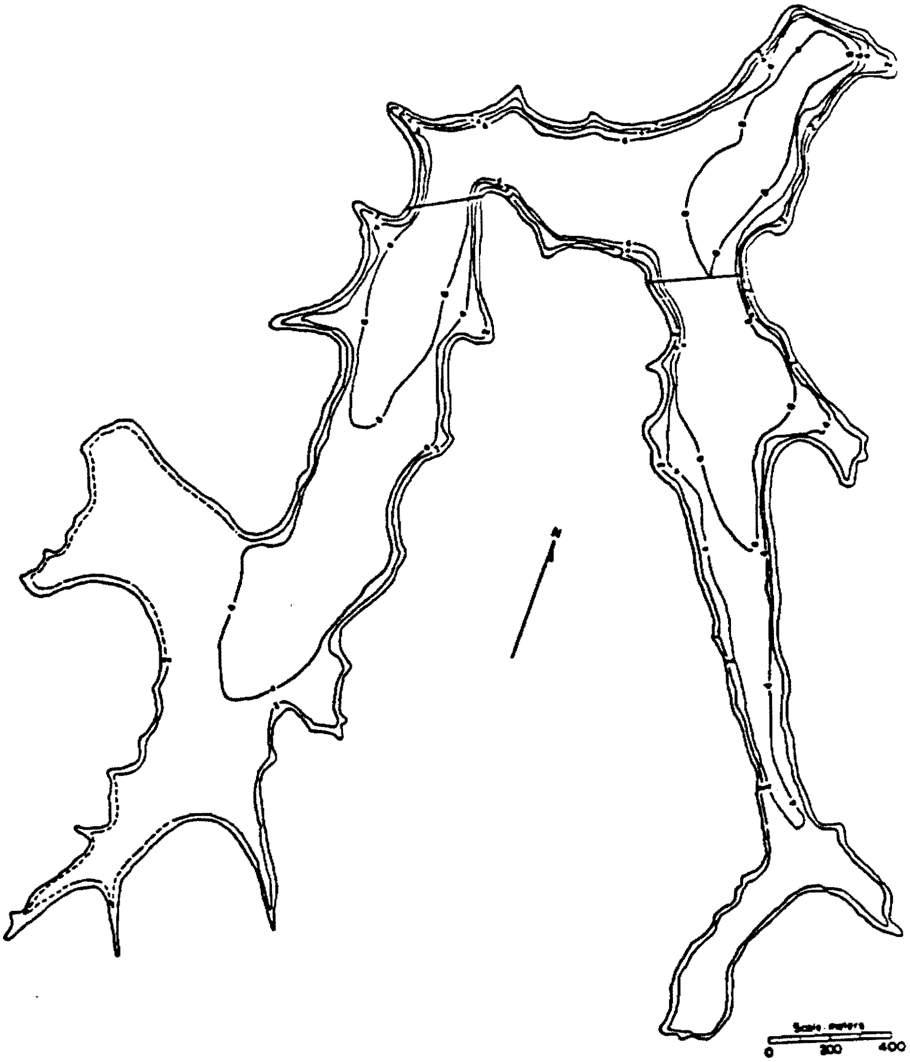


Figure 2. Flat Top Lake, Raleigh County, West Virginia.

5. Compare young-of-the-year bluegill growth rates between the limed and unlimed arms.

In addition to the data requirements for the objectives, sediment characteristics, lake transparency, pH, and total alkalinity were measured in pre- and post-treatment samples. Pre- and post-treatment water quality analyses, which inluded nutrient and metal concentrations, were also conducted by IS&T.

As ANC in a variety of lake types and locations continue to be eroded by acidic deposition, increased interest in the future by state agencies and private groups (e.g., lake associations) in liming projects of a maintenance or protective nature may result (Fraser et al. 1987). A knowledge of expected biological responses to liming projects in circumneutral to marginally acidic, sensitive lakes is paramount in the decision to lime these types of lakes. Fraser et al. (1985) categorized the lake types that have most frequently been limed for purposes of restoration or protection from acidic deposition and summarized the biological responses from each category.

- No fish present; acidic waters with high concentrations of heavy metals.
- No fish present; acidic waters with high concentrations of aluminum, but low levels of other metals.
- Some resident fish, but no reproduction occurring; acidic waters.
- Fish present and reproducing; slightly acidic waters.

Briefly, category 1-3 lakes generally have shown significant physical, chemical, and biological responses after neutralization; however, the relatively few liming studies on category 4 lakes (i.e., most closely related to Flat Top Lake) have shown few significant post-treatment biological responses. The potential responses in circumneutral to marginally acidic lakes (e.g., Flat Top Lake) are expected to be more similar to liming applications in non-acidified environments, which have been conducted to increase the production of fish populations, than in acidified environments, which are conducted to improve water quality for fish survival. A summary of historical liming applications in non-acidified waters presents the primary factors that have influenced post-liming responses in these types of systems.

Historical liming applications

The first applications of liming materials to surface waters was undoubtedly patterned after the common agricultural practice of using neutralizing chemicals to amend soil acidity for increased crop production. Neess (1948) published "Development and status of pond fertilization in central Europe" in Transactions of the American Fisheries Society which detailed liming applications to enhance fish production in European and Asian fish culture ponds that had acidic sediments low in Ca^{2+} content. In the United States, the first reported attempts at liming took place in the 1940's and 1950's as some dystrophic bog ponds and lakes were limed primarily in Michigan and Wisconsin (Hasler et al. 1951; Waters 1956; Waters and Ball 1957; Stross and Hasler 1960; Elser et al. 1986). Liming as a common management tool in the United States began in the 1950's when circumneutral to slightly acidic fish ponds (e.g., bass-bluegill ponds) were recommended for liming treatments to enhance the effectiveness of fertilizer applications to increase pond carrying capacity (Snow and Jones 1959; Boyd 1979, 1981, 1982). Liming-induced increases in primary productivity and fish productivity in these systems were attributed to:

- a pH-induced increase in the availability of phosphorus from the sediments (Boyd 1979),
- a pH-induced increase in microbial activity and nutrient mineralization in the sediments (Pamatmat 1960),
- an increase in the availability of carbon dioxide for photosynthesis (Arce and Boyd 1975),
- an increase in the euphotic zone in dystrophic systems because of the precipitation of suspended humates (Stross and Hasler 1960),

- release of nutrients from organic rich sediments because of ion-exchange processes involving Ca^{2+} (Neess 1948).

In conclusion, the degree of post-liming responses for *any* lake type are influenced by the site-specific water quality, biological, and sediment charactersitics before the treatment, the application method and dosage used, and the degree of biological damage caused by acidification. Based on the circumneutral pre-treatment conditions (i.e., neutral pH, low levels of inorganic aluminum) and lack of pre-treatment ecosystem damage to Flat Top Lake, the post-liming response of the phytoplankton based food chain (zooplankton biomass, YOY bluegill growth) was expected to depend on whether phosphorus was liberated from neutralized sediments and/or calcite dissolution acted as a fertilizer in that the increased supply of dissolved inorganic carbon would promote increased phytoplankton primary productivity.

Study Site

Flat Top Lake is a 94.2 hectare (ha), privately owned, multiple-use reservoir located (Dam location - Latitude 37° 37′ 30″N, Longitude 81° 06′ 12″W) approximately 1/2 mile east of Ghent, West Virginia in Raleigh County. It is the largest and at the highest elevation of any private lake in West Virginia. The lake was created after the dam was constructed downstream of the Beaverpond Branch and Glade Creek confluence in 1950. The lake is located at the top of Flat Top Mountain, 2,901 feet above sea level, which is located just north of the Southern Blue Ridge Mountain Province. Several intermittent streams and springs flow into Flat Top Lake, which drains into Glade Creek through the Glade Creek Reservoir to the New River. IS&T estimated the hydraulic residence time of Flat Top Lake at 0.59 years by dividing lake volume (1,821.75 ha-feet) by the total volume of all inputs to the lake (3,069.2 ha-feet/year). Flat Top Lake serves as the water supply for lake residents and the water supply for Ghent is taken from Glade Creek immediately downstream of Flat Top Lake. For this reason, the West Virginia Department of Health routinely monitors water quality in Flat Top Lake. The watershed of Flat Top Lake encompasses an area of 1,780 ha that is dominated by hillsides that are heavily wooded with deciduous and coniferous vegetation. The east arm watershed is approximately 660 ha and the west arm watershed is approximately 1,120 ha. The soils in the east arm drainage consist almost exclusively of the DeKalb series and the soils in the west arm drainage are made up of the DeKalb, Gilpin, and Ernest series (U.S. Department of Agriculture 1975). These low (DeKalb) to moderately (Ernest and Gilpin) fertile soils were formed from acidic material weathered primarily from sandstone, siltstone, or shale. The area immediately surrounding the lake has been developed into approximately 370 lots which support seasonal and permanent homes surrounding the majority of the lakeshore. A beach and a recreational area are located on the northeast shore. Access to Flat Top Lake is restricted to property owner's and their guests by a security gate. The Flat Top Lake Owner's Association reserves all management rights for the lake and the adjacent property.

Assessments of the sport fishery, eutrophication, and extent of acidification of Flat Top Lake were conducted by the Department of Fisheries and Wildlife Sciences of Virginia Polytechnic Institute and State University in 1985 (Sheehan and Leonard 1986) and in 1986 (Orth and Helfrich 1987) resulting in an overall summary of the condition of the lake and the development of management recommendations for the Flat Top Lake Owner's Association (Helfrich and Orth 1988). Briefly, the fish assemblage is dominated by bluegill (*Lepomis macrochirus*), largemouth bass (*Micropterus salmoides*), yellow perch (*Perca flavescens*), black crappie (*Pomoxis nigromaculatus*), and smallmouth bass (*Micropterus dolomieui*). Various species of trout (e.g., usually rainbow trout, *Salmo gairdneri*), channel catfish (*Ictalurus punctatus*) and fathead minnows (*Pimephales promelas*) have been stocked by the Association. Bluegill showed moderate growth rates and an adequate size-frequency distribution; however, largemouth bass showed relatively slow growth rates, especially for the younger age classes, and a small percentage of fish of quality size (300 mm or larger). Food habit studies (Sheehan and Leonard 1986, Smith 1989) have shown that the diet of largemouth bass is composed primarily of crayfish for the first few years with a greater reliance on bluegill and yellow perch in later years. The yellow perch population was characterized by a unusually high percentage of fish greater than 250 mm. Flat Top Lake fishermen have noticed a decline in the number of smallmouth bass caught during the last decade. Eutrophication and episodic acidification during the spawning season have been implicated as possible reasons for this decline (Sheehan and Leonard 1986).

Apparent local eutrophication is occurring in the littoral areas adjacent to tributary inlets and in numerous shallow bays (less than 2m). The opinion of the majority of property owner's is that aquatic vegetation (e.g., primarily *Najas spp.*) has reached nuisance levels in many of the shallow coves and bays, particularly in the west arm during the late summer-fall period. Efforts to control *Najas spp.* with mechanical control methods or grass carp (*Ctenopharyngodon idellus*) are being considered by the Association. Land use practices in the watershed and natural processes have contributed to the increased awareness by property owner's that sedimentation is increasing in Flat Top Lake. Construction, farming, livestock grazing, and lumbering within the drainage area increases the erodibility of the land where a high percentage of the transported sediment settles out within Flat Top Lake. The west arm watershed appears to be contributing a disproportionately high amount of sediment to the lake. It has been recommended that the Flat Top Lake Owner's Association determine the major sources of these transported sediments and attempt to minimize them (Helfrich and Orth 1988). The application of fertilizers, herbicides, and insecticides by the property owners and other watershed inhabitants, the possibility of the improper maintenance of septic systems, and a high level of road salt runoff from a West Virginia Highway Department storage facility within the west arm watershed, can and probably has increased the concentration of undesirable compounds within Flat Top Lake.

The character of the Flat Top Lake water is directly related to its geographical location and watershed characteristics. Flat Top Lake is a softwater lake (i.e., low total alkalinity and hardness) because of the low fertility, acidic, low-carbonaceous soils within the watershed. Because Flat Top Lake is located on the western slope of the first major mountain range east of the Ohio Valley, it receives precipitation that is acidic with a weighted mean pH of approximately 4.3 with a mean annual $H+$ deposition of 0.47 kg/ha (Wisniewski and Keitz

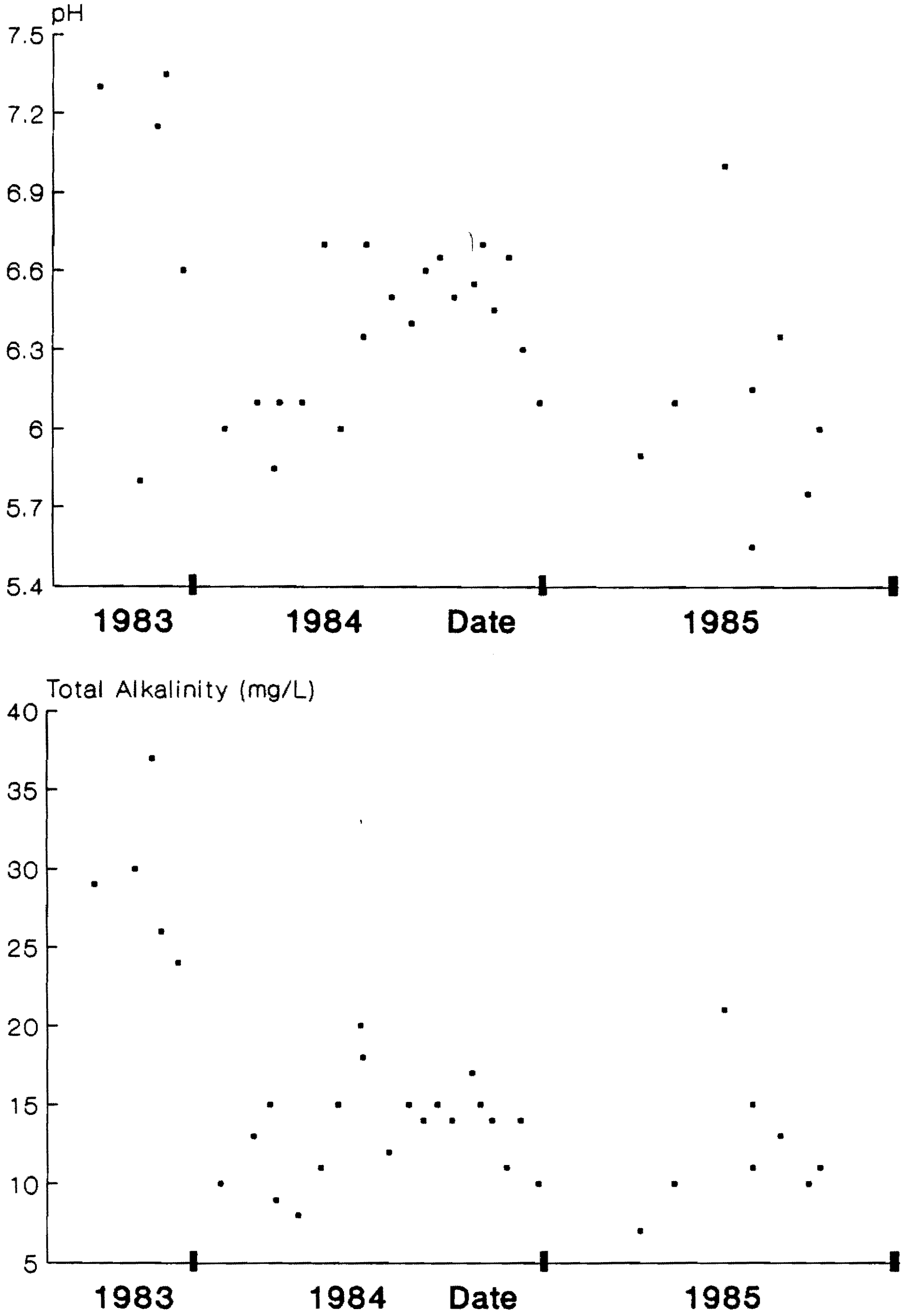


Figure 3. Average pH and alkalinity (mg/L) values for Flat Top Lake between 1983-1985 (WV Department of Health).

1982). An analysis of data collected by the West Virginia Department of Health between September 1983 through December 1985 indicated that pH and alkalinity (Figures 3a and 3b) may be decreasing with possible concurrent increases in certain heavy metals (e.g., iron and manganese) and that 12 month mean values for pH, alkalinity, manganese, and iron violated standards established by the United States Environmental Protection Agency for the protection of freshwater aquatic life (Sheehan and Leonard 1986). The pH of the tributary streams has been recorded as low as 5.0 on several occasions, primarily in the east arm tributary after rainfall (William Herold, WV Dept. of Health, personal communication). There is no acid mine drainage affecting the lake (Jim Belcher, WV Dept. of Energy, personal communication). Periodic water quality monitoring conducted by VPI&SU in 1986 indicated very low alkalinity (2-6 mg/L) on the 6/25/86 sample with increasing alkalinity throughout the summer/fall period to 12-13 mg/L on 8/13/86. Mean pH during the 1986 summer/fall period was 6.52 (range 6.24-6.85).

Although no apparent signs of biological stress or damage was apparent, the water quality data, geographical location, watershed soil characteristics, and the economic and recreational importance of Flat Top Lake to the property owners determined that liming was an appropriate action to increase the resistance of Flat Top Lake to acidic deposition.

Methods

Lime application

The water quality objective for Flat Top Lake was to increase water column alkalinity in the east arm by approximately 10 mg/L as $CaCO_3$, a doubling of alkalinity. IS&T and LLI scientists determined that a limestone dose of approximately 25.4 dry metric tonnes (24.5 mg/L) was needed assuming a dissolution efficiency of 41%. DeAcid, a titration-based computer model (Saunders et al. 1985) was used to estimated the dose. The east arm (25.5 ha) of Flat Top Lake was treated with approximately 28.8 dry metric tonnes of limestone (i.e., calcite powder) between 13-20 July, 1987. An estimated 1,270 bags (22.7 kg each) of "No. 10 Pulverized Limestone" produced by U.S. Gypsum Company (Kimballton, Virginia) and bagged and delivered to Flat Top Lake by Limestone Dust, Inc. (Bluefield, Virginia) was applied using slurry box technology (Figure 4). The dose applied was 12% greater than the design dose. This brand of limestone is dry-crushed with 99.9% by weight of the material passing through the No. 100 screen (150 microns), 88.6% passing through the No. 200 screen (75 microns), 74.1% passing through the No. 270 screen (53 microns), and 70.0% passing through the No. 325 screen (45 microns). Typical chemical analysis and the trace element content of "No. 10

Pulverized Limestone" is given in Table 1. Renovation Systems, Inc. (RSI, Sterling, Virginia) supplied one RSI Model 2V slurry box and one RSI Model 4V slurry box.

The slurry boxes (Figure 4), which were a new design and previously untested, were mounted onto Jon boats and were designed to take dry limestone powder dumped into a hopper where it was then sucked into a venturi apparatus and mixed with the lake water that was being pumped via a portable gas-powered water pump. The water and limestone slurry was then pumped into the lake as the boat moved along at low speeds. The model 4V was equipped with four outflow hoses each with a venturi apparatus. The model 2V was equipped with just two outflow hoses and venturis and thus operated at a slower rate. The limestone bags were transported to the "liming boats" directly or to nearby boat docks using up to two shuttle boats. IS&T scientists divided the east arm into four treatment zones (Figure 5) with zone boundaries corresponding to adjacent lot numbers. Limestone dose was calculated for each zone individually to facilitate the accurate application of limestone on a volume-weighted basis. Zones were recommended to be treated in alphabetical order to maximize limestone slurry contact with the water, thereby enhancing water-column dissolution of the limestone. On 13 July 1987, the first day of operation, 89 bags (2.02 tonnes) of lime were applied to zone A with the slurry box technique previously described. At this rate it would have taken approximately two weeks to complete the application. On the second day of operation (14 July 1987), one of the four outflow hoses on the 4V model and one of the two hoses on the 2V model was used to mix water (actually the limestone slurry) directly with the dry limestone in the hopper. This method greatly increased the rate of limestone passing through the venturi and resulted in 480 bags (10.91 tonnes) of limestone being applied to zones A and B. On the third day of operation (15 July 1987), 600 bags (13.64 tonnes) were applied to zones C and D. The remaining 101 bags (2.30 tonnes) were left to be applied on 20 July 1987 to zones D and B in order for a film crew to tape the event as part of a LLI production. The slurry boxes were subsequently modified to pump fresh lake water into the hopper for mixing purposes which freed up the one outflow hose used for that purpose at Flat Top Lake (Bill Johnson, RSI,

Table 1. Chemical analysis (% of weight) and trace element content (ppm in limestone) the limestone product used at Flat Top Lake, WV (courtesy of United States Gypsum Company, Kimballton, VA).

Product	% of Weight	Element	ppm
$CaCO_3$	95.96	Arsenic	0.20-0.34
CaO	54.0	Barium	100
Loss on ignition	43.2	Beryllium	50
$MgCO_3$	2.26	Cadmium	2-3
Acid solubles	1.76	Chromium	7-9
SiO_3 and insolubles	1.0	Cobalt	30-34
MgO	0.78	Copper	11-14
Free silica	0.60	Lead	15-19
Al_2O_3	0.47	Manganese	30-34
Fe_2O_3	0.14	Nickel	15-19
Sulfur	0.018	Potassium	420-600
Manganese	0.004	Silver	5-7
Phosphorus	0.0048	Strontium	167-175
		Tin	10
		Vanadium	50
		Zinc	4-15

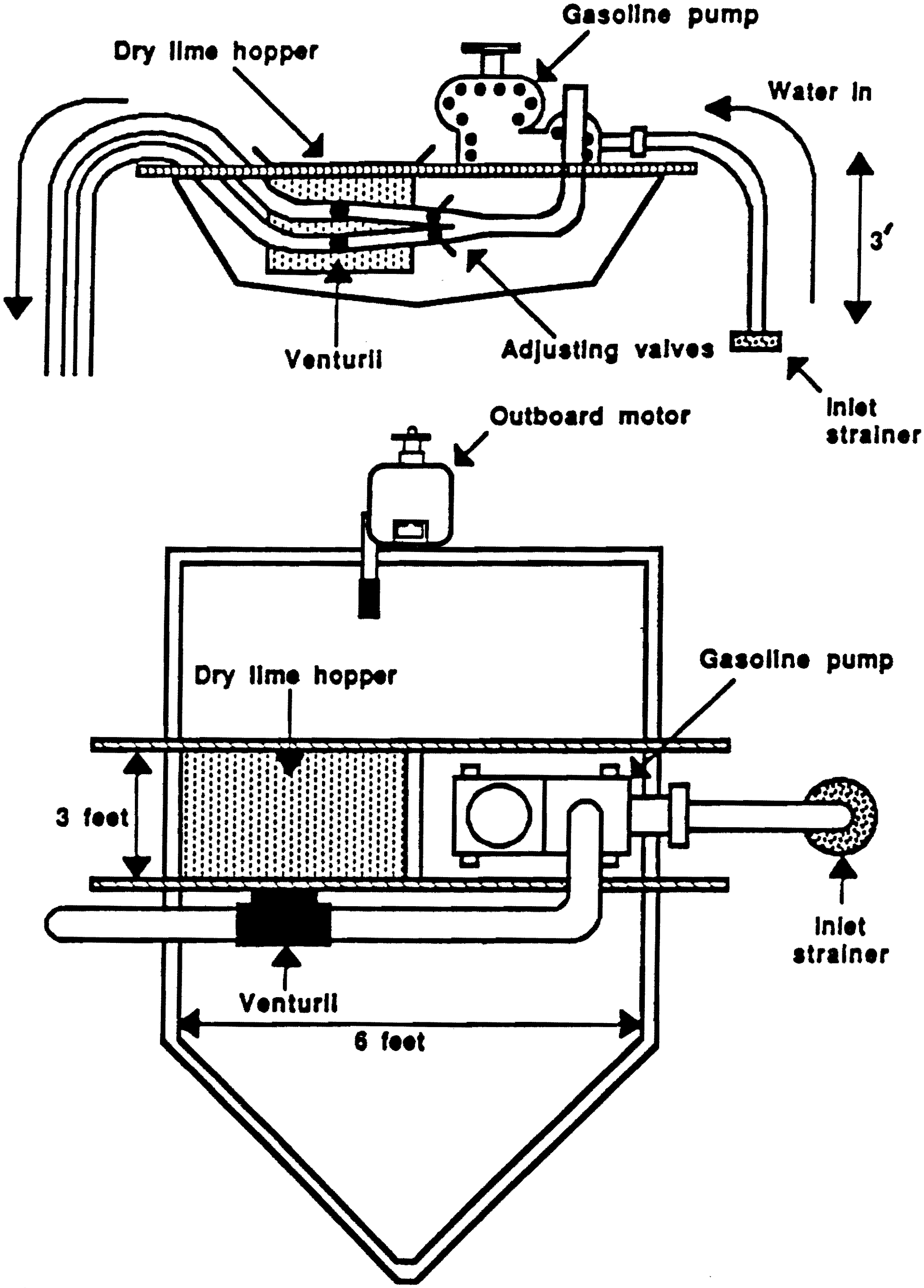
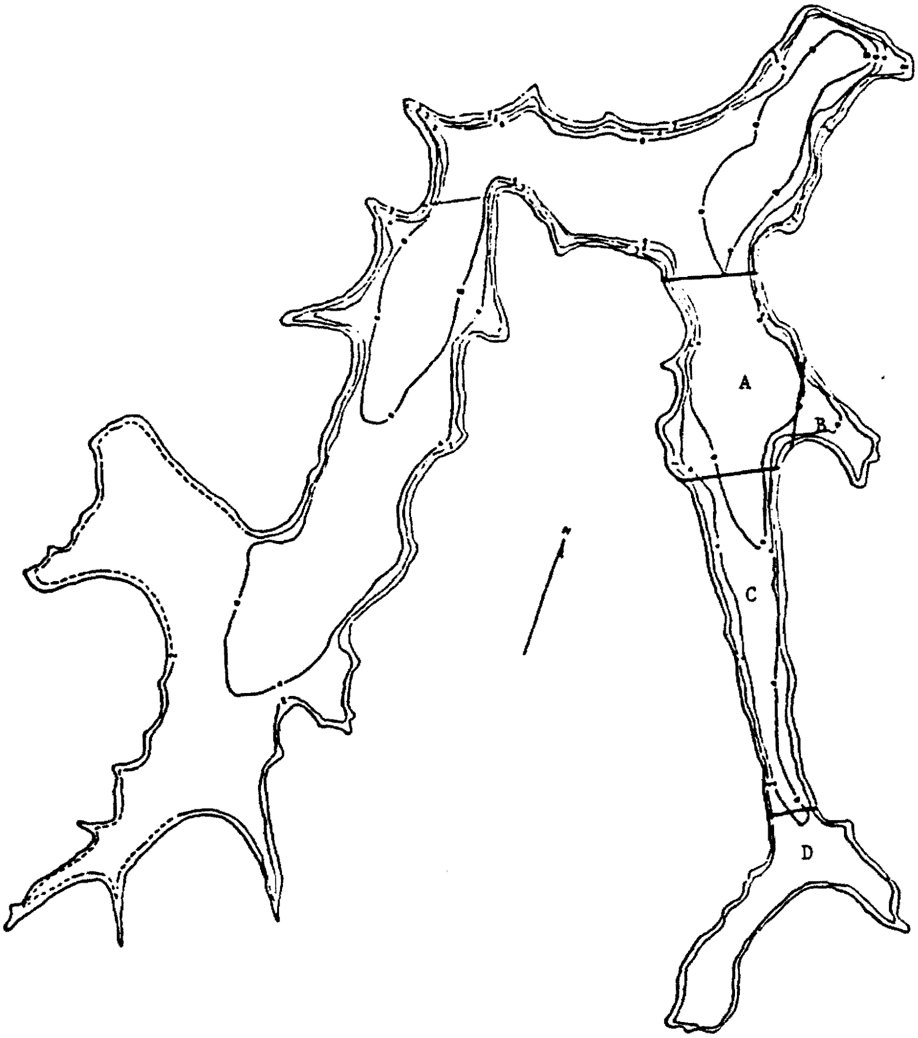


Figure 4. Cross-sectional and top view of limestone slurry box developed by Renovation Systems, Inc. (RSI, Sterling, VA).



Zone	#Bags
A	565
B	82
C	367
D	256
TOTAL	1270

Figure 5. Treatment zones and calcite dosages.

personal communication). The slurry boxes proved to be an effective method to apply lime in dissolved form which increases dissolution efficiency and may prove to be a cost-effective method of application to small lakes with boat access.

The liming operation crew numbered between eight and nine persons for each day worked for a total of 26 person-days (i.e., one person working approximately eight hours). Two to three people were needed in each boat depending on whether the driver could navigate the boat while operating the outflow hose used for mixing. The shuttle crew consisted of one to two boat driver's and one to two persons loading shuttle boats located on shore adjacent to the boat ramp where the lime was stacked after delivery. The average application rate for the 4V model was 0.63 tonnes per hour and was 0.40 tonnes per hour for the 2V model. The limestone cost was $25.45 per tonne delivered (charged for 28 tonnes) and slurry box rental was $100 per day for a total materials cost of $1,113.

Alkalinity and pH

Total alkalinity was measured on four occasions before the application of lime and on seven occasions after the application at 1 m and 3 m depths for each of the six sampling stations in the east and west arms (Figure 6). The samples were collected using a 4.2 L opaque Van Dorn water sampler and were transferred to clean opaque Nalgene bottles to a cooler without ice. The samples taken on 24 July 1987 and 29 July 1987 were immediately analyzed on-site and all other samples were analyzed back at the VPI&SU laboratory that evening. Alkalinity samples were collected in late afternoon (5-6 pm) which minimized the time period they were stored (2-3 h). A Fisher Accumet 825mp pH meter was used and was calibrated with commercially obtained pH 4.0 and pH 7.0 buffers. Laboratory prepared buffers

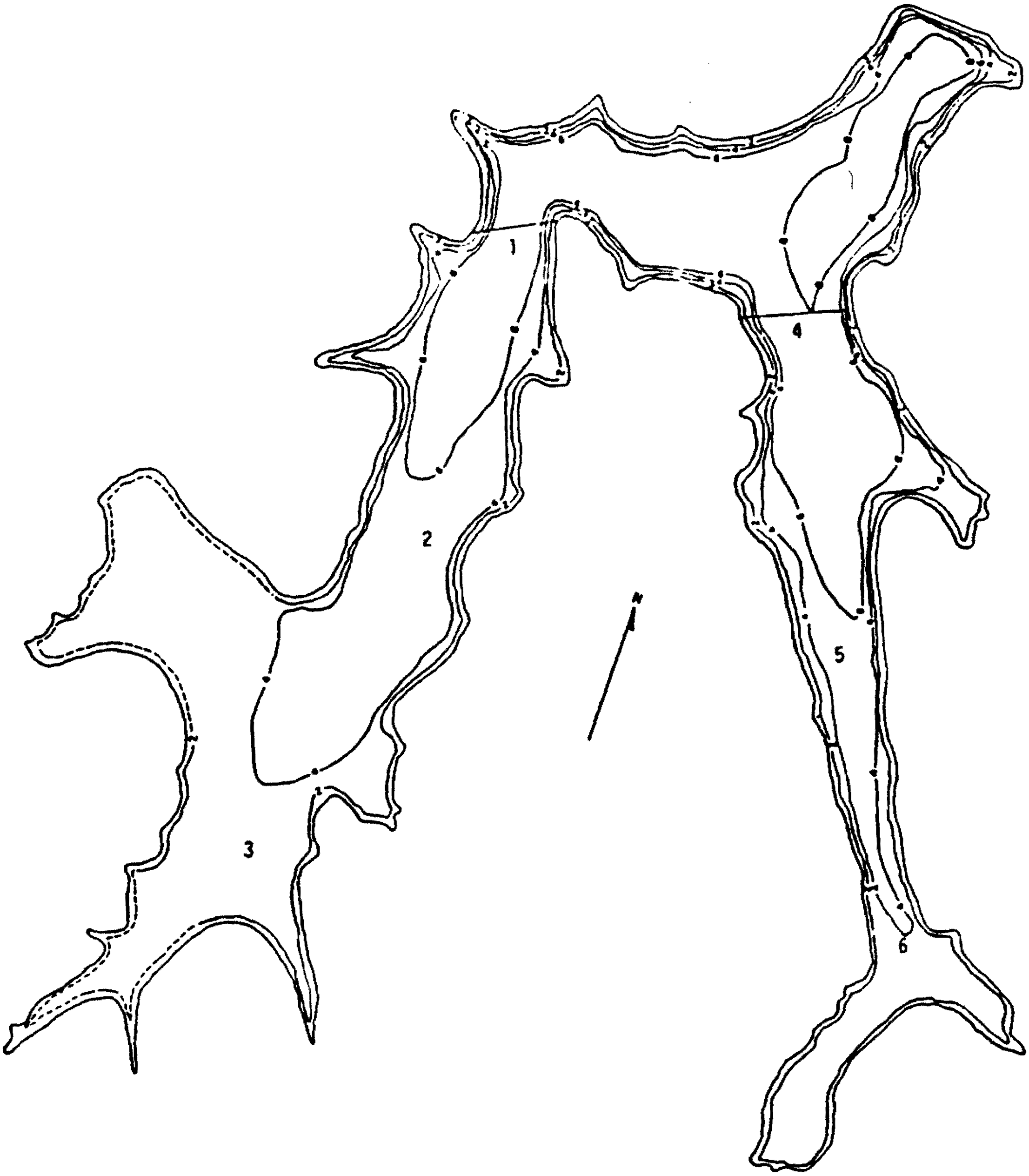


Figure 6. Sampling stations (VPI&SU).

of low ionic strength (pH's 4.008, 6.865 and 7.413) were used on two occasions and provided no observed benefits over commercially prepared buffers. The potentiometric titration of low alkalinity method (APHA et al. 1975) was used for all samples.

The pH for all 1 m and 3 m samples was measured immediately prior to the alkalinity titrations. Due to the low ionic strength of the samples, the pH meter took between 2-5 min to stabilize on a value. Five minutes was used as a standard time period after which the pH was recorded. On one occasion, pH readings were compared to IS&T readings taken with their HydroLab unit at the same time, site, and depth and were within 0.10 of a pH unit.

Phytoplankton gross productivity

The oxygen-evolution method using light and dark bottles (Vollenweider 1969; Lind 1985) was used to estimate phytoplankton gross productivity six times before the application of lime and six times after the application. Duplicate initial, light and dark bottle water samples were taken at five depths between 1 m and 3 m at 1/2 m intervals at site 2 in the west arm and site 5 in the east arm using a 4.2 L opaque Van Dorn water sampler. The 300 ml BOD bottles were allowed to overflow for approximately three times their volume. Different water samples were used to fill each of the two sets of initial, dark, and light bottles per depth. The duplicate light and dark bottles were suspended under a carboy float onto a PVC rack and chain device at the same depth as the associated water sample was obtained. The rack consisted of round sections of 6 inch diameter PVC pipe with two slots cut into opposite ends which allowed the duplicate light bottles to be snapped in at the neck of the bottle which allowed the bottles to lie in a virtually horizontal position. There was one rack for each of the five depths. The duplicate dark bottles were secured to the chains with heavy duty snap swivels at the same depth as the appropriate light bottles and were suspended in a vertical position. The dark bottles were made by wrapping the outside of standard 300 ml BOD bottles with several layers of heavy duty black tape and then coating the tape with a water resistant sealant (GOOP). Black spray paint was used to coat the top of the BOD bottles and cap. The dark bottles were checked for light leaks and repaired after each use.

The bottles were set in the early morning at dawn and picked up in the late afternoon to early evening. Incubation times were between 8-10 h. Incubation times were similar between the east and west arms on all occasions. Immediately after incubation, the light and dark bottles were fixed using HACH powder pillow reagents (sodium azide and sulphuric acid). The initial bottles were fixed immediately after the water samples were obtained for an arm. The azide modification of the Winkler method was used for the oxygen determinations.

The following definitions (Eley 1970) and calculations (Lind 1985) were used for the determination of plankton gross productivity.

Community Respiration (Rt) - The rate of oxidation of organic matter to provide energy for the life processes of the biota and the chemical oxygen demand of the abiotic components of the community.

Rt = (I - D) / incubation hours

I,D = dissolved oxygen concentrations in mg/L for the initial and dark bottles, respectively.

Net Productivity (Pn) - The net rate of energy storage by the community or the difference between gross productivity (Pg) and Rt.

Pn = (L - I) / incubation hours

L = dissolved oxygen concentration in mg/L for the light bottles.

Gross Productivity (Pg) - The rate of energy stored as reduced organic material or the liberation of oxygen as a by-product of photosynthesis by photoautotrophic organisms.

$$Pg = Rt + Pn$$

The null hypothesis of no difference in phytoplankton gross productivity (Pg as mg $O_2L^{-1}h^{-1}$) between the east and west arms was tested with the Wilcoxon Signed Rank Test (Hollander and Wolfe 1973) for the six pre-treatment samples. Daily average gross productivity taken from the duplicate sample average from each of the five depths was used as the estimate for the respective arm. This test determined the similarity between the two arms in gross productivity prior to the treatment. The same procedure was followed for the six post-treatment samples to determine possible liming effects on gross productivity (i.e., increase or decrease in Pg as mg $O_2L^{-1}h^{-1}$ in the limed arm relative to the unlimed arm).

Phytoplankton biomass

Phytoplankton biomass was estimated by the concentration of chlorophyll *a* pigment extracted from the phytoplankton obtained in the water sample. Chlorophyll *a* constitutes approximately 1-2% of the dry weight of organic material in all planktonic algae and is the preferred indicator for algal biomass estimates (APHA et al. 1975). Chlorophyll a was determined six times before the application of lime and six times after the application. Duplicate samples were taken at each of the six sampling stations using a water column sampler made of 3 inch diameter PVC pipe which obtained approximately 6 L of water from the upper 3 m of the water column. The water was stored in 10 L plastic cans until return to the laboratory that evening. Water transparency was also determined at each site immediately after the chlorophyll *a* water sample was obtained. The Secchi disc procedure as described by Lind (1985) was followed.

Upon return to the laboratory that same evening, approximately 1-2 L of the well mixed 6 L sample was vacuum filtered under low pressure through Whatman GF/C glass fiber filters. Two glass fiber filters were needed per sample to insure a large enough concentration of chlorophyll *a* to allow accurate measurements. On most occasions, the filters were stored in the freezer for further preparation the following day. The modified dimethyl sulfoxide (DMSO) extraction procedure of Burnison (1980) was used to prepare the samples for spectrophotometric analysis. The absorbances were measured at 750 nm and 664 nm using a 1 cm pathlength cuvette on a Cary 219 spectrophotometer, which was capable of narrow band-widths necessary for accurate chlorophyll *a* determinations.

The presence of pheophytin, a degradation product of chlorophyll *a* which absorbs light and fluoresces in the same region of the spectrum, can cause overestimates (Vernon 1960). The equation of Lorenzen (1967) was used to calculate pheophytin corrected chlorophyll *a* and was as follows:

$$\text{Chlorophyll } a \text{ mg/m}^3 = \frac{A \times K \times (664_b - 664_a) \times v}{Vf \times l}$$

where,

A = Absorption coefficient of chlorophyll *a* (11.41, Jeffrey and Humphrey 1975)

K = a factor to equate the reduction in absorbancy to initial chlorophyll *a* concentration (2.429)

664_b = absorbance before acidification minus 750 nm reading

664_a = absorbance after acidification minus 750 nm reading

v = milliliters of DMSO and acetone used for extraction

Vf = liters of water filtered

l = pathlength of cuvette in cm (1).

The null hypothesis of no difference in phytoplankton biomass (mg chl. *a*/m^3) between the east and west arms was tested with the Wilcoxon Signed Rank Test for the six pre-treatment samples. Separate tests were run for the lower (site 1 vs. site 4), middle (site 2 vs. site 5), and upper (site 3 vs. site 6) arm site comparisons as well as for the east arm vs. west arm comparison. The average of the duplicate samples at a site were used as the daily estimate for the site-specific comparisons and the average of the upper, middle, and lower arm sites within an arm was used as the estimate for the arms comparison. These tests determined the similarity in phytoplankton biomass of the two arms and among the upper, middle, and lower arm sites prior to the treatment. The same procedure was followed for the six post-treatment samples to determine possible liming effects on phytoplankton biomass (i.e., increase or decrease in mg chl. *a*/m^3) in the limed arm relative to the unlimed arm.

More specifically, the null hypothesis of no difference or lower phytoplankton biomass in the west arm was tested with the same procedure for the post-treatment samples that showed a difference in alkalinity between the east and west arm sites (site 3 vs. site 6 on 20 July, 29 July, and 7 August 1987 was only applicable test). The alternate hypothesis for this test, however, was site 6 would have higher phytoplankton biomass (1-tailed) than site 3 possibly due to the larger supply of available dissolved inorganic carbon.

The upper, middle, and lower region sites in each arm occurred approximately at the same locations within the respective arm and conditions between the arms appeared relatively similar for a given region. The separate region specific tests in a paired sample design, however, assumed the two sites within a region were valid paired samples (e.g., observation in site 6 is correlated with observation in site 3). Friedman's two-way analysis-of-variance test (Hollander and Wolfe 1973) was conducted to test if there was a significant difference between the upper, middle, and lower regions within each arm. If this test showed a significant difference between regions in each arm, the Sign Test (Hollander and Wolfe 1973) was conducted to determine the relationship the sites had to each other (e.g., upper > middle > lower).

Secchi disk depth was evaluated as a predictor of chlorophyll *a* concentration for each arm with bivariate linear regression (Kleinbaum and Kupper 1978) to assess the applicability of Secchi disk depth to estimate chlorophyll *a* for possible future lake eutrophication monitoring by the Association. The null hypothesis of no difference in Secchi disk transparency (m) between the east and west arms was tested with the Wilcoxon Signed Rank Test for the six pre-treatment samples. Separate tests were run for the lower (site 1 vs. site 4), middle (site 2 vs. site 5), and upper (site 3 vs. site 6) arm site comparisons as well as for the east arm vs. west arm comparison. The average of the upper, middle, and lower arm sites within an arm was used as the estimate for the arms comparison. This test determined the similarity between the two arms and the upper, middle, and lower sites between each arm in transparency prior to the treatment. The same procedure was followed for the six post-treatment samples to determine possible liming effects on water transparency (i.e., increase of decrease in Secchi depth) in the limed arm relative to the unlimed arm.

Phytoplankton density

Vertical tows taken from the lake bottom to the surface with an 80 μm mesh Wisconsin style plankton net were used to collect net phytoplankton for density estimates of the large dominant genera. Duplicate tows for each of the six sampling sites were taken two times before the application of lime and two times after the application. The average of the duplicate tows for each site were used as the site estimate in number of organisms per liter except in the case of colonials (e.g., *Synura spp.*) which each were counted as one organism. Net phytoplankton were preserved in 4% buffered formalin. The taxonomic keys of Prescott (1962,

1978) were used for identification purposes. Ten fixed square cells that were randomly chosen originally in a Sedgewick-Rafter (S-R) cell (1 ml) that was divided into 171 equal sized cells were scanned and total counts for all genera present were made. The equation used to obtain the density of a particular genera was as follows:

$$\#/L = \frac{C \times E \times PV}{TV} \times 1000$$

where,

C = total count of organisms in 10 cells

E = expansion factor for estimated number per 10 S-R cells (17.1)

PV = volume of the preserved sample (ml)

TV = volume of the tow (ml).

The density of phytoplankton less than 80 μm in size (nannoplankton) was determined from whole (unfiltered) samples which were obtained from the water samples collected for chlorophyll *a* analysis. The approximate 6 L sample was well shaken before 500 ml were poured into a storage bottle and preserved with 1% Lugol's solution. Duplicate samples for each of the six sampling sites were taken two times before the application of lime and two times after the application. The average of the duplicate samples for each site were used as the site estimate in number of organisms per liter. Organisms within a colony were counted separately. Sedimentation chambers which had a volume of 50 ml were filled and left to settle for approximately two days. An inverted microscope equipped with a Whipple ocular micrometer was used utilizing oil immersion at 1000x for identification and enumeration purposes. The taxonomic keys of Prescott (1962, 1978) were used for identification purposes. After the slide was scanned to determine if the organisms appeared to be distributed randomly, one strip count the width of the whipple square for the entire diameter of the circular microscope depression was made. The equation used to obtain the density of a particular genera was as follows:

$$\#/L = C \times E \times 20$$

where,

C = total count of organisms for the strip count

E = expansion factor for estimated number per 50 ml settled sample (333).

Qualitative analysis of the relative abundances of the net phytoplankton and the nannoplankton before the application of lime and after the application was made for these data.

Associated water quality determinations

Water temperatures and dissolved oxygen concentrations were determined 11 times during the course of the study. All six sites were sampled on all dates from the surface to the bottom at 1 m intervals using a Yellow Springs Instruments (YSI) digital temperature-dissolved oxygen meter.

Total phosphorus, soluble orthophosphate, total kjeldahl nitrogen (TKN), nitrate nitrogen, and ammonia was estimated at sites 2 and 5 at 1 m and 4 m depths on three occasions before the application of lime and three occasions after the application. The samples were obtained with a 4.2 L opaque Van Dorn water sampler and stored in acid-washed Nalgene bottles on ice until arrival at the laboratory. The samples were analyzed by water chemistry researchers in the agriculture engineering department at VPI&SU.

Water quality analyses was also conducted by IS&T on 22 August 1986, 31 March 1987, 19 August 1987. Sample sites corresponded to site 2, site 5, and immediately upstream from the dam.

Lake sediment samples were collected by Kathleen Moynan, VPI&SU graduate student at that time, on 6 June 1987 and on 4 September 1987 and were analyzed for pH, nutrients, and metals (only pH, calcium and phosphorus utilized, Appendix 11) at the Soil Testing and Plant Analysis Laboratory at VPI&SU.

Zooplankton biomass and density

Zooplankton were sampled on three occasions before the application of lime and on three occasions after the application. Vertical tows were made with an 80 μm mesh Wisconsin style plankton net from the lake bottom to the surface at each of the six sampling sites per sampling date. Zooplankton were preserved in a 4% buffered formalin solution. Cladocerans and rotifers ($>$ 80 μm) were identified to genus and copepods were separated into calanoid and cyclopoid adults and copepod nauplii (i.e., sub-adults) (Edmondson 1959). The density (#/L), average size, and biomass (μg/L) were determined for each group based on one vertical tow per site per sampling date.

The cladocerans and copepods were identified, counted, and total lengths measured for biomass determinations using a dissecting microscope. The concentrated sample was poured into a petri dish that had five fixed squares of equal size representing 14.5% of the total surface area of the entire petri dish. The sample was mixed with a dissecting needle until the organisms appeared randomly arranged. All of the organisms contained in the five squares were identified and counted. The first 24 members of a group, if that many were encountered, were measured (mm or μm). Counts for each site per sampling date were duplicated and additional members of a group were measured if 24 were not measured in the first count. An average biomass value was determined for the group by taking the average of the 24 (or less if 24 organisms were not encountered) biomass estimates obtained from the group's length-weight equation (Table 2). The equations used for the density and biomass estimates were as follows:

$$\#/L = \frac{C \times E}{TV}$$

where,

C = total count for organisms

E = expansion factor for estimated number per sample (6.89)

TV = volume of the tow (L).

$$\mu g/L = \frac{C \times E \times AB}{TV}$$

where, C, E, and TV are as before and AB equals the average biomass of the group.

Rotifers were identified and counted using a phase-contrast binocular microscope. The entire area of a Sedgewick-Rafter cell (1 ml) was used. The equations used for the density and biomass estimates were as follows:

$$\#/L = \frac{C \times PV}{TV} \times 1000$$

Table 2. Length-dry weight equations and constant dry weights used for the determination of zooplankton biomass.

Group	Length-Dry Weight or Weight	Units	Source
Cladocerans			
Daphnia spp.	$W = 1.5 \times 10^{-8} L^{2.84}$	μm, μg	Dumont et al. 1975
Ceriodaphnia spp.	$W = 5.91 \times 10^{-6} L^{2.02}$	μm, μg	Dumont et al. 1975
Bosmina spp.	$W = 26.6 L^{3.13}$	mm, μg	Dumont et al. 1975
Diaphanosoma spp.	$W = 1.76 \times 10^{-6} L^{2.11}$	μm, μg	Dumont et al. 1975
Alona spp.	$W = 15.92 L^{3.84}$	mm, μg	Dumont et al. 1975
Chydorus spp.	$W = 89.43 L^{3.93}$	mm, μg	Dumont et al. 1975
Copepods			
Cyclopoid (Adult)	$W = 2.2 \times 10^{-8} L^{2.82}$	μm, μg	Dumont et al. 1975
Calanoid (Adult)	$W = 7.9 \times 10^{-7} L^{2.33}$	μm, μg	Dumont et al. 1975
Sub-Adults	$W = 1.17 \times 10^{-6} L^{2.20}$	μm, μg	Dumont et al. 1975
Rotifers			
Asplanchna spp.[1]	$W = 0.037V + 0.022$	μm^3, μg	Dumont et al. 1975
Keratella spp.	$W = 0.11$	μg	Dumont et al. 1975
Conochilus spp.	$W = 0.08$	μg	Wetzel and Likens 1979
Ptygura spp.[2]	$W = 0.10$	μg	None
Polyarthra spp.	$W = 0.74$	μg	Dumont et al. 1975
Gastropus spp.[3]	$W = 0.21$	μg	Dumont et al. 1975
Kellicottia spp.	$W = 0.10$	μg	Wetzel and Likens 1979
Trichocerca spp.	$W = 0.36$	μg	Dumont et al. 1975

[1] Volume determined using equation for an ellipsoid.

[2] Dry weight estimated based on comparative size to *Conochilus spp.* which is similar in shape.

[3] Dry weight determined by average *Gastropus spp.* length (mm) using equation presented in Dumont et al. 1979 ($W = 1.87 \times 10^{-4} L^{1.52}$).

where,

C = total count for organisms

PV = volume of the preserved sample (ml)

TV = volume of the tow (ml).

$$\mu g/L = \#/L \times B$$

where B equals the fixed biomass of that genus of rotifer. Dry weights and equations used to determine rotifer biomass are given in Table 2.

Zooplankton groups were analyzed qualitatively (biomass and density) by comparisons between upper (sites 3 versus 6), middle (sites 2 versus 5), lower (sites 1 versus 4), and arm averages for the three pre-lime and three post-lime samples.

Young-of-the-year bluegill growth

Differences in daily growth rates of young-of-the-year (YOY) bluegill between the east and west arms were tested with the Wilcoxon Rank Sum Test (Hollander and Wolfe 1973) for the period in which there was a difference in alkalinity. The otolith aging technique that was introduced by Pannella (1971, 1974) and validated for bluegill by Taubert and Coble (1977) was used to estimate the number of days after swim-up (i.e., the stage of first exogenous feeding). Average daily growth rate (ADG, mm/d) after swim-up was determined as follows:

$$\mathrm{ADG} = \frac{\mathrm{TL\ capture} - \mathrm{TL\ swim\text{-}up}}{\mathrm{age\ (d)}}$$

where, TL = total length in mm. TL swim-up was assumed 6 mm as reported in Carlander (1969) for bluegill.

Bluegills were captured primarily at area G (Figure 7) in the west arm and area H in the east arm by a 3 mm mesh trawl that was towed at speeds approximating 1 m per second. Specimens were preserved in 70% ethyl alcohol. Bluegill that were captured on 29 July, 10 August, and 11 August 1987 were subsampled for the smaller specimens. Only bluegill whose swim-up date was estimated at 7 July 1987 or later were used in the analysis in order to insure that a high percentage of that individual's life was spent during the period where alkalinity in the east arm was relatively higher than in the west arm. Bluegill that were captured on 29 July 1987 and were used in the analysis spent a minimum of 68% of their lifespan during the period where alkalinity differed between the arms and bluegill captured on 10 August and 11 August 1987 spent a minimum of 79% of their lifespan during this period. It is unlikely that bluegills this size would migrate between the east and west arm capture areas.

The extraction and preparation procedures for the sagittae follow Taubert and Coble (1977); however, the procedure differed for a few steps.

1. Bluegill were measured to the nearest 0.1 mm with an ocular micrometer and positioned using a dissecting microscope.
2. A drop of water was placed on the bluegill and the head was dissected using a pair of microdissection forceps and an ordinary sewing needle. The saggittae were easily spotted because they rapidly sank in the drop of water after dislodgement.
3. After the saccular membrane was cleaned off, the sagittae were secured to a glass microscope slide with clear super glue (DuPont brand) with the convex side up.
4. Moist 600 grit sandpaper with an adhesive backing was used on the index finger to gently sand the top of the sagittae. The inner rings were lost if too much pressure was applied.

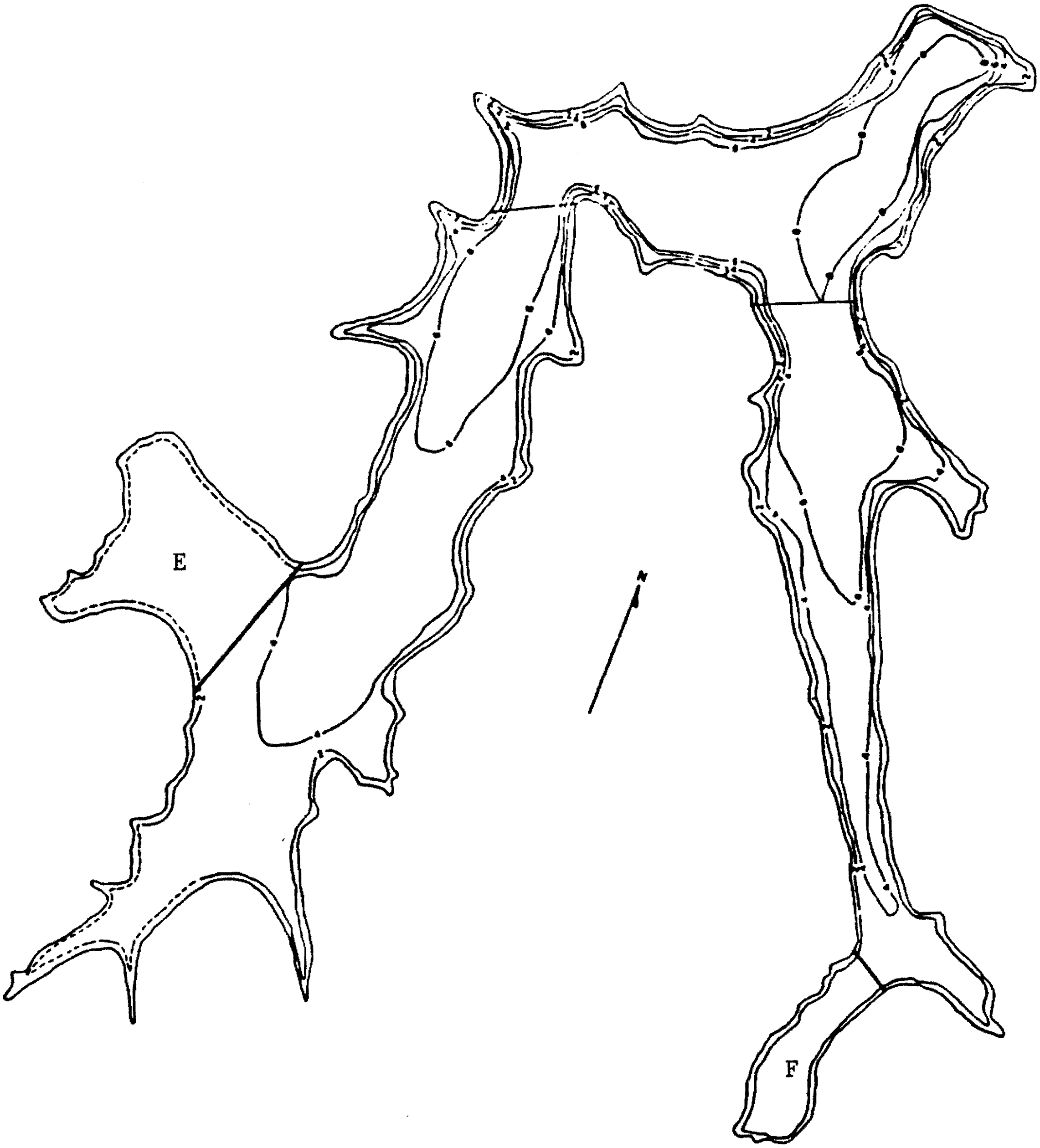


Figure 7. Littoral areas sampled for the collection of YOY bluegills.

Pressure was then concentrated towards the periphery of the otoliths to expose the outermost rings. Generally sagittae needed very little sanding.

5. The sagittae were rinsed in water and dried with a Kimwipe. A disposable butane lighter was used to burn the otolith for about 10 s.
6. Sagittae were placed in 1N HCL for about 10 s which made the rings very distinct. At this point the sagittae were ready for daily age estimation.

A daily sagittal ring is composed of a lightly colored calcareous layer and a darker proteinaceous layer (Pannella 1980). Burning the otolith in step 5 seemed to intensify the darkness of the proteinaceous layer. A binocular microscope at 450x magnification was used to count the number of alternating light and dark bands which represent one day for bluegill (Taubert and Coble 1977). The mean of three ring counts was used as the estimate of daily age. The sagittae slides were assigned a random number so no knowledge of bluegill total length or capture site was known prior to aging. No two counts of the same sagittae were made in consecutive order and no specific sagittae was aged twice in one day. Only one of the two sagittae were prepared and aged in most cases; however, a small number of sagittae were unreadable or were damaged in which case the other sagitta was analyzed. Prolarval rings were apparent for most fish and were easily recognized from the more distinct daily rings.

Results

Alkalinity

Prior to the application of limestone, alkalinity was similar between the two arms (Figure 8). During the 43 day sampling period before the treatment (29 May-10 July 1987), alkalinity increased at an average rate of 0.66 mg $L^{-1}week^{-1}$ in the east arm and 0.54 mg $L^{-1}week^{-1}$ in the west arm. Site-specific and average arm alkalinity values for the entire pre- and post-treatment data set are given in Appendix 1.

The application of limestone to the east arm resulted in an average increase in alkalinity of 44% (from 12.25 mg/L on 10 July 1987 to 21.92 mg/L on 20 July 1987). The west arm showed a 22% increase for the same time period. The post-treatment increase rate between the 20 July - 1 October 1987 period (after the initial calcite dissolution) for the east arm (0.48 mg $L^{-1}week^{-1}$) was similar to the pre-treatment rate (Table 3), however, the west arm demonstrated a increase rate twice that of the east arm (0.99 mg $L^{-1}week^{-1}$) for the same period. Relatively sharp increases were noted in the west arm between the 10-20 July (3.43 mg $L^{-1}week^{-1}$), the 24-29 July (1.98 mg $L^{-1}week^{-1}$), and the 10 August-3 September 1987 (1.39

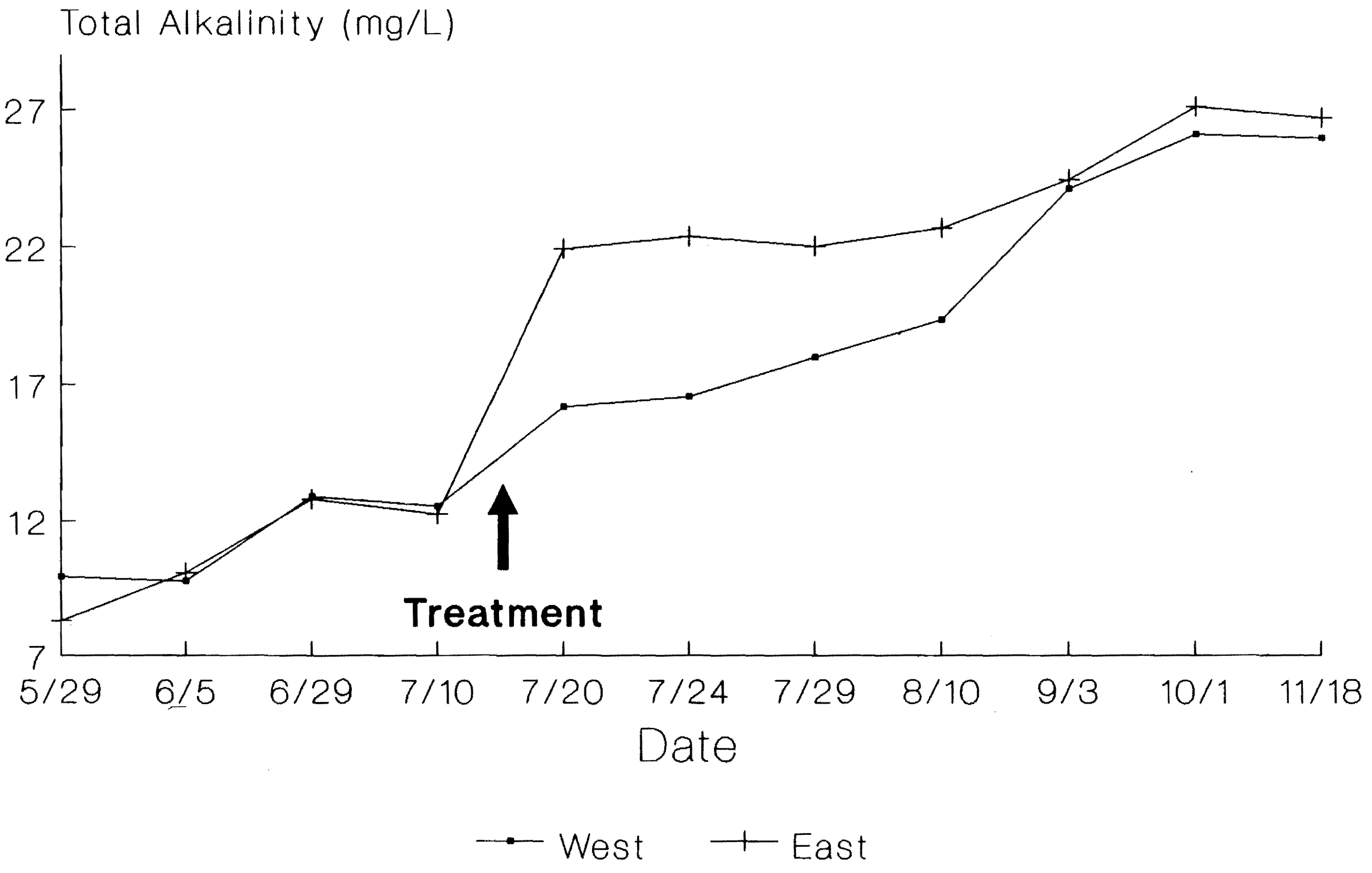


Figure 8. Total alkalinity (mg/L) for the west and east arms. Values are the mean from the 3 sites per arm.

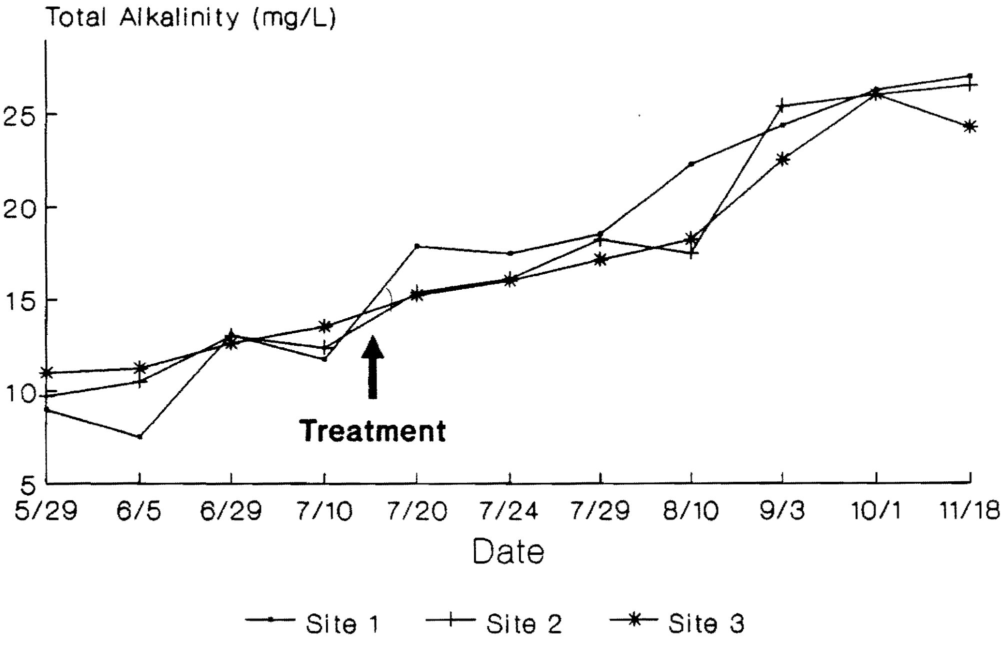
Table 3. Rate of change (adjusted to mg $L^{-1}week^{-1}$) in total alkalinity (mg/L) between successive samples.

	West			East			West	East
Date	1	2	3	4	5	6	$\overline{X}$	$\overline{X}$
7/10-7/20	5.29	2.78	2.21	7.23	6.02	10.00	3.43	7.75
7/20-7/24	-0.67	1.31	1.31	-1.75	3.73	0.44	0.65	0.81
7/24-7/29	1.40	2.97	1.58	0.70	-3.68	1.40	1.98	-0.53
7/29-8/10	2.19	-0.44	0.65	0.88	2.48	-2.19	0.80	0.39
8/10-9/3	0.62	2.30	1.24	1.02	-0.11	0.62	1.39	0.51
9/3-10/1	0.47	0.16	0.88	0.44	0.91	0.66	0.50	0.67

mg $L^{-1}week^{-1}$) samples. The east arm did not demonstrate a weekly increase rate in alkalinity higher than 1 mg $L^{-1}week^{-1}$ between any two successive sampling dates with the exception of 10-20 July 1987. These data suggested a possible influx of limestone dissolution products into the unlimed arm. Analysis of site-specific trends supported this hypothesis.

The site-specific trends in alkalinity (Figures 9a and 9b) strongly suggested that diffusion of limestone dissolution products from the relatively higher alkalinity east arm to the relatively lower alkalinity west arm had taken place after the treatment. Before the treatment, site 3 measured consistently higher in alkalinity than site 2 and site 2 measured consistently higher than site 1 (i.e., alkalinity increased towards the upper arm sites). This pattern was somewhat evident in the east arm as sites 5 and 6 fluctuated between the highest values; however, as demonstrated in the west arm, the lower arm site (site 4) consistently had the lowest alkalinity. One week after the limestone application to the east arm, site 1 (normally the lowest relative alkalinity site) measured higher alkalinity than either site 2 or 3; the closest site to the limed arm increased in alkalinity the earliest. Site 1 had the highest relative alkalinity of the three west arm sites until the 3 September 1987 sample demonstrated a higher alkalinity in site 2, the next closest site to the east (limed) arm. Site 3 also demonstrated a relatively sharp increase in alkalinity on the 3 September 1987 sample as well as the 1 October 1987 sample.

As mentioned earlier, the 10-20 July, the 24-29 July, and the 10 August-3 September 1987 time periods recorded the sharpest relative increases in alkalinity for the west arm. One week after the application of lime, site 1 recorded a 52% increase (5.29 mg $L^{-1}week^{-1}$) in alkalinity, site 2 increased by 24% (2.78 mg $L^{-1}week^{-1}$), and site 3 increased by 13% (2.21 mg $L^{-1}week^{-1}$). This supports the earlier hypothesis that site 1 experienced an increase in alkalinity prior to site 2 and site 3 because of its proximity to the limed arm. The increases at all three sites were above the normally observed increase rate (approximately 0.48-0.66 mg $L^{-1}week^{-1}$) without the effect of limestone dissolution, which suggested all three sites experienced at least some induced alkalinity increase one week after the application. The



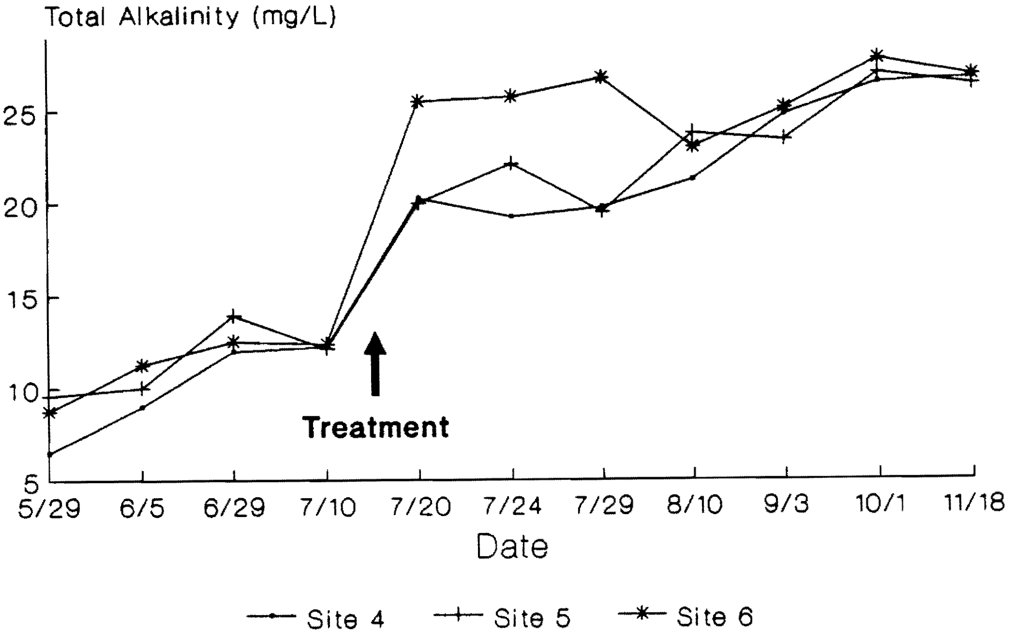


Figure 9. **Total alkalinity (mg/L) for the west (sites 1-3) and east (sites 4-6) arm sites. Values are the mean from the 1m and 3m samples.**

relatively large increase shown in the west arm between the 10 August-3 September 1987 time period was dominated by relatively large increases in alkalinity at site 2 (2.30 mg L^{-1}week^{-1}) and site 3 (1.24 mg L^{-1}week^{-1}) in relation to site 1 (0.62 mg L^{-1}week^{-1}). During this period, alkalinity in site 1 was very similar to alkalinity in the east arm. This substantiates the hypothesis that the mixing of limestone dissolution products was a result of diffusion from relatively higher alkalinity to lower alkalinity areas. In the time period between 3 September-1 October 1987, site 3 experienced the highest relative increase rate (0.88 mg L^{-1}week^{-1} compared to 0.16 and 0.47 mg L^{-1}week^{-1} for sites 2 and 1). During this period, alkalinity at sites 1 and 2 were very similar to the east arm. The site-specific graphs and weekly alkalinity rate analysis demonstrated higher than expected increases in alkalinity throughout the summer and fall in the unlimed (west) arm because of the diffusion of limestone dissolution products into that arm.

pH

Before the application, both arms showed a trend of slightly increasing pH values with time (Figure 10). The east arm demonstrated a higher average pH than the west arm on three of the four pre-treatment samples. The average pH on 10 July 1989, three days before the lime application, was 7.07 in both arms. The application of lime resulted in an average increase of approximately 0.3 pH units in the east arm (from 7.07 on 10 July 1987 to 7.39 on 20 July 1987). The west arm average pH increased approximately 0.15 pH units (from 7.07 on 10 July 1987 to 7.23 on 20 July 1987) which was probably a result of limestone diffusion. The limed (east) arm demonstrated a higher pH than the west (unlimed) arm between the application date and mid-August. Both arms had similar pH's thereafter. The site-specific and average arm pH values for the entire pre- and post-treatment data set are given in Appendix 2.

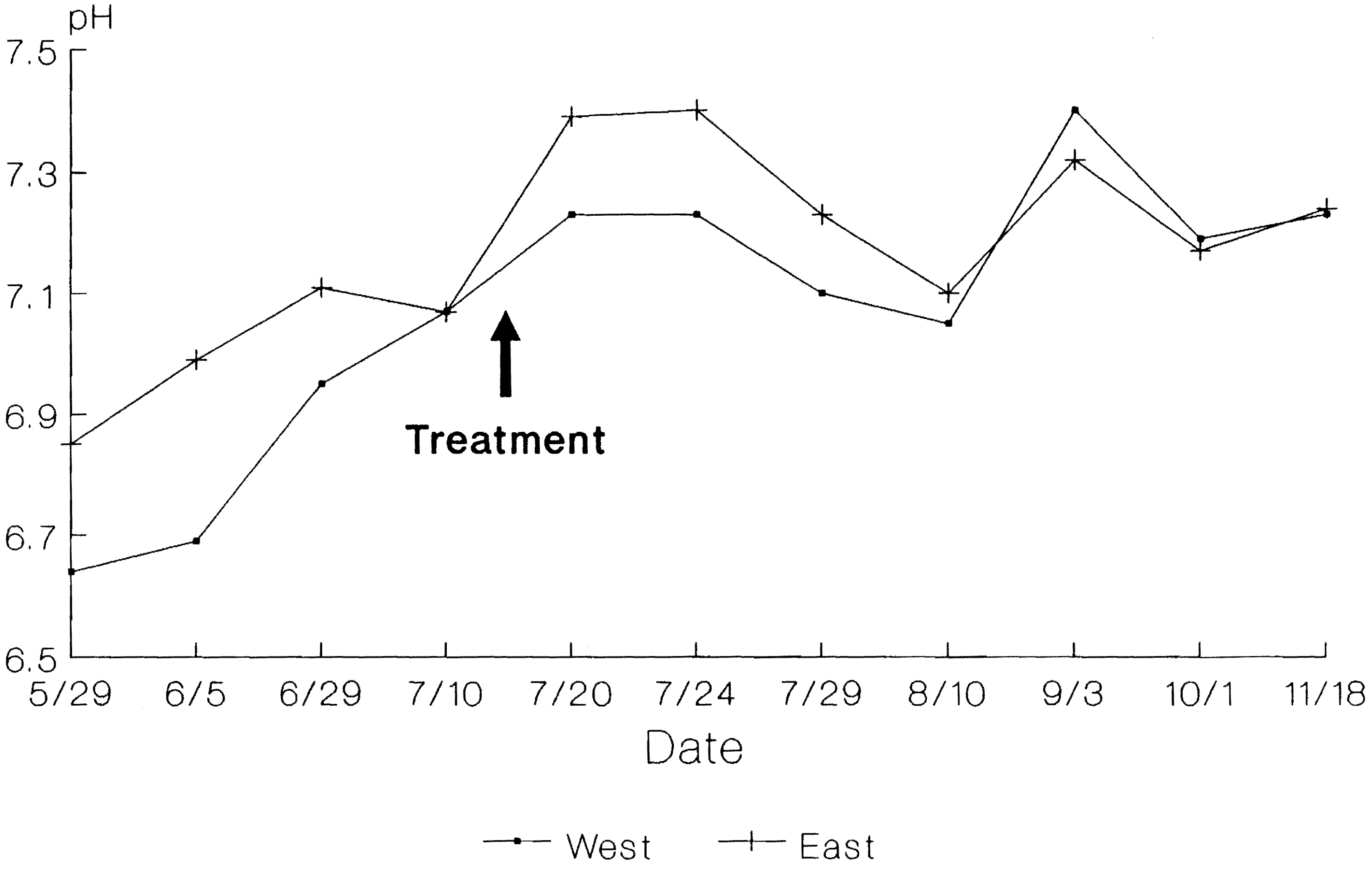


Figure 10. pH for the west and east arms. Values are the mean from the 3 sites per arm.

Phytoplankton gross productivity

Phytoplankton gross productivity was similar between the east and west arms throughout the study (Figure 11). Depth-specific and average arm gross productivity data are given in Appendix 3. Gross productivity was relatively higher in both arms for the early (25 May 1987) and late (18 November 1987) samples and fluctuated between 0.022 and 0.041 mg $O_2L^{-1}h^{-1}$ for the mid-season samples.

The Wilcoxon Signed Rank Test failed to reject the null hypothesis of no difference in gross productivity (Pg as mg $O_2L^{-1}h^{-1}$) between the east and west arms before the treatment (P = 1.00, N = 6) and after the treatment (P = 0.83, N = 6).

Phytoplankton biomass

Phytoplankton biomass was very similar between the two arms throughout the study (Figure 12). The data exhibited a wave appearance with the lowest values recorded on the earliest sample (29 May 1987) and the highest values recorded on the latest sample (18 November 1987). After the application of lime, chlorophyll *a* decreased in both arms on the initial sample (20 July 1987). In subsequent samples, chlorophyll *a* increased in both arms. The site-specific and average arm values for the entire pre- and post-treatment data set are given in Appendix 4.

The site-specific chlorophyll a graphs (Figures 13a and 13b) showed a trend of increased chlorophyll *a* levels towards the upper sites in each arm for the period between 29 May through 3 September 1987 (10 samples) in the west arm and for the period between 6 June

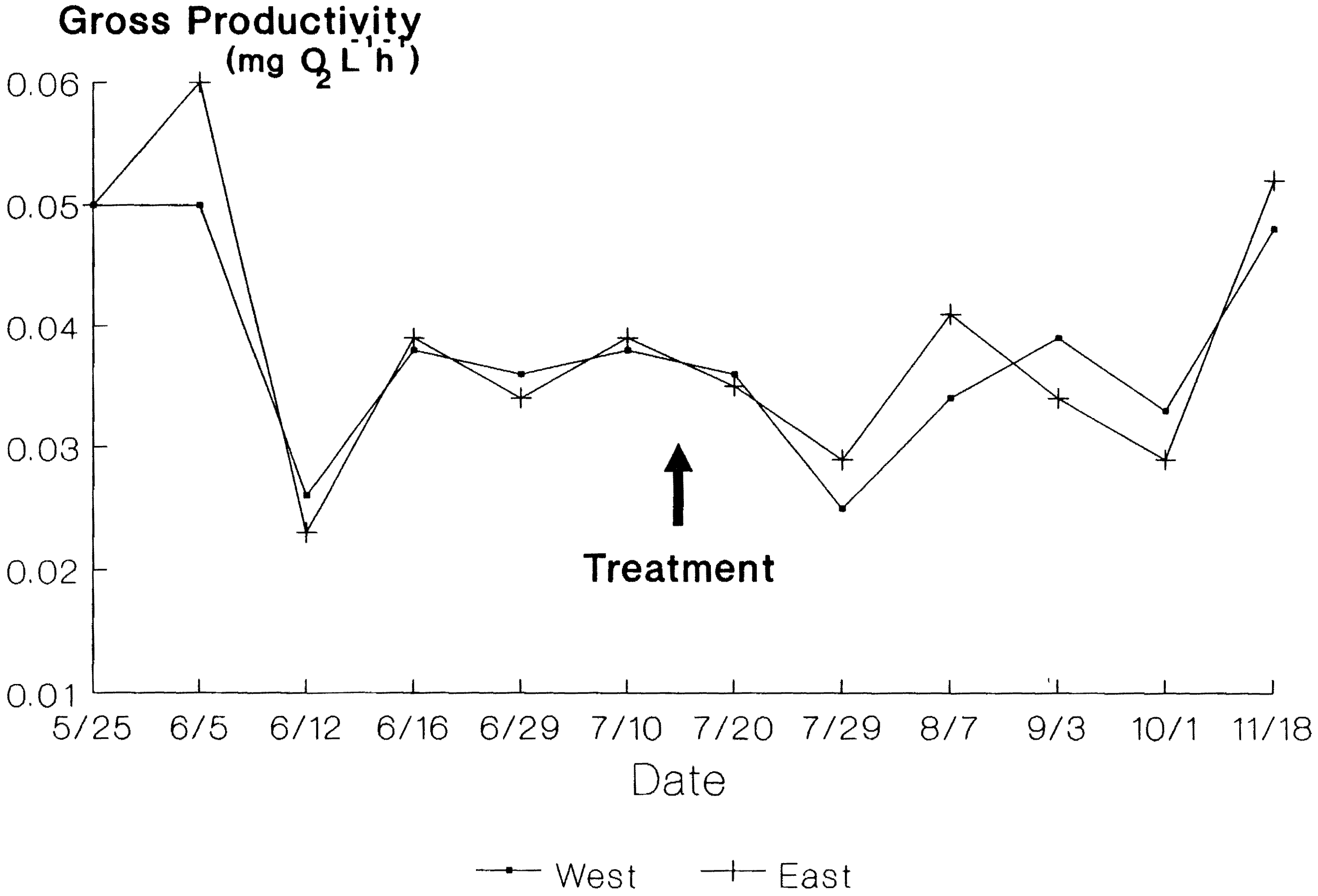


Figure 11. Gross phytoplankton productivity for west and east arms (sites 2 and 5). Values are the mean from the five depths per duplicate sample

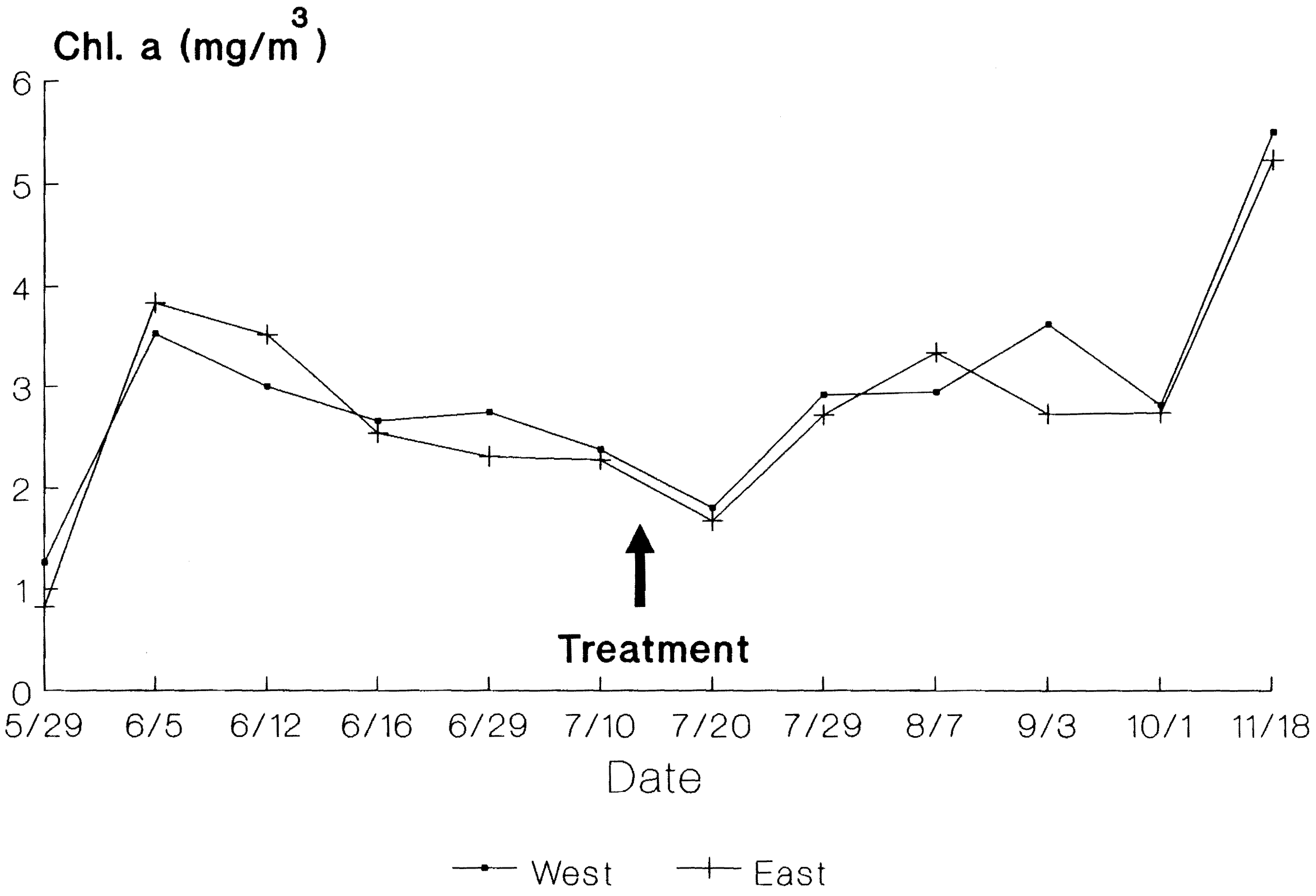


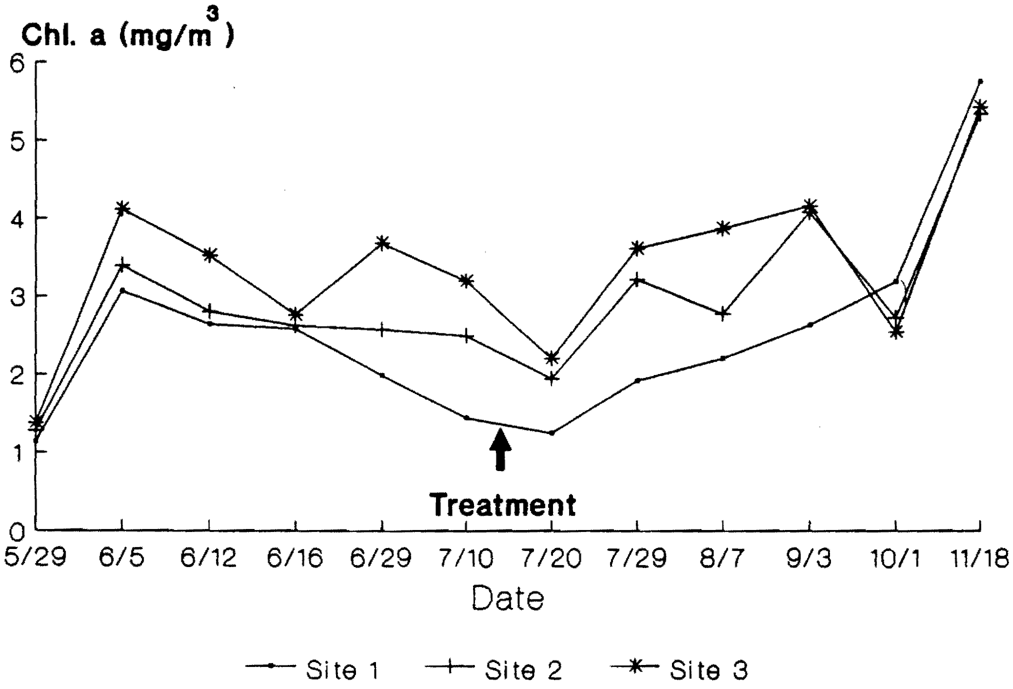
Figure 12. Chlorophyll a concentration (mg chl. a/m^3) for the east and west arms. Values are the mean from the 3 sites per arm.

through 7 August 1987 (eight samples) in the east arm. Samples taken before and after the above periods showed either a reverse spatial trend (i.e, decreased chlorophyll *a* concentrations towards the upper sites) or no trend towards the upper or lower sites.

Friedman's test rejected the null hypothesis of no difference in chlorophyll *a* between the upper, middle, and lower arm sites within each arm for the periods that showed higher chlorophyll *a* values towards the upper arm sites (29 May through 3 September 1987 in the west arm, $P = 0.0000$, $N = 10$; 6 June through 7 August 1987 in the east arm, $P = 0.0003$, $N = 8$). The Sign Test for the within arm site-specific comparisons gave strong evidence ($P < 0.004$ for all comparisons) that the upper site > middle site > lower site in each arm within the stated periods. Because the samples taken outside the stated periods showed an apparent reverse spatial trend in most cases, this did not invalidate the use of the paired-sample design to test for liming effects.

The Wilcoxon Signed Rank Test failed to reject the null hypothesis of no difference in phytoplankton biomass (mg chl. a/m^3) between the east and west arms before the treatment ($P = 0.40$, $N = 6$) and after the treatment ($P = 0.40$, $N = 6$). Results for each of the site-specific comparisons before and after the treatment are given in Table 4.

Alkalinity was sufficiently different between sites 3 and 6 for the 20 July, 29 July, and 7 August 1987 samples to test the null hypothesis of the west arm site (site 3) having equal or lower phytoplankton biomass (mg chl. a/m^3) than the east arm site (site 6) and conclude that the east arm had higher phytoplankton biomass because of the increased supply of dissolved inorganic carbon. The Wilcoxon Signed Rank test failed to reject the null hypothesis for the site-specific comparison (site 6 vs. site 3, $P = 1.00$, $N = 4$).



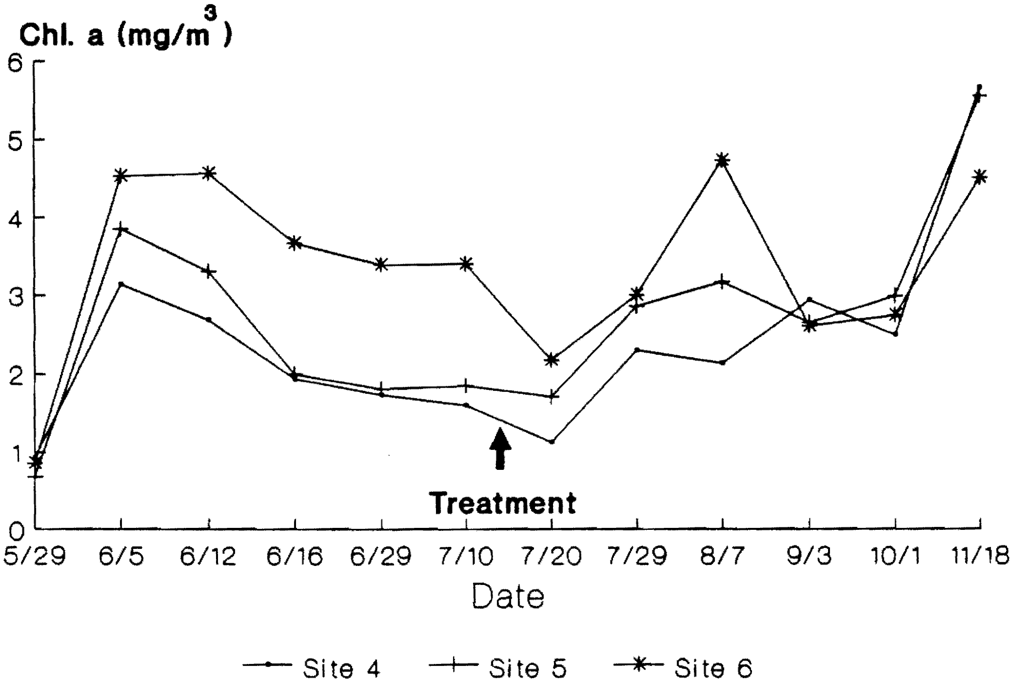


Figure 13. Chlorophyll a concentration (mg chl. a/m^3) for the west (sites 1-3) and east (sites 4-6) arms. Values are the mean from the duplicate samples.

Table 4. Probability (P) values for the determination of significant differences ($\alpha = 0.05$) in chlorophyll *a* concentration (mg/m^3) between the site-specific and mean arm comparisons with the Wilcoxon Signed Rank Test ($N = 6$).

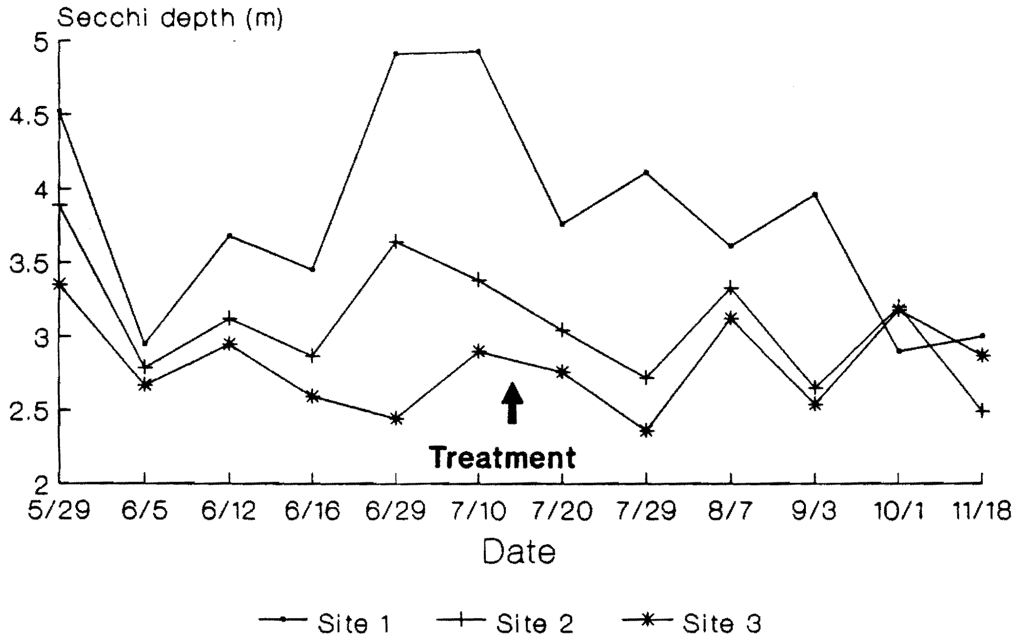
Comparison	Pre-treatment		Post-treatment	
1 vs. 4	$P = 0.834$	$\overline{1} = 2.15$ $\overline{4} = 2.00$	$P = 0.295$	$\overline{1} = 2.83$ $\overline{4} = 2.77$
2 vs. 5	$P = 0.402$	$\overline{2} = 2.53$ $\overline{5} = 2.25$	$P = 0.834$	$\overline{2} = 3.35$ $\overline{5} = 3.15$
3 vs. 6	$P = 0.142$	$\overline{3} = 3.11$ $\overline{6} = 3.40$	$P = 0.834$	$\overline{3} = 3.64$ $\overline{6} = 3.29$
West vs. East	$P = 0.402$	$\overline{W} = 2.60$ $\overline{E} = 2.55$	$P = 0.402$	$\overline{W} = 3.27$ $\overline{E} = 3.07$

Secchi disk transparency

The inverse of Secchi disk transparency showed the same general patterns between sampling sites within each arm (Figures 14a and 14b) as did chlorophyll *a* (Figures 13a and 13b). This suggested that higher chlorophyll *a* values resulted in lower Secchi disk transparencies because of the increased light attenuation caused by increased chlorophyll *a* concentrations. The site-specific Secchi disk transparency graphs showed a trend of decreased Secchi depths towards the upper arm sites for the period between 29 May 1987 through 3 September 1987 (10 samples) in the west arm and for the period between 6 June 1987 through 7 August 1987 (eight samples) in the east arm. Site-specific Secchi depth spatial and temporal trends corresponded to the site-specific chlorophyll *a* spatial and temporal trends for both arms.

The graph of the average arm Secchi disk transparencies (Figure 15) indicated higher transparency in the east arm in comparison to the west arm for the post-treatment samples. The Wilcoxon Signed Rank Test failed to reject the null hypothesis of no difference in transparency between the east and west arms for the pre-treatment samples ($P = 0.834$, $N = 6$). The post-treatment test, however, rejected the null hypothesis and concluded the east arm had higher transparency than the west arm ($P = 0.036$, $N = 6$). Results for each of the site-specific comparisons before and after the treatment are given in Table 5.

The linear regression of Secchi depth and chlorophyll *a* for the combined data set yielded a significant straight line equation that could be used to predict summer phytoplankton biomass with the Secchi disk procedure (mg Chl. $a/\mathrm{m}^3 = -1.09$ (SD, m) $+ 6.47$, $P = 0.0000$, $R^2 = 0.43$, $N = 72$, Figure 16).



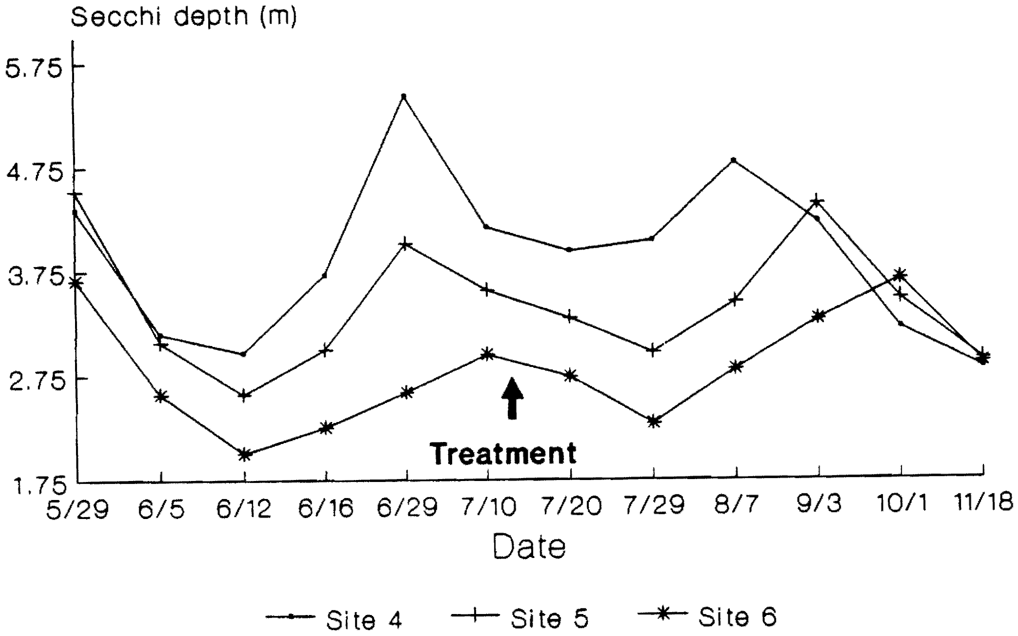


Figure 14. **Secchi depth transparency (m) for the west (sites 1-3) and east (sites 4-6) arm sites.**

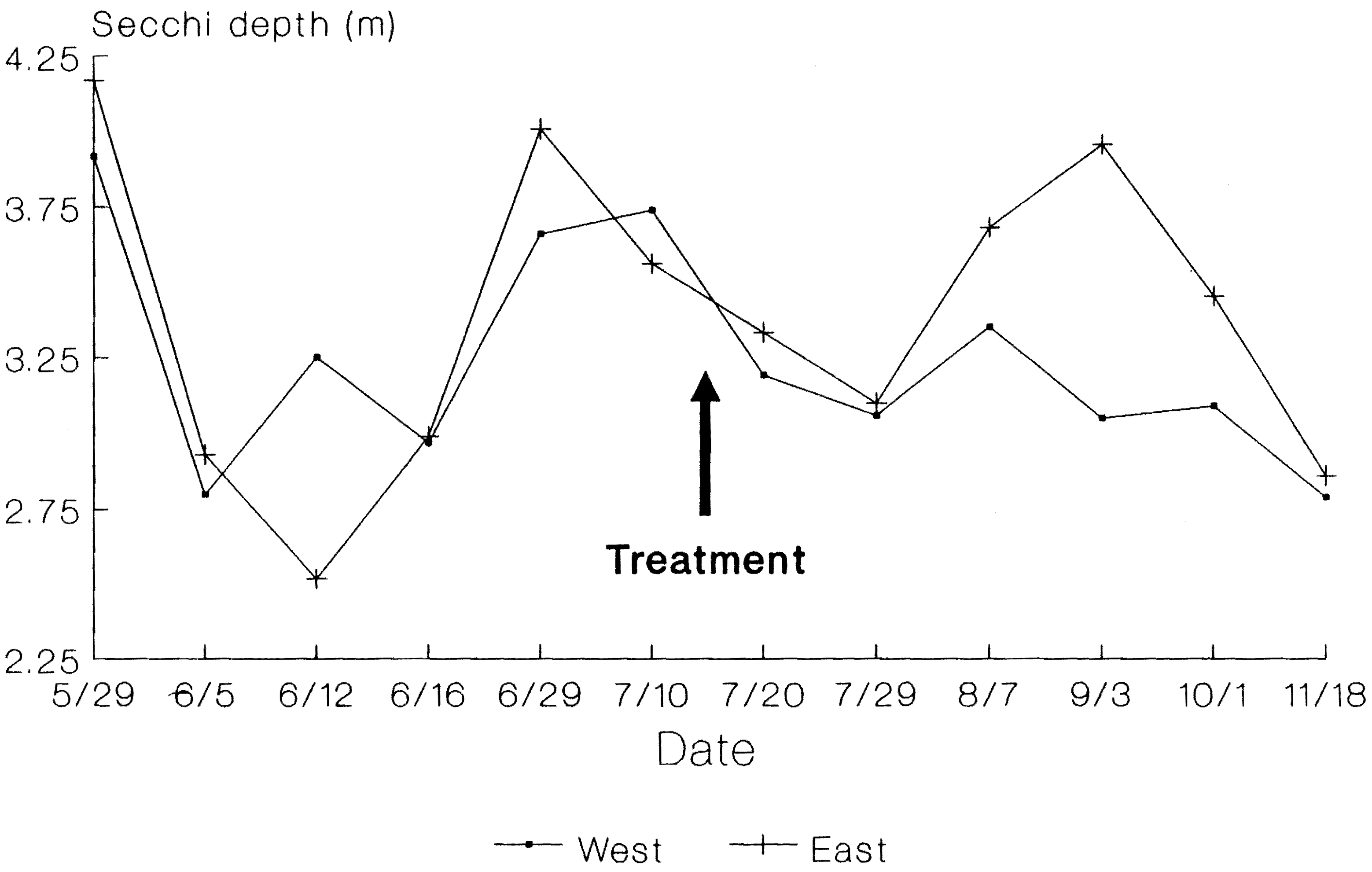


Figure 15. Secchi depth transparency (m) for the west and east arms. Values are averaged for the 3 sites per arm.

Table 5. Probability (*P*) values for the determination of significant differences ($\alpha = 0.05$) in Secchi disk transparency (m) between the site-specific and mean arm comparisons with the Wilcoxon Signed Rank Test ($N = 6$).

Comparison	Pre-treatment		Post-treatment	
1 vs. 4	$P = 0.834$	$\bar{1} = 4.07$ $\bar{4} = 3.96$	$P = 0.173$	$\bar{1} = 3.56$ $\bar{4} = 3.84$
2 vs. 5	$P = 0.295$	$\bar{2} = 3.28$ $\bar{5} = 3.46$	$P = 0.036^{*}$	$\bar{2} = 2.91$ $\bar{5} = 3.42$
3 vs. 6	$P = 0.675$	$\bar{3} = 2.82$ $\bar{6} = 2.67$	$P = 0.787$	$\bar{3} = 2.81$ $\bar{6} = 2.94$
West vs. East	$P = 0.834$	$\bar{W} = 3.39$ $\bar{E} = 3.36$	$P = 0.036^{*}$	$\bar{W} = 3.09$ $\bar{E} = 3.40$

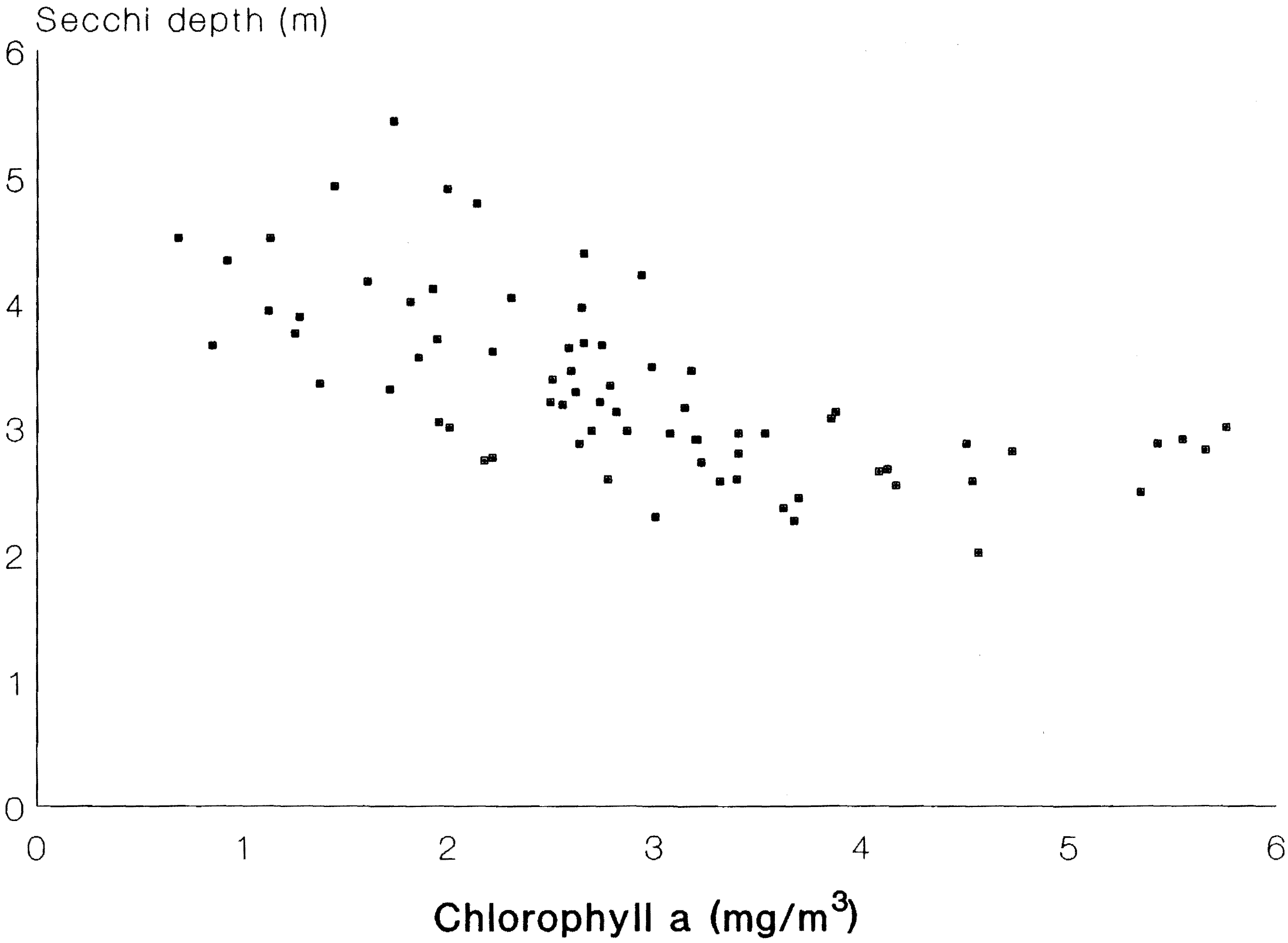


Figure 16. Plot of the associated Secchi disk transparency (m) and chlorophyll a (mg/m³) estimates from the 6 sites on all sample dates.

Phytoplankton density

The dominant genus of net phytoplankton sampled was *Dinobryon spp.*, which comprised 45.3% of the total for the whole lake. *Anabaena spp.*, a member of the Cyanophyta (blue-greens), was the next most abundant genus at 23.0%. *Ceratium spp.* (10.0%), *Staurastrum spp.* (8.2%), *Desmidium spp.* (6.0%), and *Synura spp.* (5.1%) were the other common net phytoplankton sampled on a whole lake basis. Table 6 gives the relative percentages and absolute abundances of the dominant net phytoplankton before and after the application of lime on a per arm basis. The entire net phytoplankton data set on a site-specific basis is given in Appendix 6.

For the combined pre-treatment samples, the west arm had a slightly higher density of net phytoplankton; however, *Ceratium spp.* and *Synura spp.* were the only genera that showed an order of magnitude or higher density in the west arm relative to the east arm. *Desmidium spp.* was relatively more abundant in the east arm; however, a very high relative density at only one site (site 6) on one sample date (29 June 1987) dominated the estimate.

For the combined post-treatment samples, the west arm again showed a higher density of net phytoplankton. However, *Dinobryon spp.*, *Ceratium spp.*, and *Synura spp.* showed a relative decrease in density in both arms with no large (i.e., an order of magnitude) differences between the east and west arms. *Anabaena spp.* and *Staurastrum spp.* increased in relative density in both arms, however, *Anabaena spp.* showed approximately a three-fold higher density in the west arm relative to the east arm.

The dominant genera of nannoplankton sampled was the small (less than 10 μm) colonial green algae (Chlorophyta) *Gemellicystis spp.* which comprised 34.4% of the total for the whole lake. *Gloeocystis spp.* was the next most abundant genera at 10.2%. *Dinobryon spp.* (10.1%),

Table 6. Mean density estimates and relative abundance of common net phytoplankton for the pre-treatment and post-treatment samples.

	Pre-Treatment				Post-Treatment				Lake	
	West		East		West		East		$\bar{X}$	
Group	#/L	Rel. %	#/L	Rel. %	#/L	Rel. %	#/L	Rel. %	#/L	Rel. %
Chrysophyta										
Dinobryon spp.	1328.8	48.9	1132.8	55.0	729.6	33.9	510.5	41.2	925.4	45.3
Synura spp.	283.1	10.4	83.0	4.0	19.0	0.9	26.9	2.2	103.0	5.1
Chlorophyta										
Staurastrum spp.	17.6	0.6	17.1	0.8	335.9	15.6	297.9	24.0	167.1	8.2
Desmidium spp.	84.5	3.1	361.1	17.6	41.3	1.9	7.1	0.6	123.5	6.0
Pyrrhophyta										
Ceratium spp.	540.5	19.9	196.5	9.6	29.1	1.3	50.7	4.1	204.2	10.0
Cyanophyta										
Anabaena spp.	398.6	14.7	229.4	11.1	933.8	43.3	318.5	25.7	470.1	23.0
Others	65.4	2.4	39.1	1.9	66.7	3.1	27.9	2.2	49.8	2.4
TOTAL	2718.4	100.0	2058.8	100.0	2155.3	100.0	1239.3	100.0	2043.0	100.0

centric diatoms (10.1%), and pennate diatoms (9.5%) were the other common nannoplankton sampled on a whole lake basis. Table 7 gives the relative percentages and absolute abundances before and after the application of lime on a per arm basis. The entire data set for nannoplankton on a site-specific basis is given in Appendix 7.

For the combined pre-treatment samples, both arms showed similar density estimates for the common nannoplankton groups. There were no differences greater than an order of magnitude within specific groups or genera; however, centric diatoms and *Tetraedron lunula* were more abundant in the west arm and dinoflagelates (e.g., *Peridinium spp.* and *Gymnodinium spp.*) were more abundant in the east arm.

For the combined post-treatment samples, both arms again showed similar density estimates for total nannoplankton; however, the east arm showed a total nannoplankton density that was approximately double that of the west arm on the initial post-treatment sample (21 July 1987). *Gemellicystis spp.*, *Gloeocystis spp.*, and *Dinobryon spp.* (single lorica species) showed at least an order of magnitude higher density in the east arm relative to the west arm. Pennate diatoms were also more abundant in the east arm for the initial post-treatment sample relative to the west arm. For the combined post-treatment samples, centric diatoms and *Tetraedron lunula* showed a relative decrease in density in both arms with no large differences in density between the east and west arms and *Crucigenia spp.* decreased slightly in both arms and *Oocystis spp.* decreased slightly in the east arm. *Gloeocystis spp.* showed approximately a three-fold increase in both arms. *Gemellicystis spp.* and possibly pennate diatoms showed a decrease in density in the west arm and remained similar in the east arm relative to the pre-treatment samples. *Dinobryon spp.* (single lorica species) decreased slightly in the west arm and increased slightly in the east arm and, in contrast, dinoflagellates and *Selenastrum spp.* increased slightly in the west arm and decreased slightly in the east arm; however, the changes were not greater than an order of magnitude for any of the three groups. A summary of the common net phytoplankton and

Table 7. Mean density estimates and relative abundance of common nannoplankton for the pre-treatment and post-treatment samples.

	Pre-Treatment				Post-Treatment				Lake	
	West		East		West		East		$\bar{X}$	
Group	#/L	Rel. %	#/L	Rel. %	#/L	Rel. %	#/L	Rel. %	#/L	Rel. %
Chrysophyta										
Dinobryon spp.[1]	1337.9	8.3	1395.4	10.3	1148.1	10.1	1596.8	12.3	1369.5	10.1
Centric diatoms	2491.8	15.4	1380.5	10.1	983.3	8.7	616.8	4.7	1368.1	10.1
Pennate diatoms	1677.0	10.4	1324.4	9.7	901.2	7.9	1259.6	9.7	1290.6	9.5
Chlorophyta										
Gemellicystis spp.[2]	6313.4	39.0	4586.0	33.7	3163.4	27.9	4524.0	34.9	4646.7	34.3
Gloeocystis spp.[2]	600.6	3.7	788.2	5.8	1822.6	16.1	2304.9	17.8	1379.1	10.2
Selenastrum minutum	720.6	4.5	645.0	4.7	958.3	8.5	467.0	3.6	697.7	5.2
Crucigenia spp.	685.4	4.2	696.3	5.1	370.0	3.3	423.5	3.3	543.8	4.0
Tetraedron lunula	1039.4	6.4	522.6	3.8	227.4	2.0	73.0	0.6	465.6	3.4
Oocystis spp.	267.4	1.7	334.6	2.5	213.6	1.9	137.5	1.1	238.3	1.8
Pyrrhophyta										
Dinoflagellates	587.0	3.6	1111.7	8.2	819.0	7.2	778.5	6.0	824.1	6.1
Others	455.8	2.8	833.2	6.1	724.7	6.4	782.0	6.0	698.9	5.2
TOTAL	16,175.9	100.0	13,617.7	100.0	11,331.3	100.0	12,963.5	100.0	13,522.1	100.0

[1] single lorica species
[2] cell count

nannoplankton pre- and post-treatment responses and a determination of possible post-treatment responses is given in Table 8.

Associated water quality determinations

Thermal stratification and dissolved oxygen

Thermocline formation was found on the initial 29 May 1987 sample and was approximately 3 m deep. The thermocline gradually became deeper throughout the season, as expected, until fall overturn at which time temperatures became relatively isothermal at all depths. Fall overturn took place sometime between the 3 September 1987 and 1 October 1987 samples. The entire temperature-dissolved oxygen data set on a site-specific basis is given in Appendix 8.

The six sites did not show the same stratification patterns primarily because of differences in depth. The relatively shallow upper sites (sites 3 and 6, approximately 3 m deep) experienced a thermocline only between the initial spring formation until approximately 16 June 1987. On this date, the thermocline was deeper (approximately 4 m) than the depth of the upper sites. The middle sites 2 and 5, which were approximately 5 meters deep, experienced a thermocline until approximately the end of July when thermocline depth was at or just below 5 m. The relatively deeper lower sites 1 and 4 (approximately 7 m deep) experienced thermocline formation through the 3 September 1987 sample.

Dissolved oxygen was in short supply in the hypolimnion from late July until fall overturn. The west arm showed lower hypolimnion dissolved oxygen levels (below 2 ppm) sooner (20

Table 8. Summary of the absolute and relative abundance results for the common net phytoplankton and nannoplankton. The results are the responses in the post-treatment samples relative to the pre-treatment samples.

Group	Result	Post-Treatment Response Indicated
Net Plankton	Abundance decreased slightly in both arms. Slightly higher abundance in the west	No
Dinobryon spp.	Absolute and relative abundance decreased in both arms.	No
Synura spp.	Absolute and relative abundance decreased in both arms.	No
Staurastrum spp.	Absolute and relative abundance increased in both arms.	No
Desmidium spp.	Absolute and relative abundance decreased in both arms.	No
Ceratium spp.	Absolute and relative abundance decreased in both arms.	No
Anabaena spp.	Absolute and relative abundance increased in the west and remained similar in the east.	Unlikely
Nannoplankton	Higher relative abundance in east arm on initial post-treatment sample.	Possible (Positive)
Gemellicystis spp.	Higher relative abundance in east arm on initial post-treatment sample.	Possible (Positive)
Dinobryon spp.[1]	Higher relative abundance in east arm on initial post-treatment sample.	Possible (Positive)
Centric diatoms	Absolute and relative abundance decreased in both arms.	No
Pennate diatoms	No definite trends.	No
Gloeocystis spp.	Absolute and relative abundance increased in both arms. Higher relative abundance in east arm on initial post-treatment sample.	Possible (Positive)
Oocystis spp.	Absolute and relative abundance decreased slightly in the east.	No
Selenastrum minutum	Absolute and relative abundance increased slightly in the west and decreased in the east.	Possible (Negative)
Crucigenia spp.	Absolute and relative abundance decreased slightly in both arms.	No
Tetraedron lunula	Absolute and relative abundance decreased in both arms.	No
Dinoflagellates	No definite trends.	No

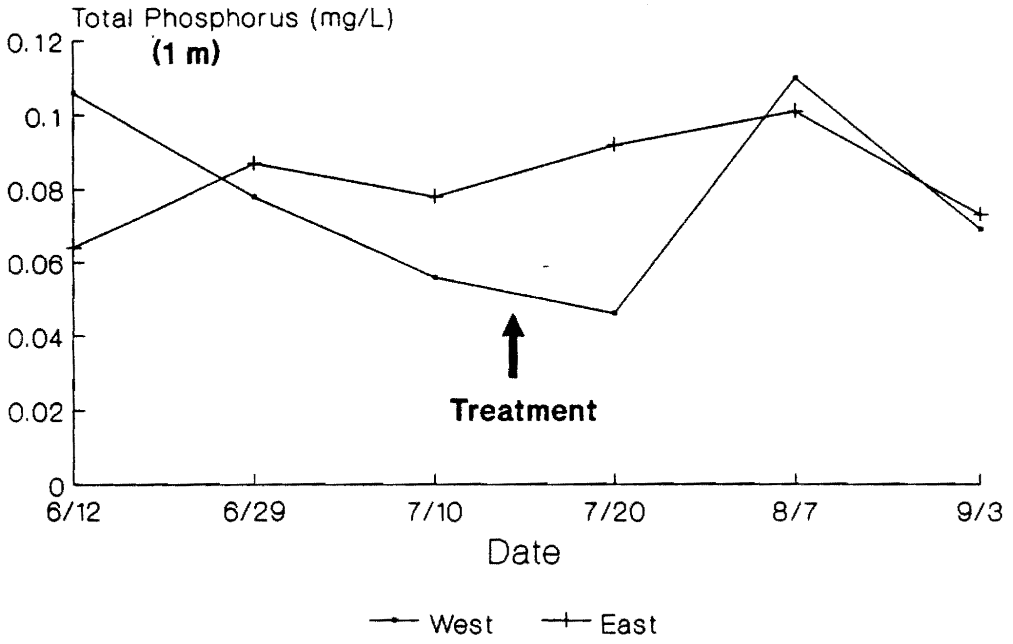
[1] single lorica species

July 1987) than the east arm which did not experience hypolimnetic dissolved oxygen concentrations below 2 ppm until the 7 August 1987 sample. On 3 September 1987, both arms showed anoxic (i.e., no oxygen) conditions below the thermocline, however, on this date the thermocline was relatively deep (about 6 m) and did not occupy a large volume of the water body.

Nutrients

Total phosphorus concentration at 1 m averaged 0.083 mg/L in the east arm and 0.077 mg/L in the west arm. Average total phosphorus concentration for the 4 m sample was 0.084 mg/L in the west arm and 0.292 mg/L in the east arm. The relatively high total phosphorus average for the 4 m sample in the east arm was caused by a very high estimate (1.33 mg/L) on 3 September 1987, and was thought to have been a laboratory contaminated sample. The east arm average (4 m sample) without this estimate was identical to the west arm average (0.084 mg/L, 4 m). Neither arm showed any apparent seasonal trends in total phosphorus concentration (see Appendix 9 for the entire data set for nutrients). In particular, the east arm was similar in total phosphorus concentrations before and after the application of lime for the 1 m sample (Figure 17a). However, at the 4 m depth, the east arm showed a slight decrease from 0.092 mg/L to 0.061 mg/L between the 10 July 1987 and the 20 July 1987 samples (Figure 17b). Total phosphorus concentration increased slightly in the next sample (0.097 mg/L) and was then estimated at 1.33 mg/L on 3 September 1987. The west arm did not show an immediate decrease after the application of lime, but did show a moderate decrease between the 7 August 1987 sample (1m, 0.110 mg/L and 4m, 0.092 mg/L) and the 3 September 1987 sample (1m, 0.069 mg/L and 4m, 0.064 mg/L).

Soluble orthophosphate at 1 m averaged 0.032 mg/L in the west arm and 0.025 mg/L in the east arm. The west arm was also higher at the 4 m depth with an average of 0.040 mg/L



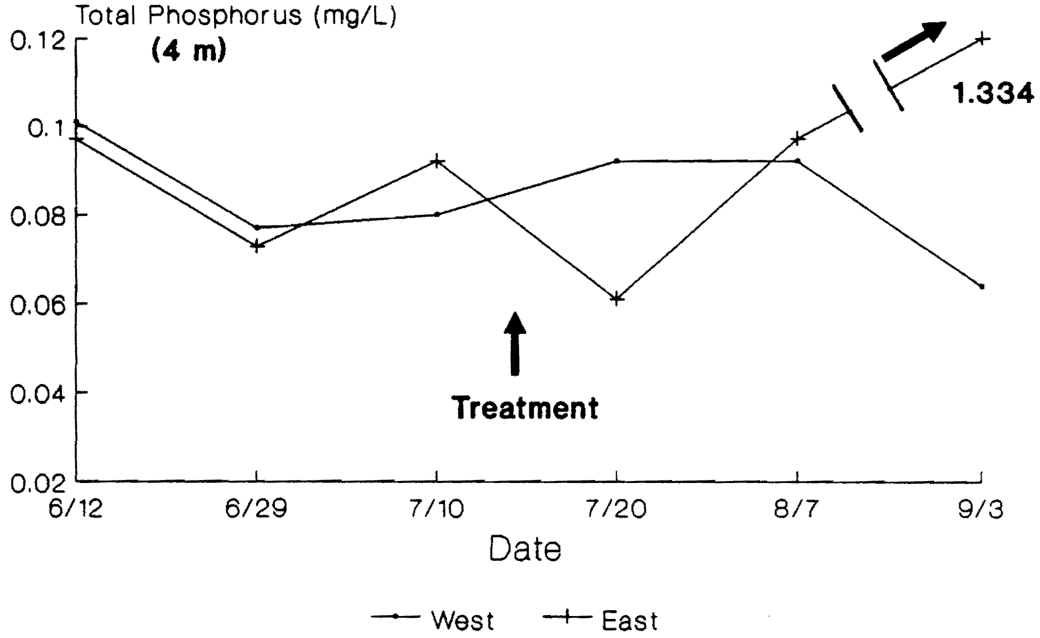


Figure 17. Total phosphorus concentration (mg/L) for the west and east arms for the 1m and 4m samples.

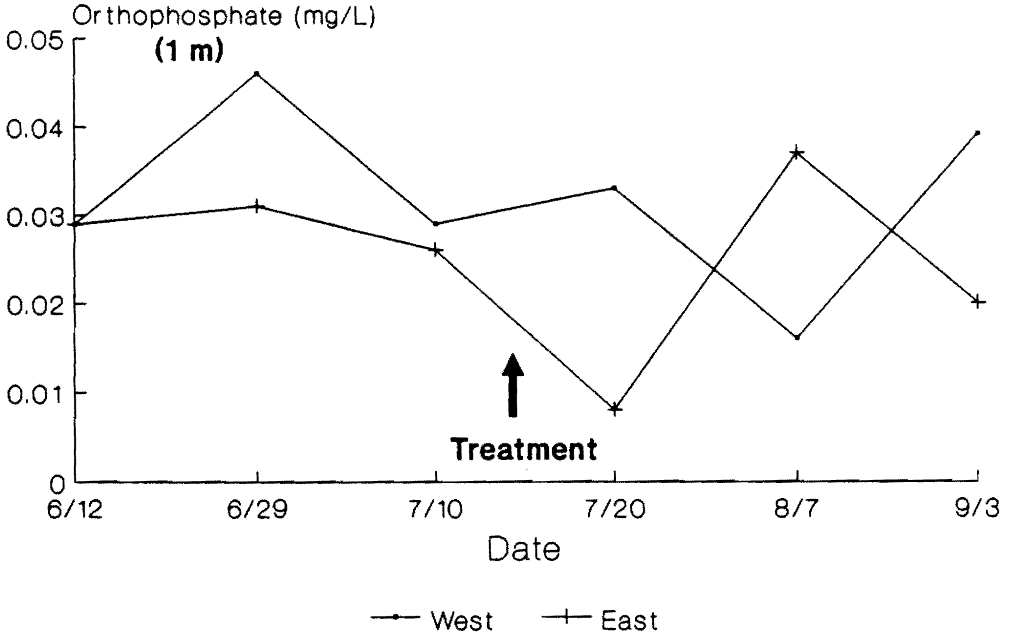
compared to 0.027 mg/L for the east arm. As with total phosphorus, there were no strong seasonal trends in soluble orthophosphate concentration for either arm. After the application of lime, orthophosphate decreased in the east arm for both the 1 m and 4 m samples (Figures 18a and 18b). Orthophosphate was at its lowest level in the east arm at this time. The west arm also showed a decrease in orthophosphate on the 20 June 1987 sample for the 4 m sample but not for the 1 m sample. In subsequent samples for both arms, orthophosphate was relatively stable at the 4 m depth, but showed larger fluctuations at the 1 m depth.

Briefly, total kjeldahl nitrogen (TKN) was similar between the east and west arms before the treatment, however, the east arm showed a relatively high estimate (4.41 mg/L) for the 20 July 1987 sample (1m). Nitrate-nitrogen appeared to be slightly higher for the 4 m sample in the east arm before the treatment and ammonia-nitrogen appeared to be slightly higher for the 1 m sample in the west arm before the treatment.

The pertinent nutrient and metal data collected by IS&T for LLI will be presented when applicable in the discussion section (see Appendix 10) as will the sediment chemistry data (see Appendix 11).

Zooplankton biomass

Total whole lake zooplankton biomass averaged for the six sites in both arms declined steadily from 25 May 1987 (253.3 μg/L) through 21 July 1987 (57.6 μg/L) and remained relatively stable, between 75-100 μg/L, for the remainder of the summer through 3 September 1987. Total zooplankton biomass for the east and west arms also declined throughout the summer but showed some differences (Figure 19). Prior to the application of lime, the east arm had a higher total zooplankton biomass on the initial 25 May 1987 sample (280.5 μg/L versus 226.1



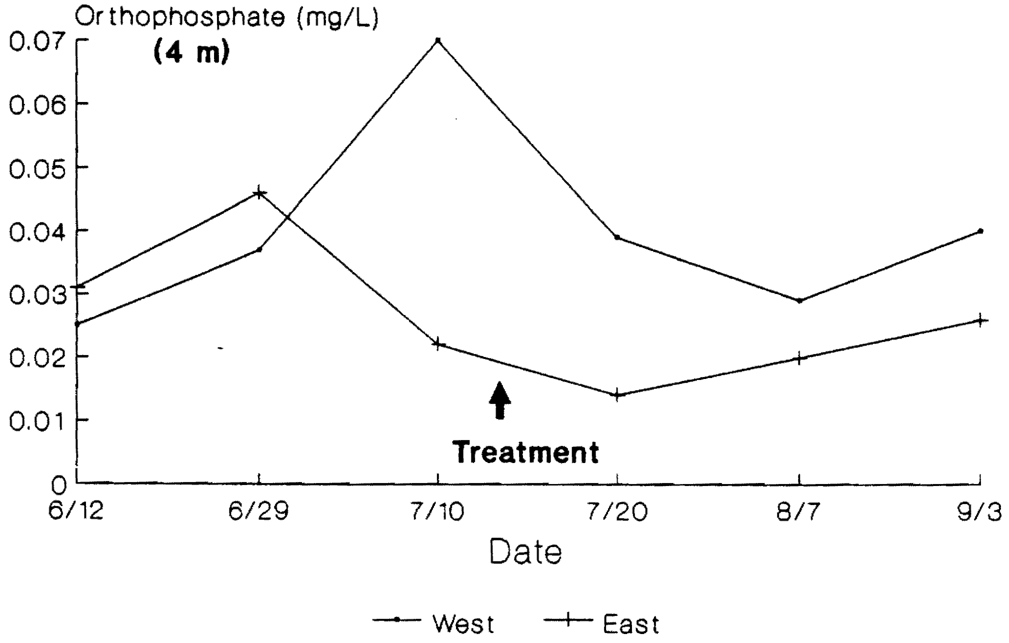


Figure 18. Orthophosphate concentration (mg/L) for the west and east arms for the 1m and 4m samples.

μg/L) and the west arm had a total zooplankton biomass of approximately double that of the east arm on the next two sample dates (212.3 μg/L versus 106.6 μg/L on 12 June 1987 and 182.3 μg/L versus 88.9 μg/L on 29 June 1987). The average pre-lime zooplankton biomass for the west arm (206.9 μg/L) was higher than the east arm (158.7 μg/L) primarily due to higher biomass estimates for *Daphnia spp.* and, to a lesser extent, cyclopoid copepods (Table 9). After the lime application, east and west arm biomass estimates for total zooplankton (73.2 μg/L, west versus 79.0 μg/L, east), cladocerans (34.8 μg/L, west versus 43.7 μg/L, east), copepods (18.9 μg/L, west versus 17.8 μg/L, east), and rotifers (19.5 μg/L, west versus 17.5 μg/L, east) were similar with little suggestion of major differences between arms. *Bosmina spp.* and copepods appeared to be dominant in the late spring with *Daphnia spp.* becoming dominant in the early to mid-summer (Figure 20). Rotifers increased in relative biomass and *Daphnia spp.* decreased from mid-to-late summer. Copepods showed their lowest relative biomass in the mid-summer samples. The entire zooplankton data set is given in Appendix 12.

After the 25 May 1987 sample in which very high biomass estimates were found at the upper arm sites (457.0 μg/L at site 3 and 514.6 μg/L at site 6), primarily because of a very large *Bosmina spp.* population, the west arm showed a pattern of decreasing total zooplankton biomass towards the middle (site 2) and upper (site 3) arm sites (Figure 21a). The east arm did not have as pronounced a decreasing trend towards the upper arm sites as did the west arm; however, the lower arm site (site 4) did have a higher total zooplankton biomass estimate than the middle (site 5) and upper (site 6) arm sites in four of the five samples taken after the 25 May 1987 sample (Figure 21b). An increasing trend in total zooplankton biomass towards the upper arm sites was found in the east arm on the first (25 May 1987) and last (3 September 1987) samples and in the west arm on the first (25 May 1987) sample. The west arm showed very similar total zooplankton biomass estimates between the three sites on the last sample (3 September 1987). Each of the common genera along with the copepod groups are

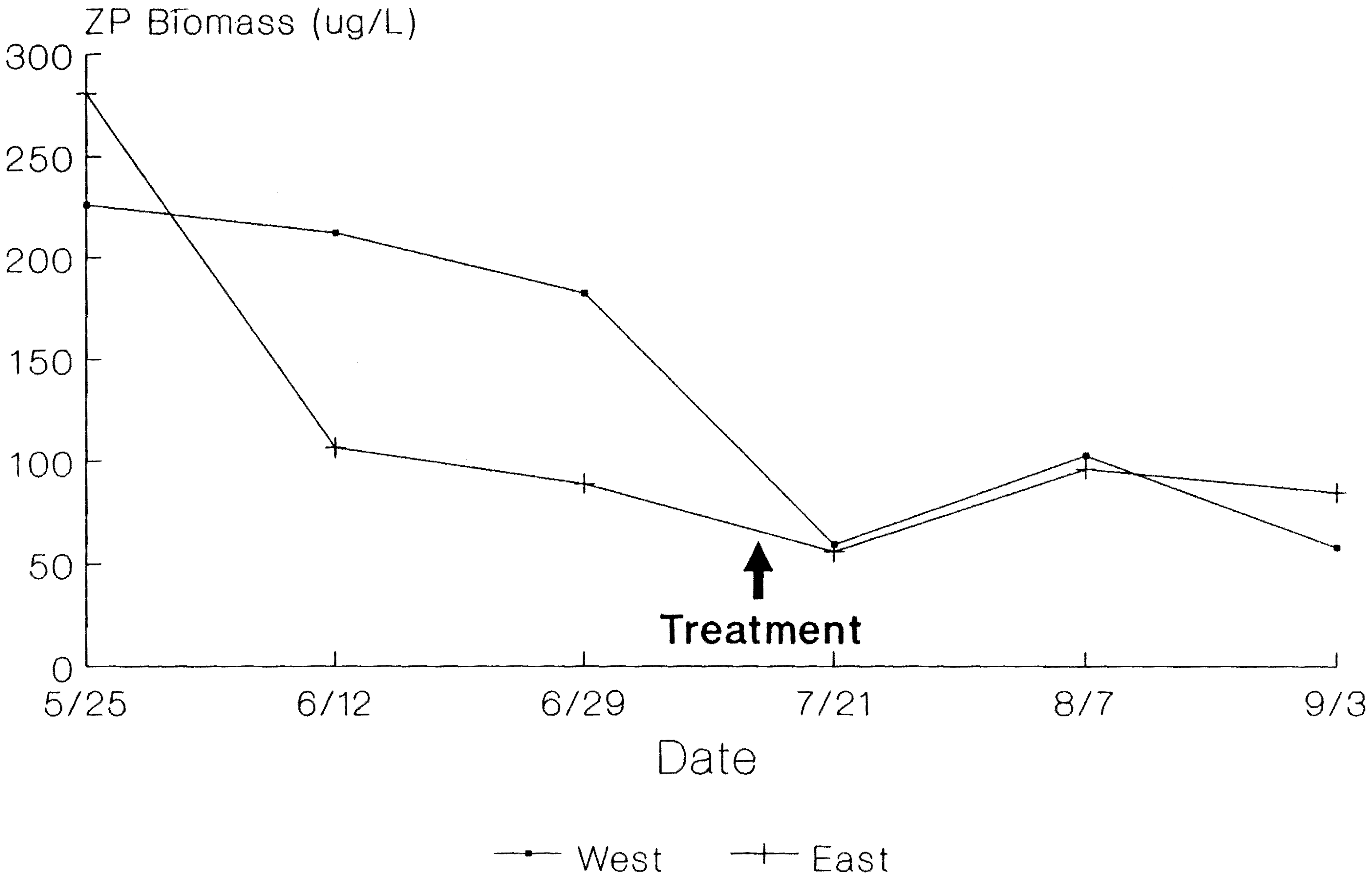


Figure 19. Total zooplankton biomass (μg/L) for the west and east arms. Values are the mean from the 3 sites per arm.

Table 9. Mean biomass estimates and relative abundance of common zooplankton genera and copepod groups for the pre-treatment and post-treatment samples.

	Pre-Treatment				Post-Treatment				Lake	
	West		East		West		East		$\bar{X}$	
Group	µg/L	Rel. %	µg/L	Rel. %	µg/L	Rel. %	µg/L	Rel. %	µg/L	Rel. %
Cladocerans										
Daphnia spp.	86.1	41.6	33.5	21.1	26.7	36.5	33.6	42.5	45.0	34.8
Bosmina spp.	36.9	17.8	53.3	33.6	4.0	5.5	1.6	2.0	24.0	18.5
Ceriodaphnia spp.	0.8	0.4	1.3	0.8	3.1	4.2	7.8	9.9	3.3	2.5
Others	0.6	0.3	0.6	0.4	1.0	1.4	0.7	0.9	0.7	0.5
TOTAL	124.4	60.1	88.7	55.9	34.8	47.6	43.7	55.3	73.0	56.3
Copepods										
Cyclopoid (Adult)	32.7	15.8	26.1	16.5	5.6	7.7	8.0	10.1	18.1	14.0
Calanoid (Adult)	24.9	12.0	11.8	7.4	11.3	15.4	8.3	10.5	14.1	10.9
Sub-adults	3.2	1.6	3.0	1.9	2.0	2.7	1.5	1.9	2.4	1.9
TOTAL	60.8	29.4	40.9	25.8	18.9	25.8	17.8	22.5	34.6	26.8
Rotifers										
Polyarthra spp.	8.4	4.1	7.9	5.0	3.1	4.2	5.6	7.1	6.2	4.8
Conochilus spp.	7.1	3.4	10.8	6.8	2.2	3.0	1.3	1.7	5.3	4.1
Keratella spp.	4.1	2.0	7.9	5.0	3.4	4.6	2.3	2.9	4.5	3.5
Ptygura spp.	0.3	0.1	0.3	0.2	3.9	5.3	6.1	7.7	2.7	2.1
Asplanchna spp.	0.1	0.1	0.4	0.3	5.7	7.8	1.2	1.5	1.8	1.4
Others	1.7	0.8	1.7	1.1	1.2	1.6	0.9	1.1	1.4	1.0
TOTAL	21.7	10.5	29.0	18.3	19.5	26.6	17.5	22.2	21.9	16.9
GRAND TOTAL	206.9	100.0	158.7	100.0	73.2	100.0	79.0	100.0	129.5	100.0

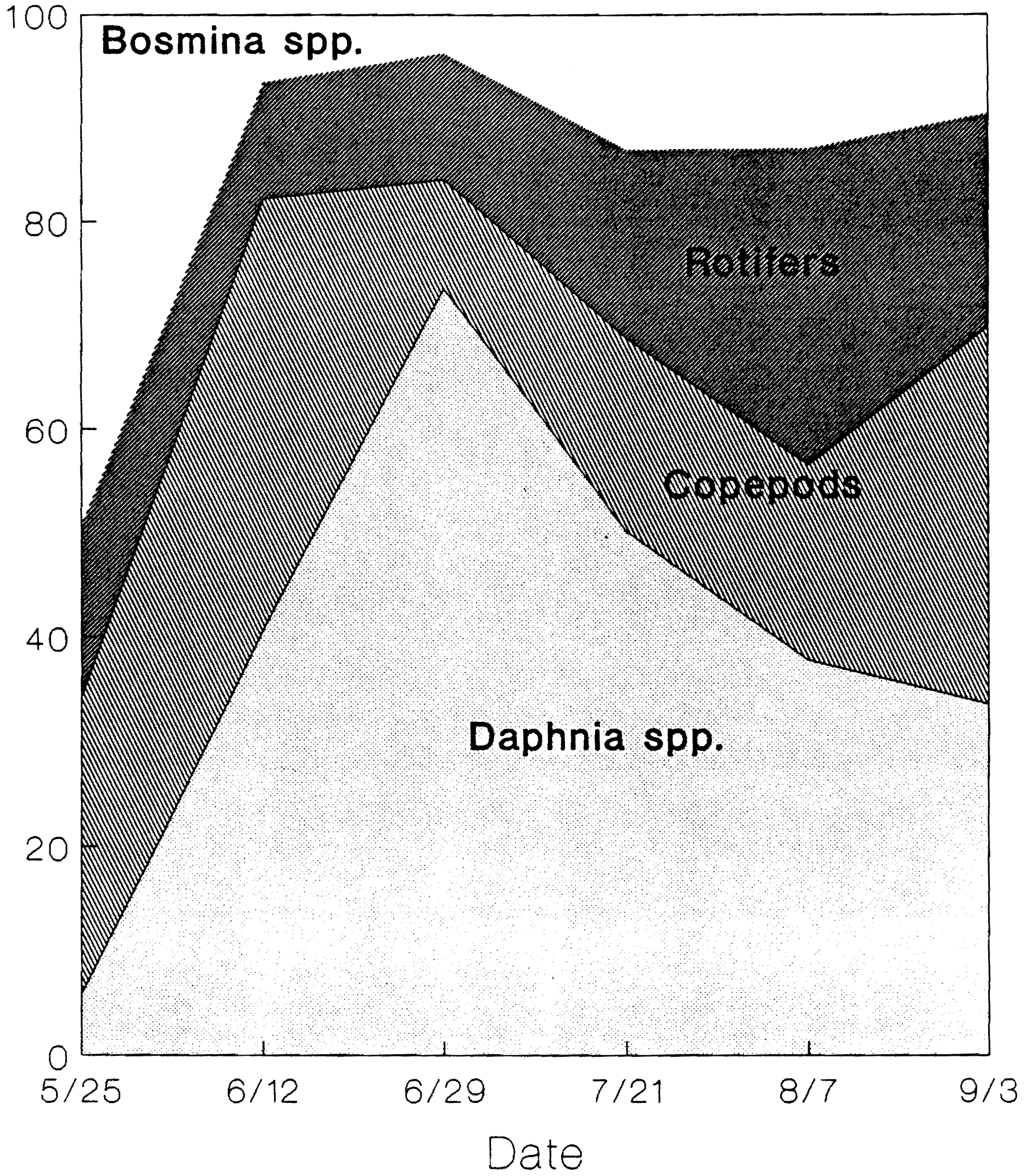
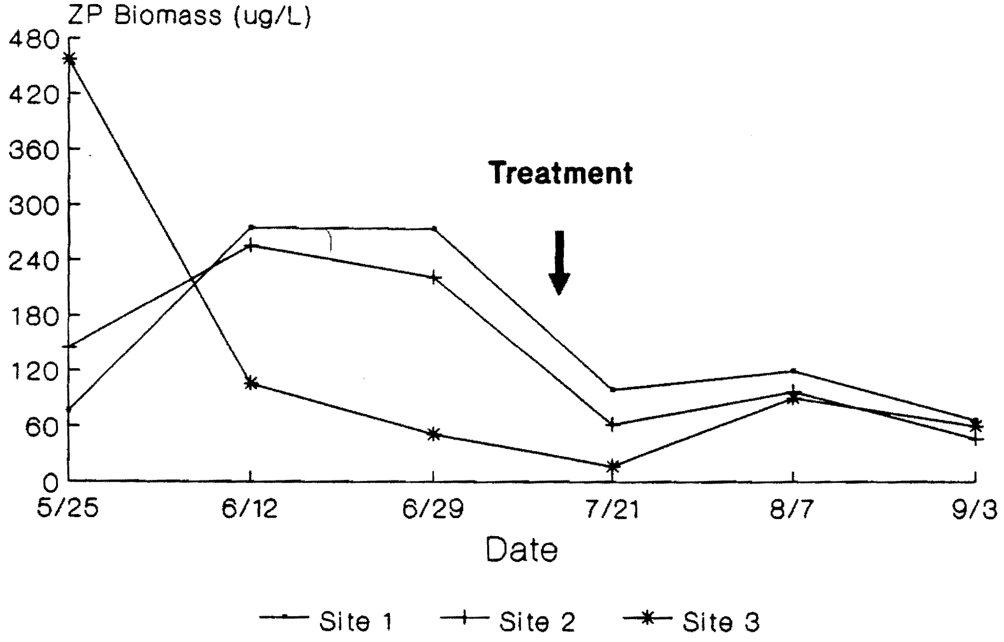


Figure 20. Relative percentages of biomass (μg/L) between Daphnia spp., Bosmina spp., copepods, and rotifers in the west and east arms based on the 6 samples.



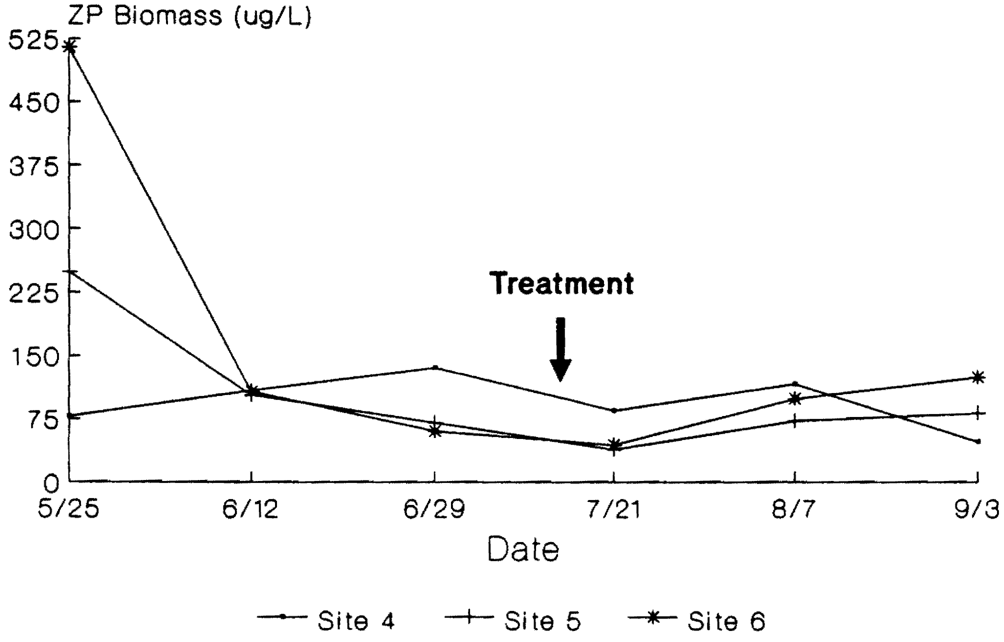


Figure 21. Total zooplankton biomass (μg/L) for the west (sites 1-3) and east (sites 4-6) arms. Values are the mean from the duplicate samples.

presented in the next section with respect to their site-specific dynamics and responses after the application of lime in relation to before the application.

Cladocerans

Daphnia spp.

Daphnia spp. was the dominant genera in terms of biomass as they comprised 34.8% of the total whole lake zooplankton biomass. In the west arm, *Daphnia spp.* comprised 40.2% of the total zooplankton biomass in comparison with 28.2% in the east arm. Whole lake *Daphnia spp.* biomass was lowest on the initial sample (25 May 1987) and increased on the next two samples up to a maximum two weeks prior to the application of lime. After the application, *Daphnia spp.* biomass remained relatively stable at moderate levels. Biomass curves for each arm had roughly the same shape; however, both arms showed large differences in amplitude before the application (Figure 22a). Prior to the application, the west arm demonstrated a higher *Daphnia spp.* biomass on all three samples with an approximately three-fold higher biomass estimate in comparison with the east arm for the two June samples. After the application, *Daphnia spp.* biomass was nearly identical in both arms on the 21 July 1987 and 7 August 1987 samples. On the final sample, *Daphnia spp.* biomass was over three times higher in the limed east arm.

Daphnia spp. biomass represented a large percentage of the total biomass for the cladocerans because of the dominance of *Daphnia spp.* on all dates sampled except for the initial sample (25 May 1987) when *Bosmina spp.* was in great abundance at the upper sites 3 and 6. *Daphnia spp.* had higher biomass at the lower arm sites (1 and 4) and decreased in biomass towards the upper ends of both arms (Figures 22b-d) in all samples except the first (25 May 1987, west arm) and the last (3 September 1987, east arm). Prior to the application

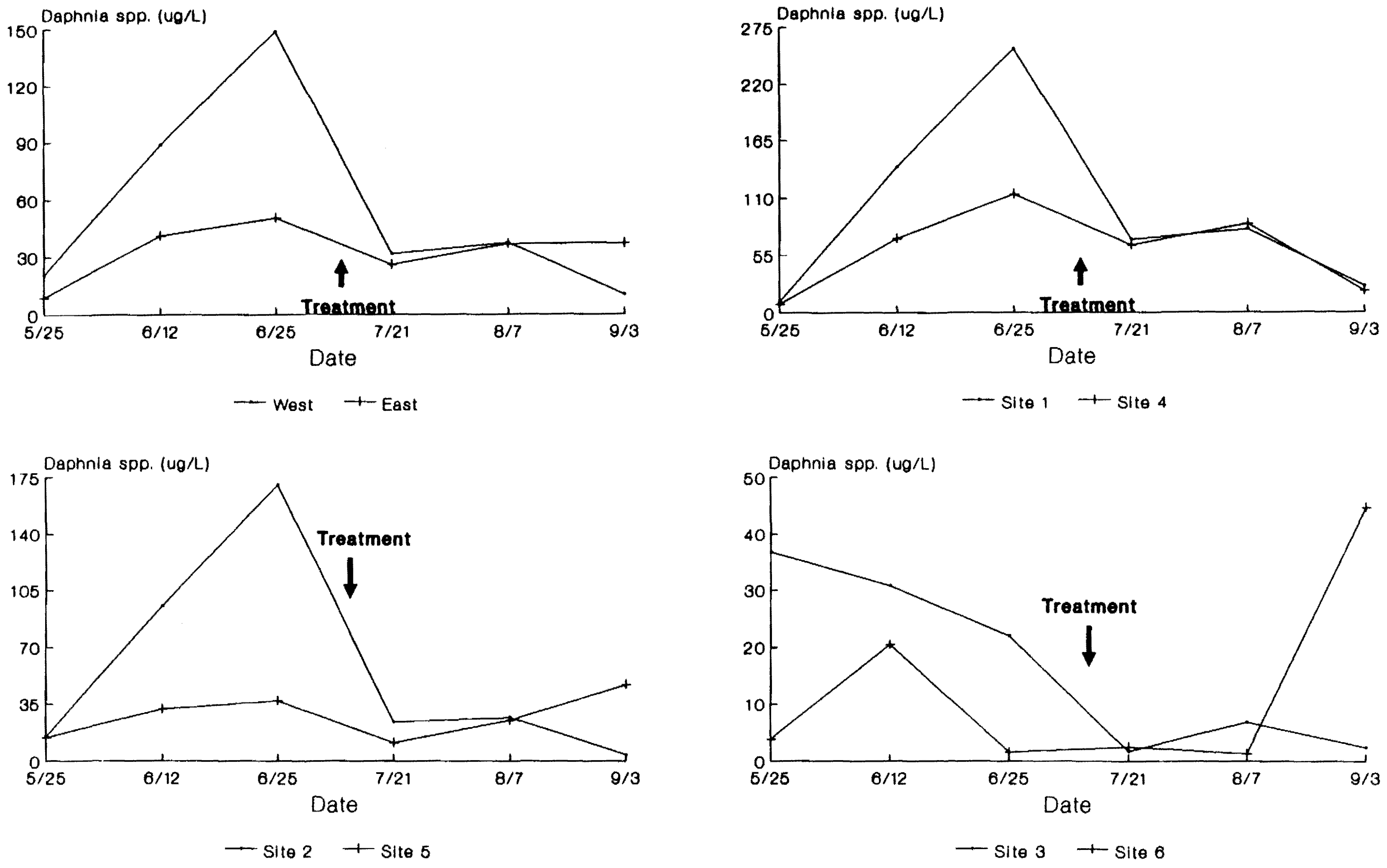


Figure 22. **Daphnia spp. biomass (μg/L) for the west and east arms and the lower, middle, and upper site-specific comparisons.**

of lime, the west arm had higher biomass estimates for all site comparisons. After the application, *Daphnia spp.* biomass was nearly identical at the lower arm sites (1 vs. 4) in all three samples. At the middle and upper sites (2 vs. 5, and 3 vs. 6), *Daphnia spp.* biomass was similar for the 21 July 1987 and 7 August 1987 samples; however, on the 3 September 1987 sample, *Daphnia spp.* had higher biomass at the upper east arm sites (5 and 6) in comparison with the upper west arm sites (2 and 3).

Bosmina spp.

Bosmina spp. was the next most dominant genera in terms of biomass as they comprised 18.5% of the total whole lake zooplankton biomass. In the east arm, *Bosmina spp.* comprised 23.1% (27.5 μg/L) of the total zooplankton biomass in comparison with 14.6% (20.4 μg/L) in the west arm. Whole lake *Bosmina spp.* biomass was highest (155.7 μg/L, east and 92.6 μg/L, west) on the initial sample (25 May 1987), obtaining 86% of its seasonal total on that date, and dropped below 10 μg/L on the second sample and stabilized between 3 and 4 μg/L for the final four samples. After the application of lime, *Bosmina spp.* biomass remained relatively stable in both arms and was similar to the biomass estimate for the sample taken two weeks prior to the treatment. Except for the initial sample, the west arm showed a higher biomass estimate than the east arm for all samples; however, the last two samples were relatively similar for both arms.

The site-specific comparisons for the upper, middle, and lower regions showed an increased *Bosmina spp.* biomass towards the upper sites on the initial sample. After the initial sample, *Bosmina spp.* biomass was so low that a definite pattern was not evident; however, the west arm showed a higher *Bosmina spp.* biomass in nearly all site comparisons for all samples.

Ceriodaphnia spp.

Ceriodaphnia spp. comprised 2.5% of the total whole lake zooplankton biomass. In the east arm, *Ceriodaphnia spp.* comprised 3.9% (4.6 μg/L) of the total zooplankton biomass in comparison with 1.4% (2.0 μg/L) in the west arm. Whole lake *Ceriodaphnia spp.* biomass increased throughout most of the summer in contrast with most of the other zooplankton genera. After the treatment, *Ceriodaphnia spp.* showed an increased biomass for the first two samples and then decreased on the final sample. This pattern was not evident for the arms comparison, primarily the west arm. The west arm showed a relatively steady increase from 29 June 1987 throughout the summer in contrast to the sharp increase and decrease that characterized the east arm.

The site-specific comparisons did not show major differences between the sites at the lower and middle regions. The highest *Ceriodaphnia spp.* biomass was found at the upper sites, most notably in the east arm where biomass reached 39.6 μg/L on 7 August 1987. The patterns displayed at the upper sites are very similar to that already discussed for the arms comparison, except the magnitude was higher.

Copepods

Cyclopoid copepods (adults)

Cyclopoid copepod adults comprised 14.0% of the total whole lake zooplankton biomass. In the east arm, cyclopoids comprised 14.3% (17.0 μg/L) of the total zooplankton biomass in comparison with 13.7% (19.2 μg/L) in the west arm. Whole lake cyclopoid biomass was highest on the first two samples with a maximum of 46.5 μg/L on the 12 June 1987 sample. Whole lake cyclopoid biomass decreased after this maximum and remained between 5 and

15 μg/L for the final four samples. Cyclopoid biomass was similar between both arms for all samples except the 12 June 1987 sample. On this date, cyclopoids were more abundant at sites 1 and 2 in the west arm in comparison with sites 4 and 5 in the east arm.

Cyclopoids did not show major differences in biomass between the upper, middle, and lower regions of the arms, especially after the application of lime. There does not appear to be any significant differences between arms or sites after the application of lime; however, site 6 was higher than site 3 on all but one sample date.

Calanoid copepods (adults)

Calanoid copepod adults comprised 10.9% of the total whole lake zooplankton biomass. In the west arm, calanoids comprised 12.9% (18.1 μg/L) of the total zooplankton biomass in comparison with 8.5% (10.1 μg/L) in the east arm. Whole lake calanoid biomass was highest on the initial sample (35.6 μg/L) and dropped to its lowest level (2.6 μg/L) on 29 June 1987, two weeks prior to the application of lime. After the application, calanoid biomass showed a slight increase. The biomass trends were similar between the two arms on all dates; however, the west arm had a higher biomass in all six samples. The greatest differences in biomass between the two arms were found in the first two samples.

The site-specific comparisons showed that on the 25 May 1987 sample, a large calanoid biomass at site 3 caused the increased west arm biomass estimate and on 12 June 1987, sites 1 and 2 showed increased calanoid biomass levels. The pattern of higher calanoid biomass in the west arm was caused by the increased biomass at sites 1 and 2 in comparison with sites 4 and 5 in the east arm for nearly all samples. The cyclopoids did not show major differences in biomass between upper, middle, and lower arm sites.

Sub-Adults (copepods)

Sub-adult copepods comprised 1.9% of the total whole lake zooplankton biomass. They also comprised 1.9% of the total zooplankton biomass in the east (2.3 μg/L) and west (2.6 μg/L) arms. Whole lake sub-adult copepod biomass was highest on the initial sample and decreased thereafter to a minimum one week after the application of lime. Sub-adult biomass showed either a stabilization or slight increase in the final two samples. The biomass trends were similar between the two arms on all dates; however, the west arm was consistently higher in all but one sample. Upper sites were higher in sub-adult biomass for most samples.

Rotifers

Polyarthra spp.

Polyarthra spp. comprised 4.8% of the total whole lake zooplankton biomass and was the dominant rotifer genera in terms of biomass. In the east arm, *Polyarthra spp.* comprised 5.7% (6.8 μg/L) of the total zooplankton biomass in comparison with 4.1% (5.7 μg/L) for the west arm. Whole lake *Polyarthra spp.* biomass fluctuated without any discernible pattern throughout the summer. After the first two samples, *Polyarthra spp.* was consistently higher in biomass in the east arm and showed greater fluctuations from one sample to the next. The west arm biomass decreased through the 21 June 1987 sample and then showed a slight increase thereafter; whereas, the east arm fluctuated in a more random manner. The site-specific comparisons showed little differences between the lower and middle regions; however, the upper region in the east arm (site 6) displayed a consistently higher biomass from 29 June 1987 throughout the summer in comparison with the upper region in the west arm (site 3) and the other sites.

Conochilus spp.

Conochilus spp. comprised 4.1% of the total whole lake zooplankton biomass. In the east arm, *Conochilus spp.* comprised 5.1% (6.0 μg/L) of the total zooplankton biomass in comparison with 3.2% (4.5 μg/L) in the west arm. Whole lake *Conochilus spp.* biomass showed a maximum (24.3 μg/L) on the initial sample and decreased to relatively low biomass levels (less than 5.0 μg/L) for the remainder of the summer. This pattern was evident for both the east and west arms which showed similar biomass trends. There were no apparent differences between sites and regions with the site-specific comparisons except for the initial sample where *Conochilus spp.* showed increased levels at the middle and upper regions in both arms.

Keratella spp.

Keratella spp. comprised 3.5% of the total whole lake zooplankton biomass. In the east arm, *Keratella spp.* comprised 4.3% (5.1 μg/L) of the total zooplankton biomass in comparison with 2.8% (3.9 μg/L) in the west arm. Whole lake *Keratella spp.* biomass reached a maximum (11.0 μg/L) on the 12 June 1987 sample; however, no discernible biomass patterns were evident throughout the season. The east and west arms comparison showed higher *Keratella spp.* biomass in the east arm on the 25 May 1987 and 12 June 1987 samples and in the west arm on 3 September 1987. These conclusions are supported by the site-specific comparisons as *Keratella spp.* biomass was higher at sites 5 and 6 in comparison with sites 2 and 3 on 25 May 1987 and 12 June 1987 and sites 2 and 3 are higher than sites 5 and 6 on 3 September 1987. The lower region sites were similar for all samples. There does not appear to be any significant biomass differences between upper, middle, and lower regions within the arms.

Ptygura spp.

Ptygura spp. comprised 2.1% of the total whole lake zooplankton biomass. In the east arm, *Ptygura spp.* comprised 2.7% (3.2 μg/L) of the total zooplankton biomass in comparison with 1.5% (2.1 μg/L) in the west arm. As was seen in *Ceriodaphnia spp.*, *Ptygura spp.* whole lake biomass showed a large increase as the summer progressed. Both arms showed similar biomass trends; however, the east arm showed a higher biomass estimate for all three samples taken after the application of lime. The site-specific comparisons showed that the increased east arm biomass levels were primarily due to a higher relative biomass at site 5 over site 2, and to a lesser extent, site 6 over site 3. Other than the high biomass estimates at site 5, there were minimal biomass differences between the regions within the arms.

Asplanchna spp.

Asplanchna spp. comprised 1.4% of the total whole lake zooplankton biomass. In the west arm, *Asplanchna spp.* comprised 2.1% (2.9 μg/L) of the total zooplankton biomass in comparison with 0.7% (0.8 μg/L) in the east arm. *Asplanchna spp.* biomass was dominated by a large relative biomass (30.3 μg/L) found at site 3 on May 7, 1987. *Asplanchna spp.* biomass was similar for the three samples taken prior to the application of lime. After the application of lime, the west arm showed a consistently higher biomass for most samples. The site-specific comparisons showed a consistently higher biomass at sites 1 and 2 in comparison with sites 4 and 5 after the application of lime in addition to the relatively high *Asplanchna spp.* biomass at site 3 on May 7, 1987. A summary of the biomass trends and the post-lime responses is given in Table 10.

Table 10. Summary of the biomass results for the common zooplankton. Included in the results are the responses in the post-treatment samples relative to the pre-treatment samples.

Group	Result	Post-Treatment Response Indicated
Cladocerans	Higher pre-treatment biomass at sites 1 and 2. Absolute biomass decreased in both arms. Relative biomass decreased in the west.	Unlikely
Daphnia spp.	Primarily pelagic. Higher pre-treatment biomass consistently in west arm. Higher biomass at sites 5 and 6 on 9/3/87. Absolute and relative biomass decreased in the west. Relative biomass increased in the east.	Unlikely
Bosmina spp.	Moderately pelagic to littoral. Higher biomass at sites 2 and 3, except on 5/27/87. Absolute and relative biomass decreased considerably in both arms.	No
Ceriodaphnia spp.	Primarily littoral when abundant. Absolute and relative biomass increased in both arms, especially in the east. Highest biomass estimates at site 6.	Unlikely
Copepods	Slightly higher biomass consistently at sites 1, 2, 6. Higher biomass at sites 1 and 2 on 6/12/87. Absolute biomass decreased in both arms. Relative biomass decreased slightly in both arms.	No
Cyclopoid (Adult)	Higher biomass at site 6 on all samples except 5/25/87. Higher biomass at sites 1 and 2 on 6/12/87. Absolute and relative biomass decreased in both arms.	No
Calanoid (Adult)	Higher biomass at sites 1 and 2 consistently. Absolute biomass decreased and relative biomass increased in both arms.	No
Sub-adults	Primarily littoral. Slightly higher biomass consistently in west arm, especially at site 3. Absolute biomass decreased in both arms. Relative biomass increased in the west.	No
Rotifers	Higher relative biomass in the east arm on sample taken immediately after liming.	Unlikely (Positive)
Polyarthra spp.	Higher biomass at site 6 for last four samples. Absolute biomass decreased in both arms. Relative biomass increased in the east.	No
Conochilus spp.	Moderately pelagic to littoral when abundant. Absolute and relative biomass decreased in both arms, especially in the east. Higher relative biomass in the east arm on sample taken immediately after liming.	Unlikely (Negative)
Keratella spp.	Higher biomass at sites 5 and 6 on 5/25/87 and 6/12/87. Higher biomass at sites 2 and 3 on 9/3/87. Absolute and relative biomass decreased in the east. Relative biomass increased in the west.	Unlikely (Negative)
Ptygura spp.	Moderately pelagic. Absolute and relative biomass increased in both arms, especially site 5 in the east. Higher relative biomass in the east arm on sample taken immediately after liming.	Unlikely (Positive)
Asplanchna spp.	Moderately pelagic to littoral. Absolute and relative biomass increased in both arms, especially in the west.	No

Zooplankton density

The dominant zooplankton genera and groups in terms of biomass were not the dominant taxa in terms of density (#/L). The rotifers comprised 71.6% of the whole lake zooplankton individuals sampled. Rotifers comprised 73.5% of all zooplankton individuals sampled in the east arm compared to 69.2% in the west arm. Rotifers were more abundant in the east arm (171 individuals/L) in comparison to the west arm (131 individuals/L). The dominant rotifer genera were *Conochilus spp.*, which comprised 31.6% of the whole lake zooplankton individuals sampled, *Keratella spp.* (19.1%), and *Ptygura spp.* (12.5%). *Conochilus spp.* showed the same abundance pattern as did *Bosmina spp.* as it obtained approximately 75% of its total abundance on the initial 25 May 1987 sample. *Polyarthra spp.* was only the fourth most abundant rotifer genera sampled; however, its large relative biomass compared to the other rotifer species made it the dominant genera sampled in terms of biomass. A summary of zooplankton genera and the copepod group's absolute and relative density estimates before and after the application of lime is given in Table 11.

Zooplankton density versus biomass comparison

Total zooplankton density declined throughout the summer as did biomass; however, density was more similar overall between the east and west arms than was biomass (Figure 23, also see Figure 19). There were no apparent differences in total zooplankton density between the arms prior to or after the application of lime, with the large *Bosmina spp.* found on the initial 25 May 1987 sample taken into account. Average zooplankton size per individual (i.e., total biomass/total density) was less than 1 μg for all dates sampled in the east arm; however, the west arm showed an average size greater than 1 μg on 12 June 1987 (1.22 μg) and 29 June 1987 (1.71 μg) caused by a relatively large *Daphnia spp.* population in the west

Table 11. Mean density estimates and relative abundance of common zooplankton genera and copepod groups for the pre-treatment and post-treatment samples.

	Pre-Treatment				Post-Treatment				Lake $\overline{X}$	
	West		East		West		East			
Group	#/L	Rel. %	#/L	Rel. %	#/L	Rel. %	#/L	Rel. %	#/L	Rel. %
Cladocerans										
Bosmina spp.	31.5	13.8	55.5	17.2	6.1	4.1	2.4	1.7	23.9	11.3
Daphnia spp.	13.1	5.7	5.2	1.6	3.3	2.2	4.3	3.0	6.5	3.1
Ceriodaphnia spp.	0.5	0.2	0.6	0.2	2.1	1.4	4.2	2.9	1.9	0.9
Others	0.4	0.2	0.5	0.2	0.8	0.5	0.5	0.4	0.6	0.3
TOTAL	45.5	19.9	61.8	19.2	12.3	8.2	11.4	7.9	32.9	15.5
Copepods										
Sub-adults	23.0	10.0	20.7	6.4	21.1	14.1	15.4	10.7	20.1	9.5
Cyclopoid (Adult)	5.5	2.4	5.5	1.7	2.0	1.3	3.4	2.4	4.1	1.9
Calanoid (Adult)	3.9	1.7	2.5	0.8	3.4	2.3	2.8	1.9	3.2	1.5
TOTAL	32.4	14.2	28.7	8.9	26.5	17.7	21.6	15.0	27.4	12.9
Rotifers										
Conochilus spp.	88.6	38.7	134.6	41.8	27.6	18.4	16.1	11.2	66.7	31.5
Keratella spp.	37.3	16.3	72.2	22.4	30.7	20.5	21.1	14.6	40.3	19.0
Ptygura spp.	2.8	1.2	2.9	0.9	38.9	25.9	61.4	42.6	26.5	12.5
Polyarthra spp.	11.4	5.0	10.7	3.3	5.1	3.4	7.5	5.2	8.7	4.1
Asplanchna spp.	0.1	0.0	0.3	0.1	3.9	2.6	0.8	0.6	1.3	0.6
Others	10.9	4.8	11.2	3.5	5.1	3.4	4.2	2.9	7.9	3.7
TOTAL	151.1	66.0	231.9	71.9	111.3	74.2	111.1	77.1	151.4	71.5
GRAND TOTAL	229.0	100.0	322.4	100.0	150.1	100.0	144.1	100.0	211.7	100.0

arm on those dates. Differences in the composition of the zooplankton taxa sampled and the average individual sizes influenced the biomass estimates, whereas, the density estimates were unaffected. The average sizes of the cladocerans (i.e., especially *Daphnia spp.*) and copepods (i.e., especially cyclopoids) showed variability between sample dates and within sample sites. The average size of *Daphnia spp.* showed the greatest variability with a low of 2.03 μg calculated for site 6 on 7 August 1987 and a high of 14.79 μg for site 4 on the same date. Average size estimates for cladocerans and copepods for each sample on a site-specific basis are presented in Appendix 13.

Friedman's test failed to reject the null hypothesis of no significant difference in average *Daphnia spp.* size among the upper, middle, and lower arm sites within the west arm; however, the east arm showed a significant difference among sites (west, $P = 0.31$, $N = 6$; east, $P = 0.006$, $N = 6$). The Sign Test concluded that site 4 was significantly different than sites 5 and 6 ($P = 0.016$ for both tests, $N = 6$); however, site 5 was not significantly different than site 6 ($P = 0.109$, $N = 6$). The other cladoceran genera and copepod groups (i.e., even cyclopoids) failed to show significant trends in site-specific average sizes. There was also variability in average sizes between samples as cladoceran genera and copepod groups showed a general pattern of a maximum average size in the late spring to midsummer samples, but a low to minimum average size for the late summer samples.

The variability in average size did not greatly affect the results of the zooplankton genera and copepod group comparisons between arms and specific sites on a biomass basis. *Daphnia spp.*, which showed the greatest variability in average size, showed the same pelagic nature, showed a consistently higher pre-lime density in the west arm, and showed a higher density at sites 5 and 6 on 3 September 1987. The arm and site-specific density comparisons between the cyclopoid adults and the calanoid adults, which also demonstrated relatively high variability in average individual biomass estimates, also yielded similar results as was found for biomass. The variability in average size for sub-adult copepods, *Ceriodaphnia spp.*, and

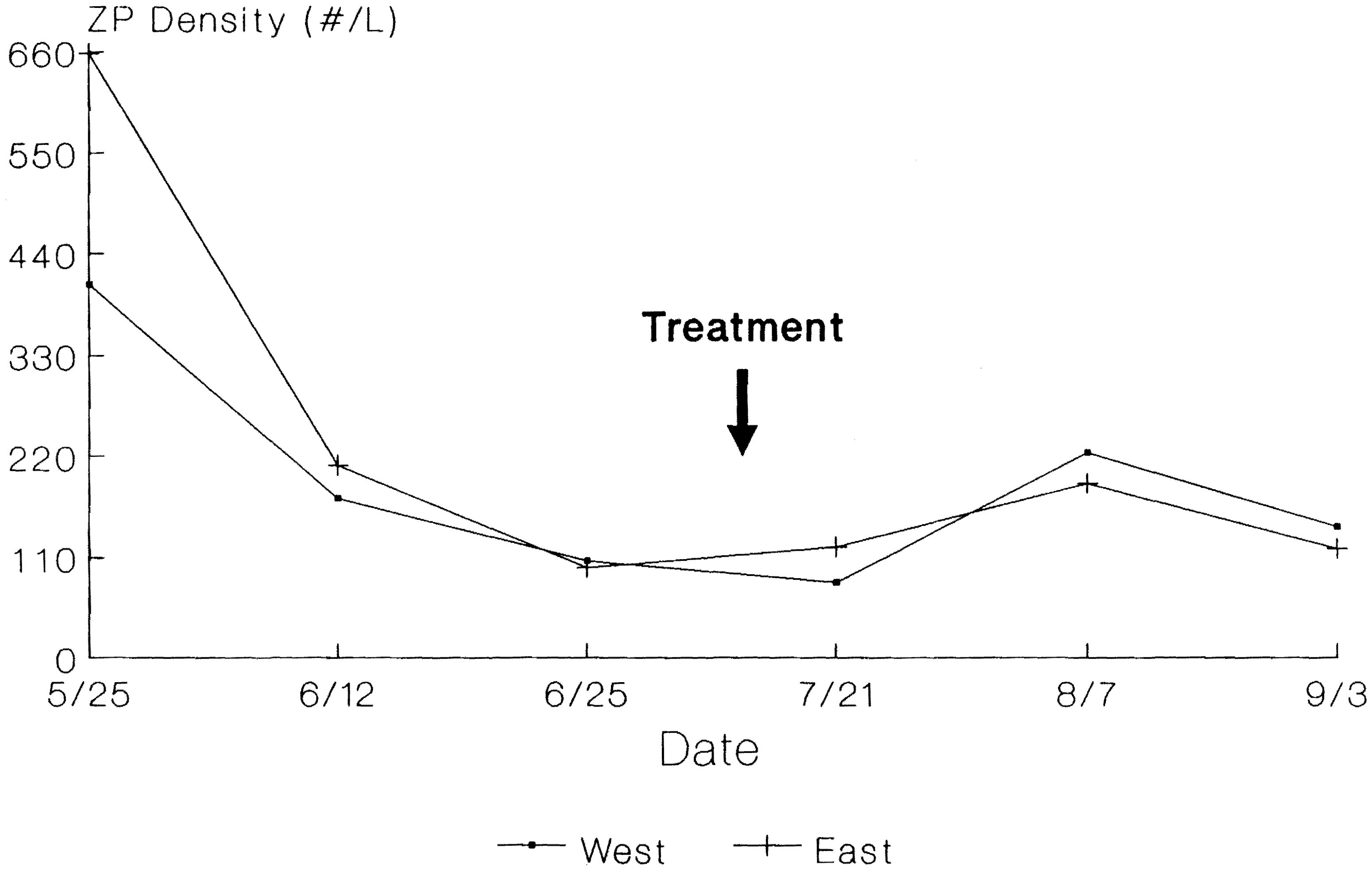


Figure 23. Total zooplankton density (#/L) for the west and east arms. Values are the mean from the 3 sites per arm.

Bosmina spp. were not as great as with the larger zooplankton individuals of *Daphnia spp.* and the other copepod groups. As before, similar pre- and post-treatment conclusions were found with density comparisons. Since a constant weight value was used for each rotifer individual within a specific genera, the results based on the comparisons between arms and sites did not differ on a biomass or density basis.

Young-of-the-year bluegill growth

Young-of-the-year bluegills (15-35 d old) from the west arm grew at an average rate of 0.45 mm/d compared to 0.41 mm/d in the east arm. The null hypothesis of no difference in bluegill growth between the arms was rejected by the Wilcoxon Rank Sum Test ($P = 0.034$; east, $N = 28$ and west, $N = 23$) concluding that the west arm bluegills grew at a faster rate. The graph of the growth rate vs. age data showed higher variability in growth for the relatively younger fish (15-20 d old) for each arm and faster growth for the younger fish in the west arm (Figure 24). Fish were separated into two age classes (15-20 and 21-35 d old) which were tested separately in order to account for possible age-growth interactions. The Wilcoxon Rank Sum Test failed to reject the null hypothesis of no difference in bluegill growth between the arms ($P = 0.597$; east, $N = 18$ and west, $N = 15$) for fish 21-35 d old. For fish 15-20 d old, however, the null hypothesis was rejected ($P = 0.012$; east, $N = 10$ and west, $N = 8$) concluding that the relatively younger fish in the west arm grew at a faster rate than comparably aged east arm fish (Table 12). Fish less than 20 d old in the west arm grew at a rate of 0.50 mm/d compared to 0.41 mm/d in the east arm. Age and growth data for the east arm and west arm bluegills is given in Appendix 14.

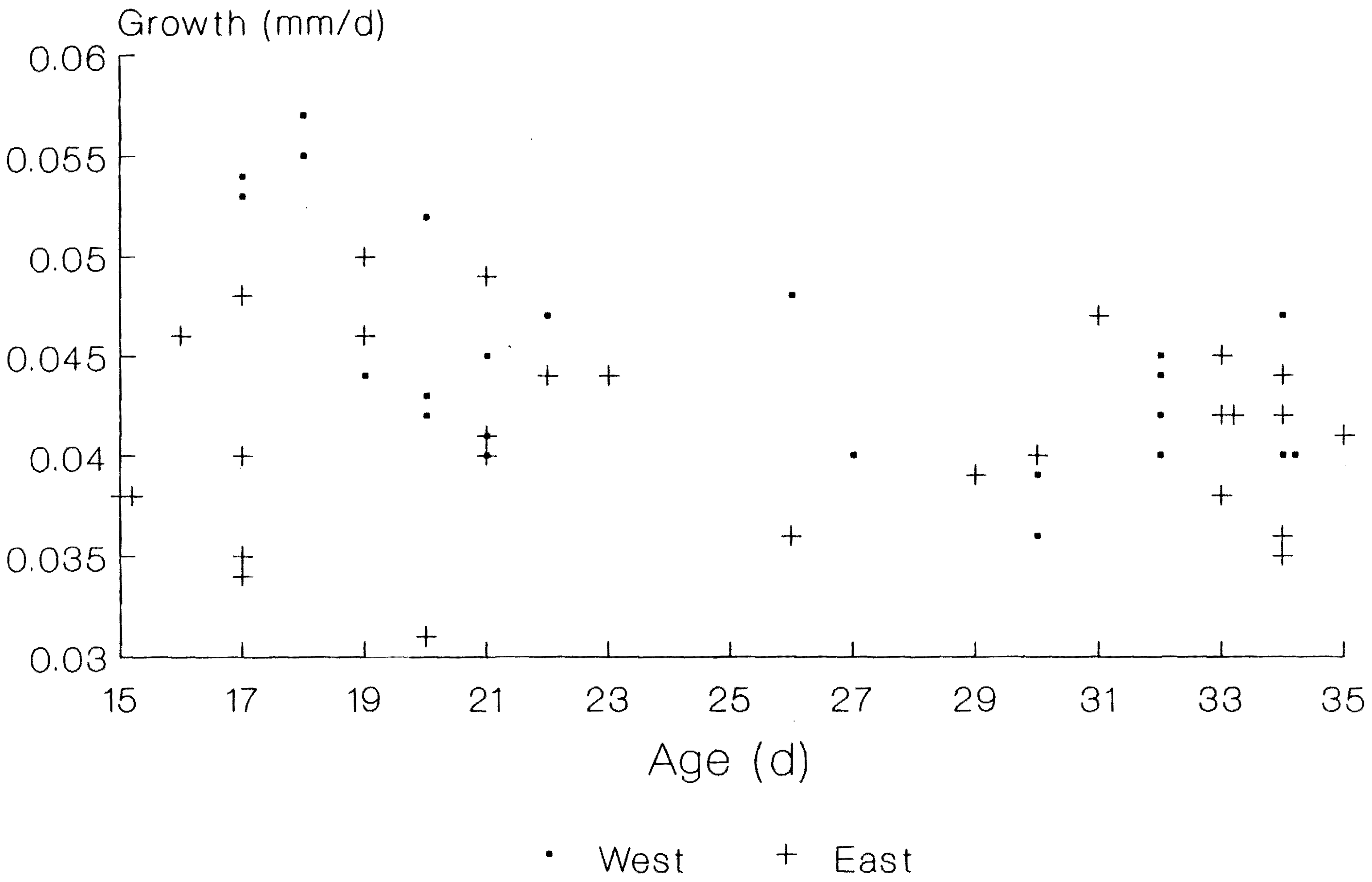


Figure 24. Age (d) - growth (mm/d) plot for YOY bluegill from the west and east arms.

Table 12. Comparison of YOY bluegill mean daily growth rates (mm/d) by age group between the east and west arms for the period when alkalinity was different between the east and west arms with the Wilcoxon Rank Sum Test ($\alpha = 0.05$).

Age Group (d)	Arm	Growth (mm/d)	*N*	*P*
15-35	West	0.45	23	0.034*
	East	0.41	28	
21-35	West	0.42	15	0.597
	East	0.41	18	
15-20	West	0.50	8	0.012*
	East	0.41	10	

Discussion

Although the character of this study was compromised due to the contamination of the west arm with calcite dissolution products within 1 month after liming, other factors were more important in determining lack of response in productivity or species composition in the limed arm. These factors, which are discussed more thoroughly in section 2, were: the inability of the calcite dose to neutralize the east arm sediments, productivity limitation by factors other than dissolved inorganic carbon (DIC), and the relatively high pre-treatment pH. I began the discussion by describing the trophic status and general plankton characteristics of Flat Top Lake which determined the primary factors that influenced the observed phytoplankton and zooplankton biomass levels and seasonal trends and species composition. Information from this section was useful as a basis in determining why the treatment to the east arm of Flat Top Lake was not sufficient to induce biological changes. In addition, trophic status determination and plankton species composition characteristics may prove useful to the Flat Top Lake Owners Association in future eutrophication studies or as baseline data for the evaluation of responses to other future management practices (e.g., grass carp introduction).

Section 1. Flat Top Lake characteristics

Trophic status

Carlson (1977) proposed a trophic state index (TSI) for north temperate lakes that has been widely used because it retains the robustness of multi-parameter indices, yet has the simplicity of single parameter indices. Carlson interrelated commonly used trophic criteria (chlorophyll *a* concentration, total phosphorus concentration, Secchi disk transparency) by a series of predictive equations (e.g., log-transformed bivariate linear regressions between Secchi depth - chlorophyll *a*, chlorophyll *a* - total phosphorus, and chlorophyll *a* predicted Secchi depth - total phosphorus) to form a common scale so that measurements of any of the trophic criteria could be used to determine trophic status. The index was scaled[2] between 0 and 100 with 0 representing extreme oligotrophic conditions (e.g., Secchi disk of 64 m, chlorophyll *a* of 0.04 mg/m^3, total phosphorus of 0.75 μg/L) and 100 representing extreme eutrophic conditions (e.g., Secchi disk of 0.06 m, chlorophyll *a* of 1,183 mg/m^3, total phosphorus of 0.77 mg/L). Wetzel (1983) and Maloney (1979) characterized Carlson's TSI values to correspond to more commonly used trophic status nomenclature (e.g., oligotrophic, mesotrophic, eutrophic, Table 13). Carlson (1977) suggested that, when available, summer chlorophyll *a* should be given priority for the purposes of classification. Flat Top Lake would be classified as oligo-mesotrophic based on mean summer (5 June through 3 September 1987 samples) chlorophyll *a* concentration (2.81 mg/m^3, Table 14), and mesotrophic based on corresponding mean summer Secchi disk transparency (3.29 m, Table 14).

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[2] Each increase of 10 units corresponded to a halving of Secchi disk transparency (m) by transforming Secchi disk values to the logarithm to the base 2 using 64 m as the zero point (i.e., $TSI = 10(6 - \log_2 SD)$).

Table 13. Trophic state categories based on Carlson's TSI (0-100). Ranges adopted from Wetzel (1983) and Maloney (1979).

	Oligotrophic	Mesotrophic	Eutrophic	Hypereutrophic
TSI	≤40	41-50	51-70	>70
Total phosphorus (μg/L)	≤12	13-25	26-99	≥100
Chlorophyll *a* (μg/m^3)	<3	3-7	8-54	>55
Secchi depth (m)	>4	4-2	2-0.5	<0.5

Table 14. Carlson's TSI values (0-100) for Flat Top Lake. Based on the mean summer chlorophyll *a* (mg/m^3), Secchi depth (m), and total phosphorus ($\mu g/L$) samples.

	West			East			West	East
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	$\overline{X}$	$\overline{X}$
Chlorophyll	38.3	40.9	42.7	38.2	39.9	43.0	40.8	40.6
Secchi depth	40.3	43.9	45.7	39.8	42.5	46.2	43.1	42.6
Total Phosphorus[1]		31.2			28.7			

[1] based on samples taken by IS&T (Appendix 10)

Carlson's TSI is most valid in lakes where total phosphorus limits primary productivity and light attenuation is primarily determined by algal biomass (Carlson 1980; Walker 1984). There is "sufficient" evidence to conclude that total phosphorus was the limiting nutrient in phytoplankton primary productivity in Flat Top Lake and that non-algal light extinction, although not excessive, may have also limited productivity. Smith (1982) found that in 127 North latitude lakes, total phosphorus was not exclusively limiting unless a total nitrogen/total phosphorus ratio (TN/TP) greater than 35 was achieved. Flat Top Lake phytoplankton productivity would be considered phosphorus limited (TN/TP = 37.0) based on average (1 m sample) 1987 pre- and post-treatment total nitrogen and total phosphorus concentrations determined by IS&T[3] (Appendix 10). Walker (1984) presented evidence that phytoplankton primary productivity in reservoirs with chlorophyll *a* (mg/m^3) - Secchi disk (m) products less than 10 mg/m^2 was limited by non-algal turbidity and did not show increased productivity at higher nutrient levels. The mean summer (5 June through 3 September 1987 samples) chlorophyll *a* - Secchi disk product for Flat Top Lake was 8.8 (range 5.5 - 10.7), indicating that non-algal light limitation from suspended sediments could have been a factor in addition to phosphorus limitation controlling productivity.

Carlson's TSI prediction for Flat Top Lake based on the mean of the pre- and post-treatment total phosphorus concentrations determined by IS&T (0.005 mg/L) was oligotrophic (Table 14) and lower than what would be expected given the observed chlorophyll *a* and Secchi disk values. Systematic differences among the TSI variables have been shown to indicate specific conditions in a lake (Osgood 1983; Carlson 1983). Lakes that have relatively low total phosphorus TSI values in comparison to chlorophyll *a* and Secchi disk values are oftentimes limited by phosphorus and lakes with relatively higher Secchi disk TSI values relative to chlorphyll *a* values oftentimes have significant non-algal light attenuation (Carlson 1980, 1983). The relationship of the TSI values for Flat Top Lake supports the

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[3] There was a large discrepancy between total phosphorus concentrations between IS&T and VPI&SU samples. Predictions of total phosphorus based on chlorophyll *a* (Carlson 1977) were much closer to the IS&T estimates (Predicted TP = 0.011 $\mu g/L$).

hypothesis that phytoplankton productivity was primarily phosphorus limited and that non-algal turbidity may be a secondary limiting factor. Therefore, differences in phytoplankton biomass and primary productivity rates and Secchi disk transparency between the east and west arms would have been expected in Flat Top Lake if the calcite application significantly influenced either phosphorus concentrations or non-algal turbidity.

Canfield et al. (1983, 1984) discouraged the use of trophic state indicators that are based solely on conditions in the pelagic zone (e.g., algal biomass, water transparency, open-water nutrients) in lakes that have abundant aquatic macrophytes. They developed an alternative trophic state predictor based on the potential water column nutrient concentration which would be obtained by adding the nutrients contained in the macrophytes with those in the water. *Najas spp.* and *Nitella spp.* were the dominant macrophyte species in Flat Top Lake reaching maximum coverage in late summer-early fall in the coves and bays and upper arm areas (Smith 1989). *Najas spp.* covered a maximum of approximately 30 acres (i.e., 13% of lake area) during the 1987 season and grew to a height of approximately 2 m to depths of 2.5 m. *Nitella spp.*, which grew to depths of 4-5 m, had a larger percentage coverage (i.e., a maximum of approximately 20-30% of the lake area) but only grew to a maximum height of approximately 30 cm. Macrophtyes appeared to cover a greater percentage of area in the west arm in relation to the east arm. The required sampling needed to estimate total water column phosphorus (i.e., water column phosphorus + phosphorus contained in the macrophytes) was not made; however, an increase in trophic state classification for Flat Top Lake from the oligo-mesotrophic range to mesotrophic may be warranted for the late summer-early fall period when aquatic macrophytes are considered.

Although Flat Top Lake would be categorized as mesotrophic, the low hypolimnetic dissolved oxygen levels (below 2 ppm) found from mid-summer to the anoxic (i.e., no oxygen) conditions found at the deeper sites (sites 1 and 4) in late summer-early fall are characteristic of eutrophic lakes (Hutchinson 1957; Cole 1983). The east arm of Flat Top Lake showed slightly higher dissolved oxygen concentrations in the hypolimnion than the west arm, probably as a result of the greater mean depth in the east arm (4.09 m, east vs. 3.66 m, west) and a larger relative volume of water contained below the thermocline. Other contributing factors could be higher relative decomposition rates in the west arm as a result of increased macrophyte abundance and higher allochthonous input from the relatively larger and possibly more fertile west arm watershed.

Low hypolimnetic dissolved oxygen levels often leads to increased rates of eutrophication, especially in surface discharge reservoirs (i.e., as opposed to hypolimnetic withdrawal), because of sediment-water interactions that can release large amounts of phosphorus which can become biologically available after thermal stratification breaks down (Hutchinson 1957; Wetzel 1975; Bostrom et al. 1982) It appears that Flat Top Lake acts as a phosphorus sink during thermal stratification and recycles phosphorus at overturn as exemplified by the maximum chlorophyll *a* concentrations occurring in the late fall sample after overturn with the highest values occurring in the pelagic zone of the deepwater areas of the lake (sites 1 and 4). After a relatively high phytoplankton biomass estimate on the 5 June 1987 sample (3.69 mg/m^3), the gradual decline on the next five samples and the significant pattern of higher biomass towards the upper arm sites supports the hypothesis that overall phosphorus availability was decreasing and the upper arm sites which did not experience prolonged stratification had relatively higher phosphorus availability because of recycling from the sediments. Bostrom et al. (1982), in their review of factors and processes which induce phosphorus release from lake sediments, reported that phosphorus release, which is controlled by oxidation-reduction reactions under anaerobic conditions (Mortimer 1941, 1942), can be as high under aerobic conditions. Mechanical mixing, bioturbation, release from live and decaying macrophytes, as well as the possible occurrence of anaerobic microzones in the sediment are all possible causes of increased phosphorus availability (Bostrom et al. 1982) and the associated increased phytoplankton biomass towards the upper arm sites. The increasing trend in phytoplankton biomass measured from 20 July 1987 through the 3

September 1987 sample was probably influenced by the increasing percentage of Flat Top Lake that was not thermally stratified as the thermocline became deeper. The relative stabilization or slight decrease from 7 August 1987 through 1 October 1987 corresponded to the maximum macrophyte production which probably competed with phytoplankton for nutrients. The relatively low sediment phosphorus concentrations (3-8 mg/L, Appendix 11) measured for Flat Top Lake in 1987 indicate that phosphorus loading from the watershed is low and phosphorus does not continually accumulate between years, which is probably a result of the relatively short residence time (0.59 years) and the probable discharge of relatively high concentrations of recycled phosphorus during spring. Evidence of significant nutrient accumulation and subsequent recycling is the appearance of filamentous or planktonic algal blooms (Hutchinson 1967) which did not occur in Flat Top Lake in any appreciable amounts in 1987, although filamentous algae were present in moderate amounts in the wind-protected coves and bays during the 18 November 1987 sample. Eutrophication caused by sedimentation and increased macrophyte growth currently appears to be more of a problem in Flat Top Lake than nutrient enrichment.

Plankton characteristics

The composition of the phytoplankton community in Flat Top Lake was characteristic of an oligo-mesotrophic lake. Based on the phytoplankton associations described by Hutchinson (1967), Flat Top Lake showed characteristics of several of the more oligotrophic associations and a few of the mesotrophic to eutrophic associations. Although four samples were inadequate to determine seasonal succession precisely, in general there was a dominant late spring diatom population that was replaced in dominance by a Chrysophyte/Chlorophyta assemblage in the summer. *Dinobryon spp.*, represented by a net plankton and nannoplankton form, and the colonial green algae, *Gemellicystis spp.* and *Gloeocystis spp.*, were the dominant genera.

The abundance of certain phytoplankton types in Flat Top Lake were characteristic of lakes that are nutrient limited. *Dinobryon spp.* is a characteristically dominant species in unproductive lakes, but can also be abundant in eutrophic lakes under low nutrient conditions often found during summer stratification (Hutchinson 1967; Sondergaard and Jensen 1986). The ratio between species number of centric and pennate diatoms increases with increasing degree of eutrophy (Nygaard 1949). Although diatom species were not identified, the abundance of centric diatoms decreased substantially from the initial sample to the final sample as pennate diatom abundance remained relatively stable between the second through final sample which may have been an indication of declining nutrient availability.

The ratio of calanoid to cyclopoid copepods has also been used as a predictor of trophic status with a low ratio indicative of more eutrophic conditions and a high ratio indicative of more oligotrophic conditions (Gannon and Stemberger 1978). The ratios for the six zooplankton samples taken at Flat Top Lake showed an increasing trend (i.e., more calanoids) towards the fourth (21 July 1987) and fifth (7 August 1987) samples and then a decline on the final sample (0.77, 0.42, 0.43, 1.35, 1.92, 0.82) which corresponds with the hypothesis of nutrient depletion (i.e., seasonal oligotrophication) occurring during thermal stratification and subsiding in September-October (i.e., increasing nutrient availability).

The seasonal patterns in phytoplankton and zooplankton biomass in Flat Top Lake appeared to simulate a herbivore-plant oscillation (Figure 25), assuming a high phytoplankton biomass in the spring, which is characteristic of temperate lakes (Hutchinson 1967). Peak zooplankton grazing rates have been estimated as high as 600% of the daily primary production (Bosselmann and Riemann 1986), which can reduce phytoplankton biomass and/or influence species composition (Porter 1977). The general trend of high *Daphnia spp.* biomass at low chlorophyll *a* concentrations (Figure 26) suggests that *Daphnia spp.*, which have relatively high filtering rates (Porter 1977; Bosselmann and Riemann 1986), should also be considered a limiting factor for phytoplankton biomass. The increase in phytoplankton biomass observed from mid-summer to fall, however, did not correspond to a measurable increase in zooplankton biomass which may have been a result of a decline in algal food quality (e.g., *Anabaena spp.*, *Staurastrum spp.*, and the colonial green algae *Gemellicystis spp.* and *Gloeocystis spp.*) or an increased reliance on an alternate food source (e.g., bacteria). Seasonal patterns in Flat Top Lake were similar to other temperate lakes, which characteristically show a dominant cladoceran and copepod abundance in early summer, followed by declines in mid-to-late summer and an increase in the relative percentage of rotifers in mid-to-late summer because of a greater reliance on bacteria as a food source or an increase in very small phytoplankton species (e.g., ultraplankton - 0.5 to 10 μm, Wetzel 1975) and increased predation pressure on planktonic crustaceans by fish and *Chaoborus spp.* (Pace and Orcutt 1981). Pelagic bluegill larvae were most abundant from mid-June to mid-July (catch indices not determined; based on general observations from tow samples) which was the period when total zooplankton biomass (especially *Daphnia spp.*, and to a lesser extent copepods) also declined. The lack of suitable planktivorous fish abundance estimates in conjunction with zooplankton biomass decreases the ability to conclude a significant "top-down" effect on zooplankton community composition and biomass (Mills et al. 1987).

Section 2. Responses

Calcite dissolution

Calcite dissolution results in an increase in total alkalinity, ANC, pH, and Ca^{2+} concentration (Boyd 1979). Sverdrup (1986) described the dissolution of calcite particles in water as a "heterogeneous solid-liquid reaction" which was controlled by diffusion with the dominant chemical reactions being:

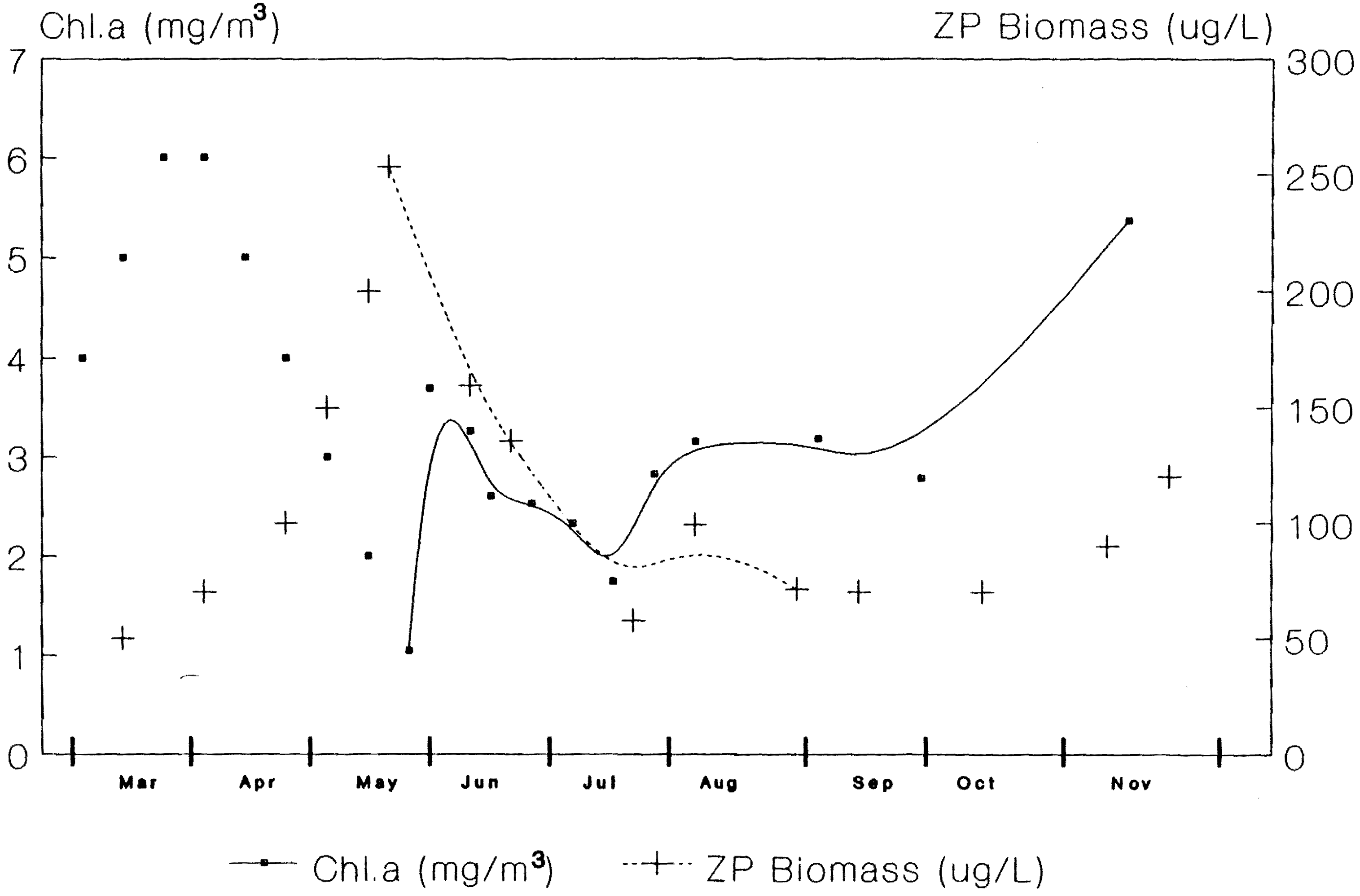

Figure 25. Estimated seasonal phytoplankton biomass (mg chl.a/m^3) and zooplankton biomass (μg/L) trends for Flat Top Lake, 1987.

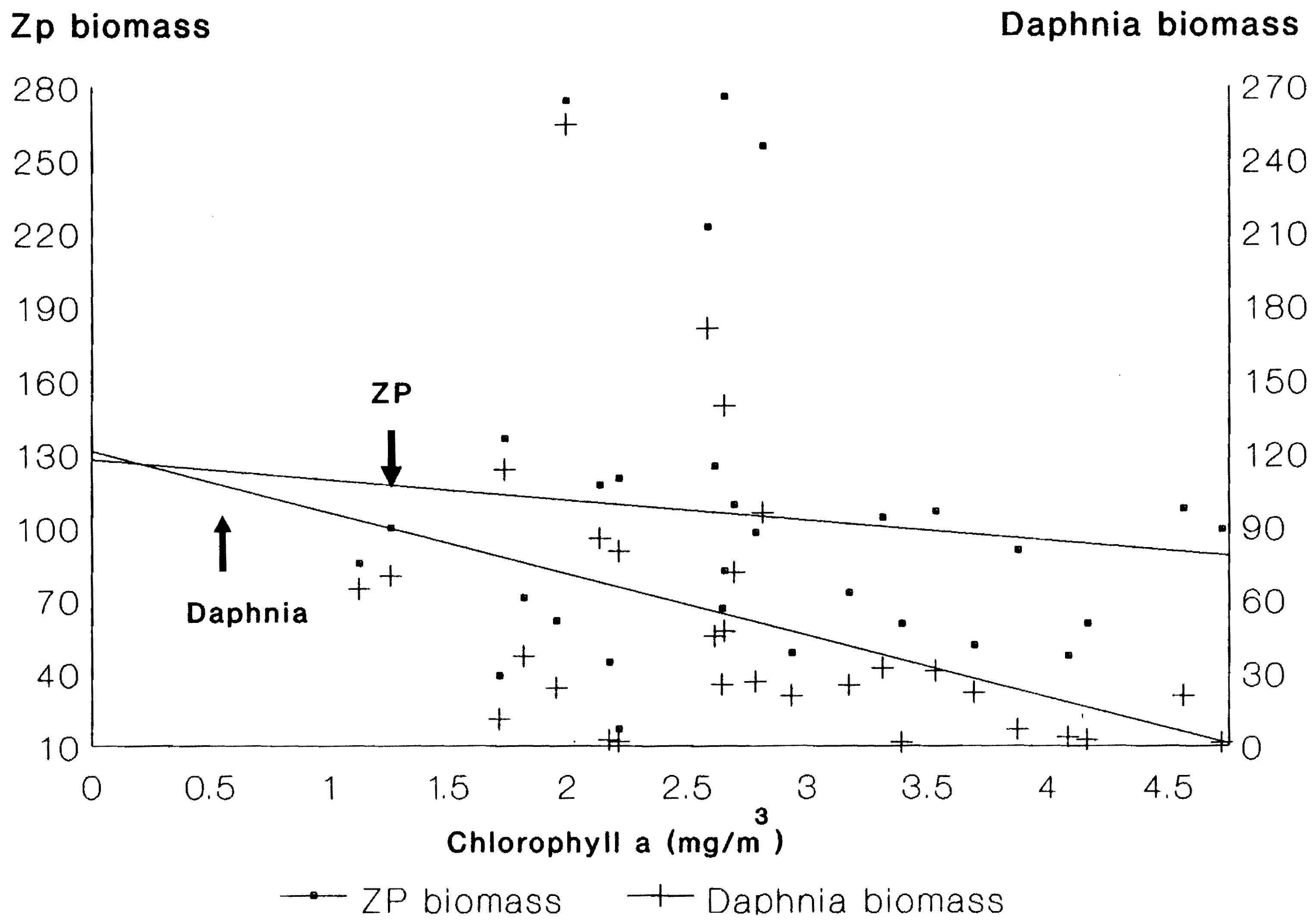

Figure 26. Zooplankton and Daphnia spp. site-specific biomass (µg/L) vs. chlorophyll a (mg/m^3) trends.

$$CaCO_3 + H^+ = Ca^{2+} + HCO_3^- \quad (1)$$

$$CaCO_3 + H_2O + CO_2 = Ca^{2+} + 2HCO_3^- \quad (2)$$

$$CaCO_3 + H_2O = Ca^{2+} + HCO_3^- + OH^- \quad (3)$$

however, equation (3) dominates at pH values of 6.5 or higher (as in Flat Top Lake). The dissolution efficiency of calcite particles is determined primarily by the particle size distribution, the initial pH of the water, the sinking depth, and the degree of wet slurrying prior to the application (Saunders et al. 1985) which can increase dissolution efficiency by as much as 40% (Sverdrup 1983).

The predicted initial dissolution efficiency of 41% by the DeAcid model was not obtained in Flat Top Lake because of a higher than expected pH prior to the treatment (pH = 7.07, 10 July 1987) and a relatively large particle size distribution for the calcite. Mean calcite particle size used at Flat Top Lake was 45 μm, whereas, mean calcite particle size was less than 20 μm for the other 21 lakes limed by LLI in 1986-1987 (Adams and Brocksen 1988). Based on the method of Sverdrup and Warfvinge (1988), the Flat Top Lake initial dissolution efficiency was approximately 8%. A post-lime pH of 7.07, mean depth of 4.09 m, and a particle size distribution that corresponded to material sieve curve #6 was used for the determination. Initial dissolution would have been highest in zone 1 (approximately 10%) and lowest in zones 2 and 4 because of depth differences[4]. Adams and Brocksen (1988) reported an initial average dissolution efficiency of 10.2% for Flat Top Lake. IS&T (1987) estimated the dissolution efficiency at the time of the post treatment sample (19 August 1987) between 14-30%

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[4] Initial dissolution efficiencies could not be extrapolated from the graph (Sverdrup 1988) for zones 2 and 4 because the adjusted pH was off the scale

depending on the degree of calcite diffusion from the east arm (e.g., 14% if calcite was contained entirely in the east arm and 30% if evenly mixed throughout the lake). The alkalinity trends analysis supported total mixing; however, the entire lake did not have similar alkalinity until the 3 September 1987 sample. The dissolution percentage was probably slightly less than 30% at the time of the IS&T post-treatment sample. Pre- and post-treatment Ca^{2+} concentrations estimated by IS&T (Appendix 10) supported the conclusions from the alkalinity trends analysis. Ca^{2+} concentrations increased by 1.47 mg/L at site 5, 1.18 mg/L near the outlet, and 0.6 mg/L at site 2 in the post-treatment sample (19 August 1987) relative to the pre-treatment sample (31 March 1987). The higher relative increase near the outlet compared to site 2 (west arm) suggested that calcite diffusion downstream was faster than into the west arm. Ca^{2+} concentration for the hypolimnion post-treatment sample near the outlet was lower than the epilimnion concentration (7.91 mg/L, epilimnion vs. 6.72 mg/L, hypolimnion) and similar to the pre-treatment Ca^{2+} concentration (6.73 mg/L, pre-treatment vs. 6.72 mg/L, post-treatment). This suggests that calcite diffusion occurred above the hypolimnion only. Because epilimnetic alkalinity did not show a decline in the east arm after the treatment, suggests that residual calcite particles that reached the sediment in non-stratified areas and possibly calcite particles suspended above the thermocline provided additional HCO_3^- to the east arm to maintain alkalinity during diffusion to relatively lower alkalinity areas.

A maximum sediment dose of 0.97 tonnes/ha (864 lb/acre) reached the east arm sediments (IS&T 1987). Slightly less than 20% of the sediment dose dissolved into the water by 19 August 1987 based upon the initial dissolution efficiency of 10.2% (Adams and Brocksen 1988) and the estimated dissolution percentage slightly less than 30% by 19 August 1987 (IS&T 1987). The simplified reacidification model of Sverdrup and Warfvinge (1985) predicted it will take a minimum of 2.5 years for Flat Top Lake to exhaust its sediment buffer capacity based on the mean hydraulic residence time (0.59 years) and sediment dose (approximately 1 tonne/ha). The model was developed from several Swedish limed lakes (pre-treatment pH less than 6.0) and is applied to estimate reacidification time to pH 6.0. Although Flat Top Lake pH has been periodically recorded between 5.5-6.0 (WV Department of Health data, Figure 3a), pH values are usually in the 6.4-7.0 range; therefore, residual calcite dissolution rate is expected to be much less in Flat Top Lake than in the Swedish lakes that this model was developed from. Residual calcite deactivation from humus and metal precipitation is not expected to be as high in Flat Top Lake than in the Swedish lakes that have higher dissolved metal and organic acid concentrations (deactivation usually occurs within 3 years, Sverdrup and Warfvinge 1985); however, the relatively higher sediment inputs from the Flat Top Lake watershed can deactivate residual calcite. The 2.5 year estimate can only be thought of as a rough approximation. Comparison of alkalinity (or ANC) values between the middle-to-upper east and west arm areas within a week to two weeks after periods of high discharge (e.g., spring snowmelt or after very heavy thunderstorms) may indicate whether the east arm residual calcite dose is providing a water column buffering source.

Phytoplankton

An increase in phytoplankton productivity and biomass was hypothesized for the east arm of Flat Top Lake after the application of lime. Liming induced increases in the supply of photosynthetically available carbon, because of higher bicarbonate (HCO_3^-) alkalinity, and phosphorus concentration, were thought to be the primary factors which would have caused the hypothesized increase. Based upon the treatment characteristics and the pre-treatment conditions at Flat Top Lake, the possibility of increased phosphorus concentration and carbon limited primary productivity will be discussed. Failure of the treatment to cause an increase in phosphorus concentration was the primary factor that no increase in phytoplankton productivity and biomass was detected in the east arm. The significance of calcite diffusion into the west arm as a confounding factor, improvements in the study design, the immediate effects of the treatment on phytoplankton productivity and biomass, and the effects of the treatment on phytoplankton community composition and lake transparency will also be discussed.

Phosphorus

The effect of liming acidified lakes on total phosphorus concentration has received attention because of its role in the rapid restoration of phytoplankton productivity and biomass to pre-acidification levels (Scheider and Dillon 1976; Fraser et al. 1985). In most studies, the phytoplankton response has followed the phosphorus response (Fraser et al. 1985). In liming projects when post-liming fertilization did not occur, neutralization of acidic bottom sediments by residual liming materials has been shown to be the major factor influencing post-liming total phosphorus concentration because of a pH-induced increase in the availability of phosphorus from the sediments (Boyd 1979), and/or a pH-induced increase in microbial activity and nutrient mineralization (Pamatmat 1960), and/or a release of nutrients from organic rich sediments because of ion-exchange processes involving Ca^{2+} (Neess 1948). Flat Top Lake was primarily phosphorus limited with acidic sediments of low fertility (mean pre-treatment sediment pH was 5.55 and sediment total phosphorus concentration was 3-8 mg/L, Appendix 11); therefore, only moderate relative increases in total phosphorus concentrations and phytoplankton levels in the east arm would have been expected if neutralization of the east arm sediments were achieved with the dose applied.

Because only the east arm received a sediment dose, the contamination of the west arm water column with calcite dissolution products did not greatly affect the determination of phytoplankton biomass responses induced from sediment derived phosphorus. However, because of thermal stratification patterns, the Wilcoxon Signed Rank Test ($P = 0.834$, $N = 6$) for the sites 3 vs. 6 comparison was the most applicable test for concluding whether phytoplankton biomass increased in the east arm because of increased levels of sediment derived phosphorus. Because the middle and lower arm sites in the east arm did not show higher phytoplankton biomass levels relative to the middle and lower west arm sites after thermal stratification subsided, no significant release of phosphorus from the sediments was induced by the treatment.

The objectives of the liming operation and the subsequent methodology used, in addition to site-specific sediment characteristics, determine whether or not phosphorus concentrations and productivity will increase after liming. Historically, the purposes behind liming lakes susceptible or damaged by acidic deposition and fish production ponds have differed. Evidence suggests calcite that reaches acidic sediments is oftentimes reduced in its ability to provide an additional buffer source because of precipitation of metals and humates that coat the calcite particles, adsorption onto clay and organic matter particles, and factors related to the hydrodynamics of calcite dissolution (Sverdrup 1983; Sverdrup and Warfvinge 1985; Fraser et al. 1987). Molot et al. (1985) suggested that using small particle sizes, dispersing the calcite over as large an area as possible, and slurrying to separate particles increased the cost-effectiveness of a liming operation. Most of the liming operations conducted in southern and western Sweden have used this approach which is designed to maximize the immediate dissolution of the calcite and to minimize the amount of undissolved calcite that reaches the sediments (National Fisheries Board of Sweden 1982). In contrast, liming rates for Southeast United States fish ponds are calculated based upon the pH of the sediment, the associated base unsaturation value, and the total exchange acidity of the sediments in order to increase the effectiveness of a fertilization program (Boyd 1974, 1976; Boyd and Cuenco 1980; Pillai and Boyd 1985). In general for Alabama ponds, enough limestone to raise the pH of the sediment to approximately 6.0-6.5 is recommended by this method, and, Boyd and Scarsbrook (1974) reported significantly higher soluble orthophosphate concentrations in limed ponds when the limed and unlimed ponds were fertilized at identical rates. Fish production in fertilized ponds as a result of liming has improved between 25-100% in reported studies (Snow and Jones 1959; Hickling 1962; Arce and Boyd 1975). Limestone is generally applied in dry form to fish ponds because a high water column dissolution percentage is not the primary goal for this type of liming operation.

The treatment methodology for the Flat Top Lake liming operation more closely resembled liming projects for acidified environments. The primary objective of the Flat Top Lake liming operation was to increase water column alkalinity in the east arm by 10 mg/L. Neutralization of the acidic bottom sediments was not an objective; therefore, pre-treatment sediment sampling to determine the amount of calcite needed to neutralize the sediments was not conducted. Flat Top Lake mean pre-treatment sediment pH was 5.6 for the west arm sites sampled and was 5.5 for the east arm sites. Based upon a simplified table of lime requirements for pond sediments of various pH's (Boyd 1982), between 3200-4800 lb/acre of $CaCO_3$ would be recommended if the texture of the Flat Top Lake sediments (for a sediment pH of 5.1-6.0) were composed of heavy loam or clays, 1600-3200 lb/acre if sandy loam, and 800-1600 lb/acre if sand. The acidic, low fertility sediments in Flat Top Lake probably resembled the sandy loam more closely than the other types which would make the maximum estimated sediment dose of 864 lb/acre for the east arm well below what would be recommended. The post-treatment sediment pH values in the east arm were actually lower (mean pH = 5.3) than the pre-treatment sediment pH values at the same sites. Therefore, no fertilization effect due to sediment phosphorus release or increased microbial decomposition rates could have been expected for Flat Top Lake. A lime application two-to-four times the actual dose would have been needed for sediment neutralization and possible phosphorus release.

Dissolved inorganic carbon

The hypothesized increase in phytoplankton productivity and biomass in the east arm due to an increased supply of photosynthetically available carbon from calcite dissolution assumed that Flat Top Lake phytoplankton productivity would be carbon limited. It will be shown that phytoplankton photosynthesis in Flat Top Lake did not achieve high enough rates to deplete the available supply of carbon in the unlimed arm because of limitation by other factors which were previously discussed (e.g., primarily phosphorus concentration, and to some extent non-algal turbidity, zooplankton grazing, and macrophyte abundance).

Carbon dioxide (CO_2) and bicarbonate (HCO_3^-) are the forms of carbon utilized by phytoplankton during photosynthesis (Ruttner 1963; Hutchinson 1967). There are two routes by which phytoplankton can obtain carbon from HCO_3^- (Ruttner 1963; King 1970):

1. the dissociation of HCO_3^- to give CO_2,

2. direct uptake of HCO_3^- by the phytoplankton where CO_2 is then extracted.

However, direct uptake of HCO_3^- is important only at very low CO_2 concentrations (less than 0.2 μmol/L), indicated by a pH of 8.6 or higher (Lund 1970; Arce and Boyd 1975; Reynolds 1984). The maximum post-treatment pH of Flat Top Lake was 7.44 (site 5 on 24 July 1987); therefore, direct utilization of HCO_3^- was not necessary for Flat Top Lake phytoplankton. Although higher rates of primary productivity and phytoplankton biomass have been achieved when HCO_3^- concentrations were increased by liming Southeastern United States fish ponds, nutrient concentrations were also increased which promoted CO_2 depletion (Thomaston and Zeller 1961; Arce and Boyd 1975; Boyd 1979); this did not occur in Flat Top Lake.

Carbon dioxide limitation has also been demonstrated in water bodies that have had sufficient nutrients to allow photosynthetic uptake of CO_2 at rates higher than can be re-supplied by atmospheric diffusion, respiration, and dissociation of HCO_3^- (King 1970; Reynolds 1984). Highly eutrophic water bodies (Schindler and Fee 1973; Burris et al. 1981; Cohen et al. 1982) and low alkalinity lakes and ponds with relatively high nutrient concentrations (Schindler and Fee 1973) are most likely to demonstrate this effect. Flat Top

Lake total phosphorus concentrations estimated by IS&T (e.g., 5-7 μg/L, Appendix 10) was slightly below the levels King and Garling (1986) estimated to cause a significant photosynthetic reduction of CO_2 concentration. Based upon the difference between observed total phosphorus concentrations and those needed to increase productivity to the point where CO_2 concentrations declined substantially, it is conceivable that a calcite dose large enough to neutralize the east arm sediments could have increased phosphorus levels enough to make the east arm of Flat Top Lake demonstrate CO_2 limitation.

Study design flaws and the effect of calcite diffusion

Based upon the hypothesis of increased phytoplankton productivity and biomass in the east arm after liming because of increased levels of dissolved inorganic carbon (i.e., a larger potential supply of CO_2 from dissociation and extractiom), the study design erroneously assumed that pre-treatment nutrient levels in Flat Top Lake were high enough to allow phytoplankton photosynthetic depletion of CO_2, which would have given the limed arm a post-treatment advantage (assuming no diffusion of calcite dissolution products). Given this, the diffusion and contamination of the west arm with calcite dissolution products had little effect on the results of the study. If a larger calcite dosage were applied to the east arm and a significant increase in east arm total phosphorus concentration was obtained, the design would have still been flawed with respect to the hypothesis of increased levels of dissolved inorganic carbon enhancing phytoplankton gross productivity because nutrient conditions would not have been similar between the two arms. Because of the low pre-treatment nutrient conditions and adequate supply of available carbon in Flat Top Lake, the only justifiable test between the limed and unlimed arms would have been increased phytoplankton productivity and biomass based on an increase in sediment derived total phosphorus concentration in the east arm. A higher sediment dose, more extensive pre- and post-treatment sediment and reliable total phosphorus sampling, more intensive post-treatment phytoplankton biomass and productivity sampling at the unstratified sites and at the stratified sites after fall and spring overturns would be recommended. The best design with respect to the dissolved inorganic carbon hypothesis would have been to treat the east arm with enough calcite to maximize total alkalinity without neutralizing the east arm sediments and allowing phosphorus release, somehow restrict calcite diffusion into the west arm (probably impossible given Flat Top Lake's hydrological and recreational characteristics) or at least intensify post-treatment sampling in the west arm areas farthest away from the east arm, and apply fertilizer at identical rates between the east and west arm.

Immediate post-treatment effects on phytoplankton

Phytoplankton biomass and productivity has been shown to decrease immediately after liming in many studies for a variety of reported reasons (Scheider et al. 1975; Wilcox and DeCosta 1984; Brettum and Hindar 1985). Bukaveckas (1988, 1989) reported a 50% reduction in chlorophyll *a* concentrations and very low primary productivity rates (as measured by the C^{14} technique, Vollenweider 1969) after liming two acidic ($pH < 5.5$) Adirondack mountain lakes. The decline was attributed to CO_2 limitation because calcite dissolution, utilizing CO_2 in the reaction (equation 2, page 101), exceeded the rate of CO_2 diffusion from the atmosphere. The pre-treatment phytoplankton community in these lakes were replaced by a post-treatment community that was more efficient at extracting CO_2 from HCO_3^-. Flat Top Lake chlorophyll *a* concentration declined 27% in the east arm between the last pre-treatment sample (10 July 1987) and the first post-treatment sample (20 July 1987); however, the post-treatment increase in pH of only 0.3 units one week after the treatment in the east arm, indicating very little CO_2 utilization during dissolution, and equivalent reductions in chlorophyll *a* concentrations in the west arm immediately after the treatment, suggests non-liming related factors caused the decline.

Phosphorus precipitation in association with metals, primarily aluminum ($ALPO_4$) but also iron hydroxide, has also caused declines in phytoplankton productivity and biomass immediately after liming (Dickson 1978; Hasselrot and Hultberg 1984; Broberg 1984). Dissolved aluminum levels, measured by IS&T (Appendix 10), were considerably lower in Flat Top Lake (ranged from 1-13 μg/L) than in more acidic lakes which often have aluminum concentrations as high as 700 μg/L or more (Hasselrot and Hultberg 1984). Flat Top Lake aluminum concentration, however, did show a reduction in the post-treatment sample (2 μg/L, 19 August 1987) in the limed arm relative to the pre-treatment sample (13 μg/L, 31 March 1987) with a concurrent relative increase in aluminum concentration in the unlimed arm in the post-treatment sample (4 μg/L, pre-treatment vs. 6 μgL, post-treatment). It is conceivable that a small amount of phosphorus may have been lost due to abiotic precipitation in the east arm, but evidently not enough to significantly reduce phytoplankton biomass in the east arm relative to the west arm. Broberg (1984) reported that at a pH of 7.2 (within the range of pH values at Flat Top Lake), phosphorus removal is mainly attributed to aluminum-phosphorus precipitates. The site-specific post-treatment chlorophyll *a* comparison between sites 1 vs. 4 ($P = 0.295$, $N = 6$) would have been the most valid test since thermocline formation during four of the six post-treatment samples would have made precipitated phosphorus unavailable until possibly at fall turnover.

Phytoplankton composition

Acid-tolerant phytoplankton species that can survive under characteristically low nutrient conditions (e.g., *Gymnodinium spp.* and *Peridinium spp.*, Dinophyceans) are usually replaced by Chrysophytes, diatoms, and Chlorophytes after neutralization of acidic lakes (Fraser et al. 1985); however, in category 4 lakes (i.e., fish present and reproducing, slightly acidic waters, Fraser et al. 1985), the dominant genera prior to liming are usually the dominant genera after liming (Yan and Dillon 1984; Blouin et al. 1984). Based on only two post-treatment samples, there were no strong indications of significant changes in the dominant net phytoplankton (larger than 80 μm) or nannoplankton genera (less than 80 μm, however, most genera were less than 10-15 μm) for the east arm relative to the west arm; however, when alkalinity was relatively higher in the east arm (21 July 1987), several nannoplankton genera were more abundant in the east arm and on the 3 September 1987 sample, the blue-green *Anabaena spp.* was more abundant in the west arm. The only detected liming related difference (within 1 month after the treatment) between the east and west arms that could possibly have caused a change in the east arm phytoplankton community was the east arm received the physical treatment and a relatively faster increase in alkalinity. The total and relative concentrations of the DIC forms (e.g., CO_2, HCO_3^- , and carbonate CO_3^{2-}) has been shown to significantly influence phytoplankton species composition; however, only at pH values lower ($pH < 6.0$) and higher ($pH > 7.5$-8.0) than those measured for Flat Top Lake (King 1970; King and Garling 1986; Williams and Turpin 1987; Bukaveckas 1988, 1989). A much larger relative difference in post-treatment pH values between the east and west arms would have been necessary to consider observed differences in phytoplankton species composition between the east and west arms as something other than sampling variability or related to non-liming factors.

Transparency

The effects of liming on water transparency has shown variable responses (Fraser et. al 1985). In Flat Top Lake, transparency increased in the limed arm relative to the unlimed arm ($P = 0.036$, $N = 6$). For liming projects in unfertilized, non-dystrophic systems, decreases in transparency have been attributed to increases in nannoplankton (Hultberg and Andersson 1982), a decrease in humus precipitation (Dickson 1980; Hultberg and Andersson 1982; Hornstrom and Ekstrom 1985), and release of organic materials from the sediments (Dickson 1980; Hasselrot et al. 1984). Increases in transparency have been attributed to precipitation of dissolved organic carbon (DOC, Driscoll et al. 1982, Fraser et al. 1985). Although Marcus

(1988) reported that DOC tended to be greater in the post-treatment samples relative to the pre-treatment samples for lakes in the LLI program, Flat Top Lake showed a decline in DOC for both the east and west arms in the post-treatment sample relative to the pre-treatment sample (Appendix 10). The east arm had a higher post-treatment DOC concentration relative to the west arm (2.14 mg/L, east vs. 1.99 mg/L, west); therefore, liming induced precipitation of DOC is not a viable hypothesis explaining why post-treatment transparency was higher in the east arm.

The significant increase in post-treatment transparency in the east arm relative to the west arm mainly occurred in sites 4 and 5 rather than 1 and 2. Based upon Secchi disk transparency and chlorophyll *a* - Secchi disk products, the most "parsimonious" explanation is that non-algal turbidity increased in the west arm due to watershed input of sediments. Secchi disk transparency was higher at site 2 vs. site 5 for all six post-treatment samples and site 1 was higher than site 4 in only four of six samples, possibly because of some sedimentation prior to site 1. The mean post-treatment chlorophyll *a* - Secchi disk products were lower at site 2 (9.46) vs. site 5 (10.52) and at site 1 (9.59) vs. site 4 (10.02) indicating relatively higher non-algal turbidity at sites 1 and 2.

Zooplankton response

In general, significant post-liming zooplankton responses have only been reported in category 3 and lower category lakes (Fraser et al. 1985). Increases in abundance have been attributed to a more favorable pH, a decrease in metal toxicity (Hasselrot et al. 1984), and an increase in the food supply (e.g., phytoplankton, detritus, and bacteria, Eriksson et al. 1983). Decreases in abundance have been attributed to rapid increases in pH and reduced phytoplankton abundances immediately after liming (Yan and Dillon 1984; Schaffner 1989) and increased fish predation (Henrikson et al. 1984; Yan 1985). Fraser et al. (1985) reported very little quantitative information was available on zooplankton responses after liming category 4 lakes and that the responses are not expected to be significant because very little biological damage had occurred before the treatment. Yan and Dillon (1984) reported that liming had no immediate or long term effects on zooplankton at Nelson Lake, Ontario (a category 4 lake). Zooplankton have responded with increased biomass after liming in situations where primary productivity has increased because of increased nutrient levels, either from natural sources or fertilizers (Fraser and Britt 1982; Yan and Dillon 1981).

In Flat Top Lake, the post-treatment zooplankton biomass response was considered to be primarily dependent on the phytoplankton response. Because the prior analysis for phytoplankton biomass, productivity, and species composition did not detect any significant responses after the treatment that would have caused a zooplankton biomass or species composition change between the arms, the relative post-treatment increase in total zooplankton and cladoceran biomass (e.g., *Daphnia spp.*) and the relative east arm decrease in rotifer abundance cannot be attributed to liming related factors.

Response in young-of-the-year bluegill growth

Significant improvements in reproduction, survival, and growth of fish populations have resulted after liming category 3 and lower category lakes (Nyberg 1984; Fraser et al. 1985). Direct improvements in water quality conditions (e.g., increase in pH, decrease in aluminum concentrations) and increases in Ca^{2+} concentrations, which decreases the permeability of gill tissue to dissolved metal uptake (Hunn 1985), are primary factors reported in restoring fish populations in limed lakes. Category 4 lakes generally have not shown significant improvements in fish populations after liming (Nyberg 1984); however, re-introduced species (Keller et al. 1980; Yan and Dillon 1984) and remnant populations (Kelso and Gunn 1982; Eriksson et al. 1983; Nyberg 1984) have responded favorably with increases in recruitment because of a reduction in mortality in the sensitive early life history stages. Increased growth rates generally have not been recorded after liming acidic lakes except in cases where fertilization has increased primary production (Eriksson et al. 1983; Fraser et al. 1985). The increase in fish growth from limed ponds in Southeast United States, Asia, and Europe was previously documented.

The original design was to collect larval bluegill from the upper pelagic zone at night and test for differences in average daily growth rates between the east and west arms for the pre-treatment and post-treatment periods separately. Larval bluegill were relatively abundant during the pelagic samples during the month of June; however, they became very difficult to catch in the post-treatment pelagic samples. YOY bluegill were abundant and relatively easy to capture in the littoral areas; therefore, after contamination of the west arm from calcite diffusion, the design was subsequently modified to use bluegill from the littoral areas that were present as pelagic larvae during the period of higher alkalinity in the east arm relative to the west arm (13 July through mid-August). Werner (1967, 1969) and Faber (1967) demonstrated that YOY bluegill migrate from the littoral zone to the pelagic zone and back to the littoral zone. This return to the littoral zone occcurred when the bluegill were between 15-20 mm total length (TL) in a Wisconsin study (Beard 1982) and between 22-25 mm (TL) in Crane Lake, Indiana (Werner 1969). The majority of the bluegill selected in this study were less than 20 mm (TL), which indicates they may have spent a majority of their lives in the pelagic zone; therefore, their estimated daily average growth rates may have been significantly influenced by the conditions in the pelagic zones of the east and west arms. Bluegill less than 20 mm (TL) prefer cladocerans and copepods less than 0.5 mm and rotifers are an important food source when bluegill are less than 10 mm (TL, Beard 1982). The west arm bluegills between 15 - 20 d old showed significantly higher daily growth rates than comparably aged east arm bluegills ($P = 0.012$; east, $N = 10$ and west, $N = 8$). Under the assumption that these fish had migrated to the littoral from the pelagic zone no more than a few days prior to capture, it appears that conditions for growth in the unlimed arm were superior to the limed arm. An increase in food availability and/or quality would be the most likely hypothesis. Mean numbers of *Daphnia spp.* (5.3/L, west and 3.8/L, east), *Bosmina spp.* (6.5/L, west and 1.2/L east), and sub-adult copepod (20.6/L, west and 14.0/L, east) was relatively higher for the west arm pelagic sites (i.e., lower and middle arm) for the combined 21 July and 7 August 1987 samples. The very small sample size, however, is a severe limitation in making definite conclusions.

Management implications

The most significant management implication that was realized from the results of this study was that calcite addition to a moderately productive, circumneutral yet acid-sensitive, warmwater reservoir had no detectable negative impacts on the biological components at three trophic levels (phytoplankton, zooplankton, zooplanktivorous fish). The low calcite dissolution percentage that can be expected for circumneutral surface waters translates into a high percentage of the added calcite reaching the sediments. In Flat Top Lake, it appears that this sediment dose made a significant contribution in maintaining target post-treatment total alkalinity values. If future monitoring of Flat Top Lake suggests possible acidification (pH near 6.0) and/or low total alkalinity values (0-5 mg/L), most likely in the spring, this study will be valuable to the Flat Top Lake Owner's Association in conducting their own liming application with confidence. For any future liming projects on Flat Top Lake, a larger calcite dose (e.g., a lakewide application of two to three times the dosage used for this project) would provide a relatively longer lasting buffer source and may provide a relatively more cost-effective treatment. However, a more immediate concern to the Flat Top Lake Owner's Association should be erosion control both along the waterfront property and within the entire watershed based on observed trends in littoral macrophyte abundance and the possibility of phytoplankton light limitation from suspended sediments.

Summary

1. The calcite application dose of 28.8 dry metric tonnes to the east arm (25.5 ha) resulted in a 44% increase in total alkalinity. Subsequent calcite diffusion into the west arm resulted in no relative difference in total alkalinity between the east and west arms within 1 month of the treatment.

2. The initial dissolution efficiency for the calcite dose was only 8-10% because of the higher than expected pH (7.07) at the time of the treatment. The pH increased approximately 0.3 units 1 week after the start of the application.

3. Residual calcite provided an effective buffer source to maintain total alkalinity in the east arm during calcite diffusion.

4. Phytoplankton biomass and gross productivity did not show a relative increase in the limed arm in the post-treatment samples. The inability of the calcite dose to neutralize the east arm sediments and induce a phosphorus release, and phosphorus limited rather than CO_2 limited primary productivity were the primary factors an increase in productivity was not realized in the east arm.

5. Although phytoplankton biomass decreased by 27% within 1 week of the treatment, there was no decrease in phytoplankton biomass immediately after the treatment from CO_2 depletion during calcite diffusion or significant phosphorus-aluminum precipitation because a similar decrease in biomass was measured in the west arm.

6. Lake transparency was significantly deeper in the east arm relative to the west arm in the post-treatment samples ($P = 0.036$, $N = 6$); however, the increased transparency in the

east arm could not be attributed to liming induced precipitation of dissolved organic carbon.

7. Although zooplankton biomass and composition of the phytoplankton and zooplankton communities showed some differences between the east and west arms, they could not be related to the treatment. Phosphorus availability, zooplankton grazing, zooplanktivore predation, and macrophyte abundance were hypothesized to be significant non-liming related factors determining the observed seasonal variations.

8. Young-of-the-year bluegill between 15-20 d old showed significantly faster growth in the west arm relative to the east arm ($P = 0.012$; east, $N = 10$ and west, $N = 8$) possibly because of a relatively larger abundance of suitable zooplankton at the pelagic west arm sites (1 and 2).

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Appendices

Appendix 1. Site-specific and mean arm alkalinity values (SE). Values are the mean of 1 and 3 m samples taken at each site.

	West			East			West	East
Date	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	$\bar{X}$	$\bar{X}$
			Pre-Treatment					
5/29/87	9.0	9.75	11.0	6.45	9.6	8.75	9.92 (0.58)	8.27 (0.94)
6/5/87	7.5	10.5	11.25	9.0	10.0	11.25	9.75 (1.15)	10.08 (0.65)
6/29/87	13.08	13.0	12.63	11.98	13.88	12.5	12.90 (0.14)	12.79 (0.57)
7/10/87	11.75	12.38	13.5	12.25	12.13	12.38	12.54 (0.51)	12.25 (0.07)
$\bar{X}$	10.33 (1.27)	11.41 (0.77)	12.10 (0.59)	9.92 (1.37)	11.40 (1.00)	11.22 (0.87)	11.28 (0.52)	10.85 (0.61)
			Post-Treatment					
7/20/87	17.88	15.38	15.25	20.25	20.0	25.5	16.17 (0.86)	21.92 (1.79)
7/24/87	17.5	16.13	16.0	19.25	22.13	25.75	16.54 (0.48)	22.38 (1.88)
7/29/87	18.5	18.25	17.13	19.75	19.5	26.75	17.96 (0.42)	22.0 (2.38)
8/10/87	22.25	17.5	18.25	21.25	23.75	23.0	19.33 (1.47)	22.67 (0.74)
9/3/87	24.38	25.38	22.5	24.75	23.38	25.13	24.09 (0.84)	24.42 (0.53)
10/1/87	26.25	26.0	26.0	26.5	27.0	27.75	26.08 (0.08)	27.08 (0.36)
11/18/87	27.0	26.5	24.25	26.75	26.38	26.88	25.92 (0.85)	26.67 (0.15)
$\bar{X}$	21.97 (1.53)	20.73 (1.88)	19.91 (1.62)	22.64 (1.23)	23.16 (1.09)	25.82 (0.58)	20.87 (0.94)	23.88 (0.64)
Overall $\bar{X}$	17.74 (2.05)	17.34 (1.85)	17.07 (1.57)	18.02 (2.13)	18.89 (1.94)	20.51 (2.27)	17.38 (1.03)	19.14 (1.20)

Appendix 2. Site-specific and mean arm pH values (SE). Values are the mean of 1 and 3 m samples taken at each site.

	West			East			West	East
Date	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	$\bar{X}$	$\bar{X}$
				Pre-Treatment				
5/29/87	6.69	6.68	6.54	6.83	6.88	6.85	6.64 (0.05)	6.85 (0.01)
6/5/87	6.76	6.71	6.60	6.98	6.98	7.00	6.69 (0.05)	6.99 (0.01)
6/29/87	6.93	6.94	6.99	6.96	7.08	7.30	6.95 (0.02)	7.11 (0.10)
7/10/87	7.05	6.89	7.26	7.07	6.97	7.16	7.07 (0.11)	7.07 (0.05)
$\bar{X}$	6.86 (0.08)	6.81 (0.06)	6.85 (0.17)	6.96 (0.05)	6.98 (0.04)	7.08 (0.10)	6.84 (0.06)	7.01 (0.04)
				Post-Treatment				
7/20/87	7.14	7.26	7.30	7.33	7.30	7.55	7.23 (0.05)	7.39 (0.08)
7/24/87	7.26	7.18	7.25	7.27	7.44	7.49	7.23 (0.03)	7.40 (0.07)
7/29/87	7.03	7.07	7.20	7.25	7.25	7.18	7.10 (0.05)	7.23 (0.02)
8/10/87	6.95	7.06	7.15	7.16	7.10	7.05	7.05 (0.06)	7.10 (0.03)
9/3/87	7.36	7.37	7.47	7.34	7.35	7.28	7.40 (0.04)	7.32 (0.02)
10/1/87	7.16	7.20	7.22	7.13	7.21	7.18	7.19 (0.02)	7.17 (0.02)
11/18/87	7.20	7.25	7.25	7.23	7.30	7.18	7.23 (0.02)	7.24 (0.03)
$\bar{X}$	7.16 (0.05)	7.20 (0.04)	7.26 (0.04)	7.24 (0.03)	7.28 (0.04)	7.27 (0.07)	7.21 (0.03)	7.27 (0.03)
Overall $\bar{X}$	7.05 (0.06)	7.06 (0.07)	7.11 (0.09)	7.14 (0.05)	7.17 (0.05)	7.20 (0.06)	7.07 (0.04)	7.17 (0.03)

Appendix 3. Depth-specific and mean arm gross productivity ($\mu g\ O_2\ L^{-1}\ h^{-1}$) (SE). Values are the mean of duplicate light, dark, and initial bottles.

	West					East					West	East
Date	1m	1½m	2m	2½m	3m	1m	1½m	2m	2½m	3m	$\bar{X}$	$\bar{X}$
Pre-Treatment												
5/29/87	50	50	60	30	40	60	40	40	50	60	50 (5.0)	50 (5.0)
6/5/87	70	50	50	40	60	70	60	40	50	60	50 (5.0)	60 (5.0)
6/12/87	28	23	37	28	16	28	26	22	28	9	26 (3.4)	23 (3.6)
6/16/87	65	21	47	33	24	59	35	44	26	29	38 (8.1)	39 (6.0)
6/29/87	41	32	41	39	29	26	45	26	28	45	36 (2.5)	34 (4.5)
7/10/87	45	50	40	25	30	57	34	32	27	44	38 (4.6)	39 (5.3)
$\bar{X}$	50 (6.4)	38 (5.7)	46 (3.8)	33 (2.7)	33 (6.3)	50 (7.5)	40 (4.8)	34 (3.6)	35 (4.8)	41 (7.3)	40 (2.5)	40 (2.7)
Post-Treatment												
7/20/87	43	40	28	35	33	35	13	40	48	40	36 (2.6)	35 (5.9)
7/29/87	27	29	20	20	27	36	39	29	14	29	25 (1.9)	29 (4.3)
8/7/87	48	41	22	27	32	59	35	43	39	30	34 (4.7)	41 (4.9)
9/3/87	39	37	22	64	34	38	19	52	43	19	39 (6.9)	34 (6.6)
10/1/87	34	42	37	20	34	29	31	31	42	10	33 (3.7)	29 (5.2)
11/18/87	54	26	51	56	51	59	44	51	39	69	48 (5.5)	52 (5.3)
$\bar{X}$	41 (4.0)	36 (2.7)	30 (4.9)	37 (7.7)	35 (3.3)	43 (5.3)	30 (4.9)	41 (4.0)	38 (4.9)	33 (8.4)	36 (2.1)	37 (2.5)
Overall $\bar{X}$	45 (3.8)	37 (3.0)	38 (3.7)	35 (3.9)	34 (3.4)	46 (4.5)	35 (3.6)	38 (2.8)	36 (3.3)	37 (5.7)	38 (1.6)	38 (1.8)

Appendix 4. Site-specific and mean arm chlorophyll *a* values (mg/m^3). Values are the mean of duplicate samples at each site.

	West			East			West	East
Date	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	$\overline{X}$	$\overline{X}$
				Pre-Treatment				
5/29/87	1.13	1.27	1.37	0.92	0.68	0.85	1.26 (0.07)	0.82 (0.07)
6/5/87	3.07	3.40	4.12	3.14	3.85	4.53	3.53 (0.31)	3.84 (0.40)
6/12/87	2.65	2.81	3.53	2.69	3.31	4.56	3.00 (0.27)	3.52 (0.55)
6/16/87	2.59	2.63	2.77	1.94	2.00	3.67	2.66 (0.05)	2.54 (0.57)
6/29/87	1.99	2.58	3.69	1.73	1.81	3.39	2.75 (0.50)	2.31 (0.76)
7/10/87	1.44	2.50	3.20	1.60	1.85	3.40	2.38 (0.51)	2.28 (0.56)
$\overline{X}$	2.15 (0.31)	2.53 (0.28)	3.11 (0.40)	2.00 (0.33)	2.25 (0.47)	3.40 (0.55)	2.60 (0.20)	2.55 (0.29)
				Post-Treatment				
7/20/87	1.25	1.95	2.21	1.12	1.71	2.17	1.80 (0.29)	1.67 (0.30)
7/29/87	1.92	3.22	3.62	2.30	2.86	3.00	2.92 (0.51)	2.72 (0.21)
8/7/87	2.21	2.78	3.87	2.13	3.17	4.72	2.95 (0.49)	3.34 (0.75)
9/3/87	2.64	4.08	4.16	2.93	2.65	2.61	3.63 (0.49)	2.73 (0.10)
10/1/87	3.19	2.73	2.55	2.49	2.98	2.74	2.82 (0.19)	2.74 (0.14)
11/18/87	5.75	5.34	5.42	5.65	5.54	4.50	5.50 (0.13)	5.23 (0.37)
$\overline{X}$	2.83 (0.64)	3.35 (0.49)	3.64 (0.47)	2.77 (0.63)	3.15 (0.52)	3.29 (0.43)	3.27 (0.30)	3.07 (0.29)
Overall $\overline{X}$	2.49 (0.36)	2.94 (0.30)	3.38 (0.30)	2.39 (0.36)	2.70 (0.36)	3.35 (0.34)	2.93 (0.19)	2.81 (0.21)

Appendix 5. Site-specific and mean arm Secchi disk depth (m) (SE).

	West			East			West	East
Date	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	$\bar{X}$	$\bar{X}$
				Pre-Treatment				
5/29/87	4.52	3.89	3.35	4.34	4.52	>3.66	3.92 (0.34)	4.17 (0.26)
6/5/87	2.95	2.79	2.67	3.15	3.07	2.57	2.80 (0.08)	2.93 (0.18)
6/12/87	3.68	3.12	2.95	2.97	2.57	2.01	3.25 (0.22)	2.52 (0.28)
6/16/87	3.45	2.87	2.59	3.71	3.00	2.26	2.97 (0.25)	2.99 (0.42)
6/29/87	4.91	3.64	2.44	5.44	4.01	2.59	3.66 (0.71)	4.01 (0.82)
7/10/87	4.93	3.38	2.90	4.17	3.56	2.95	3.74 (0.61)	3.56 (0.35)
$\bar{X}$	4.07 (0.34)	3.28 (0.18)	2.82 (0.13)	3.96 (0.37)	3.46 (0.29)	2.67 (0.24)	3.39 (0.18)	3.36 (0.21)
				Post-Treatment				
7/20/87	3.76	3.04	2.76	3.94	3.30	2.74	3.19 (0.30)	3.33 (0.35)
7/29/87	4.11	2.72	2.36	4.04	2.97	2.29	3.06 (0.53)	3.10 (0.51)
8/7/87	3.61	3.33	3.12	4.79	3.45	2.81	3.35 (0.14)	3.68 (0.58)
9/3/87	3.96	2.65	2.54	4.22	4.39	3.28	3.05 (0.46)	3.96 (0.35)
10/1/87	2.90	3.20	3.18	3.20	3.48	3.66	3.09 (0.10)	3.45 (0.13)
11/18/87	3.00	2.49	2.87	2.82	2.90	2.87	2.79 (0.15)	2.86 (0.02)
$\bar{X}$	3.56 (0.20)	2.91 (0.14)	2.81 (0.13)	3.84 (0.29)	3.42 (0.22)	2.94 (0.19)	3.09 (0.12)	3.40 (0.16)
Overall $\bar{X}$	3.82 (0.20)	3.09 (0.12)	2.81 (0.09)	3.90 (0.22)	3.44 (0.17)	2.81 (0.15)	3.24 (0.11)	3.38 (0.13)

Appendix 6. Net phytoplankton (#/L). For site estimates (SE) from the duplicate tows and for arm means (SE) from site means.

		West Arm				East Arm			
		Site 1	Site 2	Site 3		Site 4	Site 5	Site 6	
Date	Group	#/L	#/L	#/L	$\overline{\#/L}$	#/L	#/L	#/L	$\overline{\#/L}$
6/5/87	**Chrysophyta**								
	Dinobryon spp.	919.2 (54.9)	108.8 (44.4)	15.6 (15.6)	347.9 (286.9)	957.8 (100.8)	413.5 (174.3)	359.4 (9.33)	576.8 (191.1)
	Synura spp.	23.3 (20.4)	15.3 (15.3)	15.6 (15.6)	18.1 (2.62)	0.0 (0.0)	0.0 (0.0)	13.2 (13.2)	4.4 (4.4)
	Uroglenopsis spp.	1.4 (1.4)	0.0 (0.0)	0.0 (0.0)	0.5 (0.47)	15.8 (15.8)	0.0 (0.0)	0.0 (0.0)	5.3 (5.27)
	Surirella spp.	0.0 (0.0)	3.8 (3.8)	34.4 (34.4)	12.7 (10.9)	0.0 (0.0)	0.0 (0.0)	29.2 (29.2)	9.7 (9.73)
	Tabellaria spp.	0.0 (0.0)	0.0 (0.0)	17.2 (17.2)	5.7 (5.73)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Asterionella spp.	2.4 (2.4)	0.0 (0.0)	0.0 (0.0)	0.8 (0.8)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Stauroneis spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	TOTAL	946.3 (62.3)	127.9 (63.6)	82.8 (20.5)	385.7 (280.6)	973.6 (116.7)	413.2 (174.3)	401.8 (5.45)	596.2 (188.7)
	Chlorophyta								
	Desmidium spp.	0.0 (0.0)	10.7 (10.7)	496.1 (433.7)	168.9 (163.6)	0.0 (0.0)	461.6 (461.6)	0.0 (0.0)	153.9 (153.9)
	Staurastrum spp.	7.3 (7.3)	0.0 (0.0)	17.2 (17.2)	8.2 (4.98)	0.0 (0.0)	2.8 (2.78)	0.0 (0.0)	0.9 (0.93)
	Closterium spp.	0.0 (0.0)	0.0 (0.0)	155.0 (155.0)	51.7 (51.7)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Spirotaenia spp.	0.0 (0.0)	0.0 (0.0)	17.2 (17.2)	5.7 (5.73)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Netrium spp.	0.0 (0.0)	0.0 (0.0)	51.7 (51.7)	17.2 (17.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Closteridium spp.	0.0 (0.0)	0.0 (0.0)	17.2 (17.2)	5.7 (5.73)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Pediastrum spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Scenedesmus spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Micrasterias spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Cosmarium spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Spirogyra spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	TOTAL	7.3 (7.27)	10.7 (10.7)	754.4 (692.0)	257.5 (248.5)	0.0 (0.0)	464.4 (458.8)	0.0 (0.0)	154.8 (154.8)
	Pyrrhophyta								
	Ceratium spp.	41.8 (1.91)	72.8 (34.5)	112.5 (43.6)	75.7 (20.5)	32.8 (14.6)	2.8 (2.78)	13.2 (13.2)	16.3 (8.79)
	Cystodinium spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	TOTAL	41.8 (1.91)	72.8 (34.5)	112.5 (43.6)	75.7 (20.5)	32.8 (14.6)	2.8 (2.78)	13.2 (13.2)	16.3 (8.79)
	Cyanophyta								
	Anabaena spp.	107.2 (29.7)	562.3 (219.1)	1603.2 (19.0)	757.6 (442.8)	386.8 (23.4)	287.9 (215.7)	584.2 (57.6)	419.6 (87.1)
	TOTAL	107.2 (29.7)	562.3 (219.1)	1603.2 (19.0)	757.6 (442.8)	386.8 (23.4)	287.9 (215.7)	584.2 (57.6)	419.6 (87.1)
	TOTAL	1102.6 (55.7)	773.7 (237.5)	2552.9 (649.9)	1476.4 (546.6)	1393.2 (107.9)	1168.3 (846.0)	999.2 (51.0)	1186.9 (114.1)

Appendix 6, cont. Net phytoplankton (#/L). For site estimates (SE) from the duplicate tows and for arm means (SE) from site means.

		West Arm				East Arm			
Date	Group	Site 1 #/L	Site 2 #/L	Site 3 #/L	$\overline{\#/L}$	Site 4 #/L	Site 5 #/L	Site 6 #/L	$\overline{\#/L}$
6/29/87	**Chrysophyta**								
	Dinobryon spp.	1747.6 (236.0)	2365.9 (215.7)	2815.2 (145.5)	2309.6 (309.5)	1467.6 (759.7)	1689.8 (248.4)	1908.9 (48.7)	1688.8 (127.4)
	Synura spp.	67.2 (49.5)	1394.0 (1306.4)	183.0 (21.2)	548.1 (424.3)	388.3 (353.6)	29.8 (29.8)	66.3 (1.41)	161.5 (113.9)
	Uroglenopsis spp.	0.0 (0.0)	25.0 (25.0)	0.0 (0.0)	8.3 (8.33)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Surirella spp.	0.0 (0.0)	0.0 (0.0)	15.2 (15.2)	5.1 (5.10)	4.3 (4.33)	3.7 (3.73)	66.2 (1.43)	24.7 (20.7)
	Tabellaria spp.	9.7 (0.88)	0.0 (0.0)	15.2 (15.2)	8.3 (4.44)	7.7 (0.93)	14.0 (8.33)	42.8 (9.03)	21.5 (10.8)
	Asterionella spp.	0.0 (0.0)	0.0 (0.0)	5.1 (5.1)	1.7 (1.70)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Stauroneis spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	TOTAL	1824.5 (286.4)	3784.9 (1115.8)	3033.7 (131.4)	2881.0 (571.0)	1867.9 (411.4)	1737.3 (290.3)	2084.2 (55.0)	1896.5 (101.2)
	Chlorophyta								
	Desmidium spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	40.8 (40.8)	0.0 (0.0)	1663.7 (1650.8)	568.2 (547.9)
	Staurastrum spp.	23.9 (2.68)	30.2 (13.6)	26.9 (16.8)	27.0 (1.82)	28.5 (14.8)	24.6 (9.69)	46.8 (20.9)	33.3 (6.84)
	Closterium spp.	0.0 (0.0)	0.0 (0.0)	7.3 (7.3)	2.4 (2.43)	0.0 (0.0)	9.5 (2.0)	6.5 (6.48)	5.3 (2.80)
	Spirotaenia spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Netrium spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Closteridium spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Pediastrum spp.	9.7 (0.88)	0.0 (0.0)	0.0 (0.0)	3.2 (3.23)	7.7 (0.93)	0.0 (0.0)	0.0 (0.0)	2.6 (2.57)
	Scenedesmus spp.	0.0 (0.0)	0.0 (0.0)	5.1 (5.1)	1.7 (1.70)	0.0 (0.0)	3.7 (3.73)	0.0 (0.0)	1.2 (1.23)
	Micrasterias spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	16.9 (16.9)	5.6 (5.63)
	Cosmarium spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	6.5 (6.48)	2.2 (2.17)
	Spirogyra spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	TOTAL	33.6 (1.80)	30.2 (13.6)	39.3 (19.1)	34.4 (2.65)	77.0 (25.1)	37.8 (7.98)	1740.4 (1675.6)	618.4 (561.1)
	Pyrrhophyta								
	Ceratium spp.	514.5 (196.2)	1212.6 (12.5)	1288.7 (388.6)	1005.3 (246.4)	265.9 (54.9)	488.9 (100.0)	375.4 (64.3)	376.7 (64.4)
	Cystodinium spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	TOTAL	514.5 (196.2)	1212.6 (12.5)	1288.7 (388.6)	1005.3 (246.4)	265.9 (54.9)	488.9 (100.0)	375.4 (64.3)	376.7 (64.4)
	Cyanophyta								
	Anabaena spp.	80.5 (36.3)	33.3 (33.3)	5.1 (5.05)	39.6 (22.0)	86.0 (18.0)	14.3 (14.3)	16.9 (16.9)	39.1 (23.5)
	TOTAL	80.5 (36.3)	33.3 (33.3)	5.1 (5.05)	39.6 (22.0)	86.0 (18.0)	14.3 (14.3)	16.9 (16.9)	39.1 (23.5)
	TOTAL	2453.1 (517.1)	5061.0 (1123.0)	4366.8 (534.1)	3960.3 (779.8)	2296.8 (459.2)	2278.3 (368.0)	4216.9 (1701.8)	2930.7 (643.1)

Appendix 6, cont. Net phytoplankton (#/L). For site estimates (SE) from the duplicate tows and for arm means (SE) from site means.

Date	Group	West Arm				East Arm			
		Site 1 #/L	Site 2 #/L	Site 3 #/L	$\overline{\#/L}$	Site 4 #/L	Site 5 #/L	Site 6 #/L	$\overline{\#/L}$
7/21/87	**Chrysophyta**								
	Dinobryon spp.	358.2 (56.7)	191.5 (16.2)	197.0 (17.7)	248.9 (54.7)	514.9 (170.5)	299.1 (52.3)	241.6 (10.7)	351.9 (83.2)
	Synura spp.	6.3 (1.20)	0.0 (0.0)	5.8 (5.80)	4.0 (2.02)	6.5 (0.42)	15.9 (15.9)	9.0 (0.57)	10.5 (2.81)
	Uroglenopsis spp.	5.1 (5.09)	3.3 (3.25)	3.2 (3.18)	3.9 (0.62)	18.9 (5.09)	7.2 (0.78)	9.0 (0.57)	11.7 (3.64)
	Surirella spp.	0.0 (0.0)	0.0 (0.0)	14.8 (8.40)	4.9 (4.93)	0.0 (0.0)	15.9 (15.9)	4.2 (4.20)	6.7 (4.76)
	Tabellaria spp.	0.0 (0.0)	3.3 (3.25)	2.9 (2.90)	2.1 (1.04)	0.0 (0.0)	3.2 (3.20)	9.0 (0.60)	4.1 (2.63)
	Asterionella spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	4.8 (4.80)	1.6 (1.60)
	Stauroneis spp.	0.0 (0.0)	0.0 (0.0)	5.8 (5.80)	1.9 (1.93)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	TOTAL	369.6 (60.6)	198.1 (22.7)	229.5 (37.5)	265.7 (52.7)	540.2 (175.2)	341.4 (22.8)	277.6 (8.38)	386.4 (79.1)
	Chlorophyta								
	Desmidium spp.	3.8 (3.78)	19.5 (13.0)	0.0 (0.0)	7.8 (5.97)	0.0 (0.0)	3.8 (3.80)	9.0 (0.60)	4.3 (2.61)
	Staurastrum spp.	155.8 (38.9)	204.5 (22.7)	248.7 (18.3)	203.0 (26.8)	228.7 (35.9)	189.0 (10.1)	168.3 (33.7)	195.3 (17.7)
	Closterium spp.	0.0 (0.0)	0.0 (0.0)	2.9 (2.90)	1.0 (0.97)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Spirotaenia spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Netrium spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Closteridium spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Pediastrum spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Scenedesmus spp.	1.9 (1.88)	0.0 (0.0)	0.0 (0.0)	0.6 (0.63)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Micrasterias spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	3.2 (3.20)	4.8 (4.80)	2.7 (1.41)
	Cosmarium spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Spirogyra spp.	0.0 (0.0)	3.3 (3.25)	0.0 (0.0)	1.1 (1.10)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	TOTAL	161.5 (33.3)	227.3 (39.0)	251.6 (21.2)	213.5 (26.9)	228.7 (35.9)	196.2 (10.9)	182.1 (28.3)	202.3 (13.8)
	Pyrrhophyta								
	Ceratium spp.	74.3 (2.60)	61.7 (22.7)	11.6 (11.6)	49.2 (19.1)	83.8 (42.5)	110.1 (1.48)	79.9 (12.6)	91.3 (9.48)
	Cystodinium spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	TOTAL	74.3 (2.60)	61.7 (22.7)	11.6 (11.6)	49.2 (19.1)	83.8 (42.5)	110.1 (1.48)	79.9 (12.6)	91.3 (9.48)
	Cyanophyta								
	Anabaena spp.	0.0 (0.0)	0.0 (0.0)	6.4 (6.40)	2.1 (2.13)	0.0 (0.0)	0.0 (0.0)	4.8 (4.80)	1.6 (1.60)
	TOTAL	0.0 (0.0)	0.0 (0.0)	6.4 (6.40)	2.1 (2.13)	0.0 (0.0)	0.0 (0.0)	4.8 (4.80)	1.6 (1.60)
	TOTAL	605.4 (96.4)	487.1 (6.48)	499.1 (63.9)	530.5 (37.6)	852.7 (253.5)	647.7 (10.5)	544.4 (44.4)	681.6 (90.6)

Appendix 6, cont. Net phytoplankton (#/L). For site estimates (SE) from the duplicate tows and for arm means (SE) from site means.

		West Arm				East Arm			
Date	Group	Site 1 #/L	Site 2 #/L	Site 3 #/L	$\overline{\#/L}$	Site 4 #/L	Site 5 #/L	Site 6 #/L	$\overline{\#/L}$
9/3/87	**Chrysophyta**								
	Dinobryon spp.	579.4 (160.7)	1392.2 (43.6)	1659.3 (602.6)	1210.3 (324.7)	511.8 (98.9)	914.1 (4.52)	581.2 (7.07)	669.0 (124.2)
	Synura spp.	65.4 (14.7)	20.7 (12.0)	15.5 (15.6)	33.9 (15.8)	79.7 (22.1)	19.3 (12.6)	31.0 (14.9)	43.3 (18.5)
	Uroglenopsis spp.	10.2 (2.55)	0.0 (0.0)	0.0 (0.0)	3.4 (3.40)	4.7 (0.07)	6.0 (0.71)	3.8 (3.82)	4.8 (0.64)
	Surirella spp.	0.0 (0.0)	2.2 (2.18)	7.8 (7.78)	3.3 (2.32)	0.0 (0.0)	3.3 (3.33)	7.7 (7.65)	3.7 (2.23)
	Tabellaria spp.	0.0 (0.0)	0.0 (0.0)	29.8 (22.0)	9.9 (9.93)	4.7 (0.08)	3.3 (3.32)	4.0 (4.03)	4.0 (0.40)
	Asterionella spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	2.3 (2.33)	6.0 (0.68)	3.8 (3.83)	4.0 (1.07)
	Stauroneis spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	TOTAL	655.0 (172.8)	1415.1 (53.4)	1712.4 (601.3)	1260.8 (314.8)	603.2 (123.1)	952.0 (9.10)	631.5 (19.1)	728.9 (111.8)
	Chlorophyta								
	Desmidium spp.	19.3 (15.1)	29.4 (29.4)	175.7 (152.4)	74.8 (50.5)	4.6 (4.63)	6.0 (0.68)	19.1 (19.1)	9.9 (4.62)
	Staurastrum spp.	274.7 (80.1)	541.9 (25.9)	589.6 (14.7)	468.7 (98.0)	301.5 (133.4)	512.4 (167.2)	387.6 (41.1)	400.5 (61.2)
	Closterium spp.	0.0 (0.0)	5.5 (1.10)	150.2 (57.0)	51.9 (49.2)	0.0 (0.0)	6.7 (6.65)	4.0 (4.03)	3.6 (1.95)
	Spirotaenia spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Netrium spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Closteridium spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Pediastrum spp.	0.0 (0.0)	0.0 (0.0)	15.5 (15.5)	5.2 (5.17)	0.0 (0.0)	3.3 (3.33)	3.8 (3.83)	2.4 (1.19)
	Scenedesmus spp.	0.0 (0.0)	0.0 (0.0)	34.5 (34.5)	11.5 (11.5)	0.0 (0.0)	3.3 (3.33)	0.0 (0.0)	1.1 (1.10)
	Micrasterias spp.	5.7 (5.73)	3.3 (3.28)	3.9 (3.88)	4.3 (0.72)	9.3 (9.28)	2.7 (2.65)	4.0 (4.03)	5.3 (2.02)
	Cosmarium spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Spirogyra spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Pleurotaenium spp.	0.0 (0.0)	0.0 (0.0)	67.4 (36.3)	22.5 (22.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	TOTAL	299.7 (100.9)	580.1 (59.6)	1036.8 (275.4)	638.9 (214.8)	315.4 (147.3)	534.4 (155.9)	418.5 (56.0)	422.8 (63.3)
	Pyrrhophyta								
	Ceratium spp.	7.9 (3.61)	15.2 (2.12)	3.9 (3.89)	9.0 (3.31)	16.3 (11.5)	10.0 (9.97)	3.8 (3.82)	10.0 (3.61)
	Cystodinium spp.	0.0 (0.0)	0.0 (0.0)	17.3 (17.3)	5.8 (5.77)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	TOTAL	7.9 (3.61)	15.2 (2.12)	21.2 (13.4)	14.8 (3.85)	16.3 (11.5)	10.0 (9.97)	3.8 (3.82)	10.0 (3.61)
	Cyanophyta								
	Anabaena spp.	997.9 (16.8)	1529.6 (402.1)	3069.1 (582.7)	1865.5 (621.0)	260.3 (63.5)	1005.7 (29.7)	639.8 (156.3)	635.3 (215.2)
	TOTAL	997.9 (16.8)	1529.6 (402.1)	3069.1 (582.7)	1865.5 (621.0)	260.3 (63.5)	1005.7 (29.7)	639.8 (156.3)	635.3 (215.2)
	TOTAL	1960.5 (294.1)	3540.0 (512.9)	5839.5 (307.4)	3780.0 (1126.2)	1195.2 (345.5)	2502.1 (184.7)	1693.6 (235.3)	1797.0 (380.8)

Appendix 7. Nannoplankton (#/cm³). For site estimates (SE) from the duplicate samples and for arm means (SE) from site means.

		West Arm								East Arm							
		Site 1		Site 2		Site 3				Site 4		Site 5		Site 6			
Date	Group	#/L.		#/L		#/L		$\overline{\#/L}$		#/L		#/L		#/L		$\overline{\#/L}$	
5/29/87	**Chrysophyta**																
	Centric diatoms	2825.0	(75.0)	3765.0	(445.0)	4235.0	(205.0)	3608.3	(414.5)	1369.0	(571.0)	1700.0	(50.0)	972.5	(47.5)	1347.2	(210.3)
	Pennate diatoms	1435.0	(195.0)	2195.0	(405.0)	2970.0	(520.0)	2200.0	(443.1)	767.5	(119.5)	2420.0	(420.0)	745.5	(190.5)	1311.0	(554.5)
	Dinobryon spp.¹	133.0	(133.0)	403.0	(45.0)	181.0	(181.0)	239.0	(83.2)	776.5	(333.5)	565.0	(167.0)	490.5	(64.5)	610.7	(85.7)
	Dinobryon spp.²	89.7	(0.95)	134.3	(44.7)	90.5	(90.5)	104.8	(14.7)	90.5	(1.90)	182.3	(92.8)	135.1	(50.0)	136.0	(26.5)
	TOTAL	4482.7	(138.0)	6497.3	(849.7)	7476.5	(43.5)	6152.2	(881.3)	3003.6	(786.9)	4867.3	(629.8)	2343.6	(123.6)	3404.8	(755.6)
	Chlorophyta																
	Oocystis spp.	0.0	(0.0)	0.0	(0.0)	90.1	(0.50)	30.0	(30.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
	Tetraedron caudatum	0.0	(0.0)	44.8	(44.8)	44.8	(44.8)	29.9	(14.9)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
	Tetraedron lunula	1345.0	(255.0)	1790.0	(180.0)	2390.0	(420.0)	1841.7	(302.8)	1175.0	(65.0)	824.5	(275.5)	810.5	(299.5)	936.7	(119.2)
	Selenastrum minutum	177.5	(177.5)	223.8	(134.2)	680.0	(680.0)	360.4	(160.3)	44.4	(44.4)	136.3	(46.8)	0.0	(0.0)	60.2	(40.1)
	Crucigenia spp.	45.3	(45.3)	44.8	(44.8)	44.8	(44.8)	45.0	(0.17)	44.4	(44.4)	44.8	(44.8)	88.8	(3.70)	59.3	(14.7)
	Chlorosarcina spp.	44.4	(44.4)	0.0	(0.0)	0.0	(0.0)	14.8	(14.8)	46.3	(46.3)	0.0	(0.0)	0.0	(0.0)	15.4	(15.4)
	Staurastrum spp.	45.3	(45.3)	0.0	(0.0)	0.0	(0.0)	15.1	(15.1)	0.0	(0.0)	0.0	(0.0)	46.3	(46.3)	15.4	(15.4)
	Scenedesmus spp.³	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
	Gloeocystis spp.³	453.0	(453.0)	0.0	(0.0)	0.0	(0.0)	151.0	(151.0)	0.0	(0.0)	255.5	(255.5)	895.0	(895.0)	383.5	(266.2)
	Gemellicystis spp.³	2525.0	(2525.0)	0.0	(0.0)	0.0	(0.0)	841.7	(841.7)	266.0	(266.0)	0.0	(0.0)	0.0	(0.0)	88.7	(88.7)
	Treubaria spp.	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	636.0	(104.0)	0.0	(0.0)	0.0	(0.0)	212.0	(212.0)
	Pediastrum spp.	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
	Ankistrodesmus spp.	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
	Cosmarium spp.	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
	TOTAL	4635.5	(2458.2)	2103.4	(403.8)	3249.7	(1010.9)	3329.6	(732.0)	2212.2	(262.6)	1261.1	(529.0)	1840.6	(545.6)	1771.3	(276.7)
	Pyrrhophyta																
	Dinoflagellates	1123.5	(236.5)	224.0	(45.0)	540.5	(2.50)	629.3	(263.4)	636.0	(104.0)	1255.0	(65.0)	1166.0	(704.0)	1019.0	(193.2)
	TOTAL	1123.5	(236.5)	224.0	(45.0)	540.5	(2.50)	629.3	(263.4)	636.0	(104.0)	1255.0	(65.0)	1166.0	(704.0)	1019.0	(193.2)
	Cyanophyta																
	Anabaena spp.	0.0	(0.0)	89.6	(89.6)	0.0	(0.0)	29.9	(29.9)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
	Dactylococcopsis spp.	0.0	(0.0)	89.5	(89.5)	0.0	(0.0)	29.8	(29.8)	0.0	(0.0)	44.8	(44.8)	0.0	(0.0)	14.9	(14.9)
	TOTAL	0.0	(0.0)	179.1	(179.1)	0.0	(0.0)	59.7	(59.7)	0.0	(0.0)	44.8	(44.8)	0.0	(0.0)	14.9	(14.9)
	TOTAL	10241.7	(2083.8)	9003.8	(1209.0)	11266.7	(969.9)	10170.8	(654.2)	5851.7	(621.5)	7428.2	(11.0)	5350.2	(1373.1)	6210.0	(626.1)

[1] single lorica species
[2] multiple lorica species
[3] cell count

Appendix 7, cont. Nannoplankton (#/cm^3). For site estimates (SE) from the duplicate samples and for arm means (SE) from site means.

		West Arm				East Arm			
		Site 1	Site 2	Site 3		Site 4	Site 5	Site 6	
Date	Group	#/L	#/L	#/L	$\overline{\#/L}$	#/L	#/L	#/L	$\overline{\#/L}$
7/10/87	**Chrysophyta**								
	Centric diatoms	2135.0 (205.0)	801.0 (469.0)	1190.0 (80.0)	1375.3 (396.1)	851.0 (45.0)	1175.0 (25.0)	2215.0 (435.0)	1413.7 (411.1)
	Pennate diatoms	1115.0 (115.0)	877.0 (213.0)	1470.0 (200.0)	1154.0 (172.3)	893.5 (266.5)	1130.0 (110.0)	1990.0 (120.0)	1337.8 (333.2)
	Dinobryon spp.[1]	650.0 (315.0)	2810.0 (180.0)	3850.0 (500.0)	2436.7 (942.4)	1880.0 (360.0)	2075.0 (775.0)	2585.0 (805.0)	2180.0 (210.2)
	Dinobryon spp.[2]	83.5 (83.5)	136.0 (136.0)	90.5 (90.5)	103.3 (16.5)	134.5 (44.7)	277.0 (92.0)	91.5 (91.5)	167.6 (56.1)
	TOTAL	3983.5 (141.5)	4624.0 (638.0)	6600.5 (529.5)	5069.3 (787.6)	3758.8 (626.2)	4657.0 (952.0)	6881.5 (1451.5)	5099.1 (928.26)
	Chlorophyta								
	Oocystis spp.	299.0 (36.0)	434.0 (19.0)	781.0 (419.0)	504.7 (143.6)	806.5 (89.5)	553.5 (1.50)	648.0 (7.0)	669.3 (73.8)
	Tetraedron caudatum	217.4 (133.7)	268.0 (185.0)	136.8 (44.3)	207.4 (38.2)	134.3 (44.7)	46.3 (46.3)	278.5 (95.5)	153.0 (82.9)
	Tetraedron lunula	129.9 (46.2)	215.0 (34.0)	366.0 (4.0)	237.0 (69.0)	0.0 (0.0)	92.5 (92.5)	232.8 (141.3)	108.4 (67.7)
	Selenastrum minutum	345.0 (94.0)	1022.0 (388.0)	1875.0 (65.0)	1080.7 (442.6)	492.5 (134.5)	1246.5 (413.5)	1950.0 (300.0)	1229.7 (420.8)
	Crucigenia spp.	1455.0 (15.0)	1237.0 (573.0)	1285.0 (105.0)	1325.7 (66.1)	1250.0 (90.0)	1455.0 (25.0)	1295.0 (15.0)	1333.3 (62.2)
	Chlorosarcina spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	138.3 (64.7)	46.1 (46.1)
	Staurastrum spp.	21.3 (21.3)	44.4 (44.4)	0.0 (0.0)	21.9 (12.8)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Scenedesmus spp.[3]	0.0 (0.0)	373.5 (373.5)	0.0 (0.0)	124.5 (124.5)	0.0 (0.0)	0.0 (0.0)	45.8 (45.8)	15.3 (15.3)
	Gloeocystis spp.[3]	2490.0 (1700.0)	249.0 (249.0)	411.5 (411.5)	1050.2 (721.4)	898.5 (181.5)	1435.0 (1435.0)	1245.0 (2.50)	1192.8 (157.1)
	Gemellicystis spp.[3]	510.5.0 (2095.0)	14400.0 (300.0)	15850.0 (2150.0)	11785.0 (3366.1)	6135.0 (315.0)	9265.0 (4935.0)	11850.0 (950.0)	9083.3 (1652.3)
	Treubaria spp.	43.9 (43.9)	41.5 (41.5)	45.3 (45.3)	43.6 (1.11)	134.3 (44.7)	46.3 (46.3)	186.3 (94.8)	122.3 (40.9)
	Pediastrum spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	46.8 (46.8)	15.6 (15.6)
	Ankistrodesmus spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Cosmarium spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	TOTAL	10085.2 (3498.3)	18240.0 (9.0)	20750.6 (1688.0)	16358.6 (3219.3)	9851.1 (899.9)	14140.1 (2928.0)	17916.5 (555.2)	13969.2 (2329.8)
	Pyrrhophyta								
	Dinoflagellates	389.0 (138.0)	513.0 (151.0)	732.0 (8.0)	544.7 (100.3)	403.0 (45.0)	1360.0 (250.0)	1850.0 (70.0)	1204.3 (424.9)
	TOTAL	389.0 (138.0)	513.0 (151.0)	732.0 (8.0)	544.7 (100.3)	403.0 (45.0)	1360.0 (250.0)	1850.0 (70.0)	1204.3 (424.9)
	Cyanophyta								
	Anabaena spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Dactylococcopsis spp.	263.5 (263.5)	271.5 (271.5)	90.5 (90.5)	208.5 (59.0)	988.0 (92.0)	390.5 (112.5)	880.0 (130.0)	752.8 (183.8)
	TOTAL	263.5 (263.5)	271.5 (271.5)	90.5 (90.5)	208.5 (59.0)	988.0 (92.0)	390.5 (112.5)	880.0 (130.0)	752.8 (183.8)
	TOTAL	14721.2 (1234.7)	23648.5 (149.5)	28173.6 (1241.0)	22181.1 (3952.1)	15009.9 (1663.1)	20547.6 (1613.5)	27528.0 (306.7)	21025.3 (3624.1)

[1] single lorica species
[2] multiple lorica species
[3] cell count

Appendix 7, cont. Nannoplankton (#/cm^3). For site estimates (SE) from the duplicate samples and for arm means (SE) from site means.

		West Arm				East Arm			
		Site 1	Site 2	Site 3		Site 4	Site 5	Site 6	
Date	Group	#/L	#/L	#/L	$\overline{\#/L}$	#/L	#/L	#/L	$\overline{\#/L}$
7/21/87	**Chrysophyta**								
	Centric diatoms	1240.0 (100.0)	502.0 (0.0)	2515.0 (335.0)	1419.0 (588.0)	531.5 (138.5)	1215.0 (125.0)	1369.0 (391.0)	1038.5 (257.4)
	Pennate diatoms	299.0 (36.0)	628.0 (42.0)	1675.0 (1005.0)	867.3 (414.9)	612.0 (141.0)	961.5 (208.5)	2435.0 (175.0)	1336.2 (558.6)
	Dinobryon spp.[1]	1036.5 (283.5)	460.5 (41.5)	460.5 (41.5)	71.8 (52.2)	1095.5 (74.5)	1420.0 (250.0)	1450.0 (60.0)	1321.8 (113.5)
	Dinobryon spp.[2]	173.4 (89.7)	0.0 (0.0)	41.9 (41.9)	71.8 (52.2)	0.0 (0.0)	0.0 (0.0)	40.8 (40.8)	13.6 (13.6)
	TOTAL	2748.9 (237.2)	1590.5 (83.5)	4692.4 (1256.7)	3010.6 (905.0)	2239.0 (354.0)	3596.5 (583.5)	5294.8 (235.3)	3710.1 (884.0)
	Chlorophyta								
	Oocystis spp.	85.8 (2.05)	125.5 (125.5)	460.5 (41.5)	223.9 (118.8)	0.0 (0.0)	167.0 (0.0)	208.3 (126.8)	125.1 (63.7)
	Tetraedron caudatum	88.0 (88.0)	83.5 (83.5)	167.5 (167.5)	113.0 (27.3)	157.0 (157.0)	125.5 (125.5)	291.0 (128.0)	191.2 (50.7)
	Tetraedron lunula	0.0 (0.0)	125.4 (41.7)	209.0 (42.0)	111.5 (60.7)	39.3 (39.3)	0.0 (0.0)	40.8 (40.8)	26.7 (13.4)
	Selenastrum minutum	213.5 (37.5)	838.0 (252.0)	1255.0 (85.0)	768.8 (302.6)	366.5 (52.5)	419.0 (0.0)	623.5 (297.5)	469.7 (78.4)
	Crucigenia spp.	173.4 (89.7)	376.0 (125.0)	376.5 (125.5)	308.6 (67.6)	164.8 (86.2)	125.4 (41.7)	699.5 (114.5)	329.9 (185.1)
	Chlorosarcina spp.	41.9 (41.9)	83.7 (0.0)	0.0 (0.0)	41.9 (24.2)	0.0 (0.0)	0.0 (0.0)	41.9 (41.9)	14.0 (14.0)
	Staurastrum spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	39.3 (39.3)	0.0 (0.0)	0.0 (0.0)	13.1 (13.1)
	Scenedesmus spp.[3]	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Gloeocystis spp.[3]	1684.5 (1245.5)	251.0 (251.0)	670.0 (670.0)	868.5 (425.6)	2475.0 (1135.0)	5245.5 (4545.5)	4935.0 (1265.0)	4221.5 (878.1)
	Gemellicystis spp.[3]	335.0 (335.0)	545.0 (545.0)	1675.5 (754.5)	851.8 (416.3)	2115.0 (1025.0)	3410.0 (310.0)	4975.0 (1705.0)	3500.0 (826.8)
	Treubaria spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	78.5 (78.5)	0.0 (0.0)	0.0 (0.0)	26.2 (26.2)
	Pediastrum spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Ankistrodesmus spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	81.2 (2.55)	125.5 (125.5)	0.0 (0.0)	68.9 (36.7)
	Cosmarium spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	TOTAL	2622.1 (1480.2)	2428.1 (1173.7)	4814.0 (1298.0)	3288.1 (765.0)	5516.6 (2332.9)	9626.9 (4277.2)	11815.0 (1.10)	8986.2 (1846.2)
	Pyrrhophyta								
	Dinoflagellates	462.4 (374.6)	627.5 (125.5)	795.0 (42.0)	628.3 (96.0)	447.5 (54.5)	418.5 (83.5)	1068.0 (482.0)	644.7 (211.8)
	TOTAL	462.4 (374.6)	627.5 (125.5)	795.0 (42.0)	628.3 (96.0)	447.5 (54.5)	418.5 (83.5)	1068.0 (482.0)	644.7 (211.8)
	Cyanophyta								
	Anabaena spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Dactylococcopsis spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	TOTAL	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	TOTAL	5833.4 (1617.6)	4646.1 (1215.7)	10301.4 (1003.7)	6927.0 (1721.7)	8203.1 (1924.4)	13641.9 (4944.2)	18177.8 (247.9)	13341.0 (2883.4)

[1] single lorica species
[2] multiple lorica species
[3] cell count

Appendix 7, cont. Nannoplankton (#/cm³). For site estimates (SE) from the duplicate samples and for arm means (SE) from site means.

		West Arm				East Arm			
		Site 1	Site 2	Site 3		Site 4	Site 5	Site 6	
Date	Group	#/L	#/L	#/L	$\overline{\#/L}$	#/L	#/L	#/L	$\overline{\#/L}$
9/3/87	**Chrysophyta**								
	Centric diatoms	80.5 (80.5)	673.5 (141.5)	888.5 (46.5)	547.5 (241.6)	178.9 (90.1)	134.3 (44.7)	272.0 (0.0)	195.1 (40.6)
	Pennate diatoms	0.0 (0.0)	1075.0 (15.0)	1730.0 (230.0)	935.0 (504.3)	1023.0 (127.0)	806.0 (0.0)	1720.0 (180.0)	1183.0 (275.7)
	Dinobryon spp.¹	161.0 (41.0)	2335.0 (295.0)	2435.0 (185.0)	1643.7 (741.9)	1740.0 (140.0)	1700.0 (90.0)	2175.0 (455.0)	1871.7 (152.1)
	Dinobryon spp.²	98.5 (98.5)	358.5 (3.50)	280.5 (280.5)	245.8 (77.0)	222.3 (132.7)	44.8 (44.8)	45.3 (45.3)	104.1 (59.1)
	TOTAL	340.0 (138.0)	4442.0 (455.0)	5334.0 (649.0)	3372.0 (1537.7)	3164.2 (29.6)	2685.1 (0.50)	4212.3 (680.3)	3353.9 (450.9)
	Chlorophyta								
	Oocystis spp.	19.7 (19.7)	402.5 (40.5)	187.3 (93.8)	203.2 (110.8)	133.9 (45.2)	134.3 (44.7)	181.3 (90.8)	149.8 (15.7)
	Tetraedron caudatum	19.8 (19.8)	178.3 (87.7)	46.8 (46.8)	81.6 (49.0)	223.0 (46.0)	89.5 (89.5)	271.5 (90.5)	194.7 (54.4)
	Tetraedron lunula	64.0 (64.0)	404.5 (138.5)	561.0 (374.0)	343.2 (146.7)	267.5 (90.5)	44.8 (44.8)	45.3 (45.3)	119.2 (74.2)
	Selenastrum minutum	41.0 (41.0)	1482.5 (507.5)	1920.0 (330.0)	1147.8 (567.6)	356.0 (87.0)	448.0 (179.0)	588.5 (135.5)	464.2 (67.6)
	Crucigenia spp.	60.5 (60.5)	672.0 (38.0)	561.0 (374.0)	431.3 (188.1)	445.5 (2.50)	134.3 (44.7)	971.5 (428.5)	517.1 (244.3)
	Chlorosarcina spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	45.3 (45.3)	15.1 (15.1)
	Staurastrum spp.	21.3 (21.3)	44.4 (44.4)	0.0 (0.0)	21.9 (12.8)	88.5 (88.5)	44.8 (44.8)	0.0 (0.0)	44.4 (25.5)
	Scenedesmus spp.³	630.0 (630.0)	88.5 (88.5)	46.8 (46.8)	255.1 (187.8)	1065.0 (1065.0)	0.0 (0.0)	90.5 (90.5)	385.2 (340.9)
	Gloeocystis spp.³	4035.0 (1885.0)	3170.0 (3170.0)	1125.0 (1125.0)	2776.7 (862.8)	0.0 (0.0)	1074.0 (716.0)	90.5 (90.5)	388.2 (343.9)
	Gemellicystis spp.³	2085.0 (2085.0)	9335.0 (9335.0)	5005.0 (325.0)	5475.0 (2106.0)	4905.0 (205.0)	5015.0 (1165.0)	6725.0 (4275.0)	5548.3 (589.2)
	Treubaria spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Pediastrum spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Ankistrodesmus spp.	0.0 (0.0)	44.4 (44.4)	0.0 (0.0)	14.8 (14.8)	88.5 (88.5)	179.0 (179.0)	0.0 (0.0)	89.2 (51.7)
	Cosmarium spp.	170.0 (170.0)	0.0 (0.0)	0.0 (0.0)	56.7 (56.7)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	TOTAL	7146.3 (3696.7)	15822.1 (5862.4)	9453.4 (1494.3)	10807.3 (2594.4)	7572.9 (939.9)	7298.0 (493.8)	9009.4 (4749.3)	7960.1 (530.6)
	Pyrrhophyta								
	Dinoflagellates	359.5 (11.5)	1124.5 (415.5)	1545.0 (45.0)	1009.7 (347.0)	1023.0 (37.0)	761.5 (134.5)	952.5 (137.5)	912.3 (78.1)
	TOTAL	359.5 (11.5)	1124.5 (415.5)	1545.0 (45.0)	1009.7 (347.0)	1023.0 (37.0)	761.5 (134.5)	952.5 (137.5)	912.3 (78.1)
	Cyanophyta								
	Anabaena spp.	126.0 (126.0)	313.5 (41.5)	608.0 (47.0)	349.2 (140.3)	268.4 (179.7)	89.5 (89.5)	271.5 (90.5)	209.8 (60.2)
	Dactylococcopsis spp.	0.0 (0.0)	312.0 (131.0)	280.5 (93.5)	197.5 (99.2)	134.5 (134.5)	179.0 (179.0)	136.0 (136.0)	149.8 (14.6)
	TOTAL	126.0 (126.0)	625.5 (172.5)	888.5 (140.5)	546.7 (223.6)	402.9 (45.2)	268.0 (90.0)	407.5 (45.5)	359.5 (45.8)
	TOTAL	7971.8 (3972.2)	22014.1 (905.6)	17220.9 (2144.8)	15735.6 (4121.1)	12163.0 (692.3)	11013.1 (2060.7)	14581.7 (4433.1)	12585.9 (1051.7)

[1] single lorica species
[2] multiple lorica species
[3] cell count

Appendix 8. Temperature (°C) - dissolved oxygen (mg/L) data by depth.

Date	Depth (m)	Site 1		West Arm Site 2		Site 3		Site 4		East Arm Site 5		Site 6	
		Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.
5/29/87	1	23.1	8.37	23.4	8.29	23.7	8.00	23.2	8.63	23.4	8.63	23.6	8.77
	2	22.5	8.49	23.1	8.28	23.6	8.03	22.7	8.63	23.3	8.68	23.3	8.83
	3	20.6	9.06	20.6	8.45	21.8	7.74	20.4	9.67	19.7	9.82	21.1	9.44
	4	17.0	10.57	16.5	9.93	17.7	8.53	16.5	11.19	15.5	11.03	16.8	12.76
	5	12.3	7.13	13.0	3.52			12.7	8.83	13.5	8.53		
	6	10.9	4.52					10.9	5.77				
	7	10.2	2.62					10.2	2.41				
6/6/87	1	22.6	8.01	22.5	8.02	22.6	7.68	22.1	8.14	22.2	8.14	22.3	8.27
	2	22.2	7.99	22.4	8.01	22.4	7.51	22.2	8.16	22.1	8.18	22.3	8.25
	3	22.0	8.14	22.3	7.98	22.2	7.29	21.9	8.18	22.0	8.22	22.0	8.54
	4	17.6	9.69	18.9	9.56	19.1	8.41	18.8	9.96	21.6	8.37		
	5	14.6	7.12	14.6	4.53			14.3	8.60	13.6	6.57		
	6	11.8	4.02					12.3	5.29				
	7	10.9	0.94					10.9	1.75				
6/16/87	1	23.9	7.30	24.4	7.04	24.4	7.45	24.0	7.95	24.2	7.77	24.6	7.50
	2	23.4	7.26	23.9	7.11	24.2	7.17	24.0	7.77	24.2	7.80	24.2	7.42
	3	23.1	7.27	23.3	7.02	23.5	6.22	22.8	7.94	23.5	7.72	23.3	7.40
	4	21.4	7.26	21.4	6.81	21.7	5.70	21.7	8.05	22.8	7.56		
	5	16.4	6.42	16.0	4.85			16.7	8.49	15.5	6.41		
	6	13.6	3.84					13.2	5.05				
	7							11.8	1.65				
6/29/87	1	24.3	7.05	24.1	6.90	24.1	7.02	23.7	6.94	24.3	6.70	24.9	6.79
	2	24.0	7.02	23.8	7.04	23.3	7.02	23.7	7.01	24.1	6.89	24.2	6.70
	3	23.3	7.08	23.3	7.07	23.0	7.02	23.5	7.10	23.8	7.06	23.6	7.08
	4	23.1	7.11	22.3	7.11			23.3	7.22	23.6	7.25		
	5	17.8	5.45	19.4	5.15			18.6	6.69	17.2	5.79		
	6	15.1	3.49					15.2	4.37				
	7	12.9	2.82					13.2	1.99				
	8	12.2	1.48										
7/10/87	1	25.6	7.21	25.7	7.48	26.1	7.42	25.7	7.14	25.7	7.24	26.0	7.26
	2	25.5	7.18	25.6	7.44	26.0	7.54	25.7	7.14	25.8	7.16	26.0	7.19
	3	25.1	7.26	25.4	7.47	25.6	7.48	25.6	7.12	25.6	7.13	24.9	6.93
	4	24.4	6.92	24.3	5.99	24.9	6.61	24.4	6.95	24.9	7.11	24.7	7.03
	5	20.4	4.35	20.6	3.19			20.9	6.55	21.3	6.42		
	6	16.4	2.83					16.7	4.06				
	7	13.6	1.27					13.8	2.44				
7/20/87	S	24.7	6.47	25.0	6.49	24.9	6.55	24.9	6.45	24.8	6.45	25.2	6.09
	1	24.7	6.43	25.0	6.42	24.9	6.50	24.7	6.43	24.8	6.43	25.0	6.08
	2	24.5	6.37	24.8	6.39	24.8	6.37	24.7	6.43	24.6	6.37	24.8	6.18
	3	24.5	6.36	24.7	6.35	24.8	6.40	24.6	6.44	24.6	6.35	24.6	5.47
	4	24.5	6.34	24.3	5.90	24.3	5.56	24.5	6.39	24.5	6.25		
	5	22.0	4.15	22.7	2.65			22.4	5.33	23.1	4.73		
	6	16.9	1.85					17.7	3.62				
	7	14.7	1.50					14.8	2.20				

Appendix 8, cont. Temperature (°C) - dissolved oxygen (mg/L) data by depth.

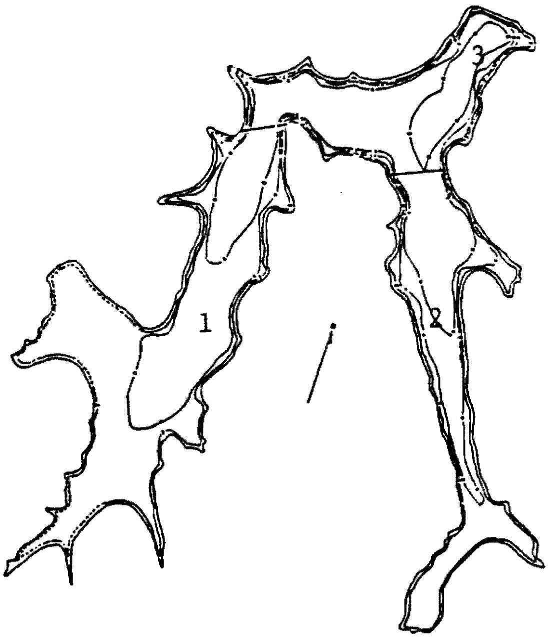
		Site 1		West Arm Site 2		Site 3		Site 4		East Arm Site 5		Site 6	
Date	Depth (m)	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.
7/29/87	S	25.7	6.73	25.9	6.82	25.9	6.87	25.4	6.85	25.4	6.78	25.4	6.46
	1	25.7	6.68	25.8	6.77	25.8	6.85	25.5	6.84	25.5	6.77	25.5	6.44
	2	25.7	6.67	25.8	6.73	25.8	6.84	25.5	6.82	25.5	6.76	25.5	6.43
	3	25.7	6.66	25.8	6.68	25.8	6.81	25.5	6.82	25.5	6.72	25.5	6.38
	4	25.7	6.63	25.7	6.62	25.7	6.03	25.6	6.82	25.5	6.71		
	5	24.0	4.19	23.4	2.42			23.3	5.13	23.3	4.37		
	6	18.5	1.25					18.6	3.32				
	7	16.5	0.60					15.1	1.40				
8/7/87	S	26.5	7.02	26.4	7.04	25.9	7.07	26.4	7.01	26.1	7.01	26.2	6.69
	1	26.5	7.01	26.3	7.02	26.1	7.03	26.4	7.00	26.2	7.00	26.2	6.68
	2	26.5	6.99	26.2	7.01	26.0	6.91	26.4	7.00	26.2	7.00	26.1	6.71
	3	26.4	7.00	26.2	6.99	25.9	6.93	26.3	7.00	26.1	6.95	26.0	6.56
	4	26.3	6.96	26.1	6.93	25.8	7.06	26.2	6.99	25.9	6.67	25.9	6.44
	5	24.2	4.74	23.9	2.81			24.5	5.62	24.0	4.09		
	6	19.3	1.30					19.9	1.94				
	7							15.7	0.45				
9/3/87	S	23.1	7.10	23.2	7.34	23.0	7.70	22.9	6.98	22.7	6.94	23.1	6.90
	1	23.1	7.07	23.2	7.17	23.0	7.48	22.9	6.94	22.6	6.94	22.8	6.82
	2	22.4	6.93	22.6	6.98	22.4	7.51	22.5	6.86	22.1	6.77	22.3	6.74
	3	22.1	6.95	22.3	7.14	22.0	7.71	22.2	6.82	22.0	6.58	22.1	6.63
	4	22.0	6.96	22.1	7.35	21.9	7.71	22.1	6.81	22.0	6.67	22.0	6.70
	5	21.9	6.93	21.9	7.26			22.0	6.60	22.0	6.67		
	6	21.8	6.30					21.8	6.02				
	7	17.7	0.12					17.2	0.12				
10/1/87	S	18.2	7.64	18.0	7.85	17.3	8.26	17.8	7.56	17.5	7.94	17.0	7.94
	1	18.2	7.60	18.0	7.84	17.5	8.21	18.2	7.57	17.8	7.90	17.0	7.85
	2	18.2	7.70	18.0	7.83	17.4	8.22	18.1	7.57	17.7	7.92	17.0	7.84
	3	18.1	7.74	18.0	7.89	17.2	8.30	18.1	7.57	17.7	7.92	16.8	7.94
	4	18.1	7.74	17.7	8.03	17.1	8.40	18.0	7.69	17.5	7.94	16.9	7.89
	5	17.9	7.29	17.4	8.04			17.9	7.73	17.3	7.93		
	6	17.8	7.80					17.7	7.77				
	7	17.8	7.76					17.6	7.75				
11/18/87	S	8.1	9.94	8.2	10.07	8.1	10.09	8.0	9.90	8.1	9.93	8.7	9.83
	1	8.1	9.92	8.2	10.09	8.1	10.10	8.0	9.88	8.2	9.90	8.5	9.90
	2	8.1	9.96	8.1	10.11	8.1	10.17	8.0	9.86	8.1	9.92	8.4	9.87
	3	8.0	9.95	8.1	10.13	8.1	10.21	8.0	9.84	8.1	9.90	8.4	9.92
	4	8.0	9.97	8.1	10.13	8.1	10.22	8.0	9.85	8.1	9.90	8.4	9.94
	5	8.0	9.99	8.0	10.16			8.0	9.87	8.1	9.91		
	6	7.9	9.97					8.0	9.87				
	7	7.9	9.85					8.0	9.86				

Appendix 9. Nutrient analysis (analyzed by Agriculture Engineering Laboratory, VPI&SU, in mg/L).

Date	Site/Depth	Total Phosphorus	Ortho-Phosphate	Total Kjeldahl Nitrogen	Nitrate Nitrogen	Ammonia Nitrogen
			Pre-Treatment			
6/12/87	W-1m	0.106	0.029	0.720	0.188	0.412
	W-4m	0.101	0.025	1.176	0.124	0.370
	E-1m	0.064	0.029	1.454	0.172	0.225
	E-4m	0.097	0.031	0.720	0.198	0.546
6/29/87	W-1m	0.078	0.046	1.883	0.222	0.517
	W-4m	0.077	0.037	1.992	0.104	0.410
	E-1m	0.087	0.031	0.965	0.218	0.289
	E-4m	0.073	0.046	0.985	0.214	0.379
7/10/87	W-1m	0.056	0.029	1.066	0.192	0.361
	W-4m	0.080	0.070	1.802	0.200	0.543
	E-1m	0.078	0.026	1.829	0.196	0.334
	E-4m	0.092	0.022	2.679	0.196	0.381
$\overline{X}$	W-1m	0.080 (0.014)	0.035 (0.006)	1.223 (0.345)	0.201 (0.011)	0.430 (0.046)
	W-4m	0.086 (0.008)	0.044 (0.013)	1.657 (0.247)	0.143 (0.029)	0.441 (0.052)
	E-1m	0.076 (0.007)	0.029 (0.001)	1.416 (0.250)	0.195 (0.013)	0.283 (0.032)
	E-4m	0.087 (0.007)	0.033 (0.007)	1.461 (0.614)	0.202 (0.006)	0.435 (0.055)
			Post-Treatment			
7/20/87	W-1m	0.046	0.033	2.232	0.196	0.443
	W-4m	0.092	0.039	1.710	0.138	0.336
	E-1m	0.092	0.008	4.405	0.196	0.276
	E-4m	0.061	0.014	1.512	0.148	0.314
8/7/87	W-1m	0.110	0.016	2.416	0.134	0.272
	W-4m	0.092	0.029	2.345	0.184	0.291
	E-1m	0.101	0.037	2.162	0.154	0.338
	E-4m	0.097	0.020	1.512	0.168	0.231
9/3/87	W-1m	0.069	0.039	1.015	0.152	0.316
	W-4m	0.064	0.040	1.292	0.146	0.314
	E-1m	0.073	0.020	1.454	0.132	0.405
	E-4m	1.334	0.026	1.066	0.110	0.320
$\overline{X}$	W-1m	0.075 (0.019)	0.029 (0.007)	1.888 (0.440)	0.161 (0.018)	0.344 (0.051)
	W-4m	0.083 (0.009)	0.036 (0.004)	1.782 (0.306)	0.156 (0.014)	0.314 (0.013)
	E-1m	0.089 (0.008)	0.022 (0.008)	2.674 (0.889)	0.161 (0.019)	0.340 (0.037)
	E-4m	0.497 (0.418)	0.020 (0.003)	1.363 (0.149)	0.142 (0.017)	0.288 (0.029)
Overall $\overline{X}$	W-1m	0.078 (0.011)	0.032 (0.004)	1.555 (0.291)	0.181 (0.013)	0.387 (0.036)
	W-4m	0.084 (0.005)	0.040 (0.006)	1.720 (0.178)	0.149 (0.015)	0.377 (0.037)
	E-1m	0.083 (0.005)	0.025 (0.004)	2.045 (0.500)	0.178 (0.013)	0.311 (0.025)
	E-4m	0.297 (0.208)	0.027 (0.005)	1.412 (0.283)	0.177 (0.016)	0.362 (0.043)

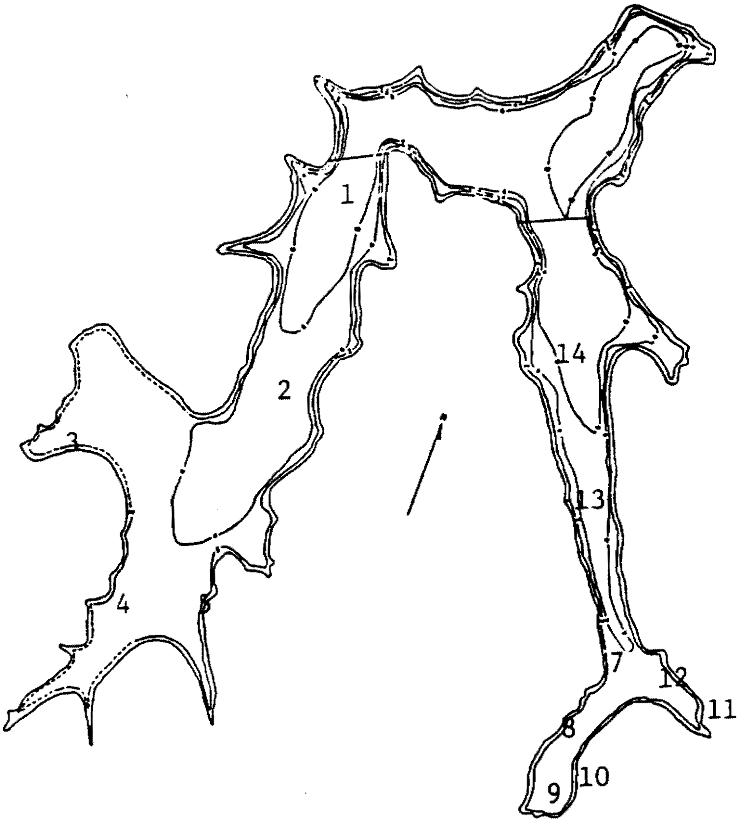
Appendix 10. Pre- and post-treatment water chemistry for Flat Top Lake conducted by International Science and Technology (IS&T), Sterling, VA. and site location map.

	Pre-Treatment (31 March 1987)			Post-Treatment (19 August 1987)			
	Station 1	Station 2	Station 3	Station 1		Station 2	Station 3
	Epilimnion	Epilimnion	Epilimnion	Epilimnion	Hypolimnion	Epilimnion	Epilimnion
Depth (m)	1.5	1.5	1.5	1.5	6.5	1.5	1.5
pH	6.83	6.79	6.85	7.02	6.41	7.19	7.23
ANC (µeq/L)	113.6	109.1	117.8	218.5	241.8	239.5	233.8
DIC (mg/L)	1.72	1.59	1.65	2.94	5.90	3.08	2.74
DOC (mg/L)	2.38	2.40	2.62	2.14	1.67	2.14	1.99
Cond (µS/cm)	278.0	269.0	275.0	226.0	253.0	231.0	231.0
Ca (mg/L)	6.73	6.56	6.74	7.91	6.72	8.03	7.34
Cd (mg/L)				0.000	0.000	0.001	0.001
Fe (mg/L)				0.03	0.04	0.03	0.03
Mn (mg/L)				0.00	1.45	0.00	0.00
Zn (mg/L)	0.009	0.010	0.008	0.005	0.008	0.002	0.011
Mg (mg/L)				2.204	2.092	2.214	2.215
Na (mg/L)	41.35	48.80	39.51	29.918	31.178	30.075	29.603
Al (mg/L)	0.016	0.013	0.004	0.005	0.001	0.002	0.006
Pb (mg/L)				0.002	0.002	0.002	0.002
SO_4 (mg/L)				5.78	5.37	5.80	5.97
Cl (mg/L)	70.90	67.50	68.90	52.90	65.60	53.60	54.60
TN (mg/L)	0.115		0.104	0.280	0.439	0.291	0.280
TP (mg/L)	0.005	0.005	0.006	0.005	0.004	0.006	0.007
NO_3 (mg/L)				0.248	0.403	0.283	0.265



Appendix 11. Selected pre-treatment (6 June 1987) and post-treatment (4 September 1987) sediment chemistry data for Flat Top Lake with site location map. Analyzed by the Soil Testing and Plant Analysis Laboratory (VPI&SU). Site location map included.

	pH		Ca^{2+} (mg/L)		Phosphorus (mg/L)	
Station	Pre	Post	Pre	Post	Pre	Post
1	5.3	5.5	360	540	7	8
2	5.5	5.4	552	420	4	5
3	6.0	5.5	492	360	4	4
4	5.5	5.4	300	276	3	3
5	6.0	5.4	348	396	3	3
7	5.7	5.4	564	384	3	3
8	5.5	5.4	336	384	2	3
9	5.3	5.3	396	276	2	3
10	5.4	5.1	348	228	3	4
11	5.6	5.3	276	336	3	3
12	5.5	5.5	420	636	3	3
13		5.2		312		4
14		5.2		420		4



Appendix 12. Zooplankton genera and copepod groups (#/L, µg/L). (SE) from site means.

		West Arm								East Arm							
		Site 1		Site 2		Site 3		Mean		Site 4		Site 5		Site 6		Mean	
Date	Group	#/L	µg/L	#/L	µg/L	#/L	µg/L	#/L	µg/L	#/L	µg/L	#/L	µg/L	#/L	µg/L	#/L	µg/L
5/25/87	**Cladocerans**																
	Daphnia spp.	3.1	10.2	3.3	14.4	6.8	36.8	4.4 (1.20)	20.5 (8.26)	1.4	8.1	4.0	14.2	1.1	3.8	2.2 (0.92)	8.7 (3.02)
	Ceriodaphnia spp.	0.0	0.0	0.1	0.1	0.4	0.8	0.2 (0.12)	0.3 (0.25)	0.1	0.2	0.0	0.0	0.2	0.6	0.1 (0.06)	0.3 (0.18)
	Bosmina spp.	10.6	6.8	32.7	25.5	184.5	245.4	75.9 (54.7)	92.6 (76.6)	10.1	12.4	59.8	45.4	413.3	409.2	161.1 (126.9)	155.7 (127.1)
	Diaphanosoma spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0.0)	0.0 (0.0)	0.0	0.0	0.0	0.0	0.1	0.2	0.0 (0.03)	0.1 (0.07)
	Alona spp.	0.1	0.1	0.0	0.0	0.0	0.0	0.0 (0.03)	0.0 (0.03)	0.0	0.0	0.2	1.4	0.0	0.0	0.1 (0.07)	0.5 (0.47)
	Chydorus spp.	0.2	0.1	1.2	0.5	0.0	0.0	0.5 (0.37)	0.2 (0.15)	0.4	0.1	0.1	0.0	0.2	0.1	0.2 (0.09)	0.1 (0.03)
	TOTAL	14.0	17.2	37.3	40.5	191.7	283.0	81.0 (55.8)	113.6 (85.0)	12.0	20.8	64.1	61.0	414.9	413.9	163.7 (126.5)	165.2 (124.9)
	Copepods																
	Cyclopoid (Adult)	6.4	13.0	7.1	18.2	8.5	50.4	7.3 (0.62)	27.2 (11.7)	6.7	19.5	10.8	65.6	6.6	25.3	8.0 (1.38)	36.8 (14.5)
	Calanoid (Adult)	3.8	15.5	6.4	44.8	9.1	74.8	6.4 (1.53)	45.0 (17.1)	3.4	10.6	6.9	47.7	5.7	20.3	5.3 (1.03)	26.2 (11.1)
	Sub-Adults	19.9	4.2	23.7	3.8	48.0	7.1	30.5 (8.80)	5.0 (1.04)	16.5	2.7	17.0	3.9	28.9	5.4	20.8 (4.05)	4.0 (0.78)
	TOTAL	30.1	32.7	37.2	66.8	65.6	132.2	44.3 (10.8)	77.3 (29.2)	26.6	32.8	34.7	117.2	41.2	51.0	34.2 (4.22)	67.0 (25.6)
	Rotifers																
	Asplanchna spp.	0.2	0.3	0.3	0.5	0.1	0.1	0.2 (0.06)	0.3 (0.12)	0.4	0.6	0.9	1.4	1.0	1.5	0.8 (0.19)	1.2 (0.28)
	Keratella spp.	18.6	2.1	38.1	4.2	33.6	3.7	30.1 (5.89)	3.3 (0.63)	24.0	2.6	59.4	6.5	53.6	5.9	45.7 (11.0)	5.0 (1.21)
	Conochilus spp.	178.0	14.2	270.5	21.6	220.8	17.7	223.1 (26.7)	17.8 (2.14)	129.5	10.4	548.0	43.8	476.7	38.1	384.7 (129.3)	30.8 (10.3)
	Ptygura spp.	1.2	0.1	1.7	0.7	2.4	0.2	1.8 (0.35)	0.3 (0.19)	2.3	0.2	5.9	0.6	2.4	0.2	3.5 (1.18)	0.3 (0.13)
	Polyarthra spp.	8.3	6.2	11.6	8.6	26.4	19.5	15.4 (5.57)	11.4 (4.09)	11.1	8.2	17.8	13.2	3.6	2.7	10.8 (4.10)	8.0 (3.03)
	Gastropus spp.	13.5	2.8	9.9	2.1	2.4	0.5	8.6 (3.27)	1.8 (0.68)	11.7	2.5	20.8	4.4	6.0	1.3	12.8 (4.31)	2.7 (0.90)
	Kellicottia spp.	3.6	0.4	2.5	0.3	0.0	0.0	2.0 (1.07)	0.2 (0.12)	4.1	0.4	1.5	0.2	0.0	0.0	1.9 (1.20)	0.2 (0.12)
	Trichocerca spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0.0)	0.0 (0.0)	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0.0)	0.0 (0.0)
	TOTAL	223.4	26.1	334.6	38.0	285.7	41.7	281.2 (32.2)	35.3 (4.71)	183.1	24.9	654.3	70.1	543.3	49.7	460.2 (142.2)	48.2 (13.1)
	TOTAL	267.5	76.0	409.1	145.3	543.0	457.0	406.5 (79.5)	226.1 (117.2)	221.7	78.5	753.1	248.3	999.4	514.6	658.1 (230.5)	280.5 (127.0)

Appendix 12, cont. Zooplankton genera and copepod groups (#/L, μg/L). (SE) from site means.

Date	Group	West Arm								East Arm							
		Site 1		Site 2		Site 3		Mean		Site 4		Site 5		Site 6		Mean	
		#/L	μg/L	#/L	μg/L	#/L	μg/L	#/L	μg/L	#/L	μg/L	#/L	μg/L	#/L	μg/L	#/L	μg/L
6/12/87	**Cladocerans**																
	Daphnia spp.	30.7	139.6	27.7	95.7	9.2	30.9	22.5 (6.72)	88.7 (31.6)	10.3	71.1	6.0	31.9	6.7	20.6	7.7 (1.33)	41.2 (15.3)
	Ceriodaphnia spp.	0.8	1.1	1.0	2.3	1.2	1.7	1.0 (0.12)	1.7 (0.35)	0.6	1.5	0.8	1.6	1.2	1.9	0.9 (0.18)	1.7 (0.12)
	Bosmina spp.	8.1	5.7	16.2	20.4	14.8	13.3	13.0 (2.50)	13.1 (4.24)	3.8	2.8	4.2	3.9	1.5	0.8	3.2 (0.84)	2.5 (0.91)
	Diaphanosoma spp.	0.5	0.5	0.3	0.9	0.9	1.1	0.6 (0.18)	0.8 (0.18)	0.1	0.3	0.3	0.3	0.7	0.6	0.4 (0.18)	0.4 (0.10)
	Alona spp.	0.1	0.3	0.0	0.0	0.0	0.0	0.0 (0.03)	0.1 (0.10)	0.1	0.2	0.1	0.1	0.0	0.0	0.1 (0.03)	0.1 (0.06)
	Chydorus spp.	0.1	0.1	0.3	0.3	0.0	0.0	0.1 (0.09)	0.1 (0.09)	0.1	0.0	0.6	0.2	1.5	0.5	0.7 (0.41)	0.2 (0.15)
	TOTAL	40.3	147.3	45.5	119.6	26.1	47.0	37.3 (5.80)	104.6 (29.9)	15.0	75.9	12.0	38.0	11.6	24.4	12.9 (1.07)	46.1 (15.4)
	Copepods																
	Cyclopoid (Adult)	6.6	75.9	10.2	77.0	7.7	34.5	8.2 (1.07)	62.5 (14.0)	3.2	8.2	5.2	35.1	8.3	48.0	5.6 (1.48)	30.4 (11.7)
	Calanoid (Adult)	4.2	21.3	5.7	46.4	2.0	10.1	4.0 (1.07)	25.9 (10.7)	1.8	7.0	1.8	7.9	1.7	8.8	1.8 (0.03)	7.9 (0.52)
	Sub-Adults	17.5	1.9	21.3	2.5	43.9	4.8	27.6 (8.24)	3.1 (0.88)	16.3	2.6	28.7	2.9	21.0	2.8	22.0 (3.61)	2.8 (0.09)
	TOTAL	28.3	99.1	37.2	125.9	53.6	49.4	39.7 (7.41)	91.5 (22.4)	21.3	17.8	35.7	45.9	31.0	59.6	29.3 (4.24)	41.1 (12.3)
	Rotifers																
	Asplanchna spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0.00)	0.0 (0.00)	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0.00)	0.0 (0.00)
	Keratella spp.	98.6	10.8	33.2	3.7	44.9	4.9	58.9 (20.1)	6.5 (2.19)	94.6	10.4	128.7	14.2	196.2	21.6	139.8 (29.9)	15.4 (3.29)
	Conochilus spp.	32.8	2.6	14.5	1.2	3.2	0.3	16.8 (8.62)	1.4 (0.67)	25.5	2.0	28.7	2.3	3.0	0.2	19.1 (8.09)	1.5 (0.66)
	Ptygura spp.	2.9	0.3	6.6	0.7	7.4	0.7	5.6 (1.39)	0.6 (0.13)	2.0	0.2	4.1	0.4	4.8	0.5	3.6 (0.84)	0.4 (0.09)
	Polyarthra spp.	17.7	13.1	4.2	3.1	4.8	3.5	8.9 (4.40)	6.6 (3.27)	2.5	1.9	2.9	2.2	1.2	0.9	2.2 (0.51)	1.7 (0.39)
	Gastropus spp.	9.9	2.1	4.2	0.9	1.1	0.2	5.1 (2.58)	1.1 (0.55)	2.0	0.4	2.3	0.5	0.0	0.0	1.4 (0.72)	0.3 (0.15)
	Kellicottia spp.	3.2	0.3	1.2	0.1	1.1	0.1	1.8 (0.68)	0.2 (0.07)	4.0	0.4	0.0	0.0	0.0	0.0	1.3 (1.33)	0.1 (0.13)
	Trichocerca spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0.0)	0.0 (0.0)	0.0	0.0	0.0	0.0	0.6	0.2	0.2 (0.20)	0.1 (0.07)
	TOTAL	165.1	29.2	63.9	9.7	62.5	9.7	97.2 (34.0)	16.2 (6.50)	130.6	15.3	166.7	19.6	205.8	23.4	167.7 (21.7)	19.4 (2.34)
	TOTAL	233.7	275.6	146.6	255.2	142.2	106.1	174.2 (29.8)	212.3 (53.4)	166.9	109.0	214.4	103.5	248.4	107.4	209.9 (23.6)	106.6 (1.63)

Appendix 12, cont. Zooplankton genera and copepod groups (#/L, μg/L). (SE) from site means.

		West Arm								East Arm							
		Site 1		Site 2		Site 3		Mean		Site 4		Site 5		Site 6		Mean	
Date	Group	#/L	μg/L	#/L	μg/L	#/L	μg/L	#/L	μg/L	#/L	μg/L	#/L	μg/L	#/L	μg/L	#/L	μg/L
6/29/87	**Cladocerans**																
	Daphnia spp.	19.8	254.2	13.5	170.8	3.5	22.1	12.3 (4.75)	149.0 (67.9)	11.3	113.5	4.8	36.9	0.6	1.6	5.6 (3.11)	50.7 (33.0)
	Ceriodaphnia spp.	0.2	0.3	0.2	0.4	0.5	0.8	0.3 (0.10)	0.5 (0.15)	0.1	0.3	1.4	2.6	1.3	3.0	0.9 (0.42)	2.0 (0.84)
	Bosmina spp.	1.9	1.6	6.6	8.4	8.1	5.0	5.5 (1.87)	5.0 (1.96)	1.2	1.0	1.5	1.2	4.0	3.2	2.2 (0.89)	1.8 (0.70)
	Diaphanosoma spp.	0.1	0.3	0.4	1.0	0.2	0.4	0.2 (0.09)	0.6 (0.22)	0.0	0.1	0.2	0.4	0.0	0.0	0.1 (0.07)	0.2 (0.12)
	Alona spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0.00)	0.0 (0.00)	0.0	0.0	0.1	0.4	0.0	0.0	0.0 (0.03)	0.1 (0.13)
	Chydorus spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0.00)	0.0 (0.00)	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0.00)	0.0 (0.00)
	TOTAL	22.0	256.4	20.7	180.6	12.3	28.3	18.3 (3.04)	155.1 (67.1)	12.6	114.9	8.0	41.5	5.9	7.8	8.8 (1.98)	54.7 (31.6)
	Copepods																
	Cyclopoid (Adult)	0.8	3.8	1.4	14.5	1.2	7.0	1.1 (0.18)	8.4 (3.17)	0.9	4.6	2.3	16.6	5.6	12.0	2.9 (1.39)	11.1 (3.50)
	Calanoid (Adult)	1.1	1.9	1.2	4.8	1.2	4.8	1.2 (0.03)	3.8 (0.97)	0.8	1.8	0.3	1.2	0.3	1.3	0.5 (0.17)	1.4 (0.19)
	Sub-Adults	13.8	2.1	6.8	0.9	12.0	1.2	10.9 (2.10)	1.4 (0.36)	7.6	1.0	16.6	1.9	33.5	3.7	19.2 (7.59)	2.2 (0.79)
	TOTAL	15.7	7.8	9.4	20.2	14.4	13.0	13.2 (1.92)	13.7 (3.60)	9.3	7.4	19.2	19.7	39.4	17.0	22.6 (8.86)	14.7 (3.73)
	Rotifers																
	Asplanchna spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0.00)	0.0 (0.00)	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0.00)	0.0 (0.00)
	Keratella spp.	18.9	2.1	26.2	2.9	23.9	2.6	23.0 (2.15)	2.5 (0.23)	19.5	2.2	31.3	3.4	42.7	4.7	31.2 (6.70)	3.4 (0.72)
	Conochilus spp.	19.6	1.6	33.9	2.7	23.9	1.9	25.8 (4.24)	2.1 (0.33)	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0.00)	0.0 (0.00)
	Ptygura spp.	0.6	0.1	0.0	0.0	2.8	0.3	1.1 (0.85)	0.1 (0.09)	0.7	0.1	2.6	0.3	1.3	0.1	1.5 (0.56)	0.2 (0.07)
	Polyarthra spp.	3.6	2.7	19.8	14.6	6.0	4.4	9.8 (5.05)	7.2 (3.72)	9.0	6.6	7.1	5.3	41.1	30.4	19.1 (11.0)	14.1 (8.16)
	Gastropus spp.	0.0	0.0	0.0	0.0	2.8	0.6	0.9 (0.93)	0.2 (0.20)	0.0	0.0	0.6	0.1	0.0	0.0	0.2 (0.20)	0.0 (0.03)
	Kellicottia spp.	32.0	3.2	10.3	1.0	0.0	0.0	14.1 (9.43)	1.4 (0.95)	43.8	4.4	2.1	0.2	0.0	0.0	15.3 (14.3)	1.5 (1.43)
	Trichocerca spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0.0)	0.0 (0.0)	0.7	0.3	0.6	0.2	0.0	0.0	0.4 (0.22)	0.2 (0.09)
	TOTAL	74.7	9.7	90.2	21.2	59.4	9.8	74.8 (8.89)	13.6 (3.82)	73.7	13.6	44.3	9.5	85.1	35.2	67.7 (12.2)	19.4 (7.97)
	TOTAL	112.4	273.9	120.3	222.0	86.1	51.1	106.3 (10.3)	182.3 (67.3)	95.6	135.9	71.5	70.7	130.4	60.0	99.2 (17.1)	88.9 (23.7)

Appendix 12, cont. Zooplankton genera and copepod groups (#/L, μg/L). (SE) from site means.

		West Arm								East Arm							
		Site 1		Site 2		Site 3		Mean		Site 4		Site 5		Site 6		Mean	
Date	Group	#/L	μg/L	#/L	μg/L	#/L	μg/L	#/L	μg/L	#/L	μg/L	#/L	μg/L	#/L	μg/L	#/L	μg/L
7/21/87	**Cladocerans**																
	Daphnia spp.	7.4	69.9	3.2	23.8	0.2	1.7	3.6 (2.09)	31.8 (20.1)	4.8	64.6	1.4	10.9	0.5	2.5	2.2 (1.31)	26.0 (19.5)
	Ceriodaphnia spp.	0.2	0.2	1.9	2.6	0.5	0.8	0.9 (0.52)	1.2 (0.72)	0.3	0.7	1.2	2.5	9.0	16.5	3.5 (2.76)	6.6 (4.99)
	Bosmina spp.	5.7	4.1	13.7	8.8	6.3	3.8	8.6 (2.57)	5.6 (1.62)	0.8	0.4	0.8	0.4	2.6	1.7	1.4 (0.60)	0.8 (0.43)
	Diaphanosoma spp.	0.3	0.4	1.1	1.1	0.2	0.3	0.5 (0.28)	0.6 (0.25)	0.0	0.0	0.0	0.0	0.2	0.3	0.1 (0.07)	0.1 (0.10)
	Alona spp.	0.0	0.0	0.1	0.5	0.0	0.0	0.0 (0.03)	0.2 (0.17)	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0.00)	0.0 (0.00)
	Chydorus spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0.00)	0.0 (0.00)	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0.00)	0.0 (0.00)
	TOTAL	13.6	74.6	20.0	36.8	7.2	6.6	13.6 (3.70)	39.3 (19.7)	5.9	65.7	3.4	13.8	12.3	21.0	7.2 (2.65)	33.5 (16.2)
	Copepods																
	Cyclopoid (Adult)	1.1	7.2	0.7	3.9	0.4	0.3	0.7 (0.20)	3.8 (1.99)	0.5	3.7	1.2	6.3	2.1	5.0	1.3 (0.46)	5.0 (0.75)
	Calanoid (Adult)	2.1	7.6	2.2	8.8	0.8	2.6	1.7 (0.45)	6.3 (1.90)	1.1	2.9	0.4	1.9	1.5	5.5	1.0 (0.32)	3.4 (1.07)
	Sub-Adults	14.6	1.6	28.8	2.0	22.9	1.7	22.1 (4.12)	1.8 (0.12)	8.1	0.9	20.3	1.2	17.6	1.0	15.3 (3.70)	1.0 (0.09)
	TOTAL	17.8	16.4	31.7	14.7	24.1	4.6	24.5 (4.02)	11.9 (3.68)	9.7	7.5	21.9	9.4	21.2	11.5	17.6 (3.96)	9.5 (1.16)
	Rotifers																
	Asplanchna spp.	1.1	1.6	1.8	2.7	0.6	0.9	1.2 (0.35)	1.7 (0.52)	0.6	0.8	0.6	0.9	0.7	1.0	0.6 (0.03)	0.9 (0.06)
	Keratella spp.	14.8	1.6	10.3	1.1	8.6	0.9	11.2 (1.85)	1.2 (0.21)	8.4	0.9	6.3	0.7	8.2	0.9	7.6 (0.67)	0.8 (0.07)
	Conochilus spp.	4.8	0.4	3.4	0.3	0.0	0.0	2.7 (1.43)	0.2 (0.12)	13.7	1.1	18.5	1.5	19.8	1.6	17.3 (1.86)	1.4 (0.15)
	Ptygura spp.	17.3	1.7	32.5	3.3	25.7	2.6	25.2 (4.40)	2.5 (0.46)	52.4	5.2	109.1	10.9	26.8	2.7	62.8 (24.3)	6.3 (2.43)
	Polyarthra spp.	2.6	1.9	2.5	1.9	1.6	1.2	2.2 (0.32)	1.7 (0.23)	2.1	1.6	1.0	0.7	6.4	4.8	3.2 (1.65)	2.4 (1.24)
	Gastropus spp.	4.8	1.0	0.3	0.1	0.4	0.1	1.8 (1.48)	0.4 (0.30)	9.5	2.0	3.9	0.8	1.2	0.3	4.9 (2.44)	1.0 (0.50)
	Kellicottia spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0.00)	0.0 (0.00)	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0.00)	0.0 (0.00)
	Trichocerca spp.	0.6	0.2	0.9	0.3	0.0	0.0	0.5 (0.26)	0.2 (0.09)	0.4	0.1	0.0	0.0	1.2	0.4	0.5 (0.35)	0.2 (0.12)
	TOTAL	46.0	8.4	51.7	9.7	36.9	5.7	44.9 (4.31)	7.9 (1.18)	87.1	11.7	139.4	15.5	64.3	11.7	96.9 (22.2)	13.0 (1.27)
	TOTAL	77.4	99.4	103.4	61.2	68.2	16.9	83.0 (10.5)	59.2 (23.8)	102.7	84.9	164.7	38.7	97.8	44.2	121.7 (21.5)	55.9 (14.6)

Appendix 12, cont. Zooplankton genera and copepod groups (#/L, μg/L). (SE) of duplicate tows.

		West Arm								East Arm							
		Site 1		Site 2		Site 3		Mean		Site 4		Site 5		Site 6		Mean	
Date	Group	#/L	μg/L	#/L	μg/L	#/L	μg/L	#/L	μg/L	#/L	μg/L	#/L	μg/L	#/L	μg/L	#/L	μg/L
8/7/87	**Cladocerans**																
	Daphnia spp.	7.4	80.0	3.4	26.5	2.1	6.8	4.3 (1.59)	37.8 (21.9)	5.8	85.2	3.2	25.0	0.6	1.3	3.2 (1.50)	37.2 (25.0)
	Ceriodaphnia spp.	0.6	0.7	1.9	2.7	3.2	5.4	1.9 (0.75)	2.9 (1.36)	0.2	0.3	0.8	1.3	21.6	39.6	7.5 (7.04)	13.7 (12.9)
	Bosmina spp.	0.9	0.4	5.4	3.3	8.2	5.8	4.8 (2.13)	3.2 (1.56)	0.3	0.1	2.8	2.2	6.3	4.8	3.1 (1.74)	2.4 (1.36)
	Diaphanosoma spp.	0.2	0.2	2.1	1.9	2.9	3.3	1.7 (0.78)	1.8 (0.90)	0.2	0.3	0.6	0.7	3.6	4.0	1.5 (1.07)	1.7 (1.17)
	Alona spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0.00)	0.0 (0.00)	0.0	0.0	0.1	0.2	0.0	0.0	0.0 (0.03)	0.1 (0.07)
	Chydorus spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0.00)	0.0 (0.00)	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0.00)	0.0 (0.00)
	TOTAL	9.1	81.3	12.8	34.4	16.3	21.3	12.7 (2.08)	45.7 (18.2)	6.5	85.9	7.5	29.4	32.1	49.7	15.4 (8.37)	55.0 (16.5)
	Copepods																
	Cyclopoid (Adult)	1.0	7.6	1.4	7.8	1.5	1.9	1.3 (0.15)	5.8 (1.93)	0.7	5.5	1.4	2.6	5.5	6.7	2.5 (1.50)	4.9 (1.22)
	Calanoid (Adult)	2.6	7.7	3.5	19.6	4.6	11.9	3.6 (0.58)	13.1 (3.48)	2.4	6.9	3.0	10.3	5.8	9.4	3.7 (1.05)	8.9 (1.02)
	Sub-Adults	14.4	1.6	24.5	2.5	36.3	3.9	25.1 (6.33)	2.7 (0.67)	10.1	1.1	17.5	2.1	27.3	3.0	18.3 (4.98)	2.1 (0.55)
	TOTAL	18.0	16.9	29.4	29.9	42.4	17.7	29.9 (7.05)	21.5 (4.21)	13.2	13.5	21.9	15.0	38.6	19.1	24.6 (7.45)	15.9 (1.67)
	Rotifers																
	Asplanchna spp.	3.0	4.5	6.1	9.1	20.2	30.3	9.8 (5.29)	14.6 (7.95)	1.2	1.7	1.2	1.9	2.0	3.0	1.5 (0.27)	2.2 (0.40)
	Keratella spp.	16.0	1.8	48.0	5.3	51.7	5.7	38.6 (11.3)	4.3 (1.24)	24.1	2.7	47.5	5.2	56.0	6.2	42.5 (9.54)	4.7 (1.04)
	Conochilus spp.	19.7	1.6	41.0	3.3	100.1	8.0	53.6 (24.0)	4.3 (1.91)	4.9	0.4	13.0	1.0	10.3	0.8	9.4 (2.38)	0.7 (0.18)
	Ptygura spp.	69.0	6.9	69.8	7.0	48.8	4.9	62.5 (6.87)	6.3 (0.68)	60.1	6.0	114.2	11.4	66.7	6.7	80.3 (17.0)	8.0 (1.70)
	Polyarthra spp.	4.6	3.4	7.7	5.7	0.0	0.0	4.1 (2.24)	3.0 (1.66)	7.6	5.6	8.5	6.3	17.3	12.8	11.1 (3.09)	8.2 (2.29)
	Gastropus spp.	15.2	3.2	10.6	2.2	8.6	1.8	11.5 (1.95)	2.4 (0.42)	4.2	0.9	10.3	2.2	1.7	0.4	5.4 (2.55)	1.2 (0.54)
	Kellicottia spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0.00)	0.0 (0.00)	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0.00)	0.0 (0.00)
	Trichocerca spp.	0.6	0.2	1.3	0.5	1.6	0.6	1.2 (0.30)	0.4 (0.12)	0.7	0.3	0.9	0.3	0.0	0.0	0.5 (0.27)	0.2 (0.10)
	TOTAL	128.1	21.6	184.5	33.1	231.0	51.3	181.2 (29.8)	35.3 (8.65)	102.8	17.6	195.6	28.3	154.0	29.9	150.8 (26.8)	25.3 (3.86)
	TOTAL	155.2	119.8	226.7	97.4	289.7	90.3	223.9 (38.9)	102.5 (8.89)	122.5	117.0	225.0	72.7	224.7	98.7	190.7 (34.1)	96.1 (12.9)

Appendix 12, cont. Zooplankton genera and copepod groups (#/L, µg/L). (SE) from site means.

		West Arm								East Arm							
		Site 1		Site 2		Site 3		Mean		Site 4		Site 5		Site 6		Mean	
Date	Group	#/L	µg/L	#/L	µg/L	#/L	µg/L	#/L	µg/L	#/L	µg/L	#/L	µg/L	#/L	µg/L	#/L	µg/L
9/3/87	**Cladocerans**																
	Daphnia spp.	4.7	25.3	1.1	3.7	0.4	2.4	2.1 (1.33)	10.5 (7.43)	2.7	20.7	11.9	47.0	7.6	44.8	7.4 (2.66)	37.5 (8.42)
	Ceriodaphnia spp.	1.0	2.0	3.2	4.3	6.2	9.0	3.5 (1.51)	5.1 (2.06)	0.4	0.6	0.5	0.9	3.6	8.0	1.5 (1.05)	3.2 (2.42)
	Bosmina spp.	0.7	0.3	3.7	3.0	10.0	6.1	4.8 (2.74)	3.1 (1.68)	0.7	0.4	1.5	1.1	5.5	3.6	2.6 (1.48)	1.7 (0.97)
	Diaphanosoma spp.	0.2	0.2	0.2	0.2	0.3	0.5	0.2 (0.03)	0.3 (0.10)	0.0	0.0	0.1	0.3	0.2	0.3	0.1 (0.06)	0.2 (0.10)
	Alona spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0.00)	0.0 (0.00)	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0.00)	0.0 (0.00)
	Chydorus spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0.00)	0.0 (0.00)	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0.00)	0.0 (0.00)
	TOTAL	6.6	27.8	8.2	11.2	16.9	18.0	10.6 (3.20)	19.0 (4.82)	3.8	21.7	14.0	49.3	16.9	56.7	11.6 (3.97)	42.6 (10.6)
	Copepods																
	Cyclopoid (Adult)	2.9	9.9	4.6	9.4	4.2	2.6	3.9 (0.51)	7.3 (2.35)	4.1	13.8	4.2	7.7	10.5	20.6	6.3 (2.12)	14.0 (3.73)
	Calanoid (Adult)	3.9	15.8	5.7	13.7	4.7	14.1	4.8 (0.52)	14.5 (0.64)	1.5	3.0	3.4	10.6	5.8	24.3	3.6 (1.24)	12.6 (6.23)
	Sub-Adults	9.6	0.9	13.7	1.4	25.2	2.6	16.2 (4.67)	1.6 (0.50)	9.7	1.2	9.7	0.9	18.3	2.0	12.6 (2.87)	1.4 (0.33)
	TOTAL	16.4	26.6	24.0	24.5	34.1	19.3	24.8 (5.13)	23.5 (2.17)	15.3	18.0	17.3	19.2	34.6	46.9	22.4 (6.13)	28.0 (9.44)
	Rotifers																
	Asplanchna spp.	0.7	1.1	0.7	1.1	0.3	0.5	0.6 (0.13)	0.9 (0.20)	0.4	0.5	0.0	0.0	0.5	0.7	0.3 (0.15)	0.4 (0.21)
	Keratella spp.	8.9	1.0	44.2	4.9	73.8	8.1	42.3 (18.8)	4.7 (2.05)	7.7	0.9	10.0	1.1	21.8	2.4	13.2 (4.37)	1.5 (0.47)
	Conochilus spp.	42.3	3.4	6.2	0.5	30.6	2.5	26.4 (10.6)	2.1 (0.86)	47.6	3.8	13.4	1.1	3.5	0.3	21.5 (13.4)	1.5 (0.47)
	Ptygura spp.	18.4	1.8	29.8	3.0	39.1	3.9	29.1 (5.99)	2.9 (0.61)	23.8	2.4	51.2	5.1	48.2	4.8	41.1 (8.68)	4.1 (0.85)
	Polyarthra spp.	5.9	4.4	10.8	1.6	10.1	7.5	8.9 (1.53)	4.5 (1.70)	0.7	0.5	7.8	5.8	16.5	12.2	8.3 (4.57)	6.2 (3.38)
	Gastropus spp.	0.7	0.1	0.5	0.1	0.0	0.0	0.4 (0.21)	0.1 (0.03)	0.0	0.0	0.4	0.1	2.4	0.5	0.9 (0.74)	0.2 (0.15)
	Kellicottia spp.	0.0	0.0	0.0	0.0	0.6	0.1	0.2 (0.20)	0.0 (0.03)	1.1	0.1	0.0	0.0	0.0	0.0	0.4 (0.37)	0.0 (0.03)
	Trichocerca spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0.0)	0.0 (0.0)	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0.00)	0.0 (0.00)
	TOTAL	76.9	11.8	92.2	11.2	154.5	22.6	107.9 (23.7)	15.2 (3.70)	81.3	8.2	82.8	13.2	92.9	20.9	85.7 (3.64)	14.1 (3.69)
	TOTAL	99.9	66.2	124.4	46.9	205.5	59.9	143.3 (31.9)	57.7 (5.68)	100.4	47.9	114.1	81.7	144.4	124.5	119.6 (13.0)	84.7 (22.2)

Appendix 13. Average size estimates (μg) for cladocerans and copepods for each sample on a site-specific basis. (SE) of site estimates.

	West			East			West	East
Date	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	$\bar{X}$	$\bar{X}$
Cladocerans - Daphnia spp. Pre-Treatment								
5/25/87	3.28	4.36	5.41	5.86	3.54	3.45	4.35 (0.61)	4.28 (0.79)
6/12/87	4.54	3.45	3.35	6.90	5.33	3.07	3.78 (0.38)	5.10 (1.11)
6/29/87	12.82	12.68	6.28	10.02	7.70	2.92	10.59 (2.16)	6.88 (2.09)
$\bar{X}$	6.88 (2.99)	6.83 (2.94)	5.01 (0.87)	7.59 (1.25)	5.52 (1.20)	3.15 (0.16)	6.24 (1.27)	5.42 (0.82)
Post-Treatment								
7/21/87	9.50	7.36	8.09	13.48	7.80	5.51	8.32 (0.63)	8.93 (2.37)
8/7/87	10.77	7.74	3.21	14.79	7.75	2.03	7.24 (2.20)	8.19 (3.69)
9/3/87	5.35	3.34	5.38	7.62	3.96	5.87	4.69 (0.68)	5.82 (1.06)
$\bar{X}$	8.54 (1.64)	6.15 (1.41)	5.56 (1.41)	11.96 (2.20)	6.50 (1.27)	4.47 (1.22)	6.75 (0.87)	7.65 (1.38)
Overall $\bar{X}$	7.71 (1.57)	6.49 (1.46)	5.29 (0.75)	9.78 (1.50)	6.01 (0.81)	3.81 (0.63)	6.50 (0.75)	6.53 (0.82)
Ceriodaphnia spp. Pre-Treatment								
5/25/87		1.17	2.25	3.53		3.17	1.71 (0.54)	3.35 (0.18)
6/12/87	1.50	2.22	1.40	2.52	2.09	1.58	1.71 (0.26)	2.06 (0.27)
6/29/87	1.43	2.14	1.46	2.40	1.82	2.30	1.68 (0.23)	2.17 (0.18)
$\bar{X}$	1.47 (0.04)	1.84 (0.34)	1.70 (0.27)	2.82 (0.36)	1.96 (0.14)	2.35 (0.46)	1.70 (0.15)	2.43 (0.23)
Post-Treatment								
7/21/87	1.03	1.32	1.62	2.17	2.09	1.84	1.32 (0.17)	2.03 (0.10)
8/7/87	1.32	1.40	1.69	1.56	1.58	1.83	1.47 (0.11)	1.66 (0.09)
9/3/87	2.07	1.37	1.46	1.59	1.84	2.24	1.63 (0.22)	1.89 (0.19)
$\bar{X}$	1.47 (0.31)	1.36 (0.02)	1.59 (0.07)	1.77 (0.20)	1.84 (0.15)	1.97 (0.14)	1.48 (0.10)	1.86 (0.09)
Overall $\bar{X}$	1.47 (0.17)	1.60 (0.16)	1.65 (0.13)	2.30 (0.30)	1.88 (0.10)	2.16 (0.23)	1.58 (0.09)	2.13 (0.13)
Bosmina spp. Pre-Treatment								
5/25/87	0.64	0.78	1.33	1.22	0.76	0.99	0.92 (0.21)	0.99 (0.13)
6/12/87	0.70	1.27	0.90	0.73	0.92	0.52	0.96 (0.17)	0.72 (0.12)
6/29/87	0.88	1.27	0.62	0.79	0.77	0.80	0.92 (0.19)	0.79 (0.01)
$\bar{X}$	0.74 (0.07)	1.11 (0.16)	0.95 (0.21)	0.91 (0.15)	0.82 (0.05)	0.77 (0.14)	0.93 (0.10)	0.83 (0.06)
Post-Treatment								
7/21/87	0.71	0.64	0.60	0.56	0.49	0.65	0.65 (0.03)	0.57 (0.05)
8/7/87	0.52	0.61	0.70	0.41	0.81	0.76	0.61 (0.05)	0.66 (0.13)
9/3/87	0.47	0.82	0.61	0.53	0.71	0.66	0.63 (0.10)	0.63 (0.05)
$\bar{X}$	0.57 (0.07)	0.69 (0.07)	0.64 (0.03)	0.50 (0.05)	0.67 (0.09)	0.69 (0.04)	0.63 (0.03)	0.62 (0.04)
Overall $\bar{X}$	4.31 (2.45)	6.76		4.60	4.53 (1.77)		5.13 (1.63)	4.55 (1.25)

Appendix 13, cont. Average size estimates (µg) for cladocerans and copepods for each sample on a site-specific basis. (SE) for site estimates.

	West			East			West	East
Date	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	$\bar{X}$	$\bar{X}$
				Cladocerans - Diaphanosoma spp. Pre-Treatment				
5/25/87						2.12		2.12
6/12/87	1.04	3.04	1.22	1.90	1.06	0.96	1.77 (0.64)	1.31 (0.30)
6/29/87	3.25	2.71	2.23	2.85	2.05		2.73 (0.29)	2.45 (0.40)
$\bar{X}$	2.15 (1.11)	2.88 (0.17)	1.73 (0.51)	2.38 (0.48)	1.56 (0.50)	1.54 (0.58)	2.25 (0.38)	1.82 (0.29)
				Post-Treatment				
7/21/87	1.03	0.99	1.41			1.33	1.14 (0.13)	1.33
8/7/87	0.95	0.91	1.17	1.70	1.30	1.13	1.01 (0.08)	1.38 (0.17)
9/3/87	1.44	1.09	1.56		1.81	1.24	1.36 (0.14)	1.53 (0.29)
$\bar{X}$	1.14 (0.15)	1.00 (0.05)	1.38 (0.11)	1.70	1.56 (0.26)	1.23 (0.06)	1.17 (0.08)	1.42 (0.11)
Overall $\bar{X}$	1.54 (0.44)	1.75 (0.46)	1.52 (0.19)	2.15 (0.35)	1.56 (0.23)	1.36 (0.20)	1.60 (0.21)	1.62 (0.16)
				Alona spp. Pre-Treatment				
5/25/87	1.86				6.93		1.86	6.93
6/12/87	6.76			4.60	1.07		6.76	2.84 (1.77)
6/29/87					5.60			5.60
$\bar{X}$	4.31 (2.45)			4.60	4.53 (1.77)		4.31 (2.45)	4.55 (1.25)
				Post-Treatment				
7/21/87		6.76					6.76	
8/7/87								
9/3/87								
$\bar{X}$		6.76					6.76	
Overall $\bar{X}$	4.31 (2.45)	6.76		4.60	4.53 (1.77)		5.13 (1.63)	4.55 (1.25)
				Chydorus spp. Pre-Treatment				
5/25/87	0.31	0.44		0.34	0.27	0.27	0.38 (0.07)	0.29 (0.02)
6/12/87	2.02	0.83		0.27	0.28	0.35	1.43 (0.60)	0.30 (0.03)
6/29/87								
$\bar{X}$	1.17 (0.86)	0.64 (0.20)		0.31 (0.04)	0.28 (0.01)	0.31 (0.04)	0.90 (0.39)	0.30 (0.02)
				Post-Treatment				
7/21/87								
8/7/87								
9/3/87								
$\bar{X}$								
Overall $\bar{X}$	1.17 (0.86)	0.64 (0.20)		0.31 (0.04)	0.28 (0.01)	0.31 (0.04)	0.90 (0.39)	0.30 (0.02)

Appendix 13, cont. Average size estimates (μg) for cladocerans and copepods for each sample on a site-specific basis. (SE) for site estimates.

	West			East			West	East
Date	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	$\bar{X}$	$\bar{X}$
			Calanoid Copepods Pre-Treatment					
5/25/87	4.10	6.99	8.22	3.12	6.88	3.55	6.44 (1.22)	4.52 (1.19)
6/12/87	5.12	8.15	5.21	3.96	4.45	5.29	6.16 (1.00)	4.57 (0.39)
6/29/87	1.79	3.99	4.15	2.20	4.69	4.79	3.31 (0.76)	3.89 (0.85)
$\bar{X}$	3.67 (0.99)	6.38 (1.24)	5.86 (1.22)	3.09 (0.51)	5.34 (0.77)	4.54 (0.52)	5.30 (0.71)	4.33 (0.45)
			Post-Treatment					
7/21/87	3.61	4.10	3.17	2.72	4.63	3.69	3.63 (0.27)	3.68 (0.55)
8/7/87	2.98	5.61	2.58	2.86	3.49	1.62	3.72 (0.95)	2.66 (0.55)
9/3/87	4.09	2.41	2.98	1.95	3.12	4.15	3.16 (0.49)	3.07 (0.64)
$\bar{X}$	3.56 (0.32)	4.04 (0.92)	2.91 (0.17)	2.51 (0.28)	3.75 (0.45)	3.15 (0.78)	3.50 (0.33)	3.14 (0.33)
Overall $\bar{X}$	3.62 (0.46)	5.21 (0.87)	4.39 (0.86)	2.80 (0.29)	4.54 (0.54)	3.85 (0.52)	4.40 (0.44)	3.73 (0.31)
			Cyclopoid Copepods Pre-Treatment					
5/25/87	2.02	2.55	5.96	2.91	6.10	3.83	3.51 (1.23)	4.28 (0.95)
6/12/87	11.48	7.58	4.48	2.60	6.80	5.80	7.85 (2.03)	5.07 (1.27)
6/29/87	5.03	10.42	6.12	5.22	7.30	2.13	7.19 (1.65)	4.88 (1.50)
$\bar{X}$	6.18 (2.79)	6.85 (2.30)	5.52 (0.52)	3.58 (0.83)	6.73 (0.35)	3.92 (1.06)	6.18 (1.07)	4.74 (0.64)
			Post-Treatment					
7/21/87	6.54	5.43	0.66	8.12	5.33	2.41	4.21 (1.80)	5.29 (1.65)
8/7/87	7.89	5.59	1.28	7.79	1.87	1.23	4.95 (1.96)	3.63 (2.09)
9/3/87	3.46	2.05	0.62	3.40	1.84	1.96	2.04 (0.82)	2.40 (0.50)
$\bar{X}$	5.99 (1.33)	4.36 (1.15)	0.85 (0.21)	6.44 (1.52)	3.01 (1.16)	1.87 (0.34)	3.73 (0.92)	3.77 (0.89)
Overall $\bar{X}$	6.09 (1.38)	5.60 (1.28)	3.19 (1.07)	5.01 (1.00)	4.87 (0.99)	2.89 (0.68)	4.96 (0.75)	4.26 (0.54)
			Sub-Adult Copepods Pre-Treatment					
5/25/87	0.21	0.16	0.15	0.17	0.23	0.19	0.17 (0.02)	0.20 (0.02)
6/12/87	0.11	0.12	0.11	0.16	0.10	0.14	0.11 (0.003)	0.13 (0.02)
6/29/87	0.15	0.12	0.10	0.14	0.12	0.11	0.12 (0.01)	0.12 (0.01)
$\bar{X}$	0.16 (0.03)	0.13 (0.01)	0.12 (0.02)	0.16 (0.01)	0.15 (0.04)	0.15 (0.02)	0.14 (0.01)	0.15 (0.01)
			Post-Treatment					
7/21/87	0.11	0.07	0.08	0.11	0.06	0.06	0.09 (0.01)	0.08 (0.02)
8/7/87	0.11	0.10	0.11	0.11	0.12	0.11	0.11 (0.003)	0.11 (0.01)
9/3/87	0.09	0.10	0.10	0.12	0.09	0.11	0.10 (0.003)	0.11 (0.003)
$\bar{X}$	0.10 (0.01)	0.09 (0.01)	0.10 (0.01)	0.11 (0.003)	0.09 (0.02)	0.09 (0.02)	0.10 (0.005)	0.10 (0.01)
Overall $\bar{X}$	0.13 (0.02)	0.11 (0.01)	0.11 (0.01)	0.14 (0.01)	0.12 (0.02)	0.12 (0.02)	0.12 (0.01)	0.13 (0.01)

Appendix 14. Age-and-growth data from bluegill otolith analysis.

ID #	Capture Arm-Date	Total Length (mm)	Daily Age Past Swim-up (SE)	Swim-up Date	Growth (mm/day) after Swim-up
67	E-8/10	13.3	16 (0.00)	7/25	0.46
5	E-8/10	11.7	15 (0.58)	7/26	0.38
20	E-8/10	12.8	17 (1.20)	7/24	0.40
38	E-8/10	21.1	34 (0.33)	7/7	0.44
34	E-8/10	20.5	31 (0.88)	7/10	0.47
37	E-8/11	18.1	30 (0.33)	7/12	0.40
56	E-8/11	20.0	33 (0.88)	7/9	0.42
63	E-8/11	20.3	34 (0.33)	7/8	0.42
24	E-8/11	20.8	33 (0.33)	7/9	0.45
18	E-8/11	18.4	33 (1.53)	7/9	0.38
49	E-8/11	18.1	34 (0.88)	7/8	0.36
64	E-8/11	20.3	35 (0.00)	7/7	0.41
10	E-8/11	15.5	26 (0.33)	7/16	0.36
15	E-8/11	16.1	23 (1.76)	7/19	0.44
25	E-8/11	20.0	33 (0.88)	7/9	0.42
33	E-8/10	17.3	29 (0.00)	7/12	0.39
7	E-8/10	17.9	34 (0.67)	7/7	0.35
14	E-8/10	14.1	17 (1.53)	7/24	0.48
121	E-7/29	14.4	21 (0.88)	7/8	0.40
143	E-7/29	14.7	21 (0.67)	7/8	0.41
16	E-7/29	12.0	17 (1.15)	7/12	0.35
96	E-7/29	15.7	22 (0.00)	7/7	0.44
81	E-7/29	15.5	19 (0.33)	7/10	0.50
93	E-7/29	11.7	17 (0.33)	7/12	0.34
77	E-7/29	11.7	15 (0.58)	7/14	0.38
69	E-7/29	14.7	19 (0.67)	7/10	0.46
94	E-7/29	12.3	20 (0.58)	7/9	0.31
68	E-7/29	16.3	21 (1.00)	7/8	0.49
119	W-8/10	15.2	17 (0.00)	7/24	0.54
47	W-8/10	20.0	32 (0.67)	7/9	0.44
115	W-8/10	19.7	34 (1.20)	7/7	0.40
22	W-8/10	16.8	30 (0.33)	7/11	0.36
71	W-8/10	16.9	27 (0.67)	7/14	0.40
40	W-8/10	17.7	30 (0.33)	7/11	0.39
13	W-8/10	14.9	17 (0.58)	7/24	0.53
19	W-8/10	18.4	26 (0.33)	7/15	0.48
17	W-8/10	16.4	20 (0.33)	7/21	0.52
30	W-8/10	19.5	34 (0.33)	7/7	0.40
54	W-8/10	18.9	32 (0.88)	7/9	0.40
26	W-8/10	19.5	32 (0.67)	7/9	0.42
53	W-8/10	20.5	32 (1.53)	7/9	0.45
35	W-8/10	22.1	34 (0.58)	7/7	0.47
51	W-7/29	16.3	22 (1.00)	7/7	0.47
6	W-7/29	16.3	18 (0.00)	7/11	0.57
32	W-7/29	14.7	20 (0.67)	7/9	0.43
62	W-7/29	14.4	20 (0.58)	7/9	0.42
12	W-7/29	14.4	21 (0.33)	7/8	0.40
73	W-7/29	14.4	19 (0.33)	7/10	0.44
42	W-7/29	16.0	18 (0.67)	7/11	0.55
58	W-7/29	14.7	21 (0.33)	7/8	0.41
87	W-7/29	15.5	21 (0.88)	7/8	0.45

Vita

David A. Coahran was born on February 3, 1963 in Terre Haute, Indiana to Beverly and Rev. J. Alan Coahran. While as a kid, all he ever cared about was going 4 for 4 and getting 5 RBI's, scoring 20 points per game, or catching a "hawg" bass. Unfortunately, some things never change, but he has to wake up and smell the coffee sometime and it took alot of coffee (and diet pepsi's) to finish this thesis. Dave completed high school at New Albany High School where he learned how to accept defeat on the football field but was on a pretty decent baseball team. He then spent 1.5 years playing baseball and taking sports journalism at Indiana University where he found out he couldn't turn on a 90 mph inside fastball or conduct very good interviews. But he seemed to always catch more fish than his partner and had a keen interest in knowing more about fish and their environment. Dave transferred to Purdue University where he got a B.S. in fisheries science in December 1985 and, after a brief stint with the Indiana Department of Natural Resources, enrolled in the prestigious Department of Fisheries and Wildlife at VPI&SU in June 1986. In September 1988, Dave took a fisheries position for the MN-DNR out of Spicer, MN. where he currently resides. This thesis was finally put to rest sometime around the X-mas season 1989. Merry Christmas!

David Coahran