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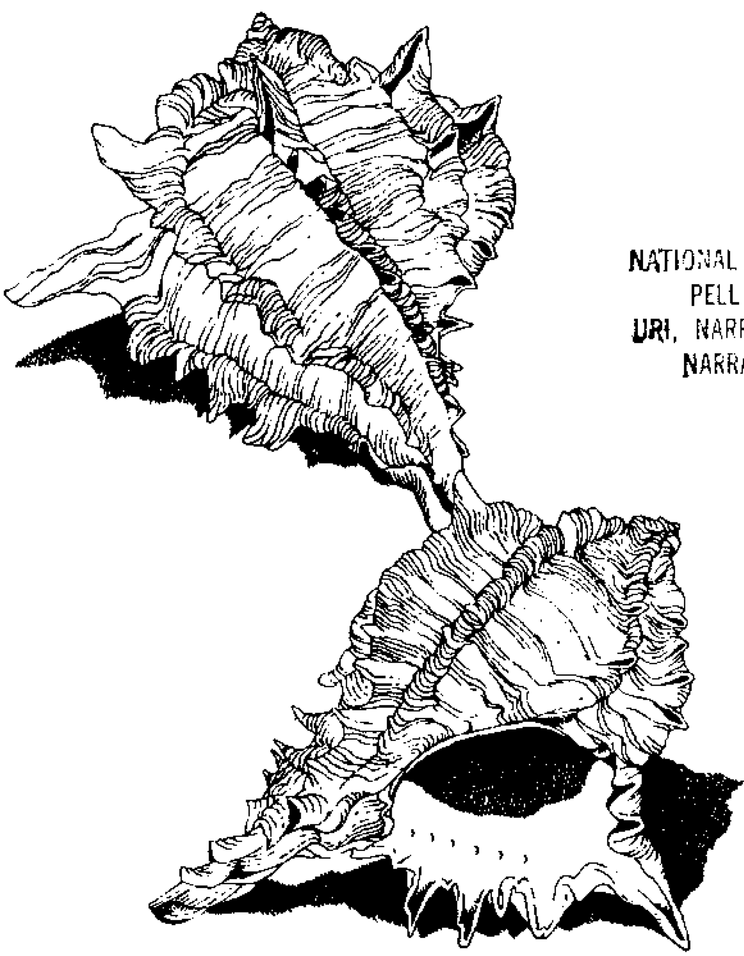

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Table of Contents

List of Figures

List of Tables

Acknowledgments

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A COMPARISON OF WATER QUALITY AT TWO RECREATIONAL MARINAS DURING A PEAK-USE PERIOD

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1. INTRODUCTION

The continued development of the coastal zone has led to a rapid increase in the number of marinas being proposed for Class SA waters in North Carolina. One of the associated problems is the potential degradation of water quality due to human waste discharge from boats docked at the marina. According to both federal and state guidelines, a Class SA water is approved for the collection of shellfish. Therefore, the level of fecal 3 coliforms in the water column cannot exceed 14 organisms/100 ml. For a proposed marina to be permitted, one of the requirements is that the design must insure that this coliform standard is met.

Unfortunately, it is very difficult to determine in advance if a particular marina design will satisfy this fecal coliform standard. Many factors must be included in the analysis, including the background coliform levels at the site, non-marina coliform sources, the flushing characteristics of the site, and the frequency and magnitude of human waste discharge from the boats moored at the marina. The development of a predictive water quality impact model that includes these variables begins with the collection of a set of field data. The design of a comprehensive field study intended to provide these data is a very complex problem due to the many interrelated parameters. In recognition of this complexity, we undertook a small pilot field study over a Labor Day weekend at two marinas. The objectives of this pilot study were to develop the necessary experience and data collection procedures to design a more comprehensive study.

We selected two North Carolina marinas for an intensive data collection program during the 1985 Labor Day weekend. This holiday was selected because we wanted to document the relationship between boat use and water quality during a period of peak boat use. One of the marinas can be characterized as an enclosed basin with a relatively restricted connection to a sound, Figure 1.1. The other site is located along the shoreline of this same sound and is a typical open water configuration, Figure 1.2. Both sites are relatively free of any sources of human waste other than what may be coming from the boats moored at these sites. In addition, the tidal ranges at both sites are comparable.

The data collection plan included characterizing the relative flushing of each site using dye tracers, surveying the number of occupied boats in the marinas, and systematic collecting of water samples at six-hour intervals during the study period to measure the concentrations of fecal coliform bacteria. Data collection began at noon on Wednesday, August 29, and continued through noon the following Tuesday, September 4. This six-day period included the Labor Day weekend, which is generally considered a time of peak boat use. By including days before and after the holiday, we were able to examine the impact of boat usage on water quality.

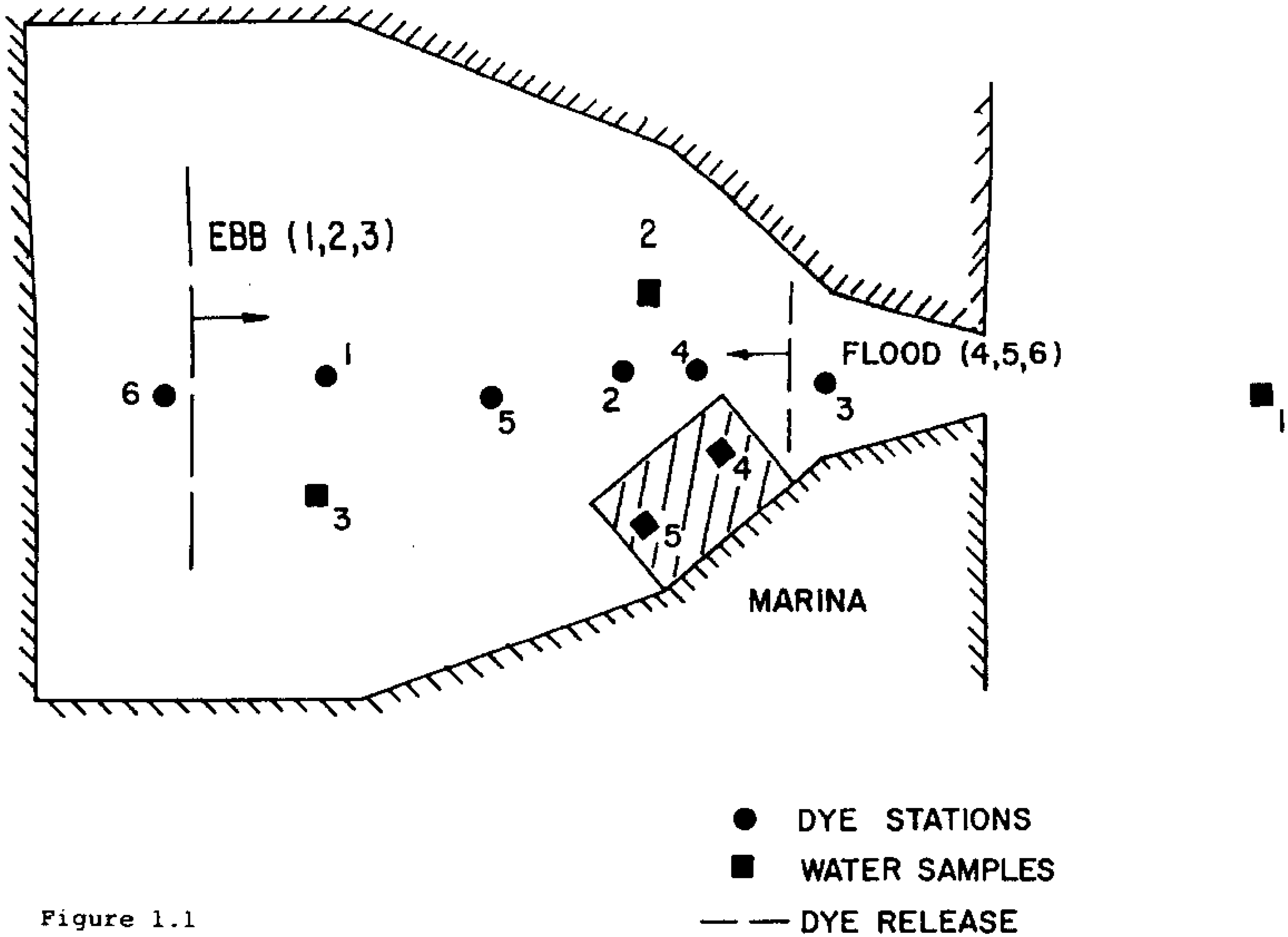

EBB (1,2,3)
FLOOD (4,5,6)
MARINA
DYE STATIONS
WATER SAMPLES
DYE RELEASE

Figure 1.1

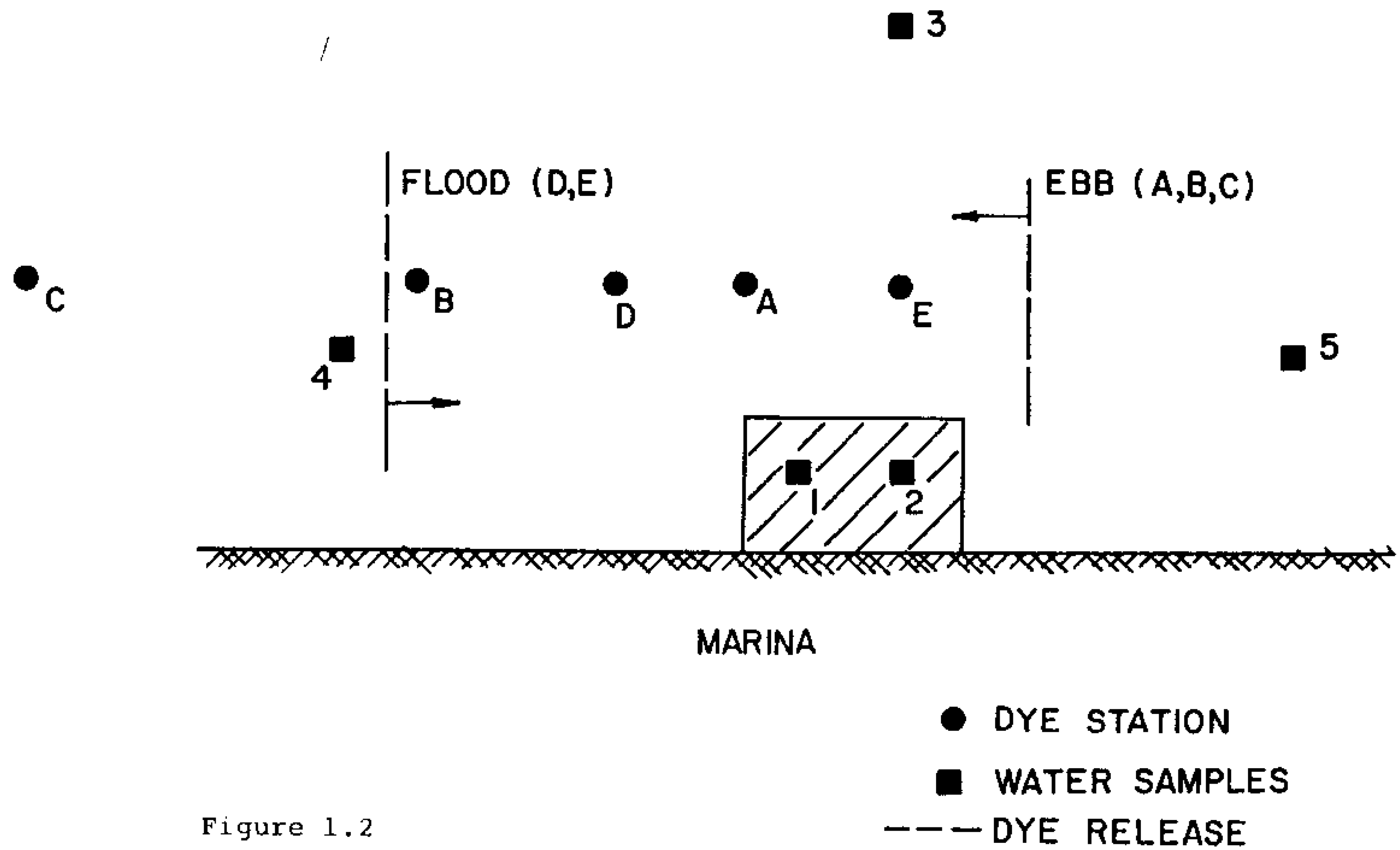

3
FLOOD (D,E)
EBB (A,B,C)
C
B
D
A
E
4
5
1
2
MARINA
DYE STATION
WATER SAMPLES
DYE RELEASE

Figure 1.2

2. DYE STUDIES

The "flushing" of a marina refers to the degree of mixing between the water within the boundaries of the facility and the adjacent waters. This flushing can be characterized as a rate of dilution which varies with distances from the marina. This mixing is the result of the tide, wind, non-tidal discharge (such as a freshwater river), and the physical geometry of the marina. The rate of dilution can be determined with dye tracer by monitoring its change in concentration as it moves away from the marina with the tide. A number of different tracer study techniques are being used in water quality studies now, but no single method is recognized currently as a standard. We elected to use a line injection of Rhodamine WT and its subsequent monitoring for a single tidal period (Kilpatrick, et al., 1970).

At each marina, 0.5 gal of dye was injected as a narrow streak at the beginning of ebb and flood tide. The locations of the injection points and the measurement stations are shown on Figures 1.1 and 1.2. A Turner Designs Model 10 flow-through fluorometer was used to record the dye concentrations at each station. Figure 2.1 shows the concentration of the dye as a function of time at a station 700 feet downstream from the point of release during the ebb tide condition at the Basin (Basin 1). Similar figures for the other dye monitoring stations are included in Appendix A.

$$QF = (V*C)/A$$

where

QF = rate of dilution, cfs
V = initial volume of dye, cu ft
C = initial concentration of dye
A = area under the dye concentration/time curve, ppb min

Table 2.1 lists the results of the dilution computations for all of the stations at both sites.

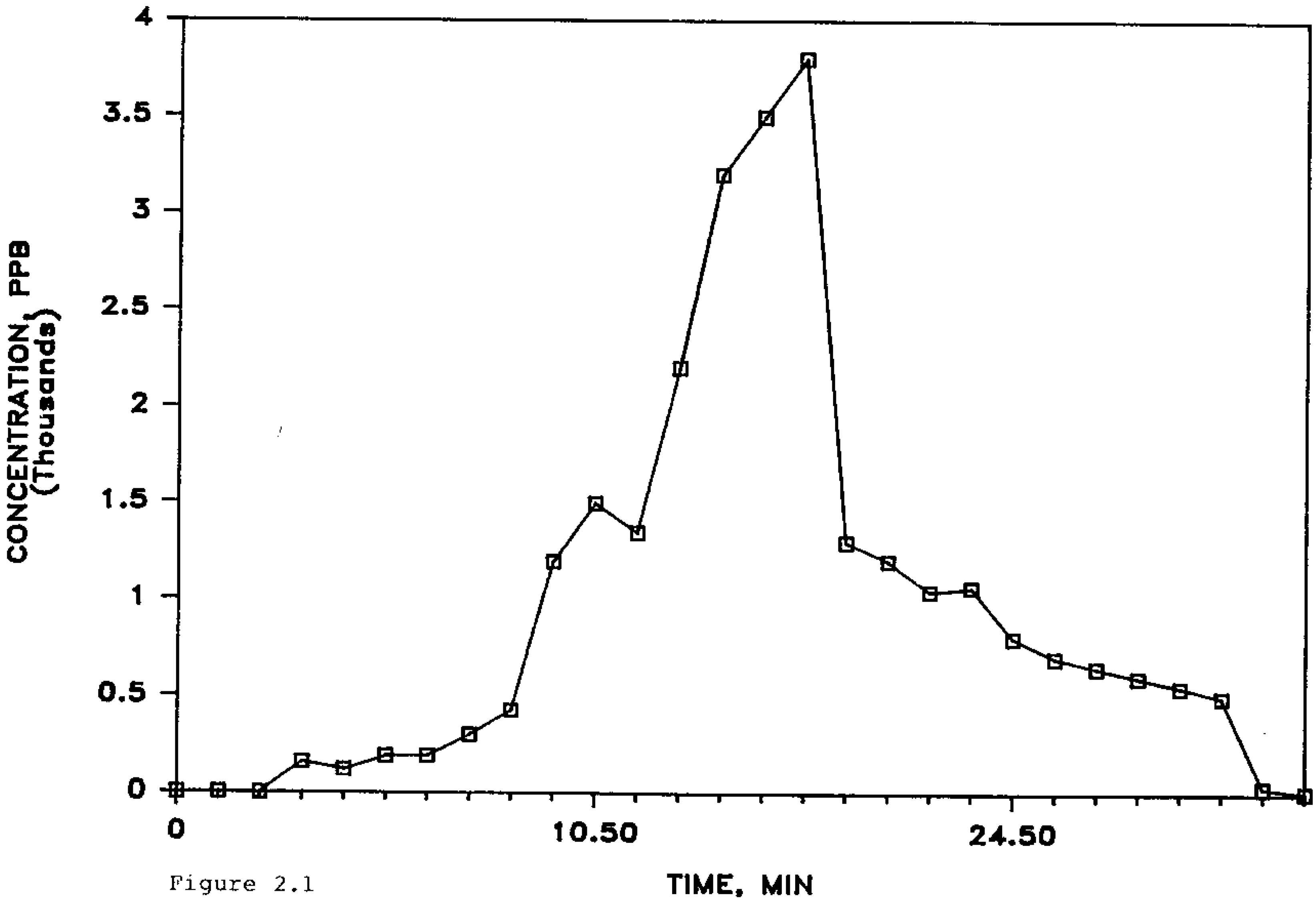

CONCENTRATION, PPB
(Thousands)
4
3.5
3
2.5
2
1.5
1
0.5
0
0
10.50
24.50
TIME, MIN

Figure 2.1

TABLE 2.1
RATES OF DILUTIONS

Station	Tide	Distance, ft	QF, cfs
Basin 1	ebb	700	34
Basin 2	ebb	1700	208
Basin 3	ebb	2200	376
Basin 4	flood	150	217
Basin 5	flood	550	868
Basin 6	flood	2250	2133
Open A	ebb	250	523
Open B	ebb	925	578
Open C	ebb	2206	1656
Open D	flood	500	163
Open E	flood	1000	315

We have used linear regressions to fit a relationship between the distance and the rate of flushing as shown in Figures 2.2 and 2.3. For the Basin (Figure 2.2), the absolute magnitude of the flushing rate for the flood tide is greater than the ebb tide for any given distance from the marina. This result is due to the fact that there was a gradual reduction in width of the basin between the point of dye release and the connection with the estuary. Thus, as the dye moved towards the entrance, there was a diminishing volume of water available to dilute the concentration.

Figure 2.3 illustrates these flushing rates for the Open Water marina. The data for the ebb tide condition illustrate the problem associated with this dye tracer technique during high wind conditions. There was a strong wind blowing throughout the period of the dye study at the Open Water site. This wind was directed onshore, angled in the direction of the ebb flow. As a consequence, during the ebb tide, the dye streak was compressed by this wind and the rate of dilution was therefore surpressed. This is seen in the data with the rate of dilution at stations A and B, about 725 feet apart, essentially the same. By the time the dye traveled 1,300 more feet to Station C, the rate of dilution had substantially increased. However, we observed that the dye streak had broken up into several discrete segments. Thus the data at this station represents the effects of the wind as well as straight dilution with distance traveled.

Because of the continual wind in the general direction of the ebb tidal flow, the beginning of flood tide was delayed several hours. We were, therefore, limited to two monitoring stations due to the onset of darkness. We have shown the rates of dilutions for these two stations as well as the line fitted for these data on Figure 2.3. This line is included for the purpose of a qualitative comparison with the other data, as just two points cannot be used to determine this relationship.

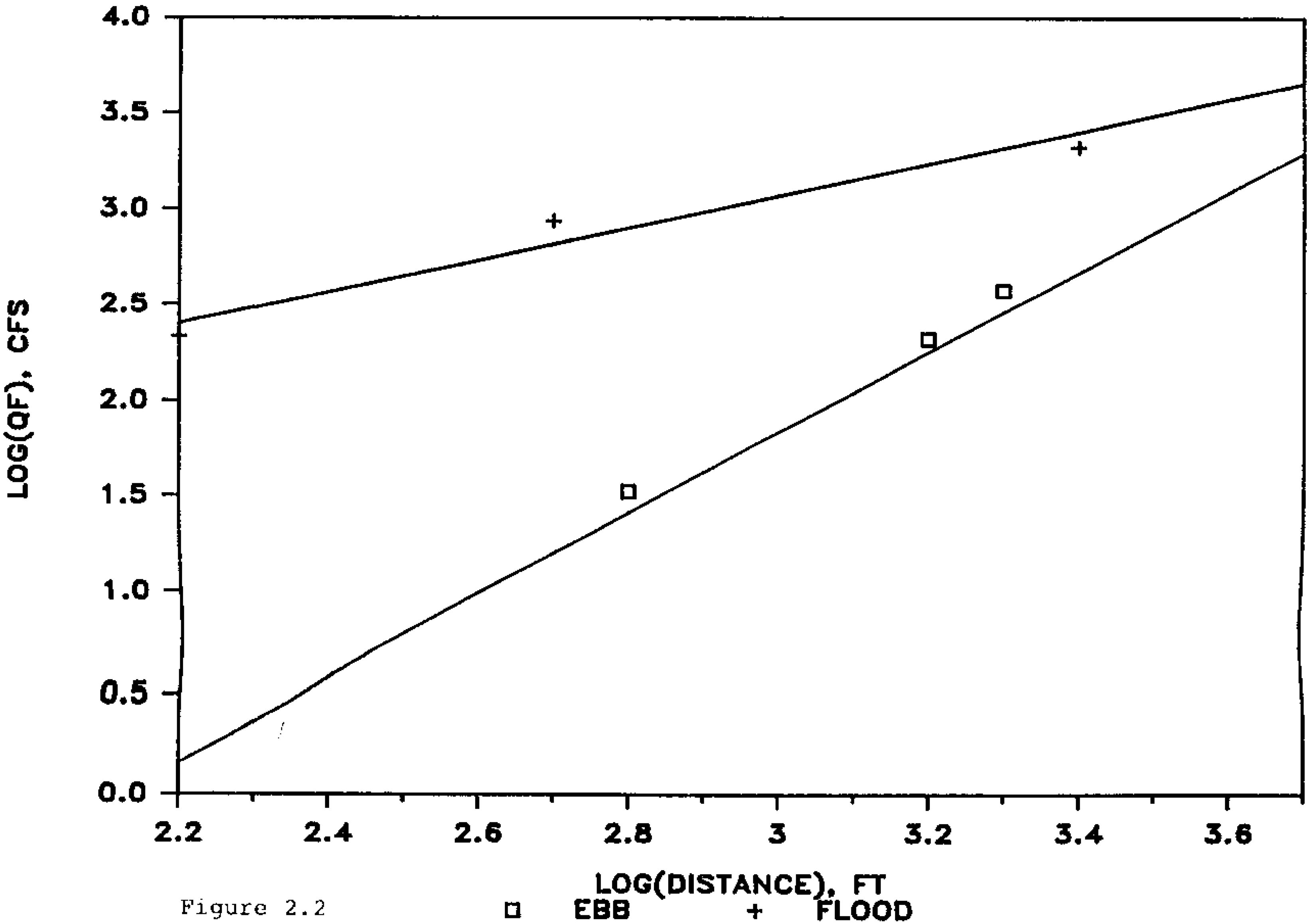

LOG(QF), CFS
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
2.2
2.4
2.6
2.8
3
3.2
3.4
3.6
LOG(DISTANCE), FT
EBB
FLOOD

Figure 2.2

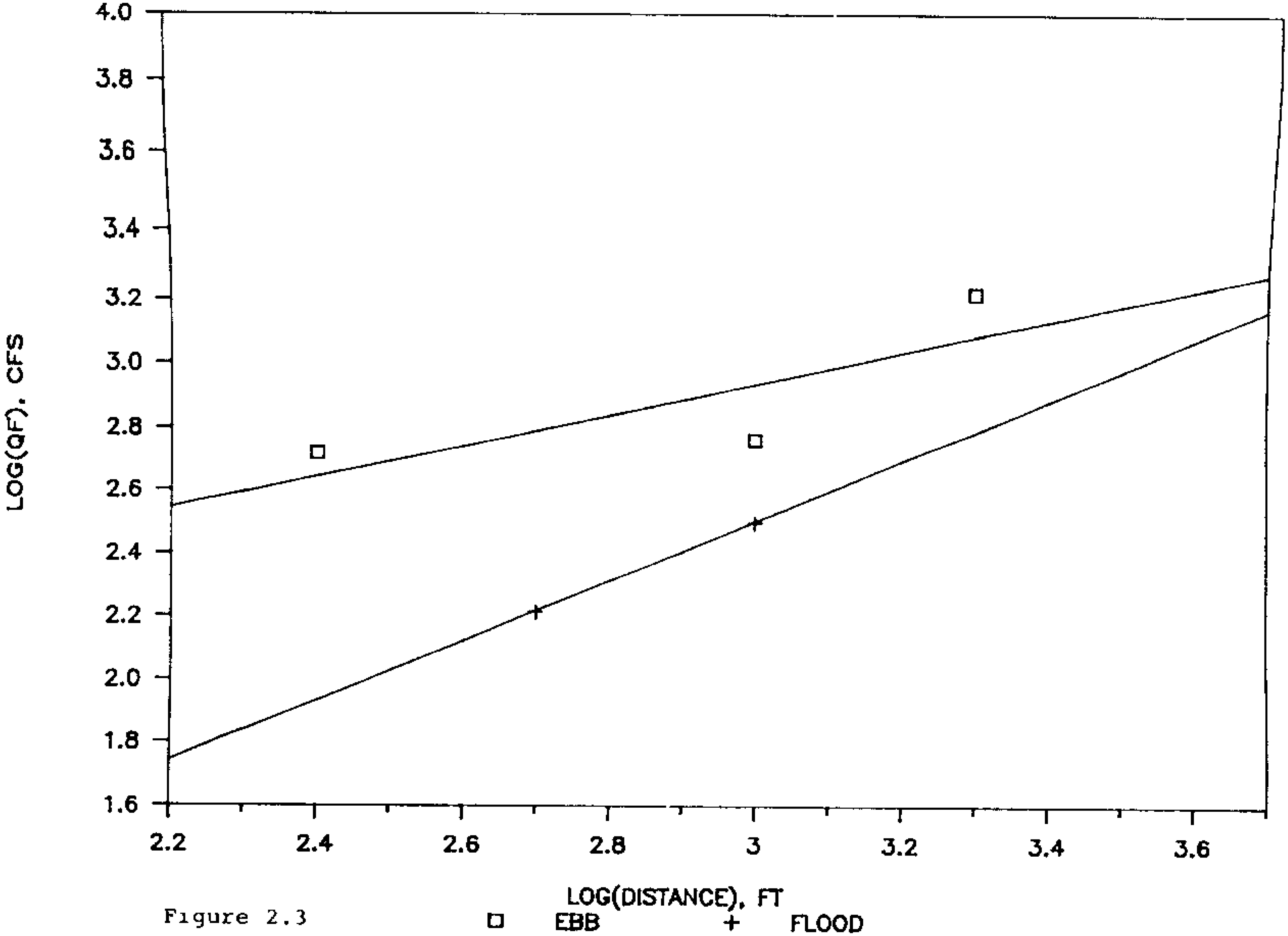
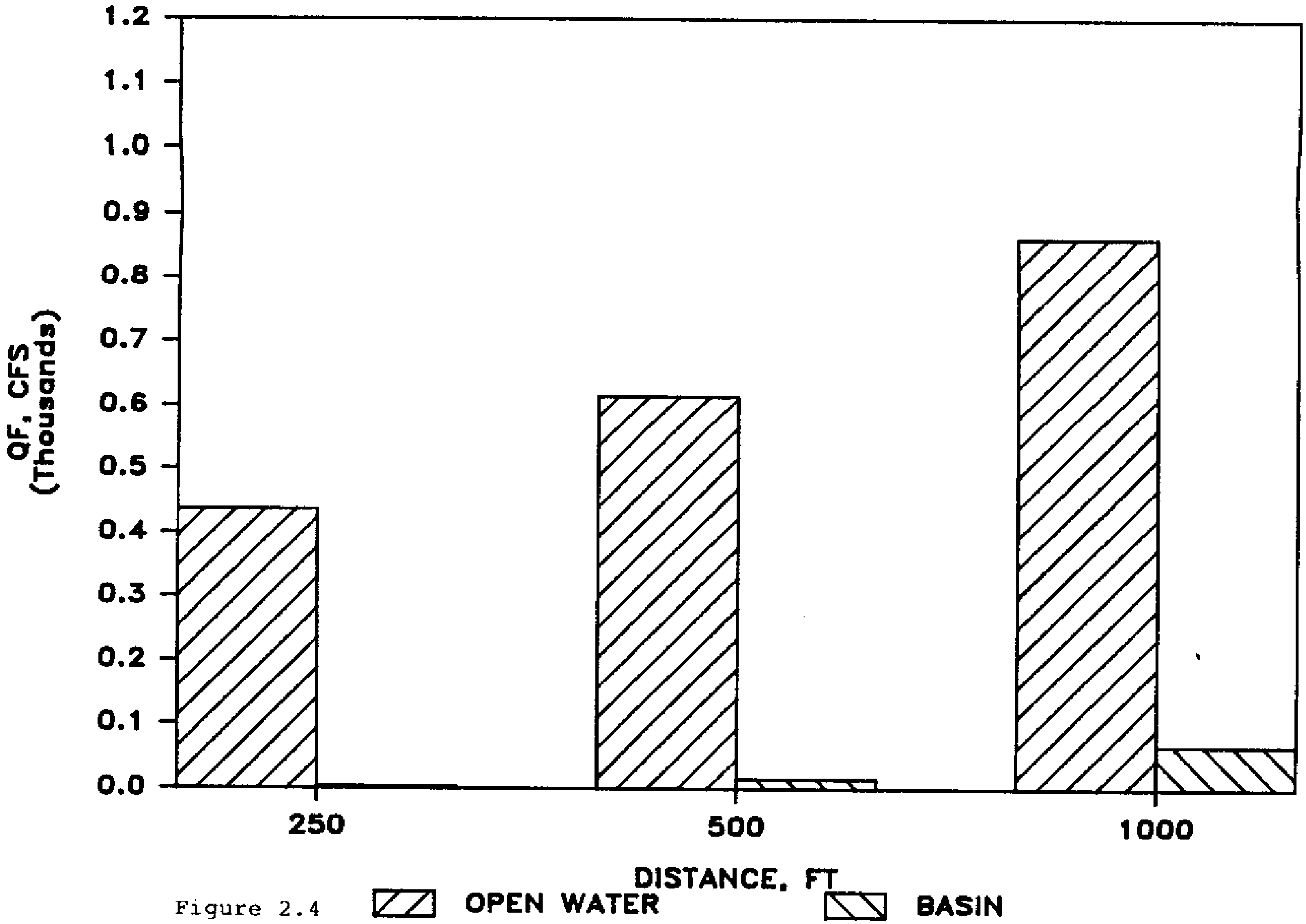
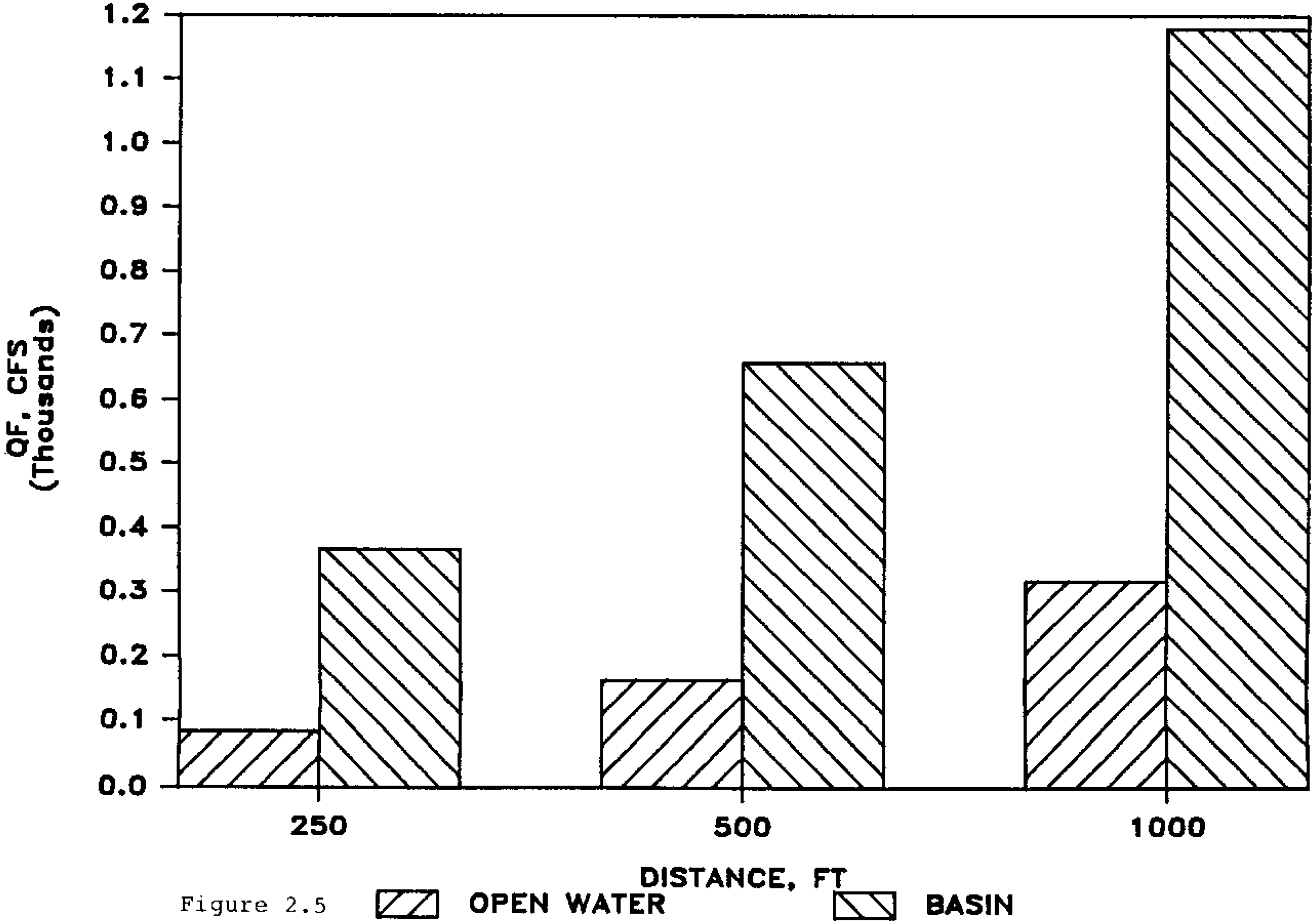

LOG(QF), CFS
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
2.2
2.4
2.6
2.8
3
3.2
3.4
3.6
LOG(DISTANCE), FT
EBB
FLOOD

Figure 2.3

Figures 2.4 and 2.5 illustrate the relative differences in dilutions (or flushing) for these two sites. Consider first the ebb tide condition shown in Figure 2.4. Not surprisingly, the Open Water site has substantially more flushing than the Basin. As the dye moves toward the entrance of the Basin, the volume of water available to mix with it is limited by the physical boundaries of the Basin. There is no similar limitation for the water available to mix with the dye for the Open Water marina. In this case, as the dye moves away from the marina with the ebb tide, it continues to mix with the full extent of the flow across the width of the estuary. In this particular case, the difference in the values for dilutions at a distance 500 feet from the marina is on the order of a factor of 10.

For the flood tide, Figure 2.5, the data indicate that the Basin was flushing better than the Open Water marina during the period of the dye studies. As noted above, the wind at the Open Water site was directed against the flood tide. Therefore it appears that this had a significant effect on the flushing. We normally would expect an Open Water site to flush better than a Basin for both ebb and flood tides of comparable ranges. The fact that our data do not show this to be the case illustrates the significance of the wind effects on this type of dye study. A continuous release method, with monitoring over several days, would be a preferable technique for these conditions.


QF, CFS
(Thousands)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
250
500
1000
DISTANCE, FT
OPEN WATER
BASIN
Figure 2.4



QF, CFS
(Thousands)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
250
500
1000
DISTANCE, FT
OPEN WATER
BASIN

Figure 2.5

3. RECREATIONAL USE

3.1 Data Collection: Recreational use data were collected for the purpose of examining the relationship between the patterns of boat usage and the observed fecal coliform concentrations. The specific objectives of this phase of the pilot project were to:

(1) determine the pattern of boat use in the study marinas,
(2) examine alternative observation methods for collecting use data, and
(3) examine the use of boat registration numbers to identify users.

To achieve these objectives, several types of data were collected for each of the study marinas. First, the patterns of boat use were examined using a schematic drawing of the slip area, with each slip numbered consecutively. During each observation period, empty slips were recorded by circling the slip number. Occupied boats were recorded by crossing out the slip number. A boat was considered occupied only if people were observed on it during the observation period. Since the Open Water marina had a launching ramp, the number of boats in the process of being either launched or removed from the water was also recorded. Second, during each observation period, the number of vehicles in the marina parking lot was also recorded. Third, the level of traffic on the primary access road to each marina was recorded using pneumatic traffic counters set to provide hourly axle counts. Fourth, on the first day of the study, the registration numbers of each boat in the marina were recorded by slip number. Throughout the study, as new boats were observed, their registration numbers were recorded again by slip number. The registration numbers of boats in the launching area of Open Water marina were also recorded. Whether or not each boat had head facilities was recorded at the same time as the boat registrations. The possibility that users would change their behavior (e.g., quit using their head facilities, wait until they were away from the marina before dumping their sewage, etc.) as a result of being interviewed limited the data collection to observational methods. Consequently, a boat was considered to have head facilities if it had a cabin area.

Data were collected during 30 15- to 20-minute observation periods at three-hour intervals throughout the daylight hours. We began at 11 a.m. on August 29 and continued through to 11 a.m. on September 4. In the Basin marina, these observations were scheduled between 8 a.m. and 8 p.m. In the Open Water marina, observations were scheduled between 7 a.m. and 7 p.m. To determine the effect of the scheduling of the observations on the data, we reversed the observation schedules on the second full day of the study. We began at 7 a.m. in the Basin marina and 8 a.m. in the Open Water marina. But this alternating of beginning time was unsatisfactory because of differences in the composition of users at the two study sites. Specifically, the Open Water marina tended to be used by fishermen who often left the marina between 7 a.m. and 8 a.m. The boats in the Basin marina were yachts. The observable use of them generally began at 8 a.m. or later.

The observation forms provided several measures of use. For each observation period, the data included the number of occupied and unoccupied boats, with and without head facilities. Using these data, both boats occupancy and slip occupancy rates were calculated for each observation period. Boat occupancy was defined as the percentage of head-equipped boats occupied by people during the observation period. Slip occupancy was defined as the percentage of the marina's slips which were occupied by head-equipped boats with people on board during the observation period. For the Open Water marina, slip occupancy was calculated for 150 slips. According to the manager of the Basin marina, there are 105 slips or dockage points in that marina. However, 20 of these dockage points appeared suitable only for short-term transient use. Thus, two slip occupancy levels were calculated for the Basin marina on the basis of all 105 dockage points and on the basis of the 85 credible long-term storage slips. Linear regression was used to examine the effectiveness of the traffic and parking lot counts for predicting the number of occupied boats. For the traffic count measure the axle count for the hour preceding the observation period was used as the independent variable. Since the purpose of the study was to examine fecal coliform pollution, the dependent varible in these regression analyses was the number of boats with head facilities occupied during the observation period.

3.2 Objective 1: Patterns of Boat Use: Both the composition of boats and the patterns of boat use differed significantly between the two study sites. Users of the Open Water marina tended to be fishermen, who spent very little time in the marina. Prior to their fishing trip, these boaters were, in general, in the marina only long enough to prepare for their fishing trip. When they returned, they were in the marina only to secure their boats, unload their equipment and supplies, and clean their catch. The composition of boats was generally restricted to fishing craft, many of which did not have head facilities. There were, however, two live-aboard boats at the Open Water marina. In addition, four charter boats operated out of the Open Water marina. Finally, 70 boats were observed in the launching area of the Open Water marina. Each was being launched or taken from the water.

A total of 184 different boats were observed at the Open Water marina during the study period. Of these boats, 124 (67.4 percent) were occupied at some time during the study period. Fifty-one (27.7 percent) had cabin areas and, consequently, were considered to have head facilities. Twenty-one (41.2 percent) were occupied at some time during the study period.

Since the purpose of this research was to examine fecal coliform of marina areas from boats with head facilities, all of the use data presented for the Open Water marina in the remainder of this section will be limited to the 51 boats with head facilities.

Users of the Basin marina tended to be pleasure boaters, who spent from several hours to entire days in the marina. Additionally, many of these boaters stayed overnight on their boats in the marina. There was one live-aboard boat at the Basin marina, but no charter boats. Although the Basin marina did have a lift for launching and removing boats from the water, only one boat was observed using that facility over the study period. That boat was being removed from the water for cleaning and painting.

The boats at the Basin marina were large yachts, all of which had head facilities. Over the study period, a total of 73 different boats were observed in the Basin marina. Of these boats, 51 (69.9 percent) were occupied at some time during the study.

Although boat composition changed, the number of boats observed in both marinas during a specific observation period tended to be relatively stable. For the Open Water marina, the number of boats with head facilities in the marina during a specific observation period ranged from 40 to 49 with the mean, median, and mode number of boats being 45.1, 45, and 46, respectively (Figure 3.1). This mode of 46 boats was observed on 10 different occasions.

The Basin marina supported slightly greater range then, from 50 to 67. There was a mean of 60.8 boats, a median of 62 boats, and a mode, observed on six occasions (20.0 percent of the observations), of 65 boats (Figure 3.2). Thus, of the 150 slips at the Open Water site, an average of 30.1 percent were occupied by boats with head facilities. For the Basin marina, 57.9 percent of all dockage points and 71.5 percent of the credible slips were, on the average, occupied by head-equipped boats during the study period.

As would be expected, the number of boats with people on board varied significantly over the study period. In the Open Water marina, the number of occupied boats with head facilities ranged from two to nine, with the mean, median, and mode being 4.1 boats, three boats, and three boats, respectively (Figure 3.1). The mode was observed on 11 occasions (36.7 percent of the observations). The comparable statistics for the Basin marina are a range of one to 23 boats, a mean of 8.3 boats, with the median and mode both being eight boats (Figure 3.2). The mode was observed on five occasions (16.7 percent of the observations).

Boat occupancy levels also varied significantly between the two study marinas (Figure 3.3). For the Open Water marina, boat occupancy (percent of head-equipped boats occupied during the observation period) ranged from 2.3 to 19.6 percent with a mean of 9.1 percent, median of 6.8 percent and mode of 6.5 percent.

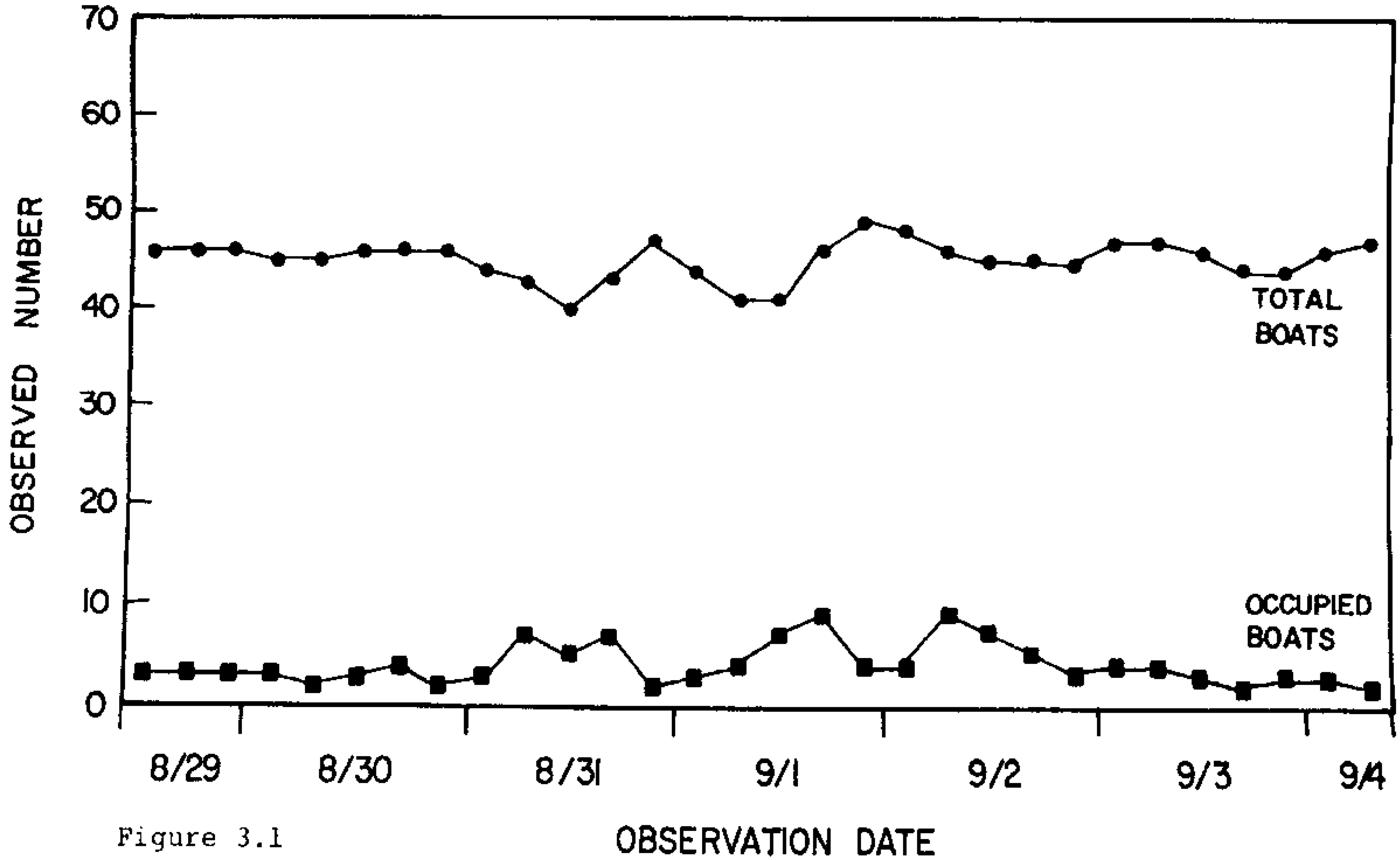

70
60
50
40
30
20
10
0
OBSERVED NUMBER
TOTAL BOATS
OCCUPIED BOATS
8/29
8/30
8/31
9/1
9/2
9/3
9/4
OBSERVATION DATE

Figure 3.1

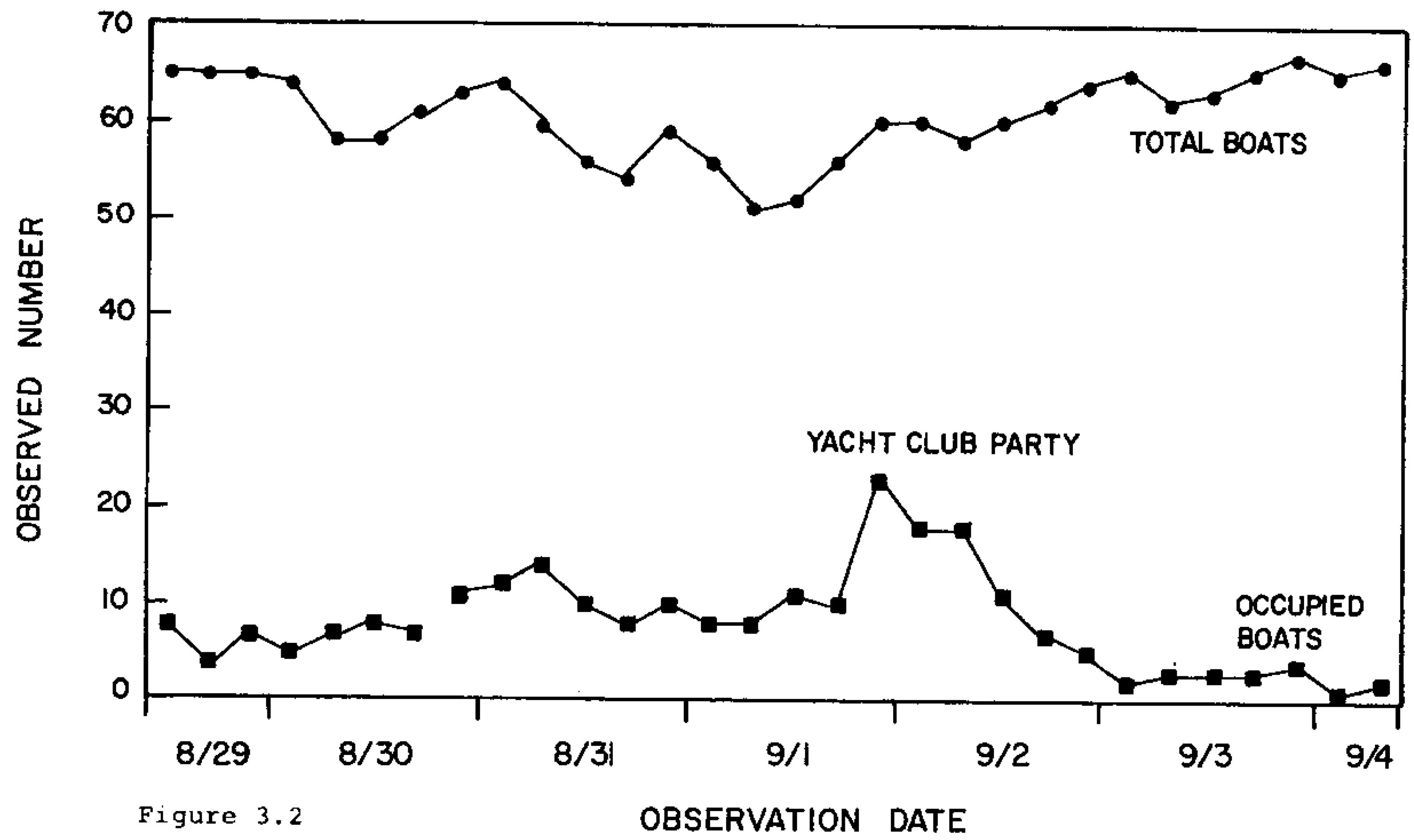

OBSERVED NUMBER
70
60
50
40
30
20
10
0
TOTAL BOATS
YACHT CLUB PARTY
OCCUPIED BOATS
8/29
8/30
8/31
9/1
9/2
9/3
9/4
OBSERVATION DATE

Figure 3.2

This mode occupancy level was observed on six occasions (20 percent of the observations). For the Basin marina, boat occupancy had a much greater range, from 1.5 to 38.3 percent, and a greater mean and median value, 13.9 percent and 13.8 percent, respectively. There was no clear mode value. The 38.3 percent boat occupancy occurred as a result of the Basin marina yacht club having a Labor Day party.

Given this variation in boat occupancy, the slip occupancy levels obviously also varied by study marina (Figure 3.4). For the Open Water marina, slip occupancy varied between 1.3 and 6.0 percent. As previously explained, two slip occupancy levels were calculated for the Basin marina. The all-dockage points slip occupancy level varied between 1.0 and 21.9 percent with a mean slip occupancy of 7.9 percent and the median and mode both being 7.6 percent. When calculated on the basis of the credible slips in the Basin marina, the slip occupancy varied between 1.2 and 27.1 percent with a mean value of 9.8 percent and both the median and mode being 9.4 percent.

Mean daily values were also calculated for the boat occupancy and slip occupancy measures (Table 3.1). Both boat occupancy and slip occupancy varied, as expected, with the holiday weekend (Figures 3.3, 3.4). The daily boat occupancy level varied between 5.4 percent and 12.3 percent at the Open Water marina and between 2.3 percent and 21.5 percent at the Basin marina. Slip occupancy varied between 1.7 and 3.8 percent for the Open Water marina and 1.8 and 14.1 percent for the credible slips at the Basin marina.

Table 3.1
Daily Boat and Slip Occupancy

Date	Open Water Marina boat	Open Water Marina slip	Basin Marina boat	Basin Marina credible slips	Basin Marina all slips
Thursday 8/29	6.5%	2.0%	9.8%	7.4%	6.0%
Friday 8/30	5.7	1.9	12.5	8.9	7.3
Saturday 8/31	11.2	3.2	18.3	12.7	10.3
Sunday 9/1	12.3	3.8	21.5	14.1	11.4
Monday 9/2	12.3	3.8	19.7	13.9	10.7
Tuesday 9/3	7.0	2.1	4.7	3.5	2.9
Wednesday 9/4	5.4	1.7	2.3	1.8	1.5

3.3 Objective 2: Alternative Observation Techniques: Obviously, an individual walking up and down the docks in a marina making notes on a clipboard creates awareness, concern, and, in many cases, a certain amount of paranoia on the part of boat owners. During the observation periods of this study, both observers were asked, among other things, what we were doing, who we worked for, and if we worked for the wildlife commission,

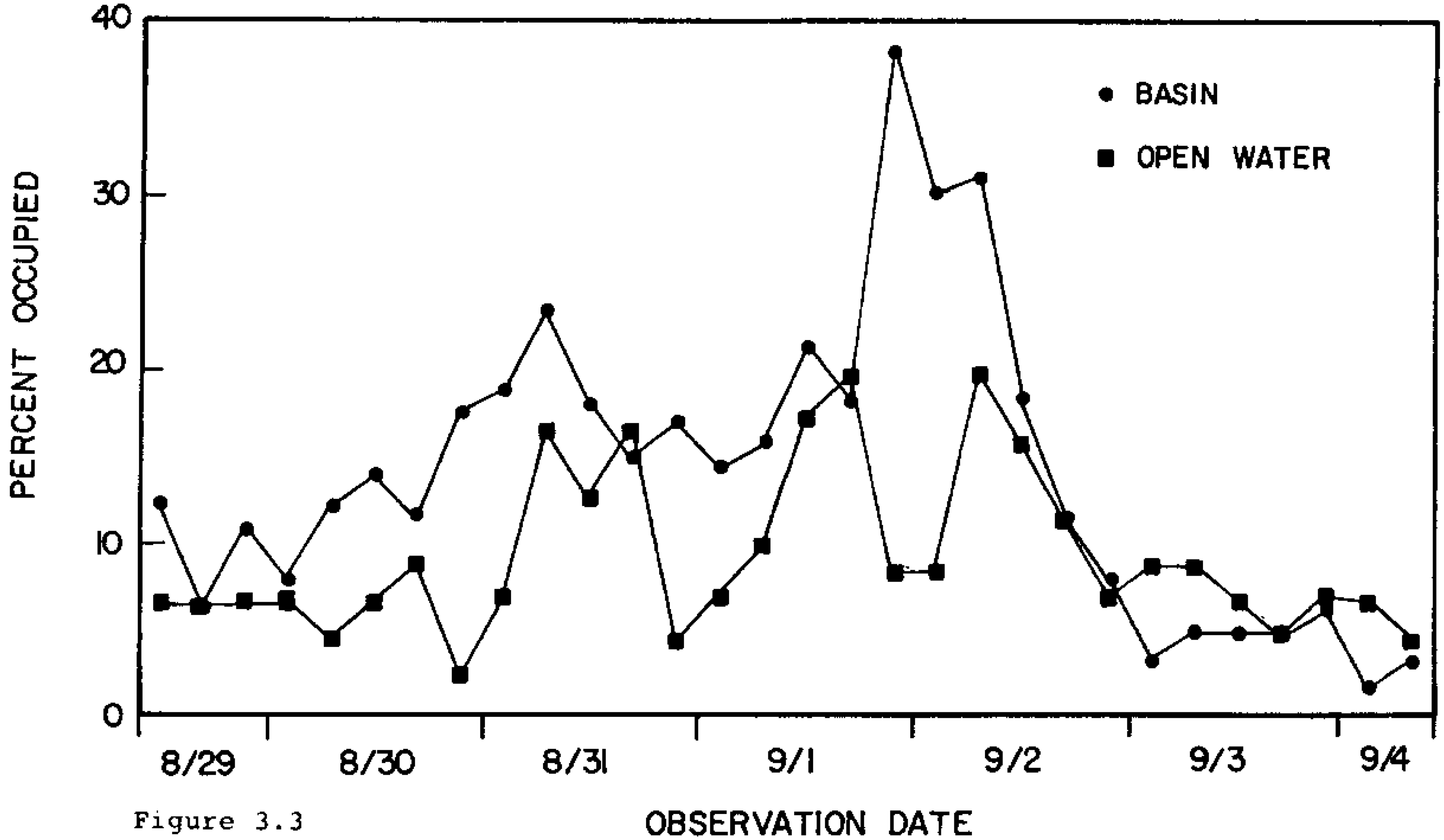

PERCENT OCCUPIED
40
30
20
10
0
BASIN
OPEN WATER
8/29
8/30
8/31
9/1
9/2
9/3
9/4
OBSERVATION DATE

Figure 3.3

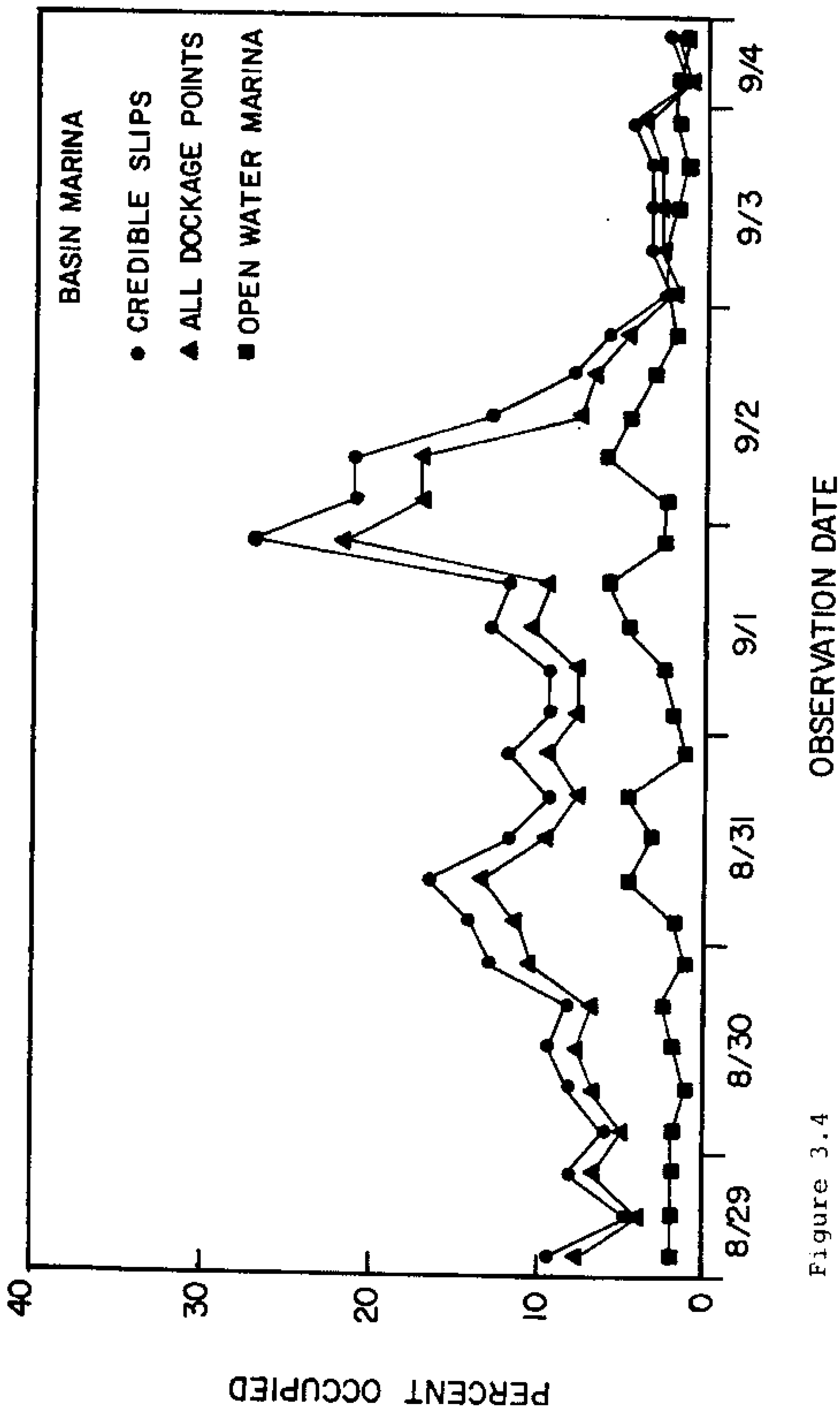

BASIN MARINA
● CREDIBLE SLIPS
▲ ALL DOCKAGE POINTS
■ OPEN WATER MARINA
PERCENT OCCUPIED
0
10
20
30
40
8/29
8/30
8/31
9/1
9/2
9/3
9/4
OBSERVATION DATE

Figure 3.4

the sheriff's office, and, interestingly, the Internal Revenue Service. Our presence undoubtedly resulted in some modification of user behavior. Consequently, a more unobtrusive data collection technique would be preferable to direct observation. For this reason, both primary access road traffic levels, measured by pneumatic traffic counters, and parking lot counts were measures as possible indicators of boat use. Linear regression was used to determine the ability of these measures to predict the number of occupied, head-equipped boats. Neither measure the number of occupied, head-eqipped boats. Neither measure provided an acceptable prediction.

For the Open Water marina, the percent of variance explained by the two measures was 12 percent and 21 percent for the traffic count and parking lot measure, respectively. Although somewhat better for the Basin marina, the explained variance was, again, low; the traffic count measure explained 23 percent and the parking lot measure explained 44 percent. Given that the Open Water marina was heavily used by individuals whose boats did not have head facilities, the poor performance of the two unobtrusive measures was expected at that site. However, even though the boats in the Basin marina were all head-equipped, neither measure performed adequately in predicting the use of that facility.

3.4 Objective Three: Identification of Boat Owners: The ability to identify the owners of boats stored in a particular marina would be very beneficial to research on the recreational use of that facility. If the boat owners were known, mail surveys could be used to collect data concerning the levels, types and frequency of use. For this reason, as part of the pilot project, the ability to collect boat registration numbers was assessed. Because some boat owners backed their boats into their slips, it was impossible to get the registration number from each boat. However, for the Open Water marina, registrations were attained for 42 (82 percent) of the 51 head-equipped boats.

Of these boats, 58 percent had North Carolina registrations, 42 percent had names, probably registered with the Coast Guard. None of the boats had out-of-state registrations. At the Basin marina, registrations were obtained for only 49 (67.1 percent) of the 73 boats. Of these registrations, 53.3 percent were North Carolina registrations, 40 percent were names, probably registered with the Coast Guard, and 6.7 percent were out-of-state registrations.

For the North Carolina registrations, the registration numbers were entered into the N.C. Wildlife Commission computer, resulting in identification of the owners, addresses and listing of the boat characteristics. While this was not done with the Coast Guard, we were informed that it would be possible. For the out-of-state registrations, an agreement with each individual state would be necessary.

3.4 Discussion of Recreational Use Patterns: As a pilot study, the purpose of this research was to provide preliminary evidence concerning the patterns of recreational use and to assess two data collection issues of potential importance to a more comprehensive research project. Concerning recreational use of the study marinas, three conclusions are especially important.

First, use patterns varied dramatically between the two study marinas. Any model developed to predict the recreational use of marinas must, consequently, include not only the number of slips in the marina, but also other characteristics of the site. Considerable research is needed to determine which characteristics should be used in such a model and the most appropriate measurement procedures.

Second, many of the generally used models for estimating fecal coliform concentrations in proposed marinas assume all of the boats in the marina will be equipped with head facilities which flush untreated fecal material directly into the marina waters. While this assumption may be appropriate for the Basin marina, it clearly is not appropriate for the Open Water marina. Thus, the factors influencing the composition of boats in a marina should also be further studied.

Third, the same coliform concentration models also assume that all of the boats in the marina will be used at some time during each day. Again, the data clearly do not support this assumption. Even with a yacht club party at the Basin marina, the highest observed boat occupancy was 38.3 percent. For both marinas, the average boat occupancy was less than 15 percent over a major holiday weekend. Further, the same model also assumes that all of the slips in the marina will be occupied by head-equipped boats used each day. The highest observed slip occupany was 27.1 percent with averages of less than 10 percent. While there is some justification for using a worst case scenario in developing the fecal coliform concentration models, the data suggest that the assumptions of the model may not be even remotely viable.

The first data collection issue assessed in this pilot project was the viability of using either traffic counts or parking lot counts as predictors of boat usage. Neither measure provided an adequate explanation of boat use. While further research may be appropriate, the evidence suggests that it probably would not be worth the effort. With sufficient resources, time lapse photography may be a viable alternative.

The second data collection issue was whether or not it would be possible to identify boat owners using boat registration numbers. Due to owners backing their boats into slips, it was not possible to obtain all registrations. With those obtained, however, it was possible to identify the owner. A more comprehensive research project should include the use of a boat to collect registration numbers.

4. MICROBIOLOGICAL STUDIES

4.1 Sampling Stations and Sampling Schedules: Five stations were designated for microbiological sampling within each marina. Two stations at the marina docks where boats were located were designated "boat stations." The other three stations, located in three different directions approximately 1,000 feet from the last boat dock in that direction, were designated "non-boat stations." When facing the water from the boat docks, these directions were in general, to the left, straight ahead, and to the right. These stations were intended to assess the extent of impact of fecal discharges from boats under prevailing hydrographic conditions and to possibly serve as "negative control" stations. They were also intended to determine the adequacy of a 1,000-foot "buffer zone" around the marina with respect to other beneficial uses of the water, such as shellfishing and primary contact recreation.

At each marina, water samples for bacteriological analysis were collected every six hours beginning at noon on Thursday, August 29, 1985, and continuing to noon on Wednesday, September 4, 1985. Thus, samples were collected four times per day before, during and after the Labor Day holiday weekend.

4.2 Sampling Methods and Fecal Coliform Analysis: Water samples from each station were collected aseptically using a standard sub-surface grab technique into sterile, wide-mouth polypropylene bottles (4- or 8-ounce capacity) (U.S. Environmental Protection Agency, 1978). Samples were stored and transported on ice to a laboratory at the University of North Carolina at Chapel Hill Institute of Marine Sciences, Morehead City, N.C. There, samples were stored at 4 C until analyzed within 24 hours of sample collection.

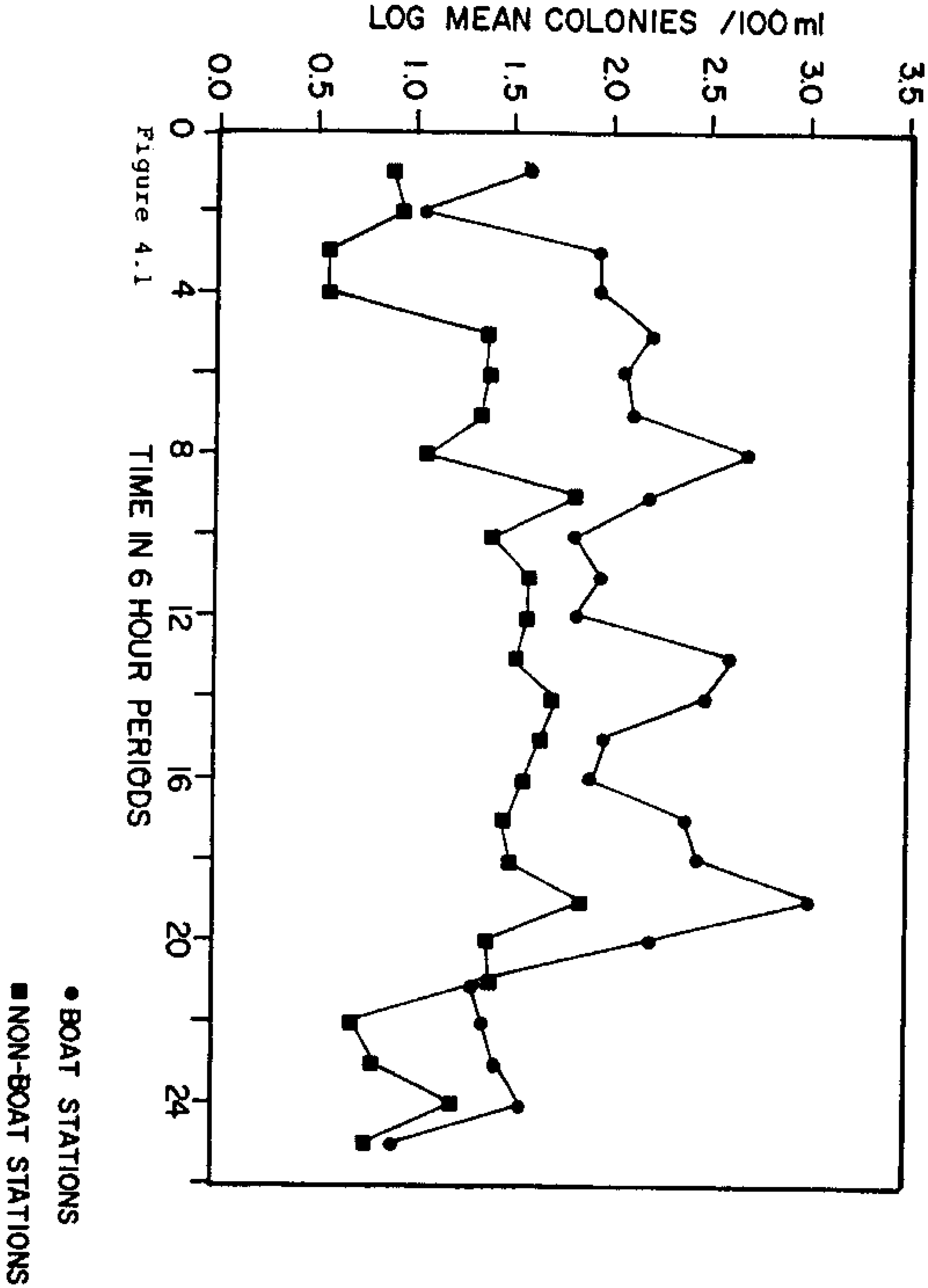
Samples were analyzed for fecal coliform bacteria by a standard, one-step membrane filter method (American Public Health Association, 1985). Briefly, samples were diluted serially 10-fold in peptone water dilution blanks (99 ml each), and duplicate 20-ml volumes of each dilution as well as undiluted water samples were vacuum-filtered onto 0.45 um porosity, gridded, cellulose, ester filters (Gelman, GN-6). Filters were then placed onto mFC agar in 60 mm diameter petri dishes, and dishes were incubated at 44.5 C for 24 hours in a dry-air incubator. Typical colonies (blue) were counted, and after correcting for sample volume and dilution, fecal coliform concentrations were computed as average number of colonies per 100 ml. For some data presentation, fecal coliform concentrations were converted to values of log per 100 ml.

Attempts to analyze replicate volumes of sample water for enterococci, another bacteriological indicator of fecal contamination, were unsuccessful due to technical problems with the culture media.

4.3 Microbiological Results: Results of fecal coliform analysis of water as average concentrations per 100 ml at each station for each sampling time are given in Tables 4.1 and 4.2 for the Basin and Open Water marinas, respectively. These data are also given as log fecal concentrations per 100 ml in Tables 4.3 and 4.4 for the Basin and Open Water marinas, respectively.

Results of fecal coliform analysis of water are summarized in Table 4.5 as mean concentrations per 100 ml at each station within each marina over the entire study period. Although these data do not take into account the changes in fecal coliform concentrations over time, they do allow for overall comparison of fecal coliform concentrations at boat and non-boat stations within each marina. It is apparent from these data that fecal coliform concentrations in both mainas were higher at the two stations near the boats than at the three other stations located in different directions about 1,000 feet away from the boats. These results indicate that fecal waste discharges from boats probably the major sources of fecal coliform contamination of water in the vicinity of the marinas. Fecal coliform levels probably decline with increasing distance from the boats due to dilution and dispersion of fecal waste discharges and possibly bacterial die-off as well. It should also be noted that for both boat and non-boat stations, fecal coliform concentrations were higher in the Basin marina than in the Open Water marina.

Fecal coliform concentrations as combined log values for the two boat stations and the three non-boat stations at each sampling time are shown in Figures 4.1 and 4.2 for the Basin and Open Water marina, respectively. This form of the data makes it possible to compare fecal coliform densities in marina waters near the boats and about 1,000 feet away from the boats as a function of time. As indicated by the results in Figures 4.1 and 4.2, fecal coliform levels at boat stations in both marinas increased during the first day of sampling (8/29/85), remained elevated over the Labor Day weekend, and then declined again after the weekend (9/3/85). In both marinas, fecal coliform concentrations at boat stations fluctuated considerably during each day. This may reflect the sporadic nature of waste discharge from boats and the variable patterns of waste dispersion and movement in the water in the vicinity of the boats. Non-boat stations in the Basin marina indicate some degree of increased fecal coliform concentrations as well as coliform persistence in the vicinity of the marina.


LOG MEAN COLONIES /100 ml
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0.5
1.0
1.5
2.0
2.5
3.0
3.5
0
4
8
12
16
20
24
TIME IN 6 HOUR PERIODS
● BOAT STATIONS
■ NON-BOAT STATIONS

Figure 4.1

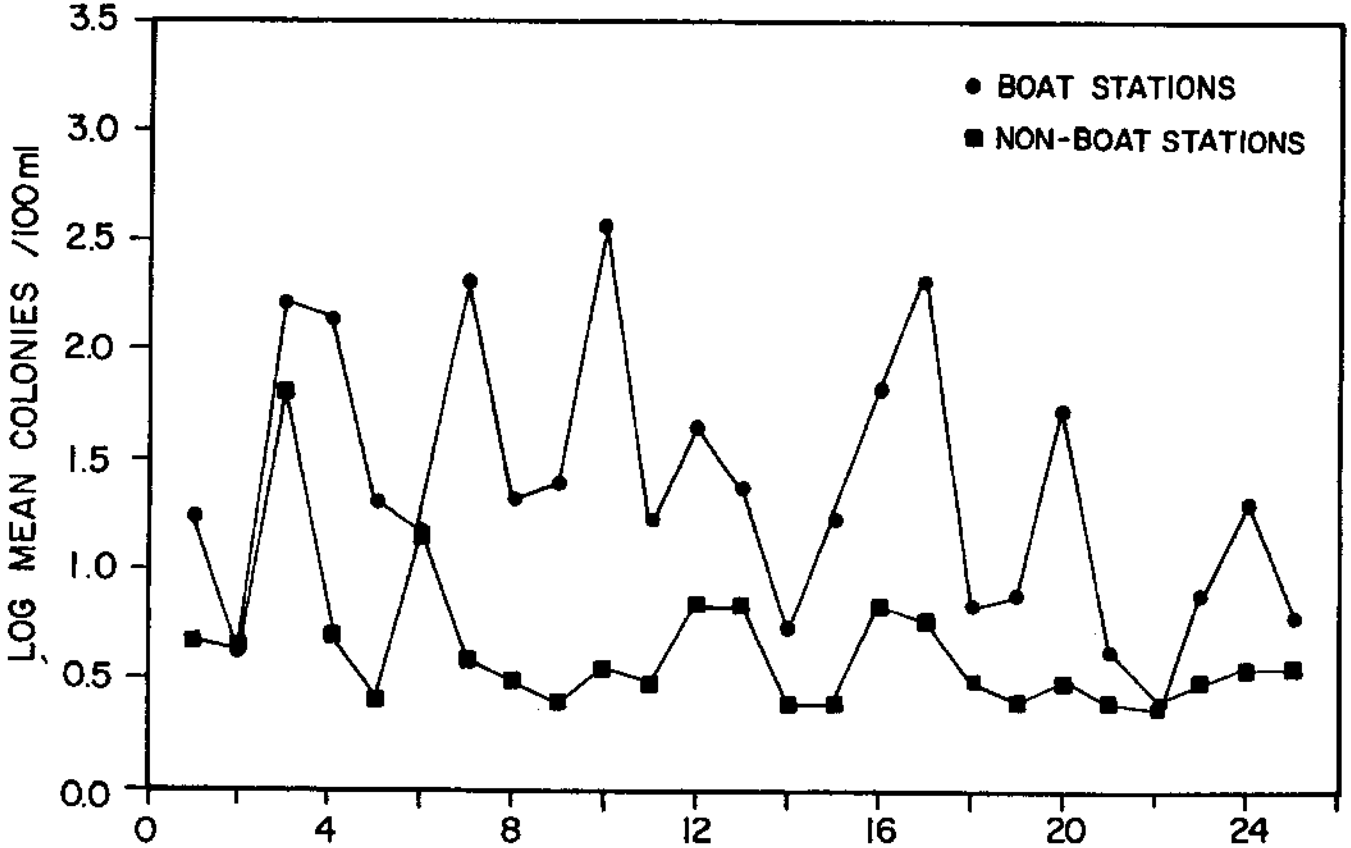

3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
LOG MEAN COLONIES /100ml
0
4
8
12
16
20
24
TIME IN 6 HOUR PERIODS
BOAT STATIONS
NON-BOAT STATIONS

Figure 4.2

Table 4.1
Mean Fecal Coliform Concentrations in Water
at Stations from the Basin Marina
Stations 1,2,3: Non-boat   Stations 3,4: Boat

		Fecal Coliform/100ml/at Station:				
Date	Time	1	2	3	4	5
8/29	12:00 PM	<2.5	5.0	37.5	60.0	25.0
	6:00 PM	<2.5	37.5	7.5	12.5	10.0
8/30	12:00 AM	<2.5	7.5	2.5	17.5	450.0
	6:00 AM	2.5	30.0	175.0	172.5	150.0
	12:00 PM	<2.5	90.0	62.5	240.0	57.5
	6:00 PM	<2.5	90.0	47.5	220.0	77.5
8/31	12:00 AM	<2.5	17.5	37.5	1150.0	225.0
	6:00 AM	35.0	32.5	270.0	120.0	200.0
	12:00 PM	12.5	37.5	32.5	255.0	17.5
	6:00 PM	7.5	312.5	25.0	142.5	57.5
9/1	12:00 AM	17.5	50.0	62.5	125.0	37.5
	6:00 AM	25.0	42.5	35.0	70.0	2400.0
	12:00 PM	7.5	37.5	52.4	190.0	500.0
	6:00 PM	170.0	25.0	22.5	40.0	225.0
9/2	12:00 AM	25.0	82.5	25.0	122.5	52.5
	6:00 AM	57.5	25.0	17.5	550.0	112.5
	12:00 PM	<2.5	75.0	175.0	417.5	200.0
	6:00 PM	30.0	100.0	125.0	2925.0	400.0
9/3	12:00 AM	<2.5	325.0	17.5	250.0	100.0
	6:00 AM	17.5	32.5	27.5	27.5	15.0
	12:00 PM	2.5	5.0	10.0	42.5	12.5
	6:00 PM	22.5	5.0	2.5	20.0	37.5
9/4	12:00 AM	<2.5	15.0	2. 5	47.5	22.5
	6:00 AM	57.5	10.0	7.5	50.0	27.5
	12:00 PM	<2.5	2.5	32.5	2.5	27.5

Table 4.2
Mean Fecal Coliform Concentrations in Water
at Stations from the Open Water Marina
Stations 1,2: Boat   Stations 3,4,5: Non-Boat

Date	Time	Fecal Coliform/100 ml/at Station: 1	2	3	4	5
8/29	12:00 PM	12.5	25.0	2.5	17.5	2.5
	6:00 PM	2.5	7.5	<2.5	2.5	10.0
8/30	12:00 AM	75.0	375.0	<2.5	425.0	250.0
	6:00 AM	60.0	322.5	2.5	<2.5	20.0
	12:00 PM	25.0	17.5	<2.5	<2.5	<2.5
	6:00 PM	2.5	95.0	<2.5	100.0	12.5
8/31	12:00 AM	75.0	575.0	2.5	5.0	5.0
	6:00 AM	35.0	12.5	<2.5	5.0	<2.5
	12:00 PM	<2.5	<25.0	<2.5	<2.5	2.5
	6:00 PM	3575.0	40.0	7.5	<2.5	<2.5
9/1	12:00 AM	2.5	117.5	5.0	<2.5	2.5
	6:00 AM	77.5	27.5	<2.5	10.0	15.0
	12:00 PM	<2.5	225.0	2.5	5.0	27.5
	6:00 PM	<2.5	12.5	<2.5	2.5	<2.5
9/2	12:00 AM	5.0	60.0	<2.5	<2.5	2.5
	6:00 AM	37.5	117.5	<2.5	7.5	20.0
	12:00 PM	7.5	600.0	17.5	5.0	<2.5
	6:00 PM	5.0	10.0	<2.5	<2.5	5.0
9/3	12:00 AM	2.5	25.0	<2.5	<2.5	2.5
	6:00 AM	30.0	95.0	2.5	<2.5	5.0
	12:00 PM	<2.5	7.5	<2.5	<2.5	<2.5
	6:00 PM	2.5	<2.5	<2.5	<2.5	<2.5
9/4	12:00 AM	2.5	25.0	<2.5	<2.5	5.0
	6:00 AM	82.5	5.0	<2.5	<2.5	7.5
	12:00 PM	5.0	7.5	<2.5	<2.5	7.5

Table 4.3
Log Mean Fecal Coliform Concentrations in Water
at Stations from the Basin Marina
Stations 1,2,3: Non-Boat Stations 3,4: Boat

		Log Fecal Coliform/100 ml/at Station:				
Date	Time	1	2	3	4	5
8/29	12:00 PM	<0.40	0.70	1.57	1.78	1.40
	6:00 PM	<0.40	1.57	0.88	1.10	1.00
8/30	12:00 AM	<0.40	0.88	0.40	1.24	2.65
	6:00 AM	<0.40	1.48	2.24	2.24	2.18
	12:00 PM	<0.40	1.95	1.80	2.38	1.76
	6:00 PM	<0.40	1.95	1.68	2.34	1.89
8/31	12:00 AM	<0.40	1.24	1.57	3.06	2.35
	6:00 AM	1.54	1.51	2.43	2.08	2.30
	12:00 PM	1.10	1.57	1.51	2.41	1.24
	6:00 PM	0.88	2.49	1.40	2.15	1.76
9/1	12:00 AM	1.24	1.70	1.80	2.09	1.57
	6:00 AM	1.40	1.63	1.54	1.85	3.38
	12:00 PM	1.88	1.57	1.72	2.28	2.70
	6:00 PM	2.23	1.40	1.35	1.60	2.35
9/2	12:00 AM	1.39	1.92	1.40	2.09	1.72
	6:00 AM	1.76	1.40	1.24	2.74	2.05
	12:00 PM	<0.40	1.88	2.24	2.62	2.30
	6:00 PM	1.48	2.00	2.10	3.47	2.60
9/3	12:00 AM	<0.40	2.51	1.24	2.40	2.00
	6:00 AM	1.24	1.51	1.44	1.44	1.18
	12:00 PM	0.40	0.70	1.00	1.63	1.10
	6:00 PM	1.35	0.70	0.40	1.30	1.57
9/4	12:00 AM	<0.40	1.18	0.40	1.68	1.35
	6:00 AM	1.76	1.00	0.88	1.70	1.44
	12:00 PM	<0.40	0.40	1.51	0.40	1.44

Table 4.4
Log Mean Fecal Coliform Concentrations in Water
at Stations from the Open Water Marina
Stations 1,2: Boat Stations 3,4,5: Non-Boat

		Log	Fecal	Coliform/100 ml/at	Station:	
Date	Time	1	2	3	4	5
8/29	12:00 PM	1.10	1.40	0.40	1.24	0.40
	6:00 PM	0.40	0.88	<0.40	0.40	1.00
8/30	12:00 AM	1.88	2.57	<0.40	2.63	2.40
	6:00 AM	1.78	2.51	0.40	<0.40	1.30
	12:00 PM	1.40	1.24	<0.40	<0.40	<0.40
	6:00 PM	0.40	1.98	<0.40	2.0	1.10
8/31	12:00 AM	1.88	2.76	0.40	0.70	0.70
	6:00 AM	1.54	1.10	<0.40	0.70	<0.40
	12:00 PM	<1.40	<1.40	<0.40	<0.40	0.40
	6:00 PM	3.55	1.60	0.88	<0.40	<0.40
9/1	12:00 AM	0.40	2.07	0.70	<0.40	0.40
	6:00 AM	1.89	1.44	<0.40	1.00	1.18
	12:00 PM	<0.40	2.35	0.40	0.70	1.44
	6:00 PM	<0.40	1.10	<0.40	0.40	<0.40
9/2	12:00 AM	0.70	1.79	<0.40	<0.40	0.40
	6:00 AM	1.57	2.07	<0.40	0.88	1.30
	12:00 PM	0.88	2.78	1.24	0.70	<0.40
	6:00 PM	0.70	1.00	<0.40	<0.40	0.70
9/3	12:00 AM	0.40	1.40	<0.40	<0.40	0.40
	6:00 AM	1.48	1.98	0.40	<0.40	0.70
	12:00 PM	<0.40	0.88	<0.40	<0.40	<0.40
	6:00 PM	0.40	<0.40	<0.40	<0.40	<0.40
9/4	12:00 AM	<0.40	1.40	<0.40	<0.40	0.70
	6:00 AM	1.92	0.70	<0.40	<0.40	0.88
	12:00 PM	0.70	0.88	<0.40	<0.40	0.88

Table 4.5
Fecal Coliform Concentrations in Water at Boat and Non-Boat Stations of the Basin and Open Water Marina

Marina Type	Station No.	Station Type	Mean Fecal Coliform per 100 ml
Basin	1	Non-boat	21
	2	Non-boat	60
	3	Non-boat	52
	4	Boat	291
	5	Boat	218
Open Water	1	Boat	166
	2	Boat	113
	3	Non-boat	3.4
	4	Non-boat	25
	5	Non-boat	17

*mean values of 25 samples collected every six hours beginning at 12 noon, 8/29/85 and ending 12 noon, 9/4/85.

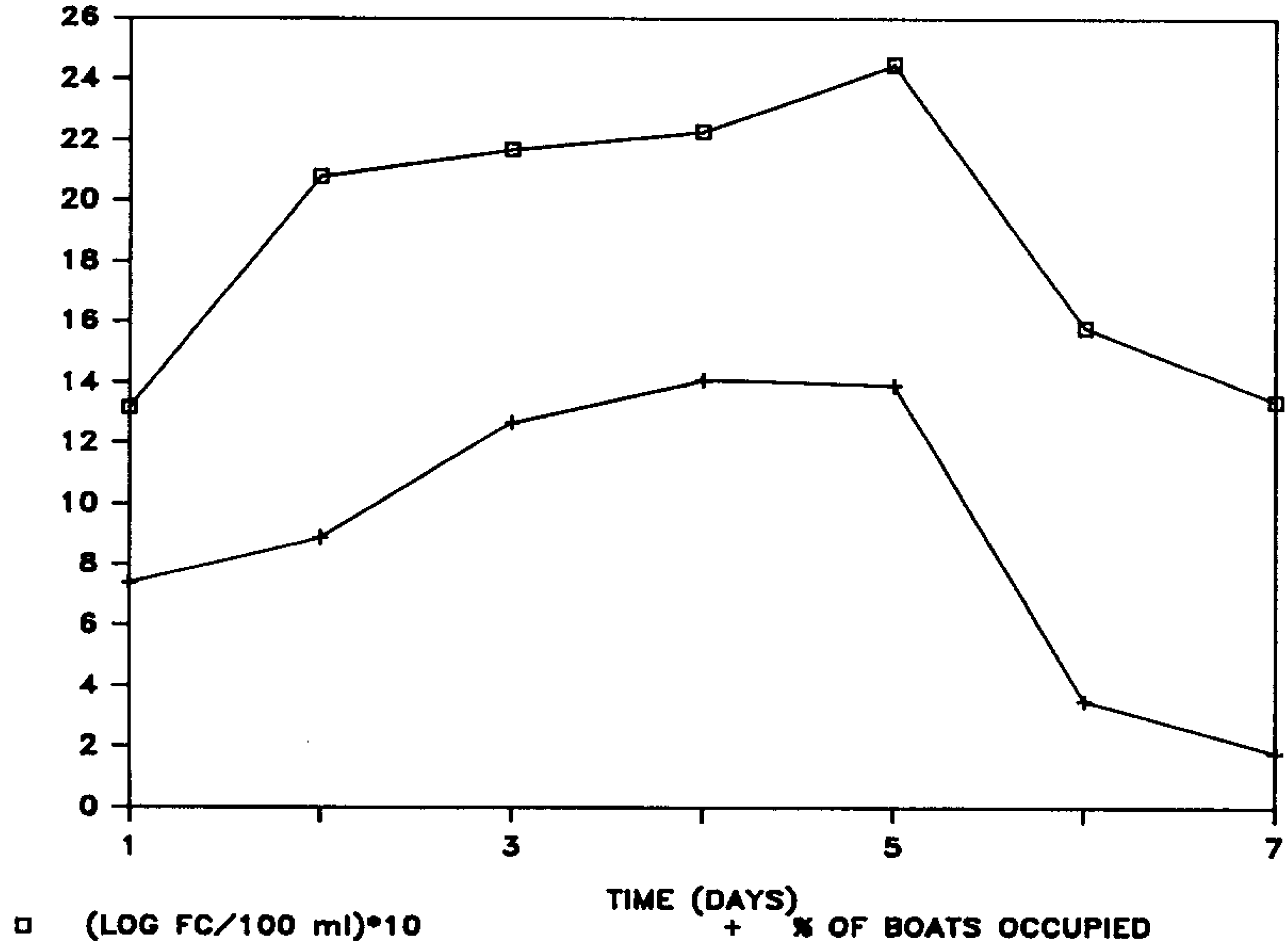
5. CONCLUSIONS

The results of this study indicate that fecal coliform levels in marinas become elevated near boats during periods of high boat occupancy and usage. In both the Basin and the Open Water marina, water samples from stations at the boat docks were well above the fecal coliform limit of 14 per 100 ml for shellfishing waters. Boat stations of the Basin marina also exceeded the U.S. Environmental Protection Agency guideline of 200 fecal coliforms per 100 ml for primary contact recreational waters. Furthermore, at the Basin marina, fecal coliform concentrations at stations 1,000 feet away from the boat docks exceeded the fecal coliform limit for shellfishing waters. At the Open Water marina, however, fecal coliform concentrations at stations 1,000 feet from the boat docks usually did not exceed the fecal coliform limits for shellfishing waters and never exceeded the limit for primary contact recreational waters. These results suggest that substantial dilution and die-off of microbial contaminants in fecal waste discharge of boats in marinas probably does occur under some physical and hydrographic conditions.

Although fecal coliform concentrations at the boat stations generally correlated with boat usage at the Basin marina (Figure 5.1), these two parameters did not correlate as well at the Open Water marina (Figure 5.2). Thus, boat usage was not an entirely adequate predictor of fecal contamination as measured by fecal coliforms. These inconsistencies may be due to differences in boat types and usage patterns at these two marinas, as discussed in Section 3.

In general, as seen in the coliform data, the mixing at the Open Water site was greater than that at the Basin. The results of the dye study supported this conclusion for ebb tide comparison. The effects of the strong wind conditions during the dye study at the Open Water marina precluded a similar comparison for the flood tide.

As noted in the introduction, the primary purpose of this study was to serve as a pilot for a more comprehensive investigation of the impacts of marinas on water quality. It is clear from the limited number of sites studied that these impacts vary significantly with the nature and level of use of the marina site. Additional studies are needed to develop reliable techniques to predict what the impacts will be for proposed marinas.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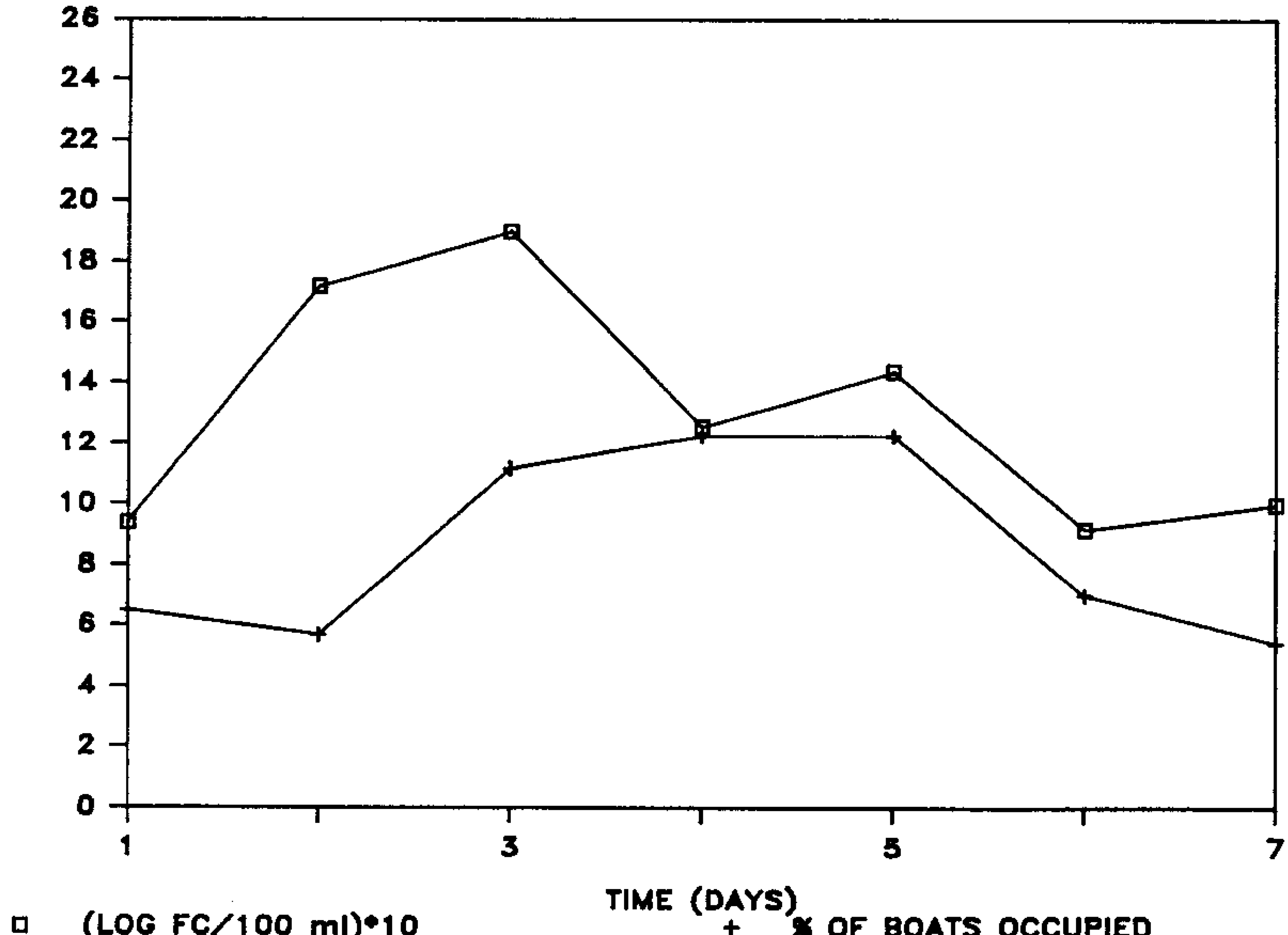
24
22
20
18
16
14
12
10
8
6
4
2
0
1
3
5
7
TIME (DAYS)
□ (LOG FC/100 ml)*10
+ % OF BOATS OCCUPIED

Figure 5.1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24
22
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18
16
14
12
10
8
6
4
2
0
1
3
5
7
TIME (DAYS)
□ (LOG FC/100 ml)*10
+ % OF BOATS OCCUPIED
Figure 5.2

REFERENCES

American Public Health Association, Standard Methods for the Examination of Water and Wastewater, 16th Edition, Washington, DC, 1985.

Kilpatrick, F.A., L.A. Martens, and J.F. Wilson Jr., Measurement of Time of Travel and Dispersion by Dye Tracing, Chapter A9, Book 3, Techniques of Water Resources Investigations of the United States Geological Survey, 1970.

U.S. Environmental Protection Agency, Methods for Microbiological Analysis in the Environment, Cincinnati, Ohio, 1978.

APPENDIX A

DYE CONCENTRATION vs. TIME CURVES

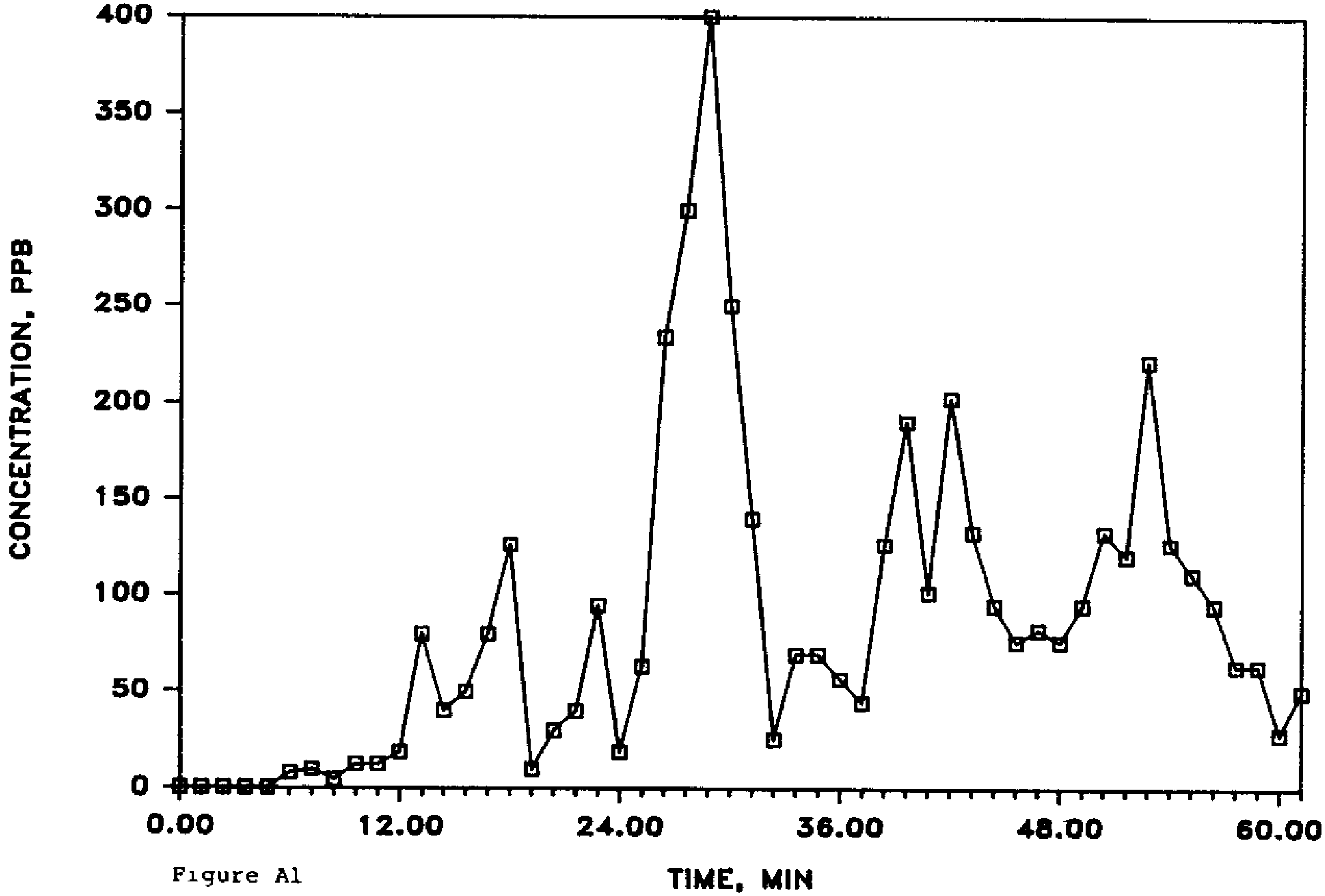

CONCENTRATION, PPB
400
350
300
250
200
150
100
50
0
0.00
12.00
24.00
36.00
48.00
60.00
TIME, MIN

Figure A1

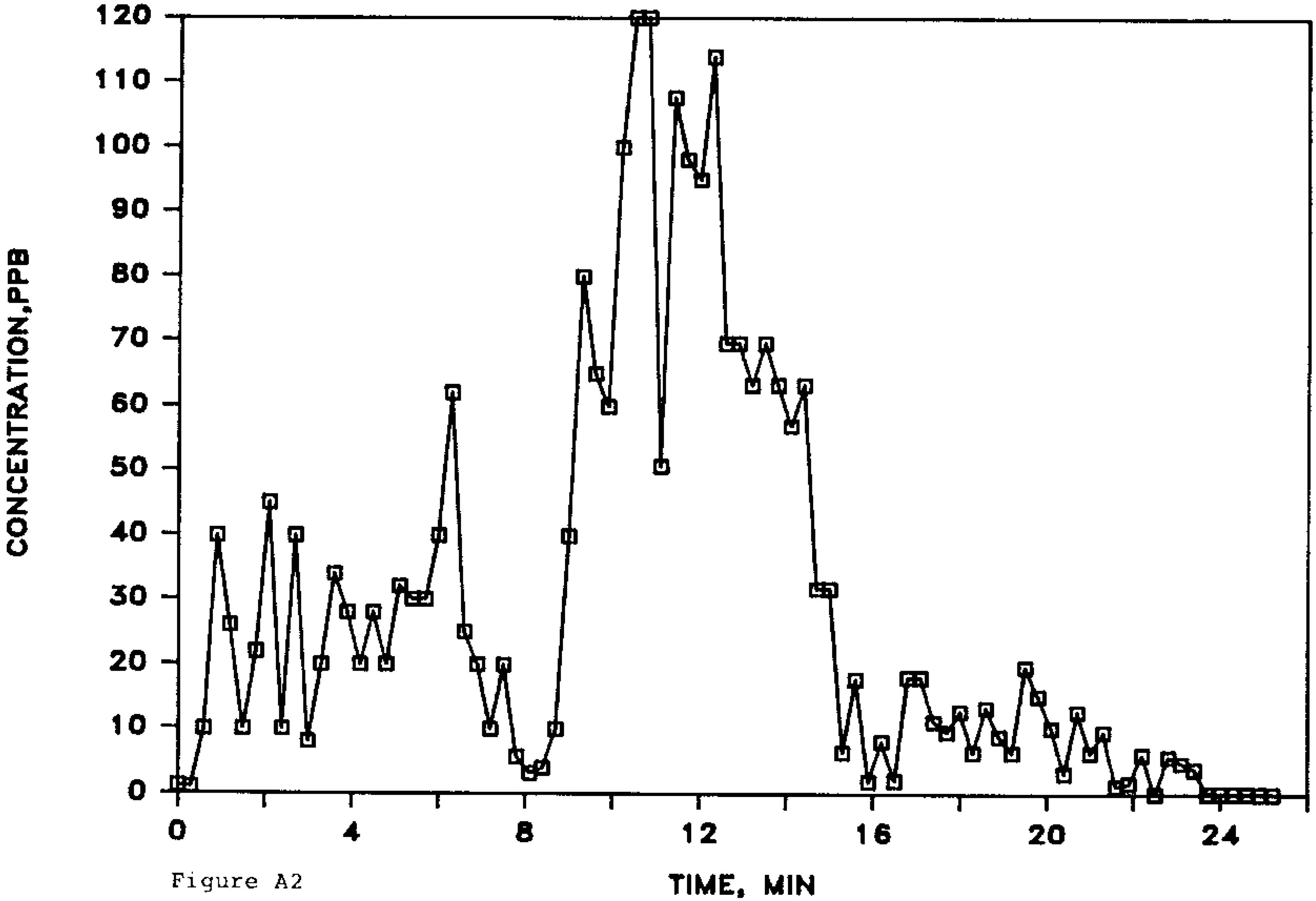

CONCENTRATION,PPB
120
110
100
90
80
70
60
50
40
30
20
10
0
0
4
8
12
16
20
24
TIME, MIN

Figure A2

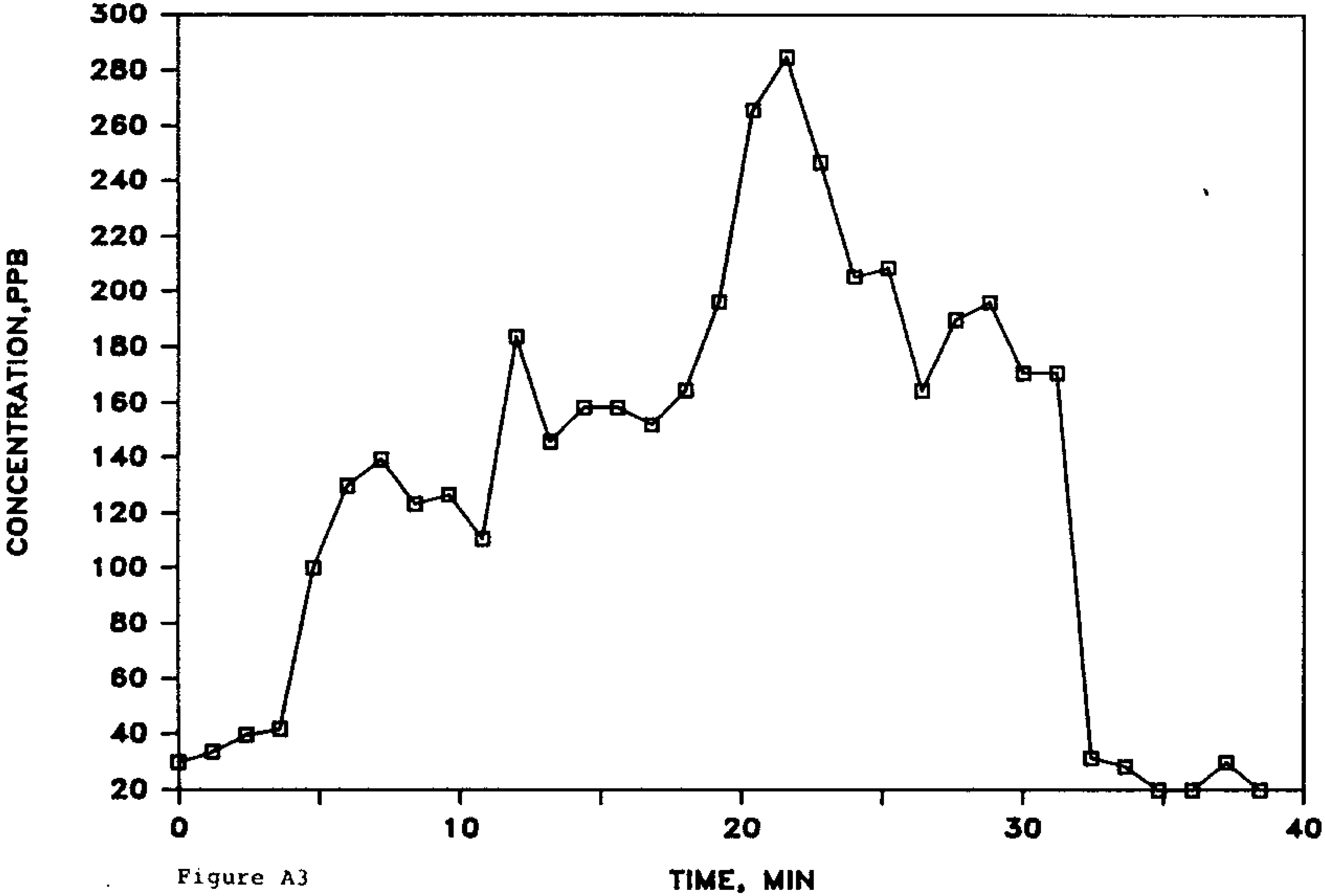
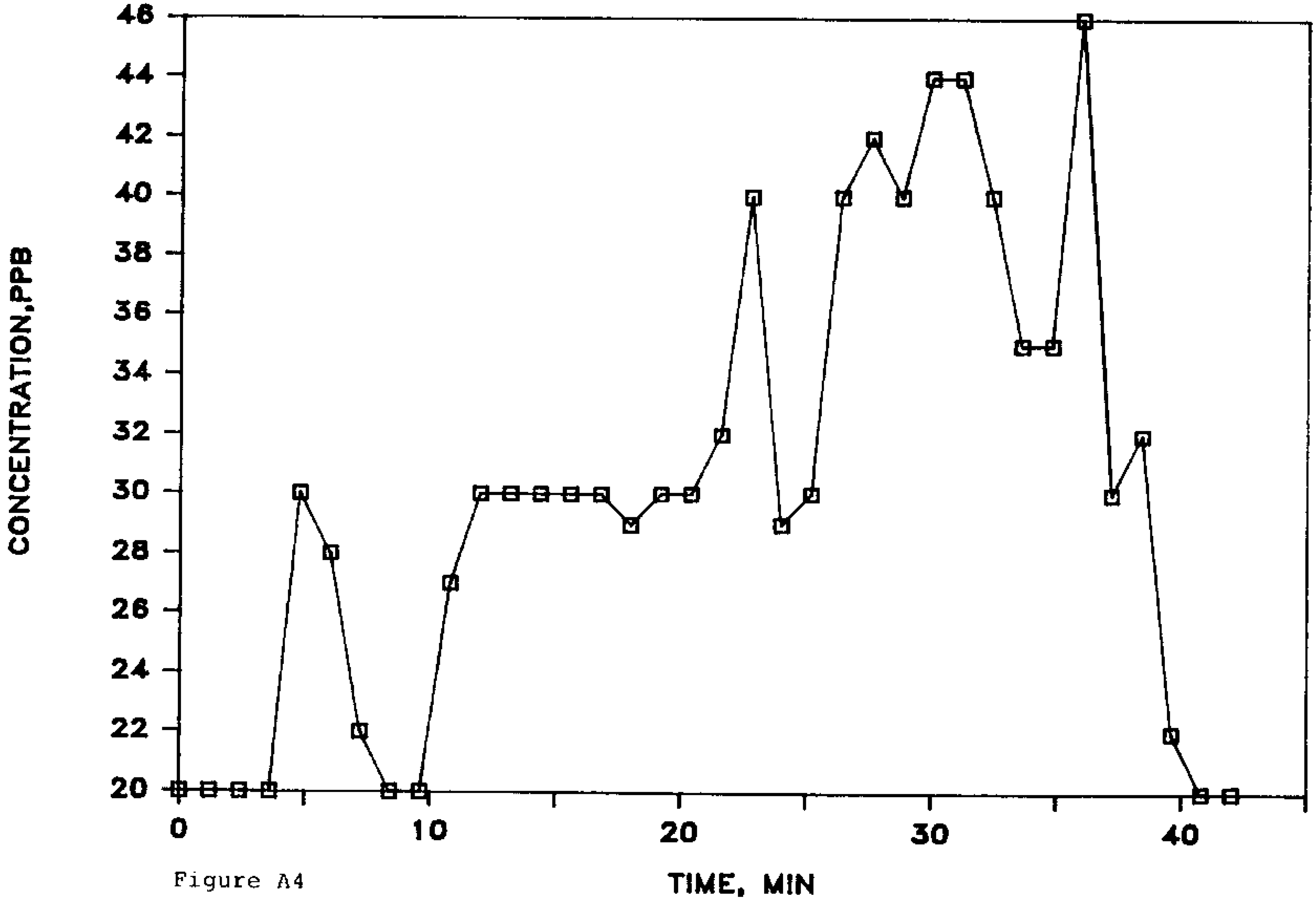
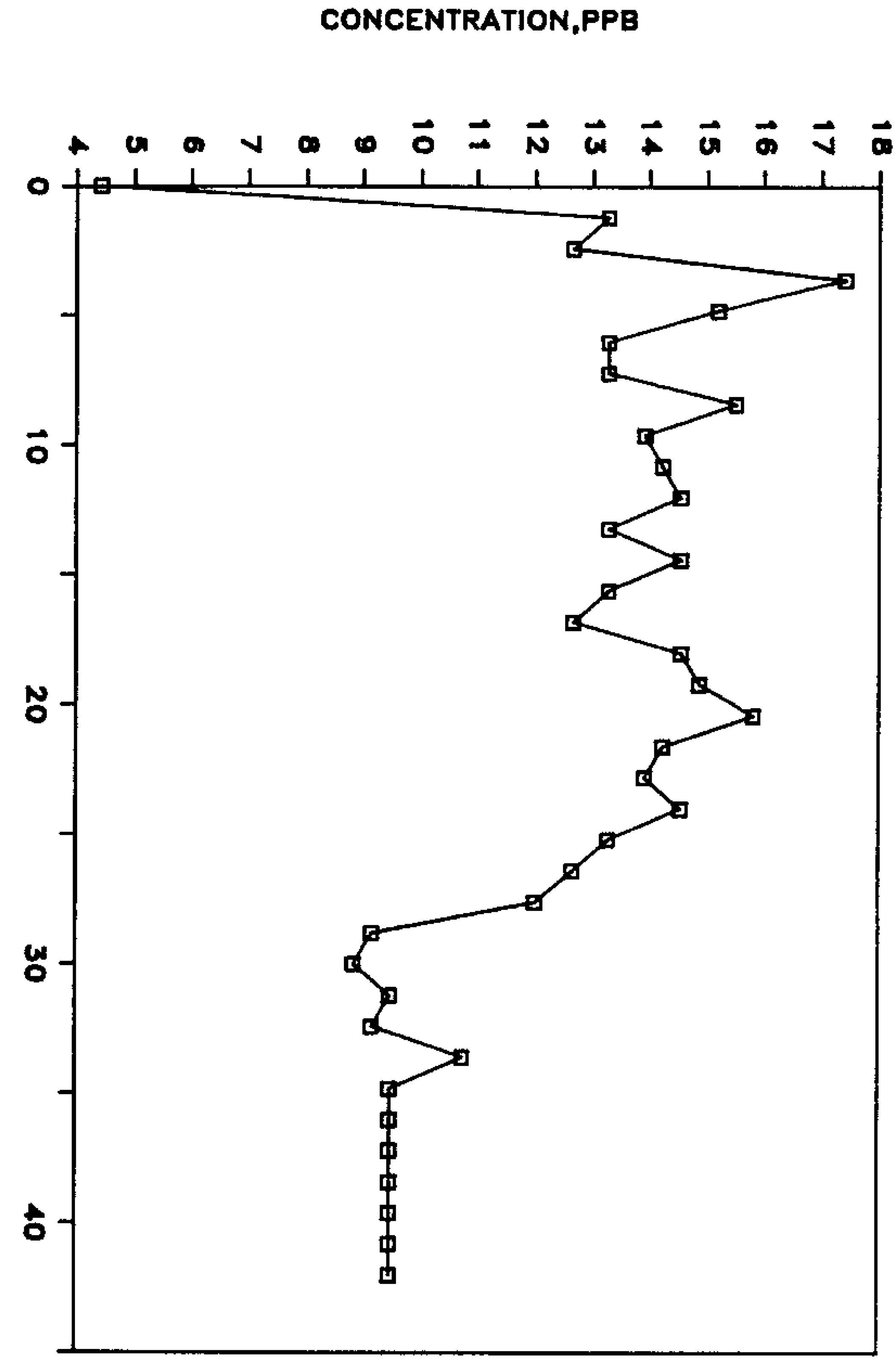

CONCENTRATION,PPB
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
10
20
30
40
TIME, MIN

Figure A3



46
44
42
40
38
36
34
32
30
28
26
24
22
20
CONCENTRATION,PPB
0
10
20
30
40
TIME, MIN

Figure A4


CONCENTRATION,PPB
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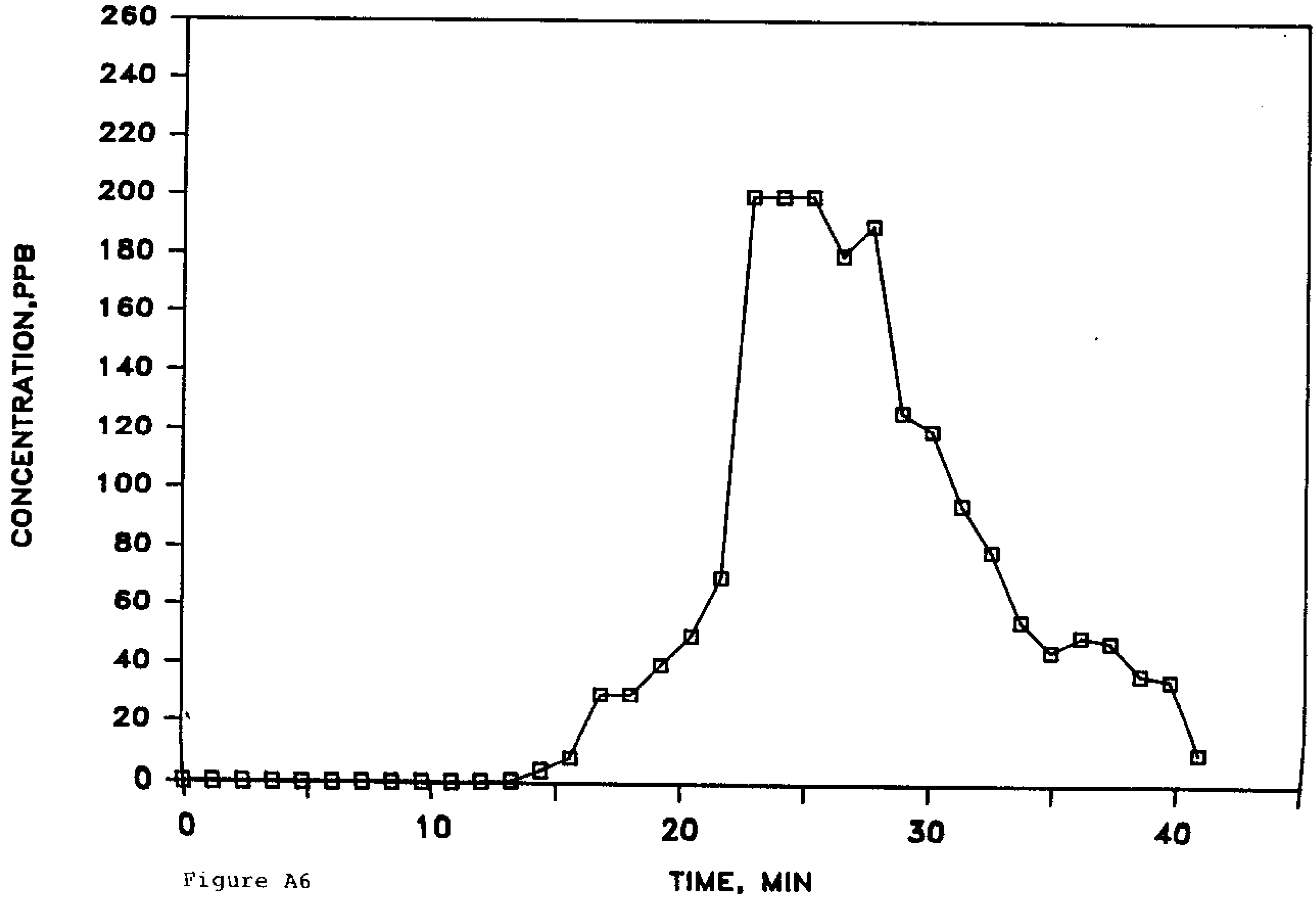
5
6
7
8
9
10
11
12
13
14
15
16
17
18
0
10
20
30
40
TIME, MIN

Figure A5


CONCENTRATION,PPB
260
240
220
200
180
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140
120
100
80
60
40
20
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0
10
20
30
40
TIME, MIN

Figure A6

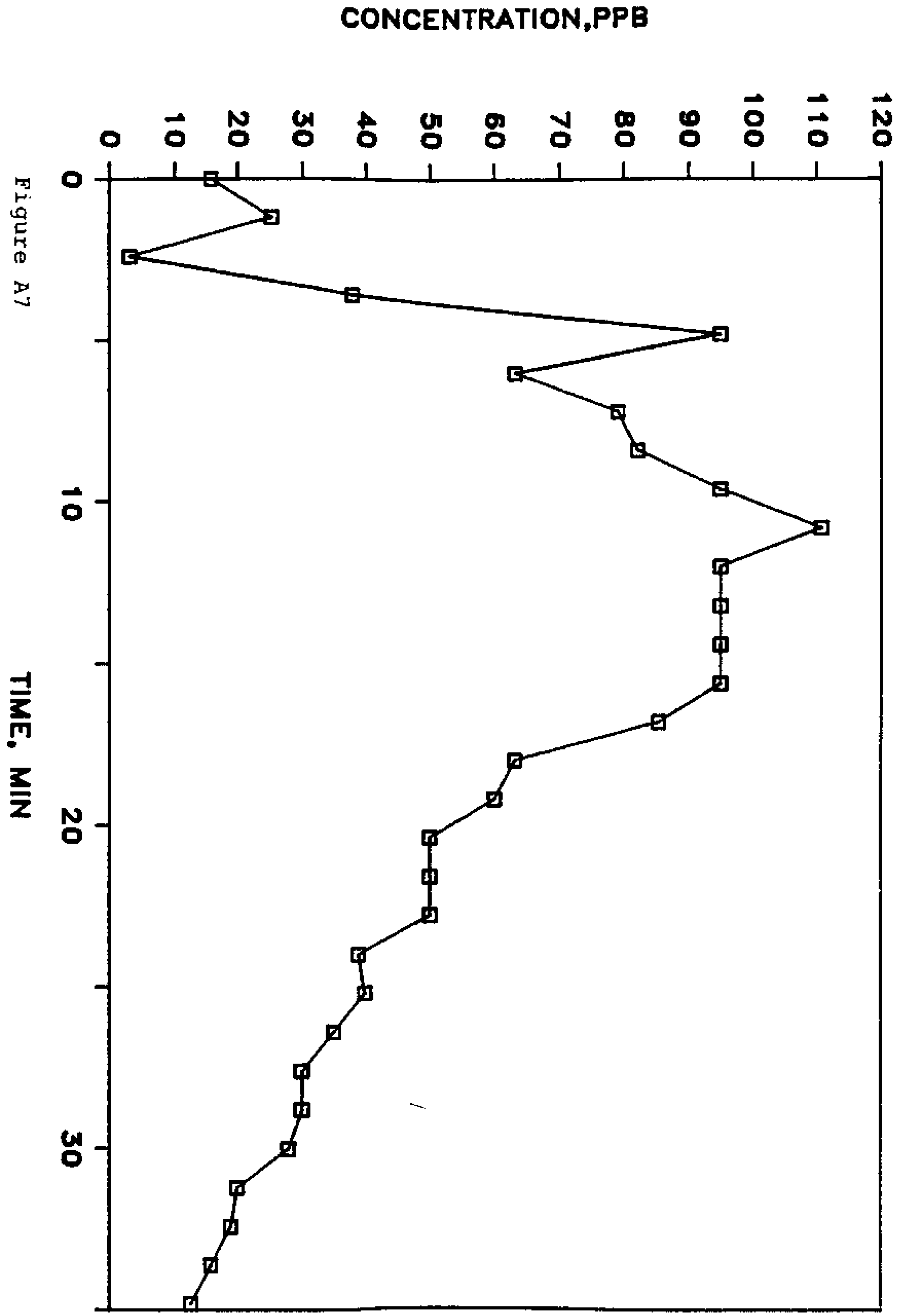

CONCENTRATION,PPB
0
10
20
30
40
50
60
70
80
90
100
110
120
TIME, MIN
0
10
20
30

Figure A7

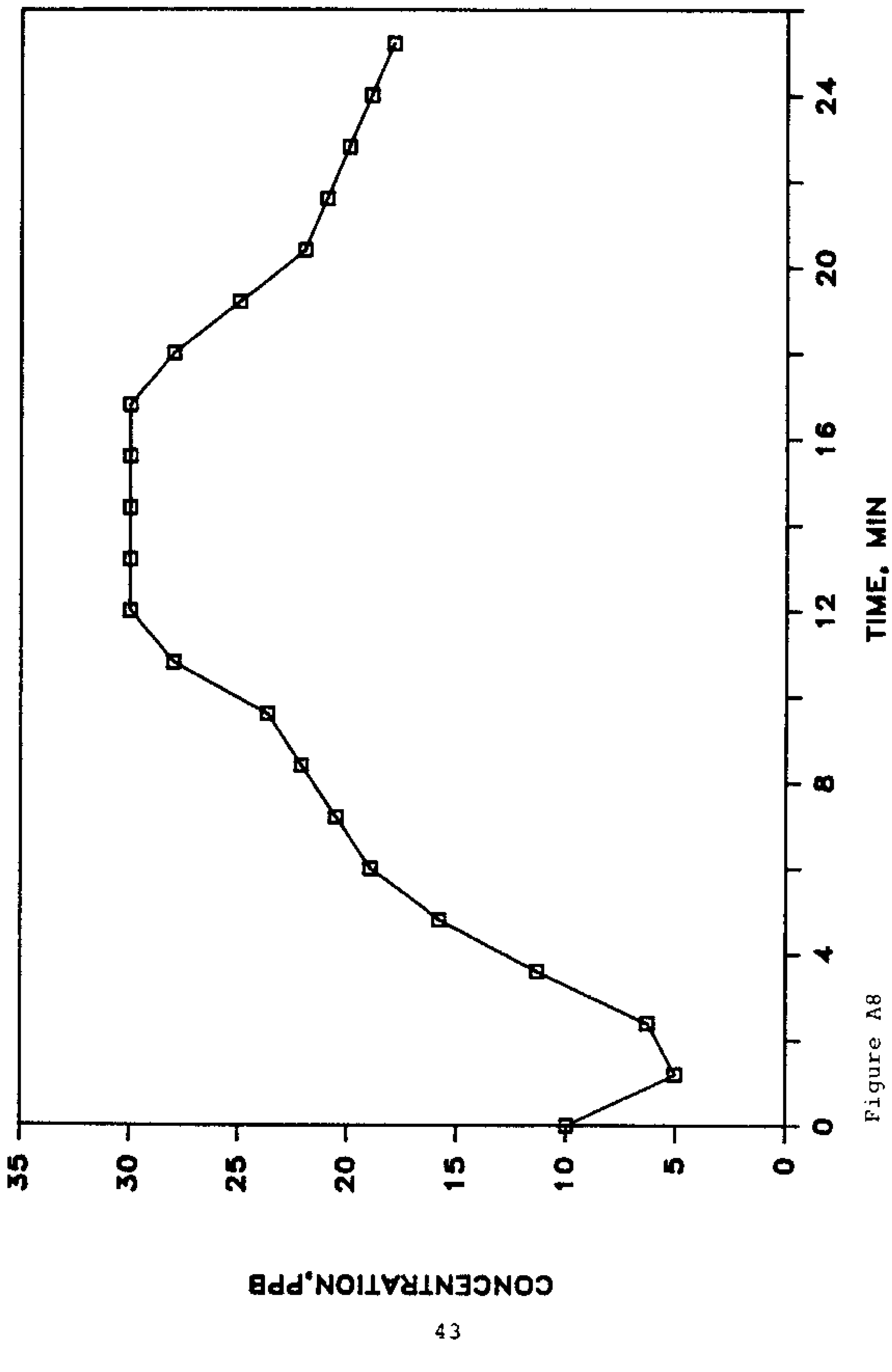
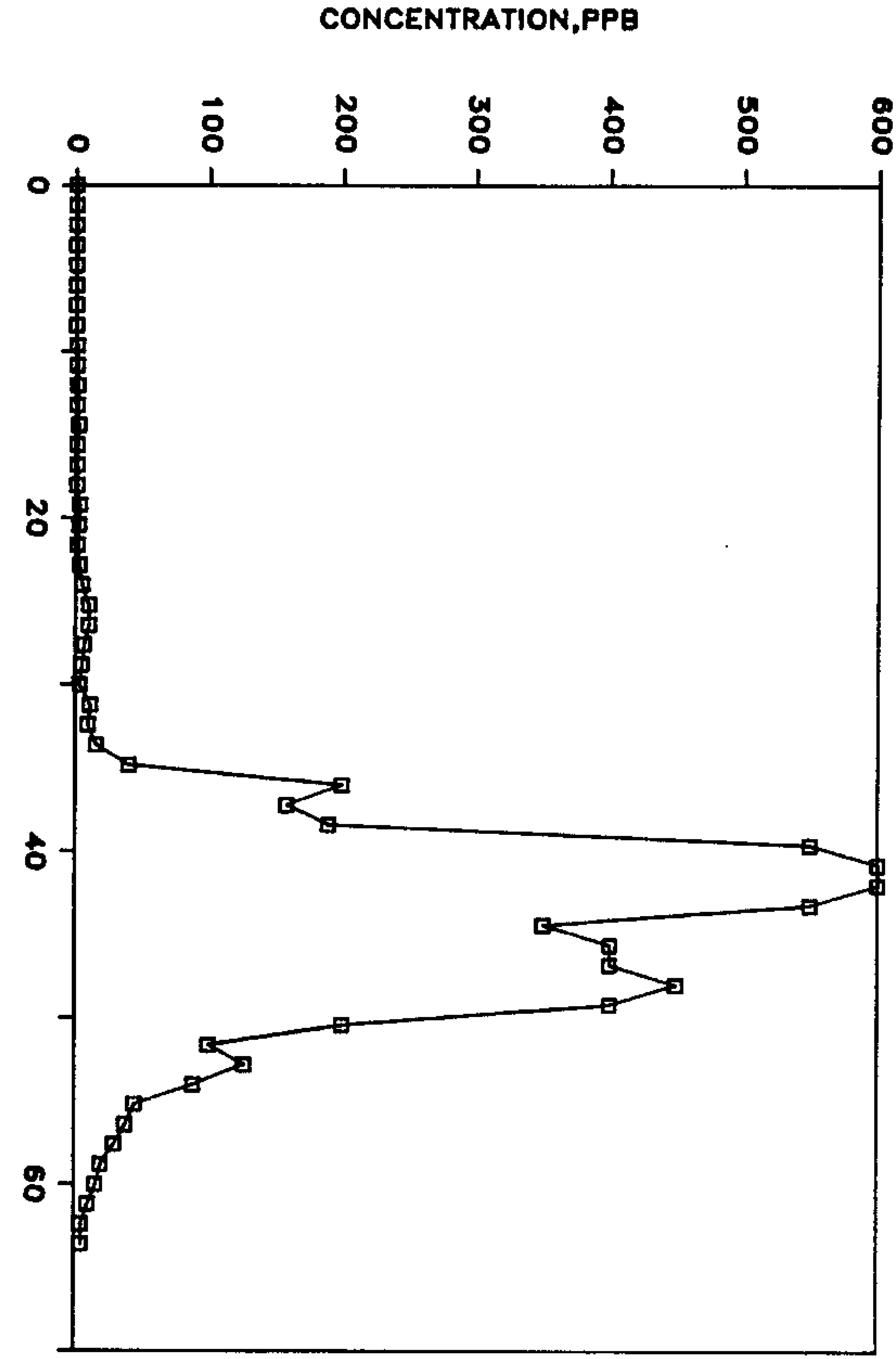


Figure A8



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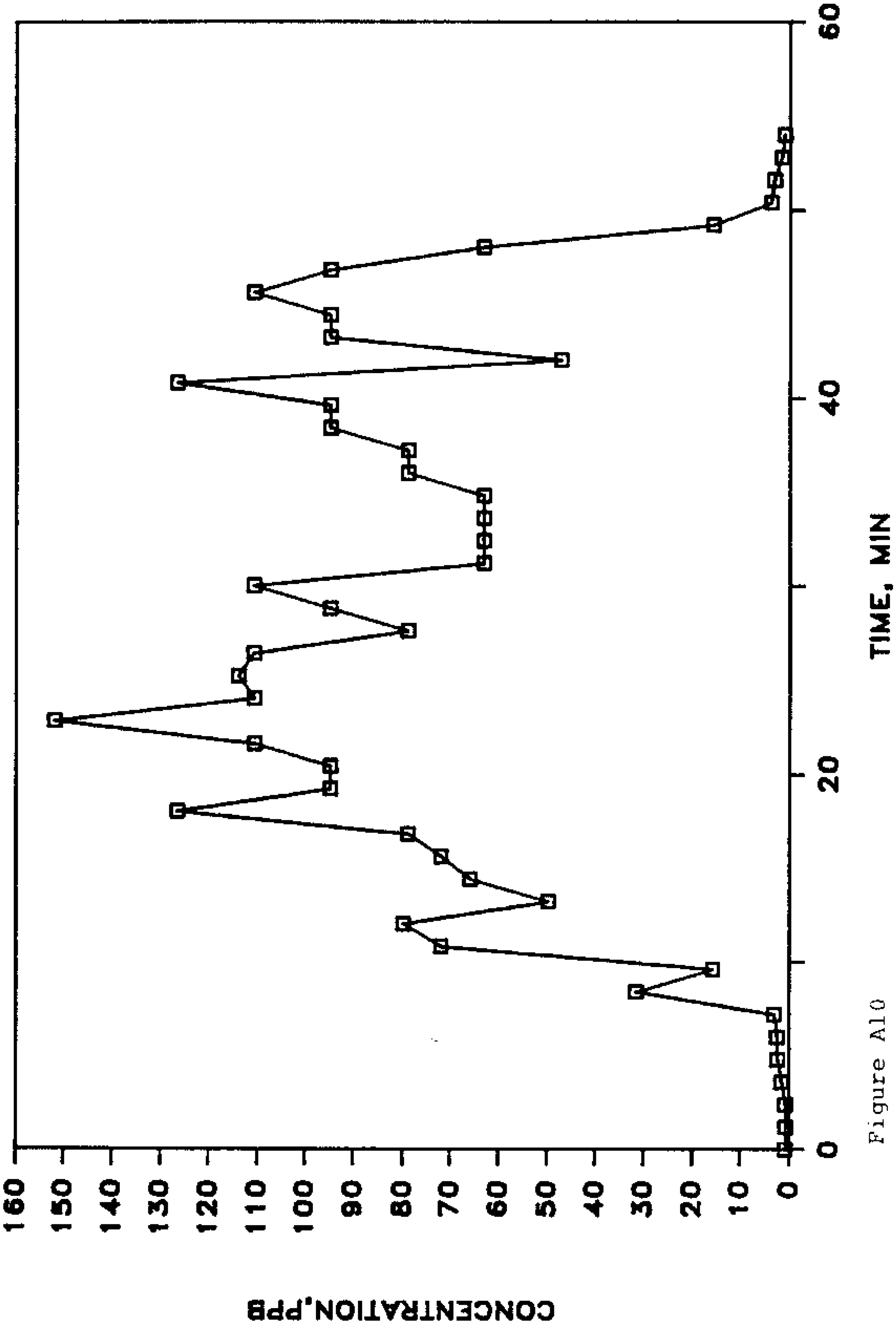
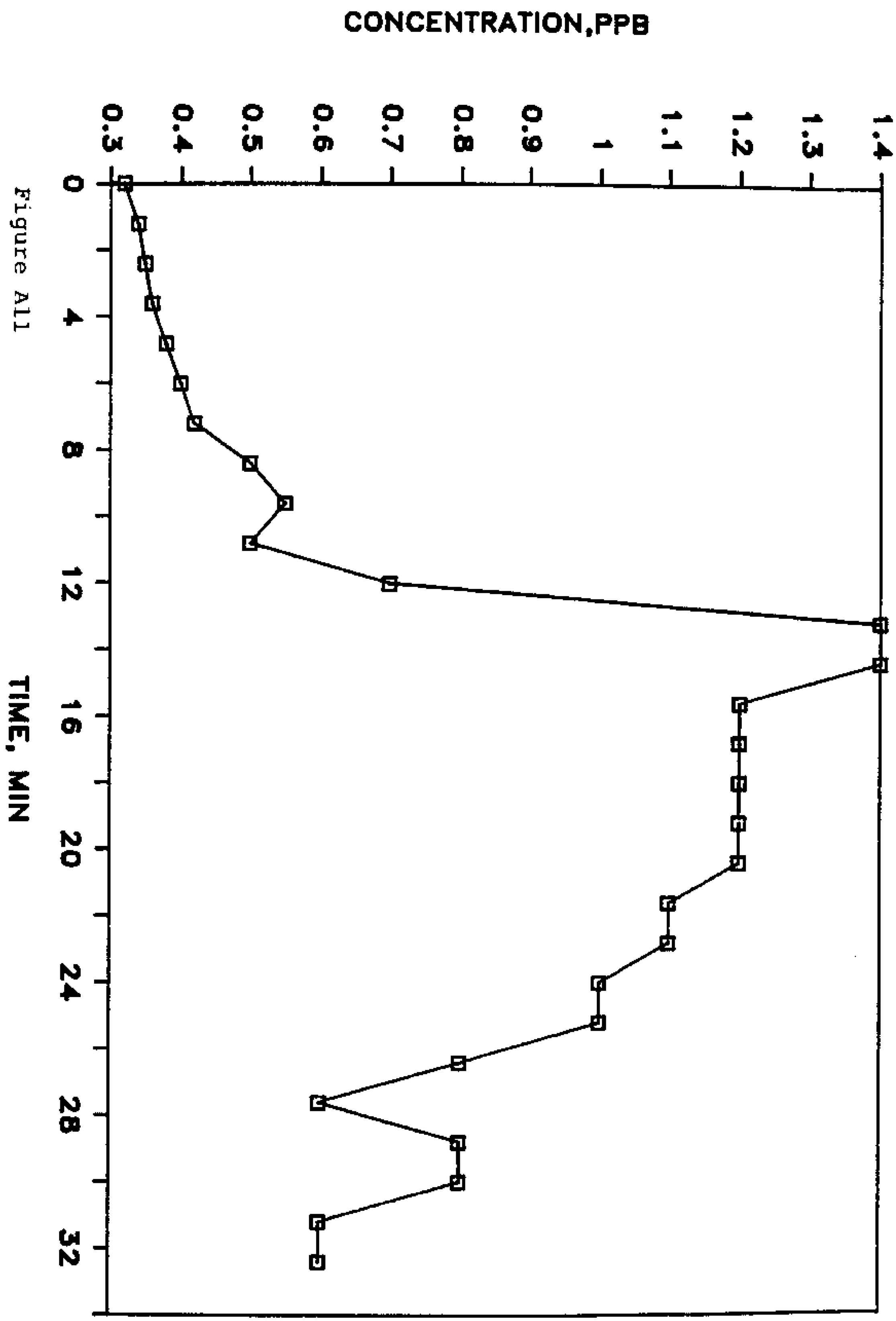

CONCENTRATION,PPB
TIME, MIN
0
20
40
60
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Figure A10


CONCENTRATION,PPB
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0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
0
4
8
12
16
20
24
28
32
TIME, MIN

Figure A11