Fish and Wildlife Habitat Assessment of the Buffalo River Area of Concern and Watershed

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In 1987, the International Joint Commission (IJC) Great Lakes Water Quality Board identified 42 Areas of Concern (AOC) within the Great Lakes Basin (a 43rd AOC has since been added to the list). For each of the AOC's, the IJC mandates the development of Remedial Action Plans, outlining the environmental problems and identifying the remedial measures to alleviate the problems.

The lower 9.2 Km of the Buffalo River is a designated AOC because of its impaired water quality and contaminated sediments. A Stage 1 RAP for the Buffalo River was completed in November 1989 by the New York State Department of Environmental Conservation (DEC) and a Buffalo River Citizen's Committee. A fish and wildlife habitat inventory and assessment was one of the RAP recommendations. The DEC conducted fieldwork as part of an EPA funded study (project title: Buffalo River Habitat Assessment). The goals of this study are to complement the efforts of the DEC's study. In addition, the data will represent a "benchmark" for the 1990's and serve as a means to evaluate remediation progress.

This report has three main sections: evaluation of siltation rates; biological surveys of fish and invertebrates; and physical characteristics of bank and channel. Each section indicates the individual(s) responsible for carrying out all the work. All comments regarding this report can be directed to J. Singer, who served as project coordinator. If you would like to obtain copies of videos, computer disks, or other materials described in this report, please contact J. Singer.

TABLE OF CONTENTS

PART I: Evaluation of Suspended Sediment Dynamics and Siltation Rates*

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* Compiled by Kim Irvine

INTRODUCTION

It is now well-known that suspended sediment may have a negative impact on aquatic habitat and organisms. Many organic and inorganic pollutants preferentially are adsorbed and transported by fines and the particulate matter itself can influence organism reproduction and growth cycles (e.g. Benes et al., 1985; Allen, 1986; Forstner and Wittmann, 1983; Loganathan et al., 1993; Stuber et al., 1982a,b). As a result, information on suspended sediment dynamics is essential when modelling chemical transport and fate for investigations related to habitat remediation (e.g. Atkinson et al., 1994; DePinto et al., 1994). The U.S. Fish and Wildlife Service has developed general guidelines for aquatic habitat suitability that consider levels of total suspended solids or the surrogate measure of turbidity. For example, Stuber et al. (1982b) indicated that the optimal level of suspended solids ranges between 5 and 25 mg l^{-1} for largemouth bass, a species that has been found in the Buffalo River. There are a variety of negative impacts that high suspended sediment concentrations can have on fishes, including reduced feeding due to poorer visual capabilities and shorter reactive distance; suffocation and physiological responses in gills; siltation and suffocation of eggs; lower disease resistance due to stress; and changes in school distribution within the water column. The impacts appear species and life-cycle dependent and Monahan and Poole (in prep.) have provided a detailed review of the suspended sediment and turbidity impacts on different fishes.

The objectives of this chapter are threefold:

1. Review past studies and available data related to: i) suspended sediment concentrations and loads to the Buffalo River Area of Concern (AOC); ii) identification of sediment sources; and iii) calculated or modelled siltation rates within the Buffalo River AOC.

2. Evaluate suspended sediment data collected at U.S. Geological Survey gauge stations on the major tributaries to the river. The concentration and loading dynamics to the AOC from "upstream sources" accordingly can be assessed.

3. Evaluate siltation rates within the Buffalo River AOC using bathymetric and dredging data collected by the Buffalo District Corps of Engineers.

The first objective is met primarily through critical review of available literature. The second objective is addressed through a combination of fieldwork, laboratory analyses and statistical evaluation of the data (including development of suspended sediment rating curves). The third objective primarily is achieved through summary of the dredging records from the Corps of Engineers, available for the period 1970-92. In addition, InterGraph's Terrain Modeler software was used to analyse the most recent bathymetric data from a test reach. Scour and deposition patterns were evaluated and this information was presented in various spatial formats (e.g. contouring, three-dimensional plots). The various information collected through these different evaluation approaches should provide a clearer view of the current suspended sediment regime as it pertains to the Buffalo River AOC.

REVIEW OF PAST STUDIES

Suspended Sediment Concentrations and Loads - The Historical Context

The sediment regime of the Buffalo River historically has been modified by anthropogenic activities. The level and type of activity within the watershed has been dynamic throughout the past 200 years, which suggests that the suspended sediment concentration and loading time series will be non-stationary. In 1810, a report by commissioners investigating a location for the western terminus of the Erie Canal suggested that the Buffalo Creek (see Figure 1) may be appropriate, with the provision that the sandbar at the mouth of the creek be removed to accomodate navigation (Sauer, 1979). To help assure a favorable response from the canal commission, the sandbar was removed in 1821 through a combination of dam works and dredging (Brown and Watson, 1981; Goldman, 1983). The dam was constructed to divert high spring flows that would help to scour a channel through the bar. In addition, a pier was constructed of timber cribs filled with stone and rock to discourage further flow of sand to the bar (Figure 1b). The Erie Canal was completed in 1825 and since that time the river and harbor have been dredged and expanded to accomodate ship traffic. By 1836 the river was being maintained at a 10 ft depth (Baxter and Heyl, 1965). Goldman (1983) noted that throughout the middle of the 19th century, the federal government funded a variety of harbor improvement projects in Buffalo. Harbor space quadrupled between 1821 and 1855. The dredging activities essentially were conducted to maintain Buffalo's position first as a commercial hub and subsequently as a manufacturing hub. The extent of channel and waterfront modification can be seen in Figures 1 through 3. The changes in the hydraulic geometry of the river and landuse along the river (Figures 1 through 3) are illustrations of the dynamics of the system that can influence suspended sediment regime.

Historically, there have been three major sources of suspended sediment to the Buffalo River AOC: soil, bed and bank erosion in the upper watershed; discharges of municipal wastes (including sanitary, combined and stormwater discharges); and discharges of industrial wastes. Symons (1940) noted that prior to 1938, 15% of Buffalo's domestic sewage and 30% of its industrial wastes were discharged directly to the Buffalo River. The Buffalo Sewer Authority sponsored two water quality studies of the Buffalo River in an effort to document the impact of the primary sewage treatment plant that began operation in 1938. Sampling for various water quality parameters was done monthly in the river between April, 1936 and December, 1939. Sampling was done again in 1946 and the water quality results were summarized by Symons (1940; 1946). Based on industrial and domestic sewage discharge sampling and monitoring, Symons (1940) indicated that prior to 1938, approximately 51,450 lbs d^{-1} (9,390 tons yr^{-1}) of suspended solids were introduced to the

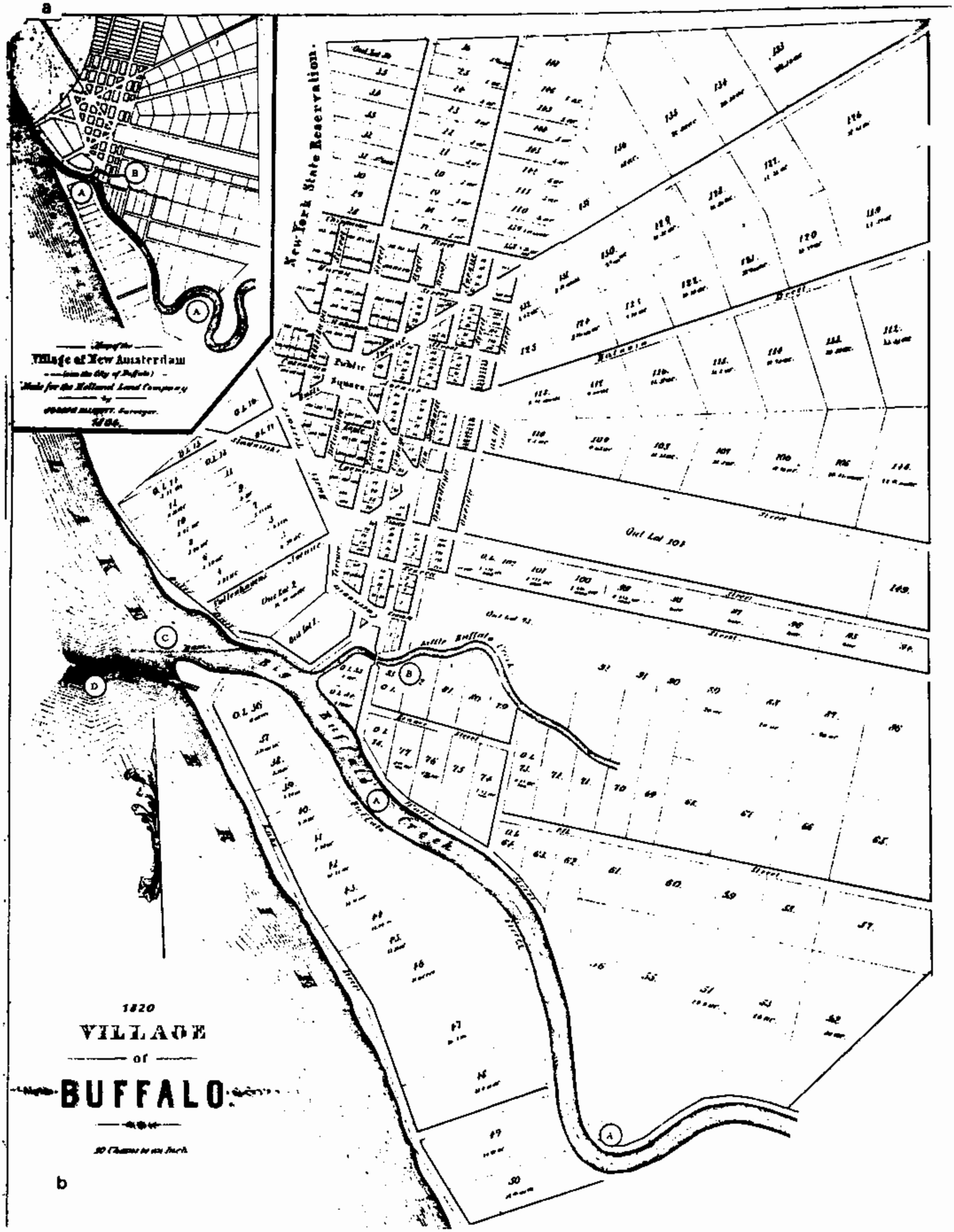

Figure 1 The Buffalo River as it existed in: a) 1804; and b) 1820 (from Baxter and Heyl, 1965). The letter C refers to the diversion dam and the letter D refers to the pier constructed of timber cribs.

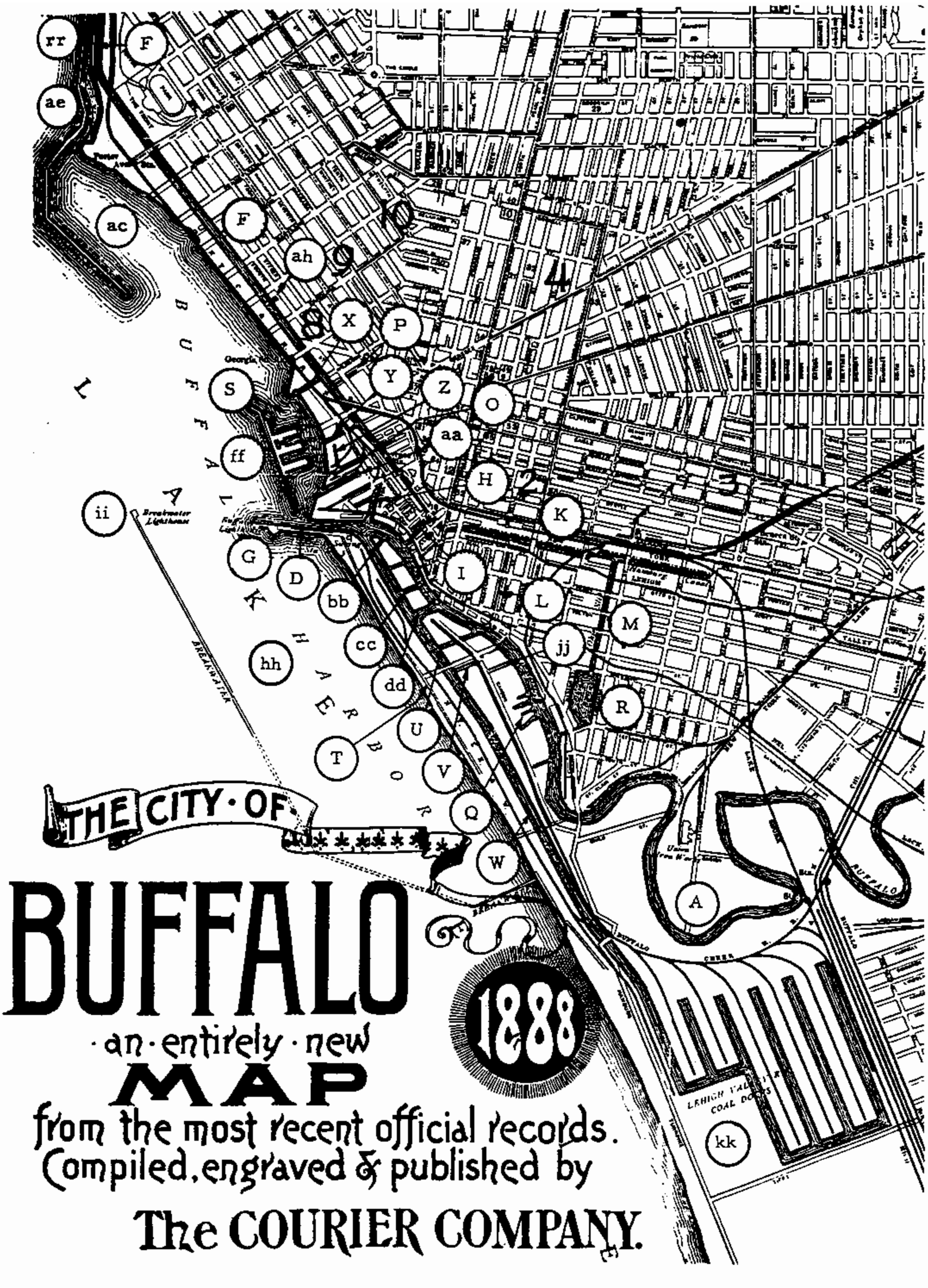

Figure 2 The Buffalo River as it existed in 1888. Although shown on the map, the three eastern slips of the Lehigh Valley Basin were never constructed (from Baxter and Heyl, 1965).

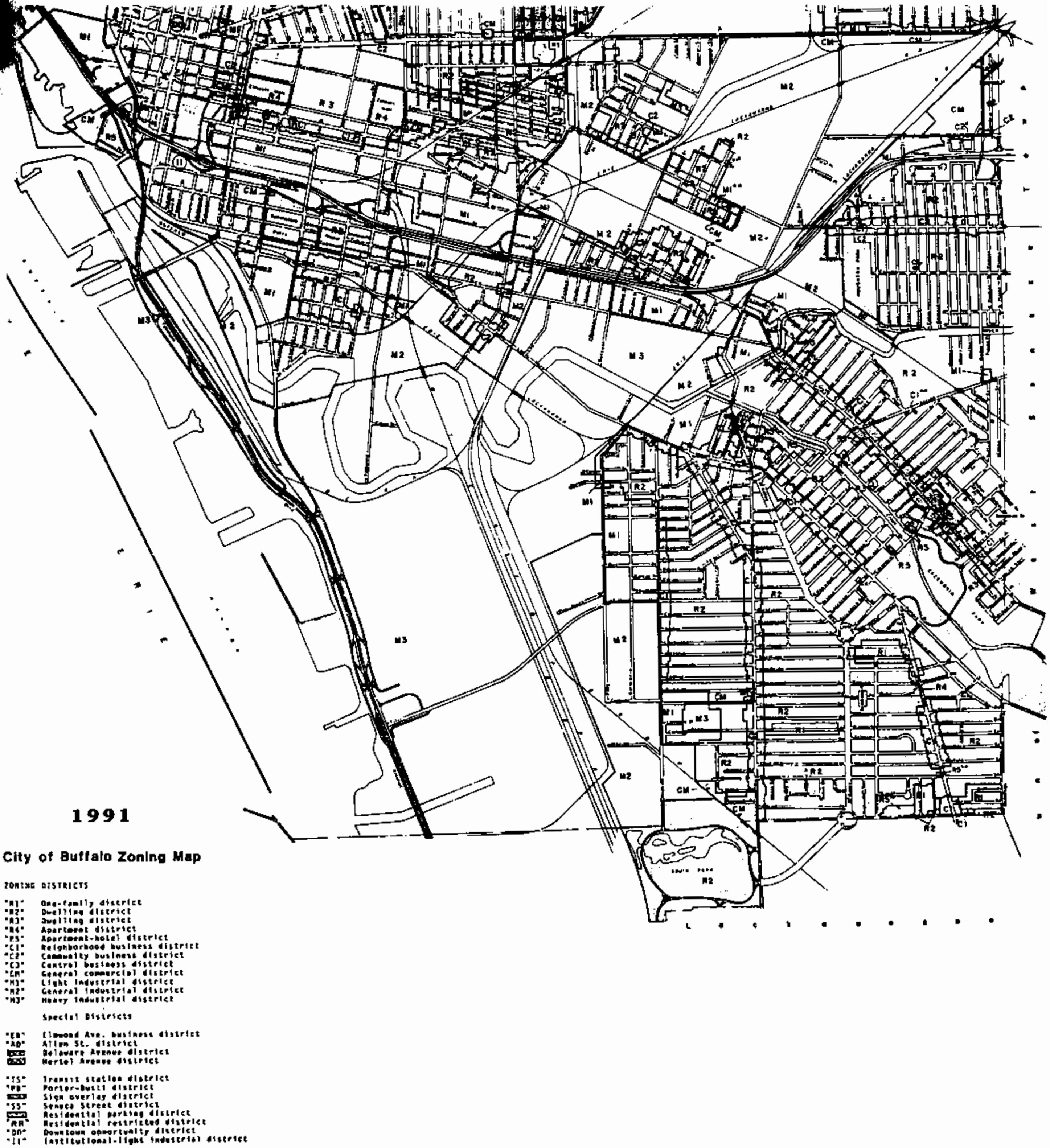

Figure 3 The Buffalo River as it currently exists.

river from these sources. The sanitary sewage represented 40% (20,700 lbs d^{-1}) of this total discharge. The pre-1938 discharge rate produced a dilution factor that averaged less than one part of diluting (river) water to one part of waste for 5 to 8 months of the year. The discharge rate of total suspended solids was reduced to 27,000 lbs d^{-1} (4,928 tons yr^{-1}) after 1938 with the construction of the primary sewage treatment plant on Bird Island and improved industrial processing. Symons (1940) also made calculations of suspended solids entering and leaving the river, based on the 43 (monthly) sample observations (Table 1). These data included both storm event and interevent sampling. Table 1 indicates that prior to 1938, inputs to the AOC from Buffalo's industrial and sanitary discharges accounted for 20% of the total suspended sediment load, the remainder primarily coming from upstream erosion. After 1938, Buffalo's industrial and sanitary discharges accounted for 30% of the suspended solids load. The relative increase in contribution primarily is an artifact of the sample framework, representing differences in discharge rates. Nonetheless, it was concluded in 1940 that upstream erosion contributed the largest proportion of suspended sediment to the AOC.

Hall (1955) summarized the costs of damages in the Buffalo River watershed due to siltation. Four areas of damage were identified: i) harbor dredging costs; ii) damage to highways (e.g. ditch clearing; roadway buckling and failure due to roadbed saturation caused by silt impeding drainage); iii) damage to industrial water supplies; iv) damage to agricultural areas from infertile washover and "swamping" of the land. Based on the analysis of 26 sediment samples collected in the harbor (locations not given), the U.S. Geological Survey concluded that 96.8% of the deposited sediment originated from the watershed (Hall, 1955). Although the results presented by Symons (1940) suggest that the industrial input was proportionally higher, deposition of the sediment in the harbor was not specifically evaluated in the earlier report. As noted, Symons (1940) also had concluded "upstream" inputs contributed the largest proportion of suspended sediment to the AOC. Hall (1955) used the Musgrave equation (a forerunner of the Universal Soil Loss Equation, but having similar physical parameters) to estimate average annual sheet erosion within the basin. A combination of erosion stakes and aerial photographs taken in 1938 and 1950 were used to estimate average annual loss to streambank erosion. Assuming a 25% delivery ratio from sheet erosion and a 100% delivery ratio from streambank erosion, Hall (1955) calculated that upstream input to the AOC was on the order of 827,459 tons yr^{-1}. This input clearly is greater than that calculated by Symons (1940), based on suspended sediment sampling. The differences in sediment input estimates may be related to model assumptions, assumptions with respect to the delivery ratio, and the flow conditions under which sampling was done. Hall (1955) also summarized dredging records from the Corps of Engineers for the period 1944-1955 and concluded, on average, 261,393 yd^3 of sediment was removed per year. The mass associated with this average volume was calculated as 169,611 tons, which suggests a trap efficiency of 20.5%. Industrial and sanitary inputs to the AOC were not considered by Hall (1955) in these calculations.

Parsons et al. (1963) examined suspended sediment characteristics of the three major tributaries to the Buffalo River: Buffalo Creek; Cazenovia Creek; and Cayuga Creek. Storm

Table 1 Calculations of Sedimentation Rates (from Symons, 1940)

	Before July, 1938	After July, 1938
Average Discharge	346 cfs	239 cfs
Suspended Solids Entering AOC	218,000 lbs d^{-1} (39,785 tons yr^{-1})	61,500 lbs d^{-1} (11,224 tons yr^{-1})
Suspended Solids Added in AOC	51,000 lbs d^{-1} (9,308 tons yr^{-1})	27,000 lbs d^{-1} (4,928 tons yr^{-1})
TOTAL SUSPENDED SOLIDS	269,000 lbs d^{-1} (49,093 tons yr^{-1})	88,500 lbs d^{-1} (16,152 tons yr^{-1})
Suspended Solids Leaving AOC	225,000 lbs d^{-1} (41,062 tons yr^{-1})	70,000 lbs d^{-1} (12,775 tons yr^{-1})
SEDIMENTATION	44,000 lbs d^{-1} (8,031 tons yr^{-1})	18,500 lbs d^{-1} (3,377 tons yr^{-1})

Table 2 Seasonal Variation in Parson's Watershed Erodibility Factor (K) (from Meredith and Rumer, 1987)

Month	Buffalo Cr. (K)	Cayuga Cr. (K)	Cazenovia Cr. (K)
January	1.5	0.8	1.0
February	1.4	1.1	1.2
March	2.0	1.6	1.7
April	1.8	1.6	2.0
May	1.9	1.7	2.1
June	2.7	2.2	2.6
July	2.8	2.4	2.9
August	3.1	2.4	2.9
September	2.7	2.3	2.5
October	2.2	2.1	1.8
November	1.8	1.7	1.6
December	1.4	0.9	1.0

event sampling was conducted between 1953 and 1961 at the U.S. Geological Survey (USGS) gauge stations on each of the tributaries (Figure 4). A relationship between discharge and suspended sediment concentration was developed for each site, having the general form:

$$[1] \qquad C = K \cdot Q^{0.85}$$

where C is suspended sediment concentration (mg l^{-1}), Q is discharge (cfs), and K is considered an empirical constant reflecting the relative erodibility and exposure of the soil to an eroding agent. Values of K for each flood were calculated as:

$$[2] \qquad K = C/Q^{0.85}$$

Parsons et al. (1963) noted that values of K for each tributary varied seasonally, with August K values being nearly three times larger than those for January. Seasonality of erosion rates and suspended sediment concentrations also has been observed for other rivers (e.g. Guy, 1964; Ketcheson et al. 1973; Temple and Sundborg, 1972; Irvine and Drake, 1987) and has been related to factors including hydrometeorologic controls, agriculture and natural plant growth. Meredith and Rumer (1987) explicitly presented the monthly mean K values for each tributary and these are reproduced in Table 2. The measure of watershed erodibility (K) generally increased with increasing time intervals between rainfall-generated runoff events, a finding consistent with the "reflex time" described by various researchers (e.g. Allen, 1974; Grimshaw and Lewin, 1980; Irvine and Drake, 1987). Based on the results of the sampling program, Parsons et al. (1963) concluded that sediment delivery from the Buffalo Creek had declined by approximately 40% during the 1953-61 period. This decline was attributed to streambank stabilization works. Suspended sediment delivery from the other two streams increased by 10% for the same period. Parsons et al. (1963) noted that the probable error in the delivery estimates was about 8%.

A study of water quality in the Buffalo River by Versar (1975) estimated sedimentation rates using Corps of Engineers dredging records and assuming, on average, that the mass of sediment dredged was equal to the mass deposited. The quantity of sediment dredged was estimated at 125,000 yd^3 per year. The number of years on which this calculation was based was not given. The spoil density of the dredged material was estimated as 1,250 lbs yd^{-3} and based on an average of 12 samples, the dredged material was 34.9% total solids. Versar (1975) therefore calculated the daily deposition rate as 75 tons and the annual deposition rate as 27,266 tons. In addition, Versar (1975) estimated suspended sediment inputs to the AOC from upstream erosion, combined sewer overflows and direct industrial inputs (Table 3). The upstream erosion estimates were based on sampling reported by the USGS. The combined sewer overflow values were based on volume estimates derived from engineering calculations and suspended solids data from South Buffalo and the sewage treatment plant influent. The direct industrial discharge inputs were based on the 13 NPDES (National Pollutant Discharge Elimination System) permits (i.e. 13 companies) filed prior to 1973 for 32 point discharges. Samples of suspended sediment also were collected by Versar (1975)

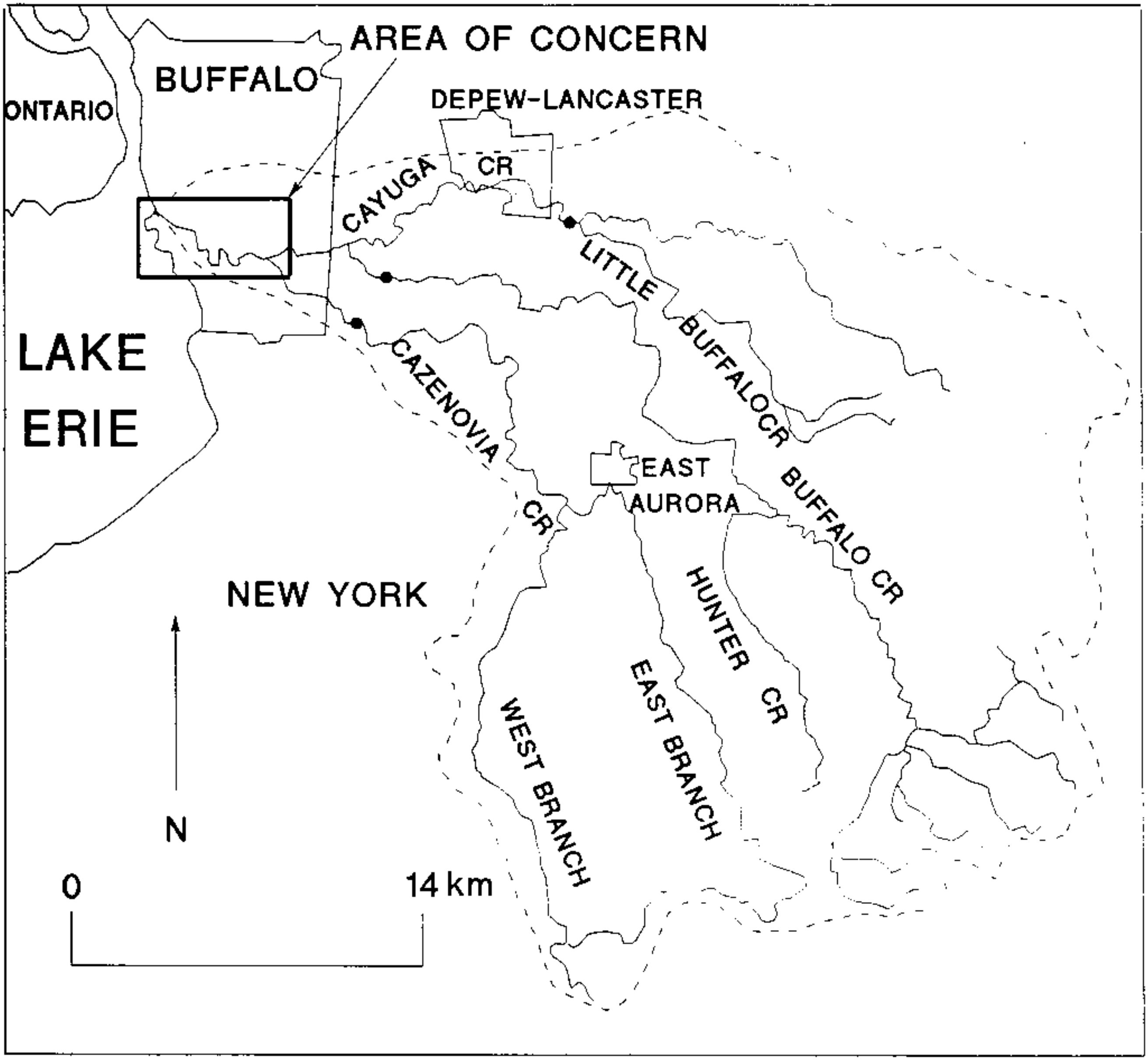

Figure 4 The Buffalo River watershed. Locations of the USGS gauge stations are shown as (•).

Table 3 Suspended Sediment Loads to the Buffalo River AOC (after Versar, 1975)

Source	Load (lbs d^{-1})	Load (tons yr^{-1})
Upstream Erosion	2,520,548	460,000
Combined Sewer Overflows	37,920	6,920
Direct Industrial Discharges	62,589	11,421
TOTAL	2,621,057	478,342

during the period August through October, 1973 at 19 sample locations and the mean concentrations of the samples are summarized in Table 4. An examination of data from the USGS shows that daily mean flows to the top of the AOC associated with this sample period ranged between 29.5 and 226 cfs. These flow values were determined by applying a proportional-area correction factor for each of the three USGS gauges and summing the corrected discharge values. The correction factor (to account for the ungauged portion of each tributary) was calculated as (after Meredith and Rumer, 1987):

[3] $$Q_T = Q_g \cdot (A_T/A_g)$$

where Q_T is the daily flow from the tributary to the top of the AOC (cfs); Q_g is the daily flow at the tributary gauge (cfs); A_T is the total drainage area at the mouth of the tributary (mi^2); and A_g is the drainage area upstream of the gauge (mi^2). The drainage areas upstream of the Buffalo, Cayuga and Cazenovia creek gauges are 144 mi^2, 94.9 mi^2, and 134 mi^2, respectively. The total drainage areas for the Buffalo, Cayuga and Cazenovia creeks are 146.2 mi^2, 124.4 mi^2, and 135.4 mi^2, respectively (Meredith and Rumer, 1987). The range of daily mean discharges for the August through October, 1973 sample period at the individual Buffalo, and Cazenovia creek gauges was 11 - 78 cfs and 13 - 106 cfs, respectively. Flows were not available for Cayuga Creek during this period, but were estimated from a regression between Buffalo and Cayuga creeks developed by Meredith and Rumer (1987). Accordingly, the estimated discharges for Cayuga Creek ranged between 4 - 49 cfs during the 1973 sample period. Estimates for Cayuga Creek also were used in the calculation of flow to the top of the AOC, as presented above.

An important early effort to reconstruct the environmental history of the Buffalo River was done by Sauer (1979) and included much data and information on suspended sediment concentrations and loadings. Three distinct sources of suspended sediment to the Buffalo River were considered: i) Runoff Sources - sediment associated with natural erosion generated by rainfall and runoff; ii) Population Sources - sediment associated with combined sewer overflows or discharge of municipal waste; and iii) Industry Sources - sediment associated with direct industrial inputs. Runoff loads were reconstructed using erosion information available in the literature and the function:

[4] $$L = [Lo \cdot (1 - P/P_N) + (L_N \cdot (P/P_N)] \cdot R/R_N$$

where L is the loading in tons per day at a point in time; P is the population of Erie County at that point in time; R is the rainfall at that point in time; Lo is the loading in the Frontier Era (i.e. prior to major settlement by Europeans); L_N is the loading in 1975; P_N is the population in 1975; and R_N is the rainfall in 1975. Population loads were calculated based on available engineering reports. Industry load estimates were based, to the extent possible, on effluent monitoring records obtained for the major industries. The modern (1975) loading estimates for each of the three sources were proportionally adjusted to reflect changes through time, based on factors such as population, landuse, precipitation, types of industry and known abatement projects. The estimated historical loadings from the three sources are

Table 4 Mean Suspended Sediment Concentrations, August-October, 1973 (after Versar, 1973)

Station No.	Water Body	Description of Station	Mean Suspended Sediment Concentration, mg l^{-1}
3	Ship Canal	Upstream of Michigan Ave. bridge	10
4	Buffalo River	Downstream of Skyway bridge	19
6	Buffalo River	Ohio St. bridge	23
7	Buffalo River	Alabama St.	50
8	Buffalo River	Hamburg St.	54
9	Buffalo River	Downstream of Katherine St.	45
10	Buffalo River	Penn Central RR bridge	34
12	Buffalo River	Downstream S. Park Ave bridge (river mile 42.16)	78
13	Buffalo River	Downstream S. Park Ave bridge (river mile 42.33)	41
14	Buffalo River	Downstream S. Park Ave bridge (river mile 42.47)	28
15	Buffalo River	S. Park Ave bridge	11
16	Buffalo River	Upstream S. Park Ave bridge (river mile 42.62)	17
17	Buffalo River	Upstream S. Park Ave bridge (river mile 42.69)	15
18	Buffalo River	Upstream S. Park Ave bridge (river mile 42.87)	12
19	Buffalo River	DL&W RR bridge	10
22	Buffalo River	Harlem Rd. bridge	24
23	Buffalo Cr.	Transit Rd. bridge	8
25	Cazenovia Cr.	Transit Rd. bridge	5
26	Cayuga Cr.	Transit Rd. bridge	38

Note: Buffalo River sites 4-19 are within the Federal Project area (dredged) and site 22 is outside the Federal Project Area (undredged).

summarized in Table 5.

The loadings calculated by Sauer (1979) may be compared to those summarized in Tables 1, 3 and 4 as a measure of quality assurance. The combined population and industry loadings calculated by Sauer (1979) for the "pre-1938" period (11,096 tons yr^{-1}) are comparable to those presented by Symons (1940) (9,308 tons yr^{-1}). It should be noted that unlike Sauer (1979), Symons (1940) did not consider inputs from the entire watershed. It is likely that the additional industrial and population inputs from upstream of the AOC would have been minimal before 1940. The population loadings estimated by Sauer (1979) for the 1972-73 period are similar to, but lower than, to those estimates made by Versar (1975). The industrial loading estimates made by Sauer (1979) and Versar (1975) for the 1972-73 also are similar, but again the Sauer (1979) estimate is lower. It appears that the population and industrial loading estimates made by Sauer (1979) are good first approximations, at least for the period 1930-1977. Sauer (1979) noted a dramatic abatement in the industrial loadings of suspended solids between the 1960's and 1970's. For example, it was estimated that industrial discharges for the period 1964-66 were on the order of 30.89 tons d^{-1}, while for the period 1975-77 the discharges were estimated at 3.08 tons d^{-1} (a 90% abatement). The loadings from runoff, as estimated by Sauer (1979) are less than those calculated by Hall (1955) (i.e. 827,459 tons yr^{-1}) and Versar (1975) (i.e. 460,000 tons yr^{-1}). However, the 1940 runoff loading estimate from Sauer (1979) is of the same order of magnitude as the post-July 1938 estimate from Symons (1940) (i.e. 11,224 tons yr^{-1}).

The suspended sediment concentration time series for the river, as constructed by Sauer (1979), is presented in Table 6. As noted above, high concentrations of suspended sediment can have an adverse impact on aquatic organisms and these data therefore are interesting to review. The concentration for 1973, (Table 6) is of the same order of magnitude as those samples collected by Versar (1975). The decline in concentration between 1966 and 1968 was attributed primarily to dilution generated through the Buffalo River Improvement Corporation (BRIC) operations that began in 1967. The BRIC was created to pump clean water from Lake Erie for use (primarily as cooling water) by industries along the river. The water subsequently is discharged to the river with the net effect of augmenting flow, reducing residence times, and providing a source of dilution. Sauer (1979) also indicated that industrial discharge abatement contributed to the steady decline in suspended sediment concentration between 1965 and 1974.

Modelling Sediment Transport and Deposition in the AOC

Three projects that involved modelling sediment dynamics within the Buffalo River AOC were completed in the late 1980's (Meredith and Rumer, 1987; Raggio et al., 1988; Corps of Engineers, 1988). Each of these projects employed the HEC-6 sediment transport model developed by the Corps of Engineers, although there were some variations in modelling approach and objectives. Two critical areas in which there were differences in modelling

Table 5 Estimated Historical Suspended Sediment Loadings, Buffalo River, in Tons per Year (after Sauer, 1979)

Period	Runoff	Population	Industry	Total
1600-1799	8595.75	0	0	8595.75
1800-1809	8603.05	7.30	0	8610.35
1810-1819	8621.30	36.50	0	8657.80
1820-1829	8650.50	98.55	0	8749.05
1830-1839	8500.85	306.60	36.50	8811.10
1840-1849	8770.95	952.65	29.20	9752.80
1850-1859	9052.00	2456.45	102.20	11610.65
1860-1869	9552.05	3781.40	299.30	13632.75
1870-1879	9606.80	4876.40	441.65	14924.85
1880-1889	10030.20	3343.40	642.40	14016.00
1890-1899	9858.60	4416.50	1595.05	15870.20
1900-1909	9639.65	4982.25	2117.00	16738.90
1910-1919	9599.50	5161.10	4533.30	19290.25
1920-1929	9179.75	5113.65	7884	22177.40
1930-1939	8486.25	4854.50	6241.50	19582.25
1940-1949	10322.20	2781.3	11285.80	24389.30
1950-1959	11585.10	3102.50	10767.50	25455.1
1960	10862.40	3431.00	9917.05	24210.45
1961	11475.6	3383.55	8267.25	23126.40
1962	8829.35	3336.10	9723.60	21889.05
1963	10278.40	3292.30	11194.55	24765.25
1964	9194.35	3244.85	14902.95	27342.15
1965	11001.10	3197.40	10209.05	20757.55
1966	10205.40	3171.85	8708.90	22086.15
1967	10752.90	3120.75	7993.50	21867.15
1968	11906.30	3095.20	5175.70	20177.20
1969	11267.55	3066.00	5694.00	20027.55
1970	10825.90	3014.90	4405.55	18246.35
1971	10267.45	3003.95	4577.10	17848.50
1972	12994.00	2993.00	3850.75	19837.75
1973	11504.80	2982.05	1963.70	16450.55
1974	11344.2	2952.85	1580.45	15877.50
1975	12048.65	2941.90	1328.60	16319.15
1976	14687.6	2934.60	1091.35	18713.55
1977	16775.40	2923.65	952.65	20651.70

ble 6 Estimated Historical Suspended Sediment Concentrations, Buffalo River (from Sauer, 1979)

Period	Concentration, mg l^{-1}	Period	Concentration, mg l^{-1}
1600-1799	15.9	1961	74.1
1800-1809	15.9	1962	76.8
1810-1819	16.0	1963	70.3
1820-1829	16.2	1964	55.9
1830-1839	16.3	1965	106.5
1840-1849	18.0	1966	91.9
1850-1859	21.4	1967	64.1
1860-1869	25.2	1968	57.3
1870-1879	27.6	1969	47.9
1880-1889	25.9	1970	41.7
1890-1899	29.3	1971	37.3
1900-1909	30.9	1972	28.4
1910-1919	35.6	1973	35.0
1920-1929	41.0	1974	22.0
1930-1939	83.6	1975	25.0
1940-1949	70.1	1976	31.5
1950-1959	52.4	1977	30.7
1960	85.1		

approach were the estimation of sediment loads reaching the top of the AOC and the treatment of fine sediment scouring.

Meredith and Rumer (1987) and Raggio et al. (1988) used the rating curves developed by Parsons et al. (1963) (i.e. eqn. [1]) to estimate the suspended sediment load reaching the top of the AOC from upstream inputs. These sediment loads subsequently were routed through the AOC. Based on the rating curves and historical flow records to the top of the AOC (1940-1985), Meredith and Rumer (1987) estimated that annual sediment yield from the watershed ranged between 140,000 and 900,000 tons yr^{-1}. Based on dredging records, the Corps of Engineers (1988) used a value of 94,100 tons as the annual suspended sediment yield from the watershed. It was recognized that the dredged mass of sediment is less than the inflowing mass, but the dredged mass was used, in part, to account for the model's inability to represent the scour of silt and clay.

The standard version of the HEC-6 model does not account for the scour of fine material (silt and clay). This limitation was recognized by Meredith and Rumer (1987) and it was indicated that estimated siltation rates may be too high. The Corps of Engineers (1988) modified the sediment size input data to account for the possible overestimation of silt and clay deposition. Specifically, the size of the bed sediment, as well as the inflowing suspended sediment, was changed to 100% very fine sand. Raggio et al. (1988) modified the HEC-6 model to consider scour of fine sediment, after the method described by Partheniades (1965) for consolidated beds. The results for model runs that both considered and did not consider fine sediment scour are presented in Figure 5. Figure 5 indicates that scour of fine material may be an important process in the Buffalo River.

Meredith and Rumer (1987) used the HEC-6 model to evaluate three different aspects of sediment transport dynamics within the AOC. First, areas of scour and deposition were identified, assuming zero incoming sediment and a range of discharges. The effects of errors in upstream erosion estimates on determining scour and deposition patterns thereby were eliminated. Second, runs were done for incrementally increased discharges to evaluate the trap efficiency of the river. Sediment input to the top of the AOC was estimated using the rating curves developed by Parsons et al. (1963). Finally, the model was run for the period May, 1983 to April, 1985 to estimate the siltation rate for the river. This estimate was compared to the siltation rate determined using Corps of Engineers bathymetric data for the same period.

Meredith and Rumer (1987) evaluated scour and deposition by running the model for a 5-day period, assuming a constant discharge on all days. Generally, it was found that the results were similar for each of the five days. Successive model runs were done using a greater discharge than the previous run. The effect of water temperature on scour and deposition also was evaluated by performing runs assuming temperatures of 34°F and 55°F. The modelled sediment transport characteristics for the two water temperatures were similar. In general, it was found that sand sized material began scouring near Mobil Oil at discharges of 6,000 cfs. This discharge rate was exceeded 1% of the time during the period

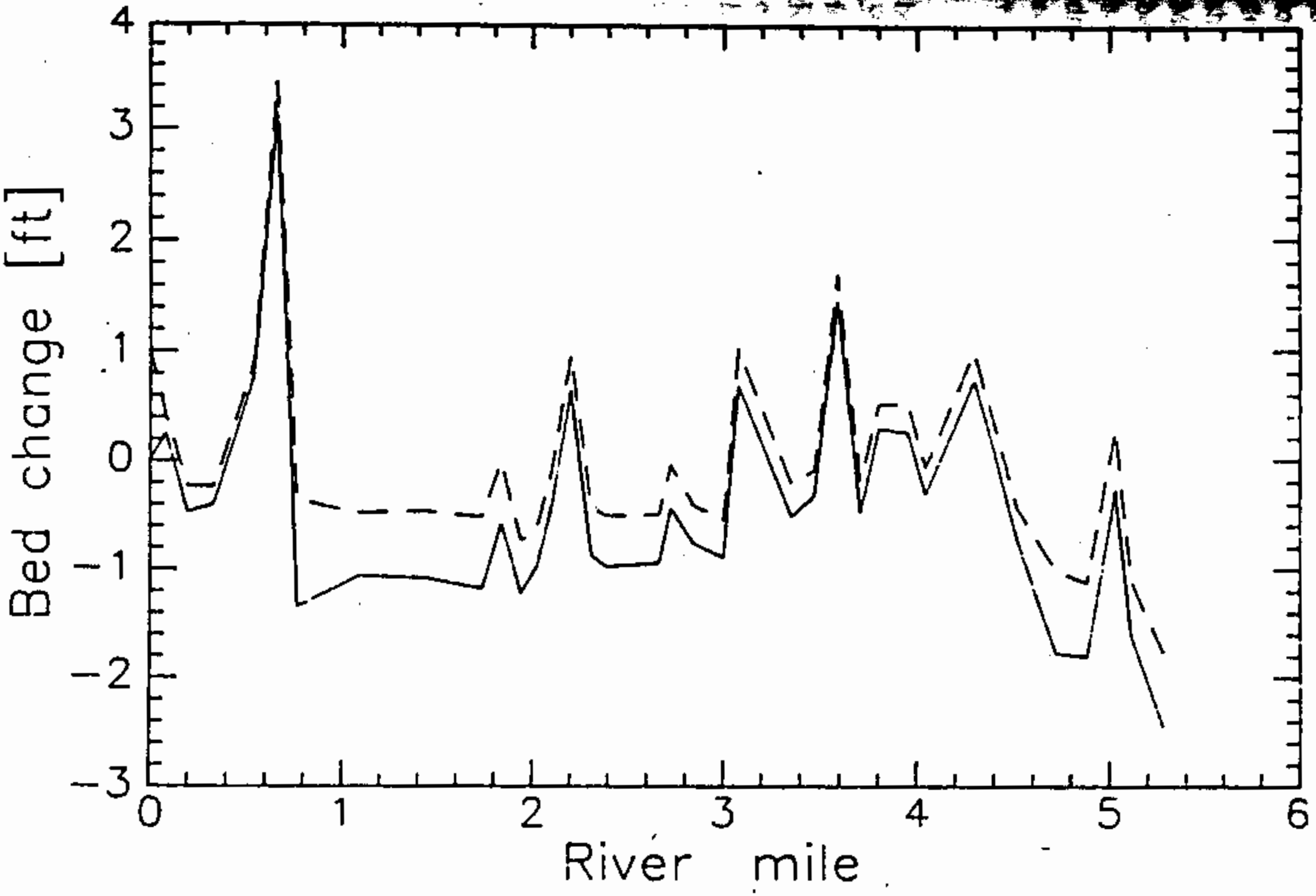

Figure 5 Comparison of modelled riverbed changes for a 5-day, 20,000 cfs flow. The solid line represents bed changes when scour of fine sediment explicitly is modelled and the dashed line represents bed changes when scour of fine sediment is not modelled. River mile 0 is at the river mouth while river mile 5.28 is 1,000 ft downstream of the federal (dredging) project limit (from Raggio et al., 1988).

1940-1985 (Meredith and Rumer, 1987). At higher discharges there was a progressive increase in the number of river sections undergoing scour of sand. The greatest discharge for which scour was estimated was 20,000 cfs. Results suggested that approximately 7,000 tons d^{-1} of sediment would be scoured from the river and moved to the mouth at this discharge. Areas of deposition as identified by the model for a discharge of 12,000 cfs are shown in Figure 6. Although deposition patterns varied slightly for the different discharges, Meredith and Rumer (1987) indicated that in general deposition occurred in the meander bends. It also should be noted that transect 27868 (Figure 6) represents the upstream boundary of the modelling effort, although this is approximately 1,000 ft downstream of the dredged channel limit. Raggio et al. (1988) extended the upstream boundary to the confluence of Cazenovia Creek and the Buffalo River to avoid possible boundary effects within the reach adjacent to Mobil Oil.

Meredith and Rumer (1987) evaluated sediment trap efficiencies for discharges ranging between 250 and 20,000 cfs. It was found that 68% of the time (i.e. for discharges less than 500 cfs), all incoming sediment would be deposited in the river. Trap efficiency also was found to vary according to sediment size. The trap efficiencies determined by Meredith and Rumer (1987) are summarized in Table 7. For comparison purposes, the results from Raggio et al. (1988) that explicitly considered fine sediment scour, also are included in Table 7. Inclusion of fine sediment scour produces considerable differences in the estimated trap efficiencies and it appears probable that the model runs from Meredith and Rumer (1987) would overestimate siltation rates. The tendency to overestimate siltation rates if fine sediment scour is not considered also is well-illustrated in Figure 5.

The third aspect of sediment dynamics that Meredith and Rumer (1987) addressed was the comparison between siltation rates estimated by the model and those calculated considering changes in river bathymetry. The period selected for evaluation was May, 1983 to April, 1985, because the bathymetric records were most complete and recent. Sediment inflow to the top of the AOC (from the rating curves of Parsons et al. (1963)) was calculated in the range of 1,069,657-1,199,482 tons. A total siltation of 553,700 tons was estimated using the HEC-6 model for the two year period. The siltation rate calculated from the bathymetric data was in the order of 280,000 tons. The higher siltation rate estimated by the model may be the result of several factors, including overestimation of sediment input to the top of the AOC, inability to model scour of fine material and assumptions made in converting sediment volume to sediment mass for the bathymetric approach.

The modelled and observed (smoothed bathymetric data) river bed changes from Raggio et al. (1988) for the May, 1983 to May, 1985 period are presented in Figure 7. Scouring of fine sediment explicitly was modelled in this run. The modelled results moderately correspond to those calculated from the bathymetric data.

Raggio et al. (1988) evaluated potential long term river bed evolution (assuming the termination of dredging activities) by operating the modified (fine scouring) HEC-6 model for a period of 25 years. Both historical (observed) flow data and a synthetic flow series

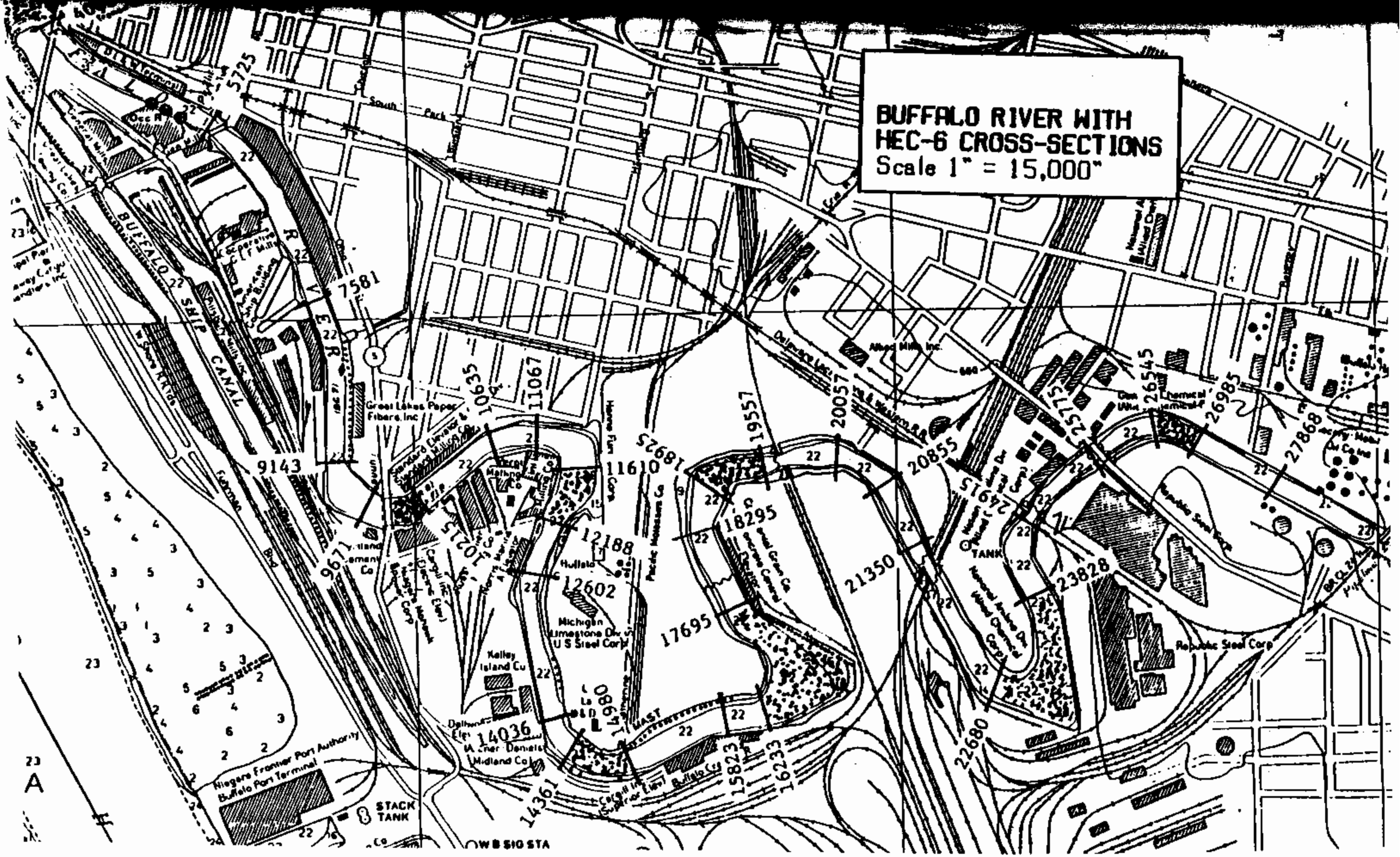

Figure 6 Areas of deposition (shaded) as estimated by the HEC-6 model for a discharge of 12,000 cfs (from Meredith and Rumer, 1987).

Table 7 Estimated Trap Efficiencies and Scour/Deposition Dynamics using the HEC-6 Model

Q, cfs	6,000	8,000	12,000	16,000	20,000
%Trap Efficiency (all sediment)	43	30	8	4	4
Depth of (excluding upstream boundary):					
Max deposition (ft)	0.49	0.47	1.04	2.21	3.43
Max scour (ft)	0.00	-0.23	-0.99	-1.06	-1.13
Avg deposition (ft)	0.20	0.18	0.07	0.07	0.07
(after Meredith and Rumer, 1987, without fine scour)					
%Trap Efficiency (all sediment)	7	3	-6	-11	-15
Depth of (excluding upstream boundary):					
Max deposition (ft)	0.53	0.68	0.87	2.05	3.14
Max scour (ft)	-0.01	-0.28	-1.20	-1.49	-1.81
Avg deposition (ft)	0.02	0.01	-0.07	-0.18	-0.34
(after Raggio et al., 1988, with fine scour)					

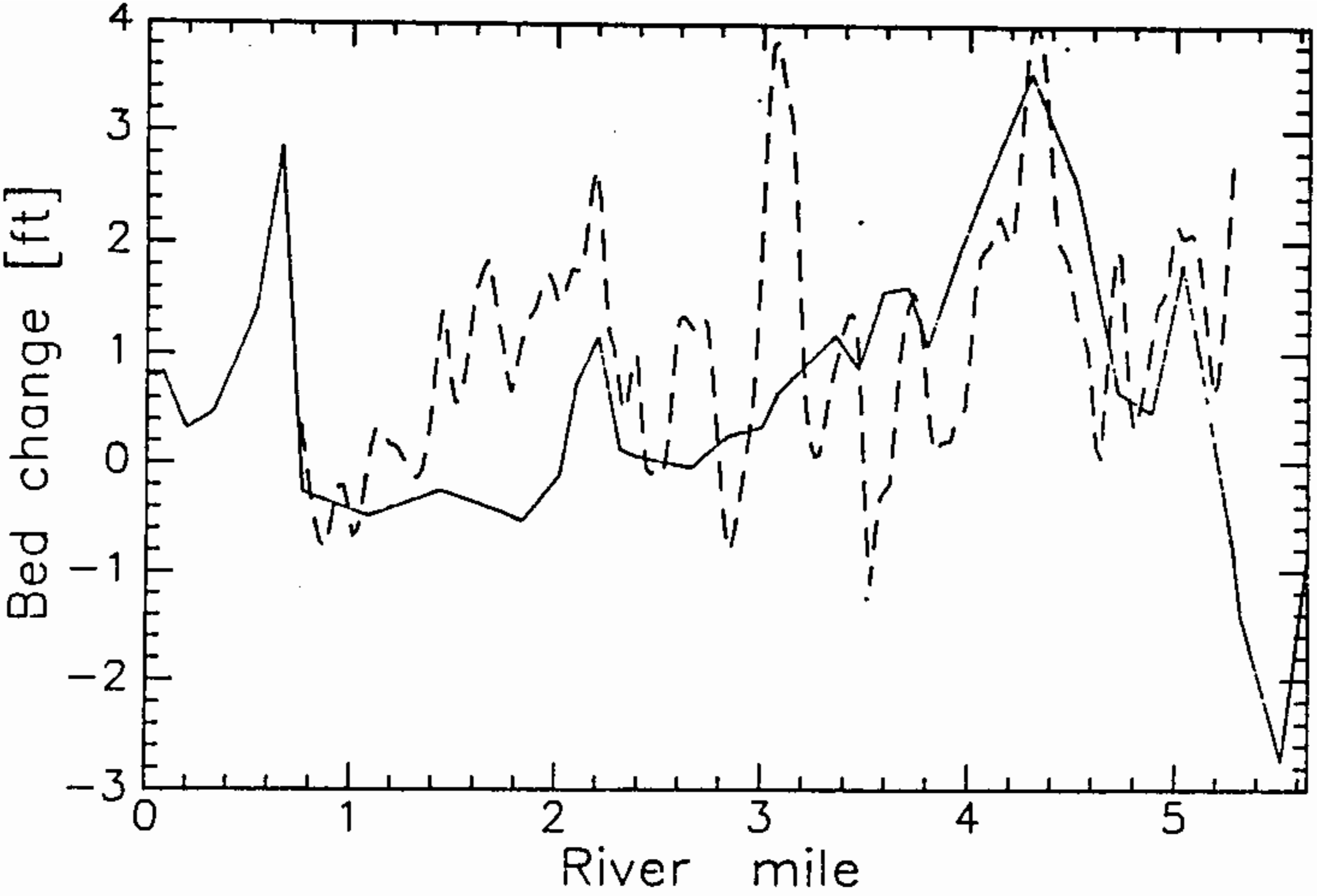

Figure 7 River bed changes between May, 1983 and May, 1985. The solid line represents the estimate made by the HEC-6 model (fine scouring included) while the dashed line represents the smoothed bathymetric data (from Raggio et al., 1988).

used in this evaluation, as were historical and synthetic lake levels. The river did not ch a dynamic equilibrium after 25 years with either flow data set. It was estimated that osition would raise the bed elevations between 3 and 6 ft by the end of the 25 year riod. The model results also indicated that natural armoring may occur in some locations uld dredging operations be discontinued.

The Corps of Engineers (1988) also used the HEC-6 model to investigate bed level elopment if dredging was discontinued. Model runs were done at five-year increments a total of 25 years (from 1986 post dredging elevations) and assuming five different lake els. Inflow data to the top of the AOC were calculated using the flow duration curves m Meredith and Rumer (1987). The Corps of Engineers (1988) study concurred with the dings of Raggio et al. (1988), indicating that the river generally would accumulate diment throughout the 25 year period. The total deposition for the 25 year period varied m 1 to 10 ft within the current navigation channel. The overall average rate of cumulation was estimated as 0.3 ft yr^{-1}. The Corps of Engineers determined that dredging rovided approximately $33,000 per year in flood damage benefits.

Most recently, Wilbert Lick and his research group at the University of California, Santa rbara, have begun applying a two-dimensional, vertically-integrated, time-dependent ydrodynamic and transport model to assess scour and deposition in the Buffalo River. This wo-dimensional model is linked to a three-dimensional, time-dependent model of the ediment bed and its properties (e.g. Lick et al., 1992). This modelling approach has two portant advantages over the HEC-6 application. First, the HEC-6 model is one-mensional, so that lateral variations in the river flow cannot be considered. Second, the pproach contains a more explicit consideration of the physical and hydrodynamic haracteristics of sediment (particularly fine-grained sediment), including flocculation and e varying critical shear stresses associated with sediments undergoing changes in water ontent (i.e. becoming compacted over time). This modelling approach produced accurate stimates of suspended sediment concentration and change in bathymetry when applied to he Fox River (Gailani et al., 1991; Lick et al., 1992). Application of the model for the uffalo River had not been completed at the time of writing, but it was anticipated that the general approach would be similar to that of the Fox River with some modification for local conditions (Lick et al., 1992).

USPENDED AND DISSOLVED SEDIMENT SAMPLING

As previously noted, high concentrations of suspended sediment can negatively impact quatic organisms and fish habitat. The first section of this chapter provided an historical erspective of suspended sediment concentrations within the Buffalo River AOC and its ibutaries. This section of the report summarizes results of a sediment sampling program onducted near the mouths of the three major tributaries to the Buffalo River. More recent ta at these locations is important because sediment entering the AOC has been estimated ing the rating curves developed by Parsons et al. (1963) (cf. Meredith and Rumer, 1987; aggio et al., 1988). Landuse changes and bank stabilization programs may have shifted the ating curves as defined by Parsons et al. (1963), thereby resulting in estimation errors for iltation rates. Suspended sediment data from sites within the AOC that have been collected rough other ongoing Buffalo River projects also will be summarized in this section.

ample Sites and Methodology

ample Sites and Sample Timeframe

Sampling was done at four locations, sites 11, 10, 5 and 6 (Figure 8). These sites were elected because of proximity to USGS gauge stations. Stage at these sites is reported on n hourly basis and the stage values were converted to discharge with the available rating ables. Measured flow rates were essential in developing suspended sediment rating curves. ampling was done at a bridge as a precaution that during high flows water velocity would e too great to allow field personnel to wade safely. Samples were collected separately in Cayuga and Little Buffalo creeks near their confluence. Separate samples were collected because the two creeks join several yards downstream of the bridge, but upstream of the auge station. It could not be determined at what point sediment from the creeks would be ully mixed and to avoid sample bias, water was collected from both creeks.

For each site, two 1-L sample bottles were filled at 0.6 of the total depth below the urface. During low flow periods the sample bottles were inserted into the water by hand and uncapped at the appropriate depth. A Wheaton Sub Surface Grab Sampler II, with an 18 ft extension, was used to collect the samples during periods of higher flow. The sample verticals were determined from preliminary sampling done across the river during low flow periods in 1991 and 1992. Between 3 and 5 samples were collected across each creek and the suspended sediment concentrations were averaged. The vertical having a concentration closest to the average was selected as the sample vertical. In all cases, the vertical determined to be most appropriate for the study was near the middle of the channel. It is recognized that the vertical best representing the "average" concentration may be different during high flows. However, study time constraints did not permit a detailed evaluation of cross-sectional concentration differences during high flows. Routine sampling commenced

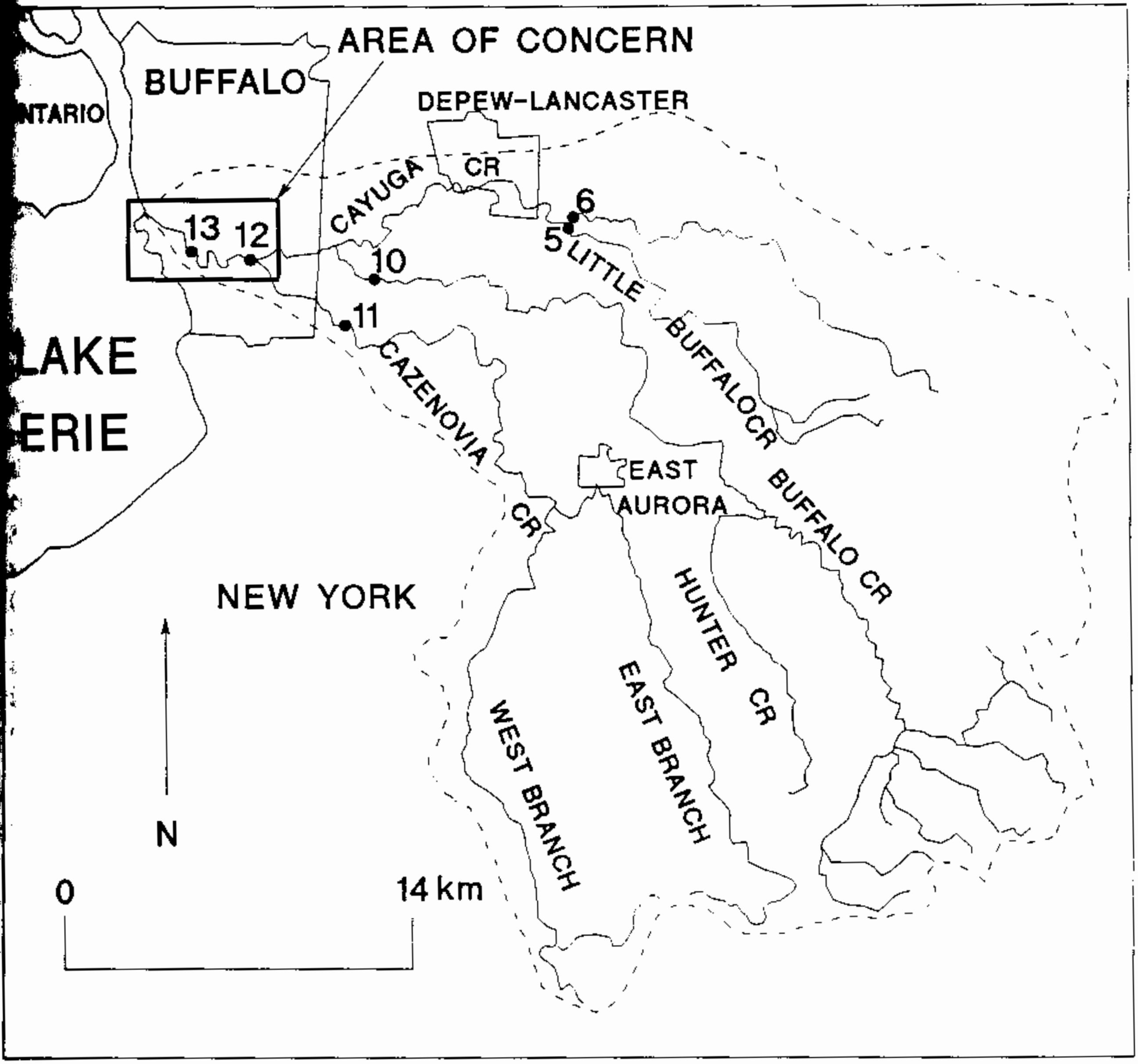

Figure 8 Buffalo River watershed and suspended sediment sample locations. Sites 12 and 13 are from Pettibone and Irvine (1994) and represent the top of the AOC and the Ohio St. bridge, respectively.

July 15, 1992 and continued until May 10, 1993. During the summer and fall of 1992 mples were collected at least weekly, while during the winter of 1992 and spring 1993 mples were collected approximately bi-monthly. The sampling scheme provided data for th event and interevent periods through the year.

Flow velocity was measured on six event days using a Montedoro-Whitney PVM-2A ctronic flow meter. Velocity was measured in the sample vertical at 0.6 of the total depth low the surface. Three 10-second average measurements were taken at each site and the an of the three measurements was determined as the representative velocity. Assuming logarithmic velocity profile, measurement at the 0.6 depth would represent mean velocity the vertical.

boratory Analysis

The samples were returned to the Soils Laboratory at Buffalo State College for the termination of suspended and dissolved sediment concentration. Holding time at room mperature for the samples was less than three days. Sample water volume was determined the difference in weight between the full and empty bottles, following the USGS ethodology described by Guy (1969). Samples that were not fractionated were passed rough 0.45 μm filters (Millipore HAWP 047) to determine suspended sediment ncentration. The general filtration procedure followed that described under Standard Method 209 C (Water Pollution Control Federation, 1985). Selected storm event samples quentially were passed through filters having pore sizes of 60 μm (Spectra/Mesh), 5 μm (Millipore SMWP 047) and 0.45 μm (Millipore HAWP 047) to determine the percent (by eight) of sand, silt and clay-sized material. This fractionation followed the methodology scribed by Irvine et al. (1990). Samples were selected for fractionation after visual inspection of the sediment concentration. The concentration had to be great enough to determine the weight of the different size classes to 0.1 mg.

For each sample, a 30 ml sub-sample of the filtrate that had passed through the 0.45 μm filter was pipetted into an aluminum evaporating dish and the filtrate was evaporated at 160°C to determine dissolved sediment concentration. The general methodology to determine dissolved sediment concentration followed that described under Standard Method 209 B (Water Pollution Control Federation, 1985). All weights in the dissolved sediment analysis were measured to 0.1 mg.

ults

A total of 43 samples were collected for analysis of suspended and dissolved sediment. wever, flow data were not available for all samples at the time of statistical analysis and results and discussion therefore focus on the 35-36 samples that had complete rmation. Although the majority of sediment load may be moved through a river during mall number of moderate events (e.g. Doty et al., 1981; Johnson and Hanson, 1976; ine, 1985), "typical" sediment concentrations also may be of interest for habitat suitability luations. In this sense, "typical" sediment concentrations may be represented by samples llected during flow conditions that would be equalled or exceeded most of the time. These on-event" flow conditions were identified through an examination of discharge data from USGS gauge stations. Accordingly, sediment samples collected when the hydrograph was ither on an obvious recession nor rising limb were evaluated. Flow duration curves were veloped by Meredith and Rumer (1987) for each of the USGS gauging stations from daily ean discharge data for the period 1938-1985 (Cayuga Cr. and Buffalo Cr.) or 1940-1985 azenovia Cr.). Considering these flow duration curves, the discharges associated with the n-event sediment samples were exceeded approximately 30-100%; 15-100% and 10-100% the time on Buffalo Cr., Cazenovia Cr. and Cayuga Cr., respectively.

Typical, non-event, suspended sediment concentrations for each sample site are ummarized in Table 8. For comparison purposes, data for the Buffalo River determined rom samples collected on the same day, are summarized in Table 8. The suspended ediment concentrations in the Buffalo River are greater than those for the tributaries, but re less than those reported historically (e.g. Tables 4 and 6). The dissolved sediment oncentrations typically are greater than the suspended sediment concentrations, a finding ot uncommon for watersheds in a humid, warm climate and/or influenced by nthropogenic activities (e.g. Irvine, 1985; Briggs and Smithson, 1986).

As expected, suspended sediment concentrations increased during storm events, with inputs from overland erosion and bed and bank scour. The maximum observed concentration at Little Buffalo, Cayuga, Buffalo and Cazenovia creeks was 338, 306, 612 and 408 mg l^{-1}, respectively. In comparison, the maximum observed suspended sediment concentration at the top of the Buffalo River AOC and at the Ohio St. bridge was 674 and 659 mg l^{-1}, respectively (Pettibone and Irvine, 1994). During storm events, the suspended sediment concentrations typically were greater than the dissolved sediment concentrations. Measured flow velocities for the six event days at Little Buffalo, Cayuga, Buffalo and Cazenovia creeks ranged between 0.01-0.37; 0.01-0.61; 0.10-0.66; and 0.05-1.22 m s^{-1}, respectively. These velocities corresponded to discharges in the range of 41.10-1,591 cfs; 71.17-1,925 cfs and 100.9-3,488 cfs for Little Buffalo/Cayuga, Buffalo and Cazenovia creeks, respectively.

Filter-fractionation to determine the size distribution of the suspended sediment was done for the samples collected during the storm event of November 23, 1992. This event

ble 8 Concentrations of Suspended and Dissolved Sediment (mg l^{-1}) for Low Flow Conditions

ittle Buffalo Cr.		Cayuga Cr.		Buffalo Cr.		Cazenovia Cr.		Buffalo R., Top of AOC		Buffalo R., Ohio St. Bridge	
$\bar{x}$	s.d.	$\bar{x}$	s.d.	$\bar{x}$	s.d.	$\bar{x}$	s.d.	$\bar{x}$	s.d.	$\bar{x}$	s.d.
2.94 12	1.44	1.19 11	0.58	3.56 12	3.85	2.99 11	2.64	6.68 10	4.09	9.04 10	3.61
258 11	51.5	182 10	67.3	240 11	75.5	196 10	79.1	210 9	62.2	206 9	68.8

oncentration; s.d. is sample standard deviation; SS is suspended sediment; DS is dissolved sediment; and n is the bservations used in the calculation of the mean and standard deviation. Data for the Buffalo River are from Pettibone (1994).

produced amongst the highest suspended sediment concentrations observed at all sites during the study. The size distributions are summarized as follows:

Little Buffalo Cr. - 4.6% sand; 93.5% silt; 1.9% clay
Cayuga Cr. - 7.4% sand; 92.5% silt; 0.2% clay
Buffalo Cr. - 5.8% sand; 93.9% silt; 0.2% clay
Cazenovia Cr. - 4.6% sand; 92.6% silt; 2.9% clay

Discussion

Sediment Rating Curves

Suspended sediment concentration dynamics often are evaluated using some type of least squares regression analysis because of the computational simplicity of the method. Although multiple least squares analysis can help to explain additional variance in the data (e.g. Guy, 1964; Abrahams and Kellerhals, 1973; Irvine and Drake, 1987), most often simple regression rating curves are developed between suspended sediment concentration and discharge (Walling, 1977; Fenn et al., 1985; Ferguson, 1986; Koch and Smillie, 1986; Irvine and Drake, 1987). These rating curves can be used to: i) complete the suspended sediment record at a site for days on which sampling was not done; ii) estimate historical sediment load for times during which only flow data were collected; iii) extrapolate future sediment loads based on synthetic hydrology; and iv) help determine the stationarity of the sediment regime.

Simple least squares regression was applied to the data collected from Cazenovia, Buffalo, Cayuga and Little Buffalo creeks using the Minitab software package (release 8) on a personal computer. The general form of the regression equations initially was:

$$[5] \qquad \hat{y}_i = b_o + b_1 x_i$$

where $\hat{y}_i$ is estimated suspended sediment concentration (mg l^{-1}), x_i is discharge (cfs), b_o is the y-intercept, and b_1 is the slope of the line. The results of this regression analysis are summarized in Table 9. The high r^2 values and significant b_1 values suggest that the models fit the data relatively well, particularly compared to results reported elsewhere (e.g. Irvine and Drake, 1987). However, it should be noted that negative sediment concentrations could be predicted for Buffalo, Little Buffalo and Cayuga creeks and this is not physically possible. The estimated model parameters therefore suggest a closer inspection of the data structure and form of the regression model.

There are five assumptions made when applying ordinary least squares regression analysis (Abrahams and Kellerhals, 1973; Blalock, 1979 pp. 386-389):

Table 9 Results of Simple Linear Regression Rating Curves

Equation	r^2	P, b_o	P, b_1
Cazenovia Cr.: $\hat{y}_i = 4.7 + 0.119(x_i)$	63	>0.20	<0.001
Buffalo Cr.: $\hat{y}_i = -26.0 + 0.209(x_i)$	75	<0.10	<0.001
Little Buffalo Cr.: $\hat{y}_i = -6.23 + 0.158(x_i)$	90	>0.20	<0.001
Cayuga Cr.: $\hat{y}_i = -8.70 + 0.136(x_i)$	92	<0.05	<0.001

P is the confidence level at which the null hypothesis (b_o or b_1 is not different from 0) can be rejected.

i) the relationship between the dependent and independent variables is linear.

ii) the error term values (e_i), also known as residuals, are normally distributed for each value of x and have a mean of 0.

iii) the variance of the residuals for each value of x is constant (i.e. the residuals are homoscedastic).

iv) the residuals are independent of x.

v) the residuals are serially uncorrelated.

Residual Analysis for Simple Linear Regression Analysis

The relationship between suspended sediment concentration and discharge at each site was curvilinear, thereby suggesting that a simple linear regression model was not appropriate for these raw data. A probability plot correlation coefficient test (Filliben, 1975; Vogel, 1986) was used to evaluate the normality of the residual distributions. Essentially, the test statistic is the product moment correlation coefficient (r) between the ordered residuals and the order statistic medians from a normal distribution. A higher value of r indicates a greater likelihood that the residual distribution is normal. The test results for the residuals from the four sites indicate that the residuals are not normally distributed at a confidence level (α) of 0.05. The means of the residuals for Little Buffalo Cr., Cayuga Cr., Buffalo Cr. and Cazenovia Cr. approximately were 0, with values of -2.4×10^{-7}; -4.2×10^{-7}; 1.3×10^{-7}; and -2.1×10^{-7}, respectively.

The residuals from the regression for each site were plotted against both the independent x variable (Q) and the predicted (y_i) values (e.g. Figure 9). There is a well-defined funnel shape in the plots for all sites, as the variance of the residuals increases with Q and y_i. This funnel shape indicates that the residuals are not homoscedastic. Draper and Smith (1981, Chapter 3) suggest that, if the plotted residuals exhibit a funnel shape, either a transformation of the dependent variable or a weighted least squares analysis may be used to meet regression assumptions. Abrahams and Kellerhals (1973) have noted that serial correlation frequently occurs in analysis of sediment data and the Durbin-Watson statistic (Draper and Smith, 1981) therefore was used to test for such correlation. It can be concluded that the residuals were not serially correlation ($\alpha = 0.05$) for Little Buffalo Cr., Cayuga Cr. and Cazenovia Cr., but could be considered serially correlated for Buffalo Cr. Plots of the raw data, results of the residual analysis and the coefficient values estimated using simple linear regression suggest that the general form of equation [5] may not be appropriate for rating curve development.

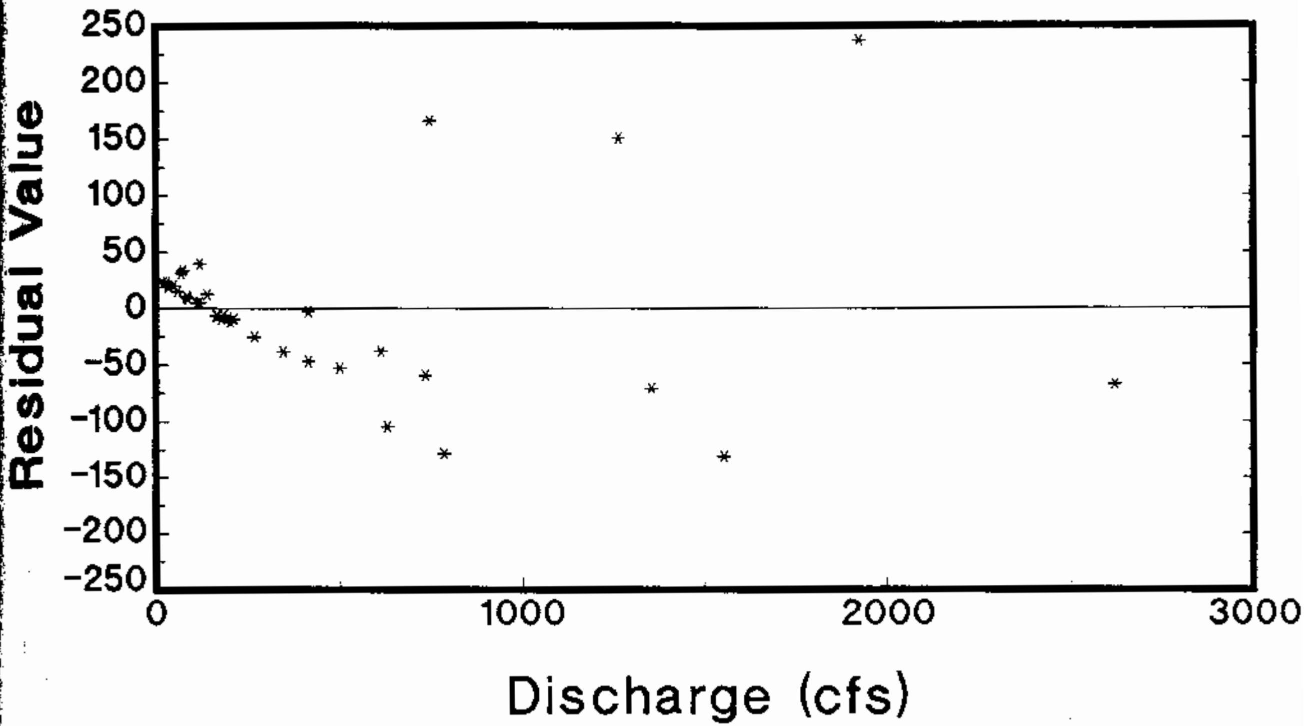

Figure 9 Regression residual values vs. corresponding discharge (x) values for Buffalo Cr. The funnel shape for the residuals with increasing values of x was observed for regressions from all sites. Similarly, a funnel shape was observed for all sites when residuals were plotted against $\hat{y}_i$ (results not shown).

Rating Curves with Transformed Data

Hydrologic systems often are non-linear and in order to use simple least squares estimation techniques for the model parameters, logarithmic transformations may be used to linearize the equations (Guy, 1964; Jansson, 1985; Koch and Smillie, 1986; Ferguson, 1987). Following exploratory evaluations with various transformations, it was decided to develop rating curves using a logarithmic (base 10) transformation of discharge and suspended sediment concentration. The general form of the regression equation using log-transformed data therefore is:

[6] $$\log_{10}\hat{y}_i = \log b_o + b_1 \log_{10} x_i$$

in which $\hat{y}_i$, is estimated suspended sediment concentration (mg l^{-1}) and x_i is discharge (cfs). The form of equation [6] often is expressed as a power function:

[7] $$\hat{y}_i = b_o x_i^{b_1}$$

The form of equation [7] was developed from a backtransformed logarithmic regression and not iteratively from the original data. Jansson (1985) noted that the two approaches represent conceptually different models, having different assumptions and with the potential of providing different results. Several researchers have noted that backtransformation biases the estimate of the dependent variable and this may lead to an underestimation of true sediment load (Jansson, 1985; Ferguson, 1986, 1987; Koch and Smillie, 1986). Various parametric and nonparametric correction factors for the backtransformed estimates have been proposed, although depending on the data structure an overestimate of the true sediment load may result (Ferguson, 1986, 1986b, 1987; Koch and Smillie, 1986, 1986b). A simply applied parametric correction factor (after Ferguson, 1986) has the form:

[8] $$C.F. = \exp(2.65s^2)$$

where:

[9] $$s^2 = \Sigma(\log y_i - \log \hat{y}_i)^2/(n - 2)$$

and C.F. is the correction factor; y_i is observed sediment concentration. This correction factor strictly is valid if the following assumptions are met (Ferguson, 1986b):

i) the true log-log regression is linear
ii) the scatter around the regression line is normally distributed
iii) the scatter has the same variance for all values of x (i.e. homoscedastic)
iv) the points defining the regression are a random sample of all possible points

The results of the regression analyses using the logarithmically transformed data are presented in Table 10 and Figures 10 through 13. The level of explained variance (r^2) is less for the regressions using the transformed data than for the regressions using the raw data. Similar reductions in r^2 were reported by Irvine and Drake (1987) for the Ausable River in Southern Ontario. Others (e.g. Fenn et al., 1985; Walling, 1977) have found that a logarithmic transformation increases the r^2 value. A benefit of the logarithmic transformation is that negative sediment concentrations are not predicted.

The means of the logged residuals for Little Buffalo Cr., Cayuga Cr., Buffalo Cr. and Cazenovia Cr. were -2.4×10^{-9}, -5.4×10^{-9}, 8.0×10^{-10}, and -3.3×10^{-9}, respectively. The probability plot correlation coefficient test was applied to evaluate the normality of the residual distributions. The residuals could be considered normally distributed down to the 0.75 probability level for Cayuga and Cazenovia creeks. The residuals could be considered normally distributed down to the 0.25 level for Little Buffalo Cr., but the residuals for Buffalo Cr. could be considered normal only to the 0.025 level. In general, the analysis using transformed data meets the assumption of normally distributed residuals. The transformed residuals (Figure 14) appear more homoscedastic than the untransformed residuals (Figure 9). The Durbin-Watson statistic indicated that the residuals could be considered serially correlated for Little Buffalo, Cayuga and Buffalo creeks ($\alpha = 0.05$), but were not serially correlated for Cazenovia Creek.

It appears that a logarithmic transformation may be appropriate for the available data. Furthermore, the power form of the equations (Table 10) facilitates a comparison of the results from this study with those from Parsons et al. (1963). It is suggested that a correction factor should be applied (e.g. eqn. [8]) if the rating curves in Table 10 are used to calculate sediment load entering the top of the AOC.

Rating Curve Comparison with Parsons et al. (1963)

As noted above, several of the recent modelling studies done for the Buffalo River used the rating curves developed by Parsons et al. (1963) to estimate suspended sediment loads entering the top of the AOC. A shift in the suspended sediment-discharge relationship may have occurred since the Parsons et al. (1963) study due to changes in landuse, soil conservation programs and bank stabilization programs. Modelling errors in the more recent sediment transport studies would result with the shift in the suspended sediment-discharge relationship.

The rating curves developed by Parsons et al. (1963) for the period 1953-61 for Buffalo Creek (Site 10) and Cazenovia Creek (Site 11) are plotted in Figures 12 and 13 with the rating curves and observed data from this study. Given the available information, it appears that samples were collected at similar locations on Buffalo and Cazenovia creeks for the two studies. Samples were not collected at the same sites on Little Buffalo/Cayuga creeks and

Table 10 Rating Curves Using Logarithmically Transformed Data

Regression Equation	Power Form of Equation	r^2	P, b_o	P, b_1
Cazenovia Cr.: $\log \hat{y}_i = -1.23 + 1.01(\log x_i)$	$\hat{y}_i = 0.059x_i^{1.01}$	55	<0.01	<0.001
Buffalo Cr.: $\log \hat{y}_i = -1.72 + 1.19(\log x_i)$	$\hat{y}_i = 0.019x_i^{1.19}$	59	<0.001	<0.001
Little Buffalo Cr.: $\log \hat{y}_i = -0.788 + 0.859(\log x_i)$	$\hat{y}_i = 0.163x_i^{0.859}$	56	<0.001	<0.001
Cayuga Cr.: $\log \hat{y}_i = -1.65 + 1.13(\log x_i)$	$\hat{y}_i = 0.022x_i^{1.13}$	73	<0.001	<0.001

P is the confidence level at which the null hypothesis (b_o or b_1 is not different from 0) can be rejected.

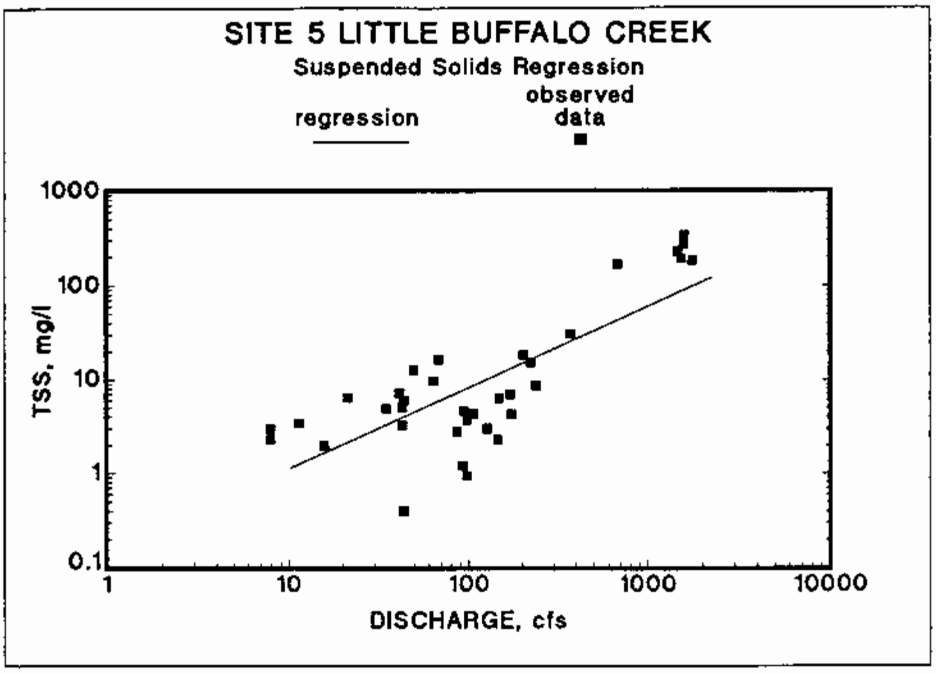

Figure 10 Suspended sediment rating curve (Table 10) for Little Buffalo Cr. Discharge values were taken from the USGS gauge downstream of the site, on Cayuga Cr.

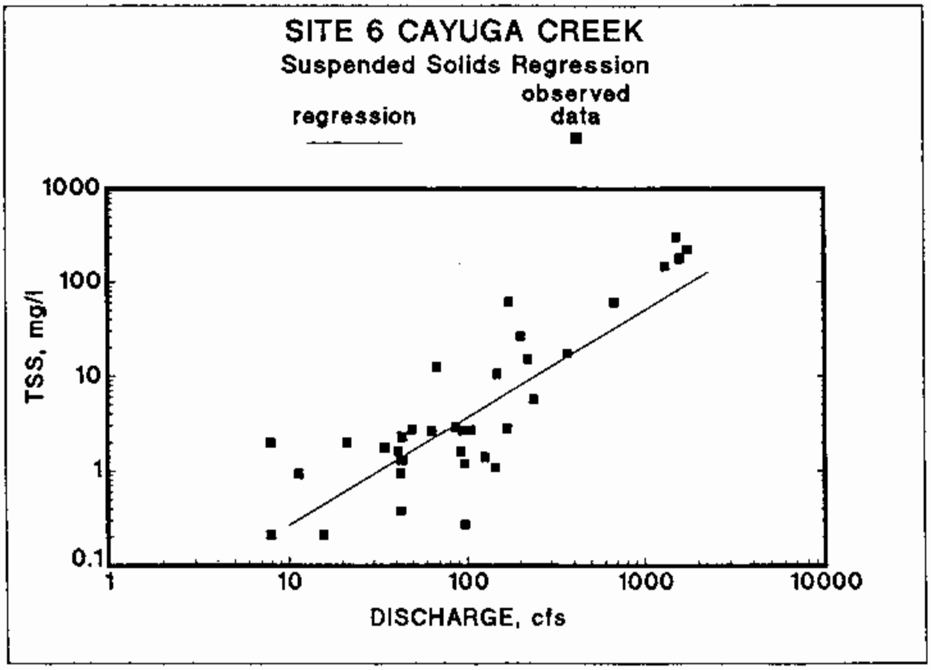

Figure 11 Suspended sediment rating curve (Table 10) for Cayuga Cr.

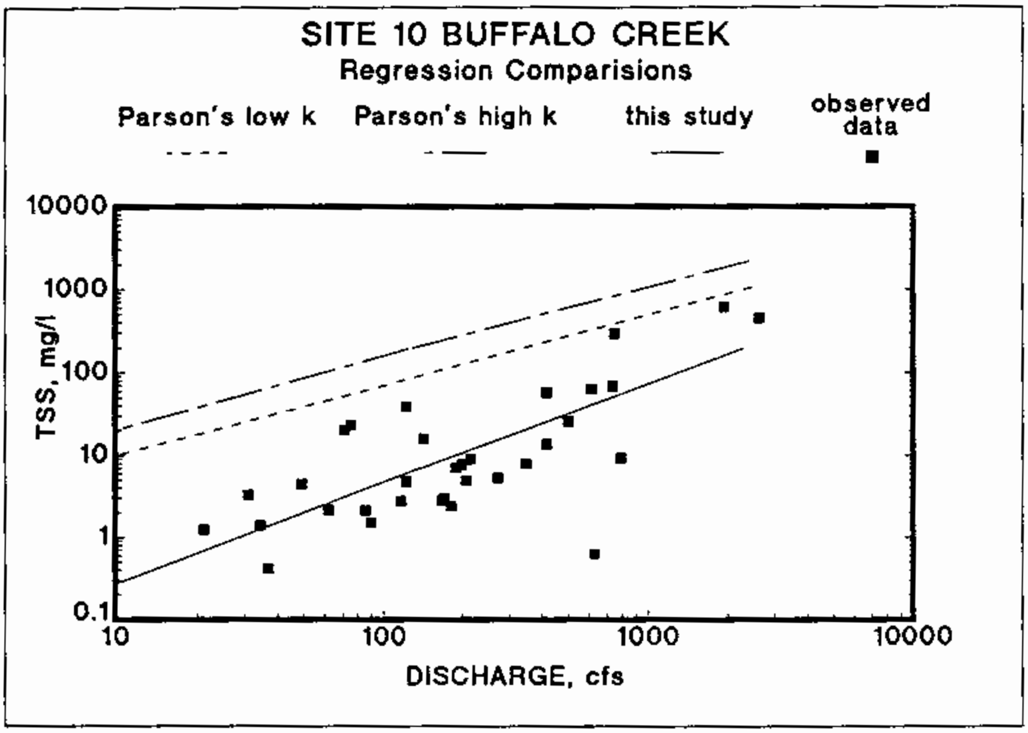

Figure 12 Suspended sediment rating curve (Table 10) for Buffalo Cr. The dashed lines represent the rating curves from Parsons et al. (1963) for the same site. The lower dashed line was calculated with the minimum K value, while the higher dashed line was calculated with the maximum K value (see text for further explanation).

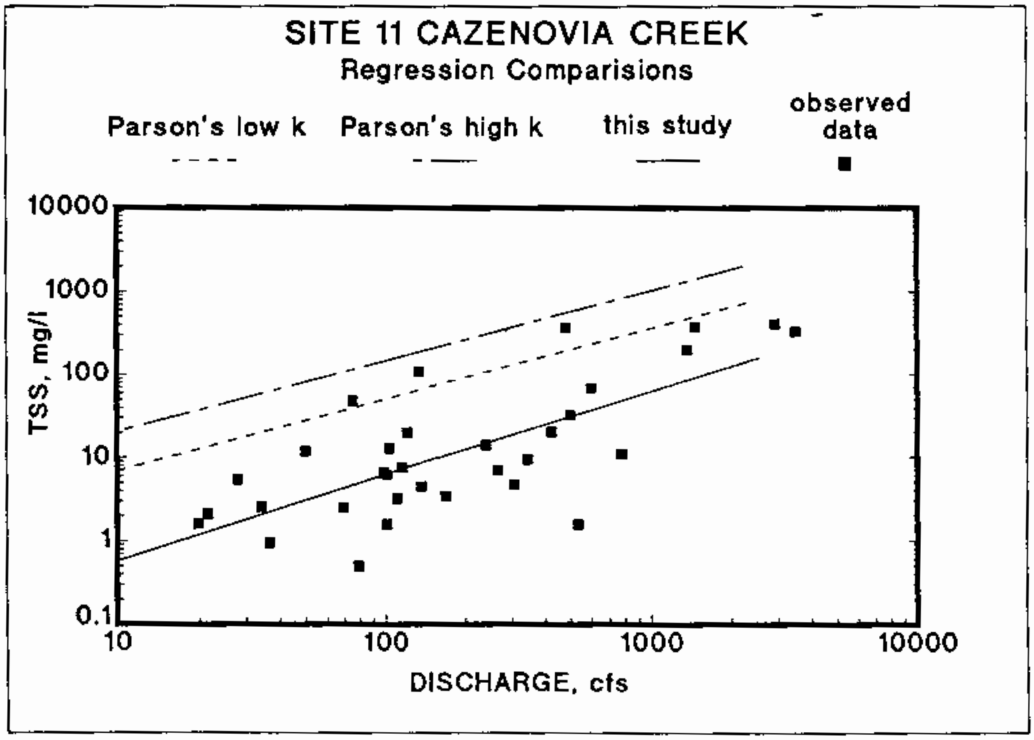

Figure 13 Suspended sediment rating curve (Table 10) for Cazenovia Cr. The dashed lines represent the rating curves from Parsons et al. (1963) for the same site. The lower dashed line was calculated with the minimum K value, while the higher dashed line was calculated with the maximum K value (see text for further explanation).

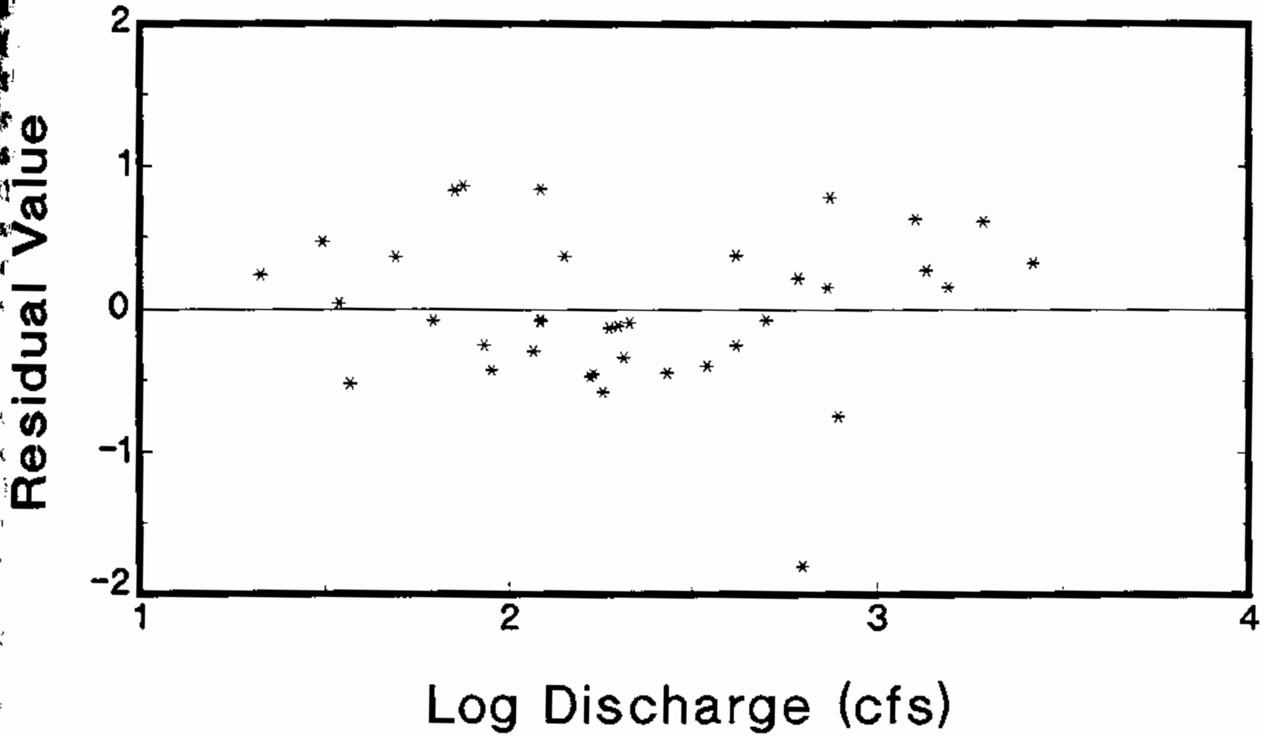

Figure 14 Regression residual values vs. corresponding discharge (x) values from the log-transformed analysis, Buffalo Cr. The reduction of the obvious funnel shape (e.g. Figure 9) when the residuals were plotted against x or $\hat{y}_i$ also was observed for the other sites (not shown).

therefore comparisons are not made between the two studies. It appears that Parsons et al., (1963) sampled Cayuga Creek approximately 260 yards downstream from the two sites in this study. It also should be noted that the Parsons et al. (1963) study focused on storm event sampling, whereas this study represents a range of flows. Sampling strategy may have some influence on the final form of the rating curve developed in each study. Figures 12 and 13 represent two separate rating curves from the Parsons et al. (1963) study. These curves were plotted using the maximum and minimum monthly value of K (soil erodibility) observed in the year (Table 2) to represent the maximum and minimum concentration expected, given a particular discharge.

Recognizing the limitations of each data set, it nonetheless appears that the rating curves developed by Parsons et al. (1963) overestimate current suspended sediment concentrations. Example calculations of the extent of overestimation are presented in Table 11. The discharges selected for the example calculations were exceeded 1% and 10% of the time, based on the daily flow duration curves (1940-85) from Meredith and Rumer (1987). Correction factors for backtransformation were not applied to the results presented in Table 11 since detailed residual analysis was not available for the Parsons et al. (1963) rating curves. It is anticipated that the correction factor might be similar for both analyses and therefore would have little impact on the relative relationships summarized in Table 11. Overestimation of incoming sediment loads using the Parsons et al. (1963) rating curves may, in part, account for the HEC-6 overestimation of siltation rates reported by Meredith and Rumer (1987).

Table 11 Predicted Sediment Concentrations (mg l^{-1}) using Rating Curves from this Study and Parsons et al. (1963)

	Concentration, mg l^{-1} Parsons, low K	Concentration, mg l^{-1} Parsons, high K	Concentration, mg l^{-1} This Study (Table 10)	% difference* low K	% difference* high K
Buffalo Cr. 2,000 cfs (1% exceedance)	895 (K=1.4)	1,983 (K=3.1)	170	81	91
500 cfs (10% exceedance)	276 (K=1.4)	610 (K=3.1)	32	88	95
Cazenovia Cr. 2,285 cfs (1% exceedance)	716 (K=1.0)	2,077 (K=2.9)	148	79	93
570 cfs (10% exceedance)	220 (K=1.0)	638 (K=2.9)	36	84	94

* % difference in sediment concentration estimated using the Parsons et al. (1963) rating curves and the rating curves developed in this study, Table 10.

BATHYMETRIC AND DREDGING RECORD ANALYSIS

The lower Buffalo River is designated a navigable channel and as such is maintained at a minimum depth of 22 ft through dredging operations. Dredging currently is conducted by private contractors, but is supervised by the Buffalo District U.S. Army Corps of Engineers. The Corps of Engineers does a bathymetric survey each year to determine the need for dredging. The surveys are done along transects at approximately 100 ft intervals, although this distance is variable around meander bends (e.g. Figure 15). These "precontract" surveys typically cover transects along the entire length of the navigable channel. Additional surveys also may be done immediately before and after dredging to compute the volume of sediment removed from the river. In some cases the "immediately before and after" surveys are done only for selected stretches, rather than the entire navigable channel.

The bathymetric data as shown in Figure 15, for example, consist of a series of depth soundings below low water datum at each transect. The low water datum (lwd) is 568.6 ft above mean water level at Father Point, Quebec (International Great Lakes Datum, 1955). It is not possible to make depth soundings across the entire channel at some transects, particularly in shallower meander bend areas. In other bulk-headed areas where banks are nearly vertical, soundings are made across the entire channel. The soundings therefore refer primarily to the dredged portion of the channel and some quiescent areas may not be surveyed.

Originally it was anticipated that the bathymetric survey data at the individual transects could be used to evaluate siltation rates after the methodology outlined by Meredith and Rumer (1987). Essentially, the cross-sectional areas at the transects would be determined for both pre- and post-dredging and the difference in sediment volume (and weight) associated with the two profiles would provide an indication of siltation rate. It had been hoped that a lengthy time series of bathymetric surveys could be obtained for analysis. However, discussions with Corps of Engineers personnel (D. Borkowski, pers. comm.) indicated that sounding data were retained for a limited time and were readily available only to 1970. It also was believed that the MSM Terrain Modeler software available at the Buffalo District Corps of Engineers would facilitate calculation and presentation of cross-sectional bathymetric areas. Unfortunately, bathymetric data collected prior to 1991 are not in a format easily transferred to the Terrain Modeler package. Manual digitization of the soundings therefore was required. In addition, after a summer of assistance from Mr. Peter Crawford, Water Control Section, Buffalo District Corps of Engineers, it was discovered that bugs existed in the software, thereby further delaying analyses. It was decided for the purposes of this report to present results from the Terrain Modeler for a section of river that successfully was analysed for the years 1990-91. The analytical methodology employed with the Terrain Modeler application also will be described. In general, the results from this analytical approach are promising, but fuller analysis would require further time commitments not available for this study.

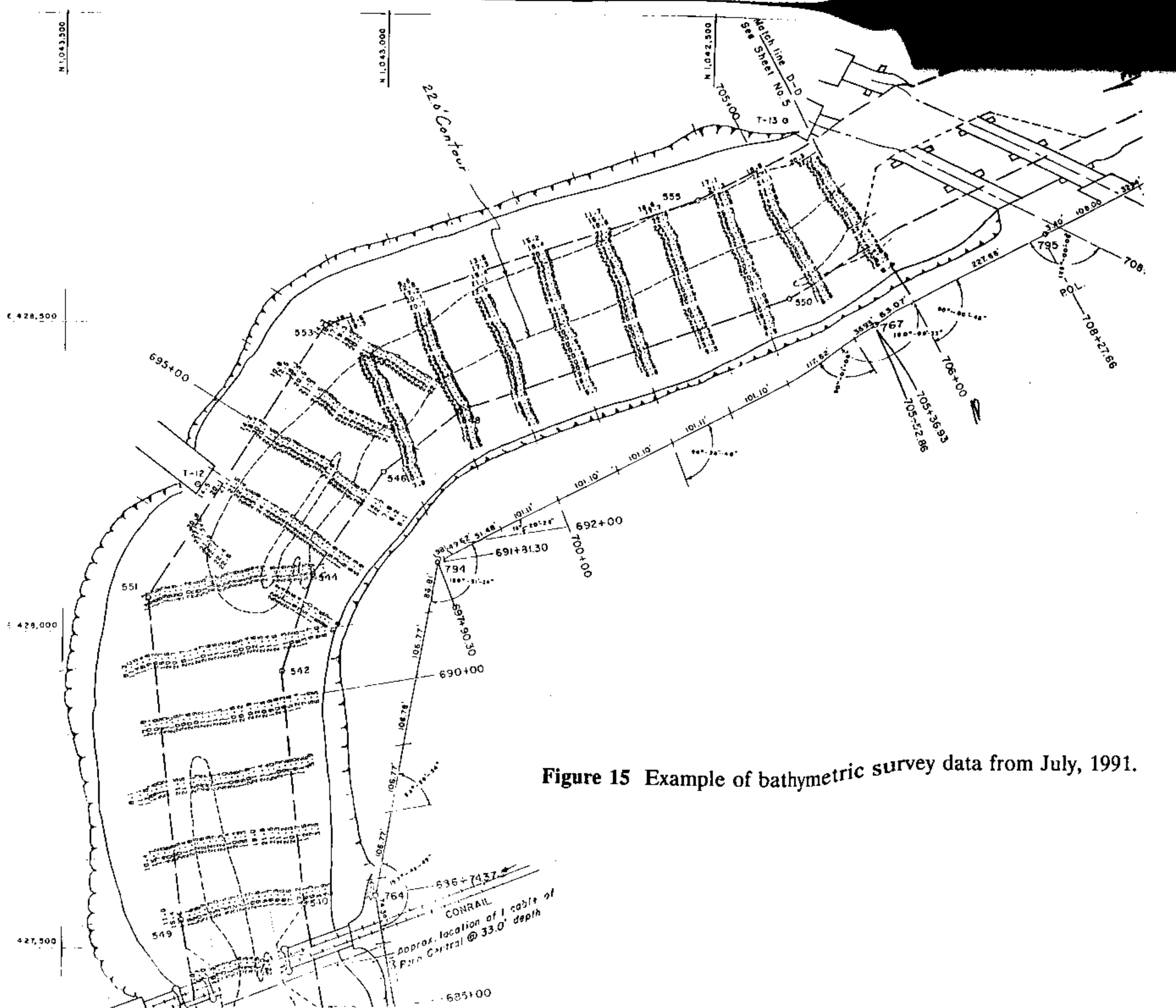

Figure 15 Example of bathymetric survey data from July, 1991.

Data were obtained from the Corps of Engineers (D. Borkowski, pers. comm.) on the total volume of material dredged from the river during the period 1970-92 as well as a quasi-quantitative estimate of dredging locations. Following the assumption made by Versar (1975) that, on average, the volume of material dredged would equal the volume of material deposited, first approximation estimates of siltation rates can be made.

Analytical Approach

The bathymetric data were analysed using the MSM Terrain Modeler software on an InterGraph Interpro 2020 workstation at the Buffalo District Corps of Engineers. Each depth sounding (either digitally transferred or manually digitized) was placed as a text element at the appropriate northing-easting coordinate in a Microstation design file (i.e. a *.dgn file). Microstation is InterGraph's CAD product. For example, if the sounding is 27.8 ft at 1,044,500 mN, 422,000 mE, then the text element -27.8 was placed in the design file at the appropriate location. Given two *.dgn files, say before.dgn and after.dgn, the goal was to: i) generate TIN (Triangulated Irregular Network) models (e.g. Figure 16) of the before dredging bathymetry, the after dredging bathymetry and the difference (where difference = after - before); ii) calculate the total volume of sediment deposited and eroded from the different areas; and iii) produce contour and wire-mesh plots of the TIN models.

MSM provides a wide array of tools for the analysis, manipulation, modification and graphical display of computerized terrain modelling data. Of particular use for this study were the tools for: i) importing text elements from *.dgn files into MSM as point (i.e. x, y, z) features; ii) creating a TIN model from the point features; iii) creating a difference TIN model; and iv) calculating volumes.

Results of Bathymetric Sounding Analysis

The bathymetric data from the after dredging survey of 1990 and the precontract survey of 1991 for transects 686 through 706 (Figure 15) were digitized and an example of the wire-mesh bathymetry plot for 1990 is presented in Figure 17. The three-dimensional model shown in Figure 17 can be rotated to provide a variety of perspectives. Interpolated bathymetric contours at 1 foot intervals for the 1990 and 1991 surveys are presented in Figures 18 and 19. Inspection of the bathymetric contours suggests that deposition occurred, in particular, on the inside of the meander bend. This deposition pattern follows classic theory of point bar development through lateral accretion. The volumes of scour and deposition calculated for the period October, 1990 to July, 1991 using the Terrain Modeler software were 5,212 yd^3 and 3,929 yd^3, respectively. The difference of -1,283 yd^3 indicates that there was a small net scouring of sediment in this reach between 1990 and 1991.

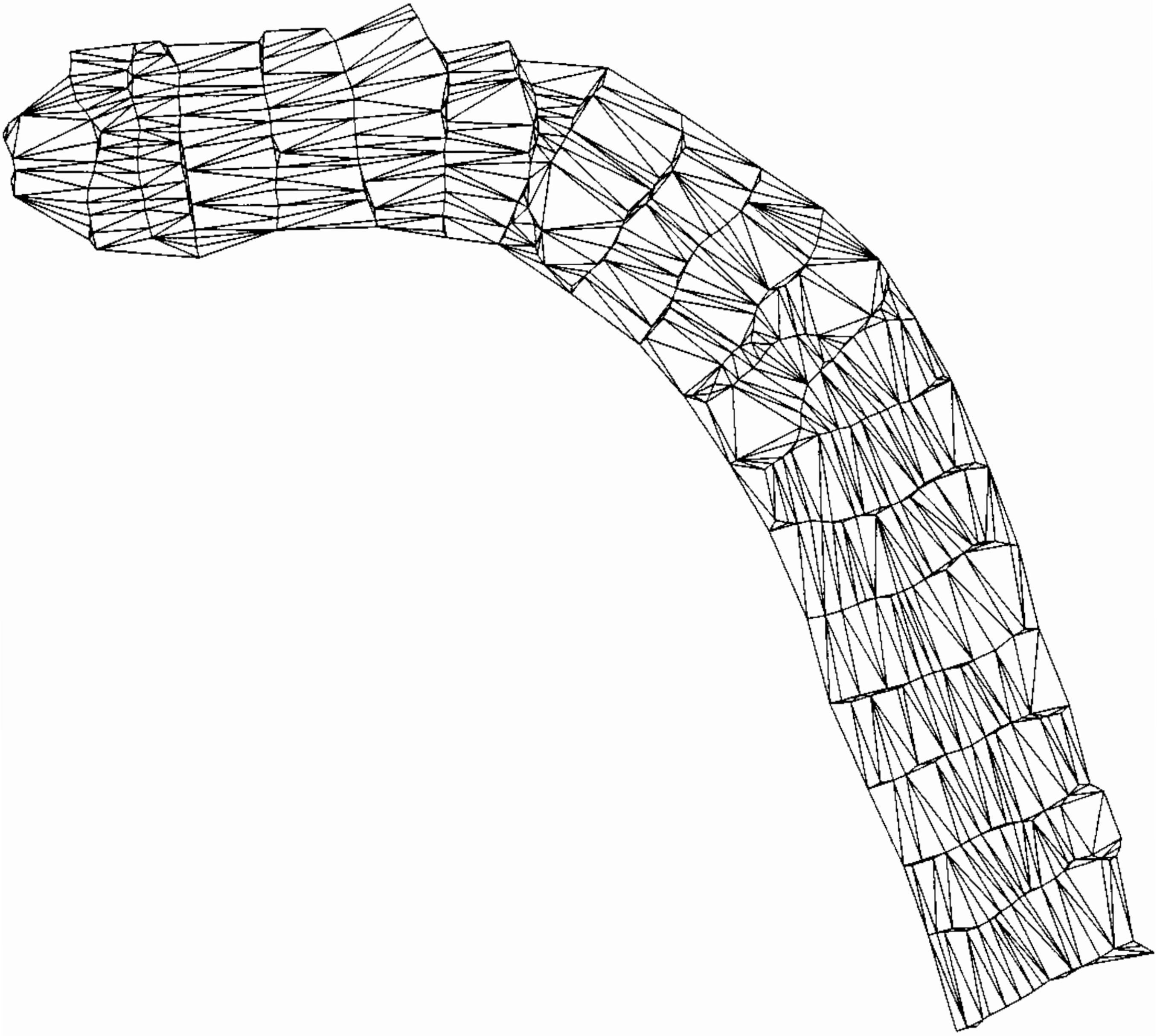

Figure 16 Top view of TIN model created from bathymetric survey data collected on October, 1990 between transects 686 and 706 (see Figure 15 for transect locations).

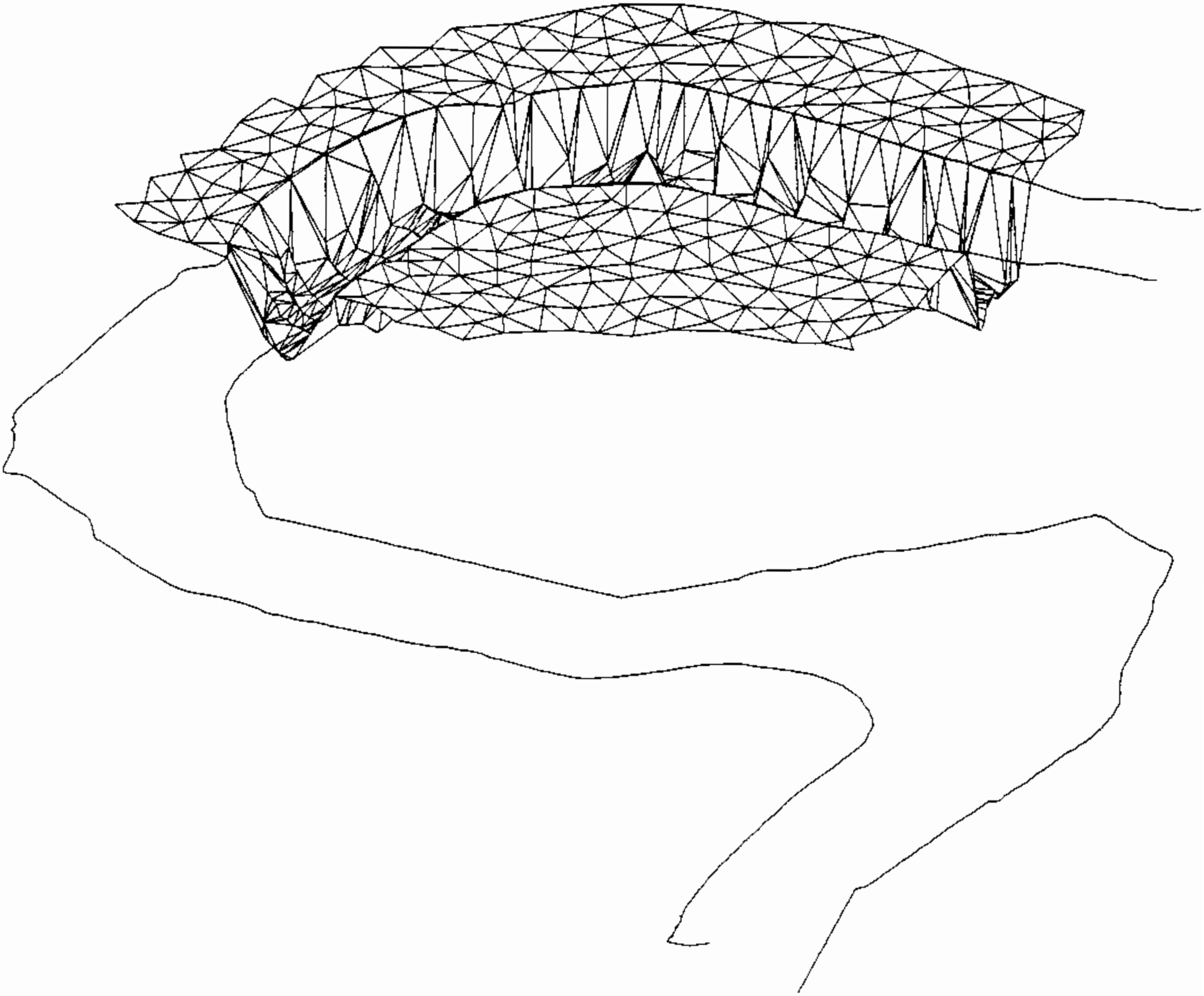

Figure 17 Three-dimensional wire-mesh bathymetry plot (transects 686-706) from data collected on October, 1990.

Figure 18 Bathymetry contours (1 ft intervals) from the after-dredging survey of October, 1990 (transects 686-706).

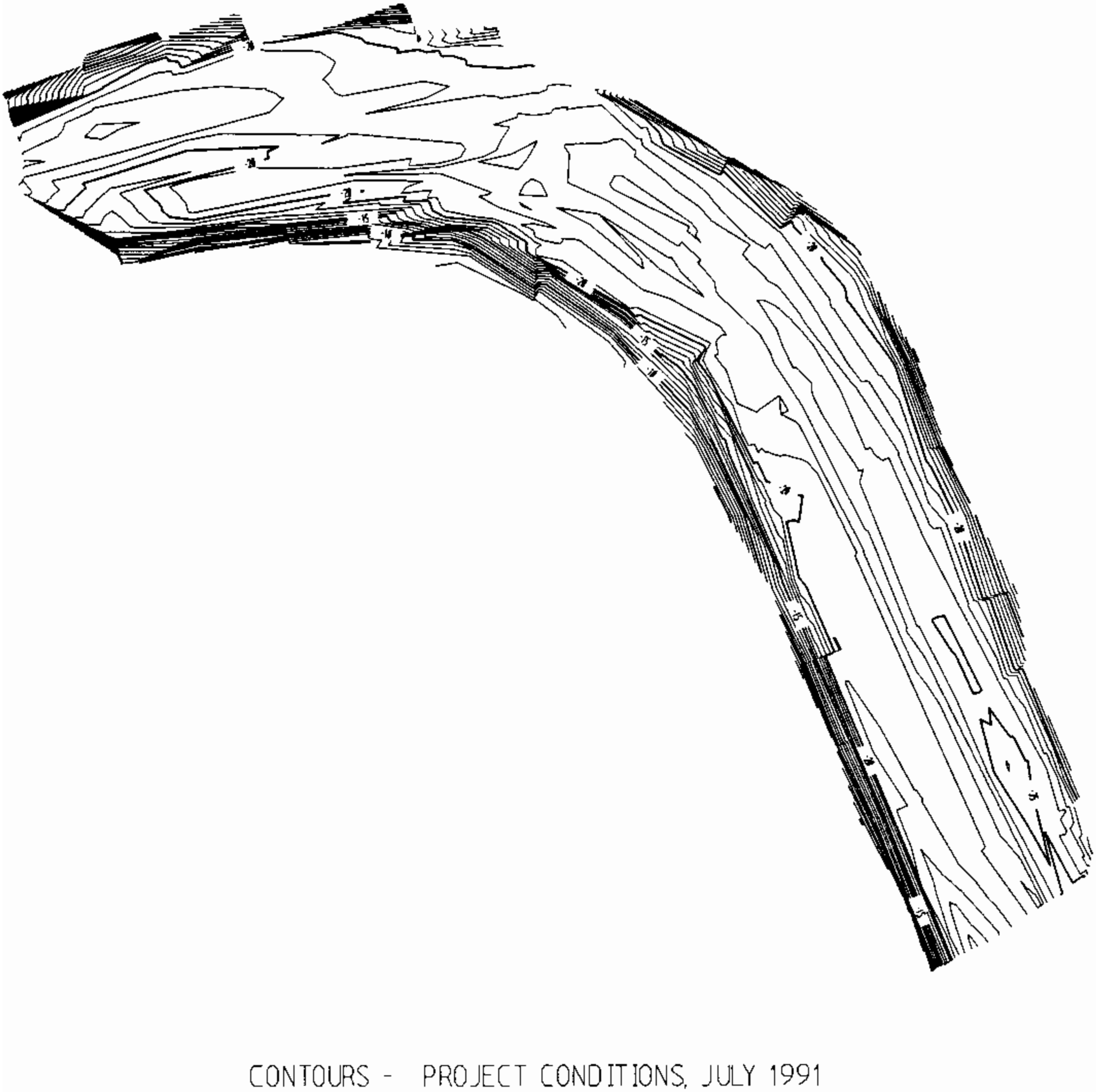

Figure 19 Bathymetry contours (1 ft intervals) from the precontract (i.e. project conditions) survey of July, 1991 (transects 686-706).

Siltation Rate Estimations Based on Dredging Records

A summary of the volume of sediment dredged from the navigation channel between 1970 and 1992 was obtained from the Buffalo District Corps of Engineers and the data are presented in Table 12. The sediment volume determinations in Table 12 are based on the bathymetric surveys of the river. The available data did not explicitly distinguish between dredging done in the river and in the ship canal. Dredging in the Buffalo Harbor was recorded as distinct from river dredging and the data presented in Table 12 do not reflect sediment removed from the harbor. Dredging was done in the period 1972-1977, but the volumetric data were unavailable for inclusion in Table 12. The dredging data reported by Hall (1955) indicated that, on average, 261,393 yd^3 of sediment was removed each year during the period 1944-55. Approximately 20 years later the annual average volume of sediment removed from the river was 125,000 yd^3 (Versar, 1975). More recently, the annual average volume of sediment dredged is 97,319 yd^3 (Table 12). Assuming, on average, that the volume of sediment dredged is equal to the volume deposited, it appears that deposition rates within the Buffalo River have declined through the past 40 years. This, of course, assumes that decline in industrial activity has not affected the channel maintenance schedule for the river.

Most studies express siltation rates in terms of mass of deposition rather than volume. It is possible to convert sediment volume to mass through direct measurement or estimation of various physical sediment properties. For example, Versar (1975) found that the spoil density of dredged material was 1,250 lbs yd^{-3} and the dredged material was, on average, 34.9% solids. Based on a dredged volume of 125,000 yd^3 yr^{-1}, the calculated dredged mass was 27,266 tons yr^{-1}. This represents a volume to mass ratio of 4.58. Meredith and Rumer (1987) converted the sediment volume to a mass assuming a specific gravity of 2.65 and a porosity of 0.6. The volume to mass ratio from Meredith and Rumer (1987) accordingly was 1.12. Finally, Hall (1955) calculated that the mass of 261,393 yd^3 of dredged material was 169,611 tons, representing a volume to mass ratio of 1.54. The assumptions made in this latter calculation were not discussed. Given the dredged volumes and reported volume to mass ratios ranging between 1.12 and 4.58, the possible mass of deposited material also is summarized in Table 12.

Records are not available to precisely determine river transects that experience the greatest frequency of dredging. However, after discussions with personnel from the Buffalo District Corps of Engineers, a quasi-quantitative estimate was provided of the relative volume of sediment removed from particular reaches. Areas experiencing the greatest level of dredging activity, and hence, greatest siltation rates, are plotted in Figure 20. The depositional areas plotted in Figure 20 correspond well with the areas of greatest deposition forecast by Meredith and Rumer (1987) using the HEC-6 model.

Table 12 Summary of Sediment Volume and Mass Dredged from the Buffalo River, 1970-1992

Year	Volume Dredged (yd^3)	Minimum Mass Dredged (tons)*	Maximum Mass Dredged (tons)
1970	133,803	149,859	612,818
1971	127,672	142,993	584,738
1978	106,283	119,037	486,776
1979	90,770	101,662	415,727
1980	170,134	190,550	779,214
1981	57,012	63,853	261,115
1982	152,312	170,589	697,589
1983-85	48,000**	53,760	219,840
1986	21,938	24,570	100,476
1987	84,772	94,945	388,256
1988	151,676	169,877	694,676
1989-90	65,774**	73,667	301,245
1991-92	55,000**	61,600	251,900
Mean S.D.	97,319 46,850		

* Minimum mass calculated with a volume to mass ratio of 1.12 and maximum mass calculated with a ratio of 4.58.

** Periods in which sampling was not done every year. The dredged volume is expressed on an annual basis. This was done by equally dividing the subsequently dredged volume (e.g. the volume dredged in 1992) by the number of years since last dredging (e.g. 2 for 1991 and 1992).

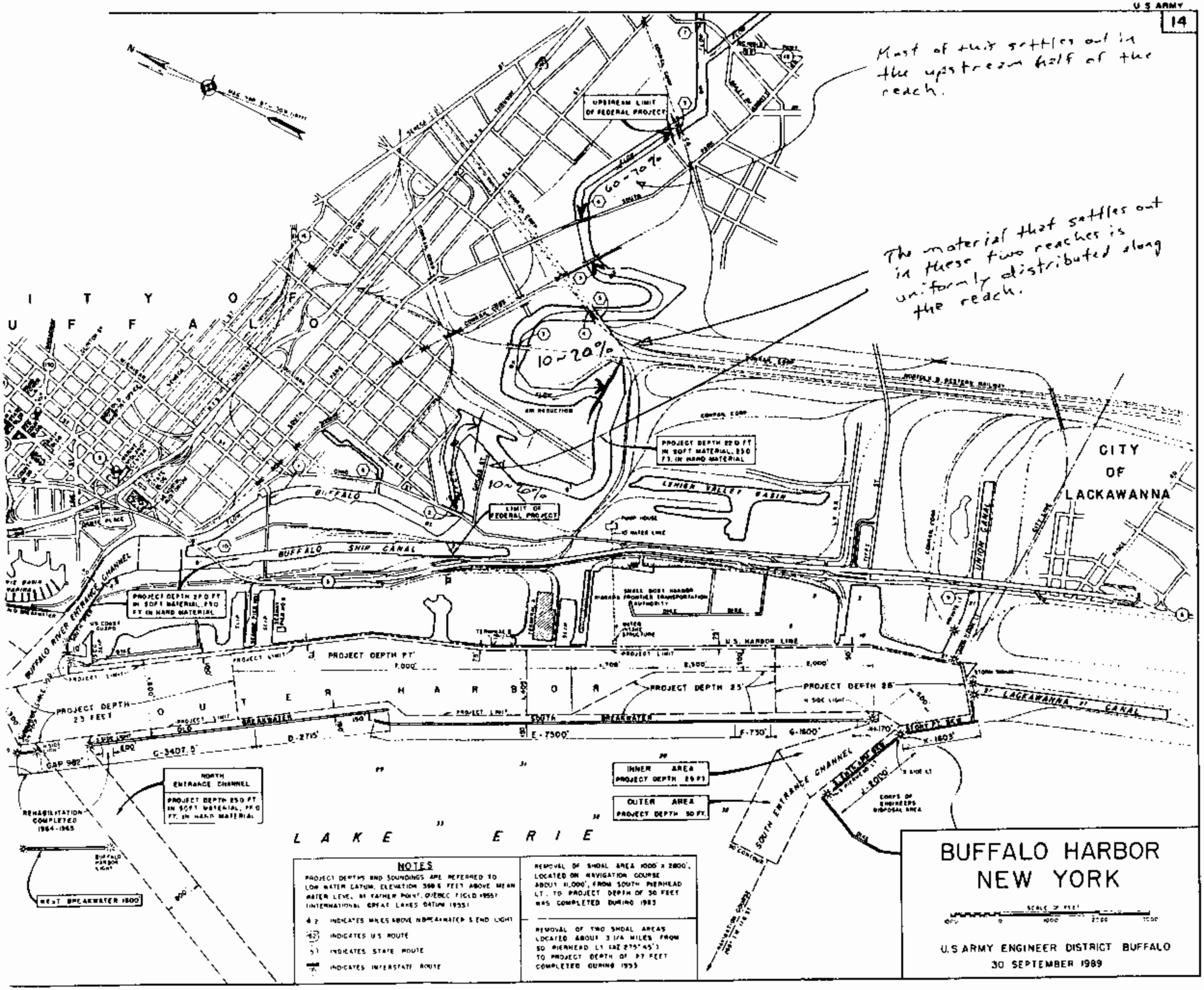

Figure 20 Estimated relative proportion of material removed and location of dredging (from D. Borkowski, pers. comm.).

CONCLUSIONS

1. The suspended sediment regime of the Buffalo River and tributaries has been non-stationary over the last 200 years. Changes in sediment regime are related to changes in the use of the river, industry along the river, municipal waste practices, soil erosion conservation and implementation of riverbank stabilization programs. However, a review of the literature for the river indicates considerable variability in the estimated watershed sediment yield rates, depending on the assumptions of the particular study.

2. In general, siltation rates appear to have declined within the Buffalo River AOC over the last 40 to 50 years, as evidenced by the volume of sediment dredged. This decline is related to municipal and industrial discharge abatement programs and a decrease in suspended sediment yield from the upper watershed. The decline in upper watershed sediment yield was detected by comparing sediment rating curves developed with data from 1953-61 and those developed with data from 1992-93. Additional suspended sediment data should be collected to verify the form of the rating curves developed from the 1992-93 data.

3. Sampling indicates that suspended sediment concentrations in the tributaries during the most frequently-occurring, steady-state conditions average between approximately 1 and 4 mg l^{-1}. Suspended sediment concentrations within the AOC average between approximately 7 and 9 mg l^{-1} under the same conditions. These sediment concentrations do not appear excessive. As expected, suspended sediment concentrations in the tributaries and the AOC increased during storms, reaching values of at least 300-660 mg l^{-1}.

4. Recent sediment transport modelling efforts for the Buffalo River AOC have used the old (1953-61) rating curves to estimate sediment loads entering the AOC. It appears that this approach would overestimate the load entering the AOC and may lead to siltation rate estimation errors.

5. Although modelling efforts may have overestimated siltation rates, in general the models consistently indicate that the Buffalo River is in an aggrading condition. Discontinuation of dredging would result in sediment deposition for most sections of the river. Estimated sediment accumulation varies between 1 and 10 ft at different river transects over a period of 25 years.

6. Areas having the greatest proportion of sediment dredged generally correspond to those areas having the highest siltation rates, as identified through past modelling efforts.

7. The MSM Terrain Modeler software (or available, similar software) has the potential to be a useful tool in evaluating bathymetric changes related to scour and deposition of sediment. This type of analysis should be pursued in future studies.

ACKNOWLEDGEMENTS

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PART II: Biological Surveys of Fish and Invertebrates

BENTHIC MACROINVERTEBRATE SURVEY[*]

METHODS

Benthic macroinvertebrates were collected on 5/18/92 and 7/17/92 at 4 Buffalo River sites and a "control site" located in Lake Erie approximately 500 meters from the mouth of the river. (Fig. 1A).

Specific collection sites were:

Site 1: mouth of the Buffalo River near the Coast Guard station and ship canal.

Site 2: immediately downstream of the Ohio St. bridge.

Site 3: between Cargill and Concrete Central.

Site 4: immediately downstream of the mouth of Cazenovia Creek.

Control site: between the Outer Harbor Breakwall and the West Breakwall, approximately 500 meters from the mouth of the Buffalo River.

The methodology described in the original proposal was followed. Briefly, a total of 4 samples were collected at each river site using a petite Ponar dredge; the 4 samples consisted of 2 replicate samples from midchannel ("deep samples") and 2 replicate samples from inshore ("shallow samples"). Samples were rinsed and condensed using a No. 30 USGS sieve and preserved in a neutralized 15% formalin - 5% glycerin solution, and later stained with Rose bengal for identification and enumeration. All samples and replicates were analyzed separately. Prior to statistical comparisons, replicates (e.g. 2 shallow samples from a given site) were pooled. At the control site in Lake Erie no suitable shallow water areas were found, and 2 samples from a depth of approximately 8 meters (similar to midchannel depths in the Buffalo River) were taken.

To provide a summary of the benthic community present at each site, average numbers of organisms in 5 major taxonomic groups (nematoda, oligochaeta, pelecypoda, amphipoda, and diptera) were expressed as percentages for each location. Numbers of organisms in these 5 taxonomic groups were compared among sites using ANOVA with Tukey's multiple means comparisons. Differences between shallow and deep samples, as well as May and July samples, were tested for significance using sign tests.

RESULTS

A total of 59 species of benthic macroinvertebrates were found, representing 13 major taxonomic groups (Tables 1-3). The 4 Buffalo River sites were generally dominated by oligochaetes ("worms"), with % compositions from approximately 80-95%. Dipterans ("midges") were the second most abundant taxonomic group at the river sites,

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[*] Section compiled by Randal Snyder

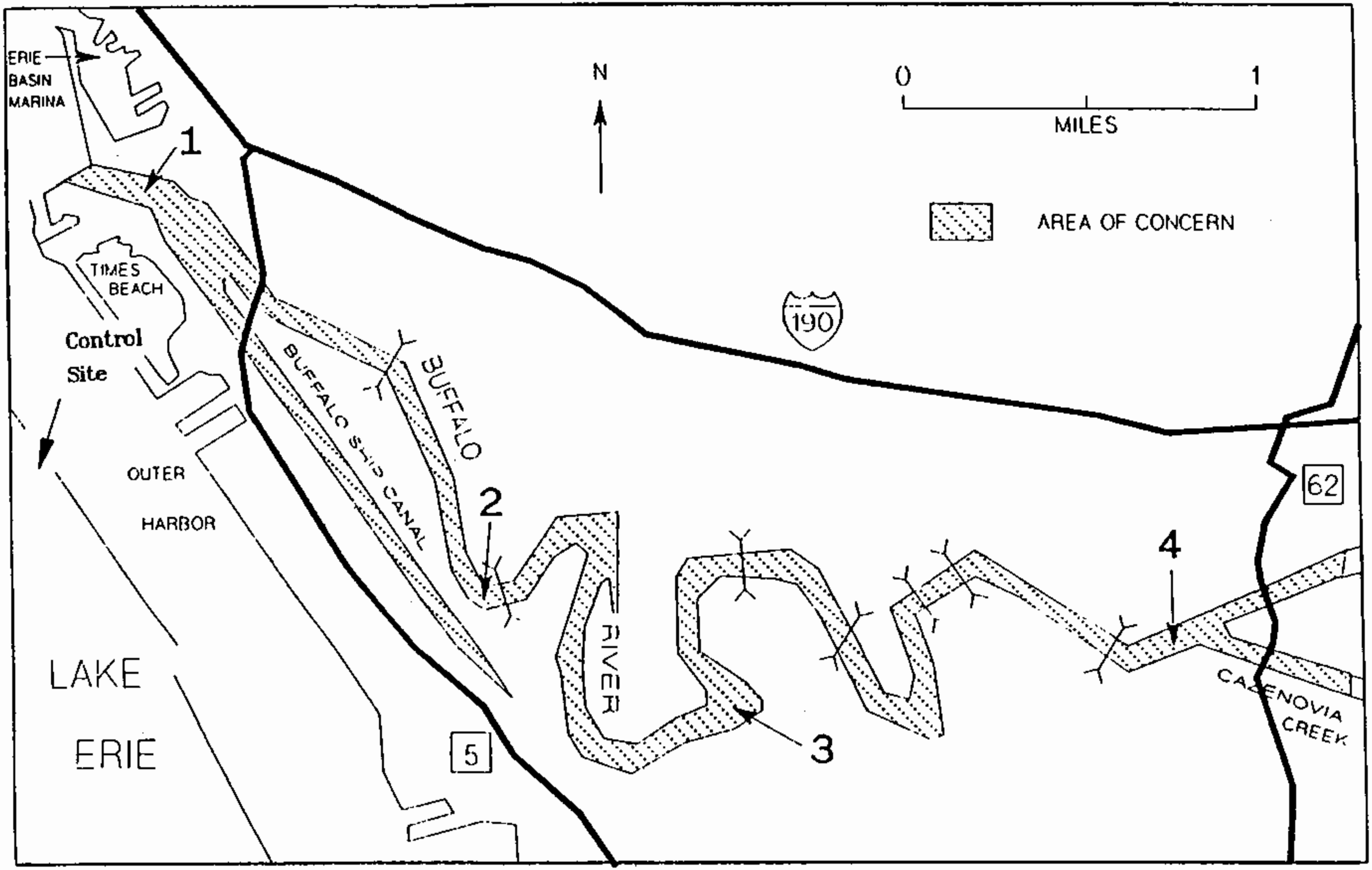

Figure 1a. Location of sampling sites in the Buffalo River AOC (adapted from NYDEC, 1989).

Table 1. Species list for benthic macroinvertebrates collected from the Buffalo River during Spring/Summer 1992 sampling. Taxon ID# is an arbritary number assigned to each taxon to simplify presentation of data in Table 2.

ID#	Phylum/Class/Order	Family	Genus/species
1	Turbellaria	*	*
2	Nematoda	Dorylaimina	Dorylaimus sp
3	Nematoda	Dorylaimina	Mesodorylaimus sp
4	Nematoda	Enoplina	Tobrilus sp
5	Nematoda	*	unknown 1
6	Nematoda	*	unknown 2
7	Nematoda	*	unknown 3
8	Nematoda	*	unknown 4
9	Oligochaeta	Lumbriculidae	*
10	Oligochaeta	Naididae	*
11	Oligochaeta	Tubificidae	imm. w/o hair chaetae
12	Oligochaeta	Tubificidae	imm. w hair chaetae
13	Oligochaeta	Tubificidae	Limnodrilus cervix
14	Oligochaeta	Tubificidae	L. hoffmeisteri
15	Oligochaeta	Tubificidae	L. claparedianus
16	Oligochaeta	Tubificidae	L. udekemianus
17	Oligochaeta	Tubificidae	Aulodrilus pigueti
18	Oligochaeta	Tubificidae	Potamothrix vejdovskyi
19	Oligochaeta	Tubificidae	Tubifex tubifex
20	Hirudinae	Glossiphoniidae	Helobdella stagnalis
21	Hirudinae	Erpobdellidae	*
22	Gastropoda	Bithyniidae	Bithnia tentaculata
23	Gastropoda	Valvatidae	Valvata sincera
24	Gastropoda	Physidae	Physella vinosa
25	Gastropoda	Planorbidae	*
26	Pelecypoda	Sphaeriidae	Pisidium sp
27	Pelecypoda	Sphaeriidae	Sphaerium sp
28	Pelecypoda	Sphaeriidae	Musculium transversum
29	Pelecypoda	Dreissenidae	Dreissena sp (quagga)
30	Pelecypoda	Dreissenidae	Dreissena polymorpha
31	Hydracarina	Hydrachnella	*
32	Isopoda	Asellidae	*
33	Amphipoda	Gammeridae	Crangonyx sp
34	Amphipoda	Gammeridae	Gammarus sp
35	Amphipoda	Gammeridae	Gammarus fasciatus
36	Amphipoda	Talitride	Hyalella azteca
37	Ephemeroptera	Ephemeridae	Hexagenia sp

(Table 1 cont)

ID#	Phylum/Class/Order	Family	Genus/species
38	Coleoptera	Elmidae	*
39	Trichoptera	Polycentropodidae	*
40	Diptera	Empididae	*
41	Diptera	Ceratopogonidae	*
42	Diptera	Chironomidae	Procladius subletti
43	Diptera	Chironomidae	Tribe Chironomini
44	Diptera	Chironomidae	Chironomus sp
45	Diptera	Chironomidae	Cryptochironomous sp
46	Diptera	Chironomidae	Cryptotendipes sp
47	Diptera	Chironomidae	Demicryptochironomus s
48	Diptera	Chironomidae	Dicrotendipes sp
49	Diptera	Chironomidae	Endochironomous sp
50	Diptera	Chironomidae	Glyptotendipes sp
51	Diptera	Chironomidae	Parachironomous sp
52	Diptera	Chironomidae	Paralauterborniella sp
53	Diptera	Chironomidae	Paratendipes sp
54	Diptera	Chironomidae	Polypedilum sp
55	Diptera	Chironomidae	Tribelos sp
56	Diptera	Chironomidae	Tanytarsus sp
57	Diptera	Chironomidae	Cricotopus sp
58	Diptera	Chironomidae	Eukiefferiella sp
59	Diptera	Chironomidae	Orthocladius sp

Table 2a. Raw counts for benthic macroinvertebrate samples collected 5/18/92. Taxon ID numbers are defined in Table 1. To convert raw count to number per square meter, multiply by 38.34. Column 1s = site 1 (shallow), column 1d = site 1 (deep), con = control site, etc.

Samples collected 5/18/92 (all reps pooled)

	ID#	1s	1d	2s	2d	3s	3d	4s	4d	con
Turbe.	1	0	0	0	0	0	0	0	0	4
Nemat.	2	1.5	0	1.5	0.5	0	0.5	0	0	0
	3	0	0	1.5	0	0	1.5	0.5	0	0
	4	0	0	5.5	2	1	1	0	0	0
	5	0.5	0	0	0	0	0	0	0	0
	6	0.5	0	0.5	0	0	0	0	0	0
	7	0	0	0	0	0.5	0.5	0	0	0
	8	0	0	0	0	0	0.5	0	0	0
Oligo.	9	0	0	0	0	0	0	0	0	0
	10	0	0	17	3.5	0	0	0	0	0
	11	112	166.5	89	150	354	426.5	27.5	61	38.5
	12	0	9	8.5	4	0	11	4.5	5.5	3
	13	12.5	8.5	3.5	0	10.5	15.5	2.5	28	0
	14	49.5	36	43	32.5	37.5	31.5	11.5	21.5	17
	15	0	6.5	0	4	0	0	2	10	0.5
	16	0	0	0	0	0	0	0	0	0
	17	0	0	3.5	4	0	5	0.5	0	0
	18	0	0	0	0	0	0	0.5	0	0.5
	19	0	0	0	4	0	26	1.5	5	0
Hirud.	20	0	0	0.5	0	0	0	0	0	0
	21	0	0	0	0	0	0	0	0	0
Gastr.	22	0.5	0	0	0	0	0	0	0	0
	23	0	0	0	0	0	0	0	0	0
	24	0	0	0	0	0	0	0	0	2
	25	0	0	0	0	0	0	0	0	0.5
Pelec.	26	3.5	4	0.5	0	1.5	1	0	0	0
	27	0	0	0	0	0	0	0	0	0
	28	0	0	0	0	0	0	0	0	0
	29	0	0	0	0	0	0	0	0	50.5
	30	4	12.5	0	0.5	0	0	0	0	1113
Hydra.	31	0	0	0	0	1.5	0	0	0	0
Isopo.	32	0.5	0	0	0	0	0	0	0	0
Amphi.	33	0.5	0	0	0.5	0	0	0	0	2
	34	0	0	0	0	0	0	0	0	0
	35	0	0	0	0	0	0	0	0	9.5
	36	0	0	0	0	0	0	0	0	0

(Tab. 2a cont)

Samples collected 5/18/92 (all reps pooled)

	ID#	1s	1d	2s	2d	3s	3d	4s	4d	con
Ephem.	37	0	0	0	0	0	0	0	0	0
Coleo.	38	0	0	0	0	0	0	0	0	0
Trich.	39	1	0	0	0	0	0	0	0	0
Dipte.	40	0	0	0	0	0	0	0	0	0
	41	0.5	1	0	0	0	0	0	0.5	0
	42	13	15	2.5	8	22.5	12	0.5	1.5	0
	43	0	0	0	0	0.5	0	0.5	1	0
	44	0	0	0	0	0	0	0	0.5	0
	45	3	5	0.5	1	1.5	3	0	0.5	0
	46	0	0	0	0	0	0	0.5	0.5	0
	47	0	0	0	0	0	0	0	0	0
	48	0	0	0	0	0	0	0	0	0
	49	0.5	0	0	0	0	0	0	0	0
	50	0	0	0	0	0	0	0	0	0
	51	0	0	0	0	0	0	0	0	0
	52	0	0	0	0	0.5	0	0.5	0	0
	53	0	0	0	0	0	0	0	1	0.5
	54	0.5	0	0	0	0	0.5	7	5	0.5
	55	0	0	0	0	0	0	0	0	0
	56	0	0.5	1	2	2	11	0	0.5	0
	57	0	0	0	0	0	0	0	0	0
	58	0	0	0	0	0	0	0	0	0
	59	0	0	0	0	0	0	0.5	0	0

Table 2b. Raw counts for benthic macroinvertebrate samples collected 7/17/92. Taxon ID numbers are defined in Table 1. To convert raw counts to number per square meter, multiply by 38.34. Column 1s = site 1 (shallow), column 1d = site 1 (deep), con = control site, etc.

Samples collected 7/17/92 (all reps pooled)

	ID#	1s	1d	2s	2d	3s	3d	4s	4d	con
Turbe.	1	0	0	0	0	0	0	0	0	0
Nemat.	2	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0
	4	0	0	0	0	0	0	0	0	0
	5	0	0	0	0	0	0	0	0	0
	6	0	0	0	0	0	0	0	0	0
	7	0	0	0	0	0	0.5	0	0	0
	8	0	0	0	0	0	0	0	0	0
Oligo.	9	0	0	0	0	0	0	0	0	0
	10	0	0	0	0	0	0	0	0	0.5
	11	14.5	24.5	20.5	100.5	26	137.5	12.5	2	25.5
	12	0	1	0	0	0	4.5	2.5	0.5	1.5
	13	2.5	26.5	7.5	37.5	17	4	1.5	1.5	0
	14	3	19	11.5	25.5	26.5	47	4.5	0	5.5
	15	0	1	1	0	0.5	6.5	1.5	0.5	0
	16	0	1.5	1.5	0.5	1	2.5	0	0.5	0
	17	0	0	0	0	0	0	0	0	0
	18	0	0	0	0	0	0	0	0	1
	19	0	0.5	0	0	0	2	0	0	0
Hirud.	20	0	0.5	0	0	0	0	0	0	0
	21	0.5	0	0	0	0	0	0	0	4.5
Gastr.	22	0	0	0	0	0	0	0	0	0
	23	0	0	0.5	0	0	0	0	0	0
	24	0	0	0	0	0	0	0	0	0
	25	0	0	0	0	0	0	0	0	0
Pelec.	26	0	0	0	0	0	0	0	0	0
	27	0	0	0	0.5	0	0	0	0	0
	28	0	0	0	0.5	0	0	0	0	0
	29	0	0	0	0	0	0	0	0	9
	30	0.5	27	0	0	0	0	0	0	21
Hydra.	31	0	0	0	0	0	0	0	0	0
Isopo.	32	0	0	0	0	0	0	0	0	0
Amphi.	33	0	0	0	0	0	0	0	0	0
	34	0	0	0.5	0	0	0	0	0	0
	35	1.5	11	0	0	0	0	0.5	0	1
	36	0	0	0	0	0	0	0.5	0	0

(Tab. 2b cont)

Samples collected 7/17/92 (all reps pooled)

	ID#	1s	1d	2s	2d	3s	3d	4s	4d	con
Ephem.	37	0	0	0	0	0	0	0.5	0	0
Coleo.	38	0	0.5	0	0	0	0	0	0	0
Trich.	39	0.5	0	0	0	0	0	0	0	0
Dipte.	40	0	0	0	0	0	0	0.5	0	0
	41	0	0	0	0	0	0	0	0	0
	42	0	0.5	0	0	0.5	0	1.5	0.5	0
	43	0.5	0	0.5	0	2.5	0	3	0.5	0
	44	0	3	0	2	0	0	0	0	0
	45	0.5	1	0.5	0	1.5	0	2	0	0
	46	0	0	0	0	0	0	0	0	0
	47	0	0	0	0	0	0	0	0	0.5
	48	0	0	0.5	0	0.5	0	2.5	0	0
	49	0	0	0	0	0	0	0	0	0
	50	0	0	0	0	0	0	0.5	0	0
	51	0	0	0	0	0	0	3.5	0	0
	52	0	0	0	0	0	0	0	0	0
	53	0	0	0	0	0	0	0	0	0
	54	0.5	0	1.5	0	0	0	13	1	0
	55	0	0	0	0	0	0	0.5	0	0
	56	0	0	0	0	0	0	0	0	0
	57	0	0	0	0	0	0	5.5	0	0
	58	0	0	0	0	0	0	0.5	0	0
	59	0	0	0	0	0	0	0	0	0

Table 3. Summary of major macroinvertebrate taxa collected in Spring/Summer 1992 expressed as number per square meter. Column 1s = sit 1, shallow samples Column 1d = site 1, deep samples, etc. con = control site.

Samples Collected 5/18/92

	1s	1d	2s	2d	3s	3d	4s	4d	con	con
Turbellaria	0	0	0	0	0	0	0	0	0	307
Nematoda	96	0	345	96	58	153	19	0	0	0
Oligochaeta	6671	8684	6307	7745	15413	19764	1936	5023	2530	2032
Hirudinae	0	0	19	0	0	0	0	0	0	0
Gastropoda	19	0	0	0	0	0	0	0	0	192
Pelecypoda	288	633	19	19	58	38	0	0	21317	67900
Hydracarina	0	0	0	0	58	0	0	0	0	0
Isopoda	19	0	0	0	0	0	0	0	0	0
Amphipoda	19	0	0	19	0	0	0	0	77	805
Ephemeroptera	0	0	0	0	0	0	0	0	0	0
Coleoptera	0	0	0	0	0	0	0	0	0	0
Trichoptera	38	0	0	0	0	0	0	0	0	0
Diptera	671	824	153	422	1035	1016	364	422	38	38

Samples Collected 7/17/92

	1s	1d	2s	2d	3s	3d	4s	4d	con	con
Turbellaria	0	0	0	0	0	0	0	0	0	0
Nematoda	0	0	0	0	0	19	0	0	0	0
Oligochaeta	767	2837	1610	6288	2722	7821	863	192	1074	1534
Hirudinae	19	19	0	0	0	0	0	0	192	153
Gastropoda	0	0	19	0	0	0	0	0	0	0
Pelecypoda	19	1035	0	38	0	0	0	0	1802	498
Hydracarina	0	0	0	0	0	0	0	0	0	0
Isopoda	0	0	0	0	0	0	0	0	0	0
Amphipoda	58	422	19	0	0	0	38	0	0	77
Ephemeroptera	0	0	0	0	0	0	19	0	0	0
Coleoptera	0	19	0	0	0	0	0	0	0	0
Trichoptera	19	0	0	0	0	0	0	0	0	0
Diptera	58	173	115	77	192	0	1265	77	38	0

comprising 3-20% of the samples collected (Figs. 1B-4). The "control site" in Lake Erie differed from the river sites in terms of dominant taxonomic groups present: samples consisted of approximately 90% pelecypoda on average, with settled zebra mussels (Dreissena polymorpha) dominating the samples (Fig. 5).

Based on the results of the ANOVA, oligochaete densities were significantly higher at site 3 than at site 4 and the control site ($p < .05$)(Fig. 6). Site 3 (along with site 4) also had high densities of diptera (Fig. 7), but differences among sites were not significant ($p > .05$). Sites were also compared with respect to number of major taxa present (see Fig. 8). Site 1 was significantly more diverse than site 4 ($p < .05$), but no other differences among sites were significant.

The results of the sign tests suggest that shallow.areas have lower oligochaete densities and higher overall diversity than deep areas in the Buffalo River (see Figs. 9-11), but these differences are marginally significant ($p < .1$). The samples collected in May contained significantly higher densities of nematodes, oligochaetes, and dipterans compared to the July samples (see Figs. 9-11)($p < .05$), but average number of species present did not differ between May and July samples ($p > .05$).

DISCUSSION

In the 1960's, the Buffalo River possessed a severely impacted macroinvertebrate community as a result of continual input of industrial pollutants and low water flows due to dredging. Biological surveys during this time often found no macroinvertebrates in the Buffalo River proper. Since the mid-1960's, the biotic conditions have improved due to closing of industries along the river, stricter pollution standards, and augmentation of river flow with Lake Erie water via the Buffalo River Improvement Project begun in 1967.

Benthic macroinvertebrate surveys from 1970-1980 generally indicated greater abundance and diversity compared to surveys carried out in the 1960's. Oligochaetes were commonly found at most sites in the Buffalo River Area of Concern, and diptera and pelecypods were sometimes present at low densities. Although improved compared to the previous decade, the river was still considered to be severely degraded due to the dominance of oligochaetes, lack of facultative or intolerant species, and low species diversity.

Based on the 1992 benthic survey, the macroinvertebrate community seems to have improved in the past 10 years in terms of abundance and diversity. Overall, the dominance of worms and midges is indicative of an impacted river, but the diversity of organisms present and the occasional appearance of intolerant species (e.g. Ephemeroptera at site 4, Hydracarina at site 3) may justify an overall rating of "moderately impacted" as opposed to "severely impacted" as in previous years.

On a site-by-site basis, major changes in the Buffalo River benthic community since 1970-1980 are summarized below. Results of the present study were compared with benthic data from Buffalo River samples provided by Bergantz 1977, Simpson 1980, and Sweeney and Merckel 1972.

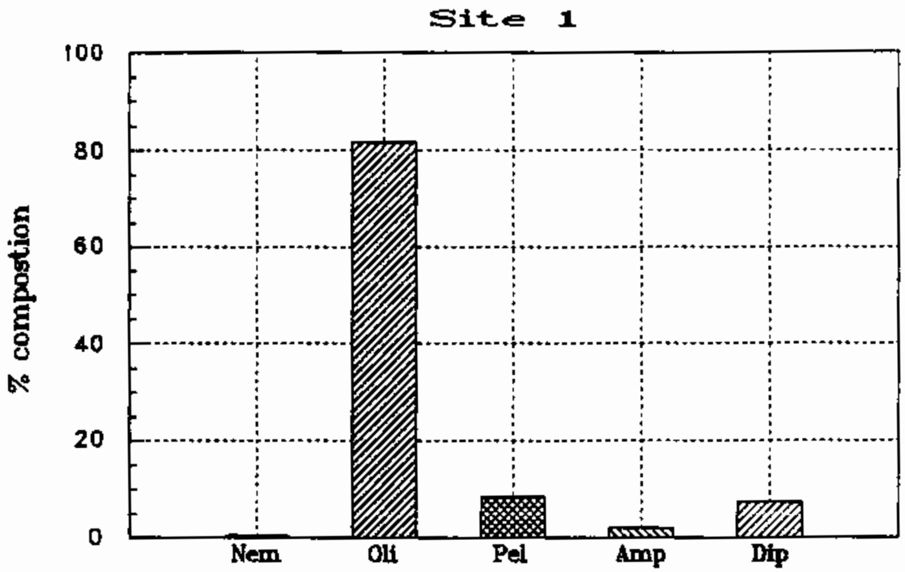

Figure 1b. Percent composition of benthic macroinvertebrate samples at Site 1 (based on total numbers). Nem = Nematoda, Oli = Oligochaeta, Pel = Pelecypoda, Amp = Amphipoda, Dip = Diptera.

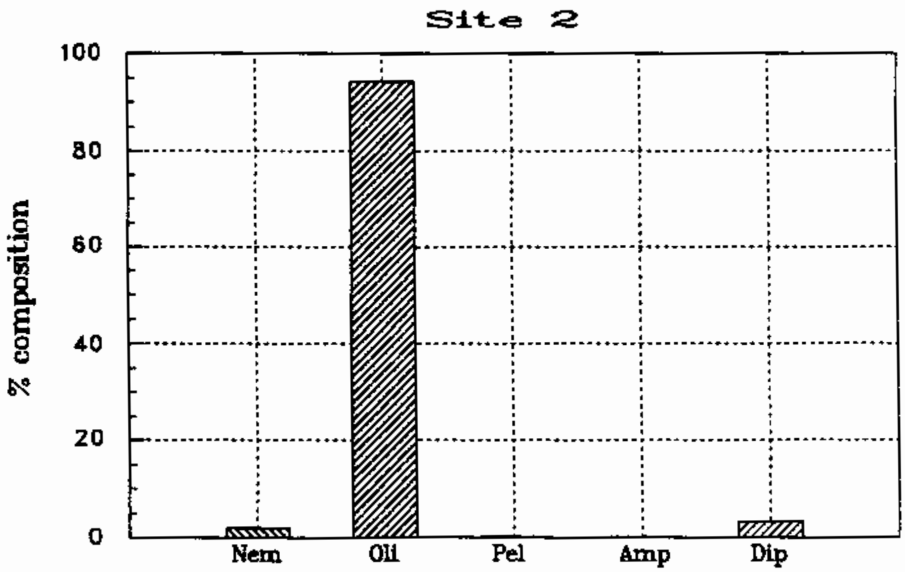

Figure 2. Percent composition of benthic macroinvertebrate samples at Site 2 (based on total numbers). Nem = Nematoda, Oli = Oligochaeta, Pel = Pelecypoda, Amp = Amphipoda, Dip = Diptera.

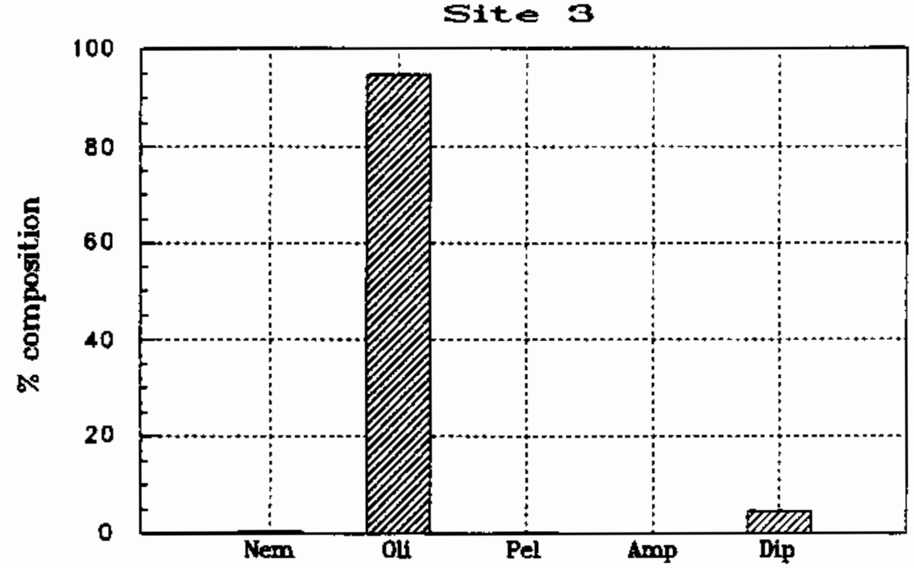

Figure 3. Percent composition of benthic macroinvertebrate samples at Site 3 (based on total numbers). Nem = Nematoda, Oli = Oligochaeta, Pel = Pelecypoda, Amp = Amphipoda, Dip = Diptera.

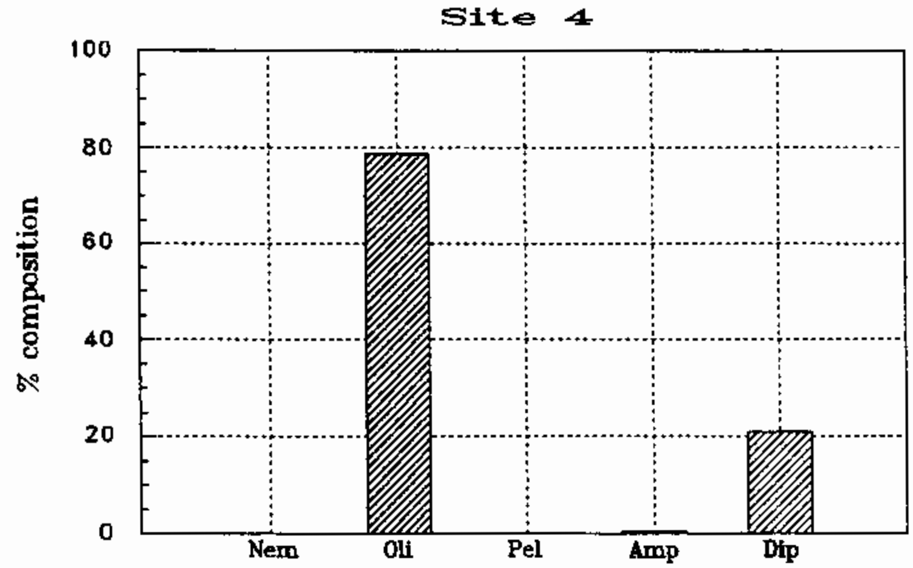

Figure 4. Percent composition of benthic macroinvertebrate samples at Site 4 (based on total numbers). Nem = Nematoda, Oli = Oligochaeta, Pel = Pelecypoda, Amp = Amphipoda, Dip = Diptera.

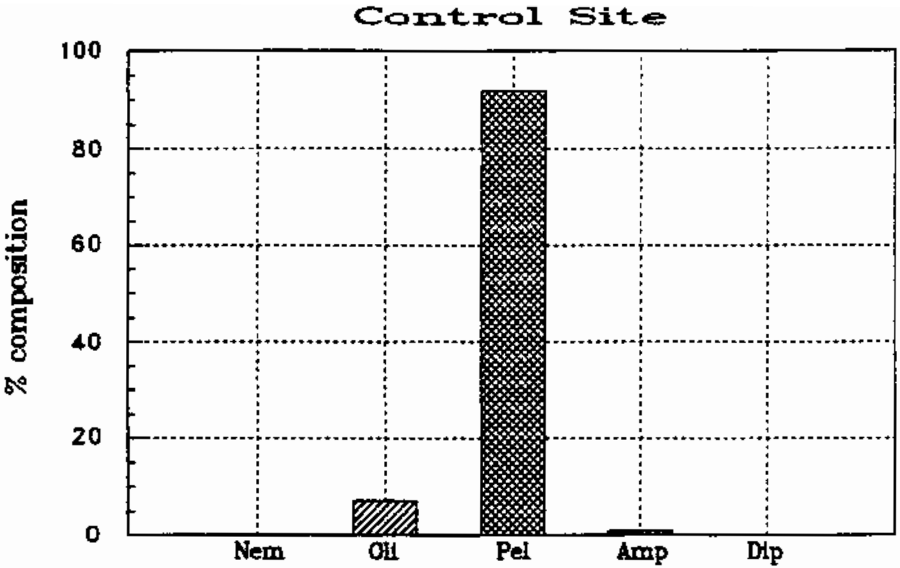

Figure 5. Percent composition of benthic macroinvertebrate samples at the control site (based on total numbers). Nem = Nematoda, Oli = Oligochaeta, Pel = Pelecypoda, Amp = Amphipoda, Dip = Diptera.

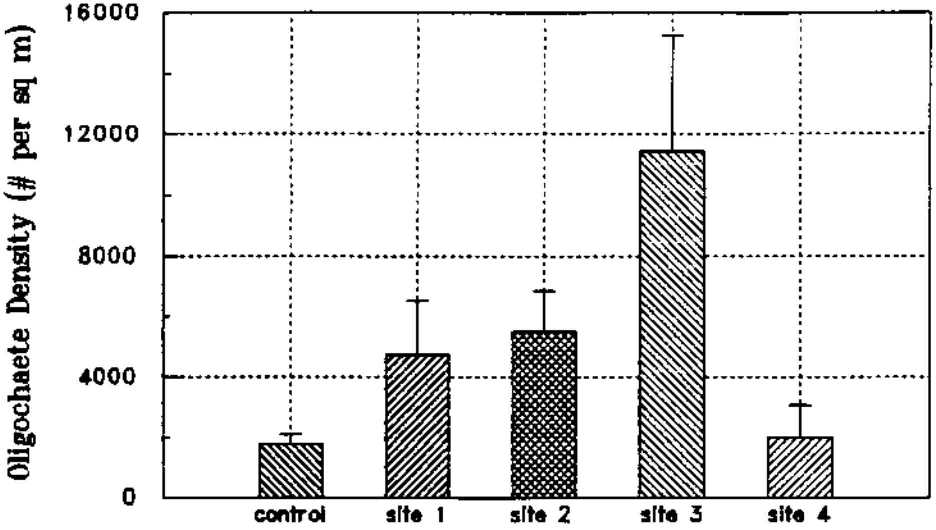

Figure 6. Site comparison for oligochaete abundance (Mean ± SE). Data pooled across depths and season.

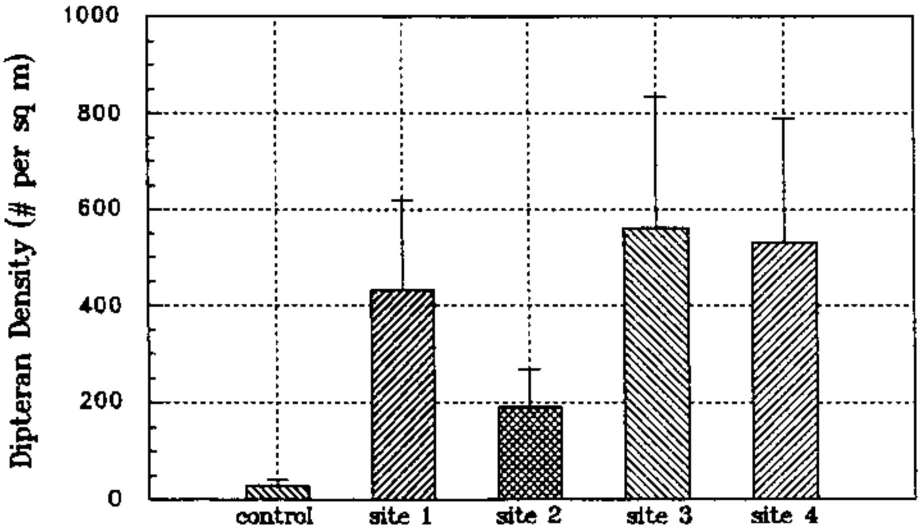

Figure 7. Site comparison for dipteran abundance (Mean ± SE). Data pooled across depths and season.

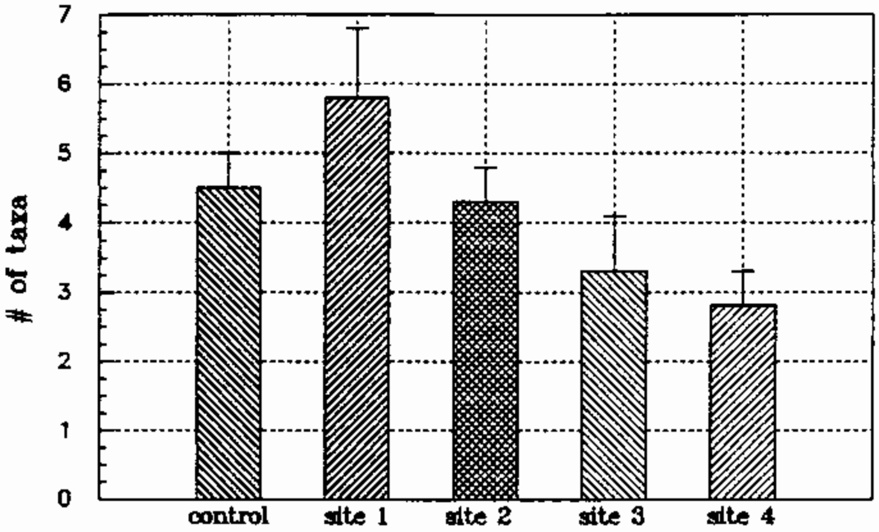

Figure 8. Site comparison for number of major taxa present (Mean ± SE). Data pooled across depths and season.

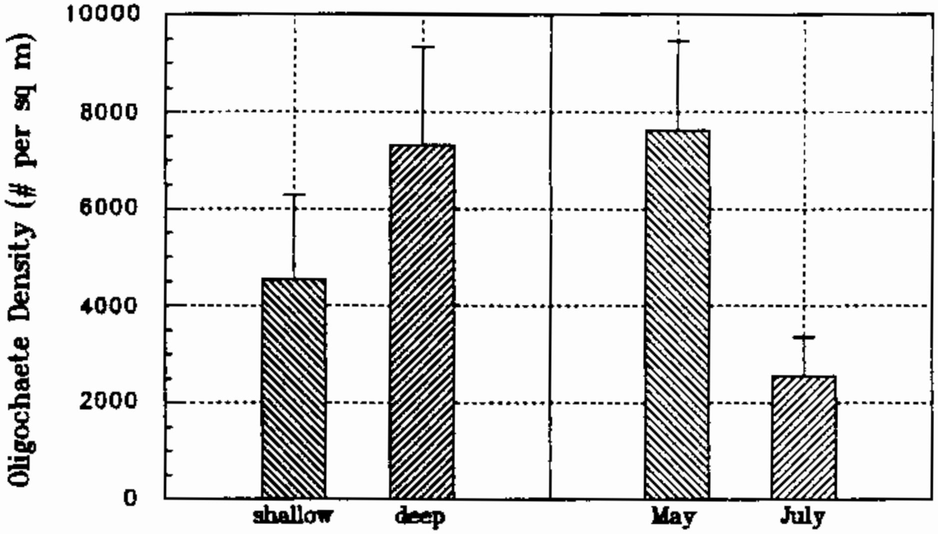

Figure 9. Depth and seasonal comparison for oligochaete abundance (Mean ± SE). Data pooled across all sites.

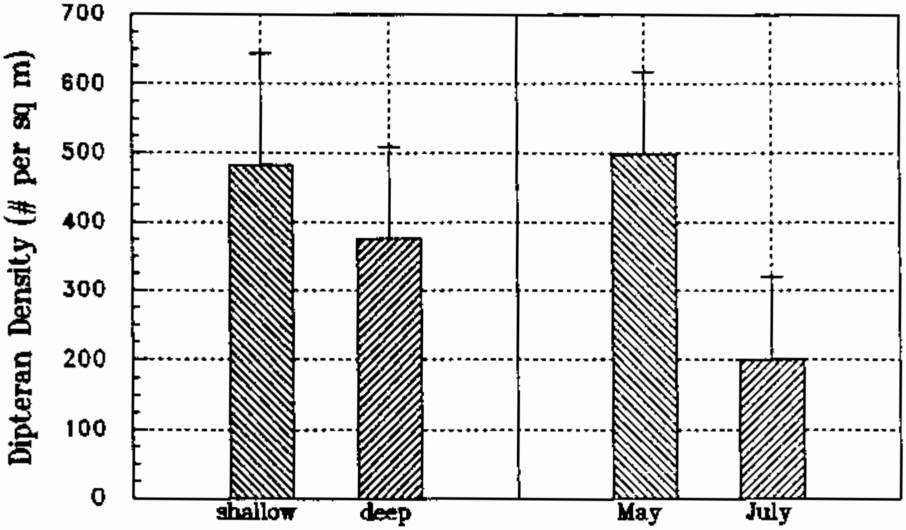

Figure 10. Depth and seasonal comparison for dipteran abundance (Mean ± SE). Data pooled across all sites.

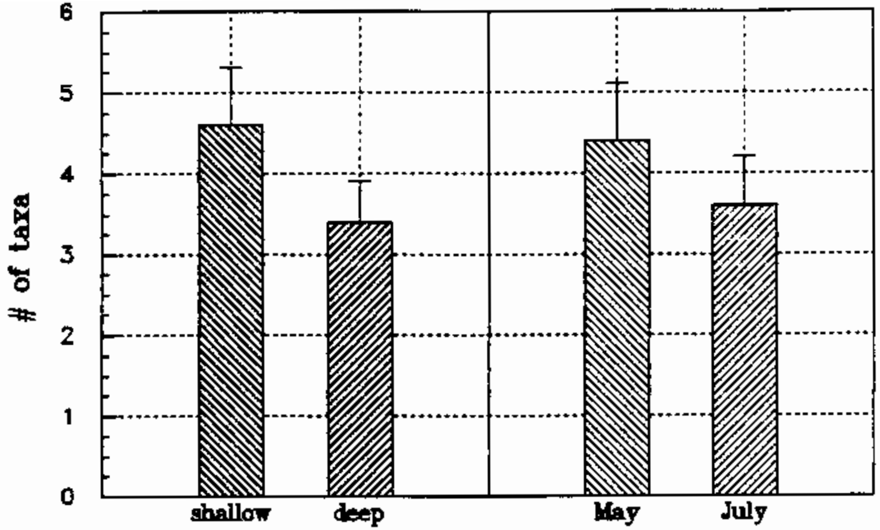

Figure 11. Depth and seasonal comparison for number of major taxa present (Mean ± SE). Data pooled across all sites.

Site 1: Oligochaete densities have remained fairly constant, while dipterans have increased in abundance. Facultative amphipods and nematodes have appeared.

Site 2: Densities of oligochaetes and dipterans have increased, and facultative amphipods and nematodes have appeared.

Site 3: Oligochaetes have increased greatly in number and reached the highest density of any site in the present study. This location has historically been described as severely impacted, and it typically had low densities of oligochaetes in the 1970's and few other taxa. We found facultative nematodes and pelecypods in 1992, dipterans present in fairly high densities, and on one occasion found relatively intolerant Hydracarina at the site.

Site 4: Oligochaetes have increased in abundance, and dipterans have appeared. Nematodes are present at low densities, and facultative amphipods have appeared. Intolerant ephemeropterans were found at low densities in one sample.

Our results indicate that shallow undredged areas tend to have greater species diversity than deeper dredged areas in the Buffalo River. Also, the May samples generally had greater species diversity and higher overall counts than the July samples. Heavy rains in June and July may have resulted in a scouring of the substrate, leading to decreased abundances in July compared to May. It is also possible that the July samples were rinsed more thoroughly, resulting in some loss of organisms, especially smaller species such as nematodes.

Future efforts should be focused on more detailed site comparisons in order to identify potential areas for remediation. To make best use of resources, we would recommend sampling over a single period in May or June, taking one sample at each site over a number of consecutive days (perhaps 5-7 days); shallow areas would be a good choice given their higher diversity. The "control site" in Lake Erie clearly differed in species composition from the river sites and should be excluded from future sampling, since it is doubtful that comparisons between this site and the river proper would be appropriate or meaningful. This design would result in a number of independent observations from each site, and would make statistical comparisons among the river sites more powerful and reliable.

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ZOOPLANKTON SURVEY[*]

METHODS

Zooplankton were collected on three dates (5/29/92, 6/24/92, and 7/21/92) at 4 Buffalo River sites and a "control site" located in Lake Erie approximately 500 meters from the mouth of the river (see Benthic Macroinvertebrate section for detailed site descriptions).

The methodology described in the original proposal was followed with slight modifications. Briefly, a total of 4 samples were collected at each river site using a 30 cm diameter, 130 um plankton net; the 4 samples consisted of 2 replicate samples from midchannel ("deep samples", average depth of 8.1 m) and 2 replicate samples from inshore ("shallow samples", average depth of 3.9 m). Samples were preserved in 7% formalin buffered with magnesium carbonate. Enumeration was performed in triplicate ($n = 3$) for each sample. Prior to statistical comparisons, replicates (e.g. 2 shallow samples from a given site) were pooled. At the control site in Lake Erie no suitable shallow water areas were found, and 2 samples from a depth of approximately 8 meters (similar to midchannel depths in the Buffalo River) were taken.

To provide a summary of the zooplankton community present at each site, average numbers of organisms in major taxonomic groups (Copepoda, Daphniidae, Bosminidae, Chydoridae, Dreissenidae, and "Other") were expressed as percentages for each location (Figs. 12-16). Numbers of organisms in these 5 taxonomic groups were compared among sites and among sampling dates using ANOVA with Tukey's multiple means comparisons. Differences in abundances of major taxonomic groups of zooplankton between shallow and deep samples were tested for significance using sign tests.

RESULTS

A total of 21 species of zooplankters were found, representing at least 6 major taxonomic groups (Tables 4-6). Samples from the control site contained higher densities of copepods overall than samples from the Buffalo River sites ($p < .05$), but no other differences among sites were significant (see Table 6). For three of the major taxonomic groups (Copepoda, Daphniidae, and Bosminidae), densities across all sites were higher in June than in May or July ($p < .05$; see Table 6). Chydoridae occurred only in the 4 Buffalo River sites, and across these river sites Chydoridae were more abundant in shallow water than in deep water ($p < .05$).

DISCUSSION

The zooplankton community at the control site appears to differ from the Buffalo River sites in several ways. Copepods comprise nearly 80% of the zooplankton community on average at the control site, and they also occur at much higher densities than in the Buffalo River proper (Table 6). Chydoridae, which typically are found in shallow water habitats (Pennak 1978), are absent from the control site (Fig. 16). Zebra mussel veligers (Dreissenidae) were very abundant at the control site on July 21, but were found at much lower densities in the Buffalo River

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[*] Section compiled by Randal Snyder

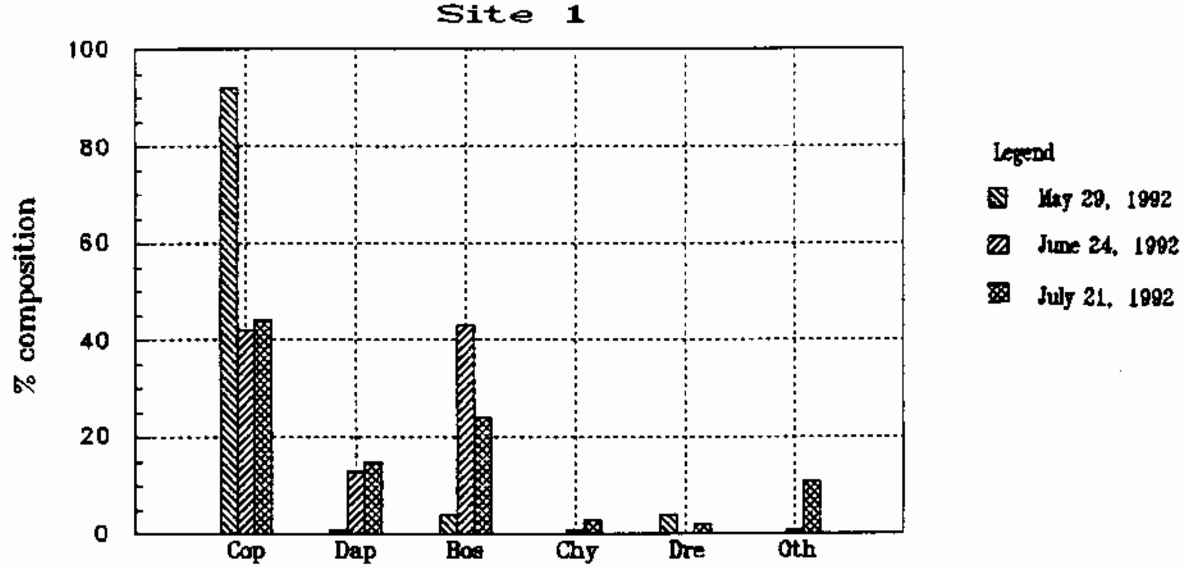

Figure 12. Percent composition of zooplankton samples at Site 1. Values for each month are shown separately as indicated in the legend. Cop = Copepoda, Dap = Daphniidae, Bos = Bosminidae, Chy = Chydoridae, Dre = Dreissenidae, Oth = Other.

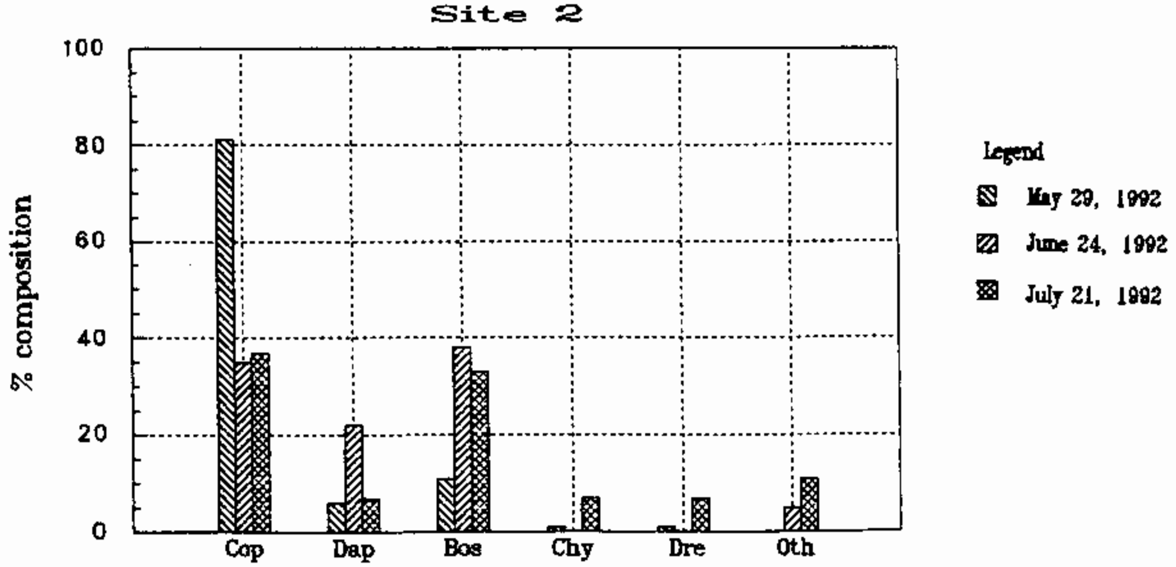

Figure 13. Percent composition of zooplankton samples at Site 2. Values for each month are shown separately as indicated in the legend. Cop = Copepoda, Dap = Daphniidae, Bos = Bosminidae, Chy = Chydoridae, Dre = Dreissenidae, Oth = Other.

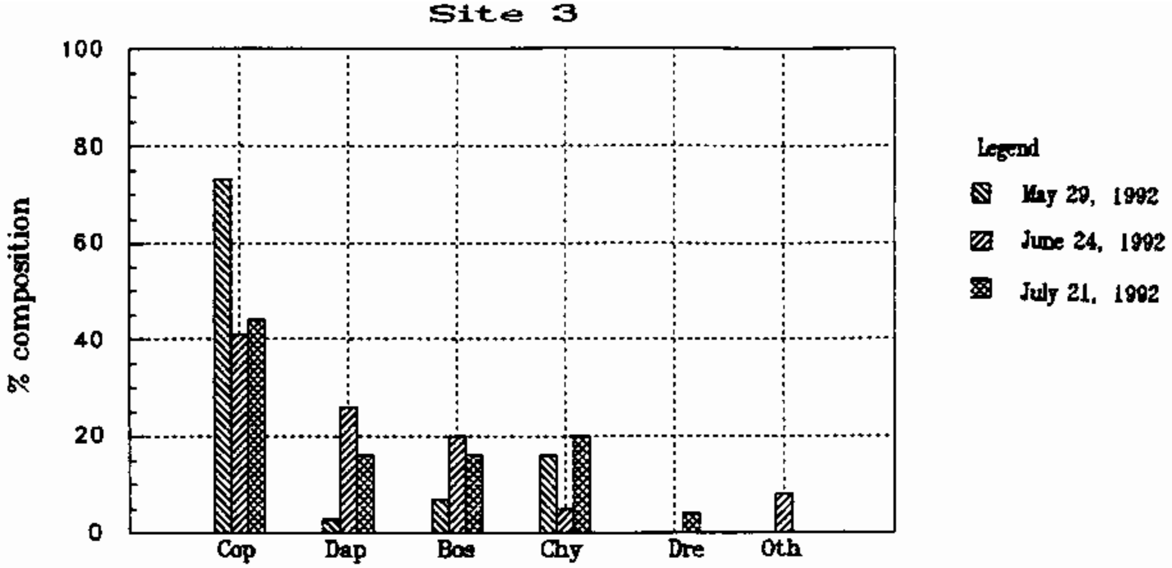

Figure 14. Percent composition of zooplankton samples at Site 3. Values for each month are shown separately as indicated in the legend. Cop = Copepoda, Dap = Daphniidae, Bos = Bosminidae, Chy = Chydoridae, Dre = Dreissenidae, Oth = Other.

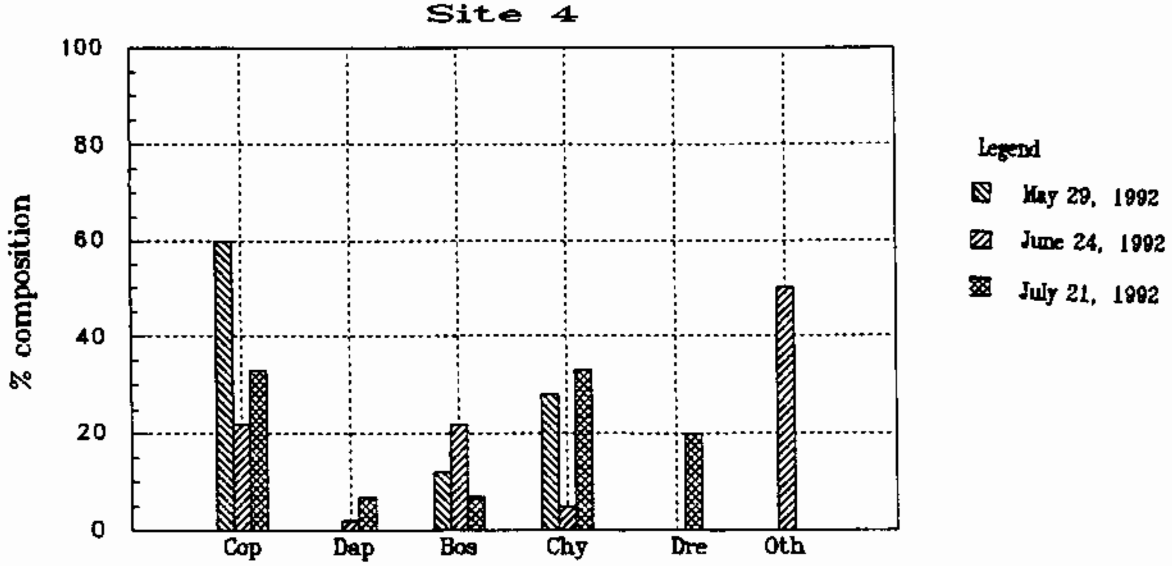

Figure 15. Percent composition of zooplankton samples at Site 4. Values for each month are shown separately as indicated in the legend. Cop = Copepoda, Dap = Daphniidae, Bos = Bosminidae, Chy = Chydoridae, Dre = Dreissenidae, Oth = Other.

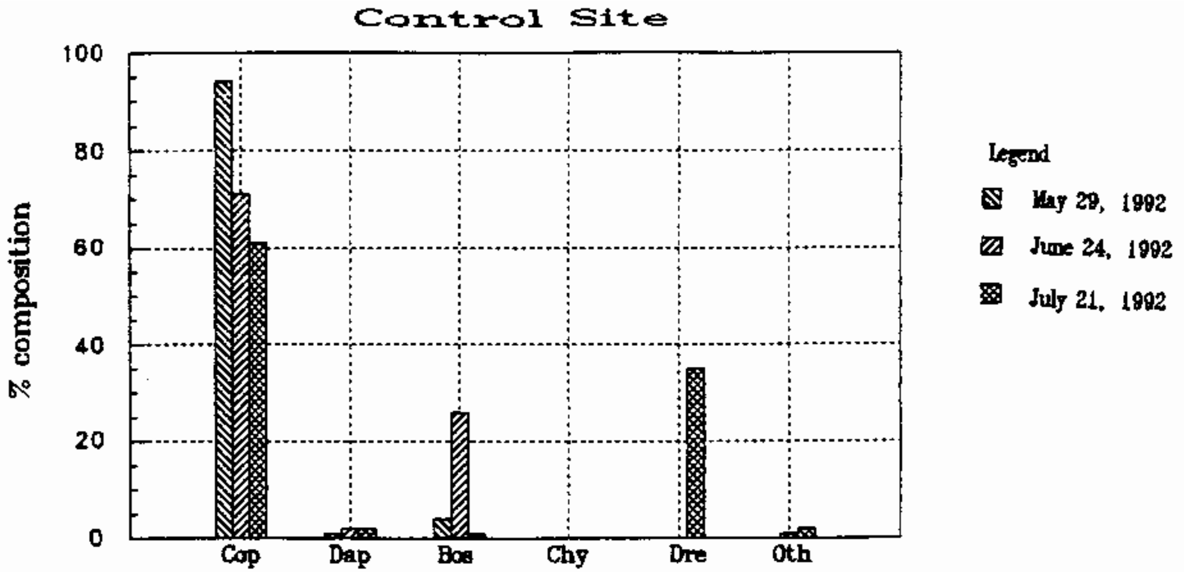

Figure 16. Percent composition of zooplankton samples at the control site. Values for each month are shown separately as indicated in the legend. Cop = Copepoda, Dap = Daphniidae, Bos = Bosminidae, Chy = Chydoridae, Dre = Dreissenidae, Oth = Other.

Table 4. Zooplankton taxa collected from the Buffalo River during Spring/Summer 1992 sampling.

- Copepoda
    - Calanoids
    - Cyclopoids
    - Nauplii

- Daphniidae
    - D. galeata
    - D. retrocurva
    - D. ambigua
    - D. pulex
    - D. longiremis
    - Misc. Daphnia species
    - Ceriodaphnia

- Bosminidae
    - Bosmina longirostris
    - Eubosmina coregoni

- Chydoridae
    - Chydorus sphaericus
    - Chydorus species
    - Ilyocryptus
    - Gammarus species

- Dreissenidae
    - Dreissena polymorpha veligers

- Other
    - Diaphanosoma
    - Holopedium gibberum
    - Leptodora kindtii
    - Bythotrephes cederstroemi

Table 5. Zooplankton densities (# per L) at each site for each collecting date (all replicates pooled). Columns as defined in Table 2.

Zooplankton collected 5/29/92

	con	con	1s	1d	2s	2d	3s	3d	4s	4d
Calanoids	1.3	1.6	0.6	0.3	0.3	1.1	0.1	1.6	0.1	0.1
Cyclopoids	19.2	28.2	1.8	5.4	1.1	2.5	1.7	9.1	0.3	0.1
Nauplii	2.3	5.8	0.4	1.0	1.5	1.0	0.1	2.9	0.1	0.1
D. galeata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D. retrocurv	0.3	0.3	0.0	0.0	0.0	0.3	0.1	0.2	0.0	0.0
D. ambigua	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.2	0.0	0.0
D. pulex	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
D. longiremi	0.1	0.2	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.0
Daphnia sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ceriodaphnia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diaphanosoma	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0
Bosmina long	0.9	1.1	0.0	0.3	0.2	0.9	0.5	1.1	0.1	0.1
Eubosmina co	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Holopedium g	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dreissena ve	0.1	0.2	0.3	0.1	0.1	0.1	0.0	0.1	0.0	0.0
Leptodora ki	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bythotrephes	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chydorus sph	0.0	0.0	0.0	0.0	0.0	0.0	2.8	0.0	0.1	0.1
Chydorus sp.	0.0	0.0	0.0	0.0	0.1	0.0	0.5	0.1	0.1	0.0
Ilyocryptus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
Gammarus sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Zooplankton collected 6/24/92

	con	con	1s	1d	2s	2d	3s	3d	4s	4d
Calanoids	10.3	11.5	4.0	3.1	6.4	11.5	1.5	5.1	0.1	0.3
Cyclopoids	31.0	31.4	6.1	4.6	12.6	24.8	7.7	23.8	1.6	2.9
Nauplii	3.4	4.4	3.1	3.1	6.2	3.4	2.6	5.3	0.9	1.4
D. galeata	0.1	0.2	0.1	0.2	0.0	0.1	0.8	0.3	0.0	0.0
D. retrocurv	0.9	0.8	4.4	2.1	17.3	17.6	2.3	23.7	0.1	0.4
D. ambigua	0.0	0.0	0.2	0.3	0.7	3.6	1.5	0.0	0.1	0.1
D. pulex	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0
D. longiremi	0.0	0.0	0.2	0.1	0.1	0.1	0.0	0.1	0.0	0.0
Daphnia sp.	0.0	0.0	0.2	0.0	0.1	0.1	0.0	0.1	0.0	0.0
Ceriodaphnia	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Diaphanosoma	0.1	0.0	0.2	0.2	3.8	4.0	2.3	4.6	10.1	5.9
Bosmina long	17.3	16.9	13.0	11.5	47.2	22.2	11.7	10.5	1.3	5.6
Eubosmina co	0.0	0.3	0.1	0.1	0.2	0.2	0.0	0.2	0.0	0.1
Holopedium g	0.7	0.8	0.1	0.3	0.0	1.0	0.0	2.0	0.0	0.0
Dreissena ve	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.1
Leptodora ki	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Bythotrephes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chydorus sph	0.0	0.0	0.2	0.1	0.5	0.2	3.8	0.6	0.6	0.8
Chydorus sp.	0.1	0.0	0.1	0.0	0.0	0.0	0.8	0.0	0.2	0.0
Ilyocryptus	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gammarus sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

(Table 5 cont.)

Zooplankton collected 7/21/92

	con	con	1s	1d	2s	2d	3s	3d	4s	4d
Calanoids	1.8	2.0	1.2	0.2	0.1	0.1	0.0	0.1	0.1	0.0
Cyclopoid	0.2	0.2	0.8	0.3	0.1	0.1	0.2	0.2	0.1	0.1
Nauplii	1.8	1.9	1.5	0.8	0.1	0.4	0.1	0.1	0.0	0.1
D. galeat	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
D. retroc	0.0	0.0	0.6	0.7	0.0	0.0	0.0	0.0	0.1	0.0
D. ambigu	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D. pulex	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D. longir	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Daphnia s	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0
Ceriodaph	0.1	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.0	0.0
Diaphanos	0.0	0.0	1.1	0.1	0.0	0.3	0.0	0.0	0.0	0.0
Bosmina l	0.1	0.0	2.3	0.2	0.2	0.6	0.1	0.2	0.0	0.1
Eubosmina	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Holopediu	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dreissena	2.5	2.1	0.1	0.2	0.1	0.1	0.1	0.0	0.1	0.1
Leptodora	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bythotrep	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chydorus	0.0	0.0	0.2	0.1	0.1	0.0	0.1	0.1	0.1	0.1
Chydorus	0.0	0.0	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.0
Ilyocrypt	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gammarus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0

Table 6. Abundance of major zooplankton groups (# per L) at each site for each collecting date (all replicates pooled). Columns as defined in Table 2.

Zooplankton counts 5/29/92

	con	con	1s	1d	2s	2d	3s	3d	4s	4d
Copepoda	22.8	35.6	2.65	6.55	2.85	4.6	1.85	13.55	0.5	0.25
Daphniidae	0.4	0.5	0	0.05	0	0.55	0.1	0.45	0	0
Bosminidae	1	1.2	0	0.35	0.15	0.85	0.5	1.05	0.1	0.05
Chydoridae	0	0	0	0	0.1	0	3.3	0.1	0.2	0.15
Dreissenid	0.1	0.2	0.25	0.1	0.05	0.05	0	0.05	0	0
Other	0.2	0.1	0	0	0	0	0.05	0.05	0	0
Total	24.5	37.6	2.9	7.05	3.15	6.05	5.8	15.25	0.8	0.45

Zooplankton counts 6/24/92

	con	con	1s	1d	2s	2d	3s	3d	4s	4d
Copepoda	44.7	47.3	13.1	10.75	25.05	39.65	11.75	34.05	2.55	4.55
Daphniidae	1	1	5	2.65	18.25	21.35	4.55	24.05	0.1	0.45
Bosminidae	17.3	17.2	13.05	11.6	47.4	22.35	11.65	10.65	1.3	5.7
Chydoridae	0.1	0	0.3	0.05	0.5	0.2	4.6	0.55	0.75	0.75
Dreissenid	0	0	0	0.05	0.05	0.05	0.1	0	0	0.05
Other	0.8	0.08	0.3	0.45	3.8	5	2.3	6.6	10.1	5.85
Total	63.9	66.3	31.75	25.55	95.05	88.6	34.95	75.9	14.8	17.35

Zooplankton counts 7/21/92

	con	con	1s	1d	2s	2d	3s	3d	4s	4d
Copepoda	3.8	4.1	3.45	1.2	0.3	0.55	0.25	0.3	0.15	0.1
Daphniidae	0.2	0	0.8	0.75	0.05	0.1	0.1	0.1	0.05	0
Bosminidae	0.1	0	2.3	0.25	0.2	0.55	0.05	0.15	0	0.05
Chydoridae	0	0	0.2	0.15	0.15	0	0.1	0.15	0.2	0.05
Dreissenid	2.5	2.1	0.05	0.2	0.05	0.1	0.05	0	0.1	0.05
Other	0.1	0.1	1.1	0.1	0	0.25	0	0	0	0
Total	6.7	6.3	7.9	2.65	0.75	1.55	0.55	0.7	0.5	0.25

(Table 6). These differences are probably due mainly to the lack of shallow water habitat at the control site. With respect to Driessena, another important factor is the high density of settled mussels in the inshore areas of Lake Erie, which would provide a large pool of veligers when reproduction peaks in July and August.

As mentioned in the benthic macroinvertebrate section, water flow augmentation by the Buffalo River Improvement Corporation (BRIC) has occurred in the Buffalo River since 1967. Although the volume of water pumped from Lake Erie into the Buffalo River today (approximately 15.5 million gallons per day; see Irvine et al., in press) is much less than during the 1970's and early 1980's, this augmentation may still result in zooplankton being transported from the Lake into the Buffalo River Area of Concern. Sites 1, 2, and 3 are all located downstream of potential BRIC discharge areas, hence a certain component of the zooplankton community at these sites could have their origins in the Small Boat Harbor/Lake Erie. Site 4, located near the mouth of Cazenovia Creek, would not be affected by BRIC water flow augmentation. Despite potential affects of BRIC discharge, the zooplankton community at site 4 generally resembles that of the other 3 Buffalo River sites; the only noticable difference was a high density of Diaphanosoma at site 4 in the June samples.

Overall, the zooplankton community in the Buffalo River appears to be at least as diverse as that in the inshore areas of Lake Erie, and does not reflect the impacted nature of river to nearly the extent of the benthic macroinvertebrate community.

ICHTHYOFAUNA SURVEY*

INTRODUCTION

Larval and adult fish surveys were conducted in close cooperation with the U.S. Fish and Wildlife Service. Several changes in protocol were adopted to insure that the data collected by both groups (SUNY College at Buffalo and U.S. F&W) were compatible and complementary. The most significant changes in protocol are summarized as follows:

1) A Miller high-speed sampler and an epibenthic sled were used to collect larval fishes on the first collection date (6/9/92). For subsequent sampling events, two .5 m plankton nets with 560 um mesh were towed for approximately 12 minutes at a speed of 50 cm per second in a circular pattern approximately the width of the river at each sampling location. One net was towed near the surface (depth of 1.0 - 2.5 m) and one below midwater (depth of 2.5 - 6.5 m). Each tow was replicated for a total of 4 tows at each site.

2) The original biweekly sampling regime for larval fishes was modified to complement scheduled sampling by U.S. F&W. SUNY College at Buffalo was asked by U.S. F&W to collect larval fishes on the following dates: 6/9/92, 6/25/92, and 7/7/92. SUNY College at Buffalo personnel also assisted on several other collecting trips lead by U.S. F&W personnel.

3) Two electrofishing trips were conducted instead of three. The third trip was not possible due to mechanical problems with the electrofishing vessel.

4) For larval and adult fishes, the small sample sizes obtained preclude meaningful statistical comparisons or calculations of catch per unit effort. Data for each are presented as numbers of each species caught, average standard length, and size range collected (for adults).

METHODS

In April 1992 SUNY College at Buffalo and the U.S. F&W cooperated in setting hoop nets in the mouth of the Buffalo River to determine if adult walleye were entering the river during the spawning season. Two 1 m diameter nets were set overnight near the entrance to the ship canal on four separate occasions from mid to late April.

Larval fishes were collected on three dates (see above) and adult fishes on two occasions (5/14/93 and 6/16/93) at 4 Buffalo River sites and a "control site" located in Lake Erie approximately 500 meters from the mouth of the river (see Benthic Macroinvertebrate section for detailed site descriptions).

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* Section compiled by Randal Snyder

Larval fishes were collected as described above, preserved in 5% formalin, and returned to the laboratory for identification and enumeration following Auer (1982). Adult fishes were electroshocked for an average of 30 min per site using a boat-mounted electroshocker, measured on board for standard lengths, and released. In cases where more than 20 individuals of a given species were collected, a subsample of 20 individuals were chosen haphazardly to be measured.

RESULTS

No walleye were collected in the hoop net sets near the mouth of the Buffalo River in April. The nets were functioning properly judging from the large numbers of other species collected (including bass and sunfish).

We collected samples representing 8 species of larval fishes and 24 species of adults from the Buffalo River sites and the control site (Table 7). Based on numbers of individuals caught, gizzard shad (*Dorosoma cepedianum*) were very abundant both as larvae and as adults. Larval *Morone* and *Lepomis* species were also abundant compared to other species present (Table 7). As adults, the most common species encountered were gizzard shad (as mentioned above), golden shiners, emerald shiners, pumpkinseed, and largemouth bass (Table 7).

Adult fish were more abundant in the May sampling period than in June (Table 8). The Buffalo River sites appear to be similar with respect to diversity and abundance of species, while the control site in Lake Erie contained noticeably fewer fish and little species diversity (Table 8); this result is probably related to the lack of shallow water habitat at the control site.

Larval fish were most abundant in the June 25 samples, and were relatively scarce in the June 9 samples (Table 9). The low abundance on June 9 is probably an artifact of the sampling method (Miller sampler/epibenthic sled), since later field tests suggested that plankton nets were much more efficient at sampling larvae at the study sites. Abundance and diversity of larval fish did not seem to differ greatly among the Buffalo River sites, and in contrast to the situation with adults, a variety of larvae were also present at the control site (Table 9).

DISCUSSION

A survey of the Buffalo River by Makarewicz et al. (1981) documented an adult fish community in the Buffalo River that is very similar to the one described in the present study. Although valuable sportsfish such as rainbow trout, muskellunge, and walleye appear to be making little use of the river, bass, sunfish, and yellow perch are fairly abundant and should provide a good recreational fishery. Given the serious longterm problem of contaminated sediments in the river, however, fish advisories must be communicated effectively to Buffalo River anglers to insure that fish are released and not consumed.

Diversity of larval fish appears to have increased since the earlier 1980's. Makarewicz et al. (1981) document just four species of larval fish in the river (gizzard shad, carp, emerald shiner, and yellow perch), and an unpublished study conducted by Adrian and Merckel in 1988 reports the presence of six species. The intensive larval fish sampling carried out by the U.S. Fish and Wildlife Service during spring and summer 1992 (Kozuchowski et al., unpublished)

Table 7. Species list and total numbers of fishes taken by electrofishing and plankton nets/samplers in the Buffalo River and control site during 1992 sampling.

Common Name	Scientific Name	Electro-fishing	Plankton net/sampler
Alewife	*Alosa pseudoharengus*	-	7
Gizzard shad	*Dorsoma cepedianum*	189	228
Rainbow trout	*Oncorhynchus mykiss*	1	-
Rainbow smelt	*Osmerus mordax*	-	11
Northern pike	*Esox lucius*	1	-
Goldfish	*Carassius auratus*	8	-
Carp	*Cyprinus carpio*	22	5
Golden shiner	*Notomigonous crysoleucas*	110	-
River chub	*Hybopsis storeriana*	1	-
Spottail shiner	*Notropis hudsonius*	20	-
Emerald shiner	*Notropis atherinoides*	252	-
Bluntnose minnow	*Pimaphales notatus*	5	-
White sucker	*Catostomus commersoni*	12	-
Redhorse species	*Moxostoma* species	20	-
Brown bullhead	*Ameiurus nebulosus*	24	-
	Morone species	-	42
White perch	*Morone americana*	1	-
White bass	*Morone chrysops*	3	-
Rock bass	*Ambloplites rupestris*	8	-
	Lepomis species	-	31
Pumpkinseed	*Lepomis gibbosus*	76	-
Bluegill	*Lepomis macrochirus*	3	-
Smallmouth bass	*Micropterus dolomieu*	11	-
Largemouth bass	*Micropterus salmoides*	36	-
	Pomoxis species	-	7
White crappie	*Pomoxis annularis*	1	-
Yellow perch	*Perca flavescens*	7	7
Walleye	*Stizostedion v. vitreum*	1	-
Freshwater drum	*Aplodinotus grunniens*	6	-
Total number of species		24	8

Table 8. Numbers (N), average standard lengths (in cm), and size ranges (in cm) of fish caught by electroshocking for each site and collection date.

	5/14/93			6/16/93		
	N	SL	Range	N	SL	Range
<u>Site 1</u>						
Carp	6	60.1	49.5-74.0	3	61.0	54.0-70.0
Smallmouth bass	2	32.0	30.5-33.5	6	23.9	12.5-29.0
Largemouth bass	2	25.8	21.5-30.0	18	14.1	10.0-23.0
White sucker	3	28.3	25.0-32.0	2	25.3	17.5-33.0
Drum	3	26.8	25.0-28.5	1	35.0	-
White perch	1	22.0	-	-	-	-
Pumpkinseed	2	12.0	12.0-12.0	1	14.0	-
Emerald shiner	18	6.3	4.5-9.0	1	5.0	-
Rock bass	-	-	-	7	16.0	4.5-19.5
Yellow perch	-	-	-	2	16.0	14.0-18.0
Goldfish	-	-	-	1	22.0	-
Redhorse	-	-	-	17	20.0	15.0-41.0
<u>Site 2</u>						
Carp	2	58.3	44.5-72.0	1	54.0	-
Rainbow trout	1	30.5	-	-	-	-
Largemouth bass	2	24.0	12.0-36.0	1	19.0	-
Smallmouth bass	-	-	-	1	8.0	-
Walleye	1	31.5	-	-	-	-
Bluegill	1	14.5	-	-	-	-
Pumpkinseed	1	13.5	-	-	-	-
Gizzard shad	12	13.7	10.5-15.5	4	13.9	13.0-15.5
Golden shiner	6	8.3	7.5-11.0	18	7.4	6.0-10.0
River chub	1	7.5	-	-	-	-
Emerald shiner	51	7.0	5.0-9.0	-	-	-
Spottail shiner	14	7.0	5.5-9.5	-	-	-
Bullhead	-	-	-	5	26.2	17.5-31.5
White crappie	-	-	-	1	6.5	-
<u>Site 3</u>						
Northern pike	-	-	-	1	59.0	-
Yellow perch	4	13.6	6.5-18.0	1	22.0	-
Drum	2	28.5	26.0-31.0	-	-	-
Largemouth bass	8	23.7	9.5-35.0	2	28.5	26.0-31.0
Bullhead	13	24.0	16.0-30.0	1	24.5	-
White sucker	4	23.3	15.0-35.0	1	13.5	-
Carp	2	40.0	36.0-44.0	-	-	-
Goldfish	1	16.0	-	1	24.5	-
Pumpkinseed	51	12.2	8.5-14.0	1	14.0	-
Bluegill	1	16.5	-	-	-	-
Gizzard shad	142	13.5	11.0-16.0	3	15.0	14.5-15.5
Emerald shiner	22	5.9	5.0-7.5	-	-	-
Golden shiner	52	8.2	5.5-13.5	-	-	-
Bluntnose	4	-	-	-	-	-

(Table 8 cont.)

	5/14/93			6/16/93		
	N	SL	Range	N	SL	Range
<u>Site 4</u>						
Largemouth bass	3	25.7	21.0-30.0	-	-	-
Carp	3	42.7	37.0-49.0	2	36.3	20.5-52.0
Bullhead	3	25.7	21.0-30.0	2	20.3	16.5-24.0
Gizzard shad	25	14.1	12.0-16.0	3	17.8	15.0-23.0
Golden shiner	25	12.4	7.0-15.5	10	10.0	7.0-16.0
Emerald shiner	159	6.3	5.5-8.0	-	-	-
White bass	2	11.0	10.5-11.5	1	13.5	-
Pumpkinseed	10	10.8	5.0-13.5	6	7.5	6.0-11.0
Spottail shiner	3	6.0	5.0-8.0	3	5.7	5.0-6.0
Bluntnose	2	-	-	-	-	-
Redhorse	-	-	-	1	32.5	-
White sucker	-	-	-	2	23.8	21.0-26.5
Goldfish	-	-	-	3	14.0	11.5-17.0
Bluegill	-	-	-	1	11.0	-
<u>Control site</u>						
Redhorse	-	-	-	2	38.8	38.5-39.0
Rock bass	-	-	-	1	13.0	-
Smallmouth bass	-	-	-	2	23.5	22.5-24.5

Table 9. Numbers (N) and average lengths (SL in mm) of larval fish caught at each site and collection date (all replicates combined).

	6/9/92		6/25/92		7/7/92	
	N	SL	N	SL	N	SL
Site 1						
Rainbow smelt	4	7.7	3	10.2	-	-
Morone species	1	4.0	1	7.5	1	9.5
Gizzard shad	-	-	5	7.6	1	6.0
Alewife	-	-	-	-	5	5.5
Site 2						
Alewife	1	6.0	-	-	-	-
Rainbow smelt	1	13.0	-	-	-	-
Morone species	-	-	30	6.7	7	9.2
Pomoxis species	-	-	6	6.3	-	-
Gizzard shad	-	-	35	8.6	4	5.9
Yellow perch	-	-	1	8.0	-	-
Lepomis species	-	-	-	-	1	5.5
Site 3						
Gizzard shad	-	-	127	7.9	21	6.2
Lepomis species	-	-	7	5.4	3	5.5
Pomoxis species	-	-	3	4.9	1	5.5
Carp	-	-	-	-	1	6.5
Site 4						
Yellow perch	1	9.0	-	-	-	-
Gizzard shad	-	-	5	6.1	30	8.0
Lepomis species	-	-	9	5.8	11	5.6
Control site						
Yellow perch	3	7.7	2	8.0	-	-
Morone species	1	4.0	1	6.5	-	-
Rainbow smelt	-	-	3	10.2	-	-
Carp	-	-	-	-	4	6.0
Alewife	-	-	-	-	1	5.0

documents 16 species of larval fish in the Buffalo River area. Clearly the larval fish community in the Buffalo River is improving with respect to abundance and diversity, and is responding well to the overall ecological improvement in the river that is gradually taking place.

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PHYTOPLANKTON SURVEY[*]

METHODS

This portion of the study examines spatial and temporal patterns of phytoplankton abundance at 5 sampling stations along the Buffalo River from the breakwall in Lake Erie upstream to the point where Buffalo and Cazenovia Creeks merge to form the Buffalo River (Fig. 17).

Integrated water column samples were collected with a weighted piece of tygon tubing with an inside diameter of 0.5 inches or 1.27 cm. This tube collects approximately 1.27 ml per each cm of its length; a 2 m length collects 253 ml. A standard collection consisted of lowering 2m of tubing into the River at the midchannel of the collection site, bending over the top of the tubing, pulling up the lower end of the tubing with an attached string, placing this lower end into a collection bottle (already containing 5 ml of acid Lugols' solution for preservation and staining) and blowing the sample out from the top end of the tubing. This was repeated a second time to retrieve approximately 500 ml of sample. A duplicate sample was similarly collected at each site and date.

Identification and counting were done on a WILD inverted microscope at 400X and phase contrast, using a modified Utermohl sedimentation chamber. Either 15 or 50 ml of sample were removed from the sample container after thorough mixing, placed in the sedimentation chamber and allowed to settle for at least 12 hours. A measured transect was counted across the main diameter of the settling chamber. Cells were identified to the smallest taxonomic grouping possible, using Prescott (1970), although the low magnification and the large amount of particulate sediment in many of the samples reduced my ability to accurately identify taxa.

RESULTS

<u>Date: 5/29/92</u>

REFERENCE SITE

		Percentage
Total Diatoms	501/ml	45.5
Asterionella formosa	112/ml	10.2
Diatoma tenue	330/ml	29.9
Dinobryon	527/ml	47.8
Total dinoflagellates	32/ml	2.9
Total flagellates	32/ml	2.9
GRAND TOTAL	1102/ml	

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[*] Section compiled by Brian Shero

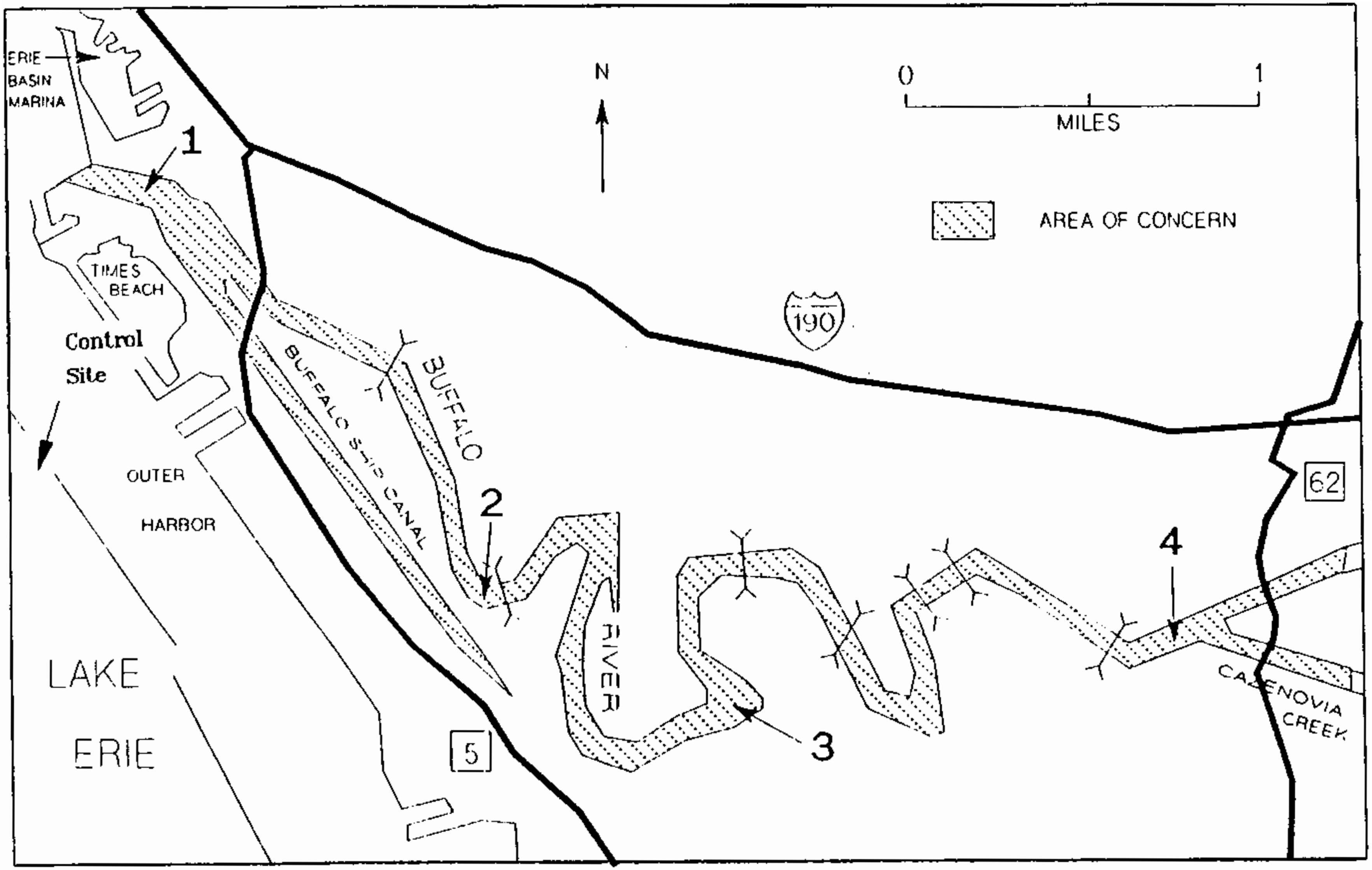

FIGURE 17. Location of sampling sites in the Buffalo River AOC (adapted from NYDEC, 1989)

SITE 1

		Percentage
Total Diatoms	156/ml	9.0
Total Chlorophyta	199/ml	11.5
Scenedesmus	142/ml	8.2
Total dinoflagellates	394/ml	22.7
Total flagellates	540/ml	31.1
GRAND TOTAL	1734/ml	

SITE 2

		Percentage
Total Diatoms	217/ml	12.0
Total Chlorophyta	676/ml	37.4
Dictyosphaerium	251/ml	13.9
Scenedesmus	262/ml	14.5
Selenastrum	76/ml	4.2
Total dinoflagellates	198/ml	10.9
Total flagellates	433/ml	23.9
GRAND TOTAL	1809/ml	

SITE 3

		Percentage
Total Diatoms	110/ml	6.2
Total Chlorophyta	408/ml	23.2
Coelastrum	142/ml	8.1
Scenedesmus	121/ml	6.9
Total dinoflagellates	185/ml	10.5
Total flagellates	841/ml	47.7
GRAND TOTAL	1761/ml	

SITE 4

		Percentage
Total Diatoms	309/ml	37.4
Total Chlorophyta	185/ml	22.4
Scenedesmus	124/ml	15.0
Dinobryon	18/ml	2.2
Total flagellates	305/ml	36.9
GRAND TOTAL	827/ml	

Date: 7/22/92

REFERENCE SITE

		Percentage
Total Diatoms	14/ml	10.4
Dinobryon	25/ml	18.5

Total Dinoflagellates	4/ml	3.0
Total flagellates	57/ml	42.2
GRAND TOTAL	135/ml	

SITE 1

		Percentage
Total Diatoms	462/ml	56.2
Scenedesmus	102/ml	12.4
GRAND TOTAL	822/ml	

SITE 2

		Percentage
Total Diatoms	888/ml	20.8
Total Chlorophyta	1385/ml	32.4
Total Cyanophyta	995/ml	23.2
Merismopedia	805/ml	18.8
Total flagellates	888/ml	20.8
GRAND TOTAL	4274/ml	

SITE 3

		Percentage
Total Diatoms	1125/ml	32.5
Scenedesmus	876/ml	25.3
Merismopedia	1421/ml	41.1
GRAND TOTAL	3457/ml	

DISCUSSION

Few previous studies of phytoplankton exist for the Buffalo River. A 1979 report by V. Ray Frederick and C. Booth for Buffalo Color Corporation reports on phytoplankton counts at 4 stations along the Buffalo River on October 11, 1978. Their report does not clearly identify the depth of the phytoplankton samples or their collection method; they were enumerated by the inverted microscope Utermohl technique.

Frederick and Booth found all stations dominated by Chrysochromulina parva which made up between 24 and 45 % of all the phytoplankton cells counted. This alga is a member of the Chrysophyceae, which are known to require an external supply of B12 or thiamin and some biotin (Hutchinson 1967), and are therefore frequently found in organically enriched environments. The next biggest group of algae were the green algae, Chlorophyta, with between 26 and 38% of all phytoplankton. Cryptophytes made up between 13 and 20% of all phytoplankton. The dinoflagellates (Pyrrophyta), blue-green algae (Cyanophyta) and diatoms (Bacillariophyceae or Bacillariophyta) generally had abundances of a few percent or less.

Major differences were found in the 1978 phytoplankton density along the river, decreasing from 5624 cells/ml at station 1 to 3648, 2937 and 2197 at stations 2, 3 and 4 respectively. Station 4 presumably represented the Lake since it had a Secchi disk depth of 265 cm compared with 85 cm for the other three stations and a higher DO (10.0mg/l vs. 6.3-7.9 mg/l) and Ph (8.5 vs 7.8-7.9). This chemical gradient is reflected in their phytoplankton counts, although the chemical data alone indicate the changes in environmental quality more directly than the plankton data.

Several major patterns were observed in the 1992 phytoplankton counts. The first pattern is that the Reference Site (RS) in Lake Erie is very different from the River sites. On 5/29/92, the RS had higher percentages of diatoms than any of the River sites, while on 7/22/92 the RS had lower percentages of diatoms than any of the River sites. Lake Erie typically experiences a spring bloom of planktonic diatoms, including Asterionella formosa, which was abundant at the RS on 5/29/92. The other diatom abundant at the RS on 5/29/92 was Diatoma tenue, a dominant form in the attached diatom community at the RS and Site 1 on that date. The diatoms found in the River sites on 5/29/92 and 7/22/92 were mainly attached diatoms which had become dislodged and entrained in the River current. Diatoms were especially abundant at sites 2 and 3 on 7/22/92, probably as a result of the high flow rate on that day and the subsequent scouring of attached diatoms from their substrates.

In addition, the RS on both 5/29/92 and 7/22/92 contained large percentages of the colonial chrysophyte Dinobryon. This genus is a common member of the phytoplankton community in Lake Erie (personal observation) and is cited in Hutchinson (1967) as representing oligotrophic, or nutrient-poor water. Dinobryon was present in small numbers at upriver sites, but was not abundant.

A second major pattern is the relative abundance of flagellates, which is higher in the River sites than in the RS on 5/29/92, but lower in the River than the RS on 7/22/92. Although these flagellates have not been identified to species in this study, they are similar to the flagellates identified by Frederick and Booth as Chrysochromulina and the Cryptophyta or cryptomonads. These taxa reached their maximum percentages at site 3 on 5/29/92 and at the RS on 7/22/92. The low percentages of flagellates reported from sites 1 and 3 on 7/22/92 may result from the counting procedure for those samples which allowed only the larger and more rigid cells to be counted. If only the samples from 5/29/92 are included, these flagellates reach their peak numbers at site 3. Although individual taxa within this group of flagellates have their own specific ecological requirements, their presence in high numbers is often associated with nutrient enrichment and high levels of organic matter. Hutchinson (1967) identifies the Chrysophyceae, Dinophyceae and the Cryptophyceae as flagellates which require external sources of B vitamins such as B12, thiamin and biotin. These flagellates are therefore often associated with organically enriched environments.

A third pattern is the general absence of the Cyanophyta or blue-green algae, except for sites 2 and 3 on 7/22/92 which had high numbers of the colonial Merismopedia. Merismopedia is cited in Hutchinson (1967) as an oligotrophic indicator, but is listed as a "polluted water algae" in Palmer (1962). Cyanophyta are often associated with nutrient enrichment because of the ability of many taxa to outcompete other algae in nitrogen depleted environments. Cyanophyta also become most abundant at higher water temperatures. Both sites 2 and 3 had high percentages of Merismopedia on 7/22/92, probably reflecting increased water temperatures. The general absence of cyanophytes from the other sample sites and dates in the Buffalo River could result from 1.) low water temperatures, 2.) reduced availability of sunlight because of turbidity, or 3.) an environment with relatively high amounts of nitrogen. The trophic status of the specific Merismopedia species in the Buffalo River remains in question.

Finally, the green alga Scenedesmus, is common at all River sites on 5/29/92, ranging from 6.9-15.0%, while being absent from the RS. On 7/22/92, Scenedesmus is again abundant at sites 1 and 3 with percentages of 12.4 and 25.3 % respectively, while not being observed at the RS. The highest numbers of Scenedesmus were found at site 3 on 7/22/92. Scenedesmus is cited by Hutchinson (1967) and Palmer (1975) as representing high nutrient waters. In addition, Hutchinson indicates that this algal genus may be facultatively heterotrophic, meaning that it can survive in the dark by absorbing organic materials from its environment. The presence of high percentages of Scenedesmus in the Buffalo River and not in Lake Erie suggests that nutrient conditions in the River are high while those in the Lake are relatively low. These high percentages may also reflect the ability of the alga to survive in the turbid, organically enriched waters of the Buffalo River.

Total concentrations of phytoplankton (cells/ml) are higher at sites 1, 2 and 3 on 5/29/92 than at the RS and are much higher at sites 2 and 3 on 7/22/92 compared with the RS. These data are similar to the findings of Frederick and Booth who found total algal concentrations at the upriver sites higher by a factor of up to 2X the concentrations at the downriver site. This general pattern of higher cell numbers at upriver sites has generally persisted from 1978 to 1992. Higher cell numbers are usually associated with higher nutrient levels and suggest that the River sites are nutrient enriched relative to Lake Erie.

These phytoplankton data were likely highly influenced by the numerous major runoff events which occurred during the 1992 spring and summer season. The summer of 1992 was unusually cool and wet, and these phytoplankton data may not represent a "typical" year to be used as a baseline. During many summers the Buffalo River flows very slowly and would be expected to allow more time for an in situ phytoplankton community to develop. In addition, in more typical years, the water temperature and chemical composition would probably differ and also affect the structure of the phytoplankton community.

In order to accurately monitor the phytoplankton community of the Buffalo River, I suggest that regular sampling should be done over a period of at least 5 years. This sampling would allow greater attention to be paid to the individual species within the phytoplankton and would allow an estimate of annual variations so that longer term changes resulting from remediation activities could be placed in a true historical context.

Finally, the relative importance of photosynthetic algae within the food web of the Buffalo River needs to be determined by examining the relative amount of primary productivity compared with respiration and heterotrophic activity among the members of the plankton community. The extreme turbidity of the Buffalo River water suggests that photosynthesis may be possible only in the uppermost portion of the water column, and that the photosynthetic phytoplankton community may be less important than the heterotrophic plankton, including the bacteria.

SUMMARY

The 1992 phytoplankton survey of the Buffalo River indicates that, as expected, the water quality of the Buffalo River is lower than the water quality at the Lake Erie Reference Site.

The River phytoplankton is often dominated by flagellates. The flagellates, along with specific taxa of Chlorophyta generally indicate high nutrient levels and high levels of organic matter. A number of the River taxa may require vitamins or may be facultatively heterotrophic, traits which are adaptive in an environment with high levels of organic matter and high turbidity. The presence of a large percentage of a cyanophyte in the upper River sites on 7/22/92, may or may not unambiguously indicate nutrient enrichment. The Lake Erie Reference Site, by contrast, was dominated by diatoms and oligotrophic taxa on 5/29/92 and had very low concentrations of all algal taxa on 7/22/92.

Cell concentrations were usually (and sometimes dramatically) higher at the River sites compared with the Lake site, indicating the higher trophic conditions in the Buffalo River compared with Lake Erie. Additional studies with more detailed taxonomic information will give a clearer indication of environmental conditions in the Buffalo River and of the relative importance of autochthonous vs. allochthonous production.

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ATTACHED ALGAE SURVEY*

METHODS

This portion of the study examines spatial and temporal patterns of algal abundance, with emphasis on the diatoms, at 5 sampling stations along the Buffalo River from the breakwall in Lake Erie upstream to the point where Buffalo and Cazenovia Creeks merge to form the Buffalo River. The substrates at the Reference Site (RS) and Sites 1 and 2 were concrete while Sites 3 and 4 were steel. All substrates were located within 2 meters of the shoreline and samples were collected between 10 and 30 cm below the water surface. Samples were scraped from the substrates and returned to the lab where they were refrigerated and qualitatively examined within 2-3 days. A portion of each sample was then prepared for a detailed microscopic examination as follows: 1. boiling in concentrated nitric acid; 2. adding potassium dichromate to complete the oxidation; 3. multiple rinsings with intervening time allowed for settling; 4. placement of suspended diatoms on coverslips; 5. evaporation of water from coverslips at room temperature; 6. mounting of coverslips onto slides using Hyrax mounting medium.

Photographs of both fresh and cleaned diatoms were made to assist in identification and counting. Slides were examined extensively during the identification process before any counts were made. Each count was made by beginning near the center bottom of a coverslip and counting a transect 100 u wide toward the top of the coverslip. Counting was continued until approximately 300 diatom frustules were counted. In some cases this required additional non-overlapping transects to be counted. All counts were made under oil immersion at 1000X.

RESULTS

The relative abundance of diatoms is expressed in Table 10A (5/9/92), Table 10B (7/22/92), and Table 10C (8/17/92) as the percentage of total diatoms counted from that sample. The discussion will focus on diatom taxa which make up 1% or more of the diatoms counted in each sample.

DISCUSSION

The abundance and even the presence or absence of attached diatoms can be greatly influenced by the type of substrate present. In this study, I attempted to sample the same substrate at all stations. This was not possible, however, because of the differences in shoreline structure along the length of the River. An additional factor which influenced the presence and abundance of diatoms was the type and abundance of other algae present. In general, the Lake and lower River stations had progressively thicker growths of Cladophora from May to August. The abundance of this green alga affects the amount and type of substrate available for diatom colonization. Many of the diatoms found at the RS and Site 1 are probably epiphytic on the Cladophora, especially as the Cladophora increased in length and surface coverage in July and August. By contrast, the upper sites 2, 3 and 4 had no Cladophora present. These upper river sites did have some filamentous green algae and variable amounts of blue-green algae present which could have influenced the types of diatoms present.

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* Section compiled by Brian Shero

TABLE 10A. RELATIVE ABUNDANCE OF DIATOMS FOR 5/29/92

Taxa	Ref	Site 1	Site 2	Site 3	Site 4
Achnanthes minutissima		3.6	10.2	5.9	16.8
total centrics		0.9	0.3	3.4	3.6
Cymbella minuta	0.7	19.6	16.6	7.3	4.5
Cymbella muelleri v. ventricosa			3.8		
total Cymbella	0.7	22.0	20.4	7.3	4.5
Cocconeis pediculus	1.7				
Cocconeis placentula		0.6			
Diatoma tenue	49.7	5.1	2.3		
Diatoma vulgarae	30.1	21.3	0.6	0.6	
Fragilaria capucina		2.4		27.6	1.9
Fragilaria vaucheriae	5.3	3.6	18.6	1.1	3.2
total Fragilaria	5.3	6.6	18.6	28.8	5.2
total Gomphonema	10.3	7.5	2.0	3.1	3.9
Melosira varians					1.0
Meridion circularae		0.9	1.2		1.3
Navicula accomoda		0.9		0.8	0.6
Navicula cryptocephala		4.8	8.1	7.8	7.1
Navicula lanceolata			2.6	5.0	5.5
Navicula tripunctata		3.6		0.6	
total Navicula		11.7	15.4	20.1	19.4
total Nitzschia	1.0	17.2	24.4	24.0	42.1
Rhoicosphenia curvata	1.3	0.6	0.6		0.6
Synedra pulchella v. lacerata					0.6

TABLE 10B. RELATIVE ABUNDANCE OF DIATOMS FOR 7/22/92

Taxa	Ref	Site 1	Site 2	Site 3	Site 4
Achnanthes minutissima	27.2	8.5	11.4	45.6	27.8
total centrics	0.3	0.8		5.2	2.7
Cymbella minuta	1.2	1.0	1.2	0.9	5.8
Cymbella prostrata v. auserwaldii	22.8	1.8	0.8	3.2	1.7
total Cymbella	24.0	2.8	2.1	6.0	7.6
Cocconeis pediculus	4.6	2.3	4.6	0.9	3.4
Cocconeis placentula				0.6	1.4
Diatoma tenue	6.9				
Fragilaria crotonensis					2.7
Fragilaria vaucheriae		2.1	11.4		0.7
total Fragilaria	4.3	2.3	11.4	8.9	4.8
total Gomphonema	8.1	2.6	6.0	1.7	2.7
Melosira varians				1.1	1.4
Meridion circularae					4.8
Navicula accomoda	5.5	1.0	1.4		
Navicula cryptocephala			3.3	3.2	
Navicula lanceolata			0.8	0.3	3.4
Navicula tripunctata	0.6	2.6	0.4		
total Navicula	8.1	8.5	10.8	8.0	14.8
total Nitzschia	1.2	4.1	9.6	10.8	14.4
Rhoicosphenia curvata		65.8	33.9	2.6	1.7
Synedra pulchella v. lacerata			7.1	1.1	
Synedra tabulata			2.3	4.6	

TABLE 10C. RELATIVE ABUNDANCE OF DIATOMS FOR 8/17/92

Taxa	Ref	Site 1	Site 2	Site 3	Site 4
Achnanthes minutissima		1.0	5.4	8.8	16.8
total centrics	1.2	0.3	13.5	12.8	2.7
Cymbella minuta			2.7	2.0	2.4
Cymbella prostrata v. auserwaldii	1.2	1.5			
total Cymbella	1.8	1.5	2.7	3.5	4.1
Cocconeis pediculus	66.9	24.3		0.5	0.5
Cocconeis placentula					0.3
Diatoma tenue			1.6		
Diatoma vulgarae		1.0	1.6	0.3	0.5
Fragilaria capucina		1.0	12.7	1.3	0.5
Fragilaria vaucheriae	0.6		9.7	3.3	7.9
total Fragilaria	0.6	1.0	22.5	5.5	10.1
total Gomphonema	19.7	10.6	1.6	2.5	7.6
Melosira varians		0.3	11.1	11.1	1.1
Meridion circularae					1.3
Navicula accomoda			2.4		
Navicula cryptocephala			2.7	12.3	7.6
Navicula lanceolata		0.5			2.7
Navicula tripunctata	0.6	1.0	3.8	6.3	1.6
total Navicula	1.2	2.5	16.0	33.2	20.9
total Nitzschia	0.3	4.1	32.0	24.9	13.6
Rhoicosphenia curvata	7.8	51.0		2.5	5.2

Another variable which must be considered when interpreting the abundance of the various diatom taxa is their method of attachment to their substrate. Many taxa are attached together into colonies and to their substrate by mucilage. Others live singly and are in fact able to move over the substrate. The velocity of water flow may affect the survival and growth of these forms differently. The unusual amount of precipitation and subsequent increased flow of the Buffalo River during 1992 definitely suggests that the patterns of diatom abundance reported in this study may not be typical for most years and may be a poor baseline for measuring future years.

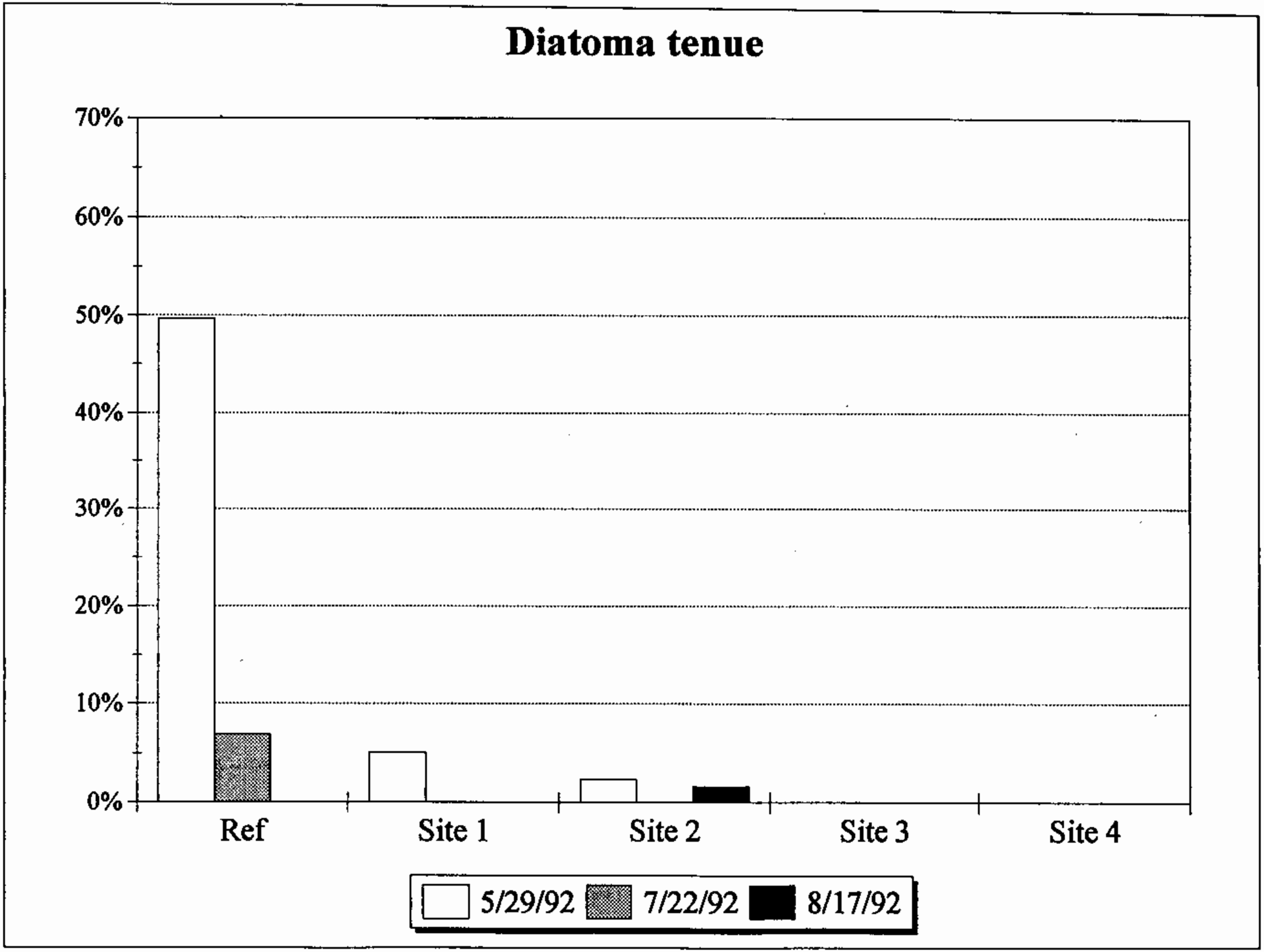
A number of spatial patterns emerge from the data which differentiate the sites. Diatoma tenue (Fig. 18) clearly differentiated between the Reference Site in the Lake and the river sites, with a dramatic decrease from 49.7% in the former to 5.1% in the latter on 5/29/92. Patrick and Reimer (1966) describe this species as found "In lakes or standing water; often found in water with relatively high conductivity or slightly salty." While these variables were not measured, conditions were clearly more favorable for this diatom in the Lake as compared with the River. It was present at 6.9% at the RS on 7/22/92 ,but did not appear at more than 1% at any other site or time. Diatoma tenue was not found at any of the sample locations examined by Martin (1991) in the upper portions of Cazenovia Creek.

Cymbella prostrata v. auserwaldii (Fig. 19) also had its highest abundance at the RS, making up 22.8% of all diatoms counted at the RS and only 0.8-3.2% of the diatoms at the other sample sites. This diatom, therefore, seems to clearly prefer the conditions along the breakwall to any of the river sites. Patrick and Reimer (1975) indicate that the ecological requirements of this taxon are not sufficiently known. The nominate variety, however, is described as an alkaliphil which is salt indifferent.

The distribution of Nitzschia spp. (Fig. 20) also clearly differentiates the Lake and River sites, increasing from 1% of the total diatoms at the RS to 42.1% at Site 4 on 5/29/92. The genus Nitzschia contains a large number of species, many of which are difficult to distinguish with the light microscope. A broad generalization about this genus is that it is most abundant in waters with middle to high nutrients, middle to high conductivity and alkaline pH. The higher numbers of this taxa upstream are probably related to higher nutrient levels and secondarily to electrolyte and pH levels. Martin (1991) found a variety of Nitzschia spp. in Cazenovia Creek, but only on one occasion did they account for more than 20% (about 40%) of the diatoms he counted.

Navicula species (Fig. 21) also generally become more abundant at sites upriver from the RS. Navicula spp., like the Nitzschia spp., live as single cells attached directly to the substrate. Many Navicula are mobile and regularly move over the substrate. Their high abundance upriver is indicative of their preference for flowing water, rather than lakeshore, and their preference for substrates not covered by other algae such as Cladophora.

Both Navicula cryptocephala (Fig. 22) and Navicula lanceolata (Fig. 23) were virtually absent from the RS and were progressively more abundant at sites farther unriver. Patrick and Reimer (1966) describe the former species as "Widely distributed in lakes, bogs, or rivers; fresh to slightly brackish water" and the later as "Widely distributed in fresh or slightly brackish water; seems to prefer water of high mineral content". Thus, even though these species



Diatoma tenue
70%
60%
50%
40%
30%
20%
10%
0%
Ref
Site 1
Site 2
Site 3
Site 4
□ 5/29/92
▨ 7/22/92
■ 8/17/92

FIGURE 18

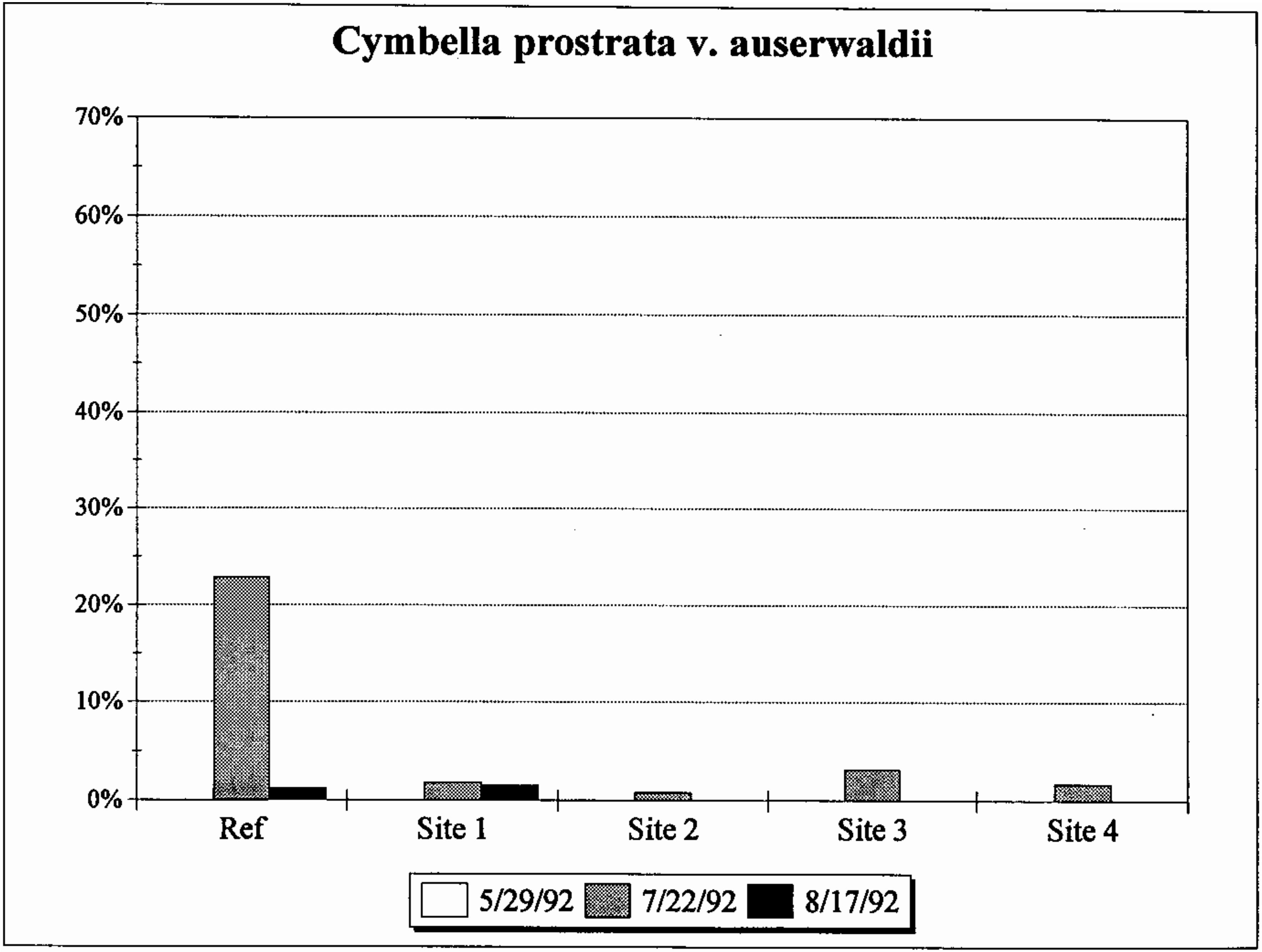

Cymbella prostrata v. auserwaldii
70%
60%
50%
40%
30%
20%
10%
0%
Ref
Site 1
Site 2
Site 3
Site 4
5/29/92
7/22/92
8/17/92

FIGURE 19

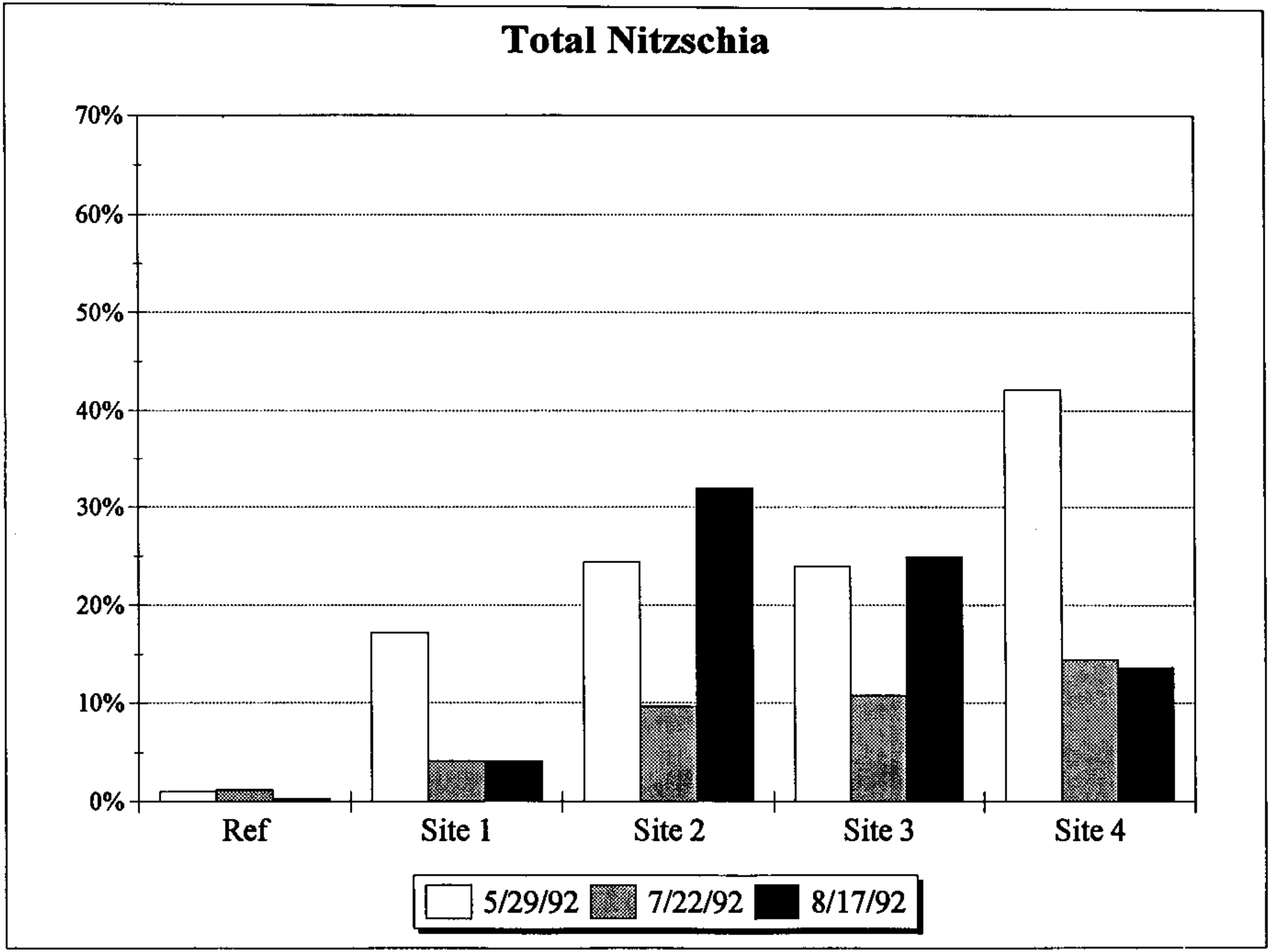

Total Nitzschia
70%
60%
50%
40%
30%
20%
10%
0%
Ref
Site 1
Site 2
Site 3
Site 4
□ 5/29/92
▨ 7/22/92
■ 8/17/92

FIGURE 20

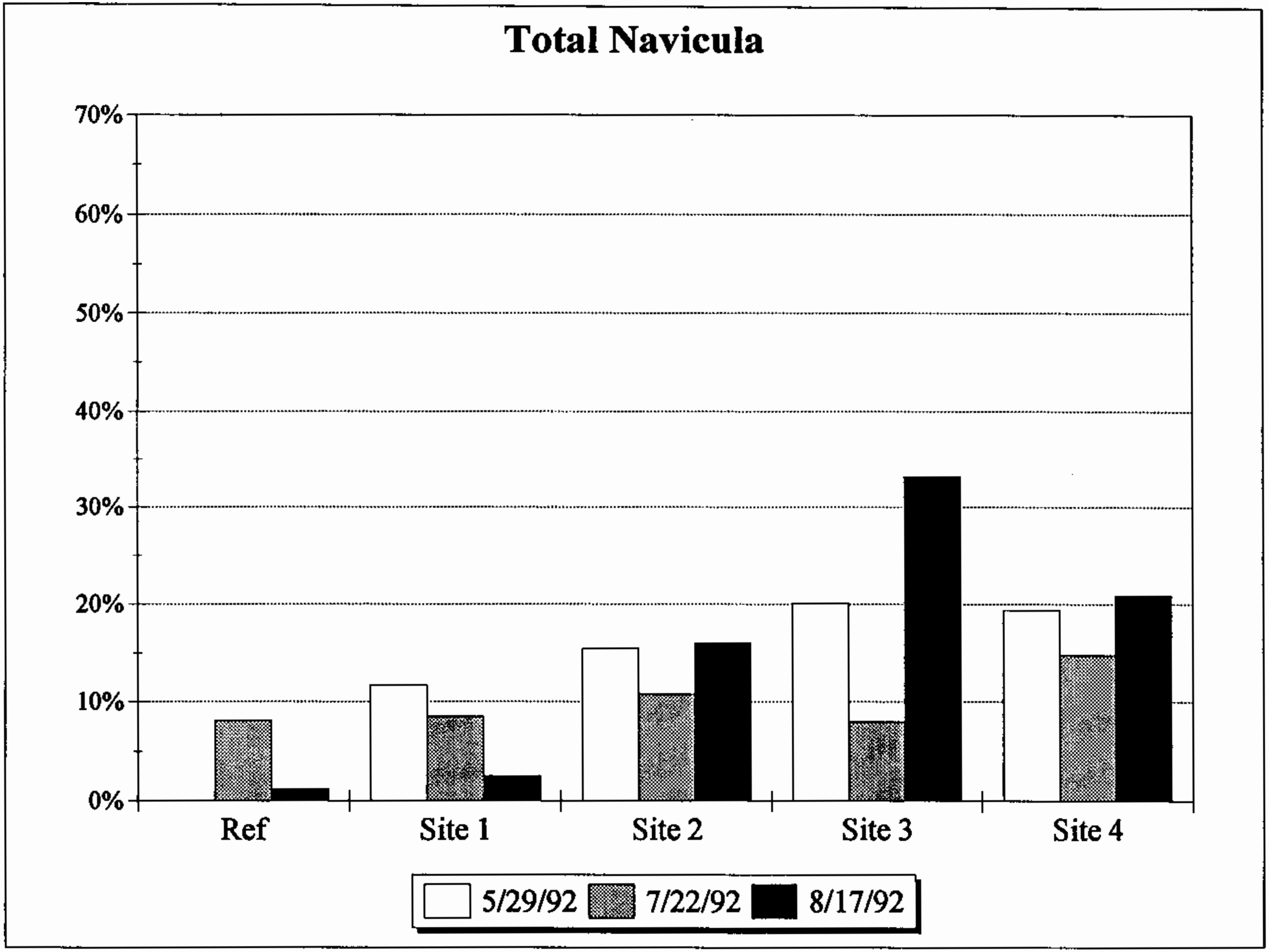

Total Navicula
70%
60%
50%
40%
30%
20%
10%
0%
Ref
Site 1
Site 2
Site 3
Site 4
5/29/92
7/22/92
8/17/92

FIGURE 21

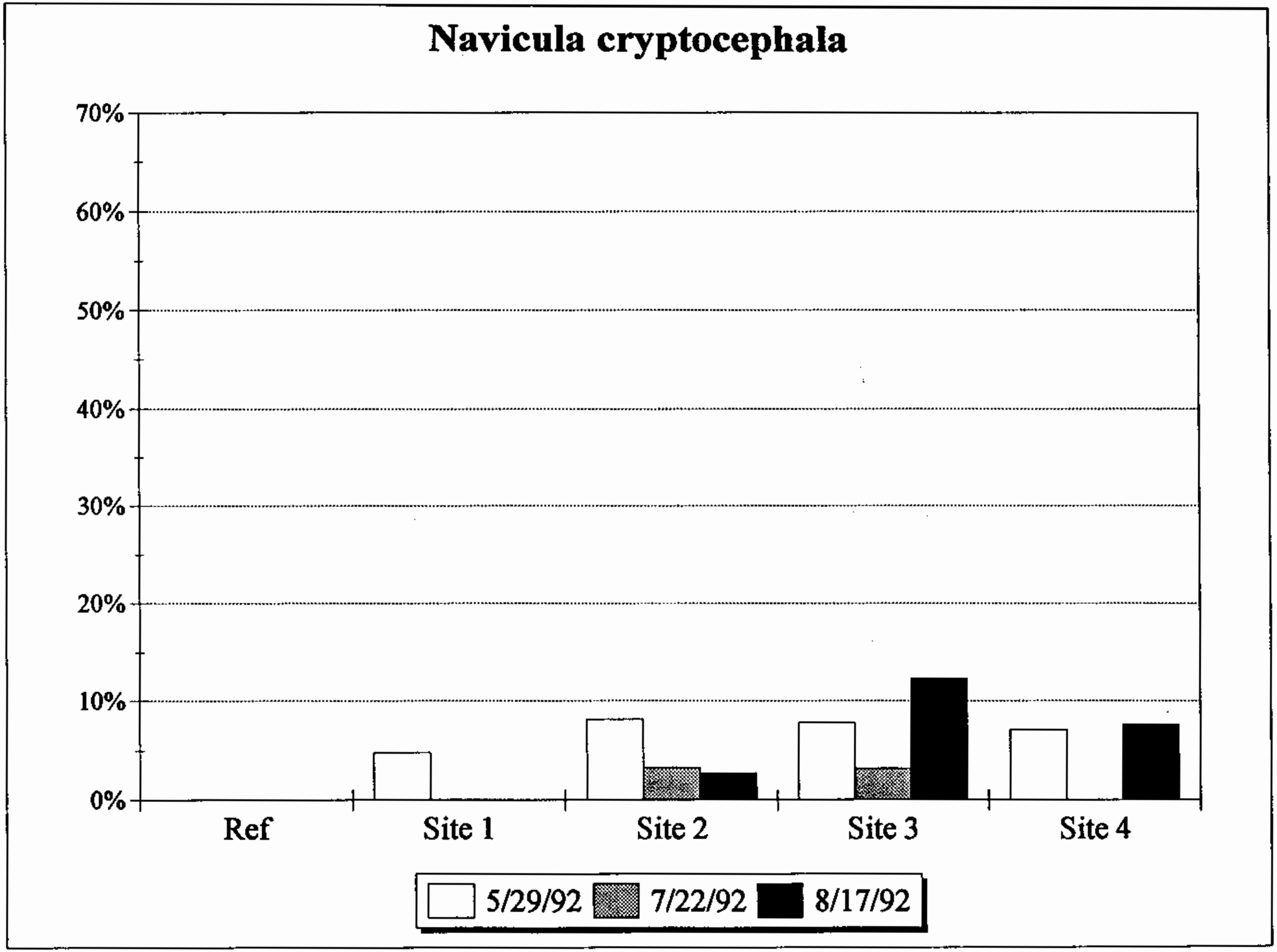

Navicula cryptocephala
70%
60%
50%
40%
30%
20%
10%
0%
Ref
Site 1
Site 2
Site 3
Site 4
5/29/92
7/22/92
8/17/92

FIGURE 22

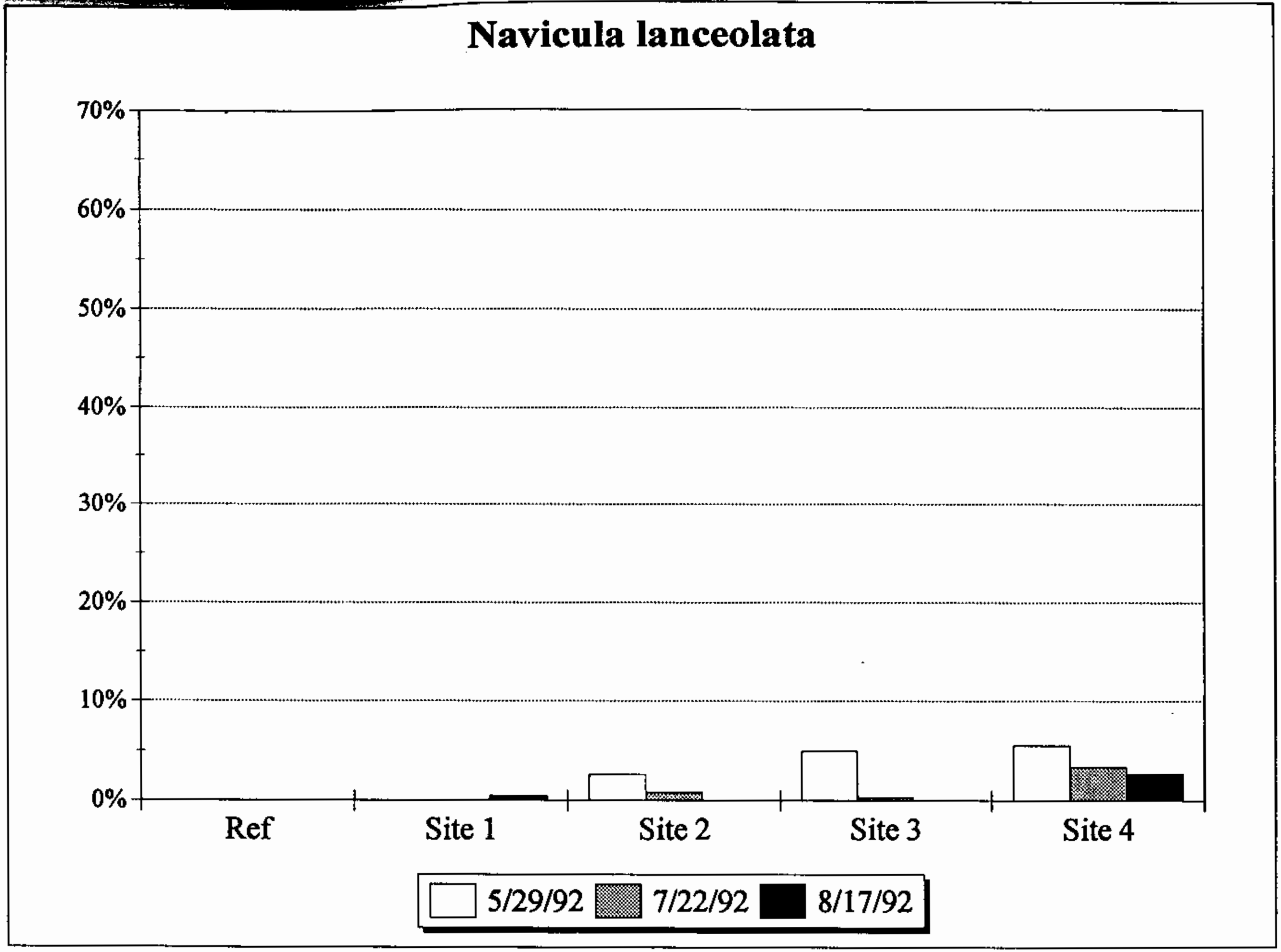

Navicula lanceolata
70%
60%
50%
40%
30%
20%
10%
0%
Ref
Site 1
Site 2
Site 3
Site 4
5/29/92
7/22/92
8/17/92

FIGURE 23

differentiate between the RS and upriver sites, the underlying causative environmental factor cannot be identified.

Cymbella minuta (Fig. 24) had its lowest abundance at the RS. Because this taxon is a very widespread species, found in a variety of environmental locations, its distribution pattern cannot be clearly interpreted.

Some taxa were most abundant at the RS and Site 1. Diatoma vulgarae (Fig. 25) is common only at the RS and Site 1 on 5/28/92. This species is described by Patrick and Reimer (1966) as "Seems to prefer cool, flowing water; often found in water with fairly high nutrient content." Martin (1991) found this taxa from May to August 1989 in Cazenovia Creek, one of the main tributary streams which join to form the Buffalo River, but never making up more than a few percent of the total attached diatom assemblage. Its abundance early in 1992 seems to be indicative of the cold water temperature and the moving water, possibly wave action, in the lower River and along the breakwall. This species clearly distinguished the RS and the lower River at Site 1 from the upper River sites. It appeared again at 1% on 8/17/92 at Site 1, but was otherwise not present at more than 1% at any other site or date.

Cocconeis pediculus (Fig. 26) shows a similar pattern, making up 66.9% and 24.3% respectively of the total diatoms at the RS and Site 1 on 7/22/92. Patrick and Reimer (1966) describe this species as "widespread" and "epiphytic on many aquatic plants" with a preference for alkaline water and salt indifferent. They further state that it is "Considered by some as resistant to moderate amounts of organic pollution". Its high abundance at the RS and Site 1 appears to be a function of the presence of Cladophora at these sites, since it found epiphytically on the green alga. Cladophora was not found upriver of Site 1 and Cocconeis pediculus was similarly absent.

On 7/22/92, the planktonic colonial rotifer, Conochilus, followed a pattern similar to these diatoms and the Cladophora, being most common at the RS, less common at Site 1 and essentially absent from Sites 2-4.

Total Gomphonema (Fig. 27) also were generally most abundant at the RS, somewhat less abundant at Site 1, and least abundant at Sites 2-4. Since many of the Gomphonema spp. are epiphytic on the Cladophora, their reduced numbers upriver reflect the absence of Cladophora and other abundant filamentour green algae at the upriver Sites.

A number of diatom taxa reached their maximum abundances at Site 1 or farther upriver. Rhoicoshphenia curvata (Fig. 28) dominates Site 1 on 7/22/92 and 8/17/92, making up 65.8% and 51.0% respectively of the total diatoms. This species was also very abundant at Site 2 on 7/22/92 with over 30% of all diatoms. Upriver from Site 2, it never accounted for more than 5.2% of the total. Patrick and Reimer (1966) describe this taxon as "A widespread species more commonly found in alkaline flowing waters" and go on to suggest that it may also be limited to low salt locations.

Cymbella muelleri v. ventricosa (Fig. 29) was found only at Site 2 on 5/29/92. However, Patrick and Reimer (1975) indicate that its ecological requirements are "insufficiently known".

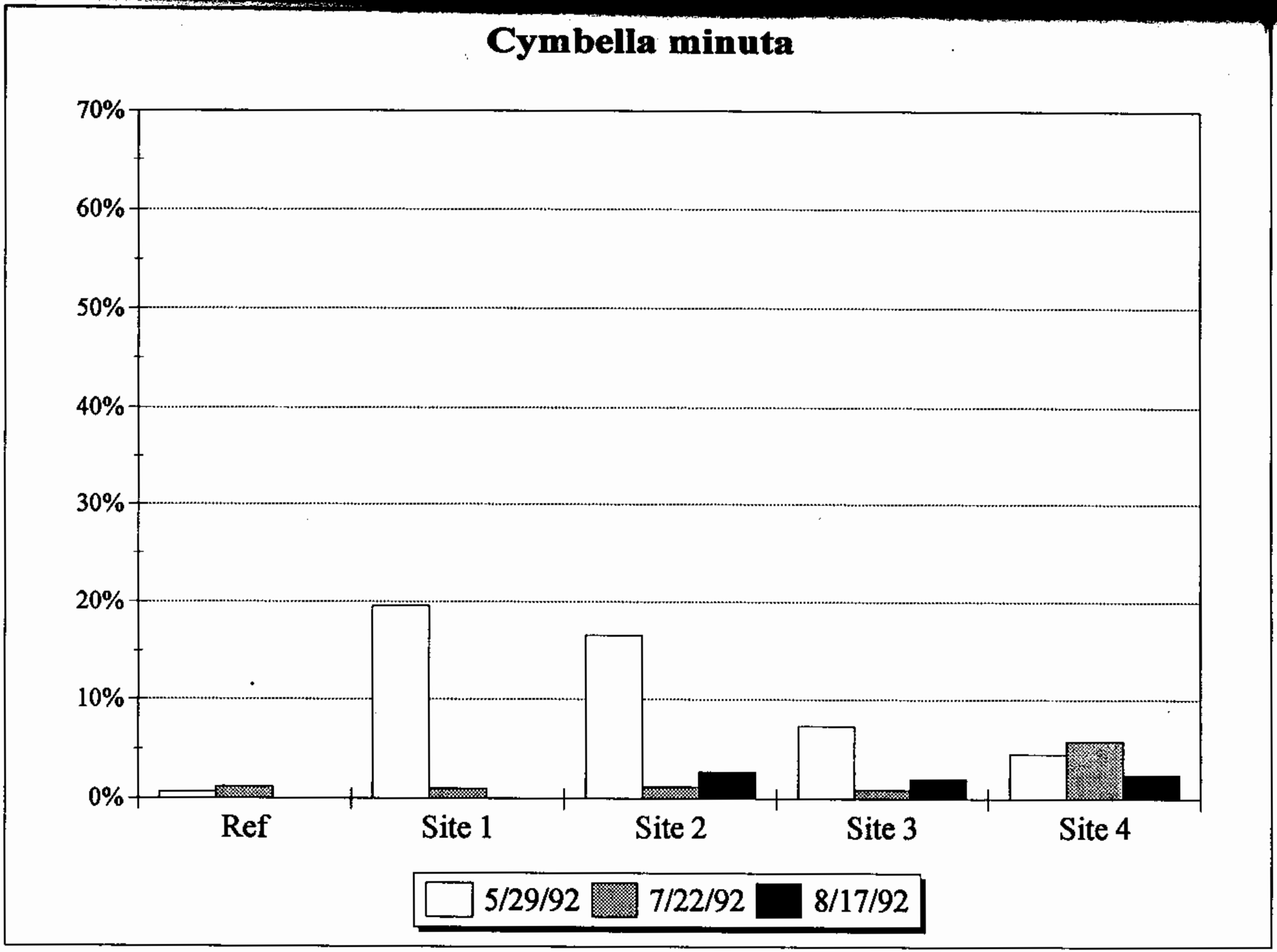

Cymbella minuta
70%
60%
50%
40%
30%
20%
10%
0%
Ref
Site 1
Site 2
Site 3
Site 4
5/29/92
7/22/92
8/17/92

FIGURE 24

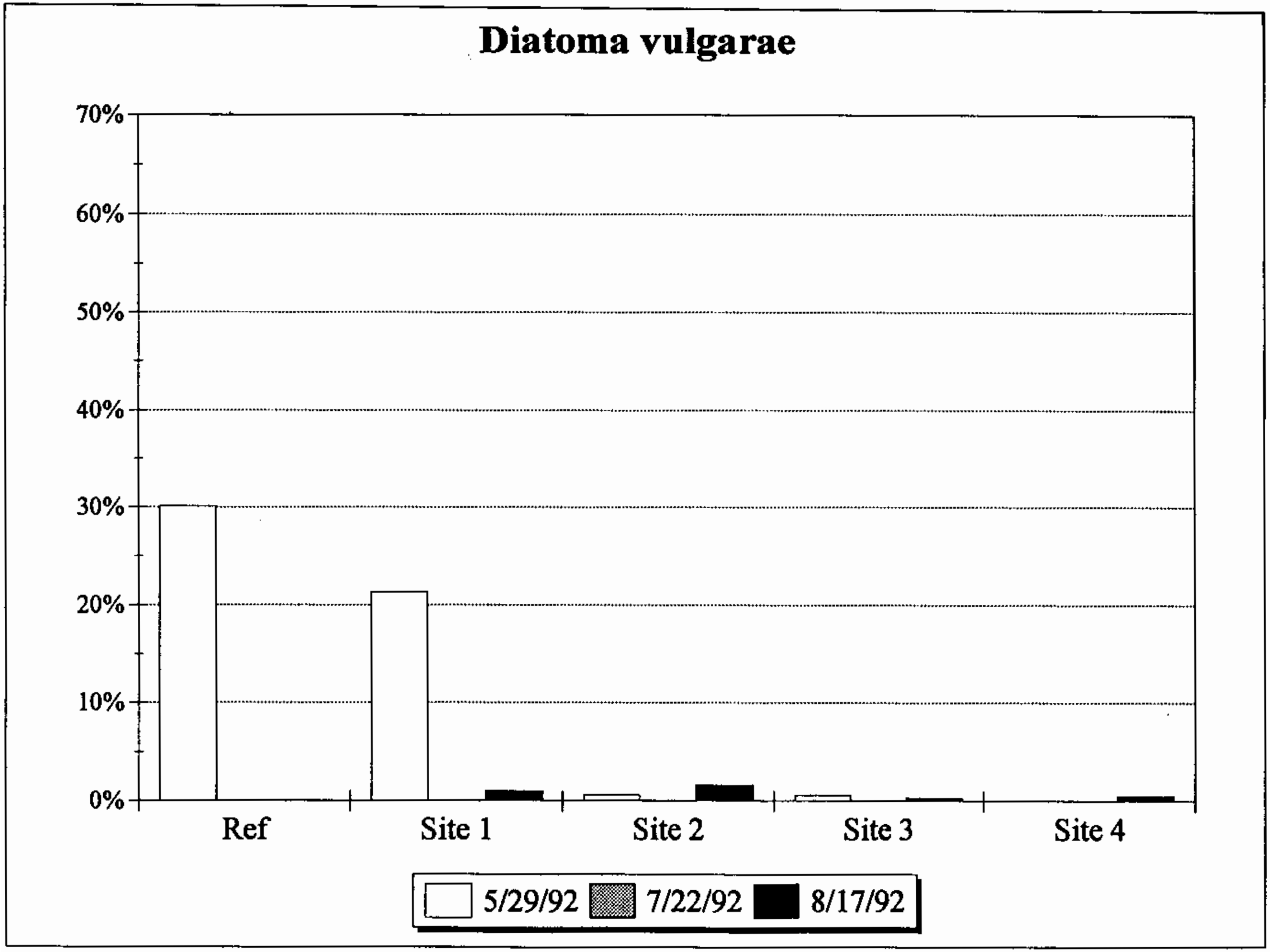

Diatoma vulgarae
70%
60%
50%
40%
30%
20%
10%
0%
Ref
Site 1
Site 2
Site 3
Site 4
5/29/92
7/22/92
8/17/92

FIGURE 25

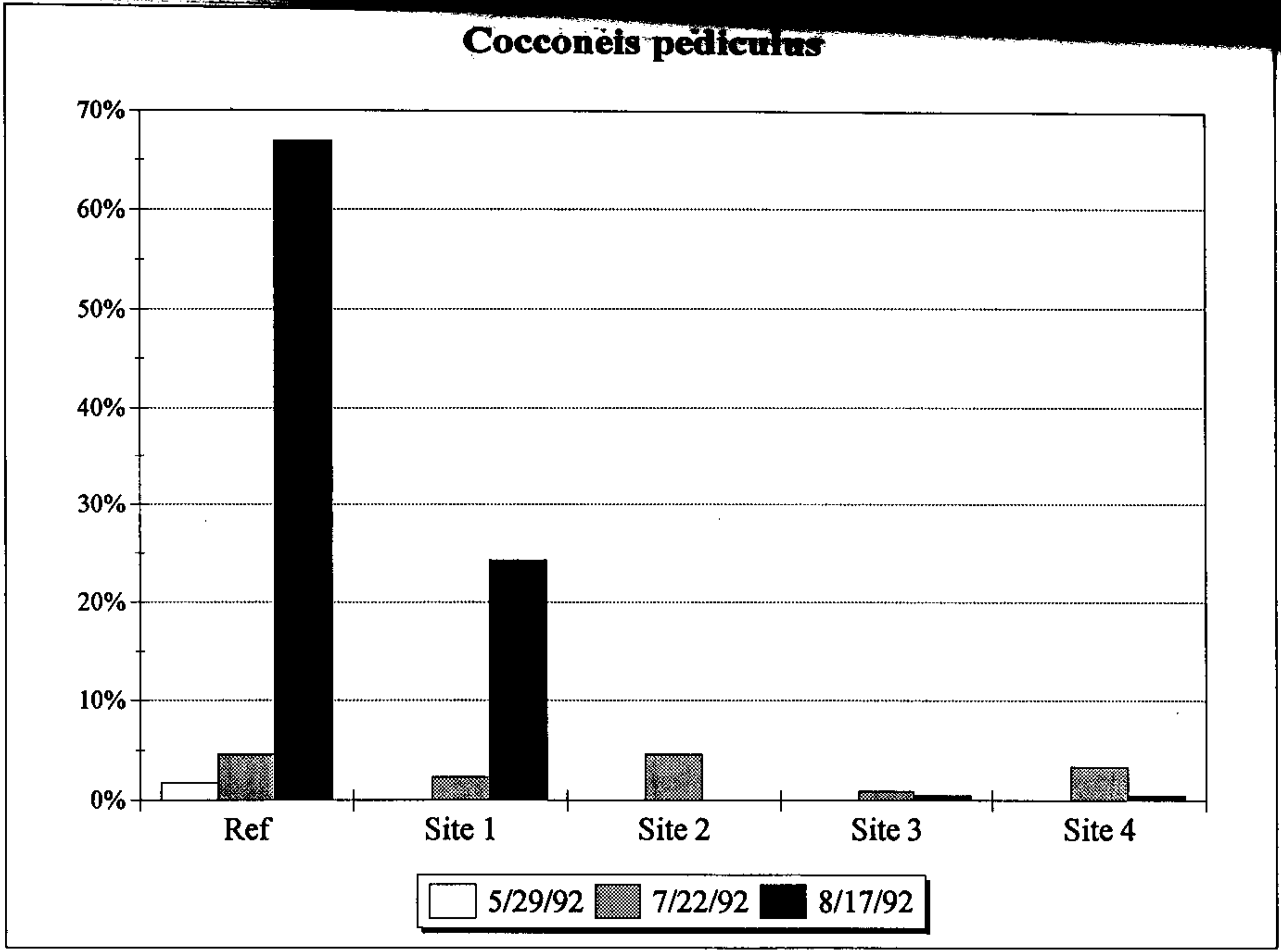

Cocconeis pediculus
70%
60%
50%
40%
30%
20%
10%
0%
Ref
Site 1
Site 2
Site 3
Site 4
5/29/92
7/22/92
8/17/92

FIGURE 26

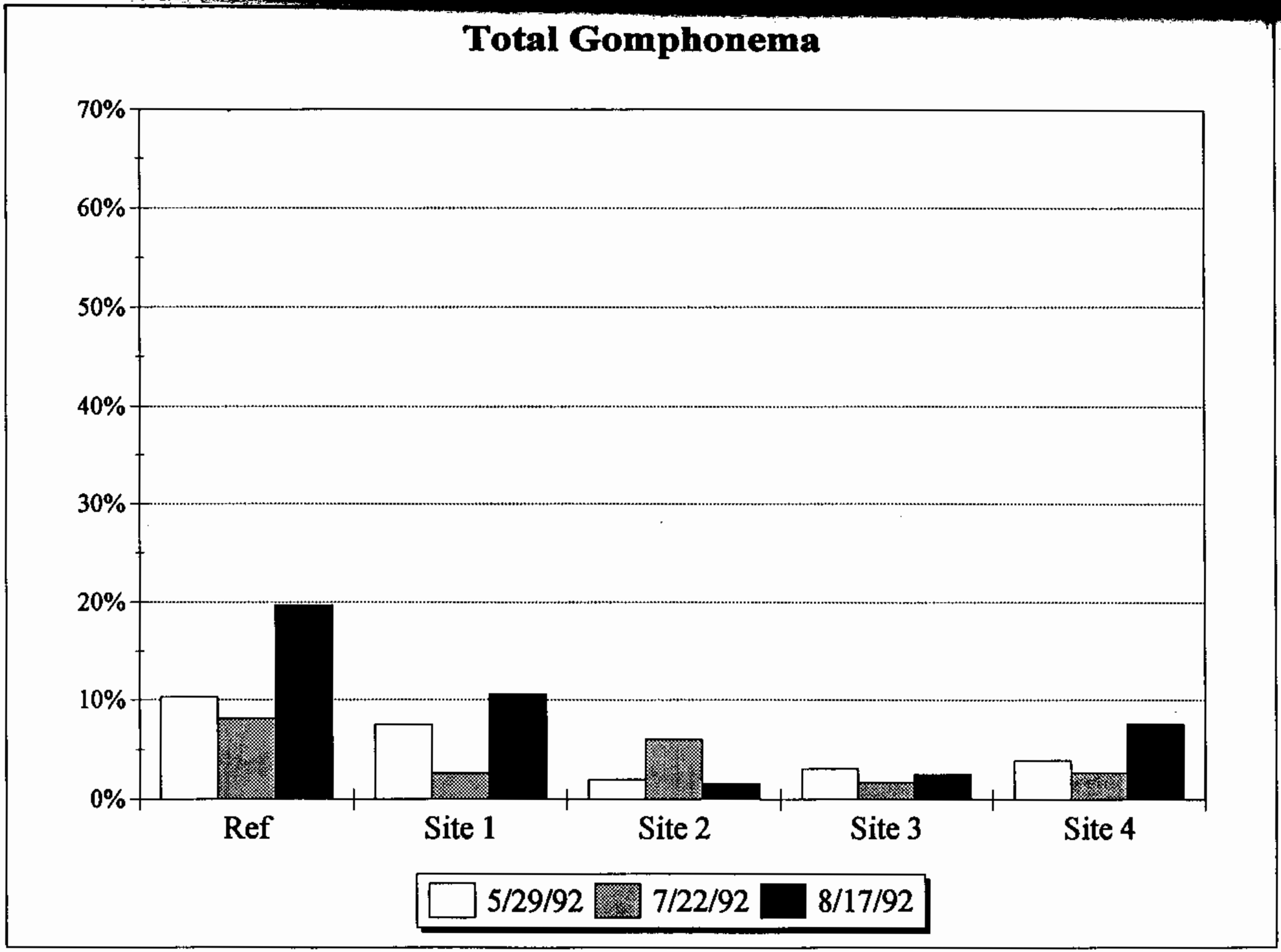

Total Gomphonema
70%
60%
50%
40%
30%
20%
10%
0%
Ref
Site 1
Site 2
Site 3
Site 4
5/29/92
7/22/92
8/17/92

FIGURE 27

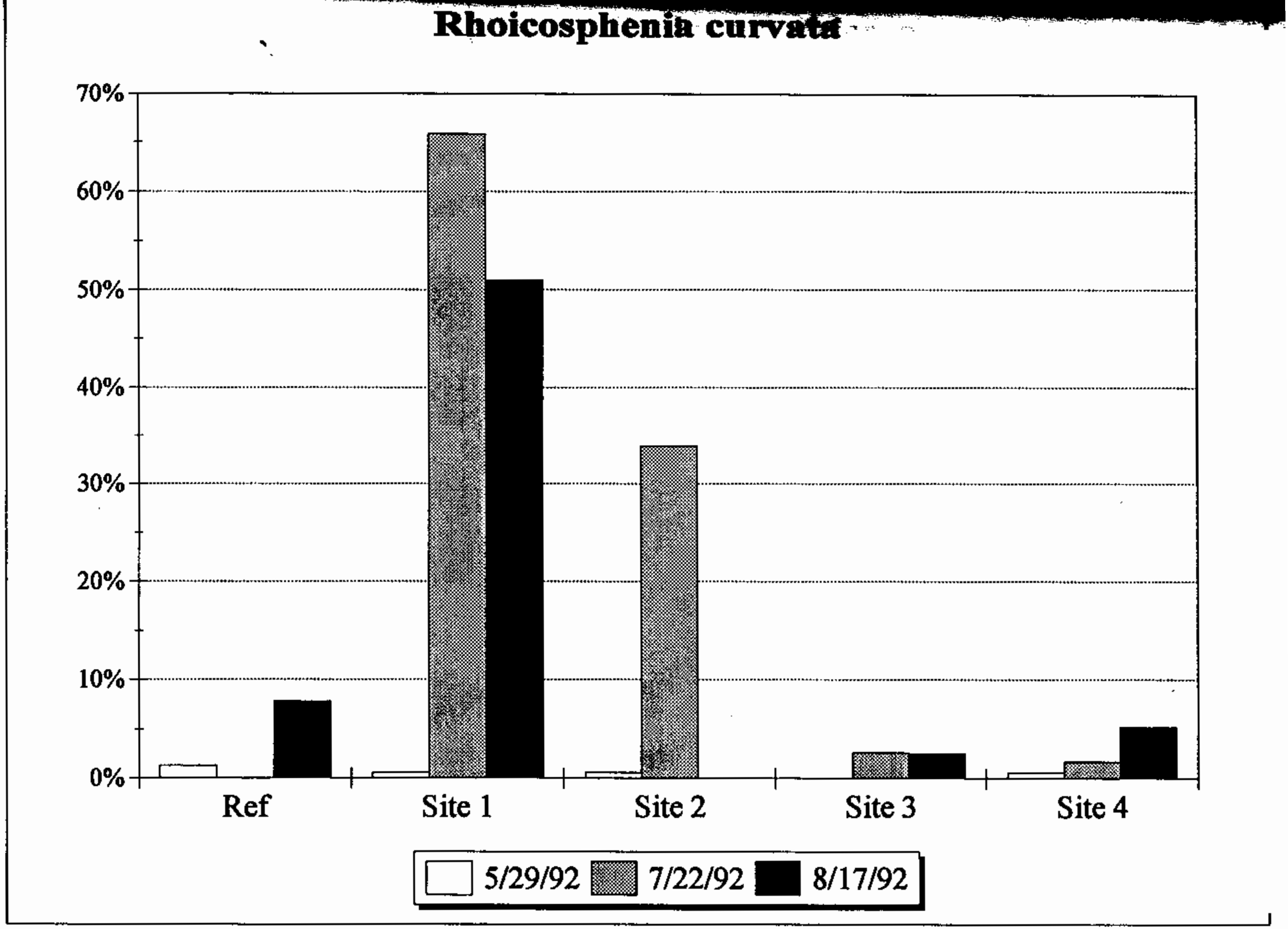
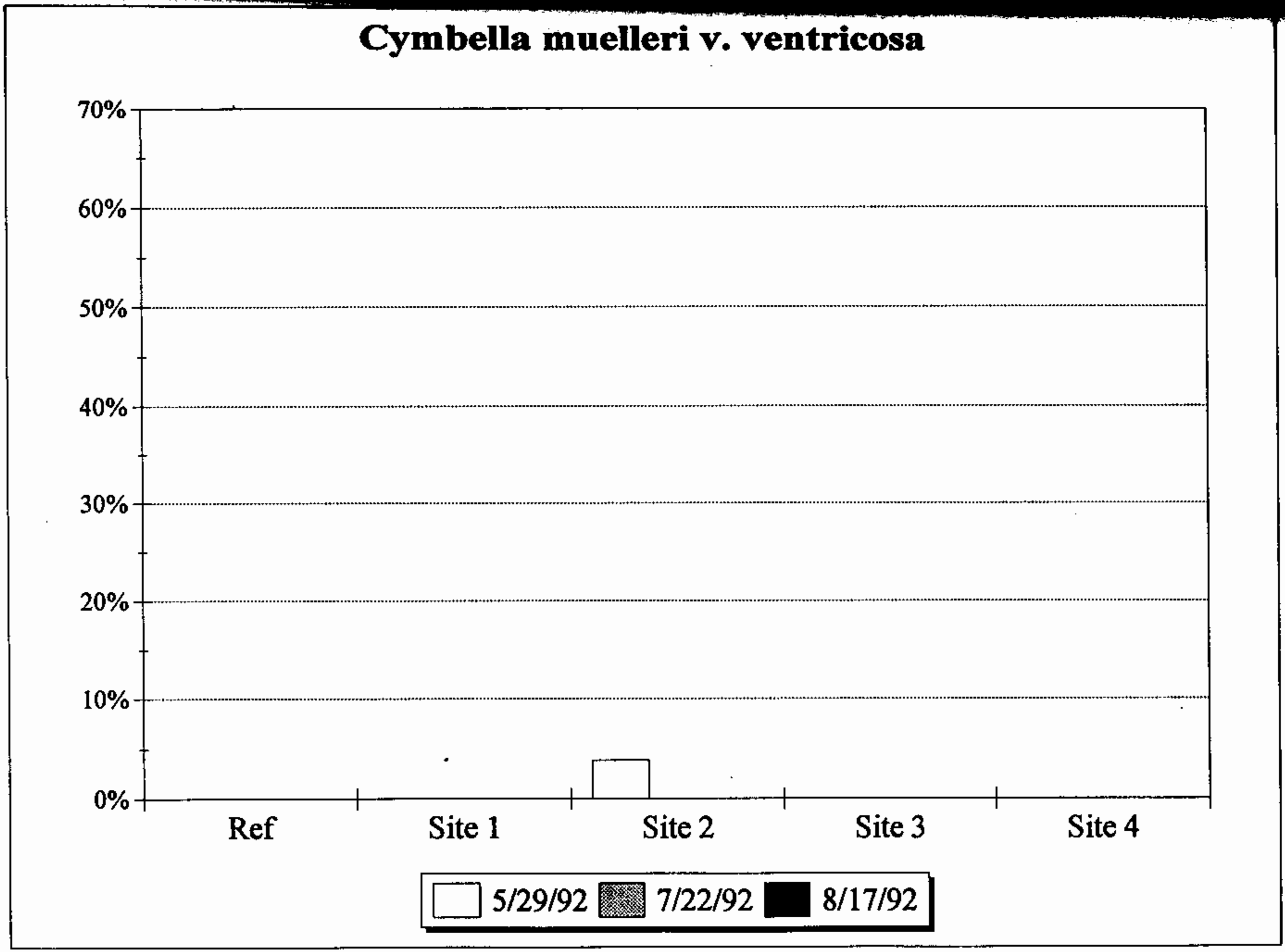

Rhoicosphenia curvata
70%
60%
50%
40%
30%
20%
10%
0%
Ref
Site 1
Site 2
Site 3
Site 4
5/29/92
7/22/92
8/17/92

FIGURE 28



Cymbella muelleri v. ventricosa

FIGURE 29

The following species reach their maximum abundances at Sites 2 or 3: Synedra tabulata (Fig. 30), Synedra pulchella v. lacerata (Fig. 31), Melosira varians (Fig. 32), total centrics (Fig. 33), Fragilaria capucina (Fig. 34), and total Fragilaria (Fig. 35). Patrick and Reimer (1966) describe Synedra tabulata (S. fasciculata) as "In water of high conductivity,sometimes slightly brackish" and Synedra pulchella v. lacerata as "Found in water of high conductivity", indicating that Sites 2 and 3 may have higher concuctivities than sites either farther upriver or downriver.

Site 2 is also the first appearance of significant numbers of centric diatoms, with 11.1% of Melosira varians and 2.4% of other centrics including Cyclotella meneghiniana, Melosira ambigua and a small Stephanodiscus. In general these centrics are all associated with relatively high nutrient conditions and are tychoplanktonic, being associated with a substrate and periodically lifted into the plankton.

Melosira varians is also common at Site 3 with 11.1% of all diatoms on 8/17/92, while it makes up only 1.1% of the diatoms at Site 4. The pattern of abundance of these centric diatoms may be related to differences in nutrient availability along the River, with Sites 2 and 3 possibly having the highest nutrient levels on 8/17/92. This possibility is supported by the high percentages of Nitzschia spp. also found at Sites 2 and 3 on this date.

Fragilaria capucina (Fig. 34) is very abundant at sites 2 and 3, with up to 25% of all diatoms counted at Site 3 on 5/29/92. Patrick and Reimer (1966) describe this species as " Seems to prefer slightly alkaline water, indifferent to small amounts of NaCl".

The general pattern at Sites 2 and 3 therefore seems to indicate higher nutrients and salts than at other sites. These nutrients and salts could come from sewage outfalls, although this is only a hypothesis which needs definitive testing by means of water chemistry analysis.

Fragilaria crotonensis (Fig. 36) is a mesotrophic indicator, tolerant of small amounts of NaCl (Patrick and Reimer 1966) which was found in significant numbers only at Site 4 on 7/22/92, where it made up 2.7% of all diatoms. This is a planktonic species which may indicate relatively high nutrient conditions at Site 4 on this date or which may have been washed into Site 4 from an upstream origin in either Buffalo or Cazenovia Creeks.

A number of diatom species show a more complex distribution pattern with less clearly defined trends. The most abundant of these is Achnanthes minutissima (Fig. 37) which has its highest abundances at Sites 3 and 4. This species is described by Patrick and Reimer (1966) as being very widespread, with wide tolerances for nutrients, pH and salt. Changes in its abundance are therefore difficult to relate to differences in specific environmental variables.

A number of seasonal patterns also were evident. These 5 patterns of diatom abundance are summarized below according to the relative abundance of the each taxon over the 3 sampling dates:

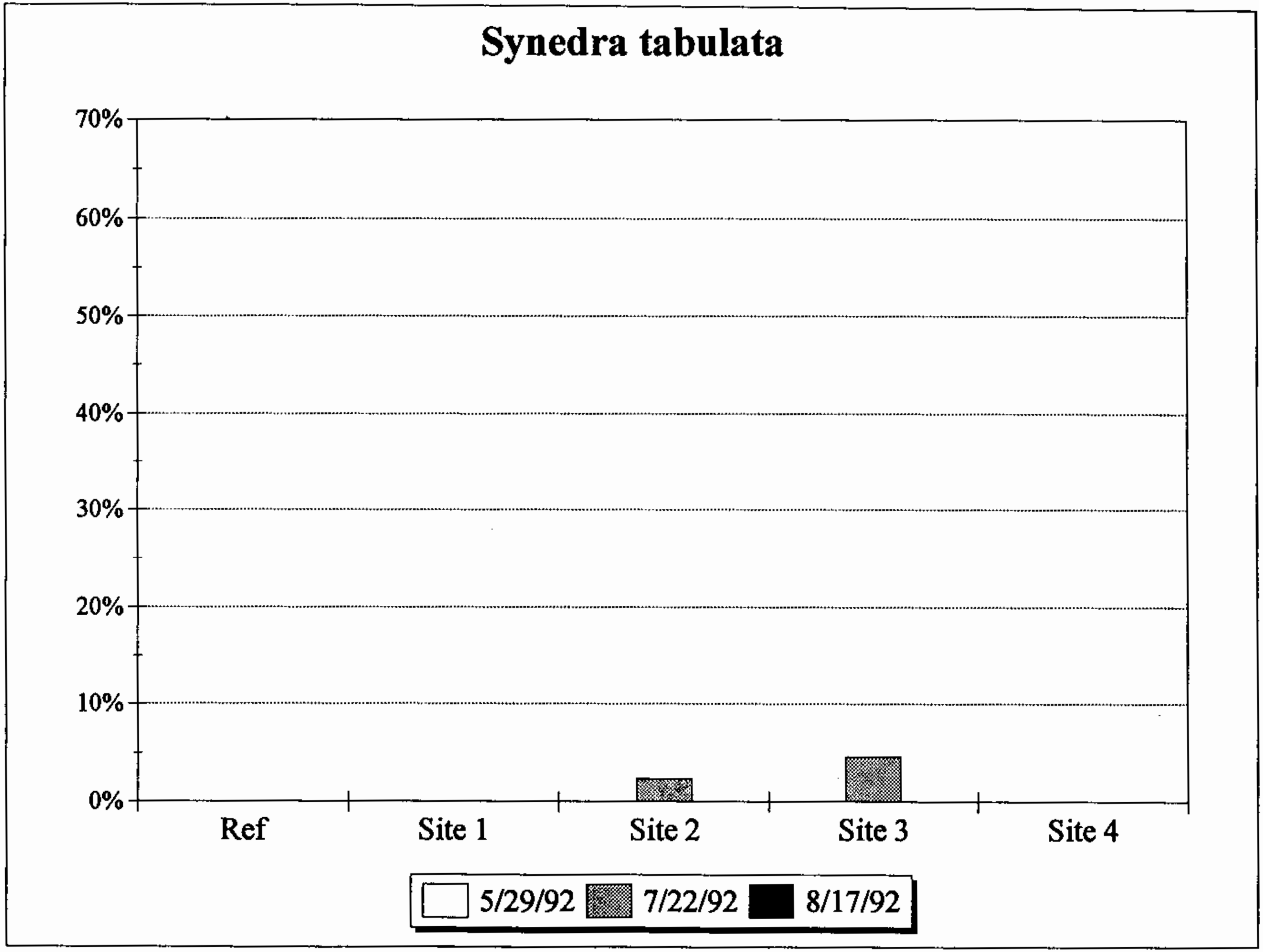

Synedra tabulata
70%
60%
50%
40%
30%
20%
10%
0%
Ref
Site 1
Site 2
Site 3
Site 4
5/29/92
7/22/92
8/17/92

FIGURE 30

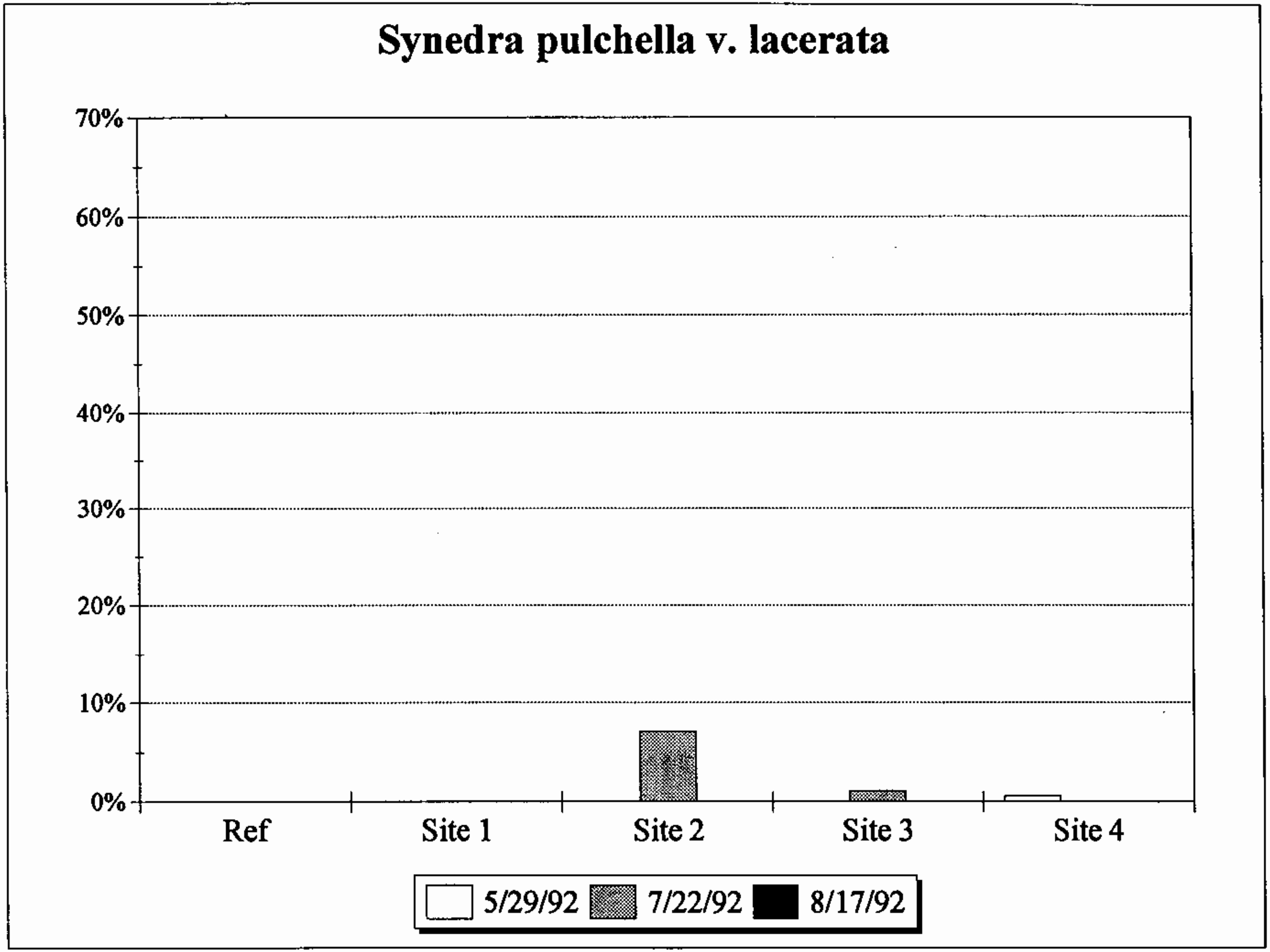

Synedra pulchella v. lacerata
70%
60%
50%
40%
30%
20%
10%
0%
Ref
Site 1
Site 2
Site 3
Site 4
5/29/92
7/22/92
8/17/92

FIGURE 31

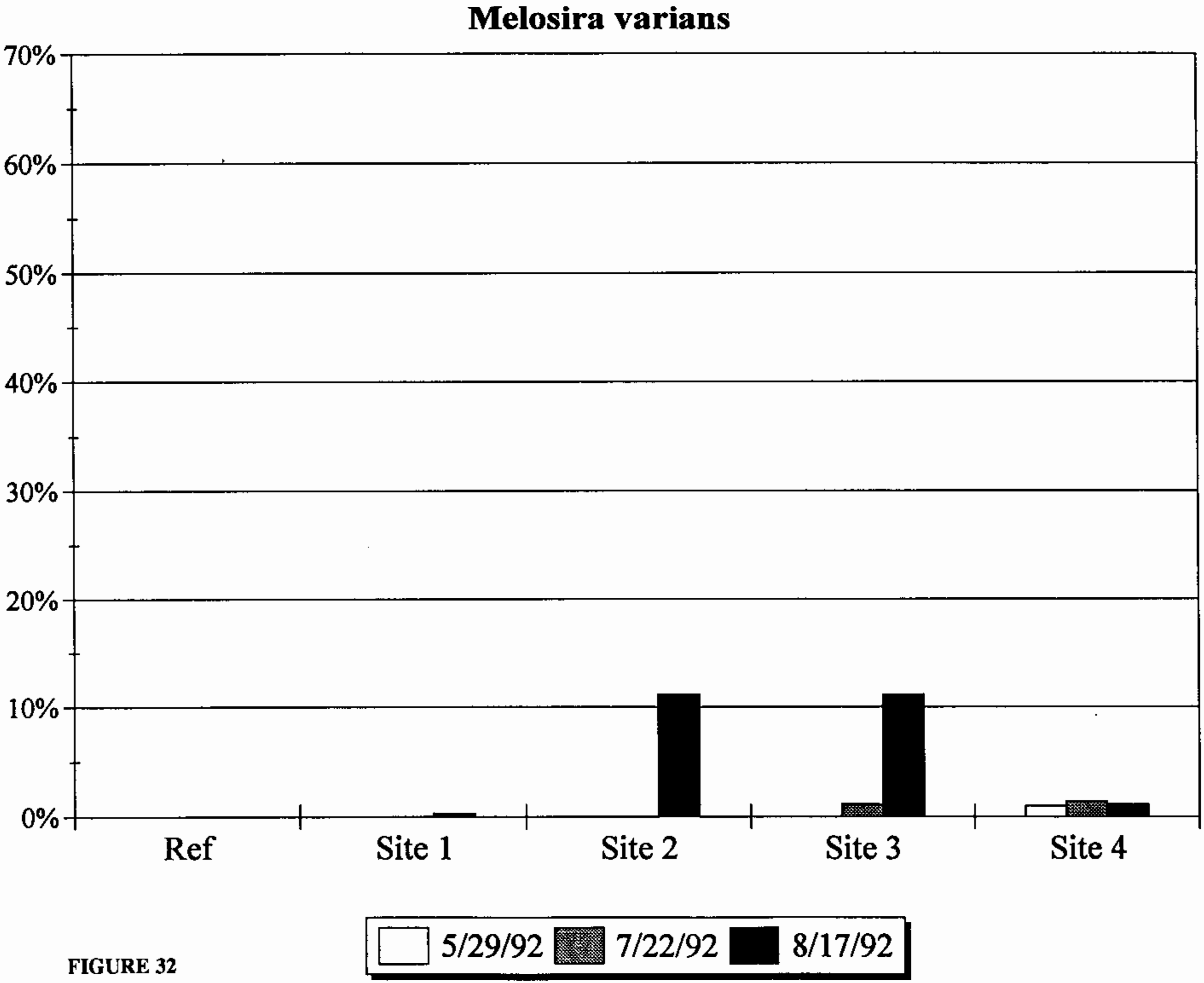

Melosira varians
70%
60%
50%
40%
30%
20%
10%
0%
Ref
Site 1
Site 2
Site 3
Site 4
5/29/92
7/22/92
8/17/92

FIGURE 32

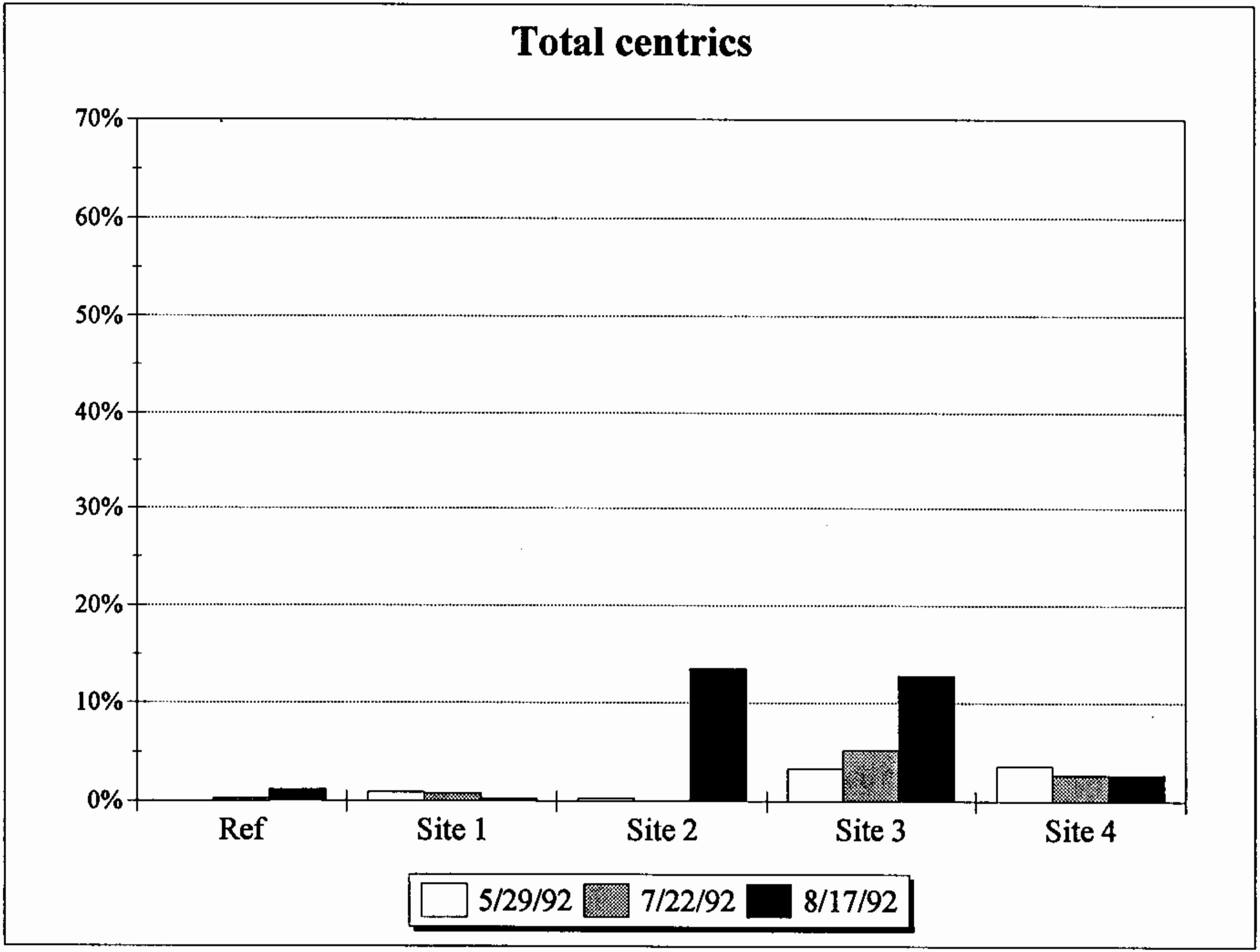

Total centrics
70%
60%
50%
40%
30%
20%
10%
0%
Ref
Site 1
Site 2
Site 3
Site 4
□ 5/29/92
▨ 7/22/92
■ 8/17/92

FIGURE 33

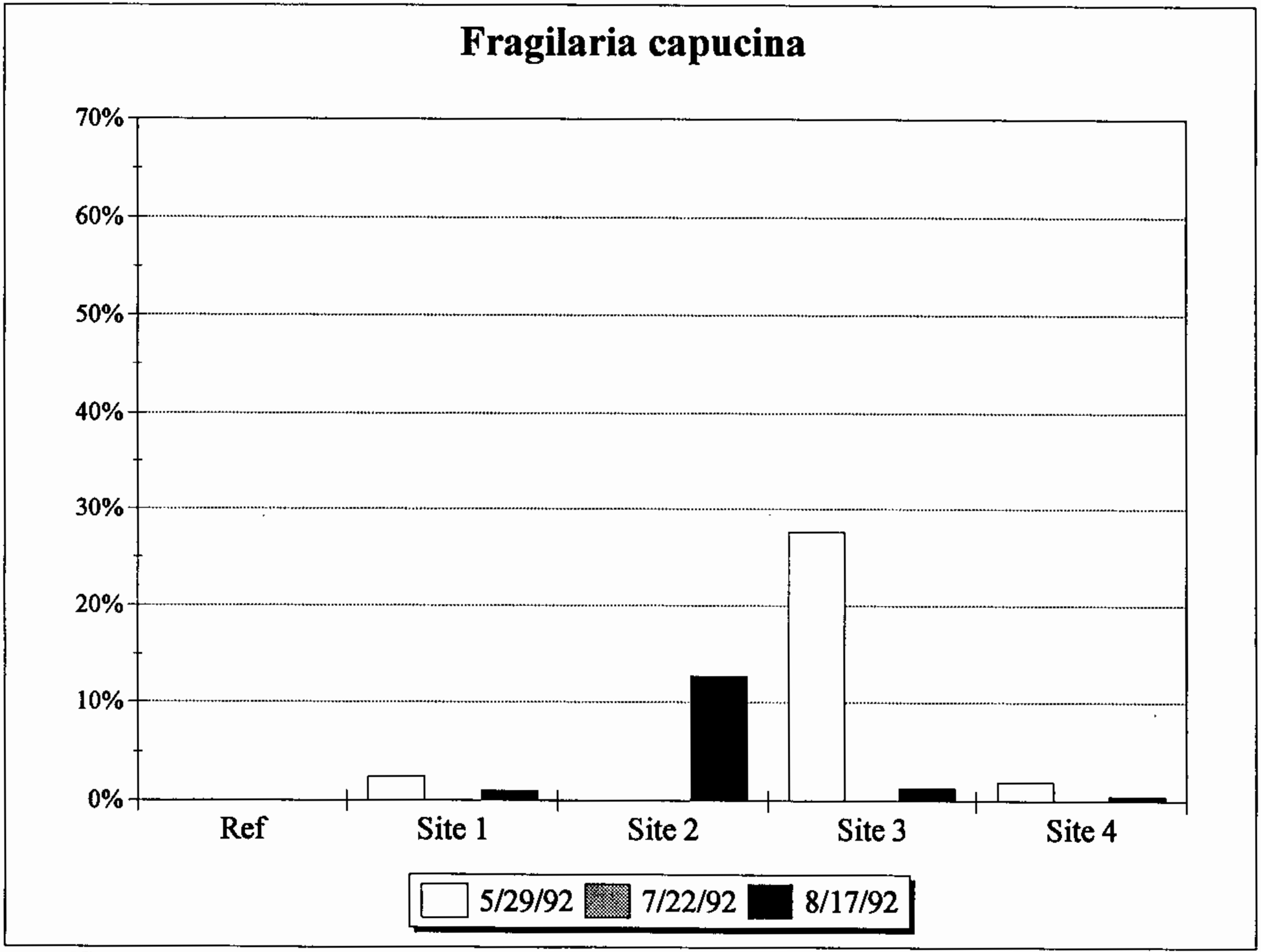

Fragilaria capucina

FIGURE 34

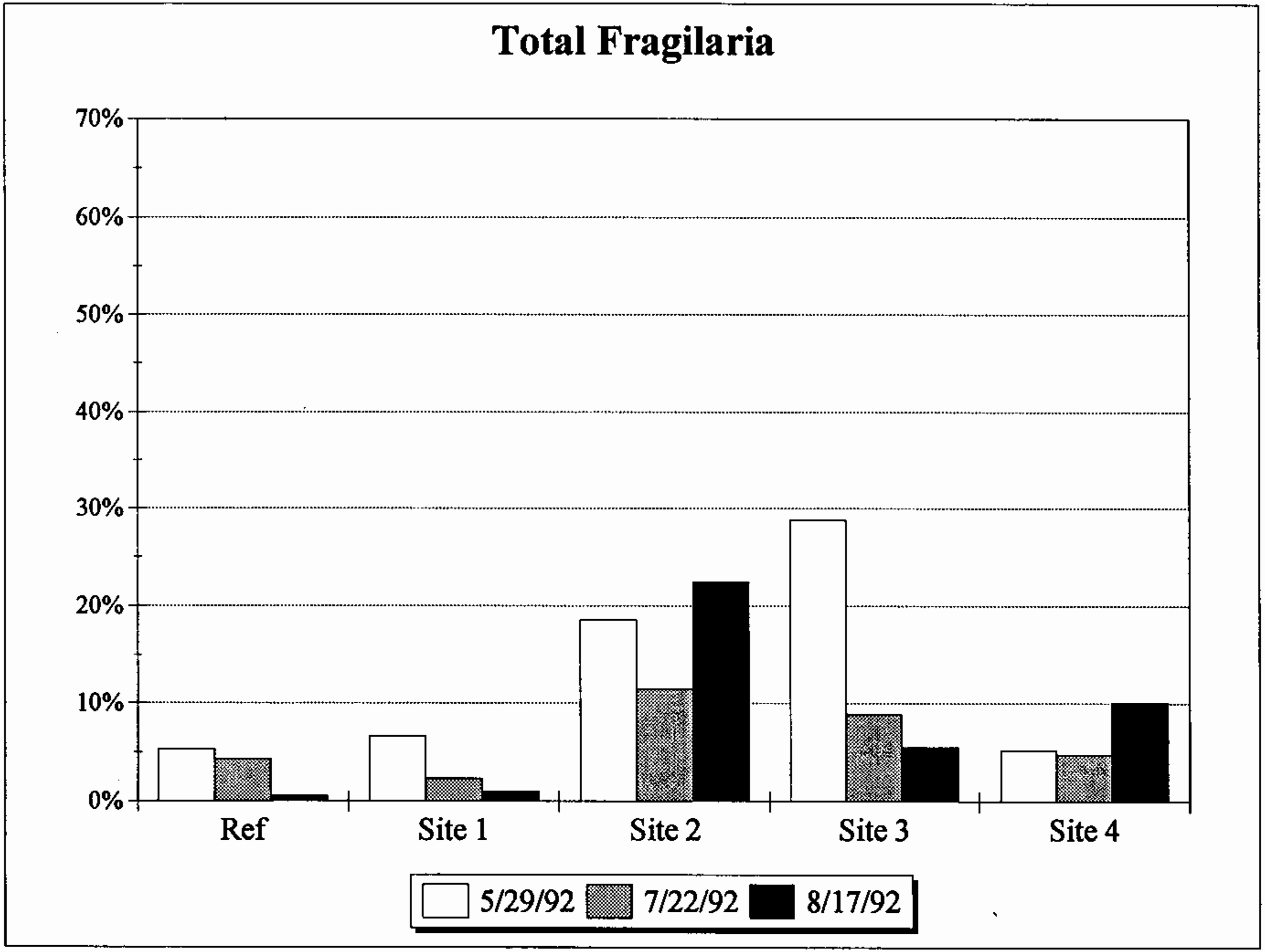
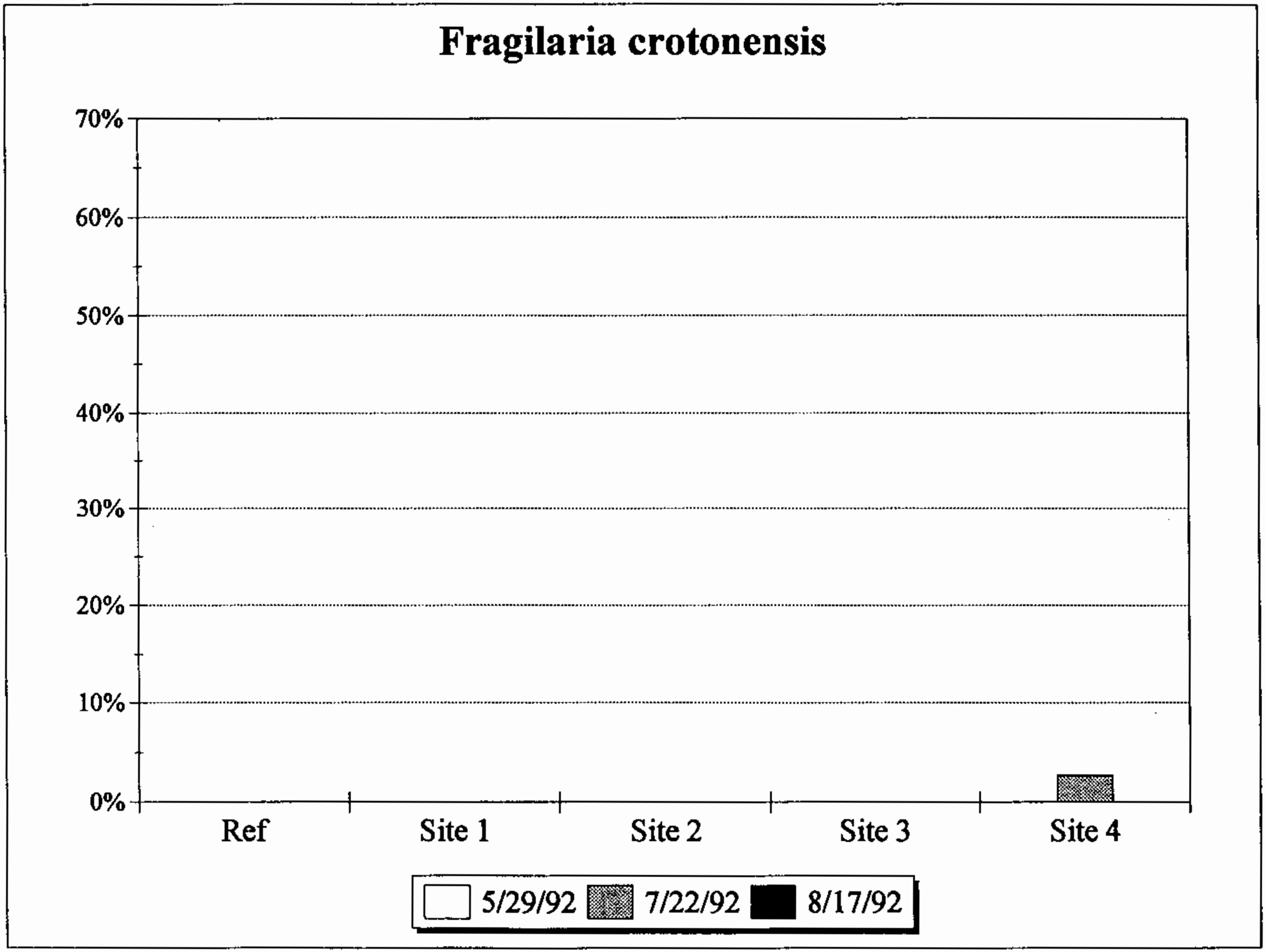

Total Fragilaria
70%
60%
50%
40%
30%
20%
10%
0%
Ref
Site 1
Site 2
Site 3
Site 4
□ 5/29/92
▨ 7/22/92
■ 8/17/92

FIGURE 35



Fragilaria crotonensis

FIGURE 36

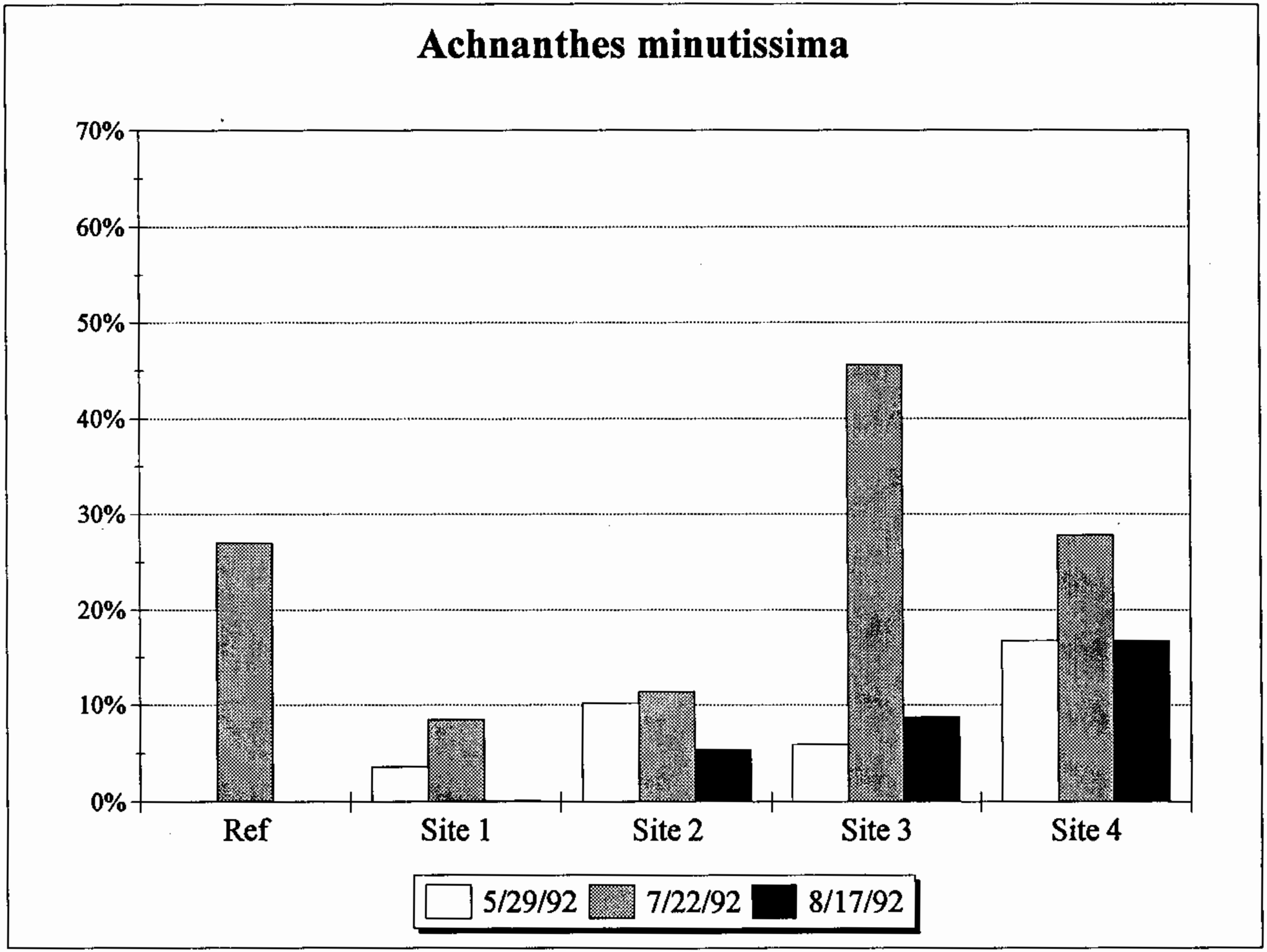

Achnanthes minutissima
70%
60%
50%
40%
30%
20%
10%
0%
Ref
Site 1
Site 2
Site 3
Site 4
5/29/92
7/22/92
8/17/92

FIGURE 37

1. HIGH-LOW-LOW

Cymbella minuta	Fig. 38
Cymbella muelleri v. *ventricosa*	Fig. 39
Diatoma tenue	Fig. 40
Diatoma vulgarae	Fig. 41

2. LOW-LOW-HIGH

Cocconeis pediculus	Fig. 42
Melosira varians	Fig. 43
total centrics	Fig. 44

3. LOW-HIGH-HIGH

Rhoicosphenia curvata	Fig. 45

4. LOW-HIGH-LOW

Achnanthes minutissima	Fig. 46
Cymbella prostrata v. *auserwaldii*	Fig. 47
Fragilaria crotonensis	Fig. 48
Navicula accomoda	Fig. 49
Synedra pulchella v.*lacerata*	Fig. 50
Synedra tabulata	Fig. 51

5. HIGH-LOW-HIGH

Fragilaria capucina	Fig. 52
total *Fragilaria*	Fig. 53
total *Navicula*	Fig. 54
total *Nitzschia*	Fig. 55

6. HIGH-HIGH-LOW

total *Cymbella*	Fig. 56

ATTACHED ALGAE OTHER THAN DIATOMS

Because algal density on substrates was highly variable, these analyses were not able to quantify biomass. The relative abundance of the macroalgae was estimated from fresh samples scraped from the substrates. Microalgae, other than diatoms, which were collected in the attached samples were not abundant. These microalgae were noted but not quantified.

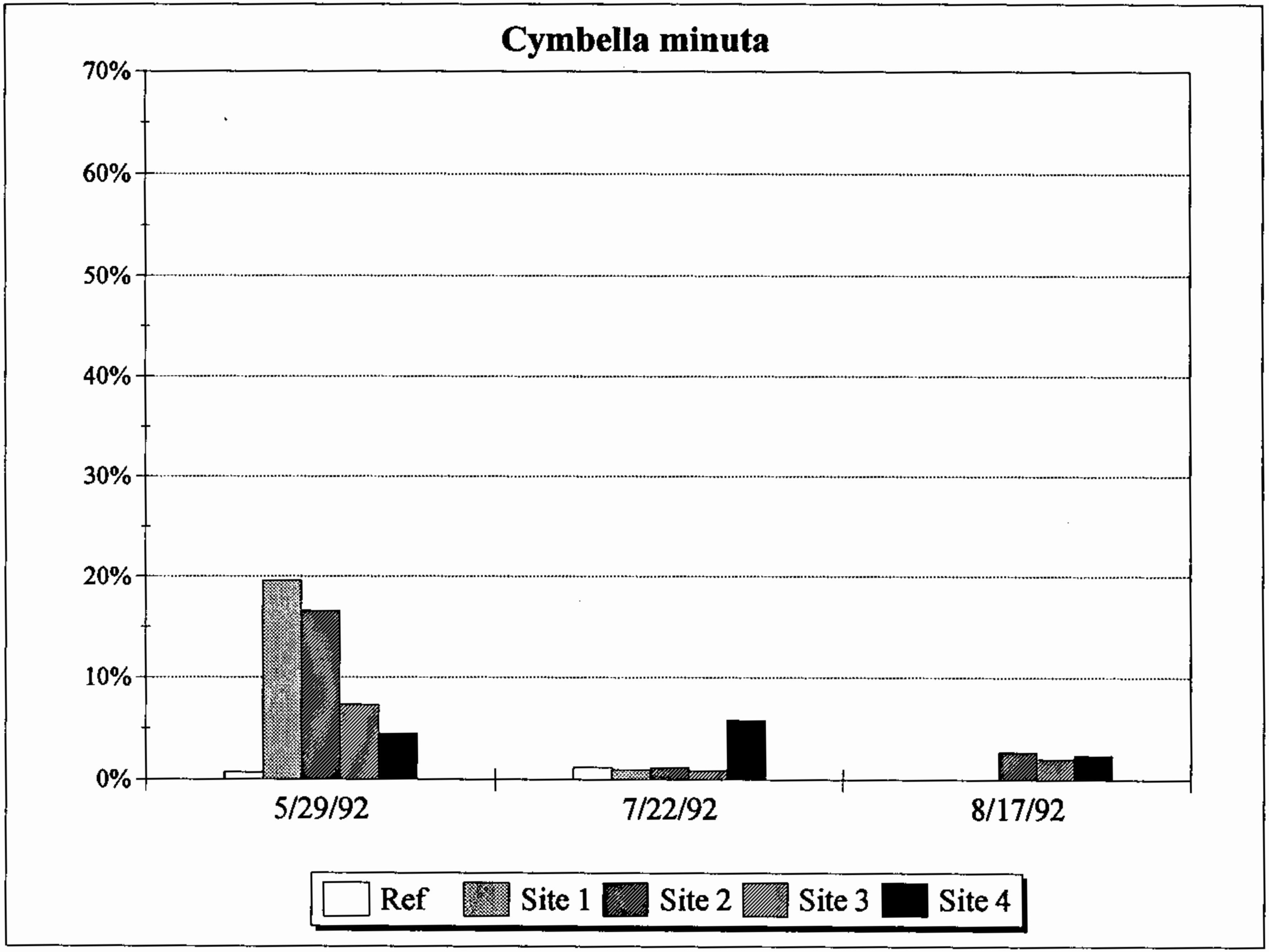

Cymbella minuta
70%
60%
50%
40%
30%
20%
10%
0%
5/29/92
7/22/92
8/17/92
Ref
Site 1
Site 2
Site 3
Site 4

FIGURE 38

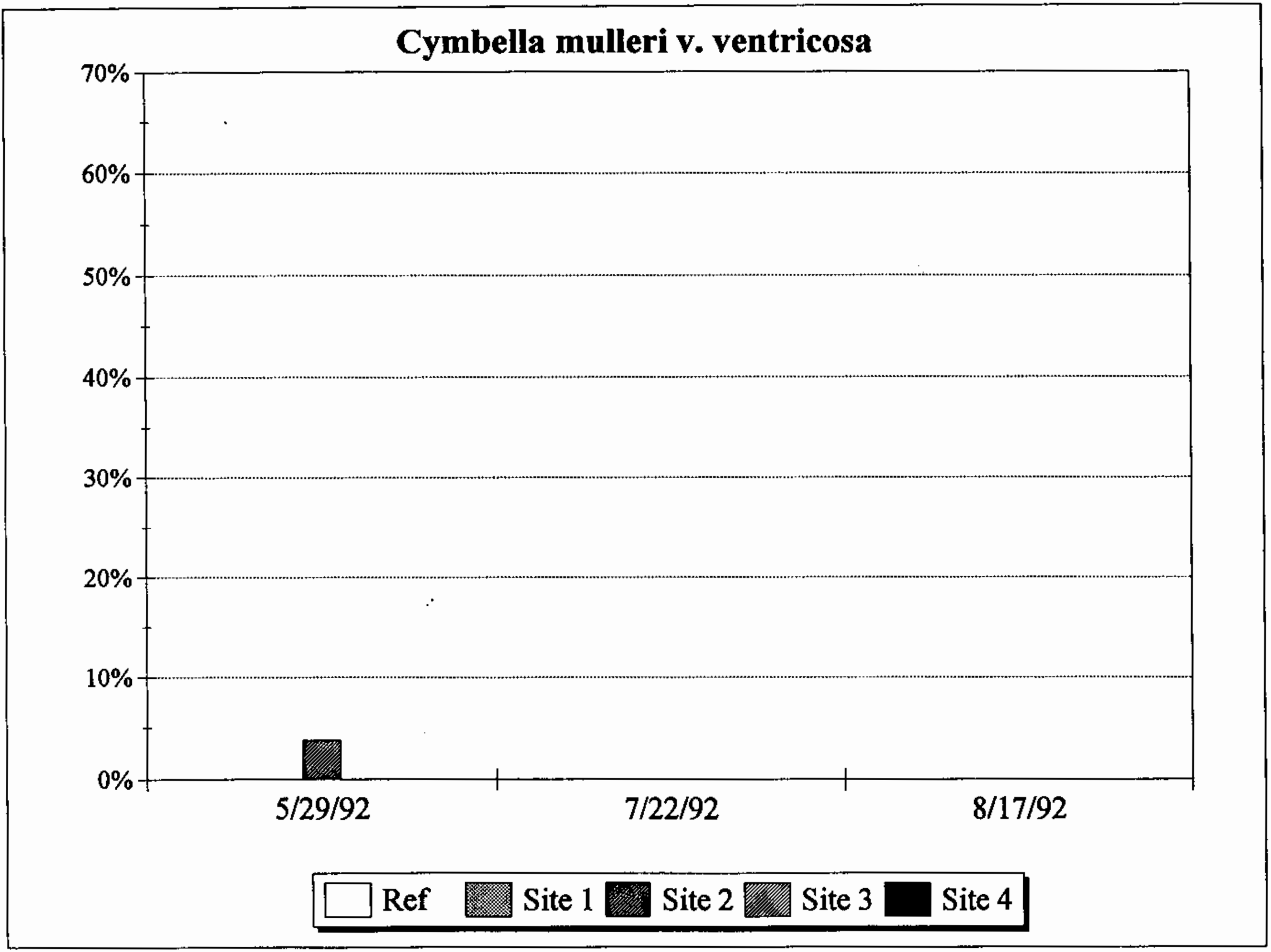

Cymbella mulleri v. ventricosa
70%
60%
50%
40%
30%
20%
10%
0%
5/29/92
7/22/92
8/17/92
☐ Ref
▨ Site 1
▨ Site 2
▨ Site 3
■ Site 4

FIGURE 39

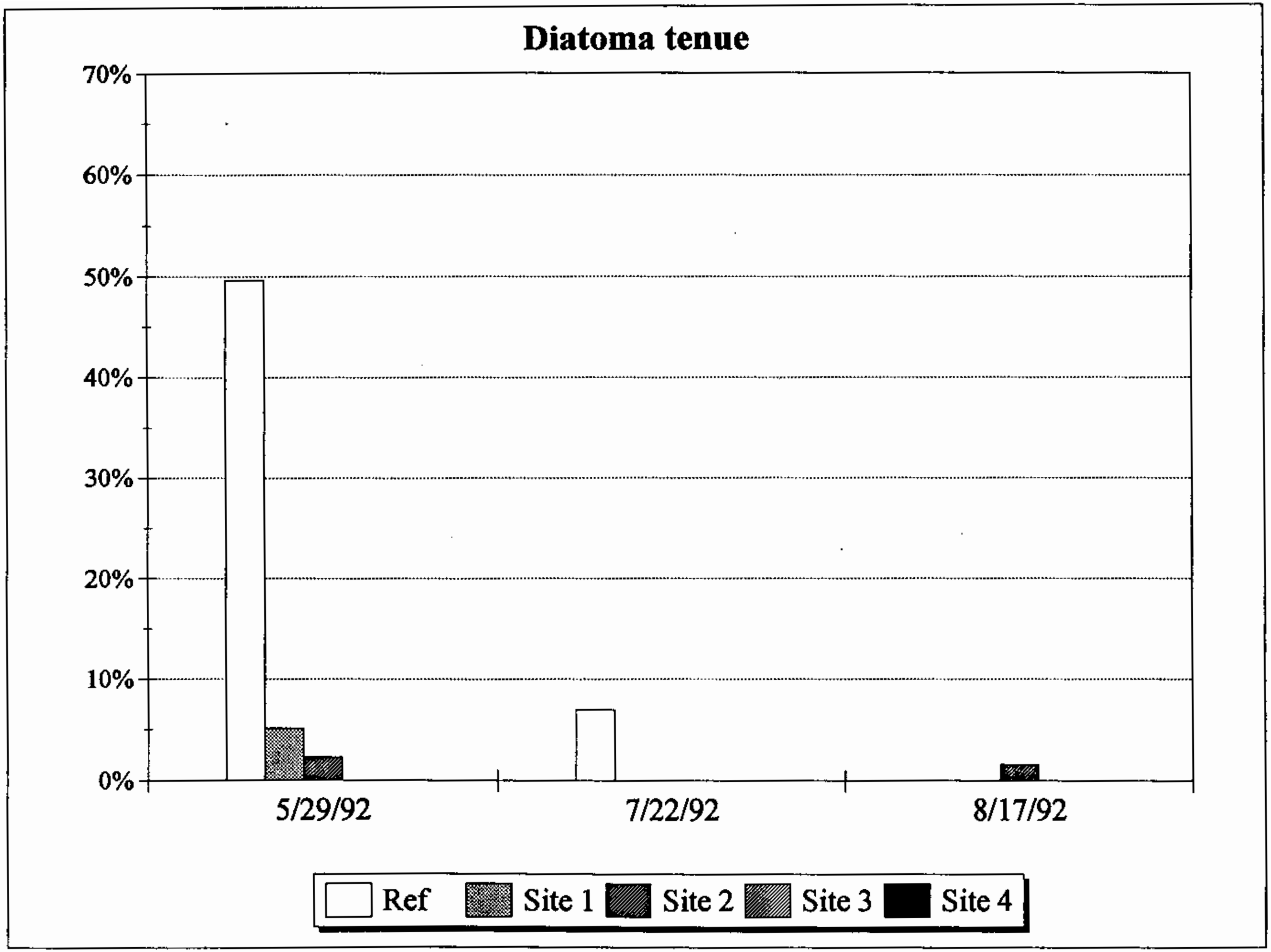

Diatoma tenue
70%
60%
50%
40%
30%
20%
10%
0%
5/29/92
7/22/92
8/17/92
Ref
Site 1
Site 2
Site 3
Site 4

FIGURE 40

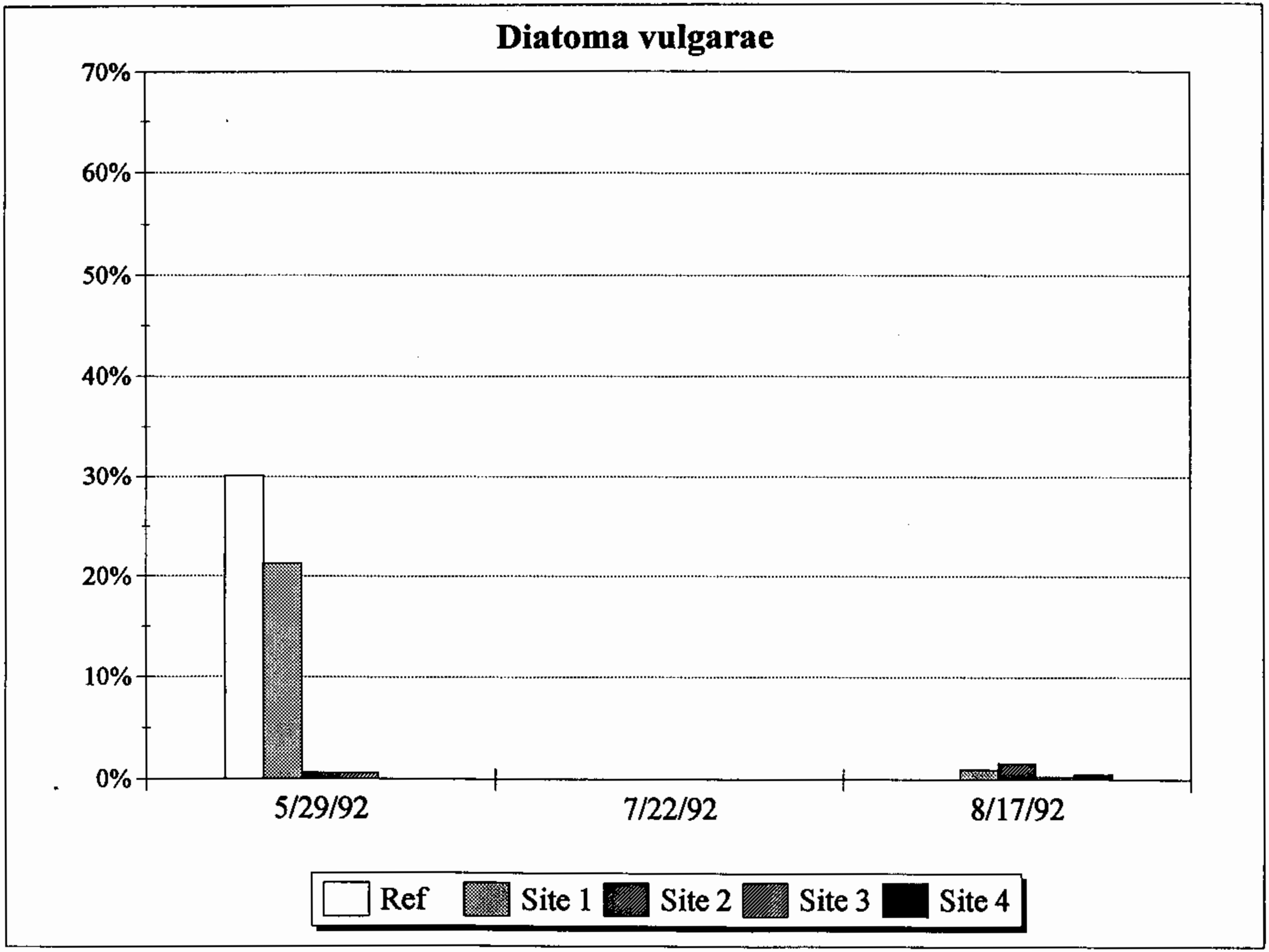

Diatoma vulgarae
70%
60%
50%
40%
30%
20%
10%
0%
5/29/92
7/22/92
8/17/92
Ref
Site 1
Site 2
Site 3
Site 4

FIGURE 41

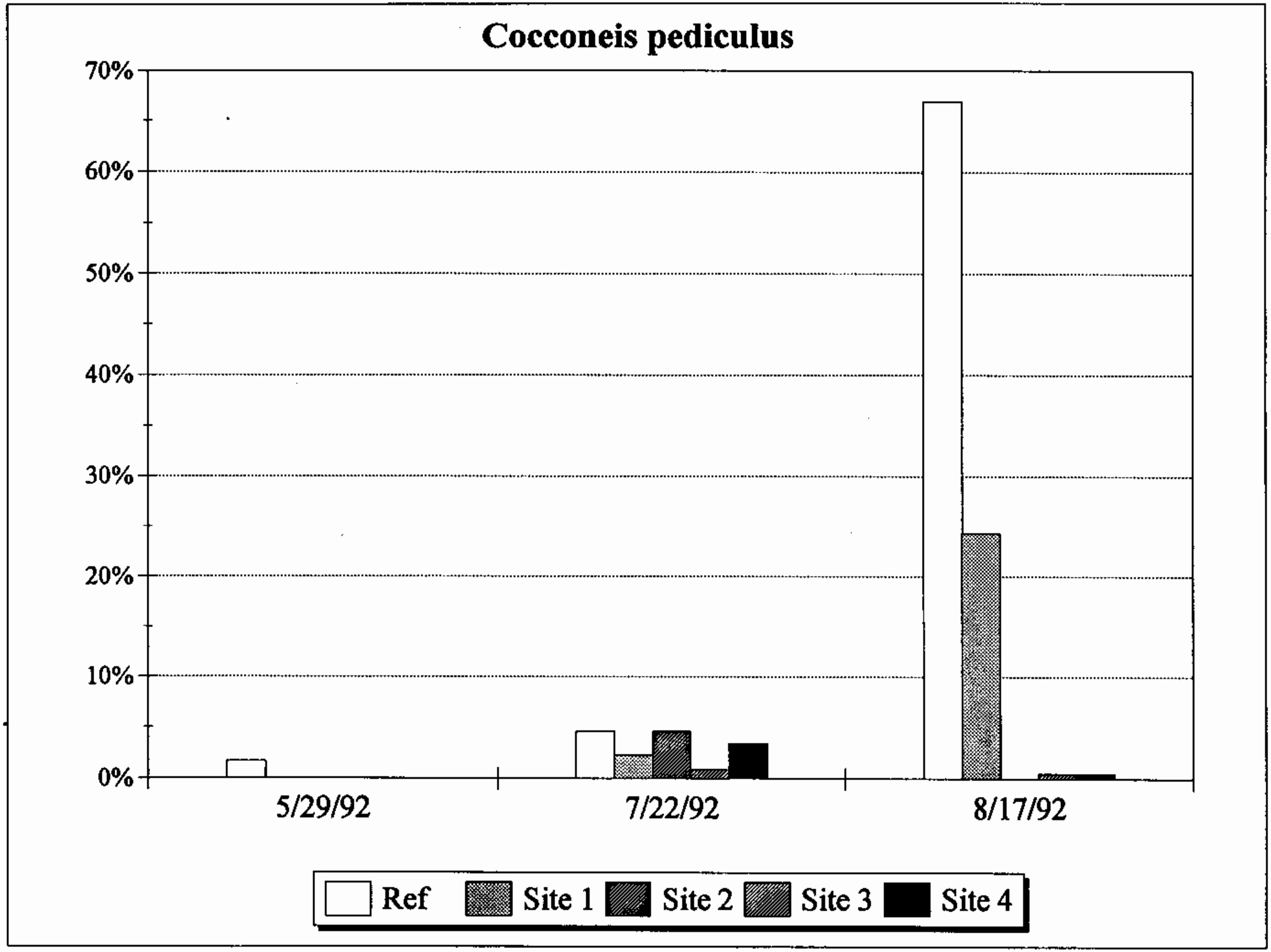
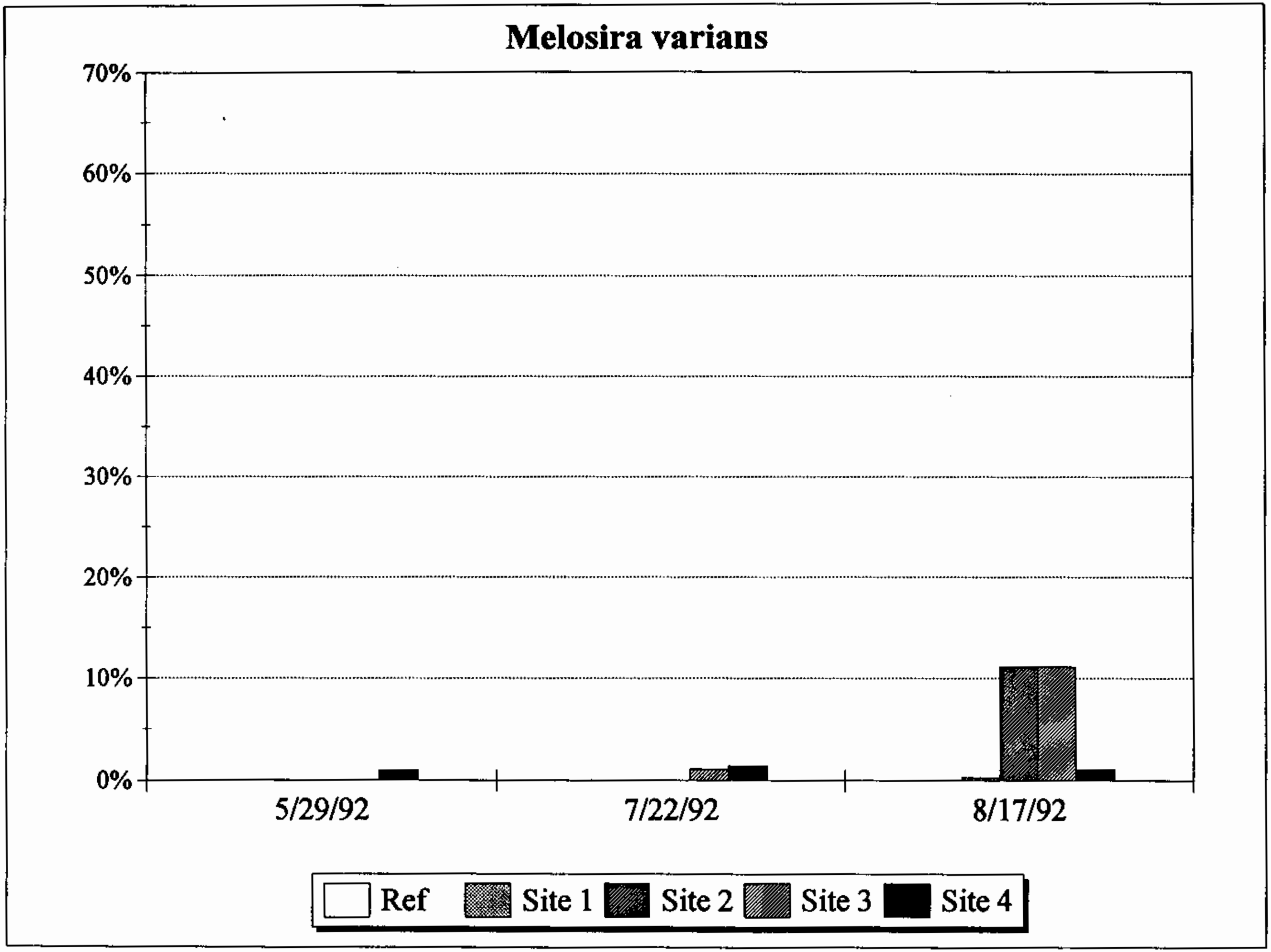
Cocconeis pediculus
70%
60%
50%
40%
30%
20%
10%
0%
5/29/92
7/22/92
8/17/92
Ref
Site 1
Site 2
Site 3
Site 4

FIGURE 42


Melosira varians
70%
60%
50%
40%
30%
20%
10%
0%
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7/22/92
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Site 1
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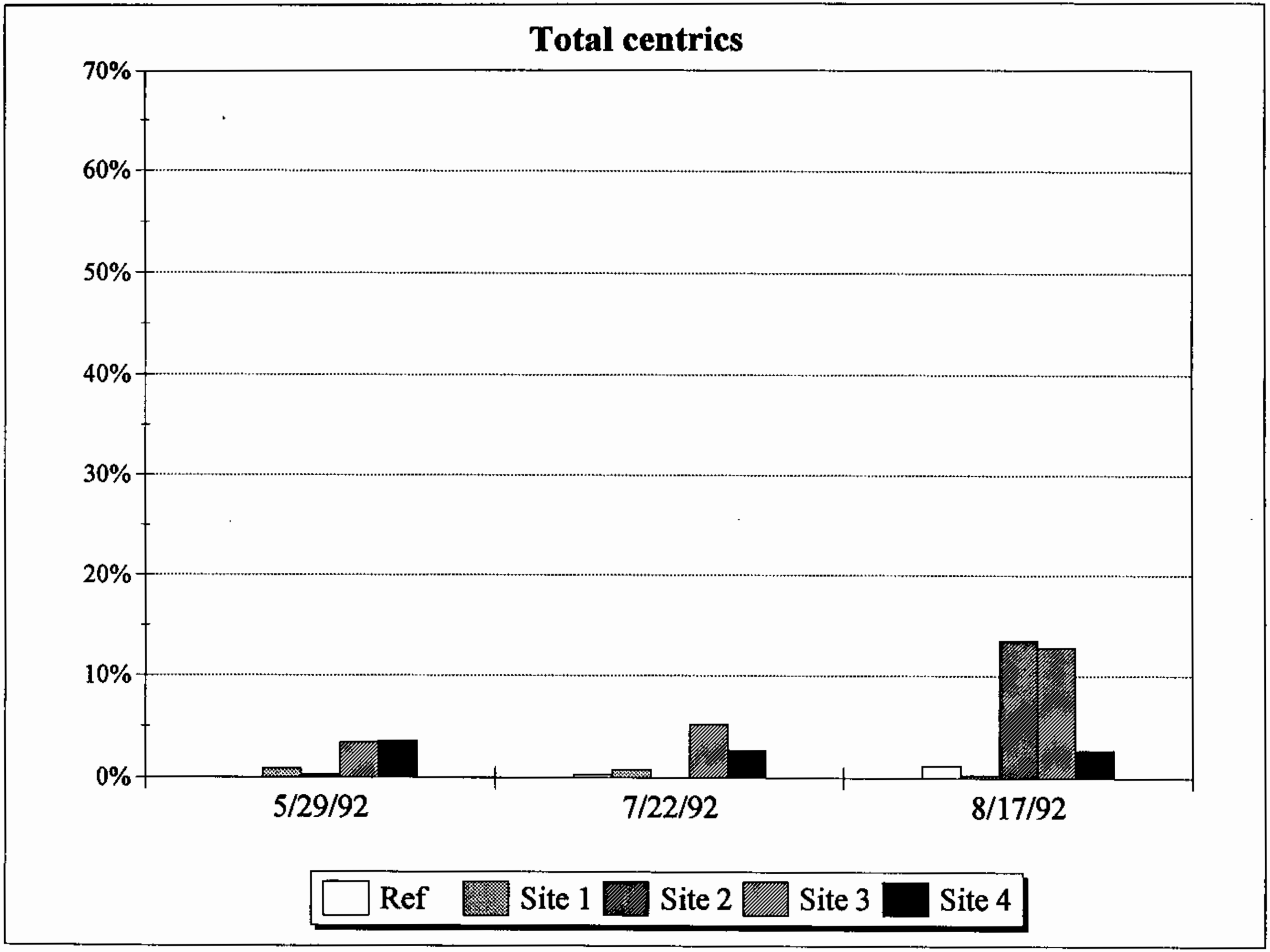
FIGURE 43


Total centrics
70%
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50%
40%
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7/22/92
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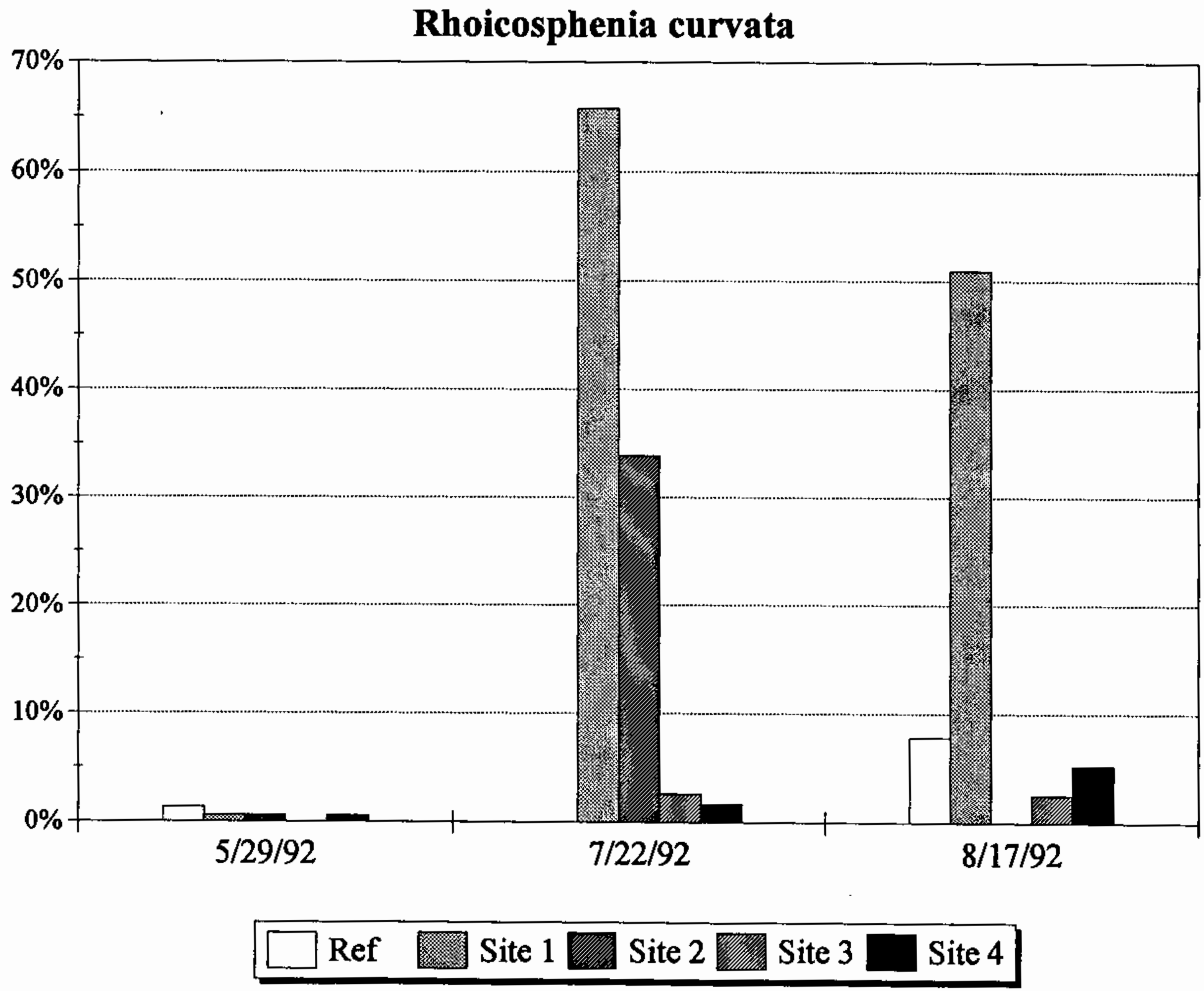
FIGURE 44


Rhoicosphenia curvata
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Site 1
Site 2
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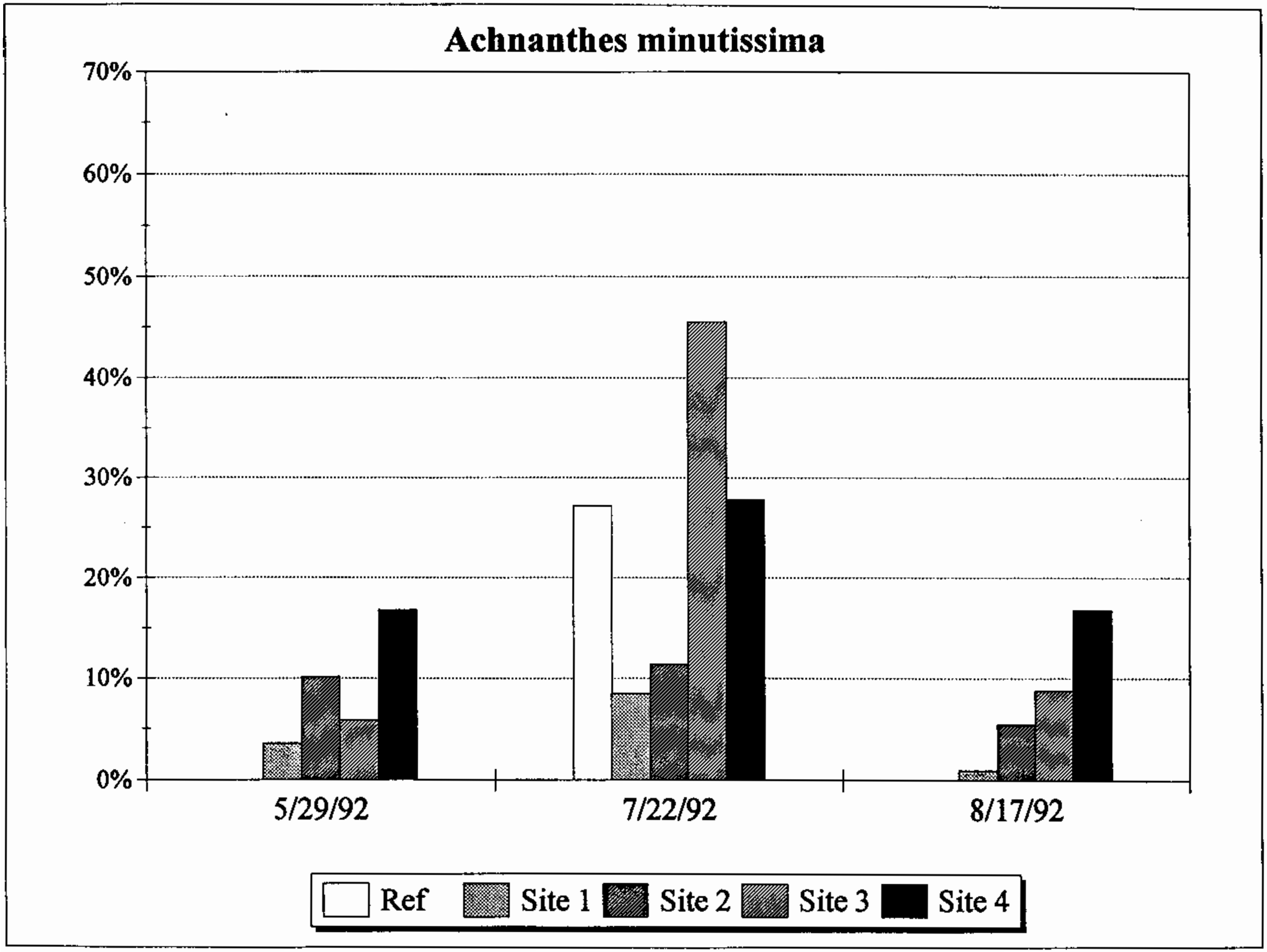
Site 4

FIGURE 45


Achnanthes minutissima
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20%
10%
0%
5/29/92
7/22/92
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Site 1
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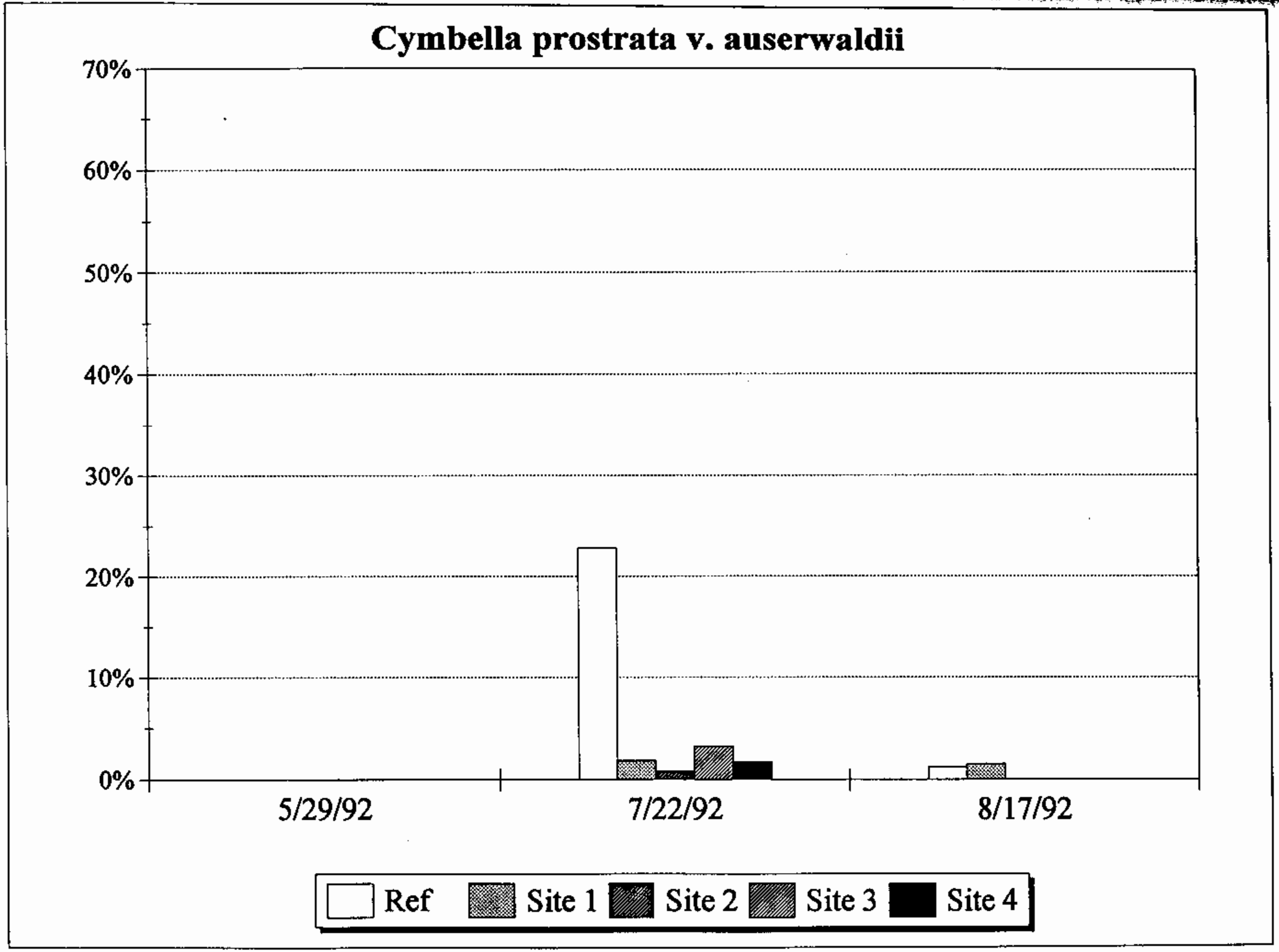
Site 4

FIGURE 46


Cymbella prostrata v. auserwaldii
70%
60%
50%
40%
30%
20%
10%
0%
5/29/92
7/22/92
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Ref
Site 1
Site 2
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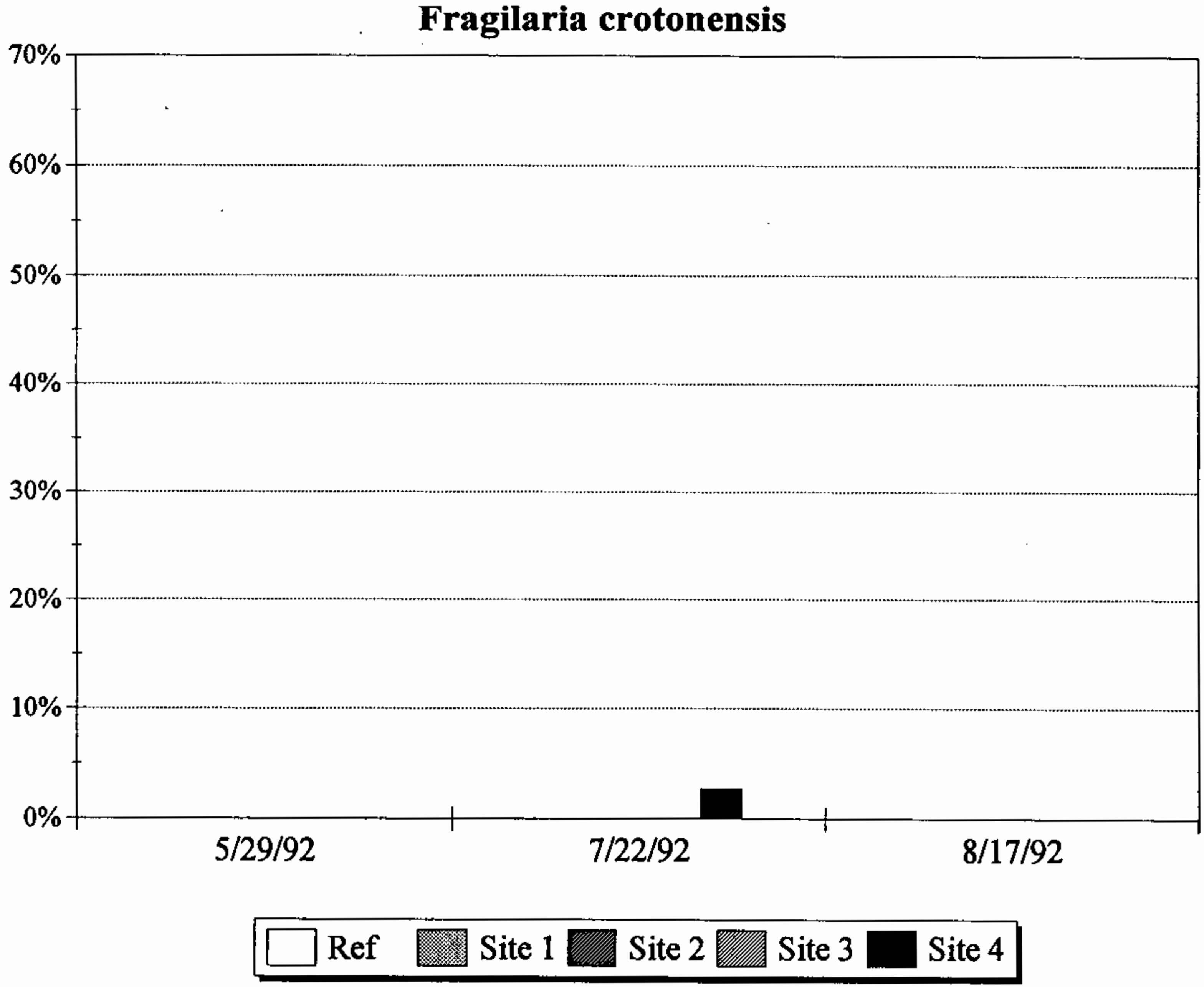
Site 4

FIGURE 47


Fragilaria crotonensis
70%
60%
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10%
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5/29/92
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☐ Ref
▨ Site 1
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■ Site 4

FIGURE 48

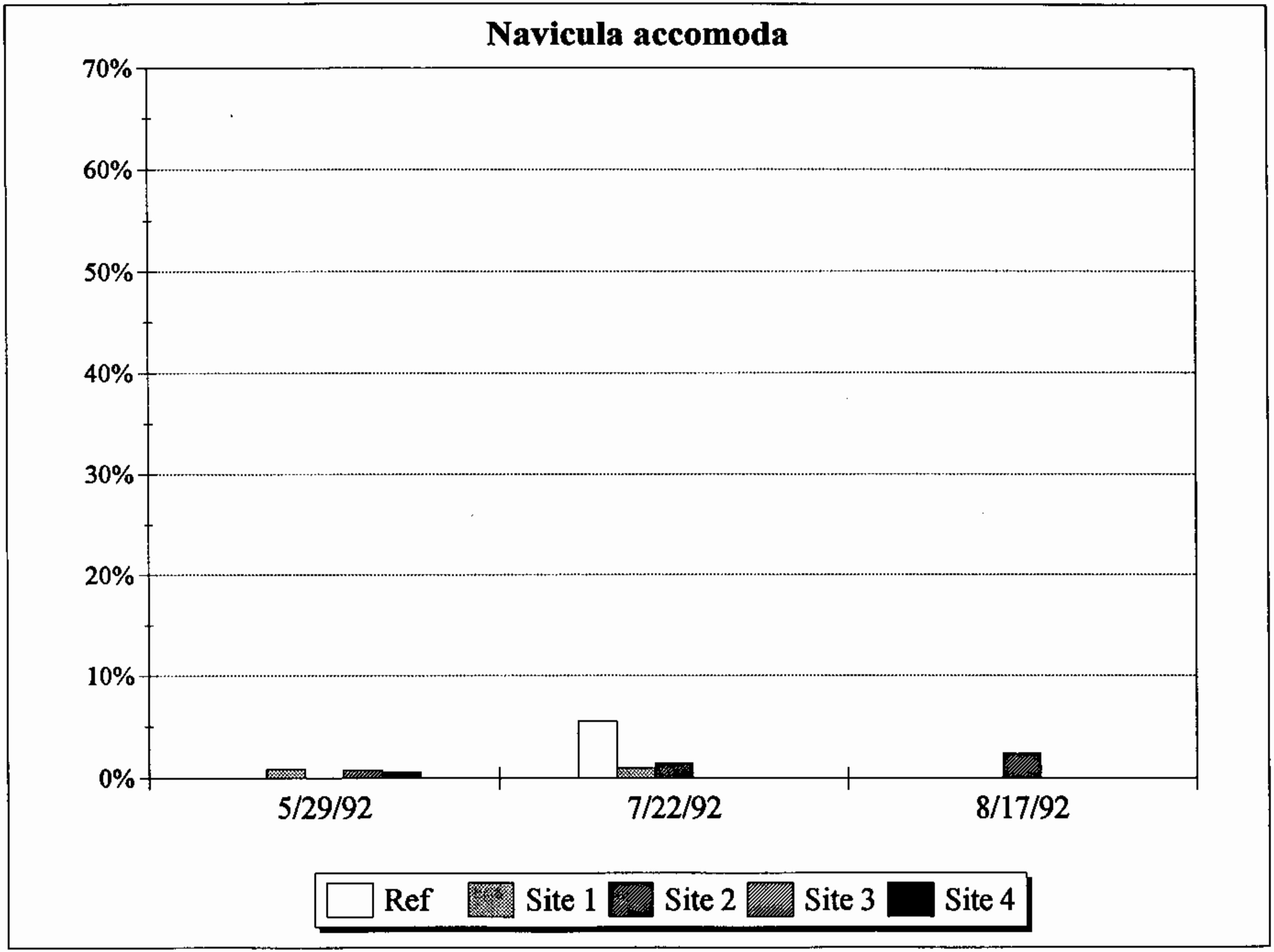
Navicula accomoda
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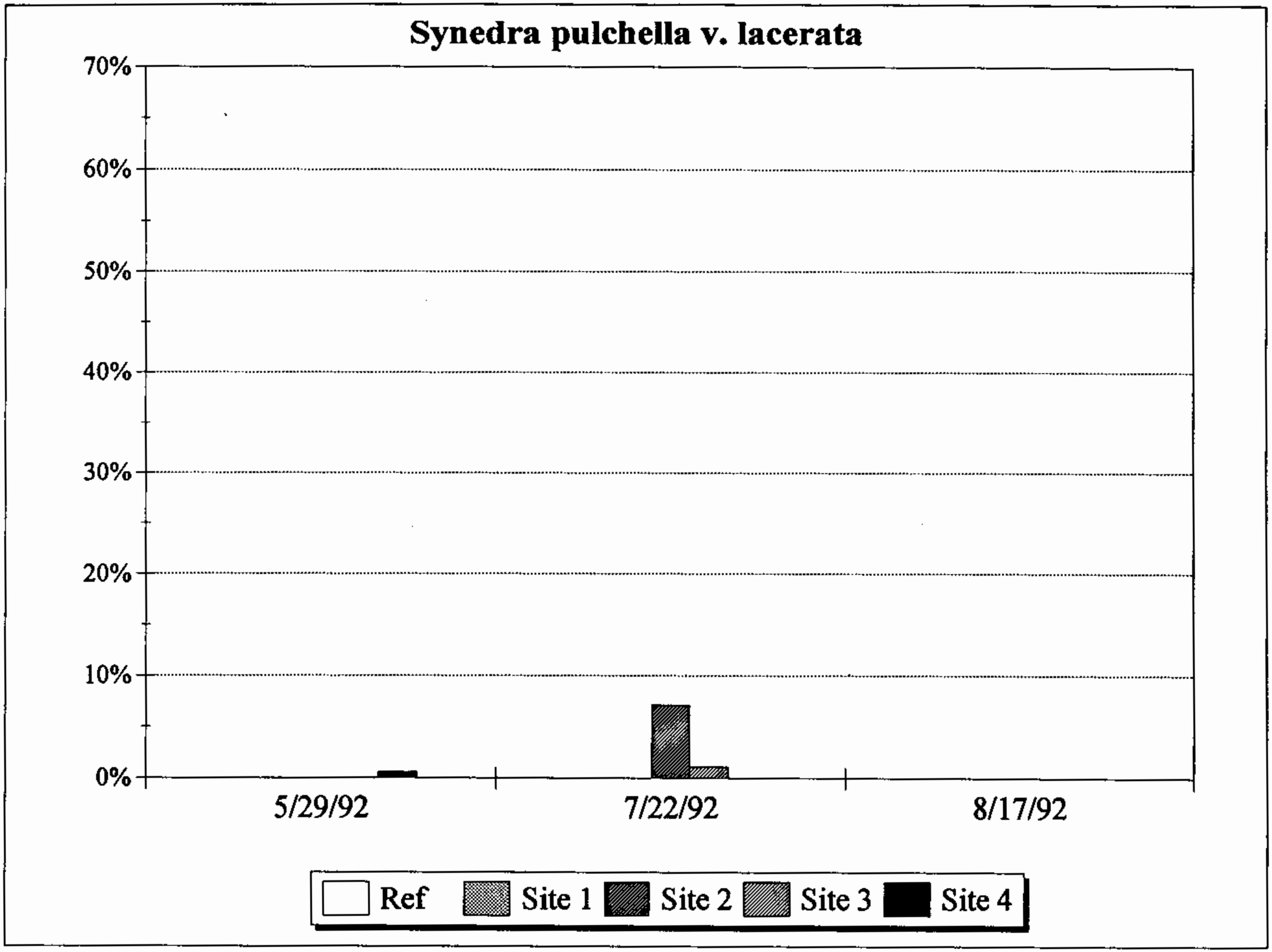
FIGURE 49


Synedra pulchella v. lacerata
70%
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40%
30%
20%
10%
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5/29/92
7/22/92
8/17/92
Ref
Site 1
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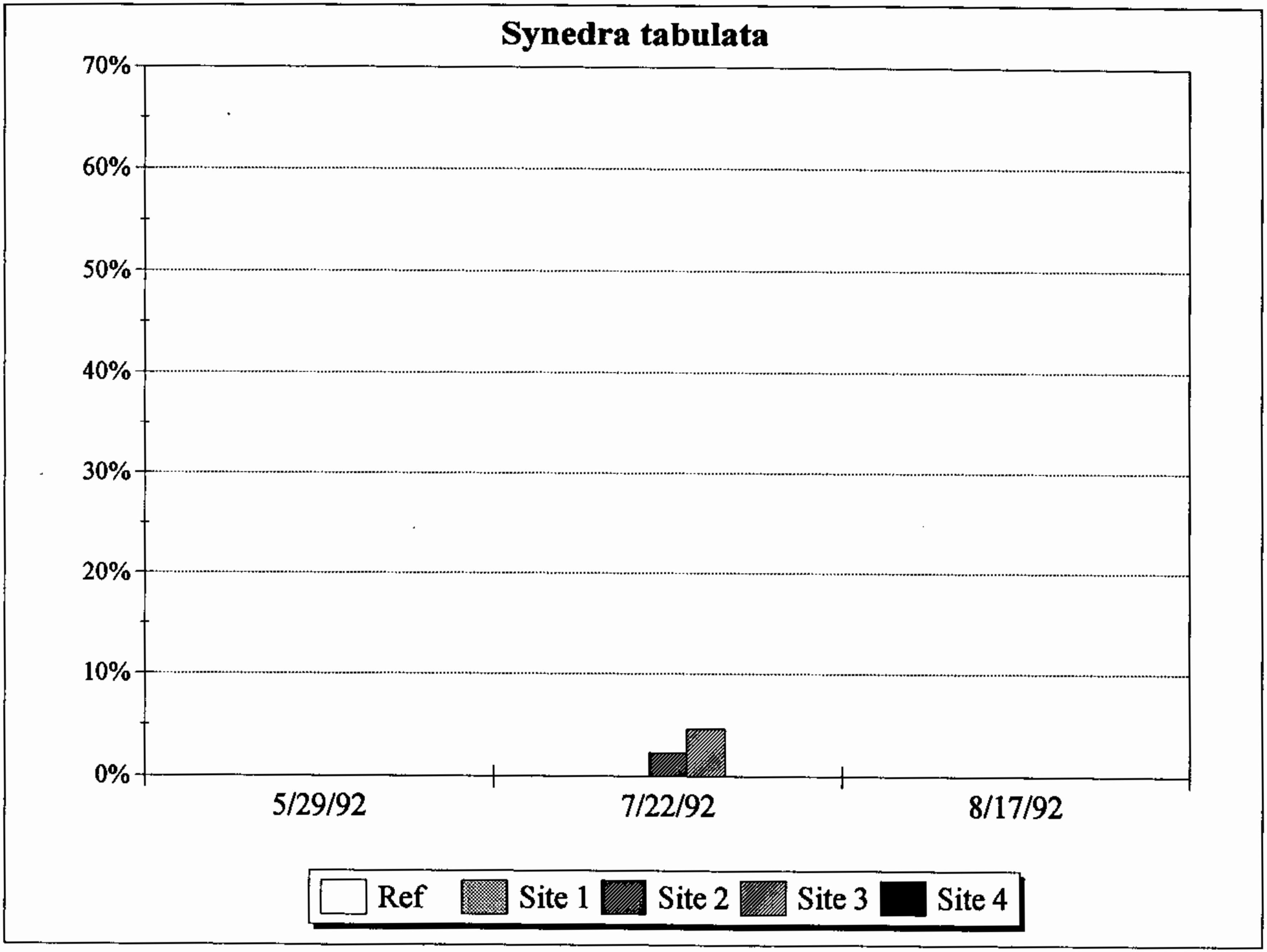
Site 4

FIGURE 50


Synedra tabulata
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10%
0%
5/29/92
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Site 1
Site 2
Site 3
Site 4

FIGURE 51

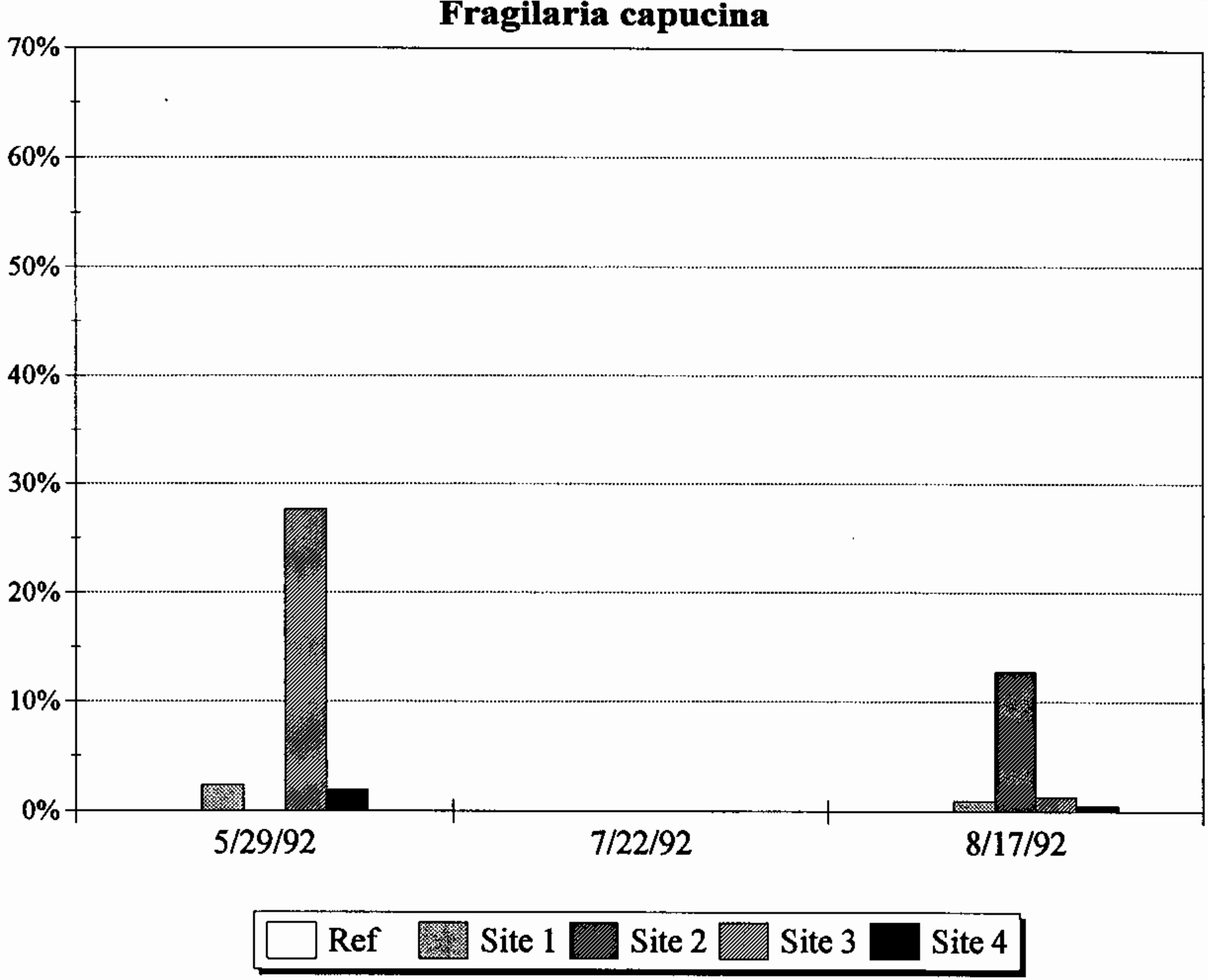

Fragilaria capucina
70%
60%
50%
40%
30%
20%
10%
0%
5/29/92
7/22/92
8/17/92
Ref
Site 1
Site 2
Site 3
Site 4

FIGURE 52

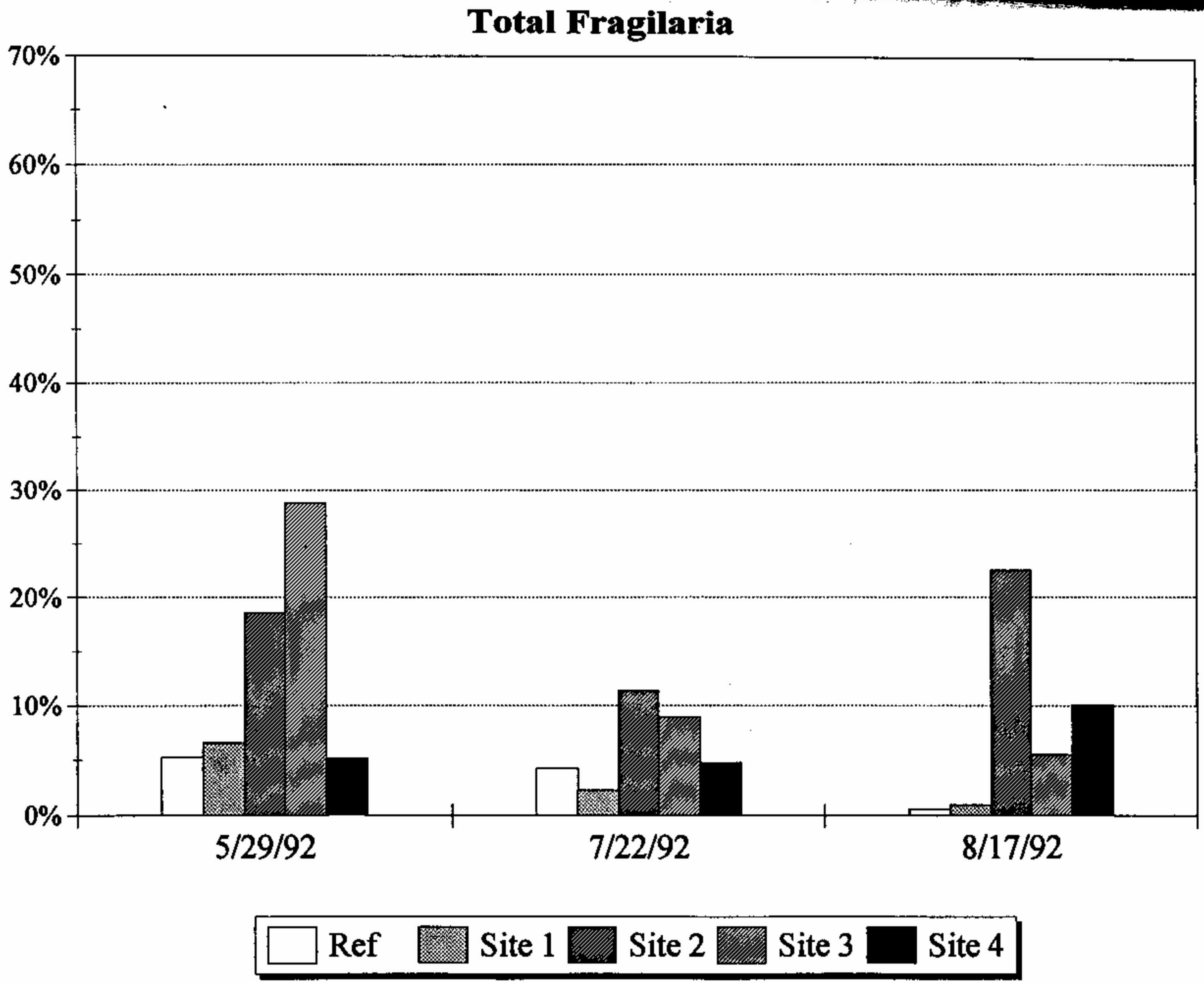

Total Fragilaria
70%
60%
50%
40%
30%
20%
10%
0%
5/29/92
7/22/92
8/17/92
Ref
Site 1
Site 2
Site 3
Site 4

FIGURE 53

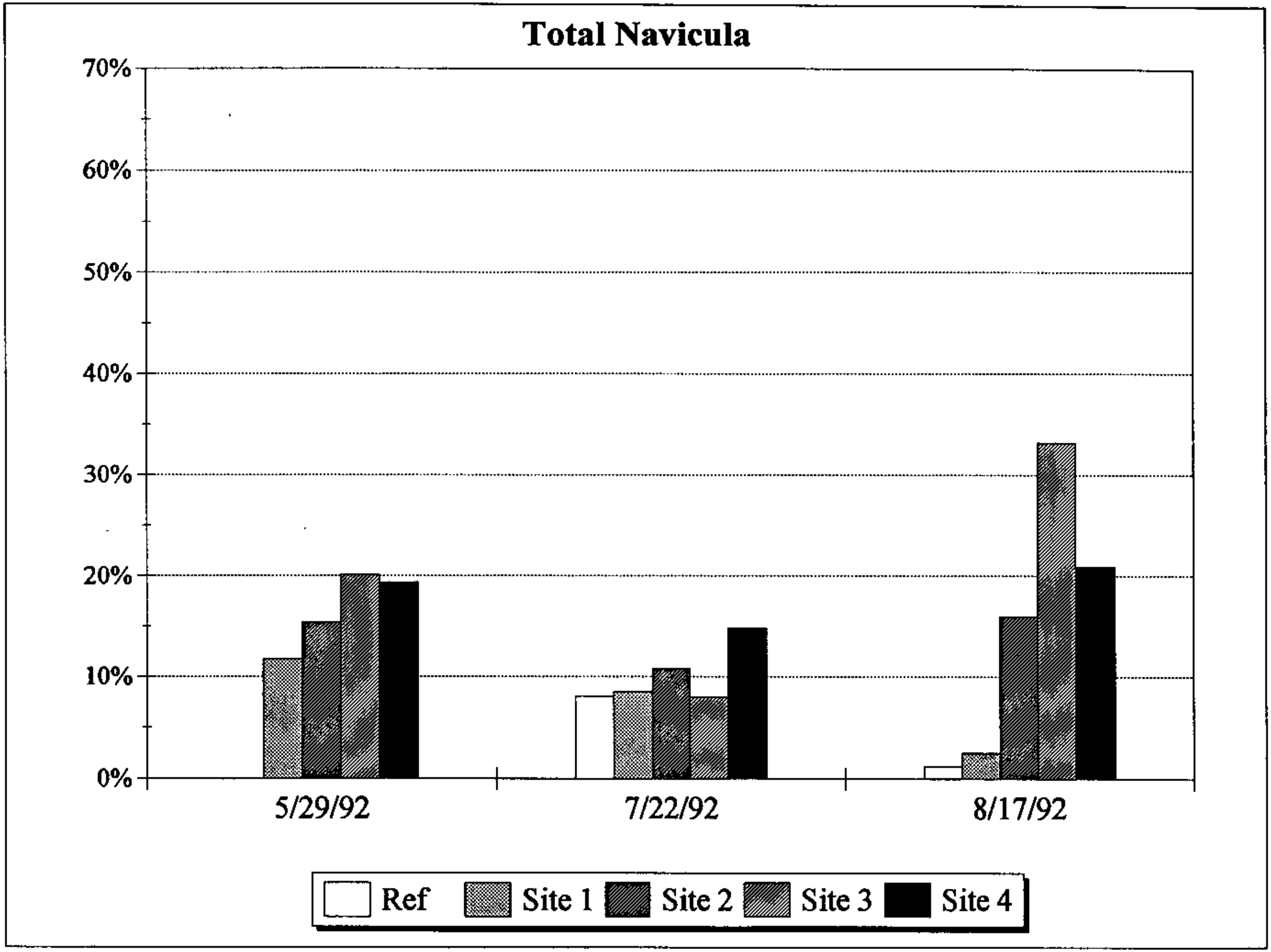
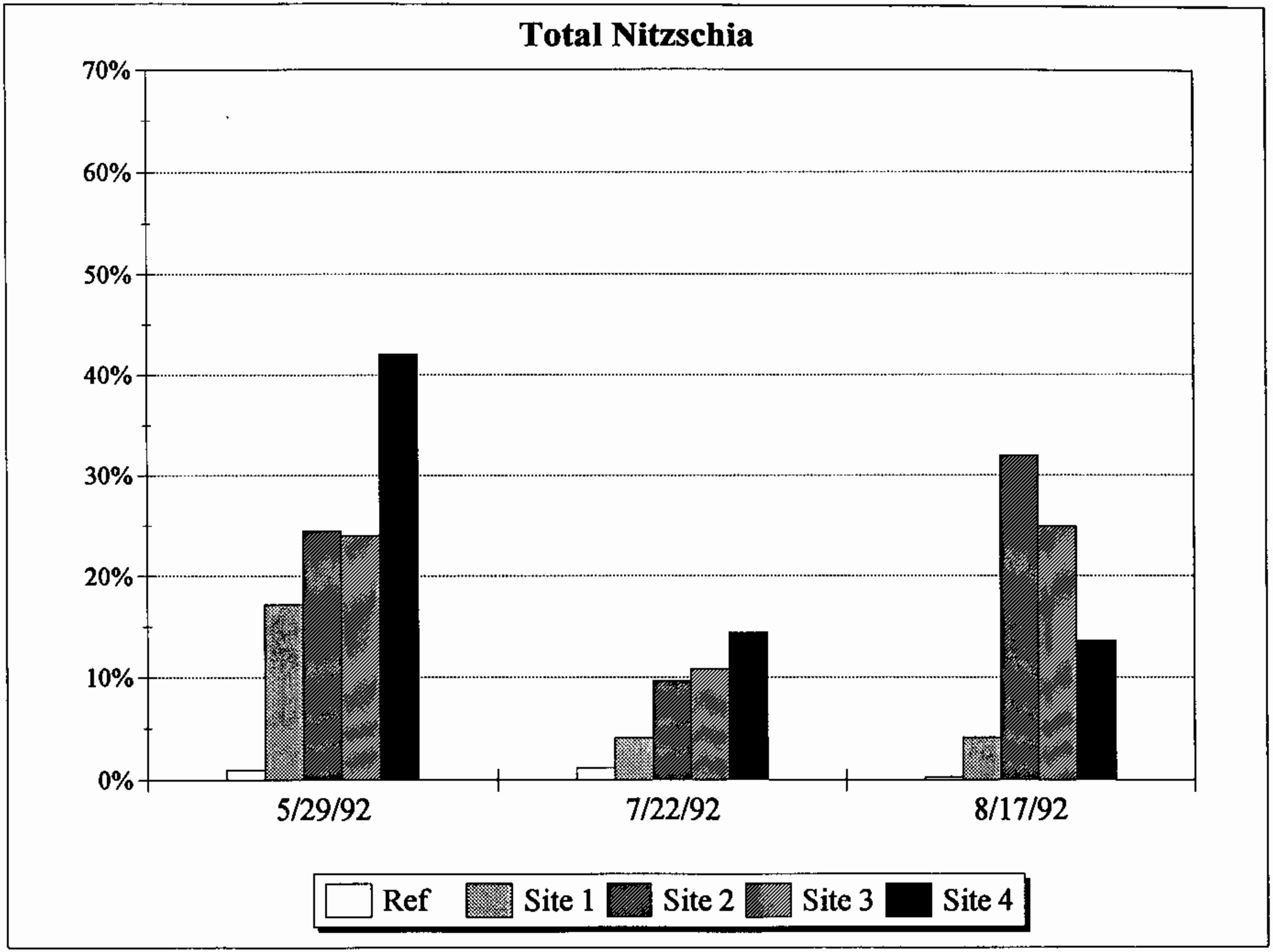

Total Navicula
70%
60%
50%
40%
30%
20%
10%
0%
5/29/92
7/22/92
8/17/92
Ref
Site 1
Site 2
Site 3
Site 4

FIGURE 54


Total Nitzschia
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60%
50%
40%
30%
20%
10%
0%
5/29/92
7/22/92
8/17/92
Ref
Site 1
Site 2
Site 3
Site 4

FIGURE 55

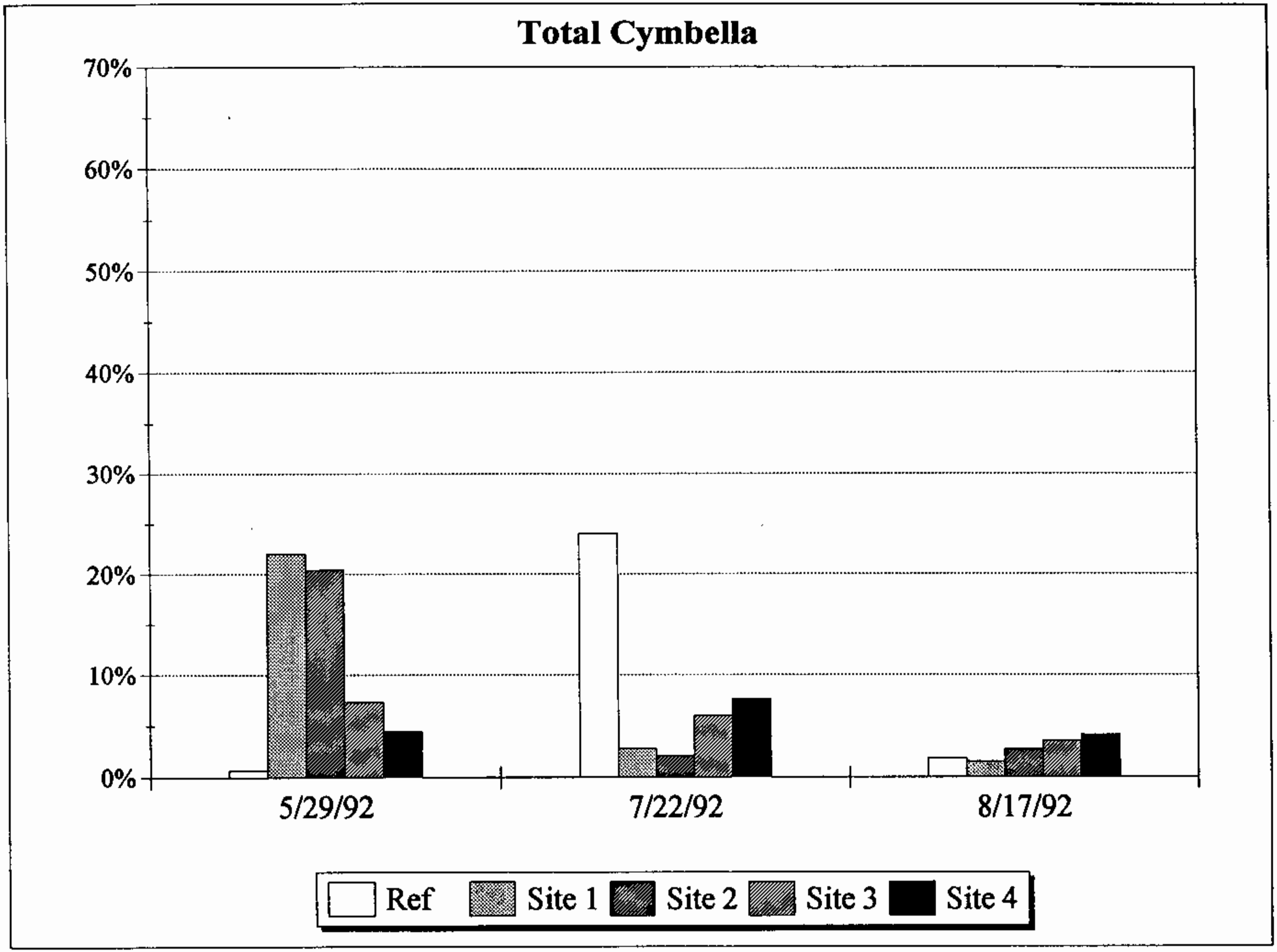
Total Cymbella
70%
60%
50%
40%
30%
20%
10%
0%
5/29/92
7/22/92
8/17/92
Ref
Site 1
Site 2
Site 3
Site 4

FIGURE 56

MACROALGAE

Reference site in Lake Erie - concrete substrate

5/29/92	Short filaments of *Cladophora* dominant
7/22/92	Longer filaments of *Cladophora* dominant, also *Ulothrix*
8/17/92	*Cladophora* filaments dominant, also *Oscillatoria* and *Bangia*

Site 1 - concrete substrate

5/29/92	*Cladophora* dominant, also *Oscillatoria*
7/22/92	*Cladophora* dominant, also *Oscillatoria*
8/17/92	*Cladophora* dominant, also *Oscillatoria*

Site 2 - concrete substrate

5/29/92	No macroalgae abundant, a few *Oscillatoria*
7/22/92	Few macroalgae, some *Oscillatoria* and *Ulothrix*
8/17/92	Few macroalgae, some *Spirogyra*

Site 3 - steel substrate

5/29/92	Few macroalgae, some *Oscillatoria*
7/22/92	Few macroalgae, some *Oscillatoria*, *Spirogyra*
8/17/92	*Spirogyra* abundant

Site 4 - steel substrate

5/29/92	Macroalgae not abundant, some *Oscillatoria* and other blue-green filaments
7/22/92	*Oscillatoria* dominant
8/17/92	*Spirogyra* dominant, also *Vaucheria*

The main pattern observed in the macroalgae is the restriction of *Cladophora* to the RS and Site 1. This genus is clearly a Lake form which is most abundant along the lakeshore and in the lowest reach of the River. Site 1 represents a transition point between the Lake and River. Because Lake water is sometimes pushed upriver by strong winds and seiches, some life forms which are primarily Lake residents appear in this almost "tidal" zone.

Present at all sites was the blue-green *Oscillatoria*. This genus is a common component of many attached algal communities. It was not present in large amounts and therefore does not appear to suggest nutrient enriched conditions (nutrient enriched waters often are characterized by excessive growths of blue-green algae).

The remaining filamentous algae are widely distributed in fresh waters and therefore do not provide specific insights into environmental conditions. They are not, however, specifically characteristic of nutrient enriched or polluted environments.

MICROALGAE

Reference Site in Lake Erie

5/29/92	
7/22/92	*Pediastrum*, *Scenedesmus*, *Tetradron*
8/17/92	

Site 1

5/29/92	
7/22/92	
8/17/92	

Site 2

5/29/92	*Pediastrum*, *Scenedesmus*
7/22/92	
8/17/92	*Closterium*

Site 3

5/29/92	*Ankistrodesmus*, *Cosmarium*, *Pediastrum*, *Scenedesmus*
7/22/92	*Scenedesmus*
8/17/92	

Site 4

5/29/92	*Pediastrum*, *Scenedesmus*
7/22/92	
8/17/92	*Pediastrum*, *Scenedesmus*

The microalgae present in the attached samples do not differ significantly between sites or dates. Most appear to be planktonic forms which have become intrained in the matrix of the filamentous macroalgae.

CONCLUSIONS

This study provides the first detailed examination of attached algae, especially diatoms, in the Buffalo River and will serve as a baseline for future studies. Whether 1992 was a typical year for the River seems unlikely, given the unusually large amount of runoff and increased flow rate. The study by Martin (1991) examined diatoms in the uppermost reaches of Cazenovia Creek, a tributary to the Buffalo River. However, the environmental conditions found in Cazenovia Creek differ substantially from the conditions found at the sites in this study.

A number of patterns emerged from the examination of attached algae along an upriver transect from Lake Erie to the joining of Buffalo and Cazenovia Creeks between 5/29/92 and 8/17/92.

One of the most clearly defined patterns was the uniqueness of the RS compared with any of the River Sites. A number of diatom species were either abundant at the RS and uncommon upriver or were uncommon at the RS and abundant upriver. This would be expected because of the different nature of the environmental conditions, including water chemistry, water clarity, and water movement among others, found in the Lake and the River.

A second clear pattern was the similarity of Site 1 at the lower end of the River to the Reference Site in Lake Erie just outside the breakwall. The abundance of the attached green alga Cladophora, the similarity of the diatom assemblages and the presence of similar plankton at these two sites clearly differentiated them from Sites 2, 3 and 4 upriver. This pattern can be attributed to the "tidal" nature of the lower River, which often has Lake water pushed upriver by strong winds and seiches.

A third pattern which emerged was a similarity between Sites 2 and 3. These sites had diatoms which were tolerant of waters with higher nutrients and some salt. This pattern also extended to Site 4, but not as consistently.

In general, the attached diatoms found in the Buffalo River are not unusual. As may be expected, they reflect the environmental conditions which currently exist in the River, such as moderately high nutrients and possibly salt. They do not, however, characterize a significantly degraded environment.

During sampling the River water was observed to be very turbid. This turbidity would greatly reduce light penetration into the River and thereby limit photosynthesis. One major byproduct of photosynthesis is oxygen, while another product is algal biomass to be transferred to higher levels of the food chain. An improvement of water transparency could result in additional algal growth. Further study needs to be done to predict whether this enhanced algal growth might consist of desirable forms, such as diatoms and planktonic green algae, or less desirable forms such as filamentous greens or blue-greens.

RECOMMENDATIONS

Future studies of the attached algae of the Buffalo River should probably use artificial substrates. This would eliminate the possible variation introduced by the differences in substrate along the shoreline of the Buffalo River. These substrates would allow sampling which could meaningfully evaluate between duplicate samples at each site and date. Depending on natural substrates did not allow this check on sample variation, because of the extremely heterogeneous distribution of algae on the natural substrates.

Artificial substrates would also allow estimates of biomass and growth rates to be made. Again, these measurements could probably not be done in a meaningful way, given the heterogeneous nature of the natural substrate.

In order to be meaningful in the context of the natural communities in the River, the artificial substrates should be made of materials which are typical of the River shoreline, such as weathered concrete, rather than the standard glass slides.

The continued use of the Reference Site needs to be evaluated. This Site did provide useful information for interpreting the algae found at Site 1, in the lowest region of the River. Site 1 was found to be a transition site between River and Lake communities. Given this knowledge, it may be desirable to continue sampling the RS as a comparison with Site 1.

REFERENCES

Martin, W. C. 1991. Diatom Populations in the East Branch of the Cazenovia Creek and in Two Streams That Flow Into It. M.S. in Ed. Project Report. Biology Department, State University of New York College at Buffalo.

Patrick, R. and C. W. Reimer. 1966. The Diatoms of the United States. Vol. 1. Academy of Natural Sciences of Philadelphia. Monogr. No. 13. Philadelphia, PA.

______________________________. 1975. The Diatoms of the United States. Vol. 2. Part 1. Academy of Natural Sciences of Philadelphia. Monogr. No. 13. Philadelphia, PA.

PART III: Physical Characteristics of Bank and Channel

SHORELINE MAP AND VIDEO

A digitized basemap was prepared using the U.S. Army Corps of Engineers (COE) sounding charts and Intergraph Software. The basemap was generated in conjunction with the determination of sediment trends and was accomplished by GeoSea Consulting (P. McLaren).

Shoreline features were mapped in the Fall 1991 and reviewed for completeness during the Summer 1992. Videotape documentation of the river banks also were obtained during this same period. Seven physical characteristics were used to describe the shoreline: concrete embankment (1); wooden pilings or dock (2); steel wall (3); sand/gravel (4); hardfill with large rubble (5); vegetation with rubble (6); and vegetation with brush/trees (7). The numbers are combined with the letter A, B, C to represent shoreline type(s) and bank gradient; A indicating a 90° wall, B indicating a moderate to steep gradient, and C indicating a gentle to moderate gradient. Using this combination scheme, shorelines characterized as 6C or 7C (vegetation and gentle to moderate gradient) have the greatest potential for habitat restoration/improvement. The shorelines in the meander known as the "Blue Tower Turning Basin" and opposite the Mobil Storage facility appear to have physical characteristics and bank gradients that hold greatest promise.

Because shoreline features were mapped with reference to COE transect numbers (painted on bulkheading or buildings) and using COE sounding charts, the upper limit of the basemap corresponds to COE chart #6. The physical characteristics map is provided with this report (Insert A). Copies of the videotapes of the shoreline are available upon request.

BOTTOM MORPHOLOGY DETERMINED BY SIDE-SCAN SONAR[*]

INTRODUCTION

Sediment bedforms are generated at the sediment-water interface by the interaction of bottom water flow and bottom topography. Thus they can be found in rivers, lakes, and oceans. The dynamics of these sediments bedforms have been widely researched (Allen, 1985) such that it is possible to determine the direction and to some extent the magnitude of the bottom currents that formed them.

A survey was conducted using a dual-frequency side-scan sonar to map the bottom morphology of the Buffalo River in July 1992 and 1993. Previous surveys were conducted in 1990 and 1991. These side-scan surveys were designed to locate all sediment bedforms and monitor their movement up- or downstream. From our analysis of the current dynamics at the sediment-water interface we were able to assess the potential for erosion and deposition of contaminated sediments within the Buffalo River. (Note: Because the water depth must be greater than seven meters in order to tow the sonar, surveys were conducted only within the dredged portions of river, i.e., between the river mouth and Mobil storage facility).

BACKGROUND

Sound has been proven a valuable tool for studying features underwater and, in particular, useful for mapping the river bottom over a large range of spatial scales. Depending in the size of feature on the bottom to be imaged, various acoustical equipment can be employed to achieve the required resolution (or the minimum horizontal distance between adjacent features for each feature to be imaged). For the purposes of this study a short-range side-scan sonar was used, which can resolve lake bottom features less than 1 meter in amplitude and a horizontal separation of a few meters or less.

All sonar systems use returned acoustic energy to form an image of the morphology of the bottom and sub-bottom. A side-scan sonar unit transmits a fan shaped sound beam to either side of the sonar fish instead of directing it downwards in the case of conventional echo sounders (Figure 1). Due to the high frequencies used (100-500 kHz) it only images the surface of the river bottom and does not penetrate significantly into the sediment. This sideways oriented sound beam is narrow in the vertical direction and wide in the direction transverse to the fish track. The strength of the returned sound beam is affected by topography of the sediment surface as well as by differing lithogies and bottom surface roughness. Objects which extend above the bottom having slopes facing the fish will return stronger signals than those slopes which face away. Thus one can utilize this geometry to determine the height of an obstacle off the bottom (Figure 2). Depressions in the bottom would only have the back wall which would reflect energy back to the sonar fish with a shadow zone in front (Figure 3).

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[*] Section compiled by P. Manley and J. Singer

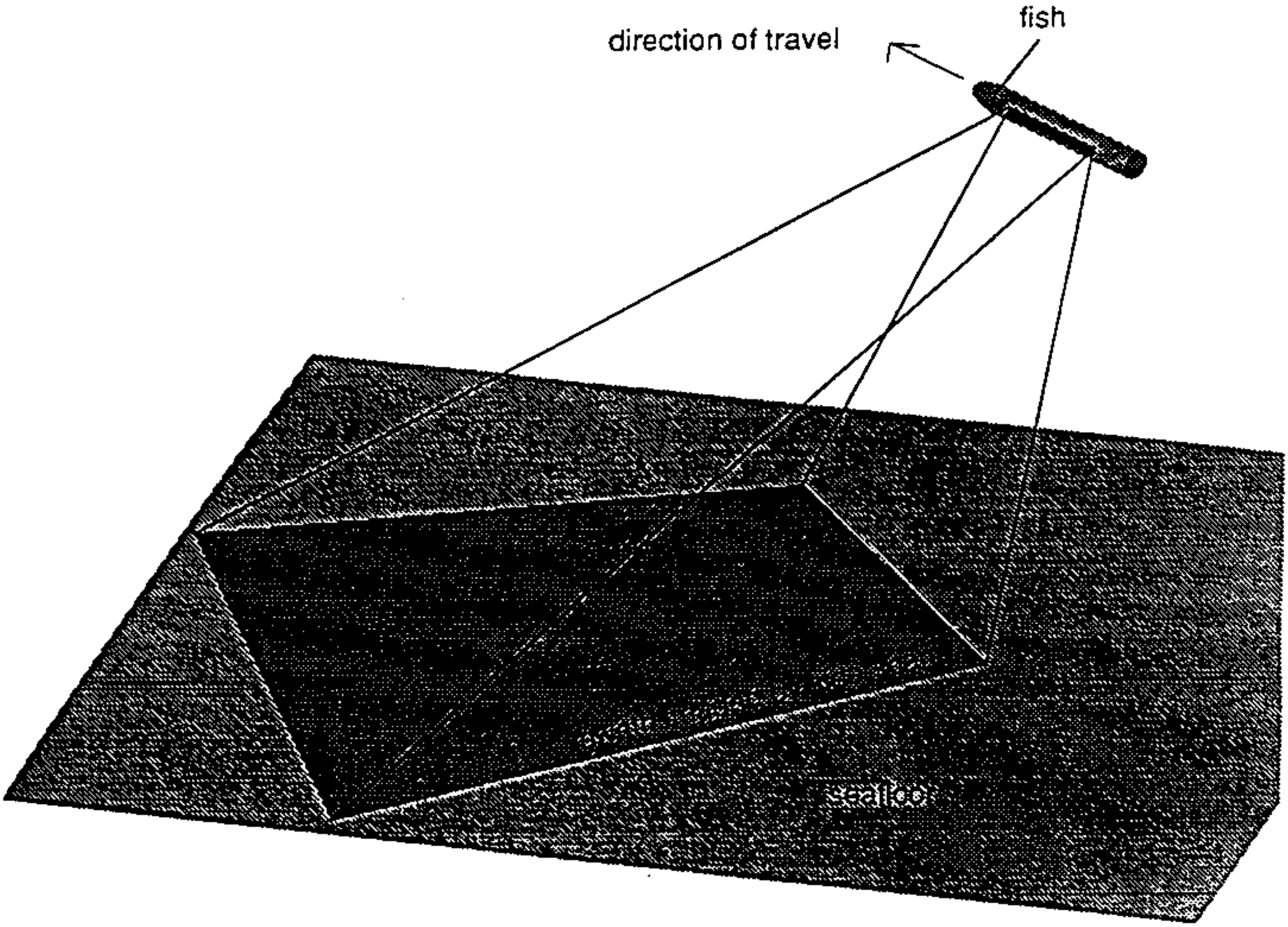


FIGURE 1. Schematic representation of the side-scan sonar energy footprint on the river bottom. This shows only half of the beam width. A similar shaped beam pattern is formed on both sides of the fish.

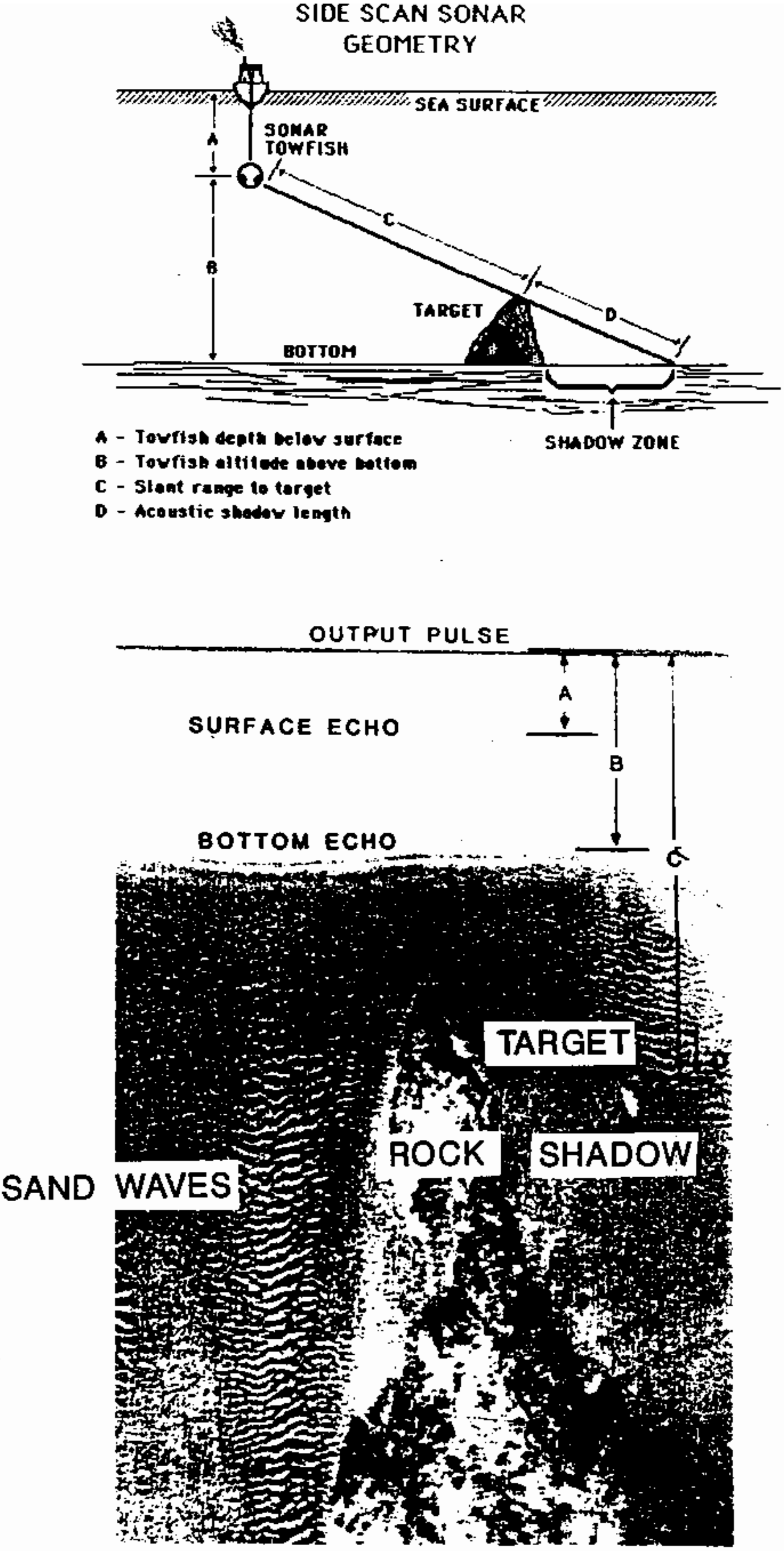


FIGURE 2. Schematic representation of the beam path as it impinges on an obstacle above the river bottom (modified from Klein, 1985).

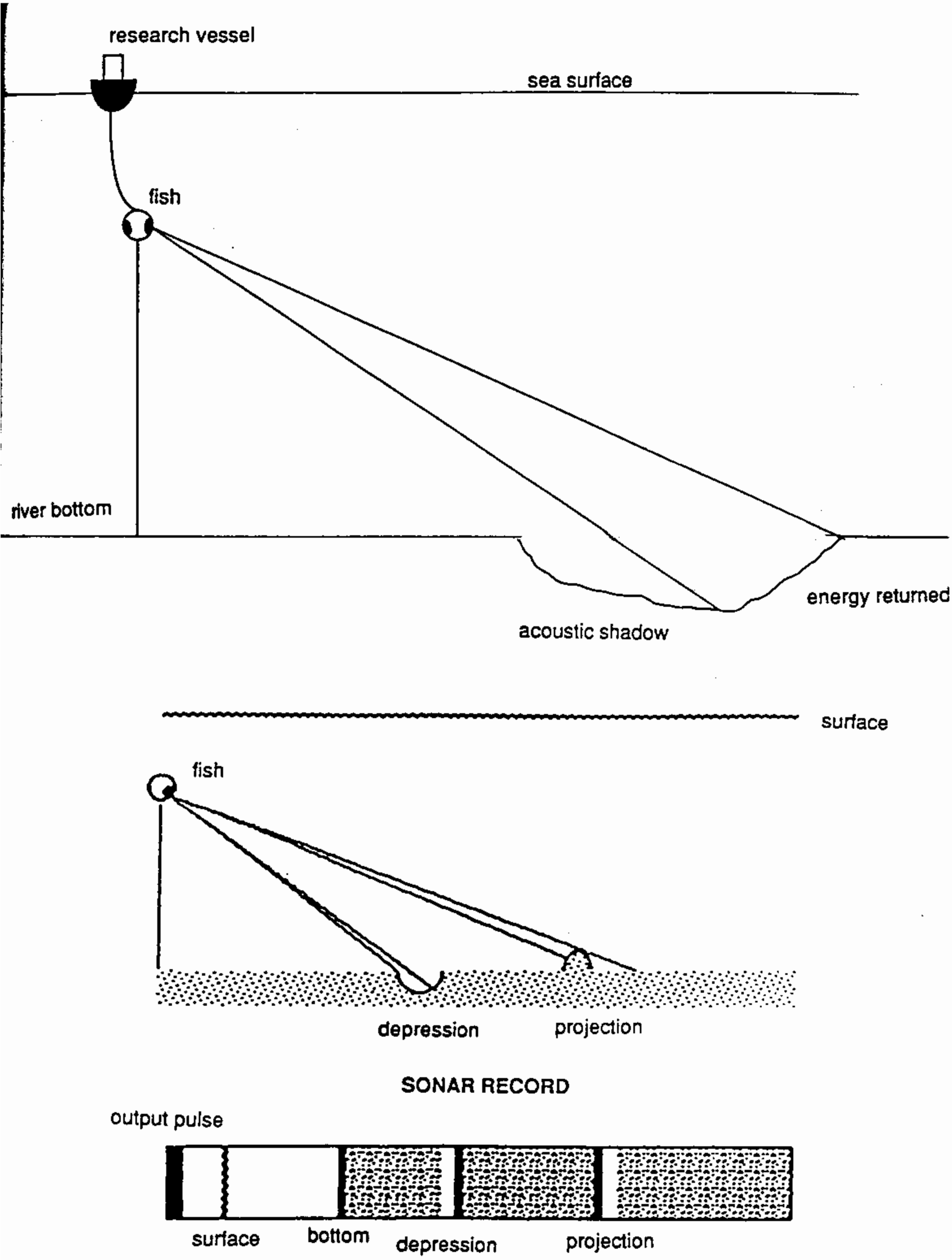


FIGURE 3. Schematic representation of the beam path as it impinges on an obstacle above and a depression within the river bottom (modified from Klein, 1985).

The rougher the river bottom is, the more energy is returned than from a smooth river bottom. Therefore a qualitative measurement of percent sand to mud size can be determined by the strength of the return. Side-scan sonar records are not plan views of the sediment surface, however, with application of simple algorithms they can be interpreted in terms of morphology of the river bottom.

METHODS

A dual frequency (100 kHz and 500 kHz) Klein Digital Sonar System 590 was used to survey the lower 8 km (approximately) of the Buffalo River within the AOC. Down river navigation was accomplished using Army Corps of Engineers' markers on the river banks (on cement walls or wooden pilings). There are approximately 100 feet between the markers, with numbers that increase in the upstream direction. The sonar fish was towed at approximately 2 to 5 meters off the bottom at a speed of 2 knots. The track of the boat was determined by calculating the slant range correction to either bank of the river and plotted on base maps (scale 1" = 100′)

The survey area includes the section of the river between COE reference numbers 783 and 518. For the purposes of this study, the AOC (between markers 783-518) has been divided into four sections (Figure 4), starting near the confluence of Cazenovia Creek and going downstream towards the mouth of the river; Section 1 (markers 783-645), Section 2 (markers 645-600), Section 3 (markers 600-538), and Section 4 (markers 538-518). Side-scan sonar records from each year (1990, 1991, 1992 and 1993) were interpreted separately for sediment bedforms, debris, and degree of reflectivity.

Several side-scan sonar records were taken for each year. Because of the resolution/range aspect of the sonar system, the entire width of the river was not always surveyed. Therefore several runs were necessary in the upstream and downstream direction. (A longer range record, which displays the river from bank to bank was taken in 1990, 1992 and 1993 but not in 1991). The records from all years were then compared, and differences between sediment bedforms and debris distribution/amount were noted. Slant range corrections were made to verify changes such as slope failure and position of sediment bedforms and debris.

For the furrow region, Section 2, the furrow images for all years were transferred onto a standardized format, since variation in the boat speed and navigation from year to year causes the records to be distorted differently (i.e., slower speed will result in a record of greater length). Army Corps of Engineers navigation maps of the areas in question were used. Adjusting for differences in lateral distance between the two formats, points indicating the center of furrow troughs were transferred onto the maps. This was done along transects drawn perpendicular to the river banks through fixed landmark points, such as the ends and corners of retaining walls (pilings, though they appear on the sonar images, were of no use since they do not appear on the COE maps). COE markers were not used because their positions on the sonar records proved inconsistent from year to year. Assuming constant boat speed between each of these initial transects, additional transects were drawn at evenly spaced intervals between them. Points marking furrow locations were then joined using tracings of the furrow patterns from the sonar images as references.

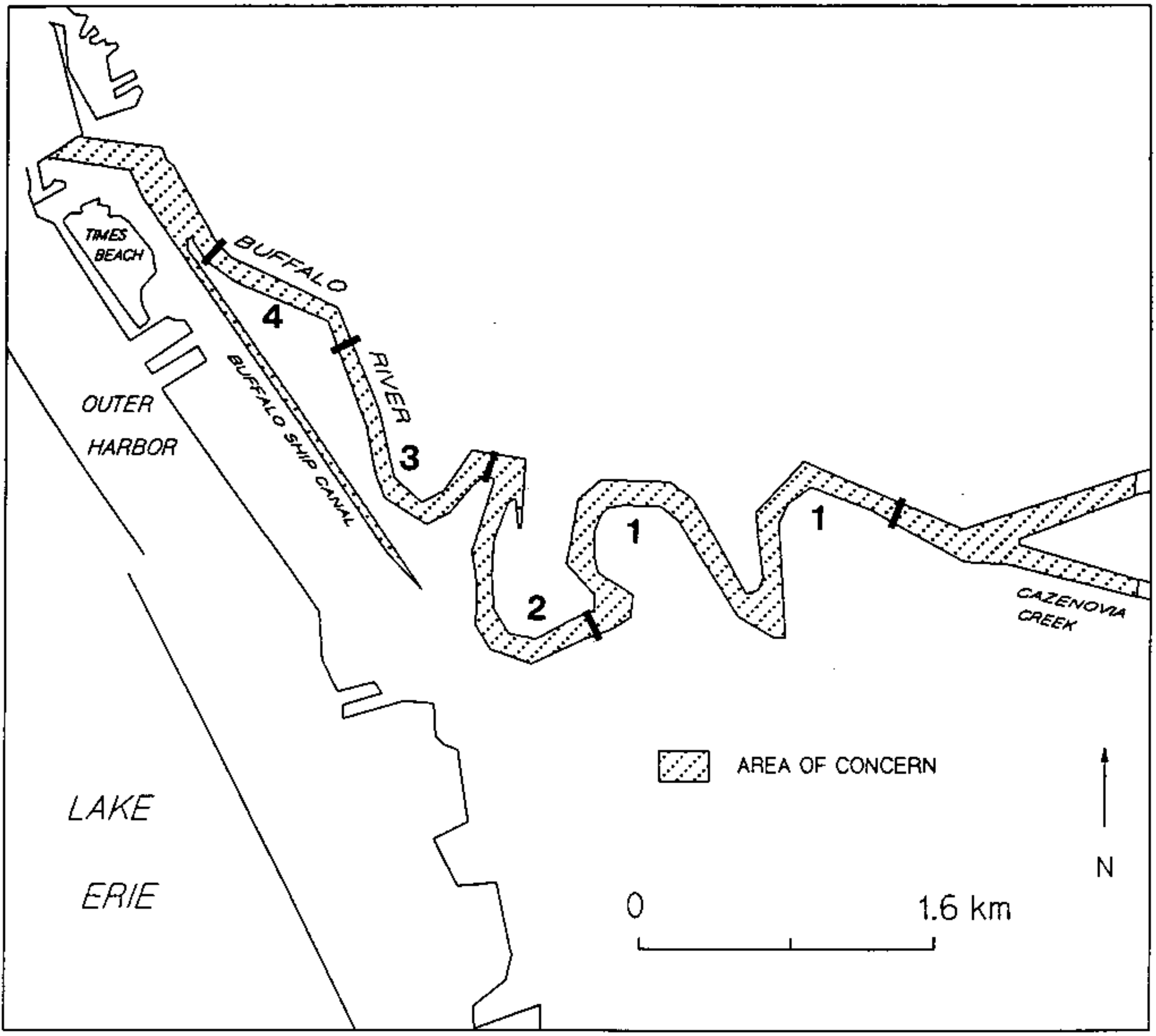


FIGURE 4. The survey area is divided into four sections (1-4). Section 1 is at the upstream end of the survey area; Sections 2, 3, and 4 are downstream towards the mouth of the river.

The standard furrow maps were then overlain and analyzed in terms of morphological changes and migration over time. It should be noted that no slant-range corrections were performed when determining furrow or bank positions. Due to the small (about 3 meters) distance between the fish and the bottom, changes due to slant range correction are negligible (< 0.5 m.).

DISCUSSION

Sedimentary Bedforms

Sediment bedforms, both depositional and erosional, are created by the interaction of currents and bottom morphology as sediment is redistributed along the river bottom. Thus they can provide information on bottom currents, or more importantly for this study, possible contaminant redistribution. Several features are notable when viewing the Buffalo River bottom with side-scan sonar: sediment tailing, slope failure, sand ribbons, sediment furrows, debris (both human-made and natural), and rock outcrops. Man-made debris on the river bottom ranges from tires to wooden pilings to vehicles (?), and natural debris such as trees and logs. The portion of the Buffalo River AOC studied has bottom sediment that is predominantly silt, with small percentages of sand, clay and occasionally gravel.

The distribution and types of sedimentary bedforms, as revealed by the side-scan sonar survey, indicate that the Buffalo River, within the AOC, has particular stretches which are definitely modified by currents, and as such are important areas for possible re-suspension of pollutant-laden bottom sediments. Therefore, it is important to understand the origin and significance of the bedforms which exist there.

Tailings

Sediment tailings were documented primarily in Section 1 and exist in the mud-dominated section. Aligned with the current direction, they form downcurrent behind obstacles which protrude above the bottom. As flow is deviated around the obstacle, a low-flow region is generated in the wake of the obstacle, allowing sediment to be deposited. Thus sections containing tailings are regions of deposition and possible sources of pollutant concentrations. As seen in the PCB-contaminated sediments in the Hudson River, high PCB loadings were associated with sediment tailings (Flood, 1990). The probability that these sediments can be resuspended and their associated obstacles removed has been documented by this study. Therefore the type, amount, and depth to contaminants in these sections must clearly be resolved by sampling and chemical analysis.

Sand Ribbons

Sand ribbons are formed by helical secondary circulation which moves the finer-grained sediment fraction into current-parallel rows leaving coarser material between the rows (Flood and Johnson, 1984; Allen, 1982). These ribbons are located more towards the channel margins where the highest percentages of sand generally is found. Mapped throughout the study area, the sand ribbons suggest that the Buffalo River within the AOC is an active system in which the sediments constantly are being resuspended and deposited. Thus, sediments in areas where sand ribbons occur should be analyzed for contaminant content.

Sediment Furrows

Sediment furrows are longitudinal bedforms which form in fine-grained, cohesive sediments of the deep-sea flood as well as in similar sediments in estuaries and large lakes (Fig. 5A). Previous studies of furrows suggest that they develop in depositional environments swept by recurring, directionally stable and episodically strong currents (Flood, 1981, 1982, 1983; Floor and Johnson, 1984). They are initiated when secondary circulation in the boundary layer align coarse, generally light debris in sand ribbon-like bedforms (Flood, 1983). The trapping of coarse-grained material in troughs and the large scale secondary circulation enhances erosion of the furrow flood and walls. Furrows tend to join in what is called a "tuning fork fashion" (Figure 5B), generally in the direction of the flow (Flood, 1983; Allen, 1982), but they have been known to join in both directions where tired significantly affect the current.

General Description of AOC

The Buffalo River has reaches dominated by deposition, whereas other reaches show that erosion is the dominant process. For a more detailed discussion on the general morphology changes within the AOC see Fuller (1992). Figure 6 shows the location of sedimentary bedforms mapped in 1991.

Section 1 (783-645): Deposition and slope failure seem to dominate in this section. Increased slope failure is coincident with those regions of river which have been dredged (1990, 1992). As slope failure occurred more debris was introduced into the river and was moved down river. Not only was extra debris introduced, but sediment as well (see an increase in sediment tailing down river of dredge sites). Though this additional sediment may be coming from an upstream source, some of the increase in sedimentation definitely is coming from the failed bank slopes.

Section 1 primarily is dominated by sedimentation. Dredge scours (on the order of 1.5 m in depth) which were imaged within days of the 1992 dredging, were mostly filled after two months. This indicates a high sediment input for this reach. Only 1 km down river from this high depositional area, we see a reach of the river which fluctuates from being depositional to highly erosive. Over the past four years, a bedrock outcrop has been alternately covered and then exposed between successive years surveys.

Section 2 (645-600): This section is dominated by sediment furrows. The long-term existence of the furrows suggests that little has changed in the flow regime, yet it is a dynamic system. Over the four year period, the furrows have undergone both lateral and longitudinal migration, convergence and divergence of individual furrows, and the addition of new furrows, and the disappearance of others (Figures 7, 8, 9). Lateral migration appears to occur as a result of uneven erosion on the furrow walls. Longitudinal migration takes place when coarse sediments at the bottom of furrow troughs are pushed along the cohesive mud of the channel surface.

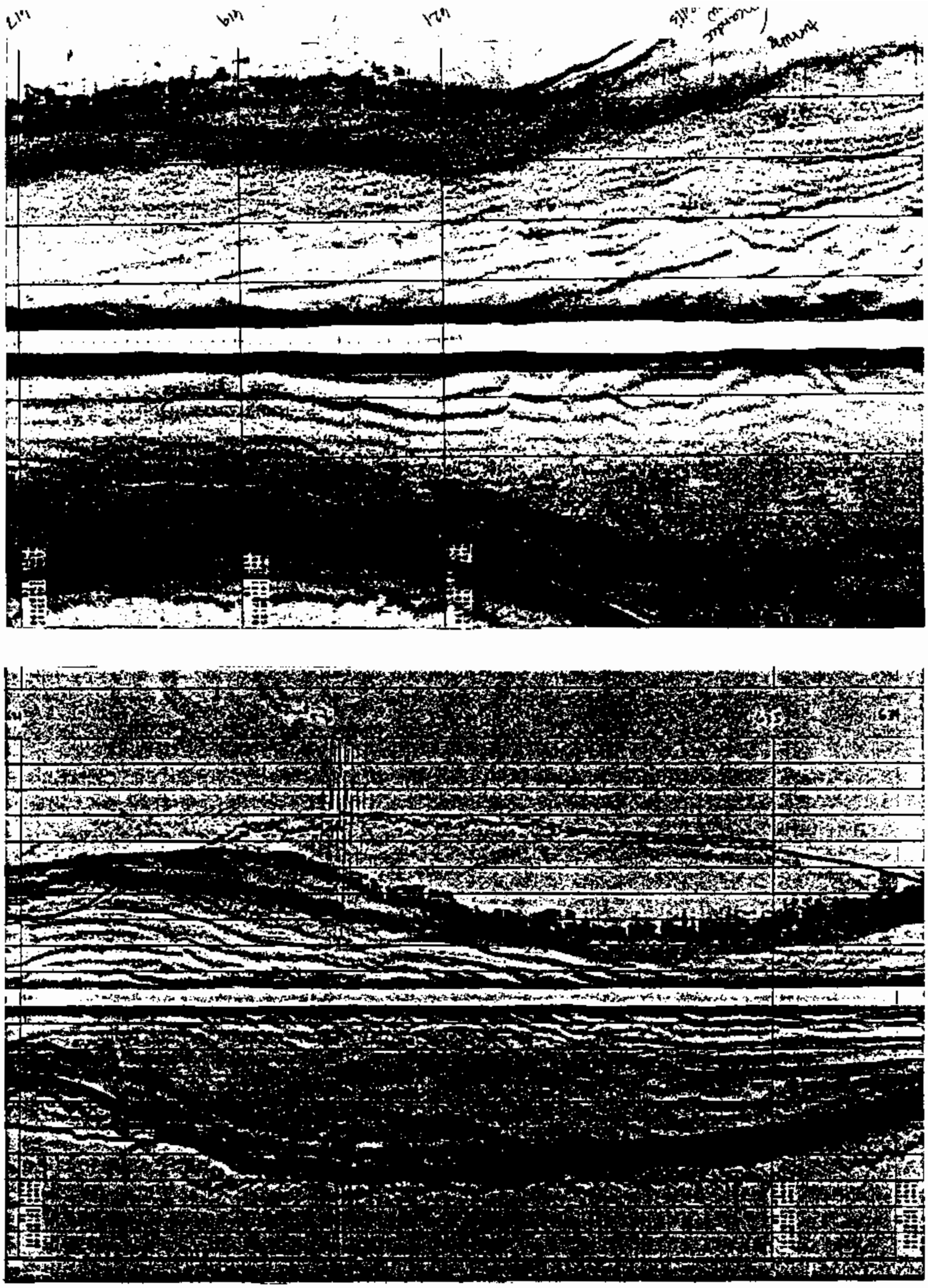


FIGURE 5A. Sediment furrows mapped in the 1990 side-scan sonar survey (top) and in the 1991 survey (bottom). The distance between horizontal lines is 10 m; the vertical lines correspond to USCOE transect markers.

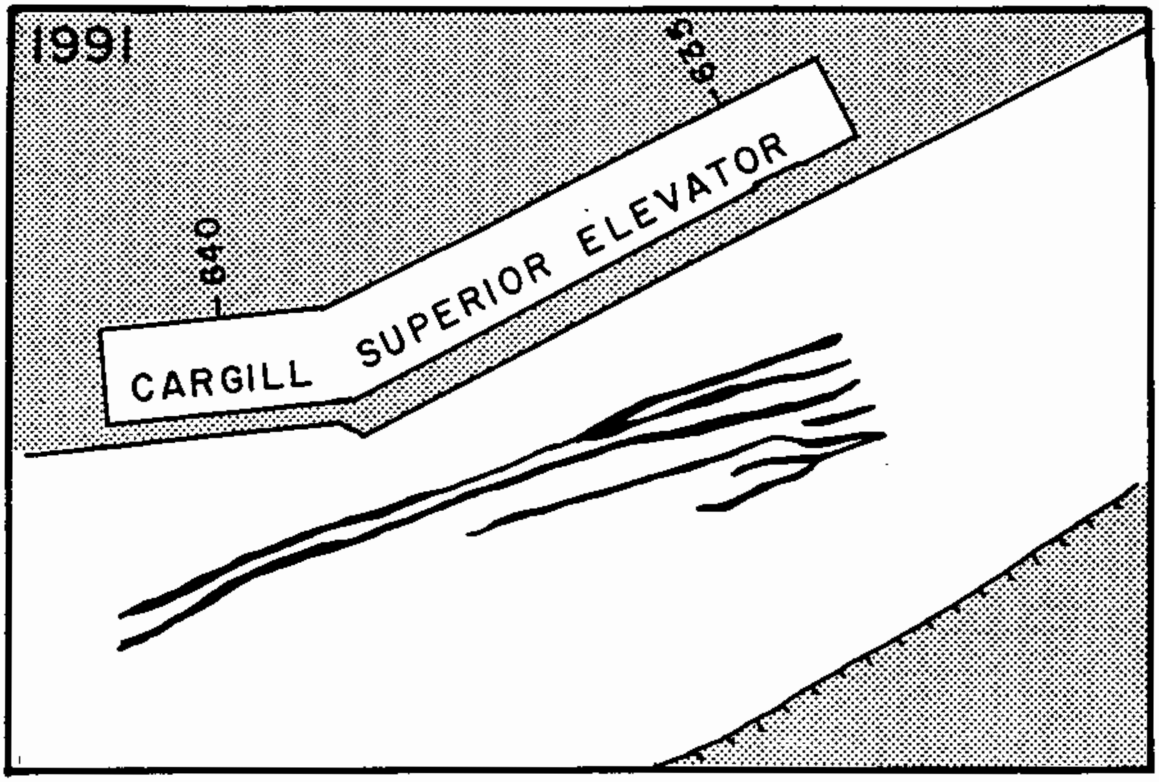


FIGURE 5B. Sketch of furrows from the 1991 survey. Numbers refer to USCOE transect numbers. Furrows exhibit tuning fork pattern, with the opening of the tuning fork pointing both upstream and downstream.

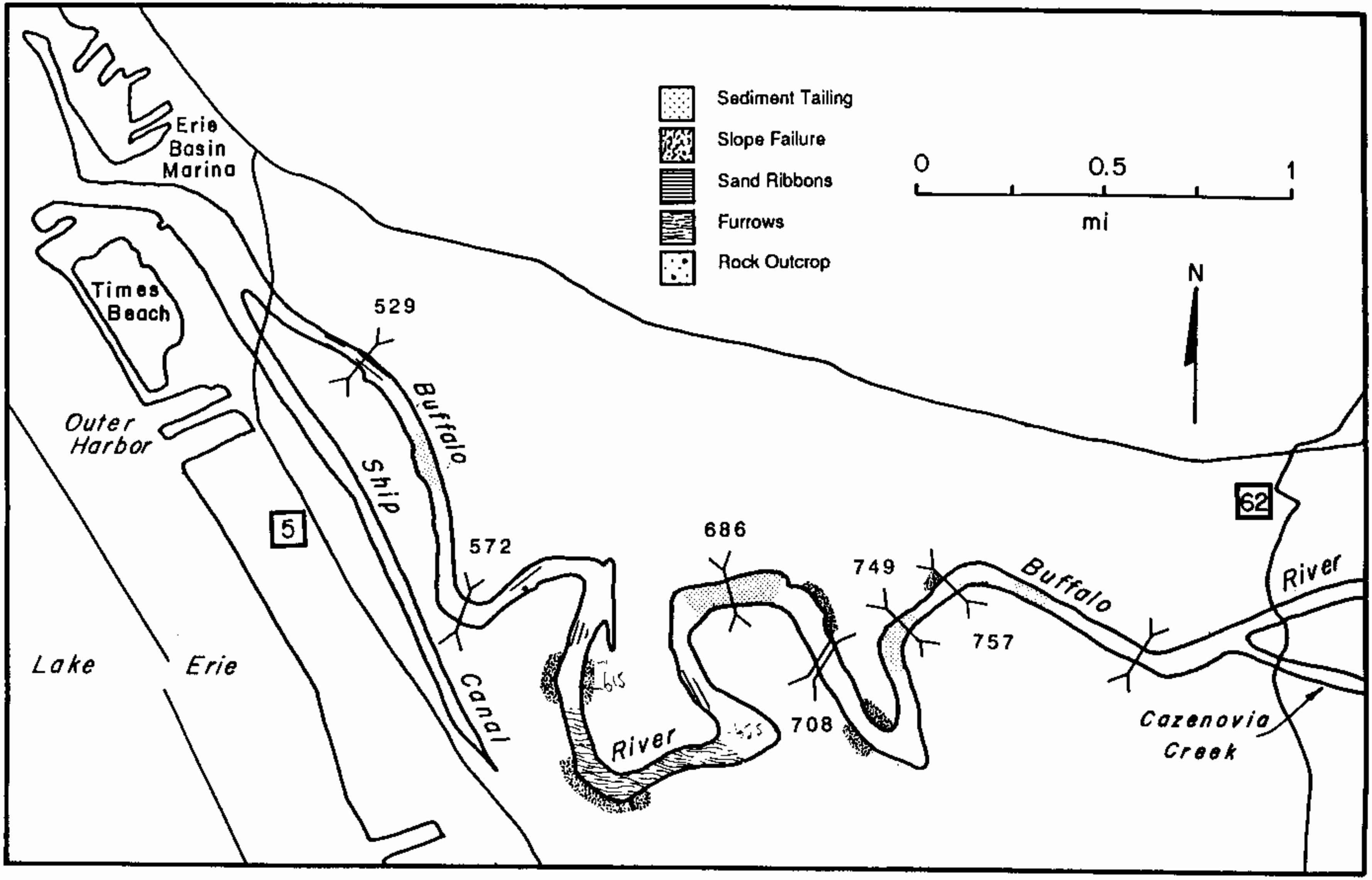


FIGURE 6. The location of bedforms mapped in the 1990 survey (From Fuller, 1992).

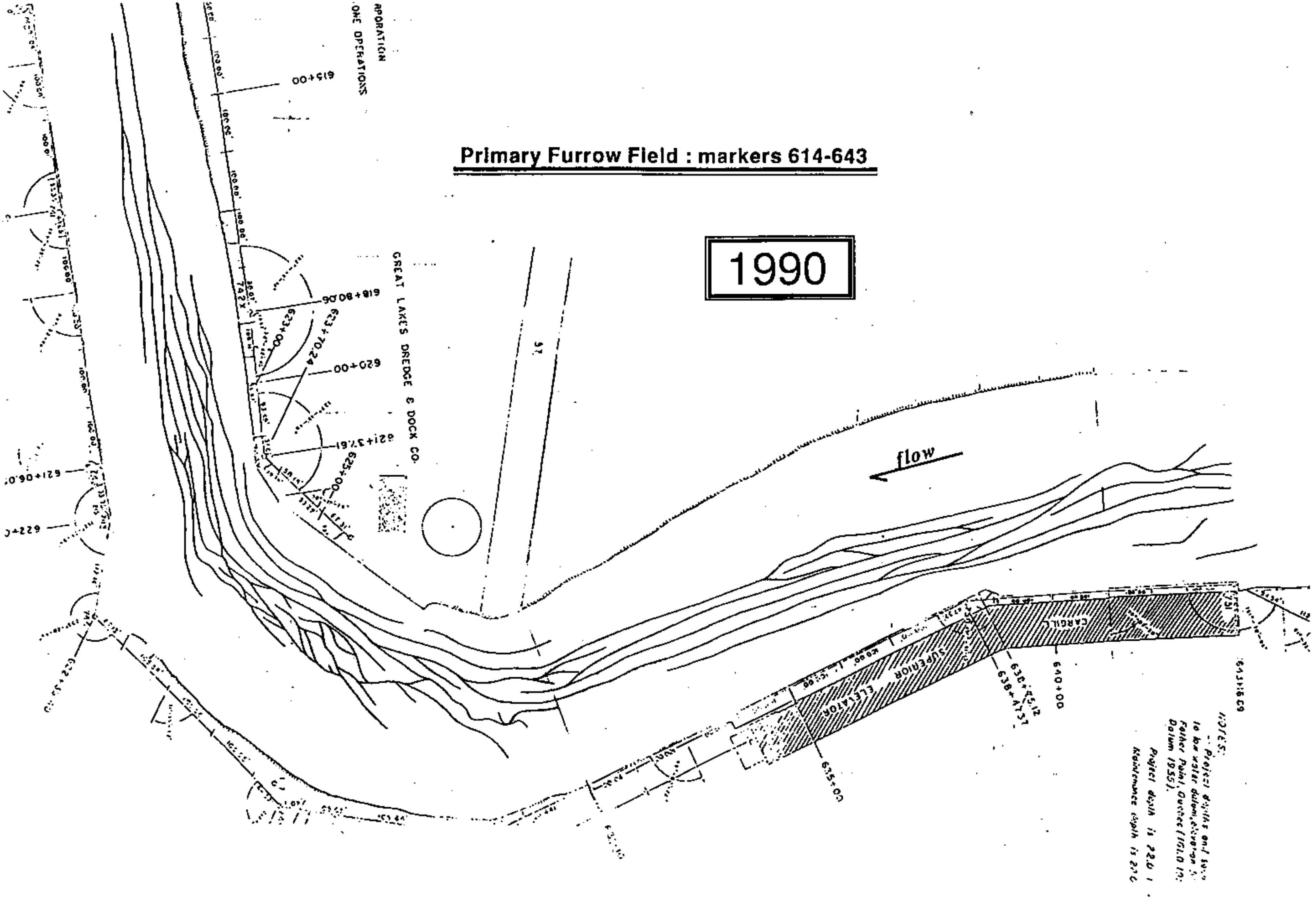
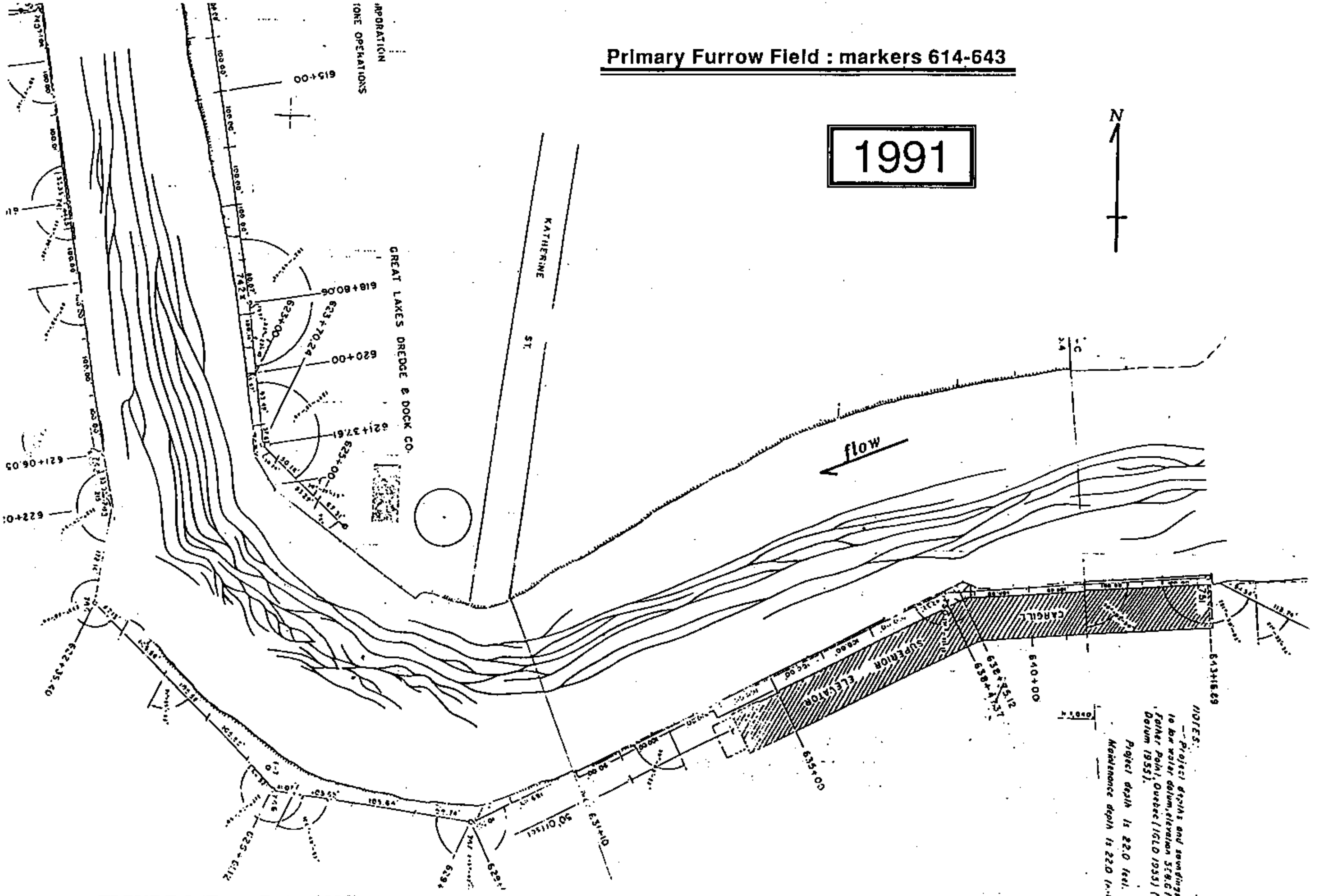


FIGURE 7 (From Ruhl, 1993)



Primary Furrow Field : markers 614-643

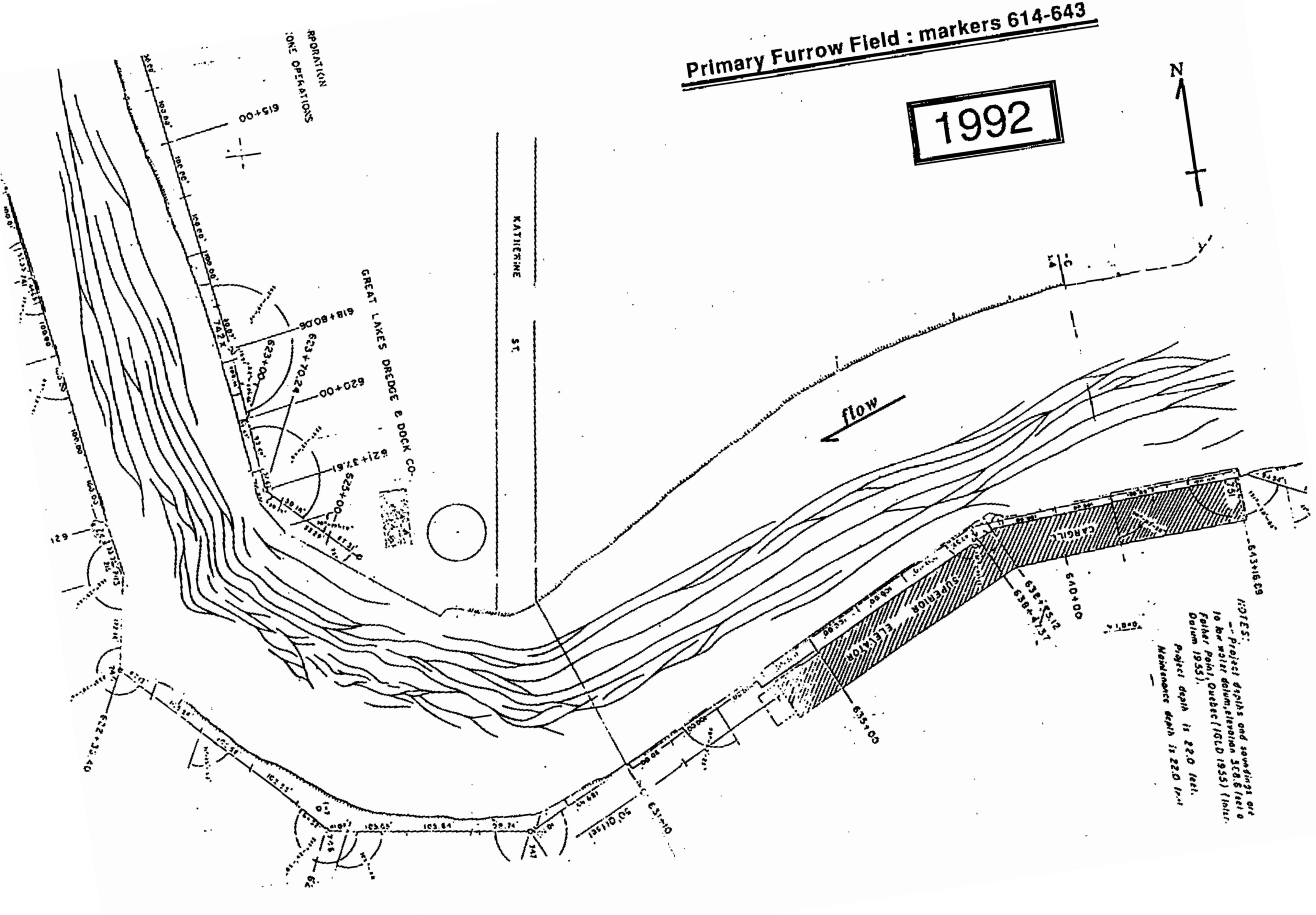
1991

NOTES:
— Project depths and soundings are in … to low water datum, elevation 568.6 feet abov… Father Point, Quebec (IGLD 1955) (Internat… Datum 1955).
Project depth is 22.0 feet.
Maintenance depth is 22.0 fe…

FIGURE 8 (From Ruhl, 1993)

Primary Furrow Field : markers 614-643

1992



Buhl, 1993)

The general trend has been of an increase in the number of furrows in this section. The presence of tuning forks, in both directions, shows that this reach can have bidirectional flow. As a site of active deposition and erosion, the furrow field is a primary source of sediment resuspension and transport. As such, it warrants special attention by those interested in understanding its potential for re-introducing hazardous materials into the surrounding environment. For a detailed study of the furrows see Ruhl, 1993.

Section 3 (600-538): This reach has current dynamics which create and destroy sedimentary bedforms. Sand ribbons have grown in length (in downstream direction), yet sediment tailings have disappeared or degraded. Dredged scours (1992 dredging) in this section showed smooth edges after two months, but were still evident one year later; implying a lower sedimentation rate than in Section 1. Slope extension or failure occurred near the dredge sites but to a lesser degree than previously seen. This probably due to the banks, in this sections, which are intermittently natural vegetated banks with areas of reinforcement (either concrete or metal walls). Since little slope failure occurred due to dredging, no additional sediment load was introduced and bedforms remained fairly constant downstream.

Section 4 (538-518): The river bottom in Section 4 contains more debris than any of the previous sections. New debris is usually pilings; the bank of this particular section are dominated by wood cribbing. Sand ribbons in this section have degraded and reappeared. The nature of the development of sand ribbons may indicate that these are more transient features due to current speeds and directions. As such, sand ribbons may be one of the dominant sedimentary features which redistributes bottom sediments along the entire river.

CONCLUSIONS

It is evident that processes of erosion and deposition are active within the Buffalo River. The presence of furrows (and sand ribbons) provides conclusive evidence of the redistribution of bottom sediments. The predominance of cohesive sediments on the Buffalo River bottom has combined with the smaller percentages of coarser sediments to create an environment in which both sand ribbons and furrows readily form.

These processes involve the re-suspension of sediments which, in the case of the Buffalo River, have been found in particular regions to contain high levels of metals and organic compounds. In areas where several contaminants have been identified, a significant amount of sediment re-suspension has been caused by currents and also dredging. This is particularly evident in the dredge areas of Section 1. The re-suspension of the sediments of the Buffalo River due to dredging may have serious repercussions for the quality of the water as a recreational area and as a viable habitat for animal life.

The lower Buffalo River is an environment that is uniquely suited to the formation and perpetuation of sediment furrows. This is due in large part to its orientation at the northeast end of Lake Erie. The alignment of the long axis of the lake with the predominant high-speed wind direction maximizes fetch. Flow reversals in the river, caused by the pile-up of this wind-blown lake water at the mouth of the river, lead to periods of rapid, turbulent, and highly erosional flow when the winds subside and the lake water retreats. The cohesive mud substrate, created by silt and clay deposition during periods of normal flow, is then abraded by ribbons of coarser sediment produced by convergent helical cells (Floor, 1983). Evidence of flow reversals is left behind in the form of "tuning forks" - furrow junctures which converge in the direction of flow in both upstream and downstream orientations (Figure 5B). As a site of active deposition and erosion, the furrow field is a primary source of sediment resuspension and transport. As such, it warrants special attention by those interested in understanding its potential for re-introducing hazardous materials into the surrounding environment.

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SEDIMENT TRANSPORT PATHS WITHIN THE BUFFALO RIVER*

INTRODUCTION

Grain size distributions of sedimentary deposits often have been used in environmental interpretations. Various investigations have explored the relationship between size populations and transport mechanism (Visher, 1969; Friedman, 1979) and the velocities necessary for erosion and transport of particles of a given size (Hjulstrom, 1934; Singer and Anderson, 1984). Disagreement persists, in part because of the unprint of the source sediment characteristics on the characteristics of the deposit (McLaren and Bowles, 1984). Progressive changes in grain-size distributions from source to final deposit have been recognized by several workers (Stapor and Tanner, 1975; McCave, 1978; Haner, 1984) and have been analyzed by a deductive model by McLaren (1981). He suggested that the mean, sorting, and skewness of grain-size frequency distributions follow trends that identify the direction of transport and the sedimentary processes of winnowing, selective deposition, and total deposition. Using a hypothetical sediment distribution and an assumption that light grains have a greater probability of being eroded and transported than heavy grains, McLaren's (1981) model demonstrated that: 1) sediment in transport must be finer, better sorted, and more negatively skewed than its source sediment; 2) a lag must become coarser, better sorted, and more positively skewed; and 3) successive deposits may become finer or coarser, but the sorting must become better and skewness more positive (p. 485, McLaren and Bowles, 1985). McLaren has developed a proprietary software package that uses changes in mean, sorting, and skewness to derive transport paths.

METHODS

A trend analysis for the Buffalo River Area of Concern was performed using the method developed by McLaren. It was determined that surface sediment samples collected during the summer 1990, prior to the beginning of maintenance dredging, represented the most complete and least disturbed record of bottom sediment distribution.

The location of the sediment samples are shown on the "physical characteristics map" (Insert A) and also are referenced with respect to the COE transect marker on Table 1. The grain size distributions for the samples were determined using a Malvern Laser Sizer (for a description of the operation of a MLS see Singer et al, 1988). Table 1 summarizes the gravel, sand, salt, and clay percentages for each sediment sample. In the table, R refers to right bank, C refers to center of channel, and L refers to left bank.

The trend analysis is based on upstream an downstream changes in mean, sorting and skewness values. It is important to emphasize that the sampling density was insufficient to be certain of the trends. There may well be eddies at each of the meanders causing counter-currents. All trends are based on samples that are predominantly mud with modes ranging from about 6.0 to 7.5 phi. There were several highly "miscellaneous" distributions, and these were not taken into account in the trend analysis.

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* Section compiled by P. McLaren and J. Singer

TABLE 1. SUMMARY OF GRAVEL/SAND/SILT/CLAY CONTENT (%)

Sample #	COE #	Gravel	Sand	Silt	Clay
1	643L	0	3	81	16
2	643C	0	2	82	16
3	643R	0	2	82	16
4	641L	0	0	79	21
5	641C	0	0	83	16
6	641R	0	2	87	11
7	638L	0	2	82	16
8	638C	0	0	78	22
9	637C	0	3	84	13
10	637R	0	1	84	15
11	637L	0	5	85	10
12	635L	0	7	84	10
13	635C	0	0	82	18
14	635R	0	6	83	11
15	629L	0	2	85	12
16	629C	0	3	81	16
17	629R	0	4	83	13
18	626R	0	7	83	10
19	626C	0	1	77	22
20	626L	0	2	87	10
21	625L	0	0	83	17
22	625C	0	1	85	14
23	625R	0	1	87	12
24	618R	0	7	84	9
25	618C	0	1	82	17
26	618L	0	7	80	13
27	616L	0	2	84	14
28	616C	0	7	80	13
29	616R	0	4	84	12
30	615R	0	5	82	13
31	615C	0	1	87	12
32	615L	0	4	80	16
33	612L	0	2	82	16
34	612C	0	11	80	9
36	611R	0	1	83	16
37	611C	0	6	83	11
38	611L	0	4	83	14
39	606L	0	1	82	17
40	606C	0	1	87	12
41	606R	50	34	14	12
43	600C	0	1	83	16
44	600R	0	5	85	9
45	597R	0	2	86	12
46	597C	0	3	86	11
47	597L	0	2	83	15
48	594L	0	8	82	10
49	594C	0	7	82	11
50	594R	0	4	84	12
51	592R	0	4	86	10
52	592C	0	5	81	15

TABLE 1. Continued

Sample #	COE #	Gravel	Sand	Silt	Clay
53	592L	0	3	86	11
54	589C	0	6	82	12
55	589R	0	1	87	12
57	586R	0	2	80	19
58	586C	0	7	82	12
59	586L	0	3	86	10
60	583L	0	1	87	12
61	583C	0	3	82	15
62	583R	0	1	84	15
63	576R	0	6	84	10
64	576C	0	3	85	12
65	576L	0	2	87	11
66	569R	0	0	86	14
67	569C	0	4	84	12
68	569L	0	2	86	12
71	564R	0	1	86	13
75	783L	0	6	83	11
76	783C	0	5	84	11
77	783R	0	61	35	4
78	782R	0	6	83	11
79	782C	0	3	87	10
80	782L	0	11	79	10
81	777L	0	3	87	11
82	777C	0	4	86	11
83	777R	0	33	62	5
84	774R	0	28	65	7
85	774C	0	8	82	10
86	774L	0	3	86	12
87	765L	0	4	84	12
88	765C	0	29	65	6
89	765R	0	7	83	10
90	760R	0	4	83	13
91	760C	0	3	85	13
92	760L	0	34	60	6
93	756L	0	3	85	11
94	756C	0	4	86	10
95	756R	0	2	86	12
96	752L	0	5	84	11
97	752C	0	5	85	10
98	752R	0	6	83	11
99	747L	72	7	18	3
100	747C	0	5	84	12
101	738L	0	3	86	11
102	738C	0	4	85	12
103	738R	0	2	85	13
104	724L	0	8	83	9
105	724C	0	12	86	12
106	724R	0	0	85	15

TABLE 1. Continued

Sample #	COE #	Gravel	Sand	Silt	Clay
107	713R	0	3	85	12
108	713C	0	2	86	13
109	713L	0	1	87	12
110	708C	96	2	2	0
112	706C	0	2	82	16
113	692R	0	8	82	10
114	692C	0	1	86	13
115	692L	0	2	87	11
116	685L	0	4	82	14
117	685C	0	2	84	14
118	685R	0	2	83	15
119	679R	0	0	85	15
120	679C	0	3	82	16
121	679L	0	3	83	15
122	675L	0	2	81	17
123	675C	0	0	84	16
124	675R	0	4	81	15
125	671R	0	1	33	15
126	671C	0	3	80	17
127	671L	0	2	88	11
128	662L	0	3	86	11
129	662C	0	0	82	17
130	652L	0	1	87	12
131	652C	0	2	88	10
132	652R	0	1	83	17
133	563R	0	3	83	15
134	557C	32	9	50	9
135	557R	0	1	81	17
136	546C	0	1	80	20
137	544C	0	2	84	14
138	537C	0	0	80	20
139	535C	0	1	84	15
140	530R	0	6	83	11
141	530C	0	3	82	15
142	526C	0	4	86	11
143	526R	45	6	42	7
144	523R	0	5	85	10
145	523C	0	7	84	9
146	520C	0	2	82	16
147	520R	0	1	86	13
148	518R	0	3	85	12
149	518C	0	9	82	10

DISCUSSION

The best interpretation is established in 8 lines (or sequences) of samples. Each line starts at the down-river end and progresses up-river. The direction is defined as up or down. Table 2 is a list of all the samples in each line and the lines themselves are shown in Figure 10. The trend statistics for each line are given in Table 3; Figure 11 shows the derived transport paths.

Lines 1 to 3: These lines start at the up-river end of the sampling stretch (Location A in Figure 11) and follow the right bank, the middle of the river, and the left bank respectively. Excellent down-river transport trends were derived with high R values (average 0.89). Both the right bank line (Line 1) and the middle-of-the-river line (Line 2) could be extended as far as Location B, beyond which the trends became ambiguous. The left bank line (Line 3), however, could be extended as far as Location C. All these lines produce x-distributions indicative of total deposition (i.e., a monotonically increasing function over the complete distribution of the deposits). Thus, once any sized particle is deposited, no further transport is likely to occur.

Lines 4 to 6: These lines continue from the down-stream ends of the three previous lines, and again follow the right bank, river middle, and left bank. Line 6 continues in a down-river direction as far as Location E. The remaining two lines indicate a reversal of direction (up-river) with Line 5 extending from Location E to Location B and Line 6 from Location D to Location C. Again, R values are high and the x-distributions indicate total deposition.

Lines 7 and 8: The remaining two lines show up-river transport from Location F to Locations E and D, respectively. The x-distributions of both are again indicative of total deposition.

The stretch of river appears to be under the influence of two distinct transport regimes, namely the out-flowing Buffalo River, and an in-flowing transport regime related to Lake Erie. Based on this analysis, the zone of mixing appears to lie between Location B and Location E. A more detailed sampling program in this area could probably determine the interrelationships between the two regimes with greater accuracy. It also should be noted that the furrow field, mapped using side-scan sonar, is present between Location B and Location D. The persistence of the furrows in all surveys conducted between 1990 and 1994 strongly suggests that the turbulent mixing between river and lake waters plays a role in furrow formation and migration.

Given that all the trends show total deposition (a findings that is consistent with cohesive sediments), the rates of deposition can be expected to decrease down the transport paths. Therefore, dredging requirements can be expected to decrease from A to B, and from F to E. Within the "zone of mixing", depositional rates will probably be relatively constant. This conclusion appears to be supported by dredging patterns; the greatest volume of sediment is removed from the upper portion of the river characterized by "spot" dredging.

CONCLUSIONS

In environments of total deposition, contaminants tend to be deposited with the natural sedimentary particles at localities downstream from specific sources. Because no further transport of contaminated particles will occur, specific contaminant "highs" can be expected that may be fairly limited in their extent. Typically in such environments, contaminant loadings

TABLE 2. LIST OF SAMPLES IN EACH LINE

line --- 1 - m2
72, 78, 82, 85, 89, 90, 95, 98, 100, 103, 106, 107, 112, 113, 118, 119, 124, 125, 129, 3, 6

line --- 2 - m2
76, 79, 82, 85, 87, 91, 94, 97, 100, 102, 105, 108, 112, 114, 117, 120, 123, 126, 129, 132

line --- 3 - m2
75, 81, 86, 87, 93, 96, 101, 104, 109, 112, 115, 116, 121, 122, 127, 128, 130, 1, 4, 7, 9, 12, 15, 20, 21

line --- 4 - m2
11, 14, 17, 23, 24, 29, 30, 36, 44, 45, 50, 51, 55, 57, 62, 63, 66, 71

line --- 5 - m2
131, 2, 5, 8, 10, 13, 16, 19, 22, 25, 28, 31, 34, 37, 40, 43, 46, 49, 52, 58, 61, 64, 67

line --- 6 - m2
26, 27, 32, 33, 38, 39, 47, 48, 53, 54, 59

line --- 7 - m2
60, 65, 68, 134, 136, 137, 138, 139, 141, 142, 145, 146, 149

line --- 8 - m2
135, 136, 137, 138, 139, 140, 143, 144, 147, 148
Line statistics for all lines of samples

Definitions:

1. **R^2** = multiple correlation coefficient derived from the mean, sorting, and skewness of each sample distribution along the line. This is a relative indication of how well the samples are related by transport.
2. **Case B**: Sediments becoming finer, better sorted and more negatively skewed in the direction of transport.
3. **Case C**: Sediments becoming coarser, better sorted and more positively skewed in the direction of transport.
4. **N** = number of possible pairs in the line of samples.
5. **x** = number of pairs making a particular trend in a specific direction.
6. **Z** = Z-score statistic: ** are those samples significant at the 99% level; * are those trends significant at the 95% level.
7. Status (i.e. net erosion, accretion or dynamic equilibrium) is determined by the shape of the X-distribution.
8. Directions indicate UP (up river) and DOWN (down river) transport.

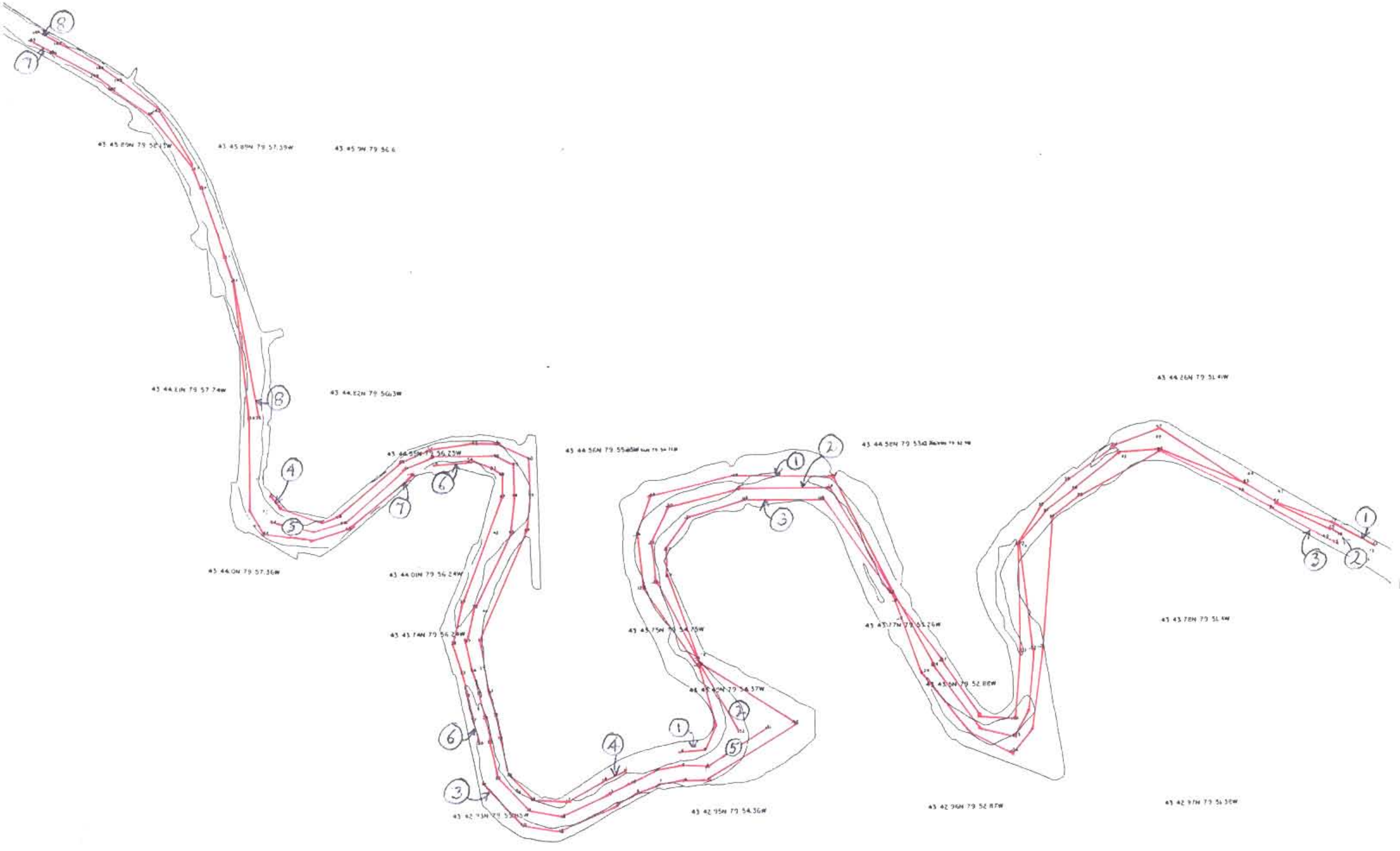

FIGURE 10. Sample lines used to determine sediment trends

TABLE 3. TREND STATISTICS FOR EACH LINE

Line	Case	R2	Direction	N	x	Z	Status
1 - m2	B	0.89	UP	210	27	0.16	Deposition
			DOWN	210	114	18.31**	
	C		UP	210	12	-2.97	
			DOWN	210	11	-3.18	
2 - m2	B	0.87	UP	190	13	-2.36	Deposition
			DOWN	190	126	22.43**	
	C		UP	190	20	-0.82	
			DOWN	190	2	-4.77	
3 - m2	B	0.92	UP	300	49	2.01*	Deposition
			DOWN	300	126	15.45**	
	C		UP	300	45	1.31	
			DOWN	300	31	-1.13	
4 - m2	B	0.96	UP	153	24	1.19	Deposition
			DOWN	153	82	15.37**	
	C		UP	153	8	-2.72	
			DOWN	153	18	-0.28	
5 - m2	C	0.92	UP	253	32	0.07	Deposition
			DOWN	253	16	-2.97	
	B		UP	253	111	15.09**	
			DOWN	253	40	1.59	
6 - m2	B	0.96	UP	55	28	8.61**	Deposition
			DOWN	55	9	0.87	
	C		UP	55	3	-1.58	
			DOWN	55	9	0.87	
7 - m2	B	0.90	UP	78	34	8.30**	Deposition
			DOWN	78	15	1.80*	
	C		UP	78	12	0.77	
			DOWN	78	2	-2.65	
8 - m2	B	0.78	UP	45	26	9.18**	Deposition
			DOWN	45	8	1.07	
	C		UP	45	0	-2.54	
			DOWN	45	4	-0.73	

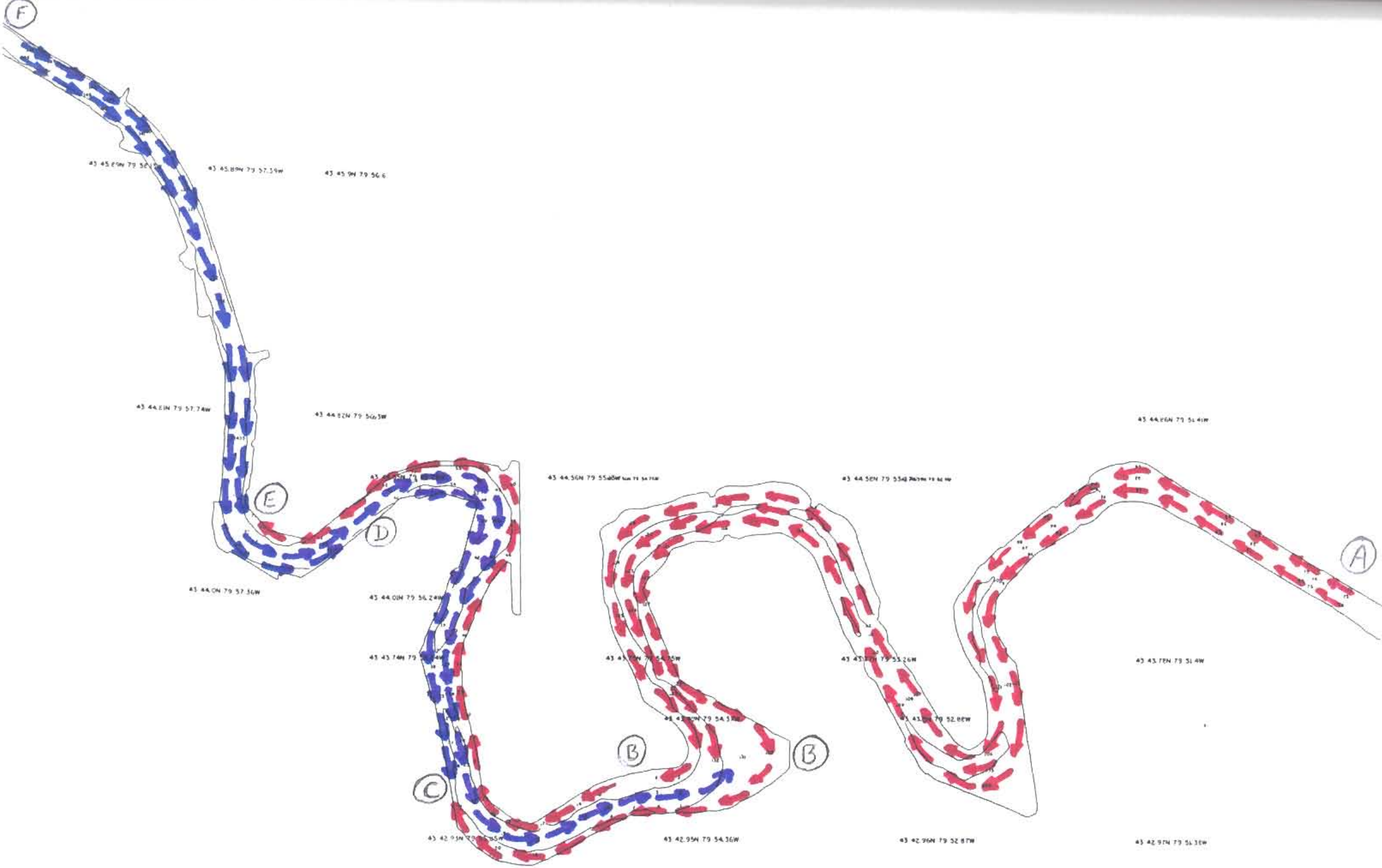

FIGURE 11. Sediment transport paths are indicated in red (down-river trends) and blue (up-river trends)

decrease fairly rapidly on either side of the "high". Also, if sources of contamination are removed, clean sediment will eventually deposit over the contaminated sediments. Further release of contaminants from buried sediments becomes a geochemical problem.

According to the derived transport paths, contaminant highs would be expected in sediments downstream from sources located between Location A and Location B, and upstream from sources located Between F and E. The mixing of the two regimes between E and B might lead to more or less equal loadings of contaminants contained in the sediments found in this area. Downcore contaminant concentrations have been determined for a number of sediment cores collected by the USEPA; these data can be further interpreted using the derived transport paths.

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WATER COLUMN MEASUREMENTS OF THE BUFFALO RIVER*

METHODS

Throughout the spring, summer, and fall of 1992 (20 sampling days) current velocity and selected water quality parameters were measured at six locations in the Buffalo River. The six sites (identified in Figure 12) were established during previous monitoring efforts on the Buffalo River. For each sampling day, the USGS and COE gage levels were recorded. The locations of the gages are shown in Figures 13 and 14.

The current velocity was measured using a Marsh-McBirney portable current meter. Measurements were taken at 1 ft. increments within the upper 6 ft. of the water column and at 2 ft. increments below left. The velocity data are in m/s. Reverse flow is indicated by a negative value for the velocity.

A SeaBird Sealogger water column profiler was used to measure pressure (psi), depth (meters), temperature (deg. C), conductivity (S/M), pH, % of transmission of light, irradiance (PAR), fluorescence, and dissolved oxygen (mg/l). Each of these parameters are measured 8 times/second as the Sealogger is lowered through the water column. This information is averaged into 0.25 second intervals and stored internally. At the end of each day, the data are transferred from the Sealogger to disk.

Using software provided by SeaBird Electronics, the data are converted to ascii format to facilitate the processing of the data. The converted Sealogger files have the extension '.ASC'. The water column data include the nine parameters listed above. A scan number also is indicated with each line of data. Because the sensors equilibrate just below the water surface for approximately two minutes before the Sealogger is lowered through the water column, these scans (usually the first 500 or so) have been excluded from each processed data set. The processed Sealogger filenames in this report are prefixed by a 'D' to indicate that the file contains downcast data only.

For days when sampling was done shortly after a rainfall, the amount of suspended sediment in the river resulted in exceeding the working limits (i.e., off-scale) of the transmissometer and fluorometer. When the transmissometer is off-scale a negative value is given (ex., -0.02); a value of 1.000 e+01 indicates that the fluorometer is off-scale. Although the fluorometer is measuring specific wavelengths associated with chlorophyll, high sediment concentrations in the water column can overwhelm the sensor.

Irradiance, expressed as PAR (photosynthetically active radiation) values, is measured using a LiCor spherical quantum sensor. The PAR sensor, in addition to the transmissometer, provides an indication of water turbidity. The PAR sensor is mounted on the upper end of the Sealogger in order to prevent it from being "shaded" by other sensors. The Sealogger is approximately 1 meter in height and therefore the first few scans provide PAR values in air (i.e., PAR sensor is above the water surface when all the other sensors are below the water surface). The PAR values in water begin when the depth is approximately 1 m. The limit of the euphotic zone is defined as 1% of the PAR value at the water surface.

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* Section compiled by J. Singer

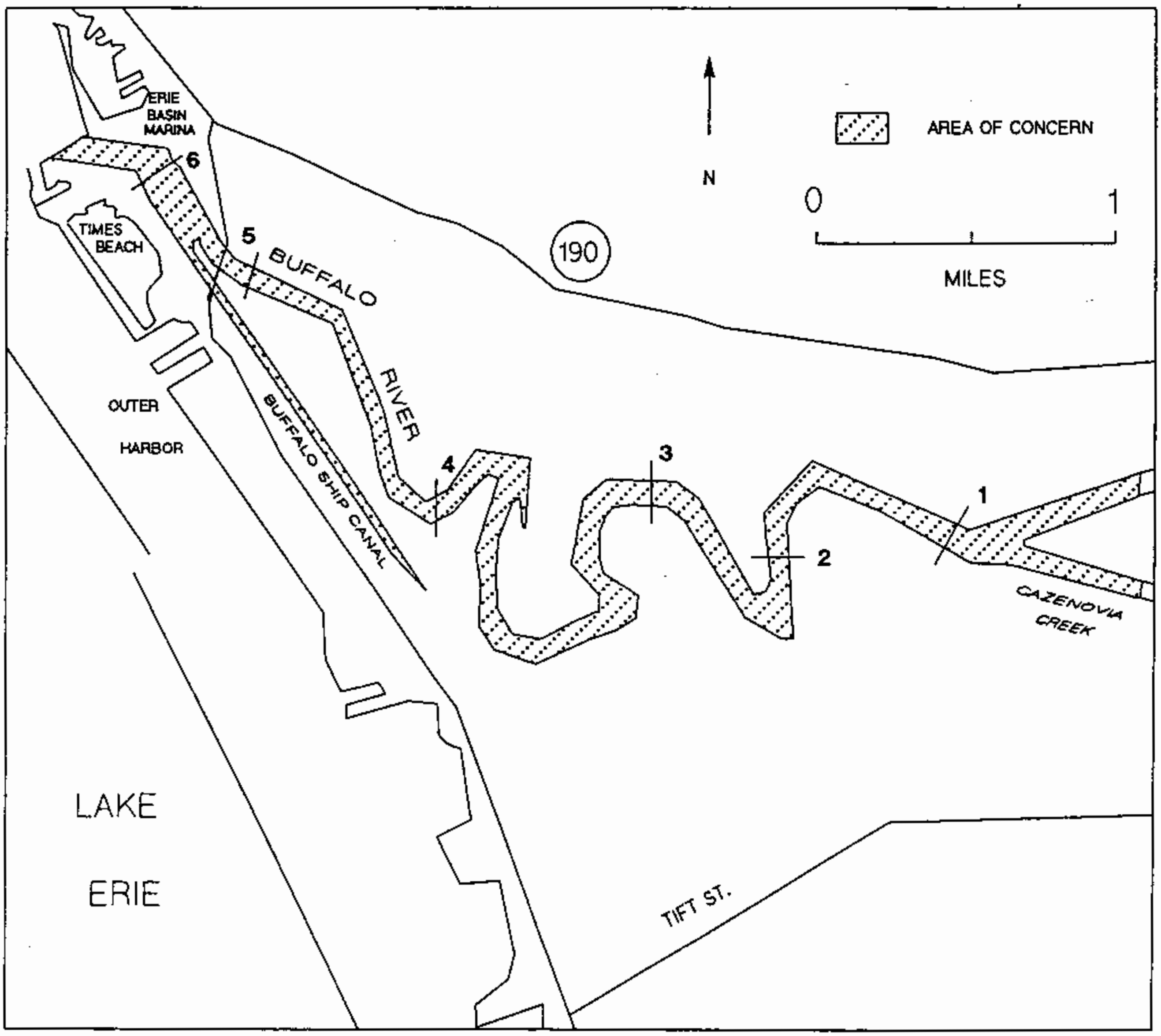


FIGURE 12. Current velocity and selected water quality parameters were measured in the middle of the channel at the six locations (1-6) in the river

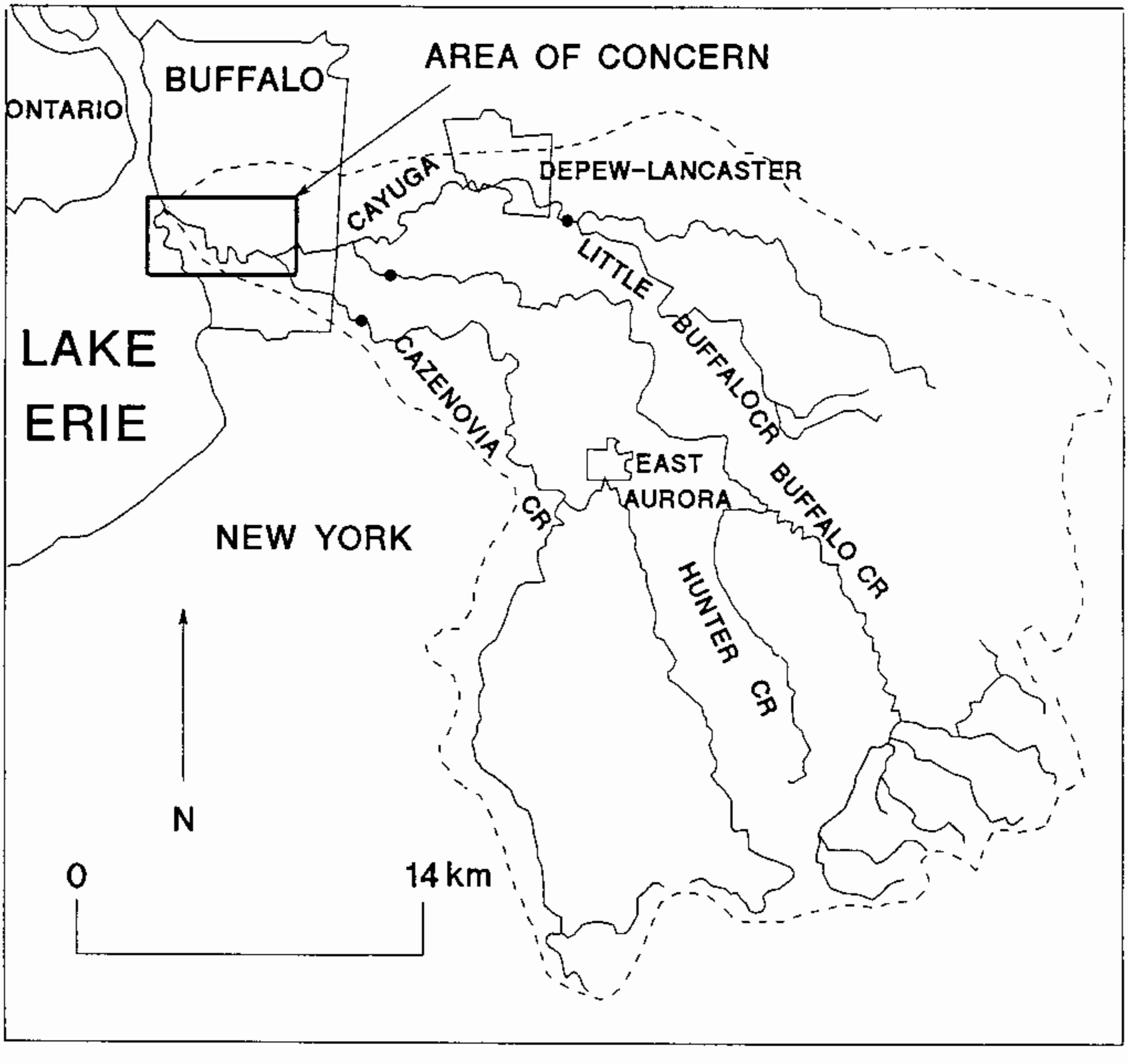


FIGURE 13. Locations of the USGS gage stations are shown as (•)

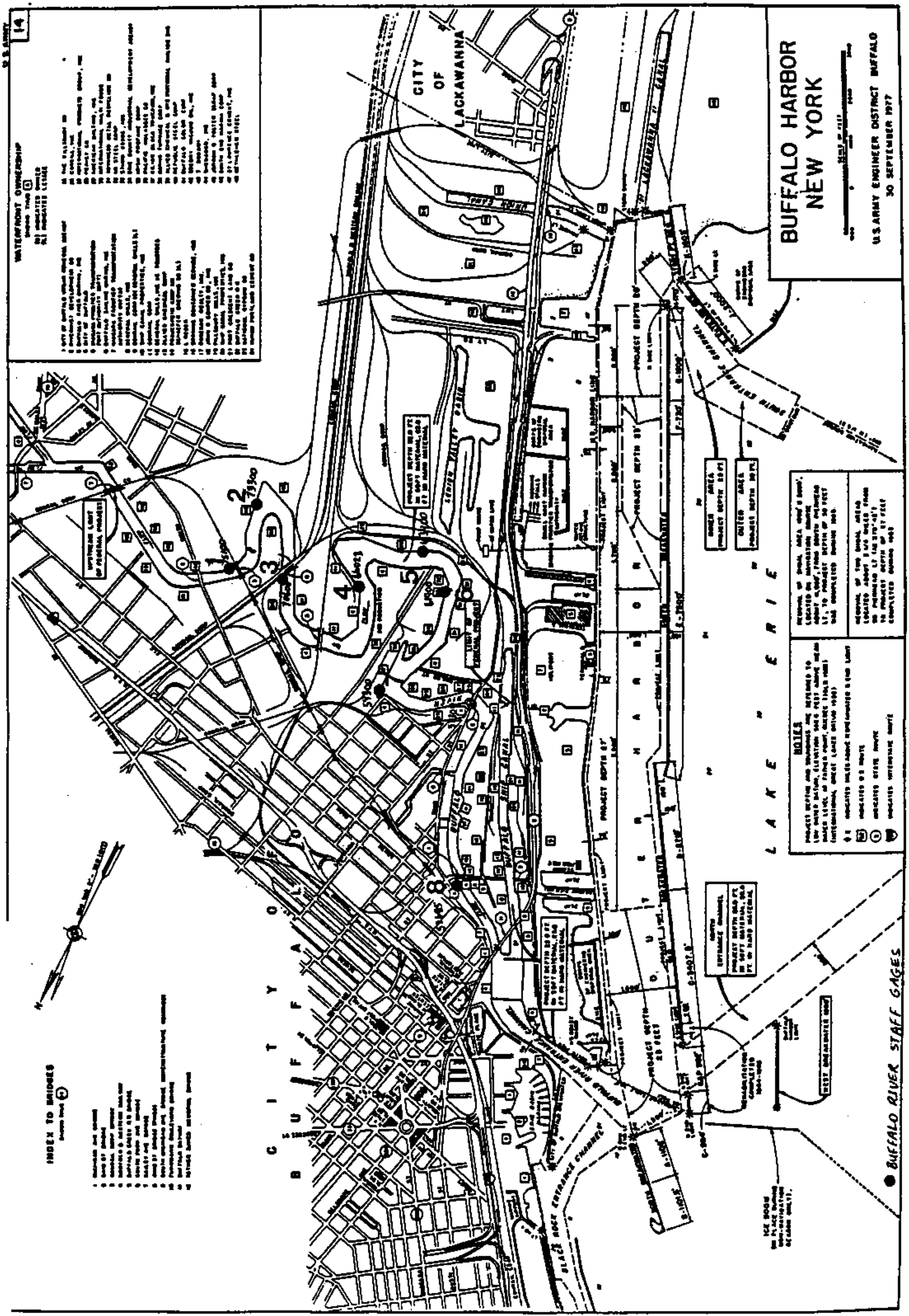


FIGURE 14. Buffalo River staff gage locations (from USCOE)

RESULTS

Table 4 is a record of USGS gage levels, Table 5 is a record of COE gage levels, and Table 6 is the record of current velocities for the 20 sampling days. The water column data at each site for each sampling day are available in ascii format on 1.44 MB disks. Because of the length of these data, only a summary is included in this report. Table 7 provides a summary of: water temperature, T(C); conductivity, cO; dissolved oxygen, DO; and percent transmission of light, Xmiss. values for these parameters are given for sites #1, #4, and #6 at 1, 4 and 7 meters depth. Because site #1 is located above the upper limit of navigational dredging, the greatest depth the Sealogger recorded data was 3 to 4 m.

DISCUSSION

At the beginning of the season (May to early June) the water column exhibited stratification with respect to temperature. The upper portion of the water column was warmer (and less dense) compared to the lower portion of the water column. Water temperature at site #1 was considerably warmer than at site #6, near the mouth of the river. The decrease in temperature from upstream to downstream, as well as from the surface to bottom, is a consequence of estuarine-type flow with warmer river waters flowing on top of colder (and denser) Lake Erie waters. These two water types also can be distinguished by their conductivity. Water column stratification is weak or absent throughout most of the summer months. The water column again becomes stratified in the Fall; in contrast to the Spring stratification, the Buffalo River waters are colder relative to Lake Erie. Water temperatures at site #1 are several degrees C lower than at the mouth of the Buffalo River, again reflecting the incursion of warmer lake waters into the Buffalo River.

The Summer of 1992 was cool and rainfall was higher than average. The results of the high levels of precipitation can be noted by rapid changes in water temperature. Water temperatures decreased by as much as 6°C between two sampling days in July (July 20, July 24). High sediment concentrations attributed to heavy rainfall and runoff are reflected in the off-scale transmissometer values (less than 0). Dissolved oxygen values fluctuated throughout the sampling season. The lowest dissolved oxygen levels (measured in mg/l) consistently occurred at site #4. It appears that the residence time of water is greater in this area or there is a source upstream of site #4 contributing to the increase in oxygen demand. The DEC and SUNY-Buffalo have been involved in modeling dissolved oxygen in the Buffalo River and their results should account for this pattern of dissolved oxygen levels.

CONCLUSIONS

Due to the higher than normal rainfall during the summer of 1992, the water column structure associated with spring, summer and fall never became very well established. Following a heavy rainfall, water temperature decreased by several degrees. The wide fluctuations in temperature are paralleled by dissolved oxygen levels. Dissolved oxygen levels for most of the summer were above 5 mg/l. The sampling site located above the Ohio Street Bridge consistently had the lowest dissolved oxygen levels. Additional efforts should focus on short-term (hourly) changes in water column structure.

TABLE 4. RECORD OF USGS GAGE LEVELS

Date	Buffalo Cr.	Cayuga Cr.	Cazenovia Cr.
5/15/92	1.08@ 9:00	3.45@ 9:00	2.36@ 9:00
5/29/92	0.98@ 9:00	3.24@ 9:00	2.25@ 9:00
6/ 9/92	0.98@ 8:30	3.18@ 8:45	2.23@ 8:45
6/15/92	0.82@ 7:30	2.83@ 7:50	2.05@ 7:50
6/22/92	0.83@ 9:30	3.02@ 9:45	2.15@ 9:45
6/26/92	0.80@ 8:00	2.98@ 8:30	2.10@ 8:30
7/10/92	1.03@ 8:30	3.25@ 8:40	2.23@ 8:40
7/20/92	1.35@ 8:00	3.71@ 8:08	2.56@ 8:08
7/24/92	2.39@ 7:30	4.22@ 8:00	3.66@ 8:00
8/31/92	1.63@10:30	4.27@10:40	2.83@10:40
9/ 4/92	2.34@ 9:30	4.67@ 9:45	3.53@ 9:45
9/11/92	1.26@ 9:00	3.64@ 9:20	2.42@ 9:20
9/25/92	1.45@10:00	4.15@10:10	2.66@10:10
10/ 9/92	1.01@ 9:30	3.27@10:00	2.23@10:00
10/16/92	1.10@ 9:30	3.48@ 9:55	2.48@ 9:55
10/30/92	no data	3.40@10:15	2.37@10:15
11/ 6/92	no data	4.71@10:00	3.61@10:00

TABLE 5. RECORD OF COE GAGE LEVELS (NUMBERS 1-8 REFER TO LOCATION IN FIGURE 14)

DATE	1	2	3	4	5	6	7	8
5/15/92	2.9@10:12 2.7@10:40	2.9@10:10 2.9@11:00	2.9@10:08	2.7@10:05 2.8@11:25	2.8@10:03 2.8@11:27	2.8@10:02	2.7@ 9:57 2.7@11:32	2.7@ 9:50 2.9@11:47
5/29/92	2.9@10:28 2.9@10:52	2.9@10:26 2.9@11:08	2.8@10:25 2.9@11:10	2.8@10:22 2.9@11:25	2.9@10:20 2.9@11:26	2.9@10:19	2.9@10:17 2.9@11:29	2.9@10:10 2.9@11:47
6/ 9/92	3.1@ 9:46 3.0@10:25	3.1@ 9:45 2.8@10:40	3.1@ 9:44 2.9@10:41	3.0@ 9:41 2.9@11:03	3.0@ 9:41 2.9@11:05	3.0@ 9:40	2.9@ 9:37 2.8@11:07	2.9@ 9:32 3.0@11:25
6/15/92	2.1@ 9:11 2.2@ 9:35	2.1@ 9:10 2.0@ 9:58	2.0@ 9:08 2.1@10:17	2.1@ 9:05 2.1@10:18	2.0@ 9:04	2.0@ 9:03	2.0@ 9:01 2.2@10:24	2.0@ 8:55 2.3@10:40
6/22/92	2.9@11:01 3.0@11:21	2.9@10:59 3.0@11:38	2.9@10:58 3.0@11:39	2.8@10:56 3.0@11:58	2.9@10:55	2.9@10:54	2.9@10:52 3.0@12:00	2.9@10:47 2.9@12:16
6/26/92	2.8@ 9:55 3.0@10:20	2.8@ 9:52 3.0@10:31	2.8@ 9:50 2.9@10:34	2.8@ 9:49 2.9@10:47	2.8@ 9:48	2.8@ 9:47	2.7@ 9:45 2.9@10:53	2.8@ 9:40 2.9@11:10
7/10/92	3.1@ 9:32 3.1@ 9:58	3.0@ 9:31 3.0@10:14	3.0@ 9:30 2.9@10:15	3.0@ 9:28 2.8@10:30	3.0@ 9:26 2.9@10:31	3.0@ 9:25	2.9@ 9:21 2.9@10:33	2.9@ 9:16 3.0@10:49
7/20/92	3.5@11:00 3.5@11:20	3.4@10:59 3.4@11:36	3.4@10:58 3.3@11:37	3.4@10:56 3.4@11:56	3.4@10:54 3.4@11:57	3.4@10:53 3.4@11:58	3.5@10:50 3.4@12:00	3.4@10:46 3.4@12:14
7/24/92	3.0@ 9:53 3.0@10:13	3.0@ 9:52 3.0@10:24	3.0@ 9:50 3.0@10:25	3.0@ 9:48 3.1@10:37	2.9@ 9:46 3.2@10:38	2.9@ 9:45 3.2@10:39	2.9@ 9:43 3.2@10:41	2.8@ 9:38 3.2@10:59
8/ 1/92	3.8@10:42	3.8@10:25	3.8@10:23	3.8@10:22	3.8@10:20	3.8@10:07	3.8@10:05	3.6@ 9:47

TABLE 5. Continued

DATE	1	2	3	4	5	6	7	8
8/31/92	3.8@10:42	3.8@10:25	3.8@10:23	3.8@10:22	3.8@10:20			3.5@9:47
	3.5@11:47	3.1@12:03	3.1@12:04	3.3@12:25	3.2@12:26	3.3@12:27		3.2@12:45
9/ 4/92	2.7@11:15	2.8@11:12	2.8@11:10	2.8@11:06	2.8@11:05		2.8@11:03	2.8@10:55
	2.7@11:37	2.7@11:49	2.8@11:50	2.8@12:03	2.9@12:05		2.8@12:08	2.9@12:25
9/11/92	3.0@11:10	3.0@10:55	3.0@10:54	2.9@10:51	2.9@10:50	2.9@10:49		2.8@10:44
		3.4@11:25	3.4@11:26	3.3@11:42	3.3@11:44	3.3@11:45		3.4@12:02
9/25/92	2.8@11:10	2.8@10:55	2.8@10:54	2.8@10:51	2.8@10:50	2.8@10:49	2.7@10:48	2.8@10:44
	2.8@11:45	2.9@11:50	2.9@12:03	2.9@12:24	2.9@12:39	2.9@12:40	2.8@12:41	3.0@12:02
10/ 9/92	4.1@11:15	4.0@11:13	4.0@11:12	4.0@11:09	4.0@11:07	4.0@11:06	3.8@11:03	3.7@10:55
	4.0@11:30	3.4@11:45	3.4@11:46	2.8@11:59	2.8@12:01	2.8@12:02	2.8@12:04	2.9@12:20
10/16/92	3.8@10:53	3.8@10:51	3.8@10:50	3.8@10:48	3.8@10:47	3.8@10:47	3.8@10:45	3.8@10:41
	3.9@11:08	3.8@11:20	3.8@11:21	3.7@11:35	3.7@11:36	3.7@11:36	3.7@11:38	3.5@11:50
10/30/92	2.5@11:14	2.5@11:13	2.5@11:12	2.4@11:10	2.4@11:09	2.4@11:08	2.4@11:07	2.4@11:03
	2.6@11:31	2.6@11:42	2.6@11:43	2.5@11:57		2.5@11:58	2.5@11:59	2.4@12:12
11/ 6/92	3.0@11:11	2.9@11:10	2.9@11:09	2.9@11:05	2.9@11:04	2.9@11:03	2.9@11:07	2.8@10:57
	2.8@12:01	2.8@12:15	2.8@12:16	2.7@12:31	2.7@12:31	2.8@12:32	2.8@12:35	2.8@12:55

TABLE 6. CURRENT VELOCITIES (Meters/Sec) FOR EACH SAMPLING DAY (NUMBERS REFER TO SIX SAMPLING SITES IN RIVER)

Date	Depth	#1	#2	#3	#4	#5	#6
5/15/92	1	0.11	0.04	0.07	0.03	0.09	0.06
	2	0.13	0.03	0.02	0.02	0.09	0.05
	3	0.12	0.01	0.04	0.02	0.07	0.06
	4	0.09	0.02	0.05	0.02	0.02	0.04
	5	0.11	0.02	0.03	0.03	0.03	0.06
	6	0.11	0.01	0.03	0.02	0.05	0.06
	8	0.10	0.01	0.01	0.03	0.03	0.07
	10	0.10	0.01	0.01	0.01	0.05	0.05
	12	0.08	0.03	0.01	-0.02	0.04	0.03
	14	0.07	0.03	0.01	0.00	0.03	0.02
	16	0.08	0.01	0.00	-0.02	0.01	0.01
5/29/92	1	0.01	-0.01	0.00	-0.05	0.03	-0.01
	2	0.01	0.02	-0.02	0.03	0.03	0.02
	3	0.01	0.03	0.00	0.01	0.04	0.02
	4	0.03	0.03	0.00	0.02	0.05	0.02
	5	0.00	0.02	0.00	0.02	0.06	0.01
	6	0.01	0.02	-0.01	0.02	0.04	0.02
	8	0.02	0.02	-0.01	0.01	0.04	0.02
	10	0.01	-0.02	-0.03	0.01	0.05	0.02
	12	0.05	-0.03	-0.02	0.02	0.04	0.02
	14	0.01	-0.04	-0.03	0.02	0.03	0.02
	16	0.02	-0.02	-0.02	0.00	0.02	0.01
6/ 9/92	1	0.04	0.05	0.01	0.02	-0.01	-0.02
	2	0.05	0.04	0.03	0.01	-0.02	-0.02
	3	0.06	0.03	0.03	-0.02	-0.03	-0.03
	4	0.05	0.03	0.02	-0.01	-0.02	-0.02
	5	0.03	0.03	0.02	-0.02	-0.02	-0.02
	6	0.06	0.03	0.04	-0.02	-0.02	-0.02
	8	0.07	0.03	0.03	-0.02	-0.03	-0.03
	10	0.07	0.04	0.02	-0.02	-0.03	-0.02
	12	0.06	0.02	0.03	-0.02	-0.03	-0.02
	14	0.05	0.02	0.02	-0.01	-0.02	-0.02
	16	0.06	0.02	0.00	-0.04	-0.03	-0.03
6/15/92	1	0.03	0.06	0.02	-0.03	-0.02	0.02
	2	0.04	0.06	0.02	-0.01	-0.01	0.02
	3	0.04	0.05	0.02	-0.02	-0.01	0.01
	4	0.03	0.05	0.02	-0.02	-0.01	0.03
	5	0.04	0.04	0.02	-0.01	-0.01	0.01
	6	0.02	0.03	0.01	-0.02	-0.02	0.03
	8	0.02	0.02	-0.03	-0.02	-0.03	0.03
	10		0.01	-0.02	-0.03	-0.04	0.03
	12		0.01	-0.03	-0.03	-0.03	0.02
	14		-0.02	-0.03	-0.03	-0.02	0.02
	16		-0.03	-0.04	-0.03	-0.04	0.02

TABLE 6. Continued

Date	Depth	#1	#2	#3	#4	#5	#6
6/22/92	1	-0.03	0.01	-0.01	0.02	0.02	0.03
	2	-0.03	0.00	-0.02	0.02	0.02	0.03
	3	-0.03	-0.02	-0.04	0.03	0.02	0.02
	4	-0.02	0.00	-0.03	0.01	0.02	0.03
	5	-0.02	-0.03	-0.02	0.01	0.02	0.03
	6	-0.01	-0.02	-0.03	0.02	0.02	0.03
	8	0.00	-0.03	-0.02	0.01	0.01	0.03
	10	0.00	-0.04	-0.01	0.03	0.03	-0.01
	12	0.01	-0.02	-0.01	0.01	0.04	-0.02
	14	0.02	-0.03	-0.01	0.03	0.05	-0.01
	16	0.02	-0.02	-0.01	0.04	0.04	-0.01
6/26/92	1	-0.06	0.03	0.04	0.04	0.08	0.07
	2	-0.06	0.01	0.03	0.04	0.08	0.06
	3	-0.03	0.01	0.03	0.04	0.09	0.07
	4	-0.03	0.02	0.01	0.04	0.09	0.05
	5	-0.04	0.02	0.00	0.04	0.08	0.05
	6	-0.02	0.02	0.01	0.04	0.09	0.05
	8	-0.01	0.02	0.02	0.05	0.07	0.05
	10	-0.01	0.02	0.02	0.05	0.08	0.05
	12	0.01	0.01	0.02	0.05	0.08	0.07
	14	0.01	0.01	0.01	0.03	0.06	0.06
	16	0.00	0.01	0.01	0.02	0.05	0.06
7/10/92	1	-0.01	0.00	0.03	0.04	-0.03	0.02
	2	-0.01	0.01	0.03	0.01	-0.02	0.01
	3	-0.01	0.01	0.01	0.01	-0.02	-0.01
	4	-0.01	0.00	0.02	0.00	-0.02	-0.01
	5	-0.01	0.02	0.03	0.01	-0.01	-0.02
	6	-0.01	0.03	0.02	0.00	-0.01	-0.02
	8	-0.01	0.03	0.03	0.02	-0.02	-0.02
	10	-0.02	0.05	0.02	0.02	-0.01	-0.02
	12	-0.01	0.03	0.03	0.01	-0.02	-0.02
	14	-0.03	0.05	0.04	0.01	-0.02	-0.03
	16	-0.01	0.04	0.03	0.00	-0.02	-0.02
7/20/92	1	0.07	0.04	0.05	0.01	-0.04	-0.09
	2	0.06	0.02	0.06	0.01	-0.02	-0.09
	3	0.06	0.01	0.06	0.01	-0.02	-0.08
	4	0.06	0.01	0.09	0.01	0.00	-0.09
	5	0.06	0.03	0.07	0.02	0.00	-0.08
	6	0.07	0.01	0.05	0.01	-0.01	-0.06
	8	0.07	0.04	0.06	0.03	0.00	-0.03
	10	0.12	0.07	0.05	0.04	-0.01	-0.03
	12	0.12	0.09	0.05	0.04	-0.01	-0.02
	14	0.14	0.09	0.05	0.03	-0.01	-0.02
	16	0.12	0.09	0.06	0.04	-0.02	0.01

TABLE 6. Continued

Date	Depth	#1	#2	#3	#4	#5	#6
7/24/92	1	0.16	0.06	0.06	0.03	0.02	0.10
	2	0.16	0.07	0.06	0.05	0.02	0.09
	3	0.16	0.06	0.06	0.03	0.03	0.10
	4	0.14	0.08	0.06	0.06	0.02	0.08
	5	0.16	0.09	0.07	0.07	0.02	0.08
	6	0.12	0.09	0.05	0.06	0.03	0.07
	8	0.15	0.09	0.06	0.05	0.05	0.08
	10	0.12	0.09	0.06	0.08	0.06	0.06
	12	0.15	0.08	0.06	0.05	0.05	0.06
	14	0.12	0.06	0.07	0.03	0.06	0.07
	16	0.15	0.06	0.05	0.04	0.09	0.08
8/ 1/92	1		0.12	0.08	0.06	0.07	0.09
	2		0.14	0.08	0.10	0.08	0.06
	3		0.13	0.10	0.10	0.06	0.05
	4		0.13	0.08	0.10	0.02	-0.04
	5		0.15	0.07	0.11	0.03	-0.06
	6		0.12	0.09	0.13	0.05	-0.03
	8		0.10	0.10	0.14	0.03	-0.06
	10		0.10	0.11	0.15	0.03	-0.01
	12		0.08	0.08	0.13	0.04	0.01
	14		0.08	0.10	0.12	0.09	0.12
	16		0.10	0.11	0.11	0.10	0.11
8/31/92	1	0.11	0.12	0.01	0.02	-0.01	-0.04
	2	0.12	0.11	0.00	-0.01	0.01	-0.03
	3	0.16	0.08	0.02	0.02	0.01	-0.07
	4	0.16	0.10	0.02	0.04	-0.01	-0.05
	5	0.18	0.11	0.03	0.01	0.01	-0.06
	6	0.21	0.16	0.03	0.04	-0.02	-0.05
	8	0.21	0.14	-0.01	0.03	-0.01	-0.02
	10	0.23	0.14	0.02	0.04	0.03	-0.03
	12	0.18	0.12	0.01	0.05	0.03	-0.02
	14	0.14	0.14	-0.03	0.05	0.03	-0.02
	16	0.11	0.16	-0.02	0.04	0.01	0.01
9/ 4/92	1	0.23	0.08	0.12	0.05	0.03	-0.04
	2	0.23	0.07	0.08	0.04	0.05	-0.02
	3	0.22	0.08	0.06	0.04	0.10	-0.01
	4	0.21	0.08	0.05	0.02	0.06	-0.01
	5	0.21	0.09	0.06	0.04	0.03	-0.02
	6	0.15	0.08	0.05	0.05	0.03	0.01
	8	0.12	0.09	0.08	0.08	0.02	0.01
	10	0.09	0.07	0.13	0.06	0.07	0.01
	12	0.05	0.08	0.16	0.07	0.13	0.02
	14	0.07	0.07	0.11	0.05	0.10	0.02
	16	0.03	0.05	0.09	0.02	0.19	0.03

TABLE 6. Continued

Date	Depth	#1	#2	#3	#4	#5	#6
9/11/92	1	-0.05	0.06	-0.02	0.01	0.07	-0.03
	2	-0.03	0.05	0.05	0.01	0.09	-0.04
	3	-0.01	0.05	0.07	0.02	0.08	-0.04
	4	0.01	0.05	0.05	0.01	0.10	-0.04
	5	0.03	0.05	0.07	0.04	0.08	-0.05
	6	0.04	0.01	0.05	0.03	0.06	-0.04
	8	0.05	0.02	0.04	0.02	0.03	-0.07
	10	0.06	0.03	0.05	0.02	0.01	-0.07
	12	0.08	0.02	0.04	0.02	0.00	-0.07
	14	0.09	0.05	0.04	0.03	0.03	-0.09
	16	0.08	0.03	0.06	0.03	0.01	-0.05
9/25/92	1	0.11	0.06	0.02	0.04	0.03	-0.12
	2	0.10	0.05	0.03	0.05	0.03	-0.08
	3	0.07	0.03	0.02	0.04	0.03	-0.07
	4	0.05	0.06	0.03	0.05	0.03	-0.08
	5	0.07	0.06	0.03	0.05	0.01	-0.09
	6	0.05	0.03	0.04	0.04	0.01	-0.09
	8	0.06	0.02	0.04	0.05	0.02	-0.10
	10	0.06	0.03	0.03	0.03	0.03	-0.01
	12	0.04	0.03	0.03	0.03	0.01	-0.01
	14	0.04	0.02	0.02	0.03	0.02	-0.01
	16	0.04	0.01	0.02	0.04	0.02	-0.01
10/ 9/92	1	0.07	0.15	0.21	0.04	-0.11	-0.17
	2	0.07	0.17	0.17	0.06	-0.11	-0.16
	3	0.10	0.18	0.19	0.06	-0.14	-0.16
	4	0.11	0.18	0.22	0.03	-0.20	-0.16
	5	0.12	0.20	0.20	0.04	-0.22	-0.16
	6	0.12	0.20	0.14	0.05	-0.17	-0.14
	8	0.10	0.16	0.15	0.05	-0.13	-0.21
	10	0.08	0.15	0.14	0.03	-0.14	-0.16
	12	0.14	0.14	0.14	0.04	-0.14	-0.13
	14	0.10	0.17	0.19	0.03	-0.14	-0.10
	16	0.08	0.18	0.17	0.03	-0.14	-0.09
10/16/92	1	-0.03	-0.02	0.02	0.09	0.09	-0.01
	2	-0.04	-0.03	0.03	0.06	0.11	0.02
	3	-0.06	-0.01	0.03	0.08	0.11	0.02
	4	-0.06	-0.02	0.03	0.07	0.11	0.04
	5	-0.06	-0.02	0.02	0.10	0.11	0.03
	6	-0.04	-0.05	0.02	0.09	0.13	0.03
	8	-0.03	-0.03	0.03	0.10	0.10	0.03
	10	-0.02	-0.03	0.05	0.10	0.09	0.04
	12	-0.02	-0.02	0.05	0.13	0.12	0.03
	14	-0.01	-0.01	0.04	0.13	0.10	0.03
	16	0.00	-0.01	0.04	0.13	0.10	0.04

TABLE 6. Continued

Date	Depth	#1	#2	#3	#4	#5	#6
10/30/92	1	0.01	0.04	0.05	0.06	-0.04	-0.08
	2	0.00	0.04	0.04	0.08	-0.03	-0.07
	3	0.01	0.03	0.03	0.08	-0.04	-0.04
	4	-0.01	0.02	0.03	0.08	-0.07	-0.05
	5	-0.02	0.02	0.02	0.08	-0.08	-0.03
	6	-0.02	0.03	0.03	0.08	-0.04	-0.04
	8	-0.01	0.03	0.01	0.06	0.04	-0.05
	10	-0.02	0.02	0.03	0.06	0.03	-0.09
	12	-0.03	0.02	0.05	0.07	0.05	-0.07
	14	-0.01	0.02	0.04	0.07	0.05	-0.06
	16	-0.01	0.02	0.04	0.06	0.04	-0.03
11/ 6/92	1	0.18	0.10	0.10	0.11	0.08	0.02
	2	0.21	0.08	0.06	0.09	0.13	0.05
	3	0.22	0.08	0.06	0.07	0.19	0.07
	4	0.24	0.09	0.09	0.07	0.16	0.10
	5	0.23	0.08	0.09	0.09	0.12	0.13
	6	0.23	0.08	0.07	0.07	0.11	0.13
	8	0.16	0.08	0.09	0.07	0.08	0.12
	10	0.20	0.08	0.05	0.07	0.10	0.07
	12	0.14	0.08	0.08	0.07	0.10	0.05
	14	0.14	0.08	0.10	0.07	0.15	0.02
	16	0.11	0.09	0.08	0.08	0.10	0.01

TABLE 7. SUMMARY OF SELECTED WATER QUALITY PARAMETERS

date	filename	site #	depth (m)	T(C)	cO	DO	Xmiss
5/15/92	BR4	1	1	16.63	0.037	6.7	58.1
		1	4	16.48	0.038	7.6	47.2
		4	1	16.30	0.034	4.2	26.2
		4	4	15.15	0.031	5.7	16.6
		4	7	14.74	0.030	6.0	27.8
		6	1	15.05	0.029	7.1	53.4
		6	4	13.14	0.025	7.4	54.5
		6	7	11.92	0.020	8.7	73.5
5/21/92	BR5	1	1	20.21	0.044	6.8	57.2
		1	4	18.08	0.043	6.7	49.1
		4	1	19.64	0.040	5.4	56.6
		4	4	13.41	0.023	5.4	62.3
		4	7	12.86	0.021	8.8	70.3
		6	1	18.33	0.036	5.0	71.7
		6	4	13.13	0.021	6.5	76.8
		6	7	12.59	0.021	9.9	67.2
5/27/92	BR6	1	1	14.71	0.039	4.1	59.5
		1	4	13.85	0.040	4.7	65.5
		4	1	14.77	0.029	4.8	53.7
		4	4	14.24	0.028	6.0	53.6
		4	7	10.71	0.021	7.2	51.4
		6	1	13.79	0.027	7.2	60.7
		6	4	10.11	0.020	8.1	70.8
		6	7	10.05	0.020	9.7	66.1
5/29/92	BR8	1	1	15.61	0.041	5.9	65.3
		1	4	14.84	0.047	7.3	60.1
		4	1	14.96	0.032	4.4	58.7
		4	4	14.15	0.028	4.9	55.0
		4	7	11.57	0.022	6.1	49.6
		6	1	14.21	0.027	6.8	60.3
		6	4	11.98	0.022	7.4	51.0
		6	7	10.66	0.025	9.8	38.3
6/9/92	BR9	1	1	21.41	0.044	5.1	49.9
		1	3	18.39	0.043	6.2	32.4
		4	1	17.63	0.035	5.6	30.8
		4	4	17.12	0.033	5.7	29.8
		4	7	17.02	0.033	5.6	34.4
		6	1	17.64	0.032	6.8	76.2
		6	4	15.63	0.024	7.3	67.7
		6	7	14.75	0.026	7.8	53.6

TABLE 7. Continued

date	filename	site#	depth (m)	T(C)	cO	DO	Xmiss
6/15/92	BR10	1	1	22.42	0.046	5.6	42.6
		1	3	18.32	0.044	7.0	35.8
		4	1	20.54	0.038	6.0	68.3
		4	4	18.48	0.031	7.0	65.6
		4	7	16.21	0.034	6.9	40.8
		6	1	19.65	0.032	5.6	77.0
		6	4	17.81	0.025	6.0	77.7
		6	7	16.19	0.031	7.4	54.1
6/22/92	BR11	1	1	17.73	0.038	3.3	45.1
		1	3	16.32	0.039	3.7	48.7
		4	1	18.58	0.036	2.4	45.7
		4	4	18.33	0.036	2.8	41.5
		4	7	18.32	0.036	2.5	33.0
6/26/92	BR12	1	1	18.44	0.044	5.6	40.7
		1	3	18.32	0.045	6.1	39.7
		4	1	18.73	0.039	1.3	55.4
		4	4	18.10	0.035	1.7	49.1
		4	6.5	17.85	0.033	2.3	38.2
		6	1	17.81	0.031	3.5	57.3
		6	4	16.73	0.026	4.2	55.0
		6	7	15.94	0.024	5.7	61.4
7/10/92	BR13	1	1	22.25	0.044	5.4	31.8
		1	4	21.89	0.045	5.1	19.7
		4	1	21.40	0.040	3.4	58.6
		4	4	21.04	0.039	3.0	56.8
		4	6.5	20.46	0.036	2.5	42.3
		6	1	21.07	0.039	3.1	70.2
		6	4	19.46	0.027	3.6	70.2
		6	7	19.01	0.028	4.9	48.4
7/20/92	BR15	1	1	22.90	0.035	4.6	21.6
		1	4	22.40	0.033	5.1	20.3
		4	1	21.34	0.026	5.2	11.2
		4	4	21.12	0.026	5.1	9.6
		4	7	20.71	0.025	4.9	7.9
		6	1	21.49	0.026	6.0	46.4
		6	4	20.82	0.025	5.9	21.6
		6	7	20.19	0.027	5.1	15.9
7/24/92	BR16	1	1	15.97	0.019	7.7	0.1
		1	4	15.88	0.018	7.8	0.3
		4	1	16.43	0.015	6.3	<0
		4	4	16.43	0.014	6.7	<0
		4	7	16.43	0.014	6.7	<0
		6	1	20.04	0.026	4.6	6.1
		6	4	17.15	0.017	5.5	0.0
		6	7	16.53	0.015	6.4	<0

TABLE 7. Continued

date	filename	site #	depth (m)	T(C)	cO	DO	Xmiss
8/1/92	BR17	1	1	15.48	0.020	6.4	0.0
		1	4	15.47	0.020	6.8	0.0
		4	1	15.83	0.021	6.2	0.3
		4	4	15.79	0.020	6.6	0.2
		4	7	15.77	0.020	6.5	0.2
		6	1	16.64	0.021	5.6	2.4
		6	4	16.35	0.021	5.8	1.4
		6	7	15.95	0.021	6.0	0.9
8/31/92	BR19	1	1	16.90	0.031	6.3	31.7
		1	4	16.46	0.029	7.0	33.8
		4	1	17.36	0.022	5.6	9.6
		4	4	17.33	0.022	6.0	8.2
		4	7	17.30	0.022	6.0	8.4
		6	1	18.07	0.020	5.7	15.2
		6	4	17.90	0.020	5.7	15.0
		6	7	18.16	0.031	5.6	14.8
9/4/92	BR20	1	1	18.06	0.021	6.4	1.0
		1	4	17.81	0.019	7.2	1.4
		4	1	18.64	0.023	7.4	0.1
		4	4	18.61	0.023	5.8	0.0
		4	7	18.60	0.023	6.0	0.0
		6	1	18.92	0.028	5.9	3.1
		6	4	18.81	0.026	6.0	2.0
		6	7	18.82	0.028	6.0	1.4
9/11/92	BR21	1	1	20.35	0.038	5.4	40.0
		1	4	19.52	0.038	5.8	37.8
		4	1	21.21	0.037	3.2	11.7
		4	4	21.19	0.037	3.6	7.1
		4	7	21.17	0.037	3.6	5.8
		6	1	20.65	0.030	3.3	27.5
		6	4	20.63	0.030	3.6	26.6
		6	7	20.61	0.030	3.6	25.8
9/25/92	BR22	1	1	12.17	0.029	8.3	48.1
		1	4	12.17	0.029	8.3	47.1
		4	1	14.35	0.022	6.8	15.4
		4	4	14.19	0.022	6.2	15.8
		4	7	13.83	0.023	6.5	11.1
		6	1	17.76	0.023	6.0	68.1
		6	4	15.76	0.021	6.8	34.2
		6	7	15.07	0.021	6.1	20.9

TABLE 7. Continued

date	filename	site #	depth (m)	T(C)	cO	DO	Xmiss
10/9/92	BR23	1	1	13.47	0.037	6.0	49.2
		1	4	13.34	0.037	7.4	48.0
		4	1	14.42	0.033	4.6	34.2
		4	4	14.43	0.033	5.1	35.1
		4	7	14.43	0.033	5.5	34.8
		6	1	16.02	0.024	6.8	53.2
		6	4	15.73	0.025	6.8	45.2
		6	7	15.49	0.026	6.6	36.3
10/16/92	BR24	1	1	11.62	0.035	7.1	58.1
		1	4	11.07	0.035	7.4	58.8
		4	1	13.37	0.036	5.0	50.4
		4	4	13.36	0.036	5.2	50.0
		4	7	13.35	0.036	5.3	48.4
		6	1	13.99	0.024	6.6	61.1
		6	4	13.56	0.029	6.8	40.0
		6	7	13.49	0.031	6.0	26.9
10/30/92	BR25	1	1	7.62	0.029	7.9	71.7
		1	4	7.52	0.028	8.3	71.6
		4	1	7.34	0.021	4.4	31.8
		4	4	7.32	0.021	6.0	31.1
		4	7	7.32	0.021	6.5	31.1
		6	1	9.34	0.021	6.4	59.6
		6	4	8.63	0.022	7.1	29.1
		6	7	9.12	0.022	6.0	14.5
11/6/92	BR26	1	1	4.62	0.018	9.0	31.2
		1	4	4.60	0.017	9.6	31.8
		4	1	6.93	0.019	6.5	22.6
		4	4	6.93	0.019	6.9	22.6
		4	7	6.93	0.019	7.4	22.5
		6	1	7.72	0.020	6.1	30.9
		6	4	7.70	0.020	6.6	30.8
		6	7	7.66	0.020	6.8	30.7

CALIBRATION

Prior to the beginning of the 1992 Field season (March), the Sealogger was shipped to SeaBird Electronics (Bellevue, Washington) for calibration of the sensors. Calibration reports are provided with this report.

SEA-BIRD ELECTRONICS, INC.
1808 136th Place N.E., Bellevue, Washington 98005
Telephone: (206) 643-9866 Telex: 292915 SBEI UR

CONDUCTIVITY CALIBRATION DATA
CALIBRATION DATE: 11-Mar-92

PSS 1978: C(35,15,0) = 4.2914 Siemens/meter

SENSOR SERIAL NUMBER = 749

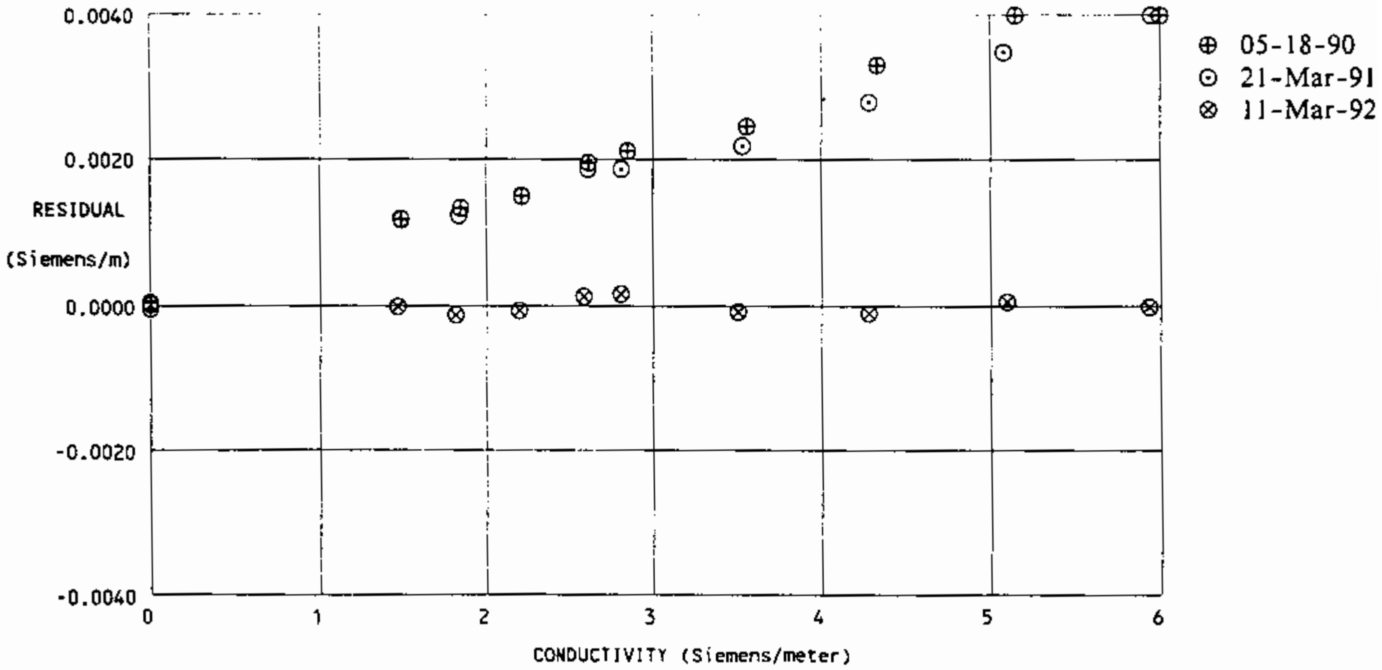
a = 6.29173975e-06
b = 4.39842381e-01
c = -4.07832856e+00
d = -1.60715421e-04
m = 4.4

BATH TEMP (°C)	BATH SAL (°/oo)	BATH COND (Siemens/m)	INST FREQ (kHz)	INST COND (Siemens/m)	RESIDUAL (Siemens/m)
31.0999	34.8474	5.92979	11.97108	5.92978	-0.00001
23.1409	34.8479	5.09353	11.15812	5.09359	0.00006
15.0645	34.8475	4.28102	10.30515	4.28092	-0.00010
6.8520	34.8475	3.50090	9.41234	3.50082	-0.00008
-1.0188	34.8471	2.80528	8.53673	2.80545	0.00017
26.9390	15.0938	2.58001	8.23347	2.58015	0.00014
19.0400	15.0937	2.19248	7.68193	2.19241	-0.00007
10.8850	15.0935	1.81220	7.09894	1.81208	-0.00012
2.8460	15.0935	1.46111	6.51441	1.46110	-0.00001
0.0000	0.0000	0.00000	3.04480	0.00002	0.00002

Conductivity = $(af^m + bf^2 + c + dt) / [10(1 - 9.57(10^{-8})p)]$ Siemens/meter, where p = pressure in dbars

Residual = instrument conductivity - bath conductivity

NOTE: Multiply Siemens/meter by 10 to obtain mmho/cm



SBE **SEA-BIRD ELECTRONICS, INC** **TELEPHONE 206 643-9866** **FAX 206 643-9954**
1808-136th Place Northeast, Bellevue, Washington 98005 USA Telex 292915 SBEI UR

Conductivity Calibration Report

Customer: Buffalo State College

SBE Job Number: 5525 Date of report: 18 March 1992

SBE Model Number: 4 Serial Number: 749

Unless instructed otherwise and if received intact (not broken) and functional, conductivity sensors are calibrated 'as received', i.e, without cleaning or other processing that would prevent determination of the sensor's drift history. If calibration uncovers problems with the sensor or demonstrates the need to clean the conductivity cell and replatinize the cell electrodes, a second calibration will be performed after the necessary work is finished.

An 'as received' calibration certificate listing the coefficients used to convert sensor frequency to conductivity will be provided. Users may judge whether the 'as received' or previously determined coefficients are more likely to represent the condition of the sensor at the time of deployment (those using SEASOFT should enter the chosen coefficients using SEACON). Calibration coefficients obtained after a repair or after cleaning and replatinizing the cell should only be used with data collected subsequent to the calibration.

'AS RECEIVED CALIBRATION' (x) Performed ( ) Not Performed

Date: 11 Mar 92 Drift since last cal: .000090 S/m/month[1]

Comments:

'POST CLEANING/REPLATINIZING CALIBRATION' ( ) Performed (x) Not Performed

Date: ______ Drift since initial cal:[2] ______ S/m/month[2]

Comments:

[1] Measured at 3.0 S/m

[2] Cleaning and replatinizing tend to 'reset' the conductivity sensor to its original condition. Therefore, lack of drift in post cleaning/replatinizing calibration is an indicator of geometric stability of the cell and the electrical stability of the sensor interface circuits. 'Drift since initial cal' is the total drift from date of the sensor's initial calibration (at time of manufacture) except where the cell has been replaced in which case the drift is referenced to the 1st calibration using the replacement cell.

SEA-BIRD ELECTRONICS, INC.
1808 136th Place N.E., Bellevue, Washington 98005
Telephone: (206) 643-9866 Telex: 292915 SBEI UR

TEMPERATURE CALIBRATION DATA
CALIBRATION DATE: 11-Mar-92

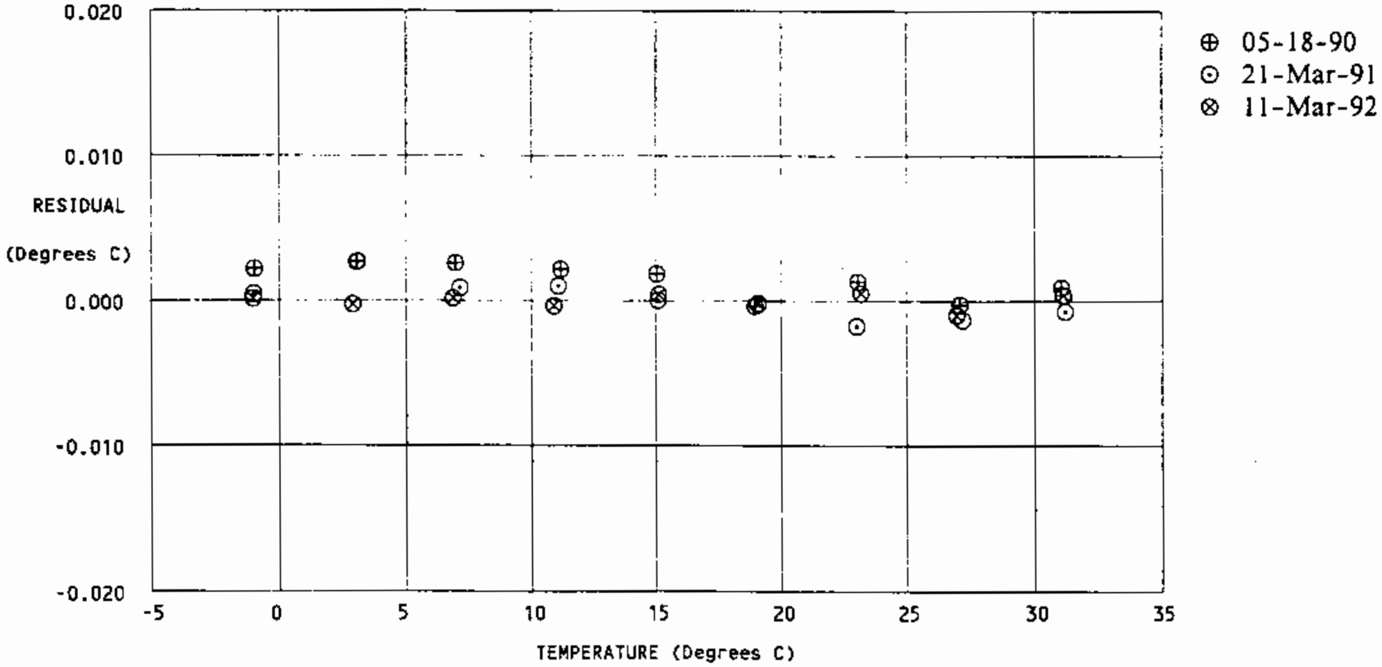
SENSOR SERIAL NUMBER = 1068

a = 3.67469627e-03 b = 5.99913006e-04
c = 1.51275597e-05 d = 2.32643475e-06
f_o = 5988.45

BATH TEMP (°C)	INSTRUMENT FREQ (Hz)	INST TEMP (°C)	RESIDUAL (°C)
31.0999	11544.89	31.1003	0.00042
23.1409	9926.89	23.1414	0.00054
15.0645	8452.75	15.0650	0.00046
6.8520	7118.88	6.8522	0.00017
-1.0188	5988.45	-1.0187	0.00013
26.9390	10677.80	26.9380	-0.00099
19.0400	9157.62	19.0399	-0.00012
10.8850	7753.55	10.8847	-0.00035
2.8460	6525.92	2.8457	-0.00027

$$\text{Temperature} = 1/\{a + b[\ln(f_0/f)] + c[\ln^2(f_0/f)] + d[\ln^3(f_0/f)]\} - 273.15 \quad (°C)$$

Residual = instrument temperature - bath temperature



SBE **SEA-BIRD ELECTRONICS, INC** **TELEPHONE 206 643-9866** **FAX 206 643-9954**
1808-136th Place Northeast, Bellevue, Washington 98005 USA Telex 292915 SBEI UR

Temperature Calibration Report

Customer: Buffalo State College

SBE Job Number: 5525
Date of report: 18 March 1992

SBE Model Number: 3
Serial Number: 1068

Unless instructed otherwise and if received intact (not broken) and functional, temperature sensors are calibrated 'as received', i.e, without repairs or adjustments that would prevent determination of the sensor's drift history. If calibration uncovers problems with the sensor, a second calibration will be required after the necessary work is finished.

An 'as received' calibration certificate listing the coefficients used to convert sensor frequency to temperature will be provided. Users may judge whether the 'as received' or previously determined coefficients are more likely to represent the condition of the sensor at the time of deployment (those using SEASOFT should enter the chosen coefficients using SEACON). Calibration coefficients obtained after a repair should only be used with data collected subsequent to the calibration.

'AS RECEIVED CALIBRATION' (x) Performed ( ) Not Performed

Date: 11 Mar 92 Drift since last cal: .001 °Celsius/year

Comments:

'POST REPAIR CALIBRATION' ( ) Performed (x) Not Performed

Date: Drift since last cal: °Celsius/year

Comments:

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DISSOLVED OXYGEN SENSOR CALIBRATION: S/N 22240 18 March 1992

Sensor Current

m = 2.5767 E-7
b = -4.3804 E-9

The use of these constants in a linear equation of the form

$$I = mV + b$$

will yield DO sensor membrane current as a function of sensor output voltage.

Sensor Compensation Temperature

k = 8.8894
c = -4.8848

The use of these constants in a linear equation of the form

$$T = kV + c$$

will yield membrane temperature as a function of temperature channel voltage with a maximum error of about 0.5 deg C. The correction to dissolved oxygen resulting from the use of this calibration should be sufficient to achieve the precision of which the sensor is capable.

SEASOFT Coefficients based on Oxfit Calibration Results

Soc	3.1211	
Boc	-0.0830	
tcor	-0.033	(nominal)
pcor	1.50e-4	(nominal)
tau	2.0	(nominal)
wt	0.67	(nominal)

barometer = 1015.21 mB
Twater = 22.71 deg C
Tcomp = 23.12 deg C
Isat = 0.706 uA
Iair = 0.718 uA
Izero = 0.027 uA

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SBE 252192-20 20 March 1992

Pressure calibration: PAINE 211-75-710-04 100 psia S/N 136419

Straight Line Fit:

Pressure(psia) = M * N + B (N = Binary output)

M = 0.02644 B = -6.45

Quadratic Fit:

Pressure(psia) = A0 + A1 * N + A2 * N * N (N = binary output)

A0 = -6.26565 A1 = 2.623170e-02 A2 = 4.396618e-08

Pressure (psi)	Output (N)	Straight Line Fit error, psi	Straight Line Fit error, %FS	Quadratic Fit error, psi	Quadratic Fit error, %FS
14.76	798.50	-0.097	-0.10	-0.051	-0.05
20.01	999.65	-0.033	-0.03	-0.012	-0.01
40.02	1757.80	0.000	0.00	-0.045	-0.04
60.04	2515.31	0.016	0.02	-0.044	-0.04
80.05	3271.93	0.008	0.01	-0.016	-0.02
100.06	4025.99	-0.066	-0.07	-0.004	-0.00
80.05	3273.99	0.063	0.06	0.039	0.04
60.04	2518.00	0.087	0.09	0.028	0.03
40.02	1761.03	0.086	0.09	0.041	0.04
20.01	1001.00	0.003	0.00	0.023	0.02
14.76	802.11	-0.000	-0.00	0.045	0.05

Output binary values are averages of 101 samples taken at 2 Hz.

SEASOFT Versions 3.3M and higher will prompt for A0, A1, and A2

SEASOFT Versions 3.3L and lower will prompt for M and B

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pH SENSOR CALIBRATION: S/N 22240 18 March 1992

The value of b as measured at electrical test was 2.5035 volts.

The following values of Vout were measured at a temperature of 22.536 deg C using +/-0.02 pH buffer solutions:

pH	Vout	Residual (pH units)
4	1.701	-0.034
7	2.488	+0.002
10	3.294	-0.035

Using phfit, the calibration coefficients for this sensors are: phvref = 0.4140
m = 4.5245

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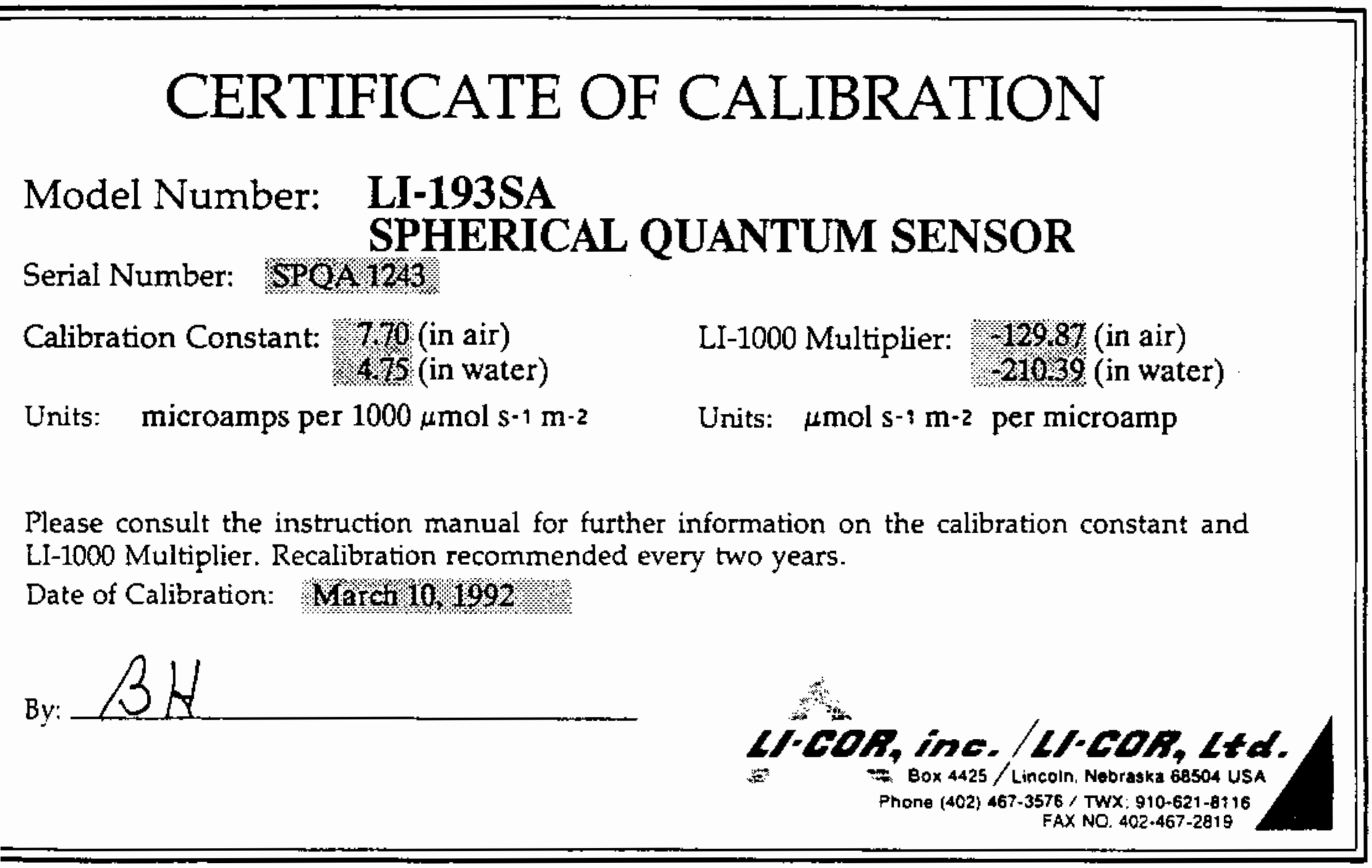

CERTIFICATE OF CALIBRATION

Model Number: **LI-193SA**
SPHERICAL QUANTUM SENSOR

Serial Number: SPQA 1243

Calibration Constant:	7.70 (in air) 4.75 (in water)	LI-1000 Multiplier:	-129.87 (in air) -210.39 (in water)
Units:	microamps per 1000 μmol s^{-1} m^{-2}	Units:	μmol s^{-1} m^{-2} per microamp

Please consult the instruction manual for further information on the calibration constant and LI-1000 Multiplier. Recalibration recommended every two years.

Date of Calibration: March 10, 1992

By: BH

LI-COR, inc. / LI-COR, Ltd.
Box 4425 / Lincoln, Nebraska 68504 USA
Phone (402) 467-3576 / TWX: 910-621-8116
FAX NO. 402-467-2819