DISSOLVED OXYGEN VARIABILITY IN THE UPPER JAMES RIVER ESTUARY

by

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I. INTRODUCTION

A mandate of the Virginia Water Control Board (VWCB) is to ensure that state water quality standards are met. Necessary steps towards this goal are (1) gathering data, (2) examining the data to understand existing conditions and the processes at work, and (3) designing and implementing appropriate water quality management plans and actions to protect water quality.

During the summer of 1989, the Piedmont Regional Office of the VWCB conducted a field study that focused on the dissolved oxygen (DO) regime in the tidal freshwater portion of the James River. The purpose of the present study is to examine those data to better understand the extent, causes, and effects of variability in dissolved oxygen concentrations, with particular attention given to whether the state's water quality standards were met. And, of course, the implications of the study findings for water quality management plans are of interest as well.

II. CONTEXT

Water quality in the tidal James River has been studied on a number of occasions. During 1983 and 1984, a large and comprehensive study was undertaken under the leadership of the Richmond Regional and Crater Planning Districts. The monitoring, in fact, continued through 1985. The data from those studies, reported by Weand & Grizzard (1986a and b), were used to re-calibrate a water quality model of the estuary (HydroQual, 1986). Some information from those studies will be used to provide the spatial context for the present study. Time scales for natural variations in water quality also will be discussed.

Spatial patterns: Wastewater discharges in the vicinity of Richmond and near Hopewell greatly influence water quality conditions in the tidal James. In order to illustrate "typical" spatial patterns, the longitudinal variation in water quality on September 27, 1983 is presented in Figure 1. (This figure has been taken from HydroQual's report {1986} and includes both field measurements and model predictions.) The concentrations of orthophosphorus and ammonia-nitrogen both increase rapidly below the fall line at Richmond in response to the wastewater discharges, and then decrease in the downriver direction. As the ammonia is oxidized, the concentration of nitrite-nitrate-nitrogen increases. The

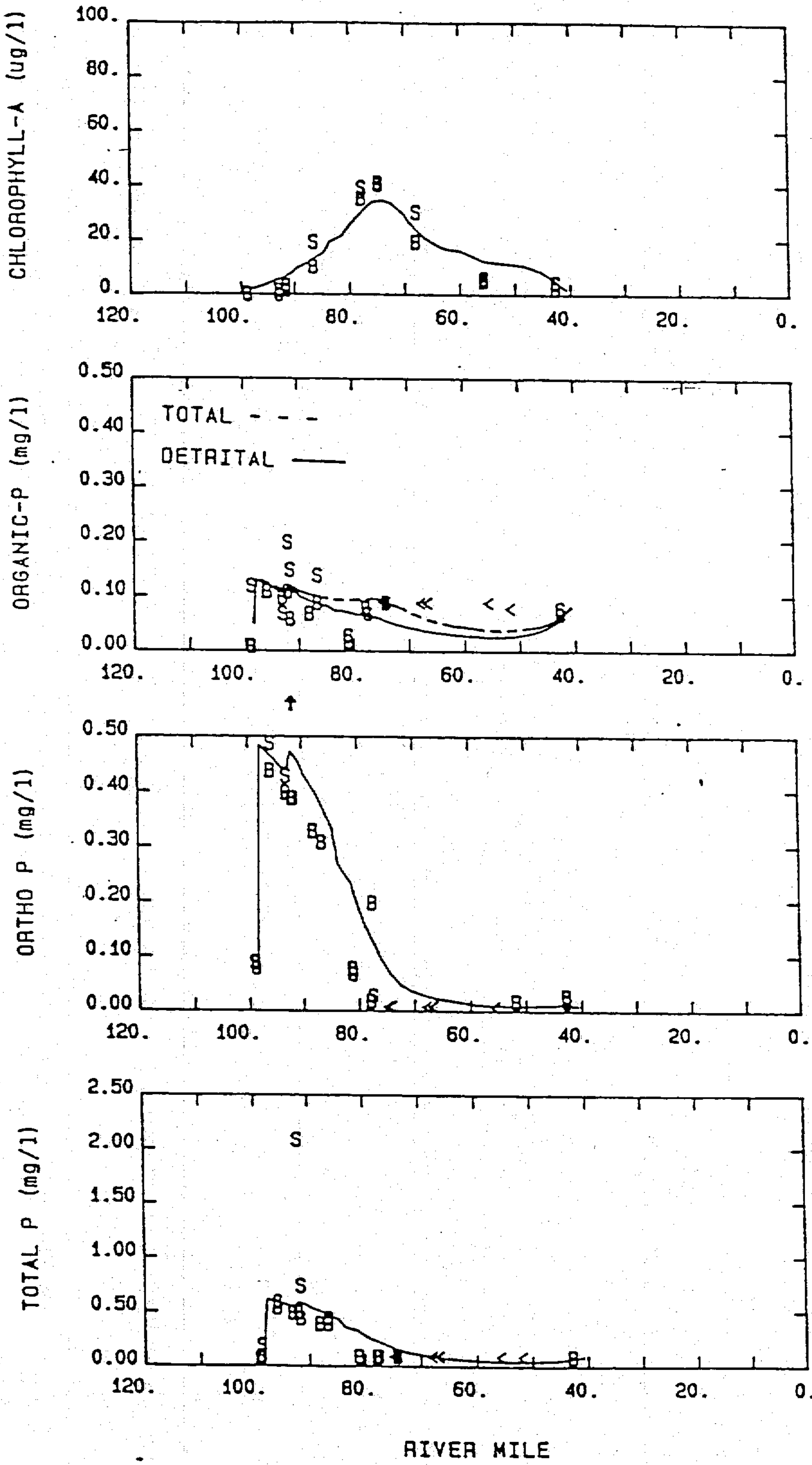

FIGURE 7-14A. JAMES RIVER VERIFICATION, SEPTEMBER 27, 1983
CHLOROPHYLL-A AND PHOSPHORUS

Figure 1. Field observations and model predictions.
(From HydroQual, 1986)

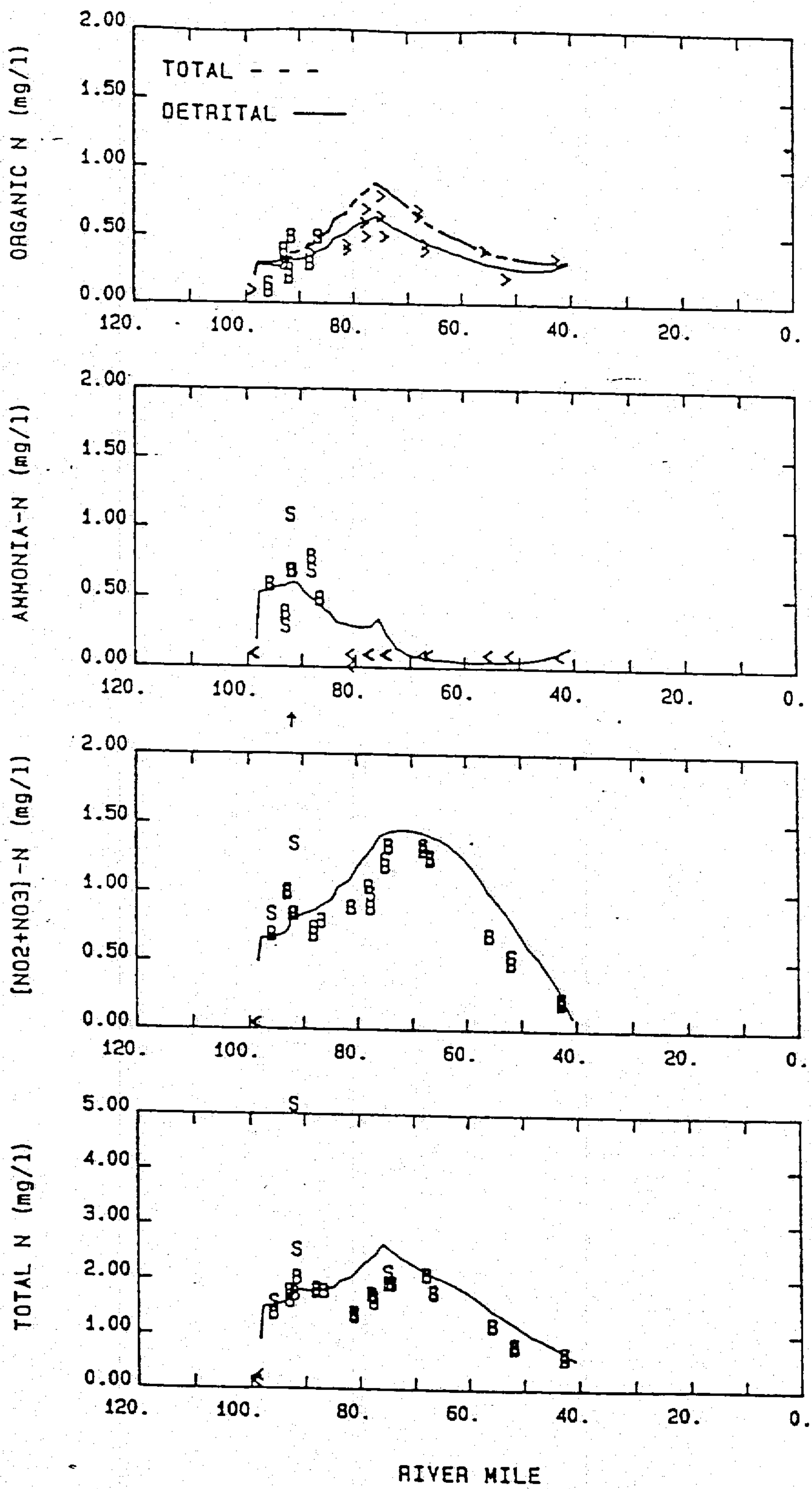

FIGURE 7-14C. JAMES RIVER VERIFICATION, SEPTEMBER 27, 1983
NITROGEN SERIES

Figure 1 (Continued). Field observations and model predictions.
(From HydroQual, 1986)

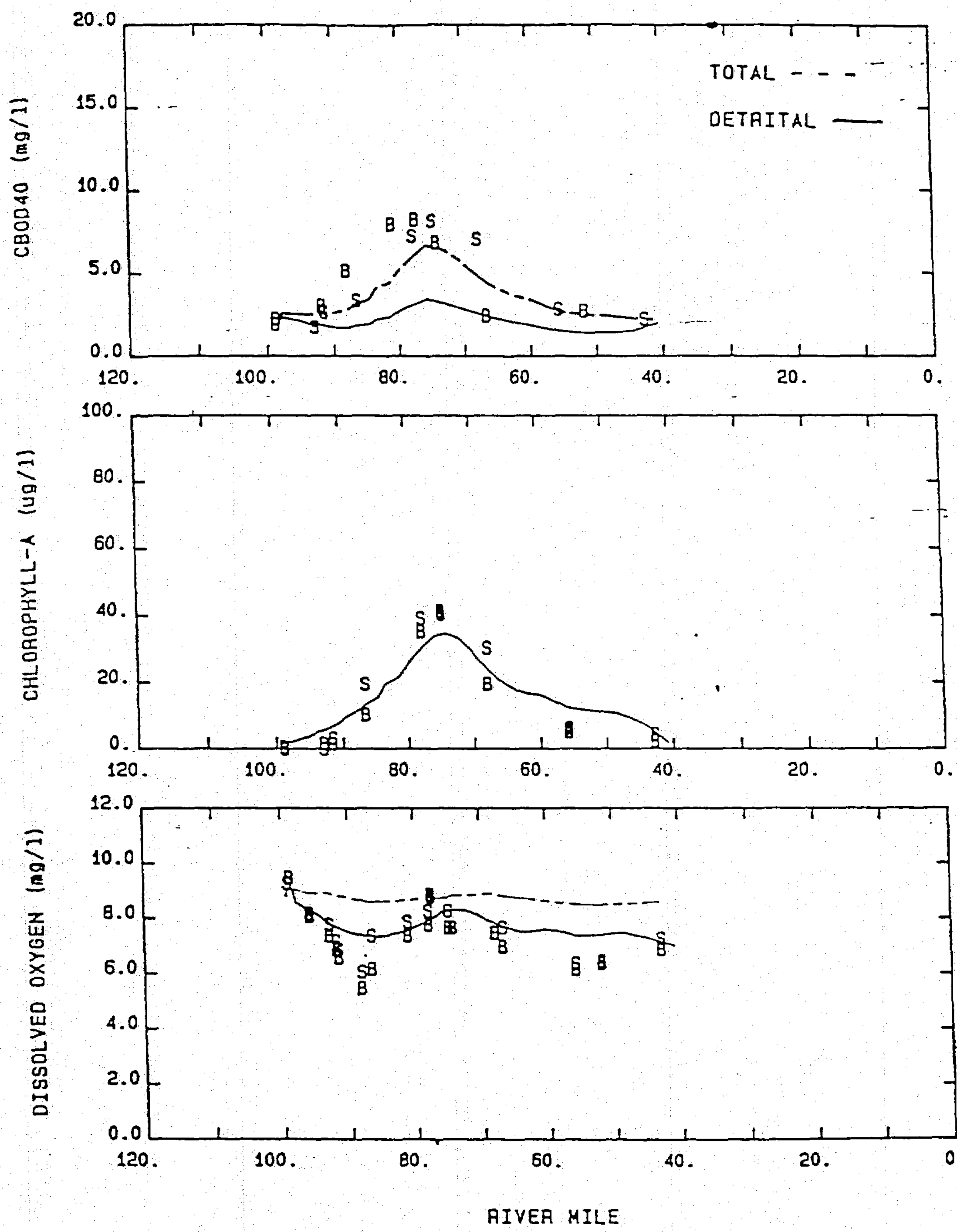

FIGURE 7-14E. JAMES RIVER VERIFICATION, SEPTEMBER 27, 1983
CBOD, CHLOROPHYLL-A, DISSOLVED OXYGEN

Figure 1 (Continued). Field observations and model predictions.
(From HydroQual, 1986)

field data suggest an initial peak downriver of the Richmond discharges with a second peak at about river mile 75, with this latter peak presumably due to Hopewell discharges. The model, however, shows a single peak at the more downriver location.

The nutrients support algal growth which also peaks at about river mile 75 on this date. It is interesting to note that the long-term oxyen demand (carbonaceous biochemical oxygen demand at 40 days or CBOD40), does not jump up near Richmond, presumably because the level of BOD removal at the Richmond plants is quite high. The BOD profile, however, shows a maximum at about the same location as the chlorophyll maximum. When algae die, decomposition of this organic matter increases the oxygen demand; presumably the CBOD and chlorophyll profiles are quite similar because decomposition of dead algae exerts a significant BOD load.

The BOD discharged from the wastewater treatment plants is oxidized in the river, decreasing ambient DO concentrations. The DO deficit is counterbalanced by natural reaeration and by the oxygen resulting from algal photosynthesis. The DO profile shows a discernible DO sag below Richmond with general recovery by about Hopewell. Downriver of Hopewell there is a second DO sag. The shape of the DO sags will vary with river flow; during periods of high runoff, the two sags will merge.

The 1989 field study focused on the reach of the river between Hopewell and the Chickahominy River, or about river mile 50 to river mile 75. Many of the stations used in the earlier studies were used in the 1989 survey.

Time scales of variability: Water quality conditions in general and dissolved oxygen concentrations in particular show a pronounced annual variation. The solubility of oxygen in water decreases as water temperature increases. During the winter, the river water can absorb more oxygen; the saturation concentration at 5 C is 12.77 mg/l (milligrams per liter; APHA, 1985). During the summer, the solubility is greatly reduced; at 25 C the saturation concentration is 8.26 mg/l. For this study, the longer term variation is not an important consideration. Water temperatures for June through September 1989 were always above 25 C and ranged to about 30 C (see Figure 3). Saturation concentration at 30 C is 7.56 mg/l, or less than 10 % below the 25 C value.

Dissolved oxygen concentrations also vary on time scales of hours. If there is a longitudinal gradient in DO, then the oxygen concentrations at a fixed point will vary with the tides. For example, the DO sag will move up and down the river with tides. At any point along the sag then, the DO record will exhibit tidal variability, perhaps with higher DO concentrations near times of high tide and minimum DO concentrations near times of low tide. If there were no longitudinal gradient, the DO would remain constant with time as well.

If there are abundant aquatic plants, and usually this means planktonic algae in the tidal James, then there can be a diurnal variation in oxygen as well. When there is sunlight and nutrients are available, the algae grow; oxygen is a byproduct of photosynthesis. Algal respiration, on the other hand, consumes oxygen. During periods of growth, there is a net production of oxygen. During the night and other periods of no growth, there is a net uptake of oxygen by the algae. The end result is a daily variation of DO with minimum concentrations typically occurring just before dawn and peak DO's occurring in late afternoon. Data from June of 1989 suggest that both the tidal and diurnal signals exist in the DO records (Figure 2). At the beginning of the deployment, the tidal signal at Buoy 69 was reasonably strong (two peaks per day), but towards the end of the deployment, the diurnal variation was stronger (one peak per day). At Buoy 76, the tidal signal remained strong throughout the deployment with two peaks every day. Peak DO concentrations differed towards the latter part of the deployment, with every other peak being relatively similar. For example, the eighth and tenth peaks

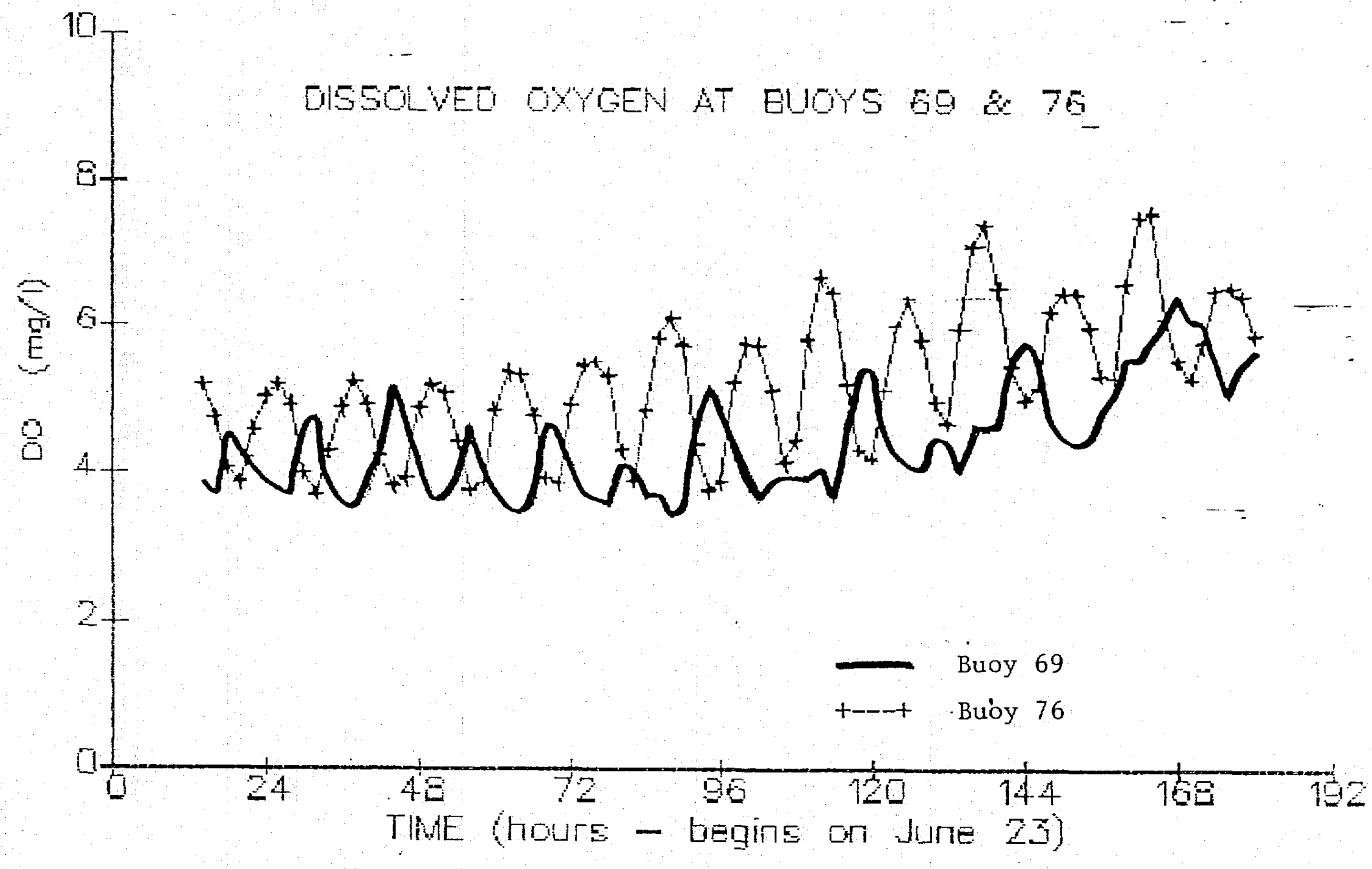

Figure 2. Short term variations in dissolved oxygen concentrations at Buoys 69 and 76 in the tidal James River.

were more similar to each other than either was to the ninth peak.

Intermediate time scales, say days to weeks, also are important and often result from meteorological features. River flow responds to local events and to those occurring in the drainage basin upriver. Fronts, storms and cloud cover all can affect algal growth as well.

III. CONDITIONS IN 1989

The field surveys had two major elements. Hydrolab data sondes, equipped to measure and record temperature, conductivity, pH, and dissolved oxygen concentrations, were deployed at six locations for six periods. Each deployment lasted several days to a week. The first deployment began on June 23rd and the last deployment ended on September 11th.

Typically at the beginning and end of each deployment, river surveys were conducted to monitor physical conditions (temperature, pH, and DO). Water samples were collected and analyzed for nutrients, chlorophyll a, and other constituents once during each deployment.

Water temperatures were above 25 C during the entire study period (see Figure 3 for two examples and the appendix for all six temperature records). Variability tended to be greater at

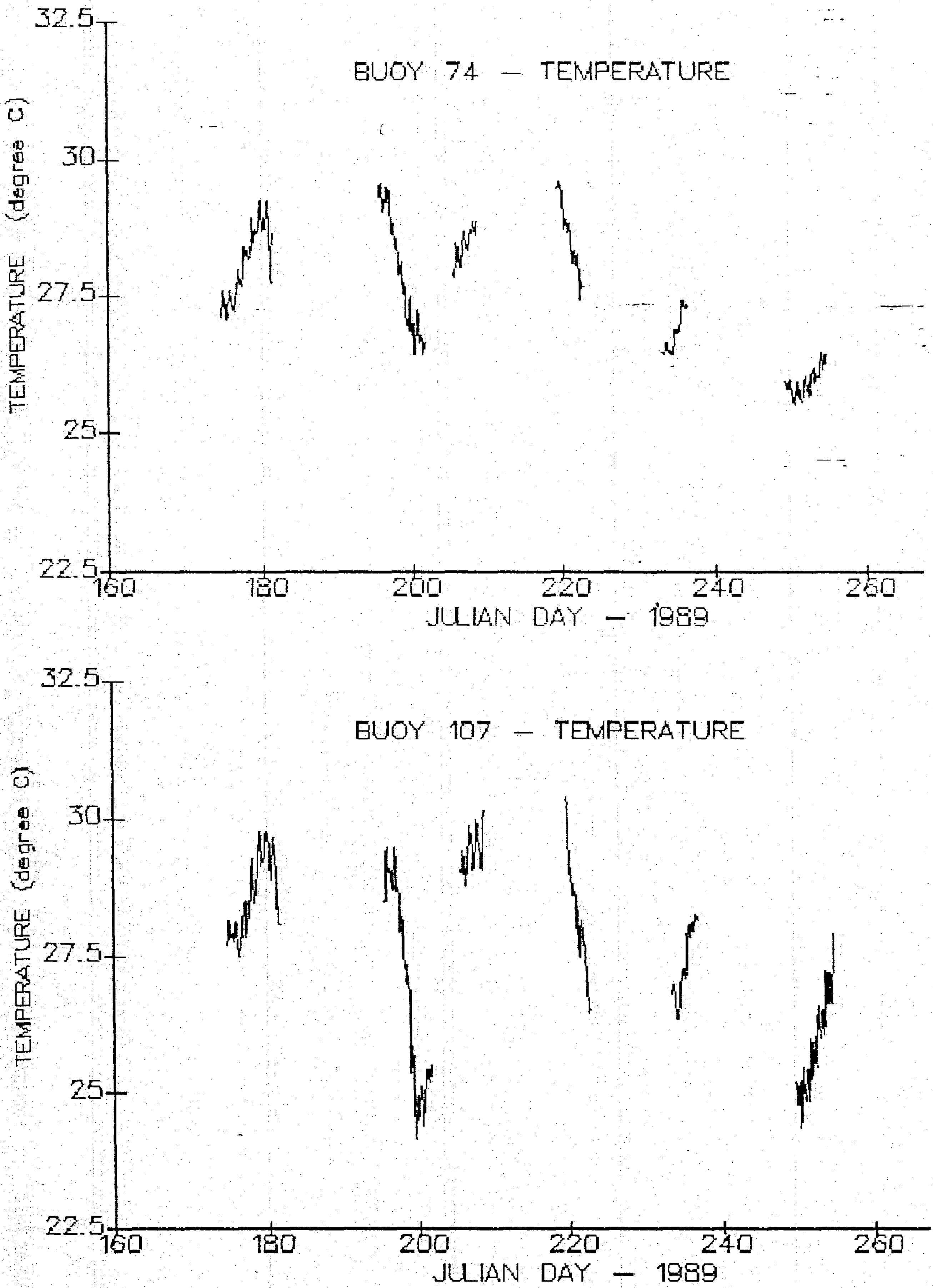

Figure 3. Temperature variations at Buoys 74 and 107.

upriver locations; for example, at Buoy 107 the temperature dropped nearly 5 C during the second deployment. The reduced temperature swings at the downriver locations are to be expected, because the large volume of water in the lower reaches of the river responds slowly to solar heating and to cooling events.

Dissolved oxygen concentrations, on the other hand, tended to be higher and to vary less at the most upriver station (See the record for Buoy 107 in Figure 4). One can note large short-term variability (tidal and diurnal variations of 1 mg/l or more) and also large intermediate-term variations, such as the general rise in DO concentrations at Buoy 74 during the first deployment of the datasondes.

The river flow across the falls at Richmond followed a pattern of generally decreasing flows with intermittent high flows lasting several days (See Figure 5). The lowest flow for the summer occurred on September 12 (Julian day 255) and was 2,574 cubic feet per second (cfs). In many summers, the river flow is below 2,000 cfs for weeks or months, but this was not the case in 1989. Thus, the river flow pattern was somewhat typical, but the entire record was elevated relative to most summers.

Two of the river surveys will be examined in some detail in an attempt to understand processes at work. First, we will

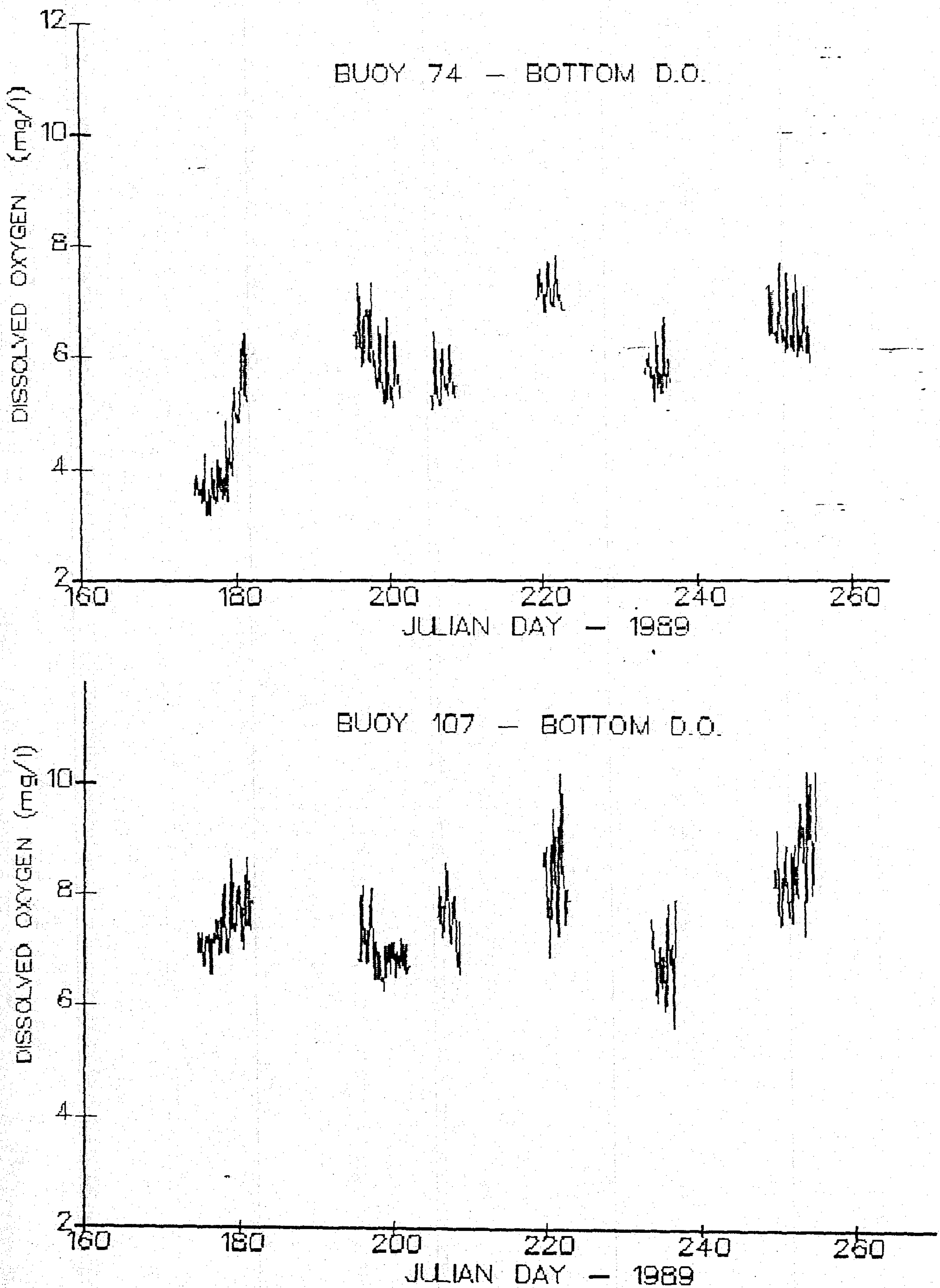

Figure 4. Variation in dissolved oxygen concentrations at Buoys 74 & 107.

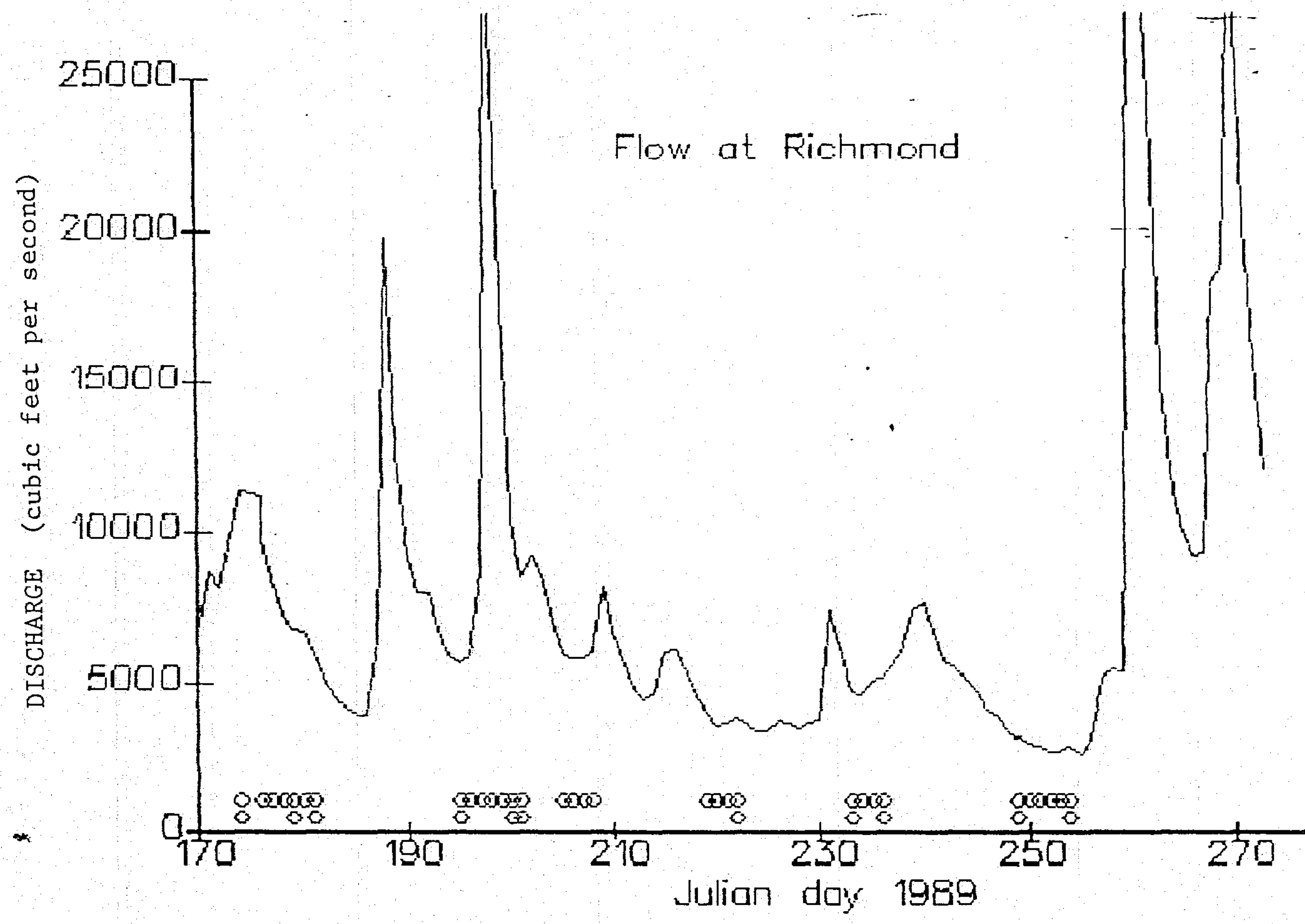

Figure 5. River flow near Richmond. (Diamonds just above x-axis indicate river survey dates. Bands of diamonds above that indicate periods when datasondes were deployed.)

look at conditions on August 10 (Julian day 222) and then look at conditions on June 28 (Julian day 179).

August 10, 1989: River flows decreased from 6,109 cfs on August 4th (Julian day 218) to 3,297 cfs on August 13 (Julian day 225); the flow on August 10th was 3,783 cfs. In other words, flows were decreasing, relatively constant and moderately low. Records for the weather station at Richmond airport show 1.55 inches of rain on August 10, but none in the preceding seven days. Dissolved oxygen conditions in the river did not vary significantly between the early morning and late afternoon surveys (See Figure 6). Both profiles showed DO decreasing from about 7.5 mg/l near Hopewell to about 6.5 mg/l at Buoy 74, and back to about 7.5 mg/l at Buoy 69.

Chlorophyll a concentrations averaged about 58 ug/l at the four upper stations (Buoys 107, 91, 86 and 76) but only 34 ug/l at the two lower stations (Buoys 69 and 74). For the upper stations, two of sixteen readings were above 70 ug/l and half of the observations were greater than 60 ug/l. There was little difference between early morning and late afternoon values, perhaps because of cloud cover associated with the rainfall.

June 28, 1989: River flows decreased from 11,485 cfs on June 23rd to 3,889 cfs on July 5th; the flow on June 28 was 6,802 cfs. For reference purposes, the long term (40+ years) mean annual flow at Richmond is on the order of 7,500 cfs. Thus, this hydrograph brackets the mean annual flow but is above typical average flows for June. The hydrograph is not nearly as "peaky" as the other storm events in the 1989 record. Rainfall of more than 2 inches was reported for Louisa on June 20th, and Buckingham on June 21st. At the Richmond airport, 0.57" fell on June 23rd, 0.01" on June 26, and traces on June 24 and June 27. No rainfall was reported for any Eastern Piedmont weather station on June 28. Nonetheless, this "storm" (or some other events occurring at that time) did have an appreciable effect on water quality.

Peak dissolved oxygen concentrations were recorded at Buoys 91 and 86 and minimum DO's at Buoy 69, with about a 3 mg/l difference between the maximum and minimum station averages (See Figure 6). DO concentrations in late afternoon tended to be about a half a milligram per liter (or more) higher than those observed in the early morning. The mean chlorophyll a concentration increased from 27 ug/l in the morning to 35 ug/l in the afternoon. Peak chlorophyll concentrations were at Buoys 91, 86, and 76 (Mean for the three stations was 37 ug/l in the morning and 47 ug/l in the afternoon). Concentrations at Buoy 107 were in the same range as those at Buoy 69 and 74 (18 ug/l in the morning and 23 ug/l in the afternoon).

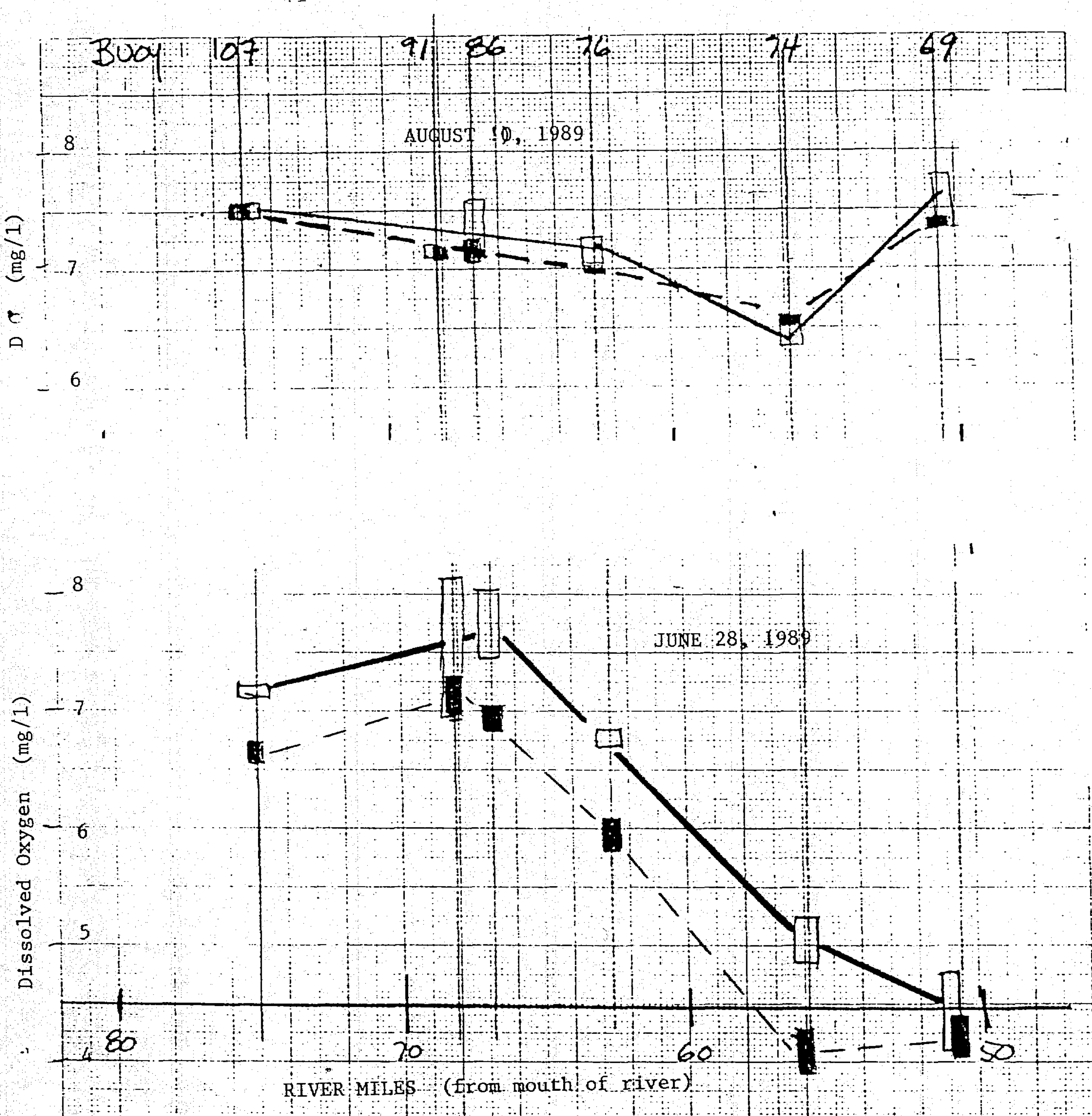

Figure 6. Longitudinal profiles of dissolved oxygen on June 28, 1989 (bottom) and August 10, 1989 (top). Dashed lines indicate early morning observations, solid lines indicate late afternnon results.

It is relevant to note that both the early morning and the late afternoon DO measurements at Buoy 69 were below 5 mg/l, suggesting that the daily average was below the 5 mg/l standard. The measurements from the datasonde show that oxygen concentrations below 4 mg/l were observed throughout the first half of the deployment (Figure 7). During the first half of the deployment, two DO peaks occurred each day (tidal signal), but during the second half, there was only one peak per day (diurnal signal) and DO concentrations tended to increase. The daily average concentration was below 5 mg/l from June 23rd through the 28th (see Table 1) and the minimum values were well below 4 mg/l from the 23rd through the 27th. Clearly, neither water quality standard was met during this several day period.

Table 1. Dissolved oxygen concentrations (in mg/l) at Buoy 69, June 1989.

Date	Minimum Value	Daily Mean Value
23	3.70	4.11 *
24	3.54	4.12
25	3.43	3.94
26	3.42	3.95
27	3.62	4.17
28	4.00	4.57

* Less than 24 hours record.

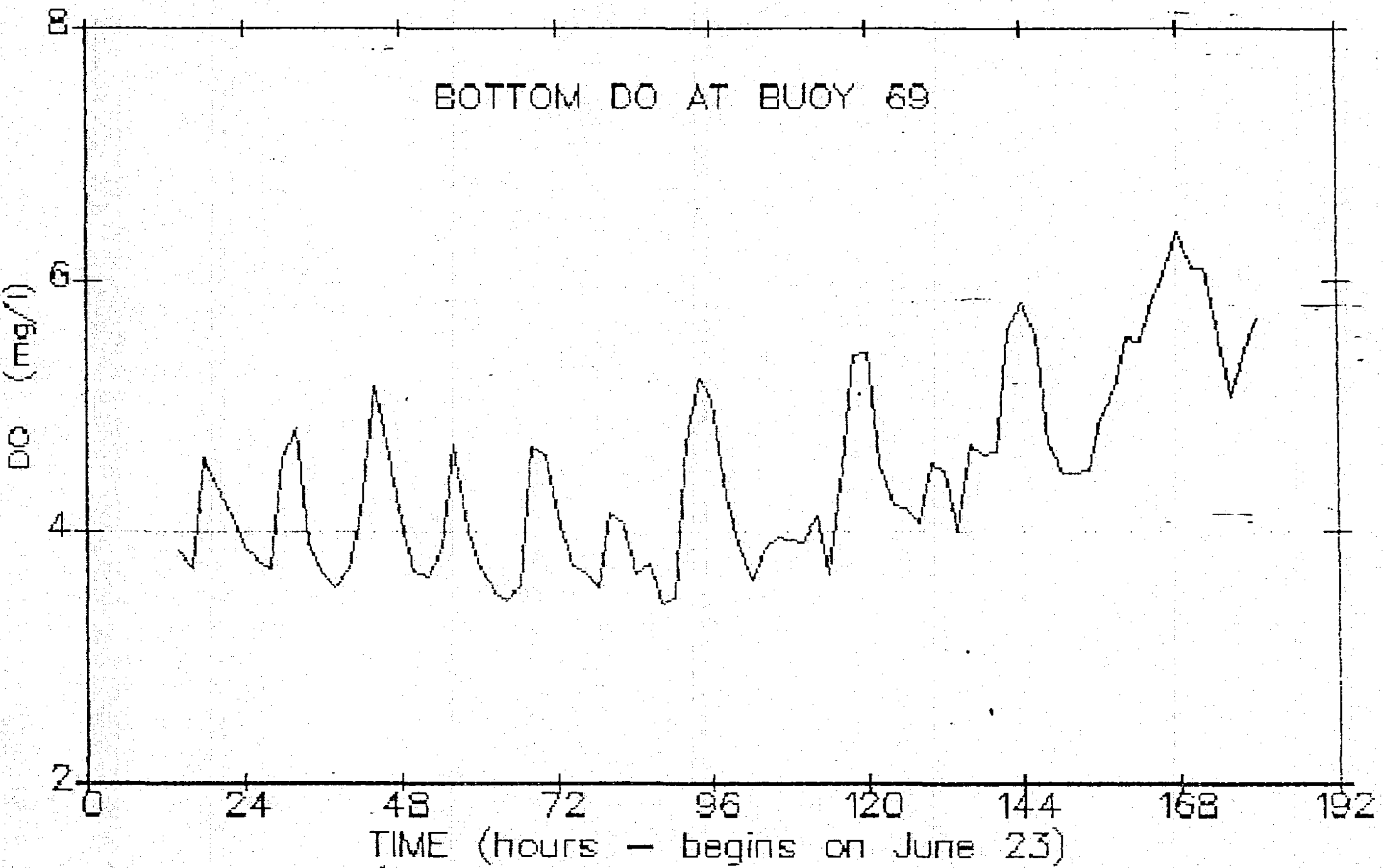

Figure 7. Short term variation in dissolved oxygen concentrations at Buoy 69 during late June of 1989.

IV. DISCUSSION

Implicit in the concept of planning is preparation for some specific goal or goals. In many studies, including the water quality management planning for the upper tidal James River, the goal is for water quality standards to be met during some "worst case". Often the "worst case scenario" has included, among other specifications, river flows at the "7Q10" level. "7Q10" denotes the lowest flow which occurs over a seven consecutive day window and occurs once during a ten year time period. Implicit in use of this concept is the idea that shorter term violations might occur more frequently than once very ten years and that violations that lasted longer than seven days might occur less frequently than once every ten years.

Field data from the summer of 1989 suggest that there may be a number of "worst case scenarios" for dissolved oxygen in the upper tidal James. In particular, it appears that certain hydrographs can degrade water quality significantly. One must ask whether the mid-June event was one which has greater, lesser, or roughly equal probability as the 7Q10 river flow. One approach towards treating point sources and non-point source pollution equitably would be to select design scenarios with comparable probabilities.

Further study of the mid-June event is needed to ascertain the reasons why this combination of events resulted in violations of both DO standards. At this time, there is nothing to indicate that this "storm" was peculiar or out of the ordinary. Further investigation is needed to determine (1) where the rainfall occurred, (2) the amount and intensity of the rainfall, (3) the degree to which the quality of the water flowing over the falls deteriorated relative to preceding and following periods, (4) solar radiation during the period when the DO standards were violated, and (5) whether any other circumstances affected water quality.

A second problem illustrated by the 1989 data is that of excessive nutrient enrichment and associated high standing stocks of algae. Conditions on August 10, 1989 approximate the low flow conditions incorporated in many model simulations. For these conditions, the DO concentrations were well above the state standards, and presumably this was due in part to the large standing stock of algae in the river. At Buoy 107, chlorophyll a concentrations were over 70 ug/l in the early morning and 58 ug/l in the late afternoon. The magnitude of the diurnal variation in DO at this station was more than 2 mg/l (Figure 8). While it is clear that the DO standards were met, it is not as evident that this situation is an appropriate foundation for a water quality management

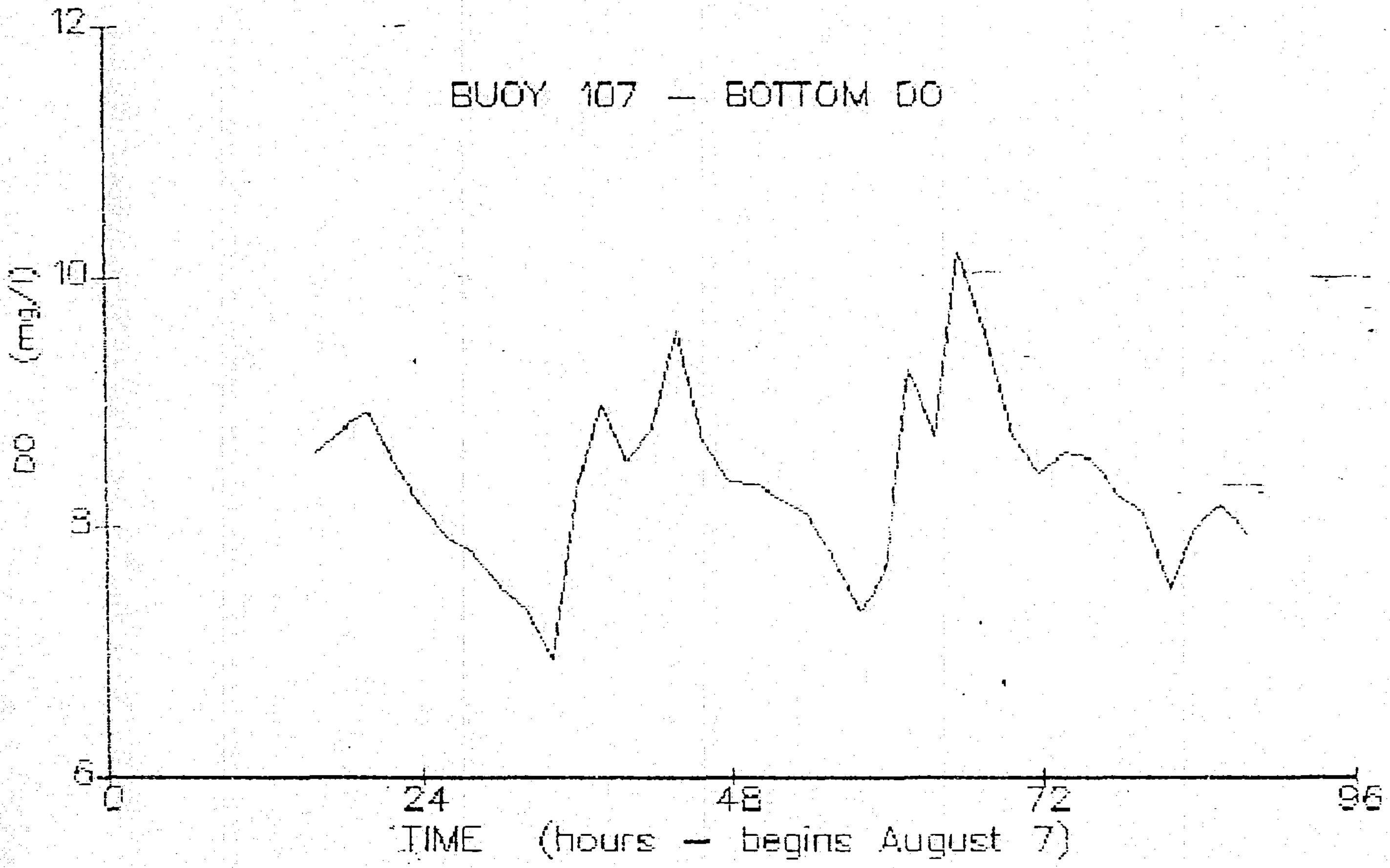

Figure 8. Short term variations in dissolved oxygen concentrations at Buoy 107 during early August 1989.

plan. When the Water Control Board was considering adoption of nutrient standards, a technical advisory panel was convened. These individuals recommended that a river be classified as nutrient enriched if chlorophyll a concentrations exceeded 25 ug/l. Early water quality management plans for the Potomac River estuary were based on a chlorophyll a maximum of 25 ug/l as well. It is the author's opinion that this is an area which warrants continued attention. Further, it is unlikely that any knowledgeable scientist would consider chlorophyll a concentrations in the 50 to 75 ug/l range as being anything but "high". Most would likely suggest that nutrient control measures were called for. Further field observations are needed to assess this situation. These should include deployment of data sondes for more than a few days, so that the resulting time series can be "decomposed" into tidal and diurnal signals. Having longer records should help give insight on the relationship between DO variations and other factors such as cloud cover, river flow, and algal populations.

V. RECOMMENDATIONS

For the past decade and longer, water quality management in the upper tidal James has emphasized the need to reduce BOD loads to the river in order to maintain dissolved oxygen concentrations at or above state standards. The 1989 data suggest that the water quality planning must explicitly incorporate nonpoint sources of pollution in the future, because a modest hydrograph in mid-June produced water quality well below the two DO standards. Other data reinforce the perception that nutrient enrichment is a problem that also demands attention. Accordingly, the following recommendations are offered for consideration.

1. Estimate the likelihood that a decrease in algal growth could result in substandard DO conditions.

Additional analysis of the 1989 data is needed to determine if (a) the longitudinal DO gradient can be related to the range of variation in DO at tidal time periods, and (b) the magnitude of the diurnal variation can be related to mean chlorophyll concentrations or other factors. In order to complete this exercise, it may be necessary to have longer time series that are available from the 1989 deployments of the data sondes.

Additional water quality model simulations should be made to determine how DO and chlorophyll concentrations vary with solar radiation. At this time, the method by which diurnal variations can be estimated using a tidal-average model is not clear.

2. Assess methods to incorporate point and non-point sources into a single water quality management approach.

It seems clear to the author that nonpoint sources of pollutants can and do affect water quality in the James River. Further study of the late June hydrograph is needed to ensure that this was not some "freak event". If it turns out to be a relatively common occurrence, then one must conclude that water quality standards are violated frequently. At present there are no widely accepted procedures that explicitly include both point and nonpoint sources of pollution in management scenarios. It appears that this difficult task must be addressed.

3. Plan for a new, time-variable or "real time" model of water quality in the tidal James.

The water quality studies of the early 1980's provide an excellent data base for the near term. At some point development, expansion of sewered areas, and other factors will result in sufficient change that the water quality management plan must be re-examined. At that time, the water quality model should be upgraded to include real-time variations in water quality. With this capability, both short-term variations in dissolved oxygen and the river response to transient, nonpoint source loadings can be examined with greater ease and certainty. It is not suggested that such studies begin immediately, but rather that the model upgrade be incorporated in such studies whenever they occur.

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HydroQual, Inc., "Water Quality Analysis of the James and Appomattox Rivers", A Report to the Richmond Regional and Crater Planning District Commissions, October 10, 1986.

Weand, Barron L. and Thomas J. Grizzard, 1986a, "Final Report: 1984-85 Monitoring", April 1986.

Weand, Barron L. and Thomas J. Grizzard, 1986b, "Final Report: Summer and Fall 1985 Monitoring", July 1986.

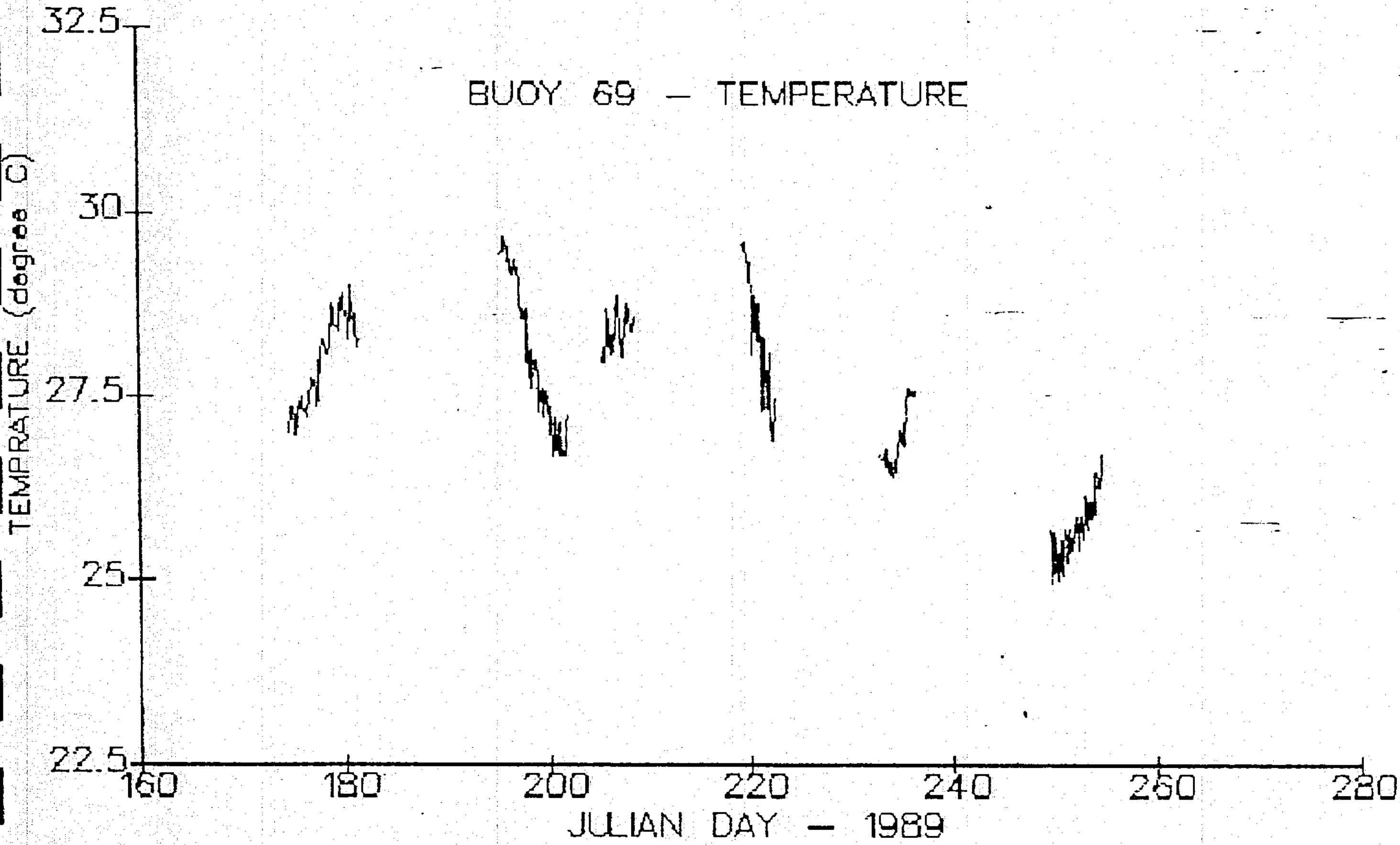
APPENDICES

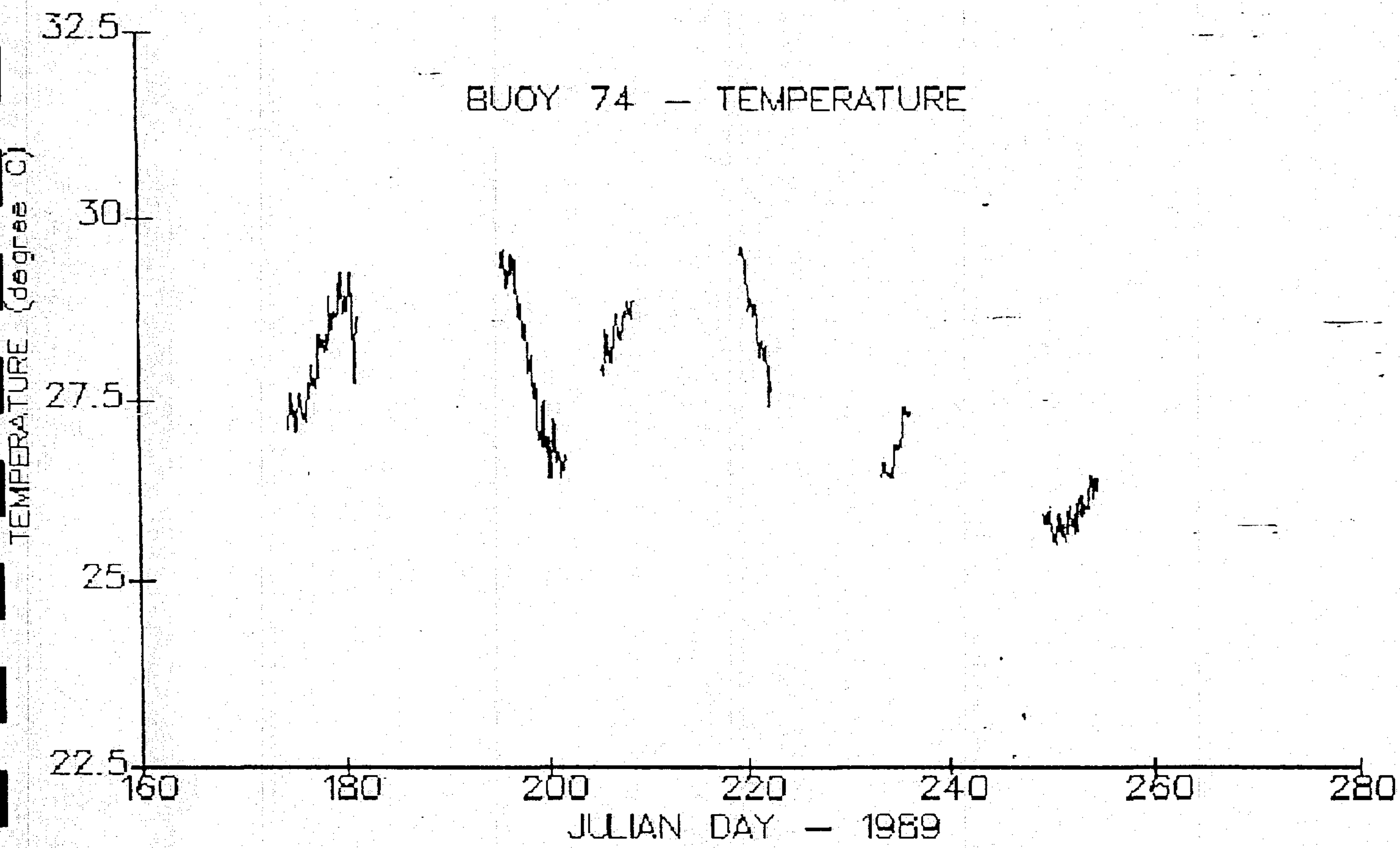
TEMPERATURE VARIATIONS

(by location)

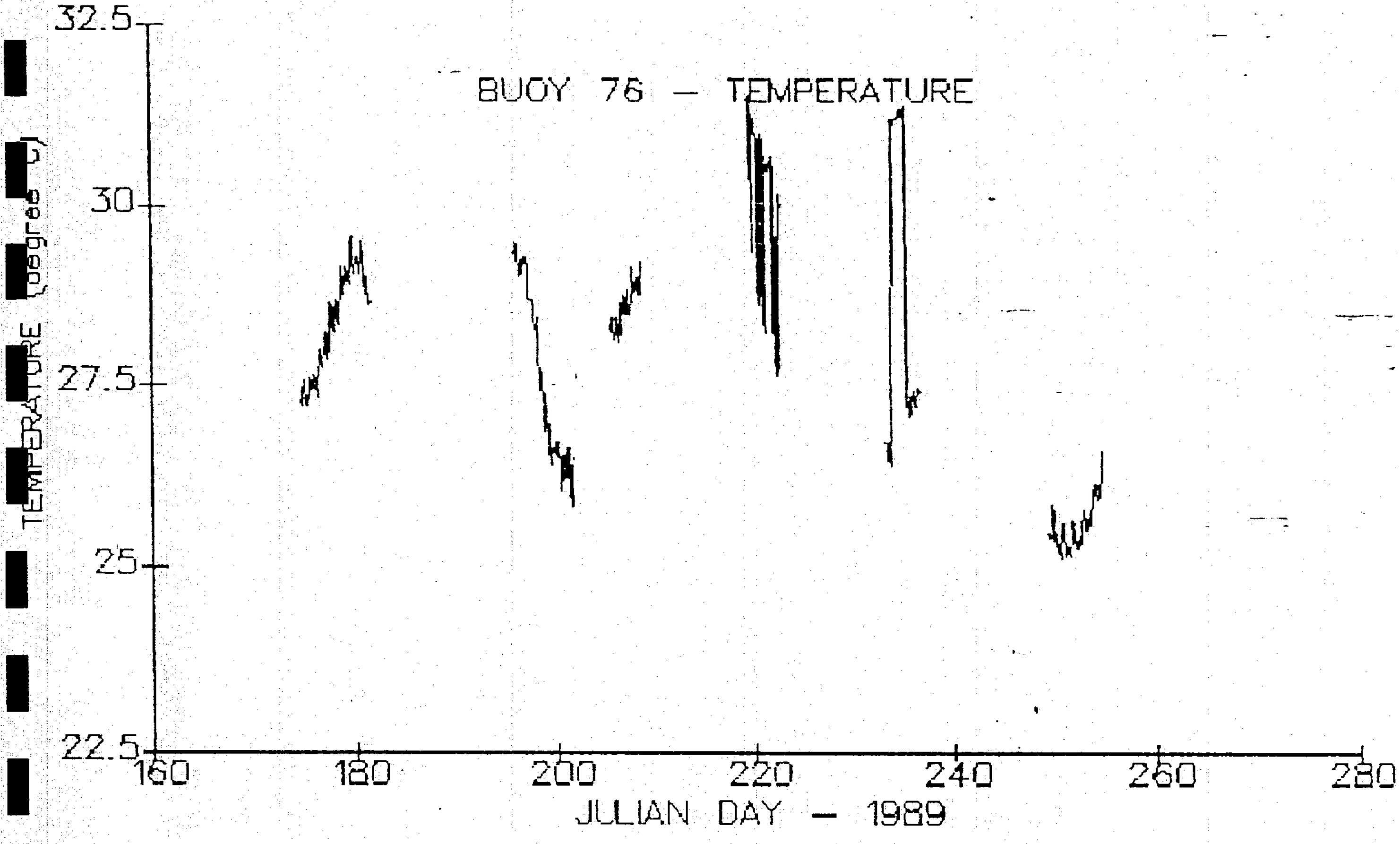
DISSOLVED OXYGEN VARIATIONS

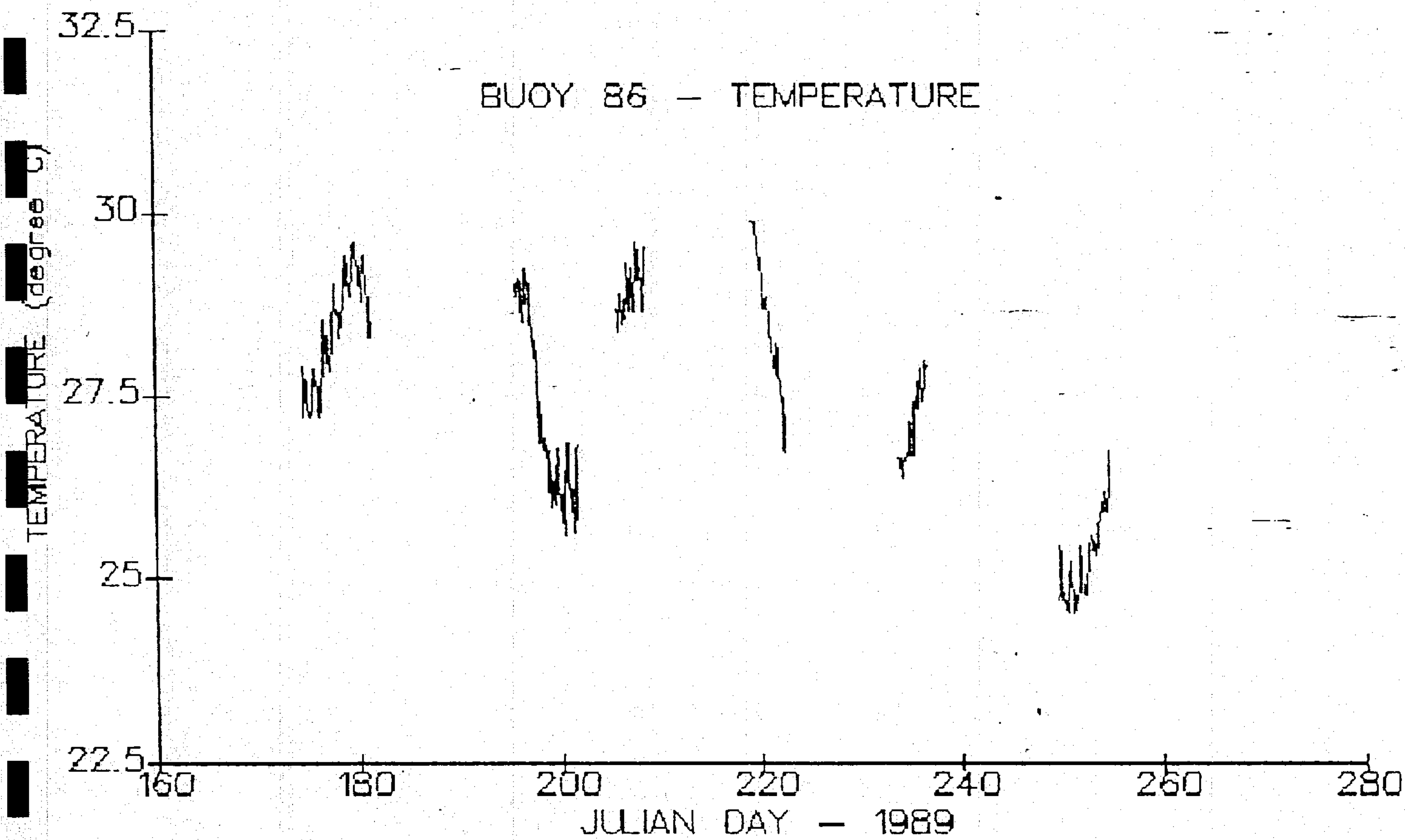
(by date and then by location)

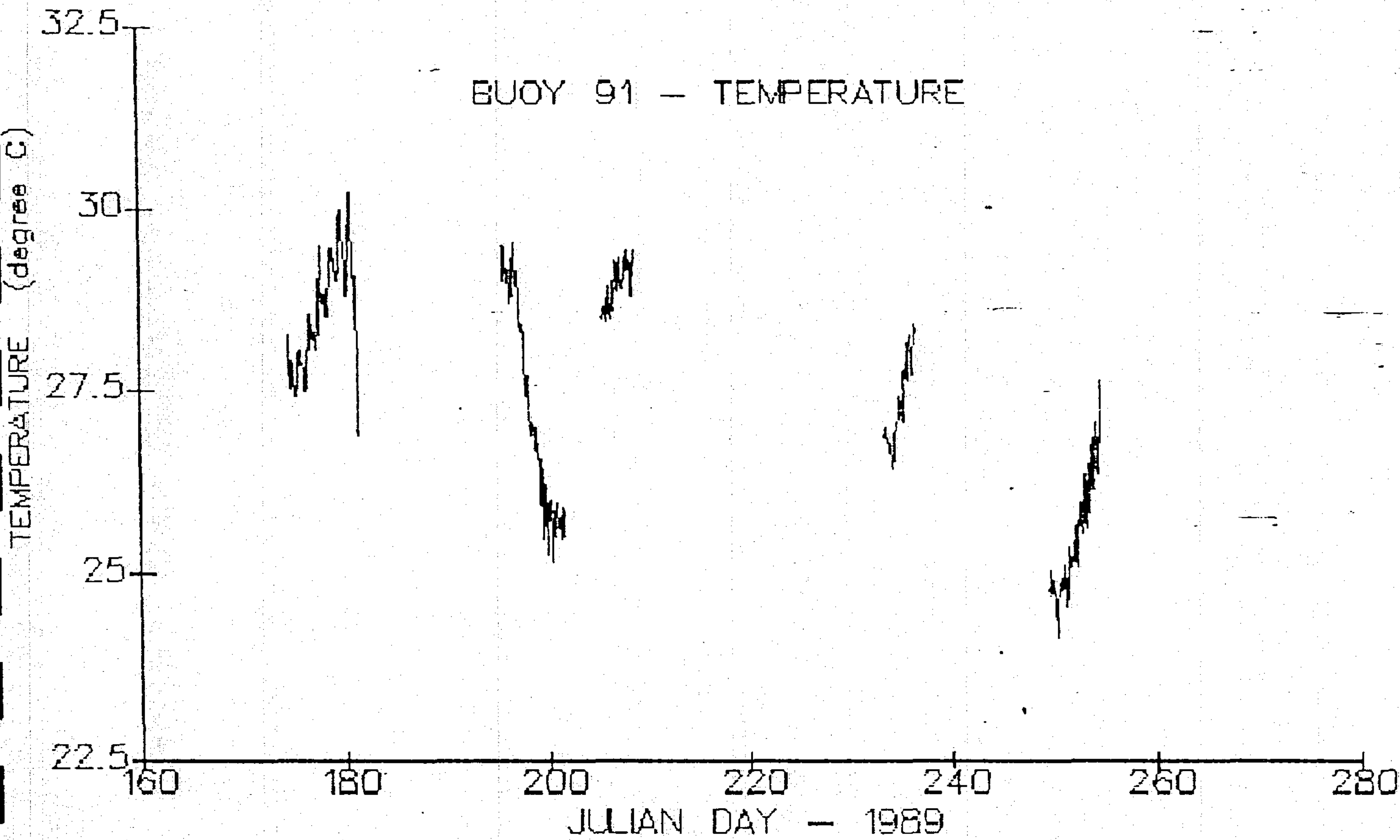

BUOY 69 — TEMPERATURE
TEMPRATURE (degree C)
32.5
30
27.5
25
22.5
160
180
200
220
240
260
280
JULIAN DAY — 1989



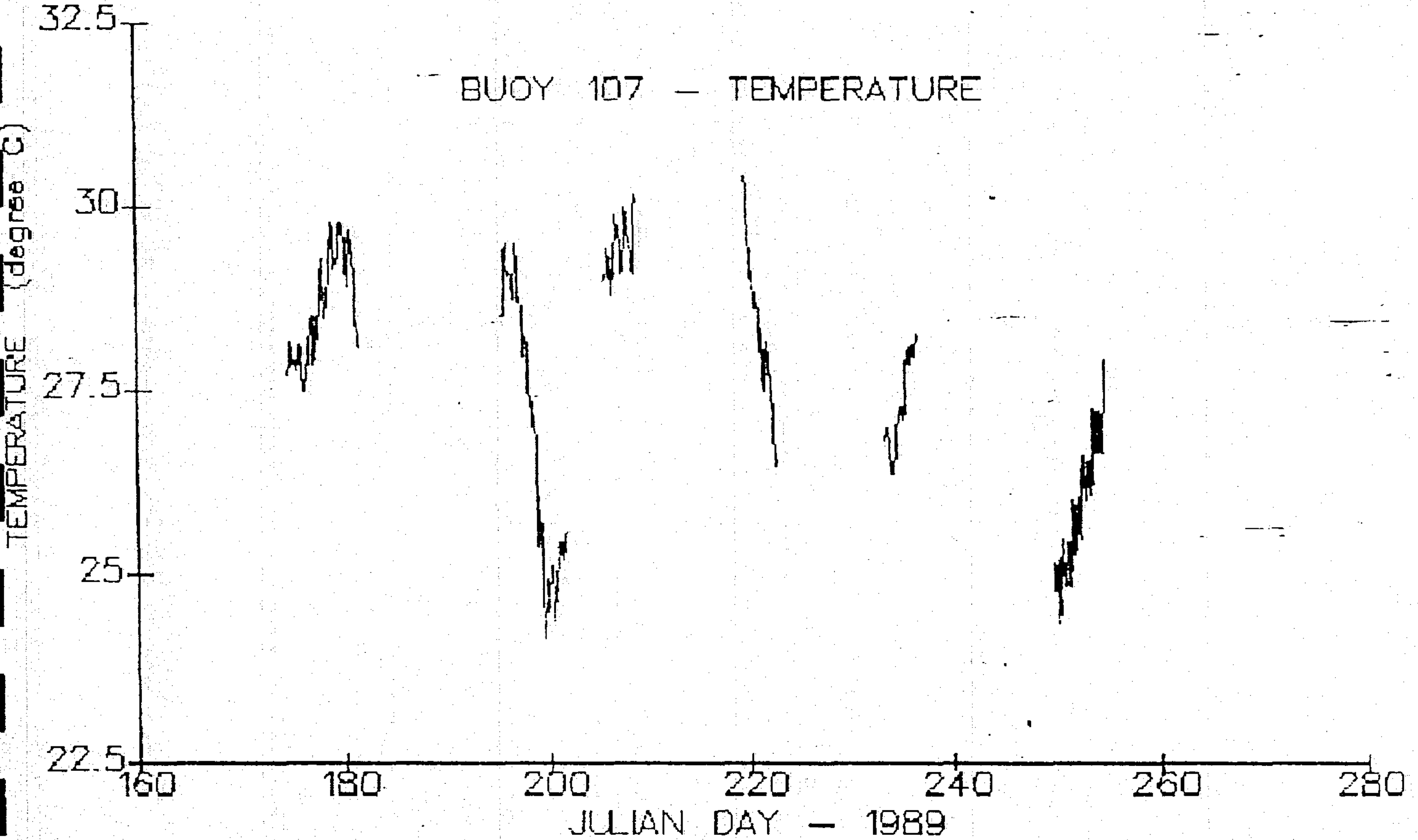
BUOY 74 — TEMPERATURE
32.5
30
27.5
25
22.5
TEMPERATURE (degree C)
160
180
200
220
240
260
280
JULIAN DAY — 1989

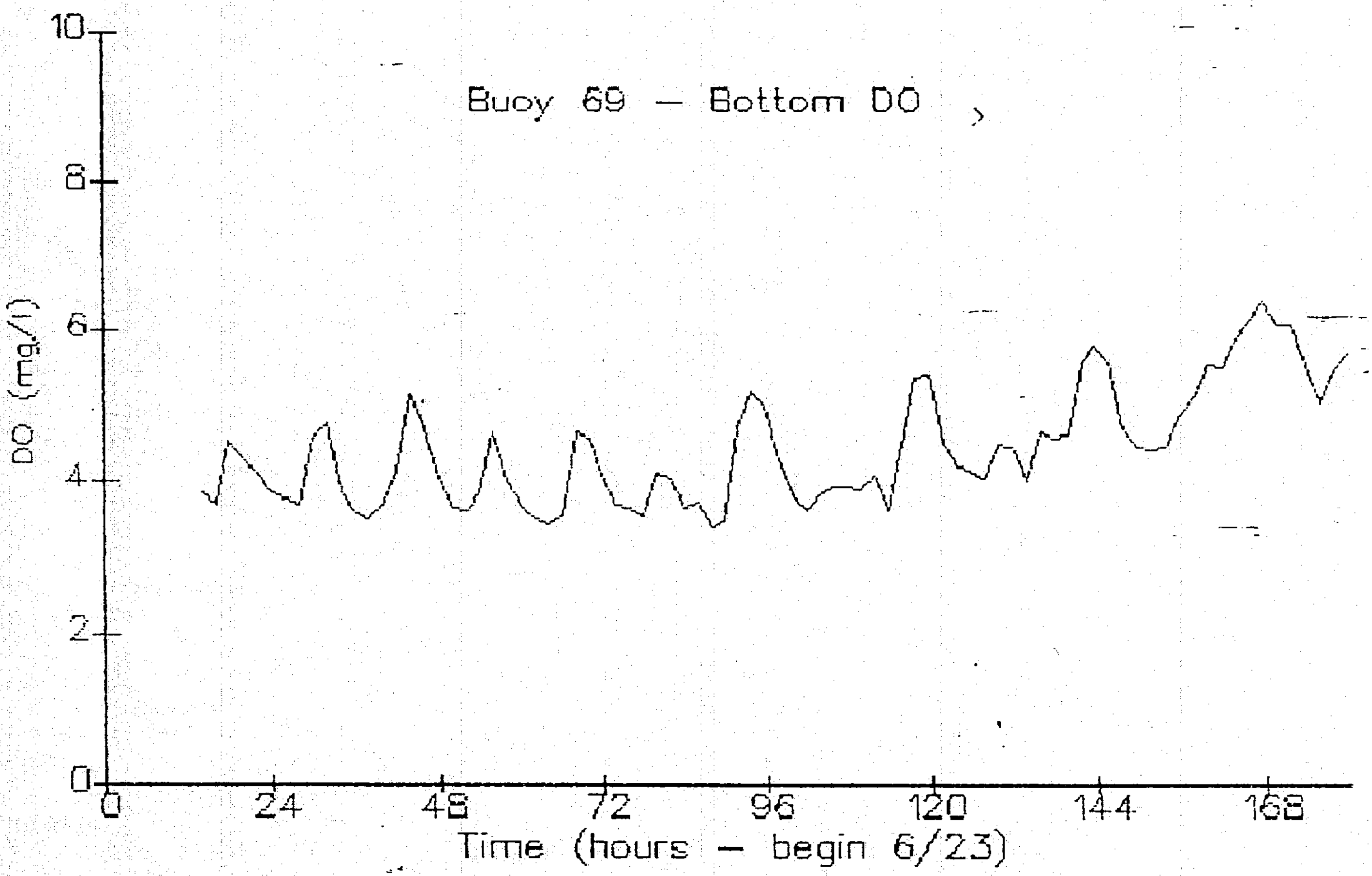

BUOY 76 — TEMPERATURE
TEMPERATURE (degrees C)
32.5
30
27.5
25
22.5
160
180
200
220
240
260
280
JULIAN DAY — 1989

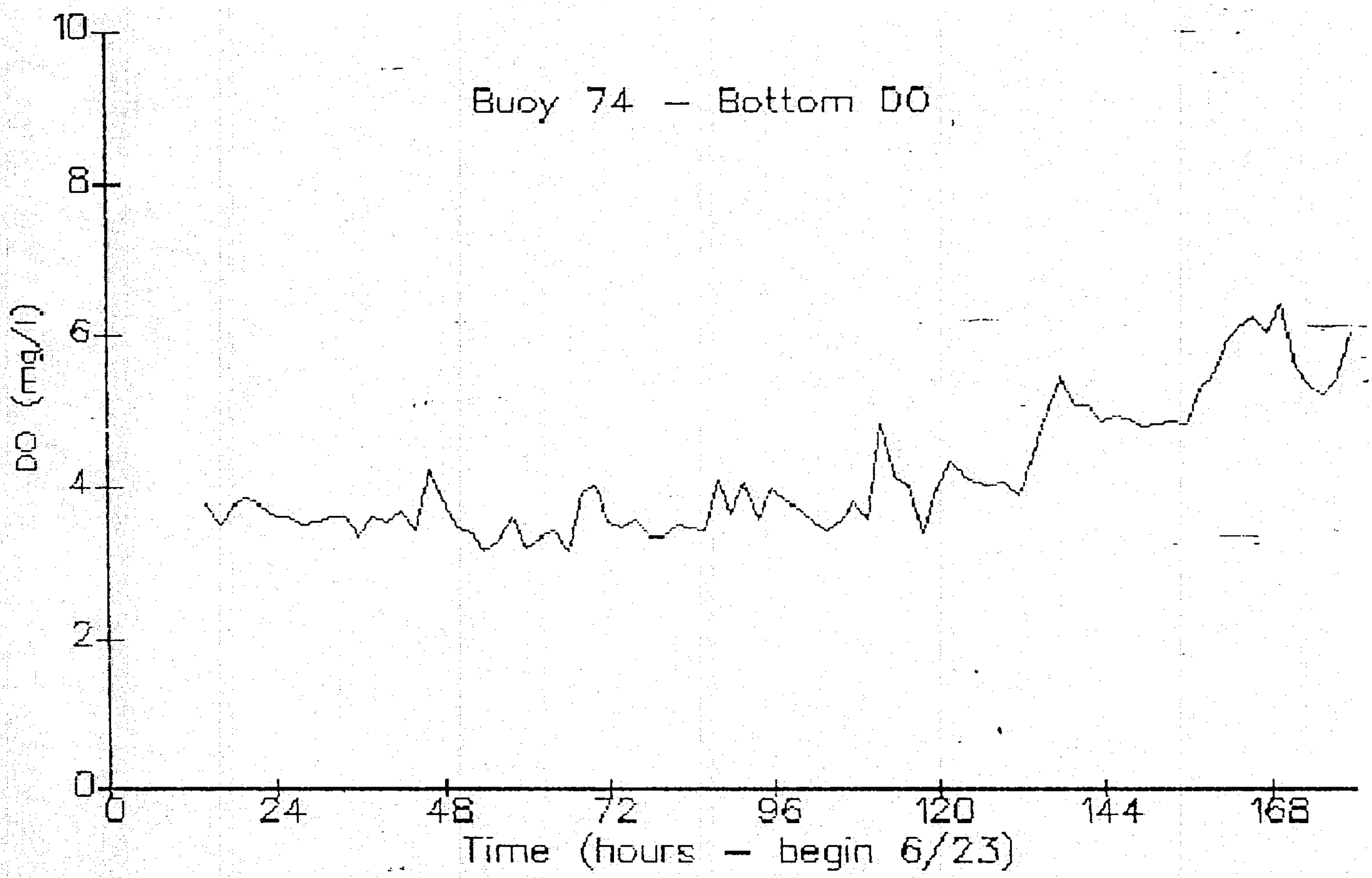

BUOY 86 — TEMPERATURE
TEMPERATURE (degree C)
32.5
30
27.5
25
22.5
160
180
200
220
240
260
280
JULIAN DAY — 1989

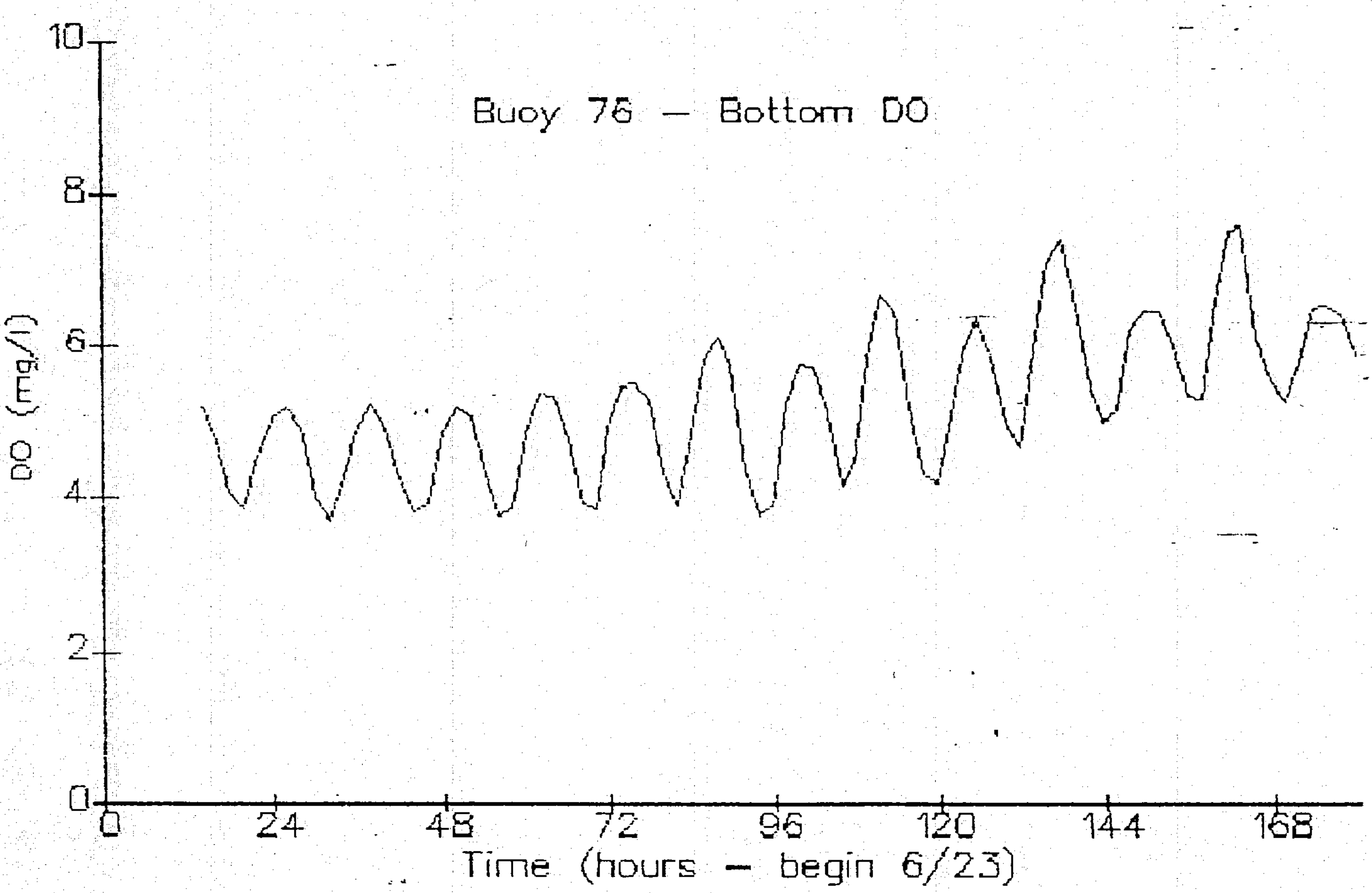


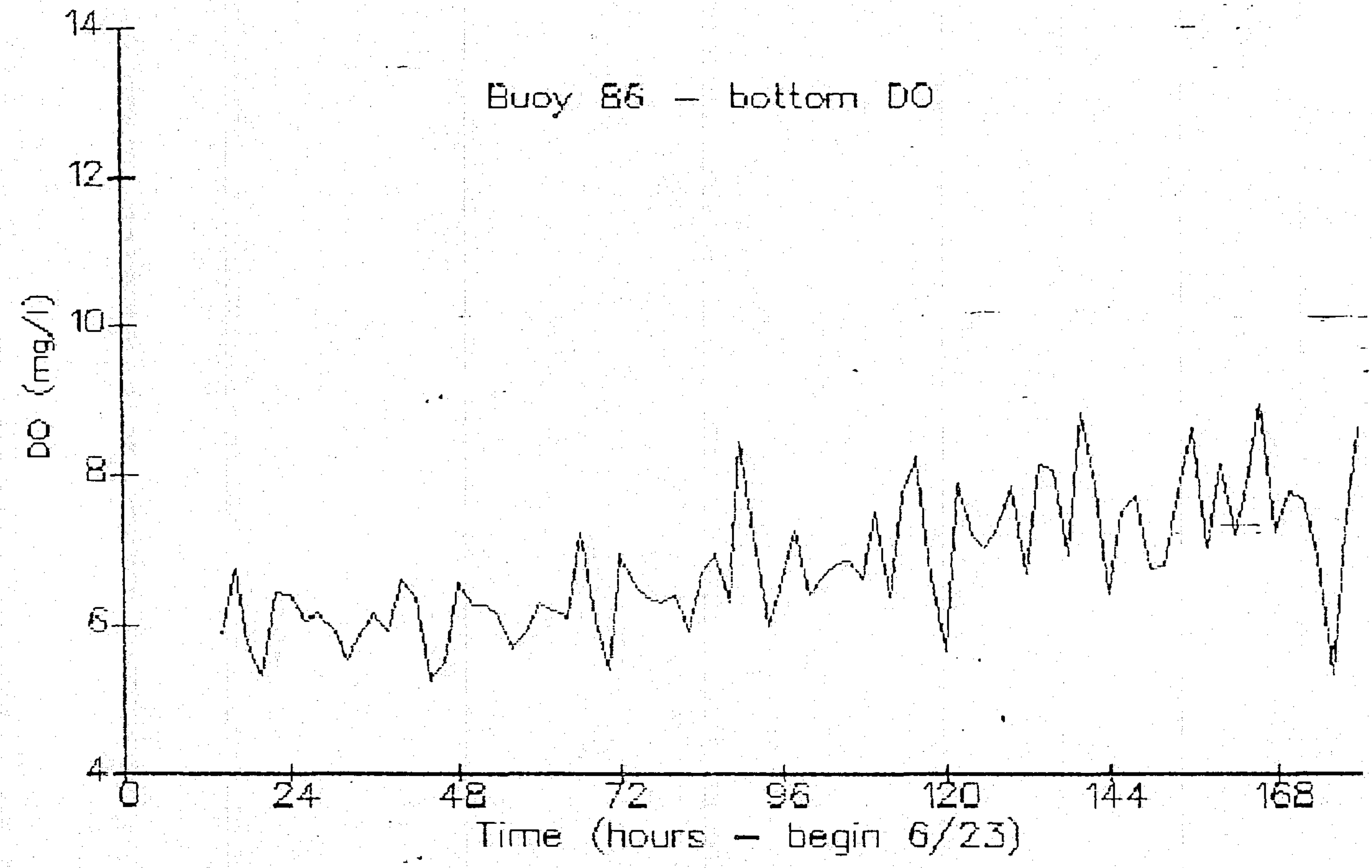
BUOY 91 — TEMPERATURE
TEMPERATURE (degree C)
32.5
30
27.5
25
22.5
160
180
200
220
240
260
280
JULIAN DAY — 1989

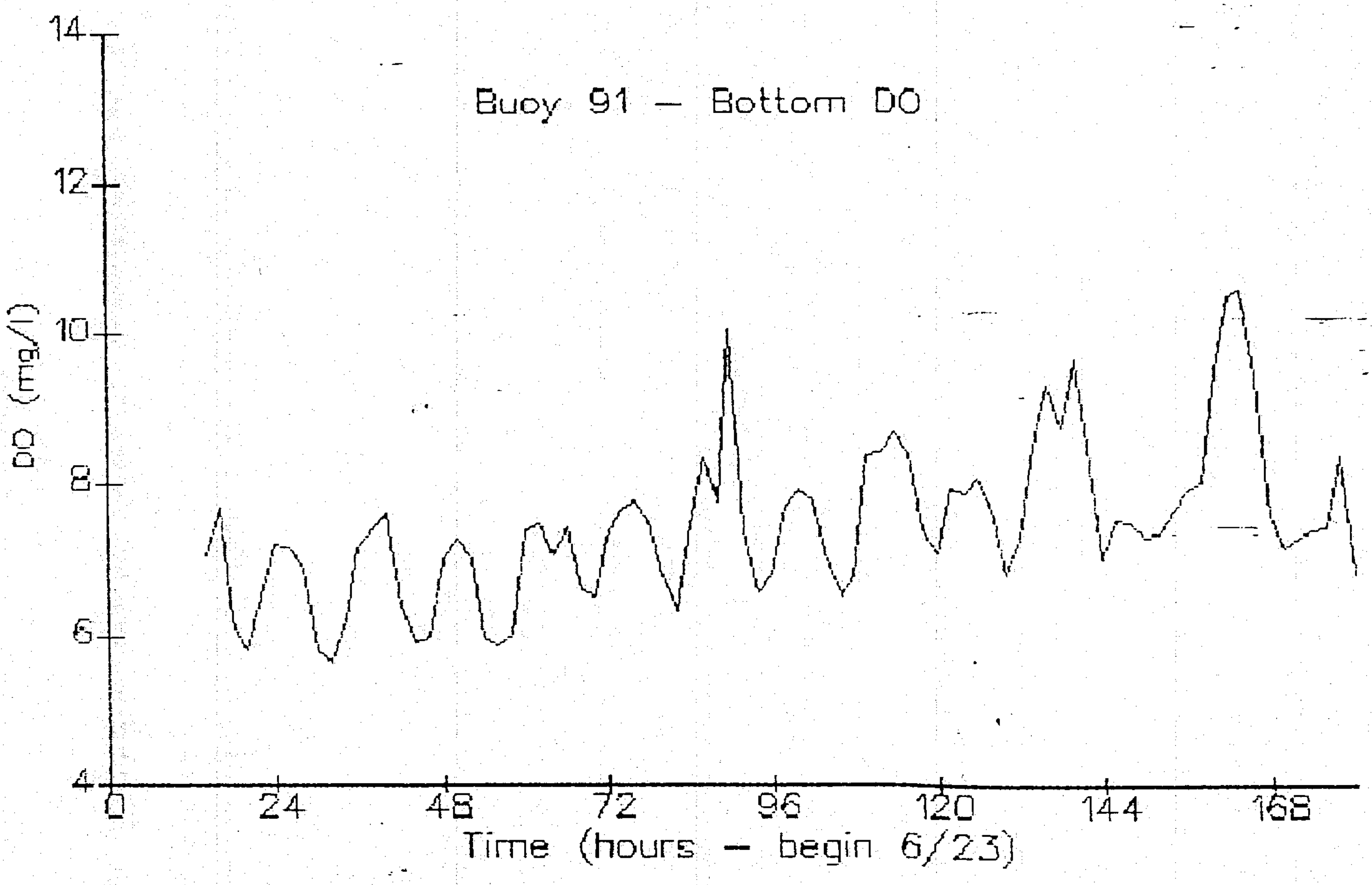

BUOY 107 — TEMPERATURE
TEMPERATURE (degree C)
32.5
30
27.5
25
22.5
160
180
200
220
240
260
280
JULIAN DAY — 1989


Buoy 69 — Bottom DO
DO (mg/l)
10
8
6
4
2
0
0
24
48
72
96
120
144
168
Time (hours — begin 6/23)

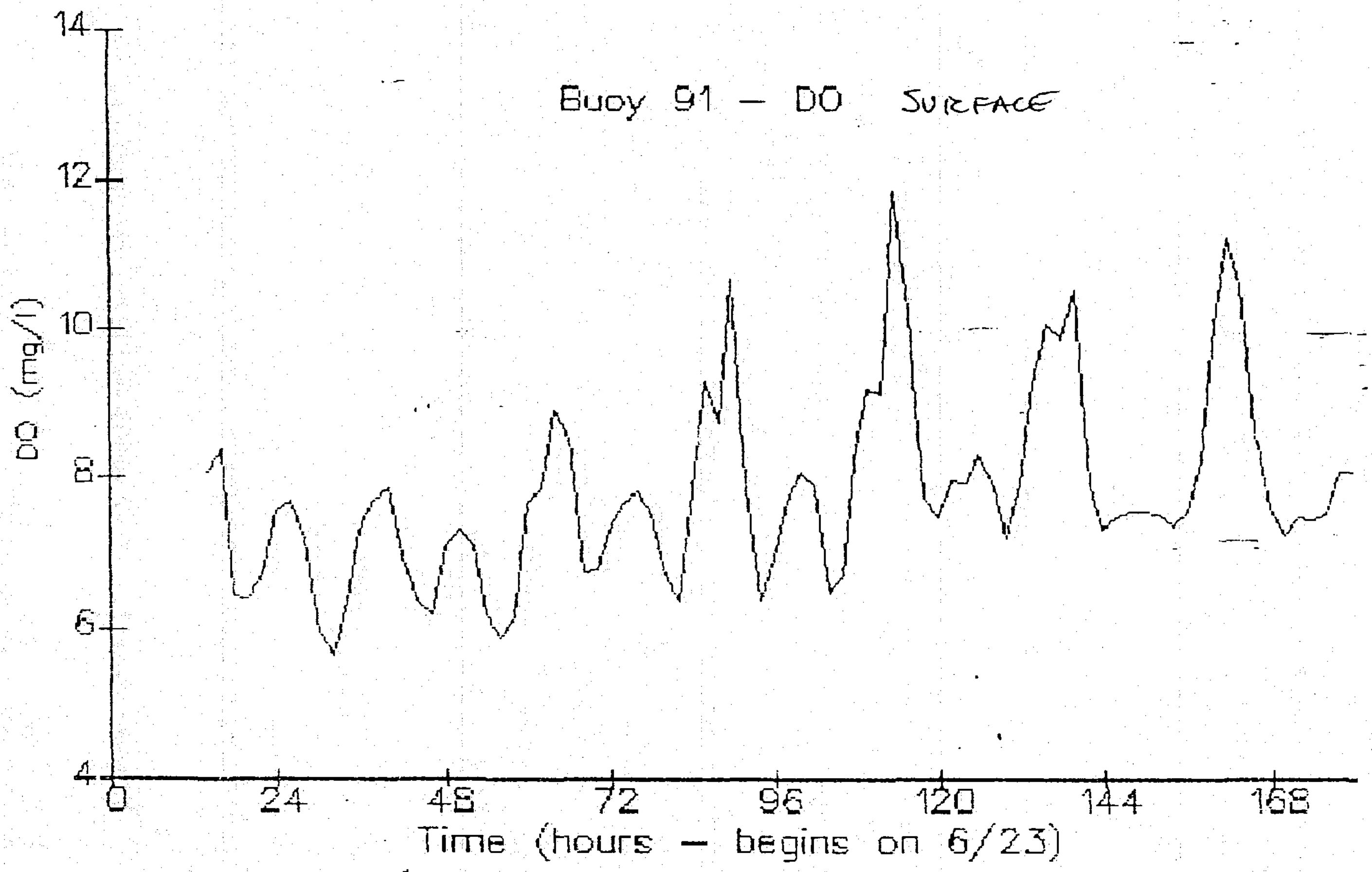

Buoy 74 — Bottom DO
DO (mg/l)
10
8
6
4
2
0
0
24
48
72
96
120
144
168
Time (hours — begin 6/23)

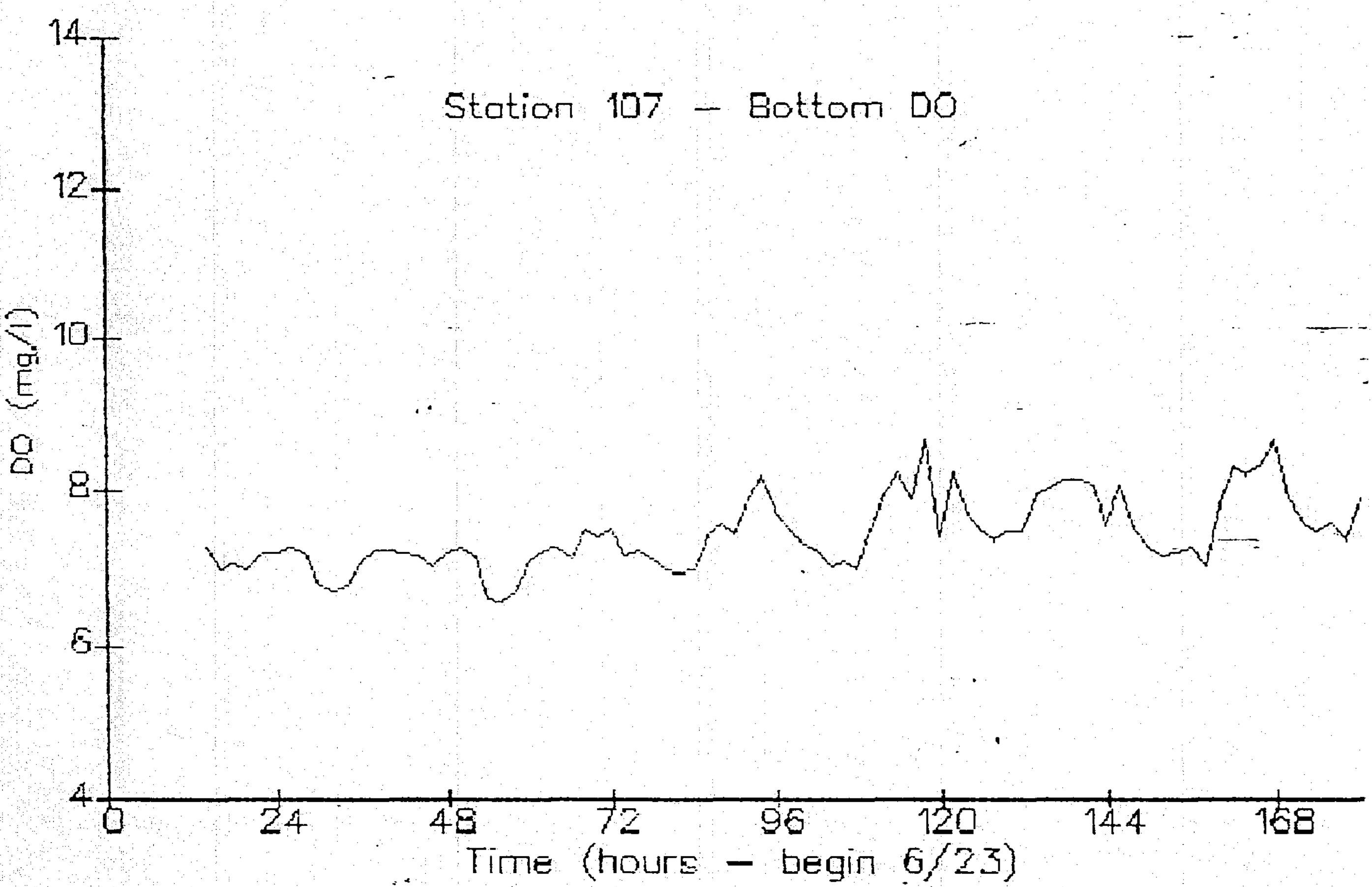

Buoy 76 — Bottom DO
DO (mg/l)
10
8
6
4
2
0
0
24
48
72
96
120
144
168
Time (hours — begin 6/23)


Buoy 86 — bottom DO
DO (mg/l)
14
12
10
8
6
4
0
24
48
72
96
120
144
168
Time (hours — begin 6/23)

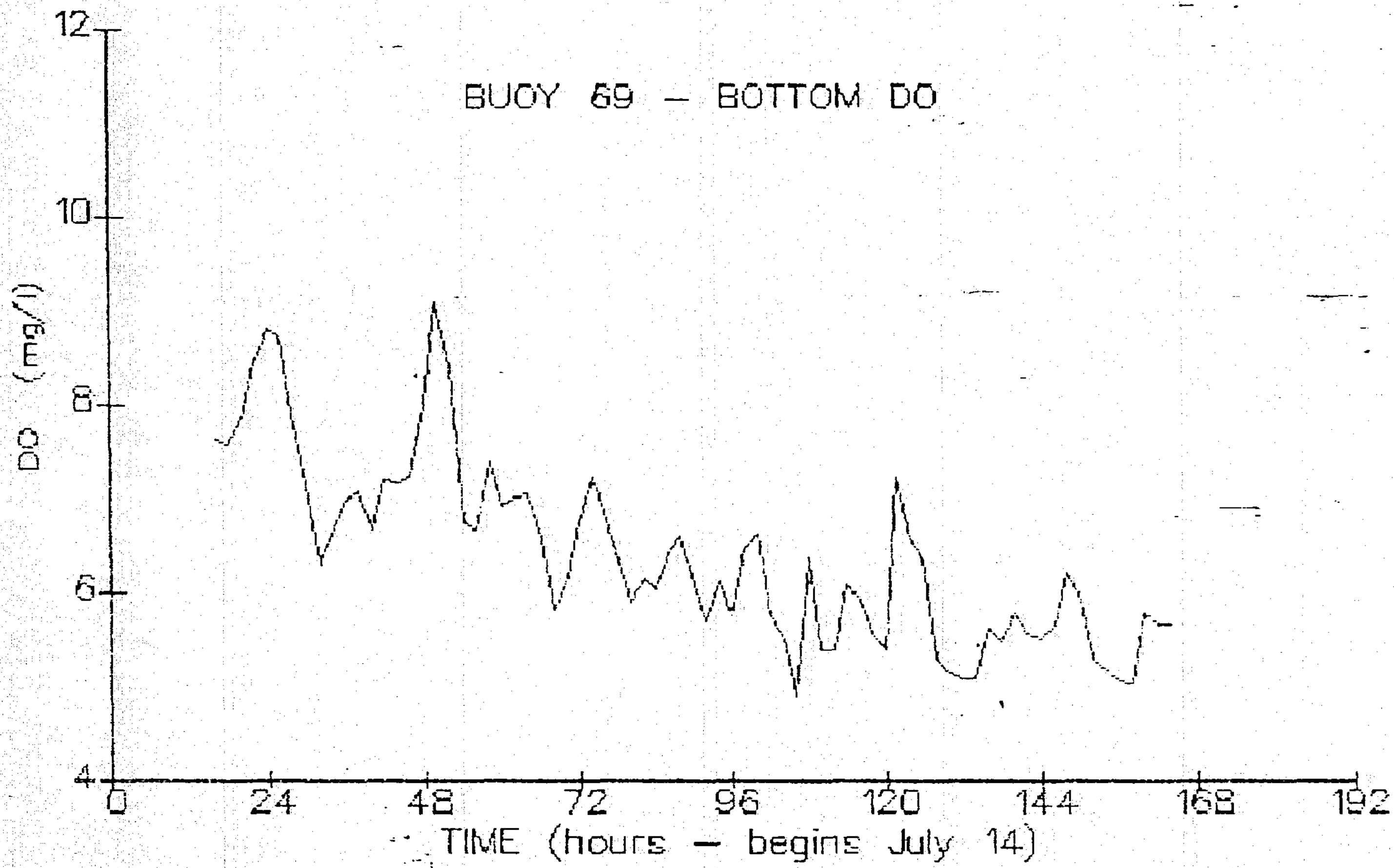


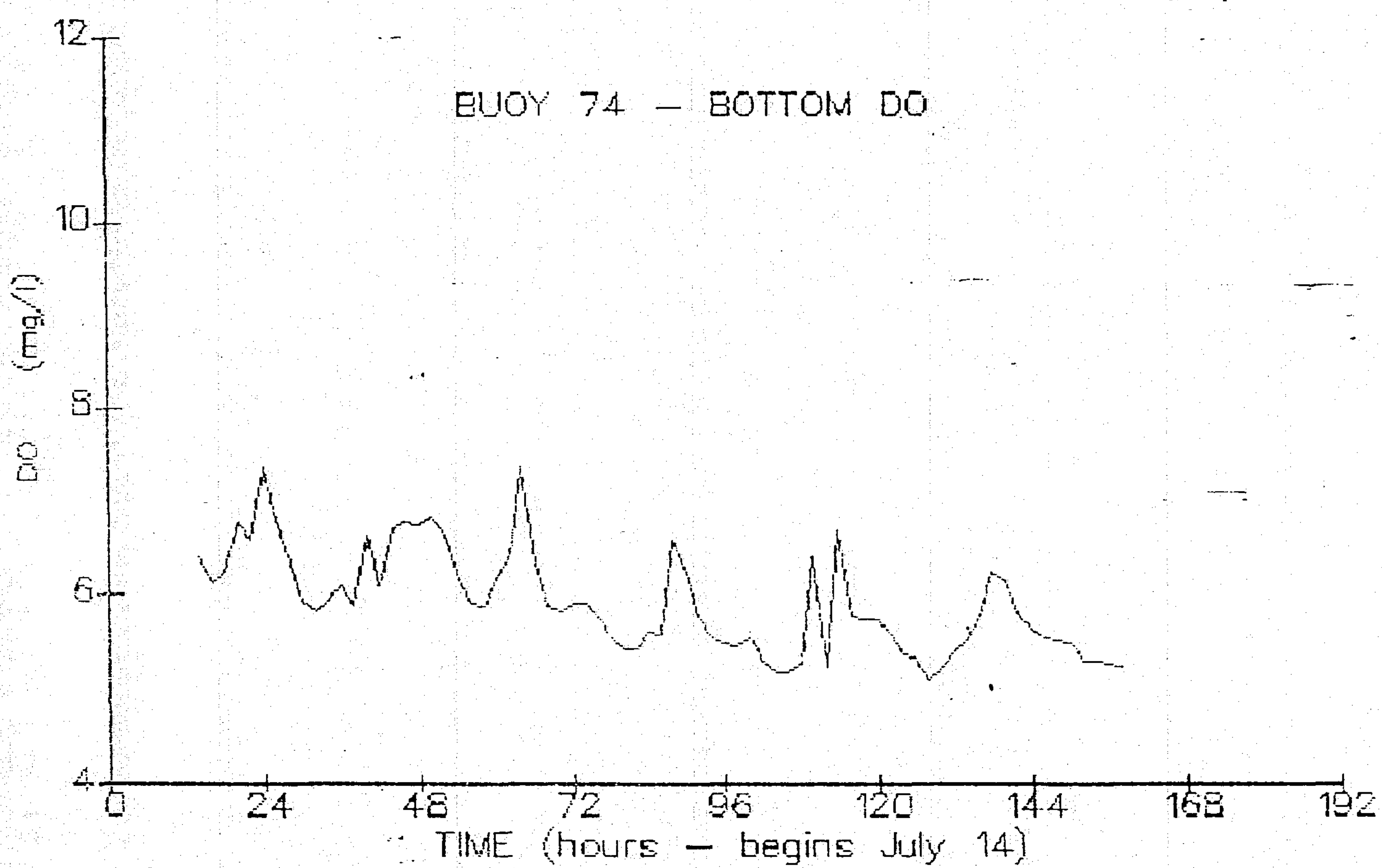
Buoy 91 — Bottom DO
DO (mg/l)
14
12
10
8
6
4
0
24
48
72
96
120
144
168
Time (hours — begin 6/23)

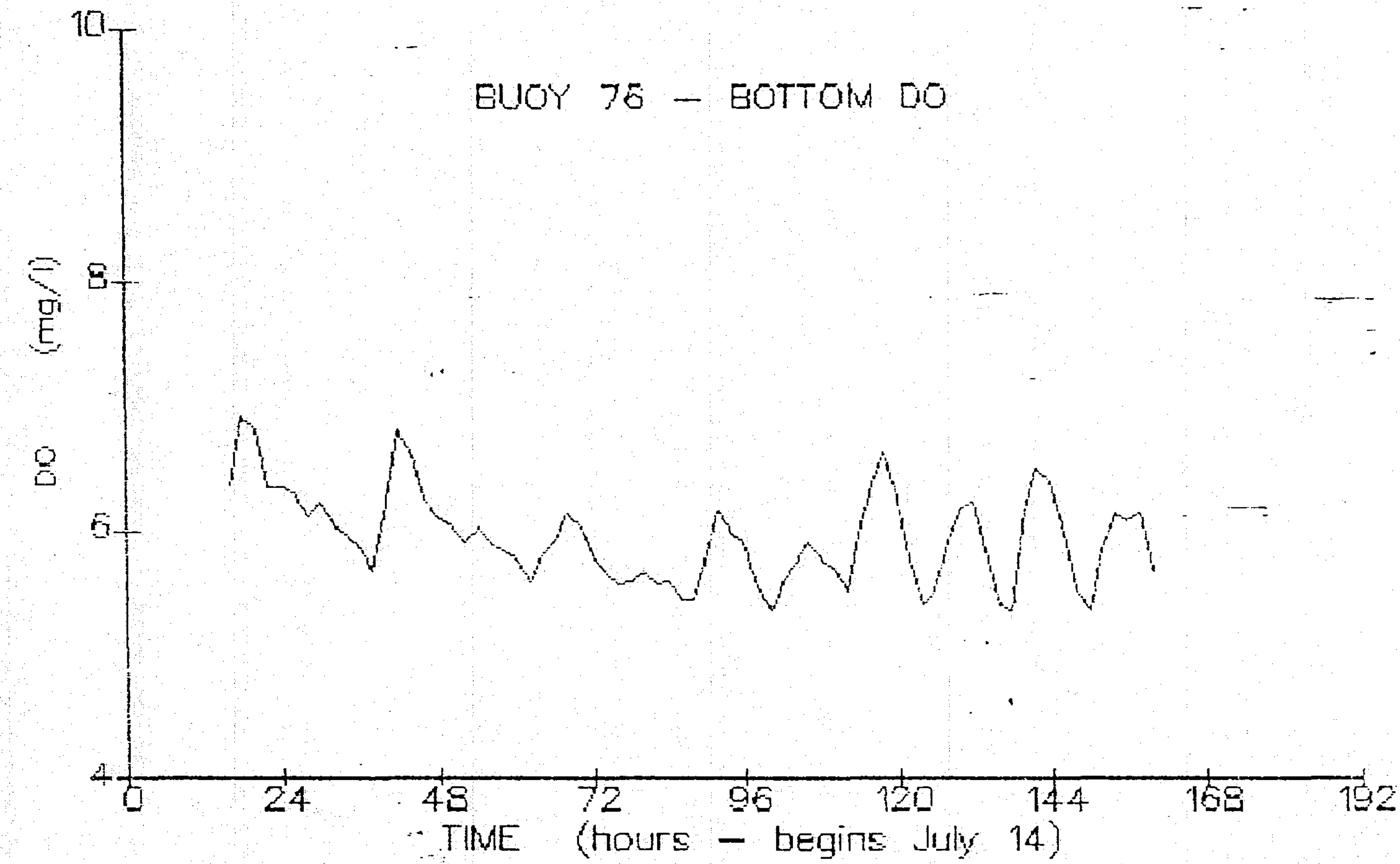

Buoy 91 — DO SURFACE
DO (mg/l)
14
12
10
8
6
4
0
24
48
72
96
120
144
168
Time (hours — begins on 6/23)

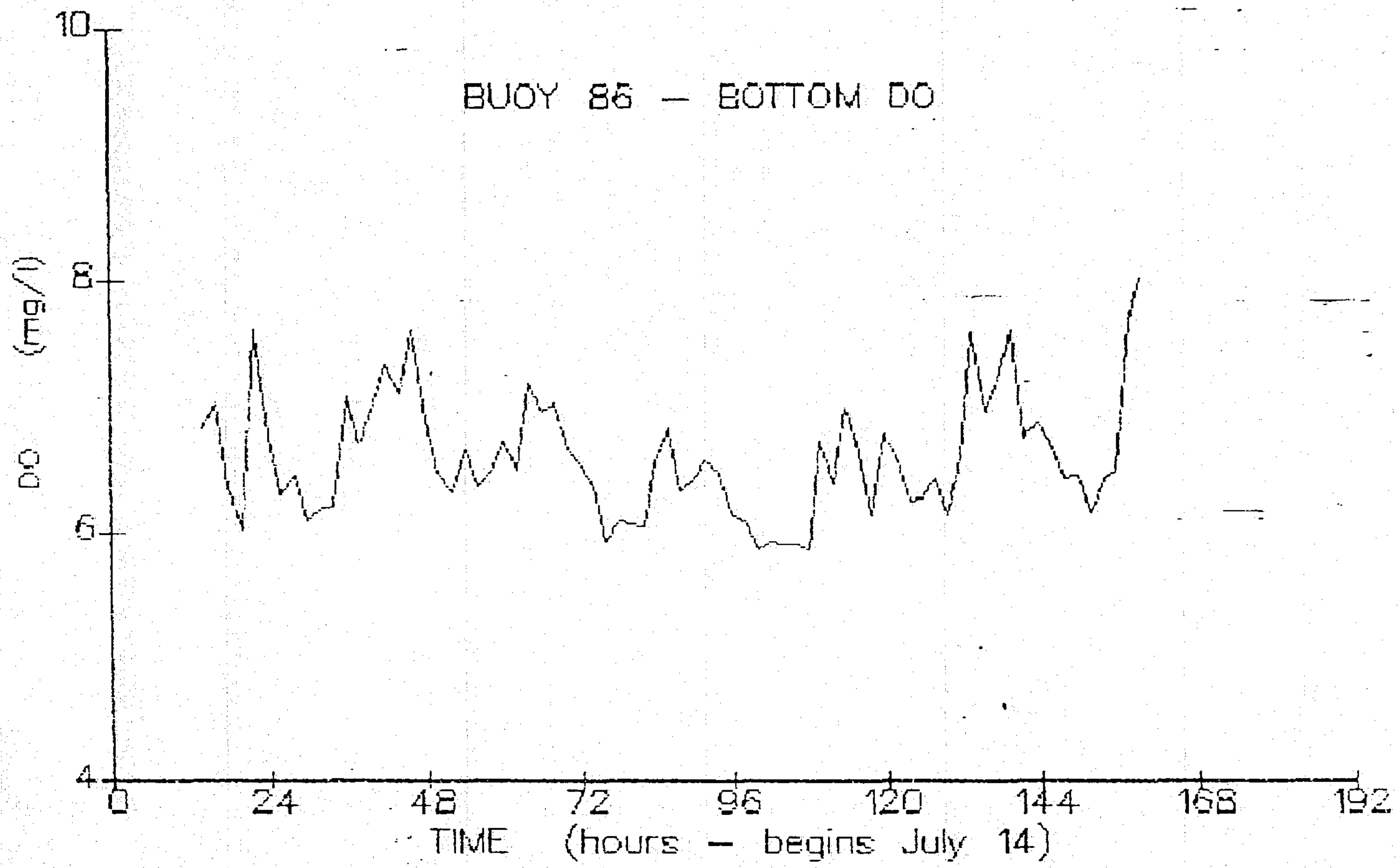


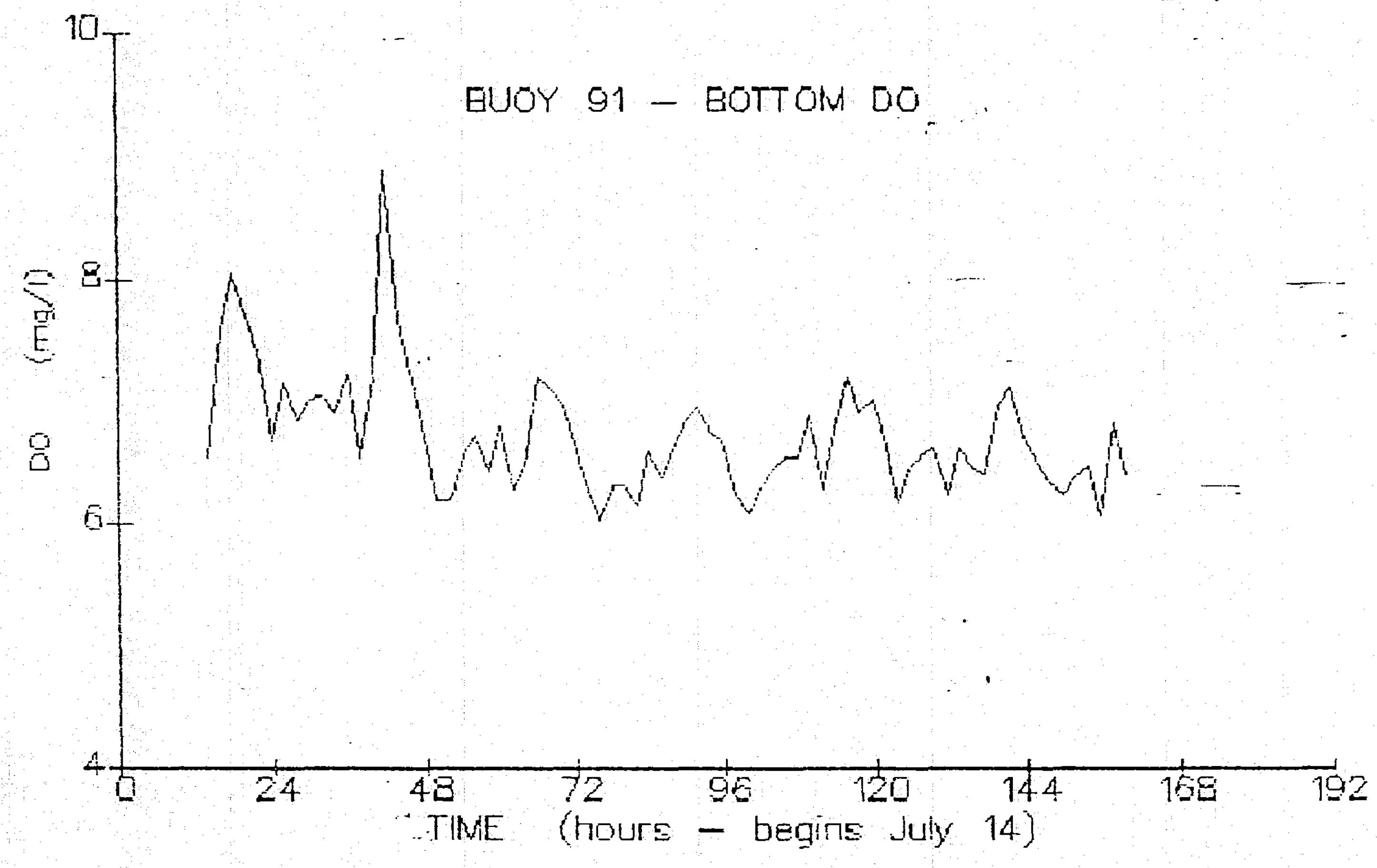
Station 107 — Bottom DO
DO (mg/l)
14
12
10
8
6
4
0
24
48
72
96
120
144
168
Time (hours — begin 6/23)

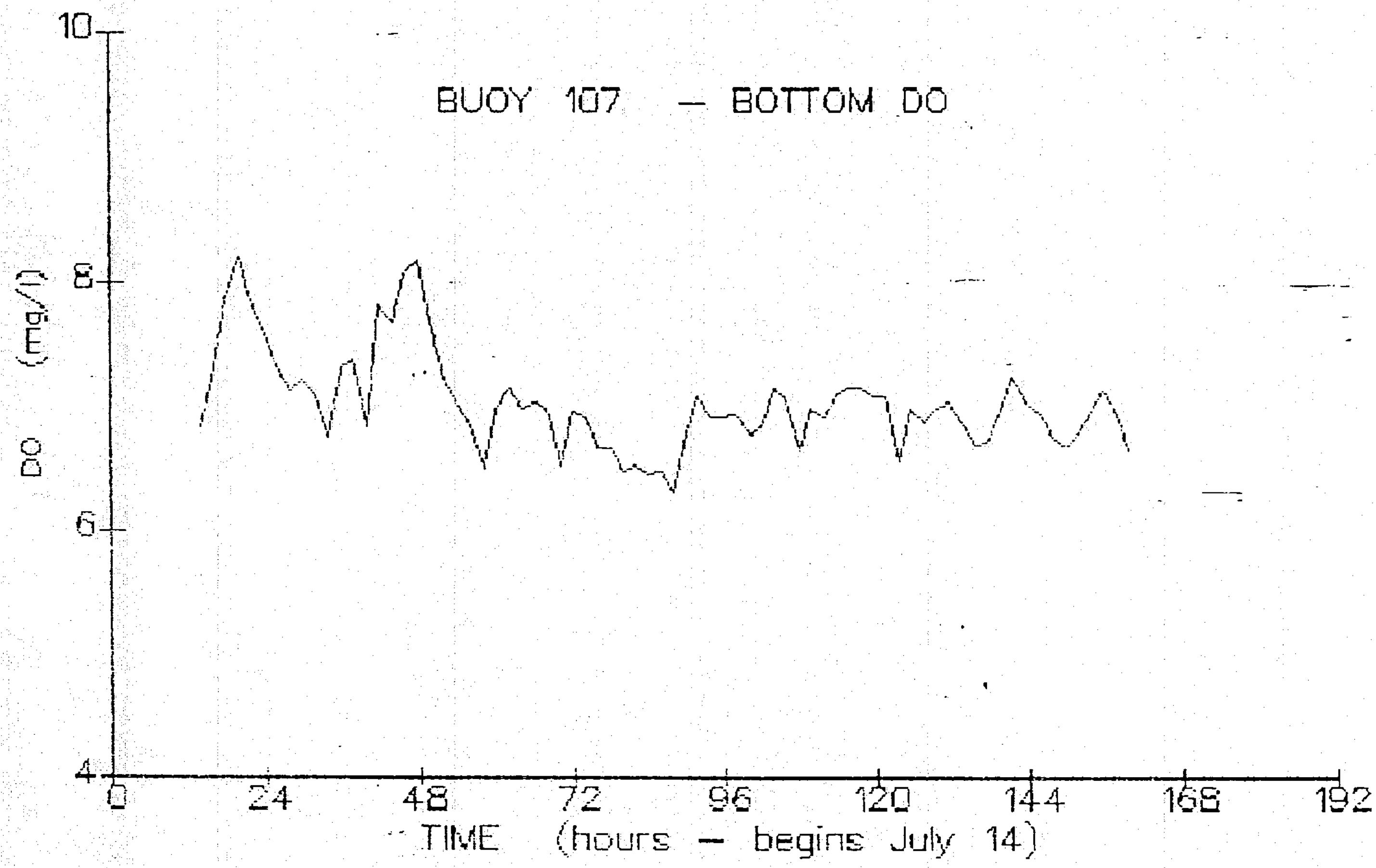

BUOY 69 — BOTTOM DO
12
10
8
6
4
DO (mg/l)
0
24
48
72
96
120
144
168
192
TIME (hours — begins July 14)


BUOY 74 — BOTTOM DO
DO (mg/l)
12
10
8
6
4
0
24
48
72
96
120
144
168
192
TIME (hours — begins July 14)

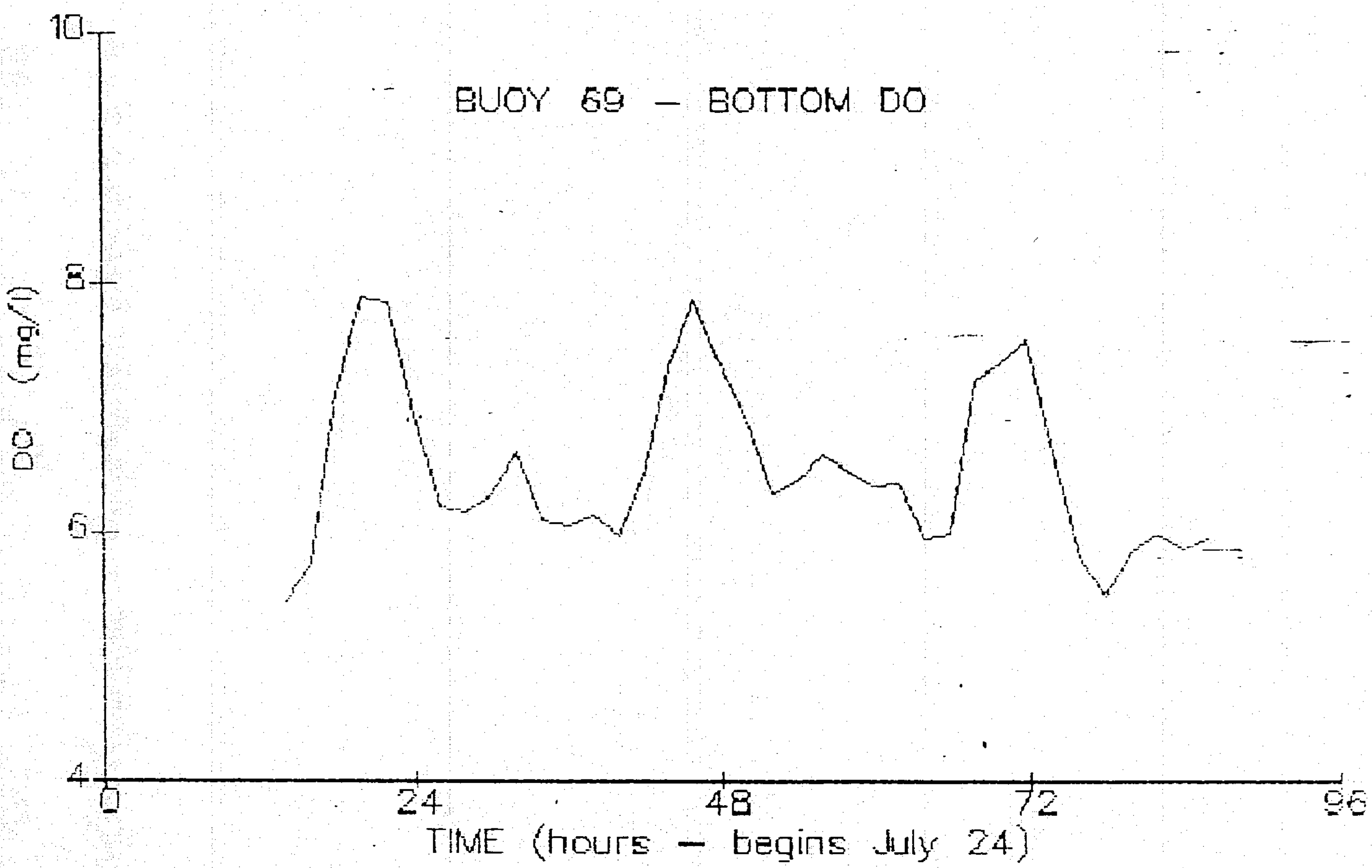

BUOY 76 — BOTTOM DO
DO (mg/l)
10
8
6
4
0
24
48
72
96
120
144
168
192
TIME (hours — begins July 14)

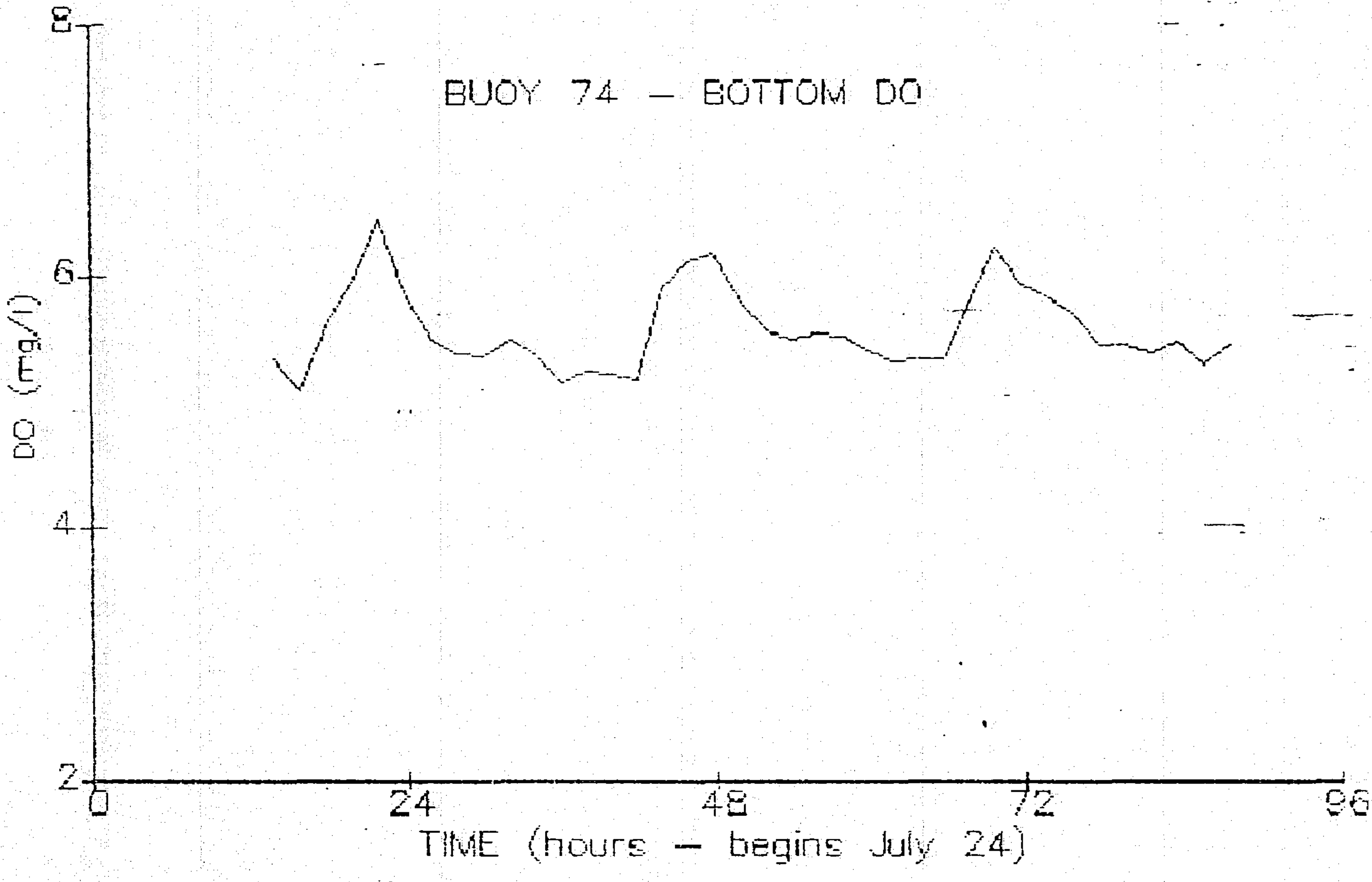

BUOY 86 — BOTTOM DO
DO (mg/l)
10
8
6
4
0
24
48
72
96
120
144
168
192
TIME (hours — begins July 14)

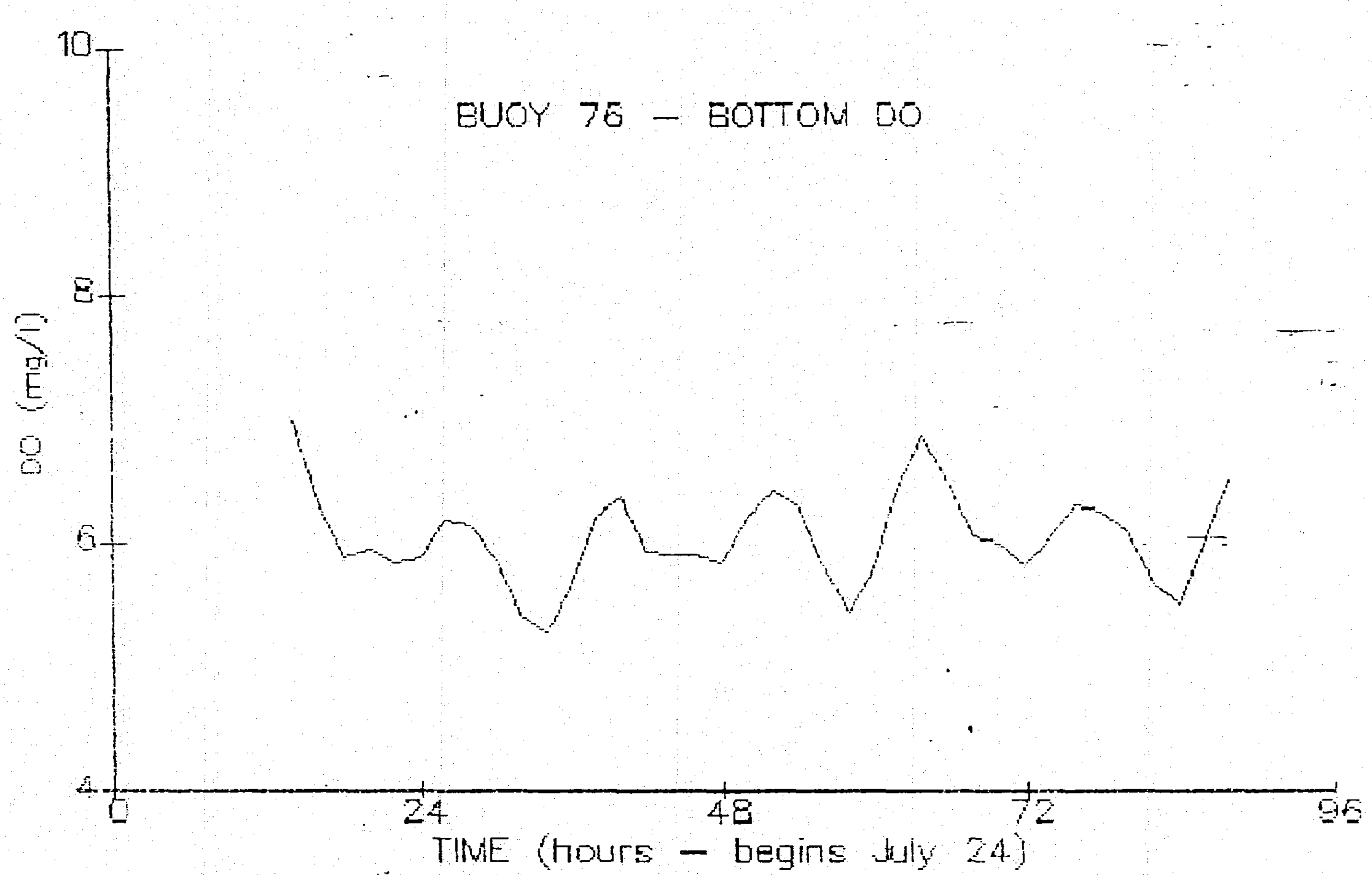

BUOY 91 — BOTTOM DO
DO (mg/l)
10
8
6
4
0
24
48
72
96
120
144
168
192
TIME (hours — begins July 14)

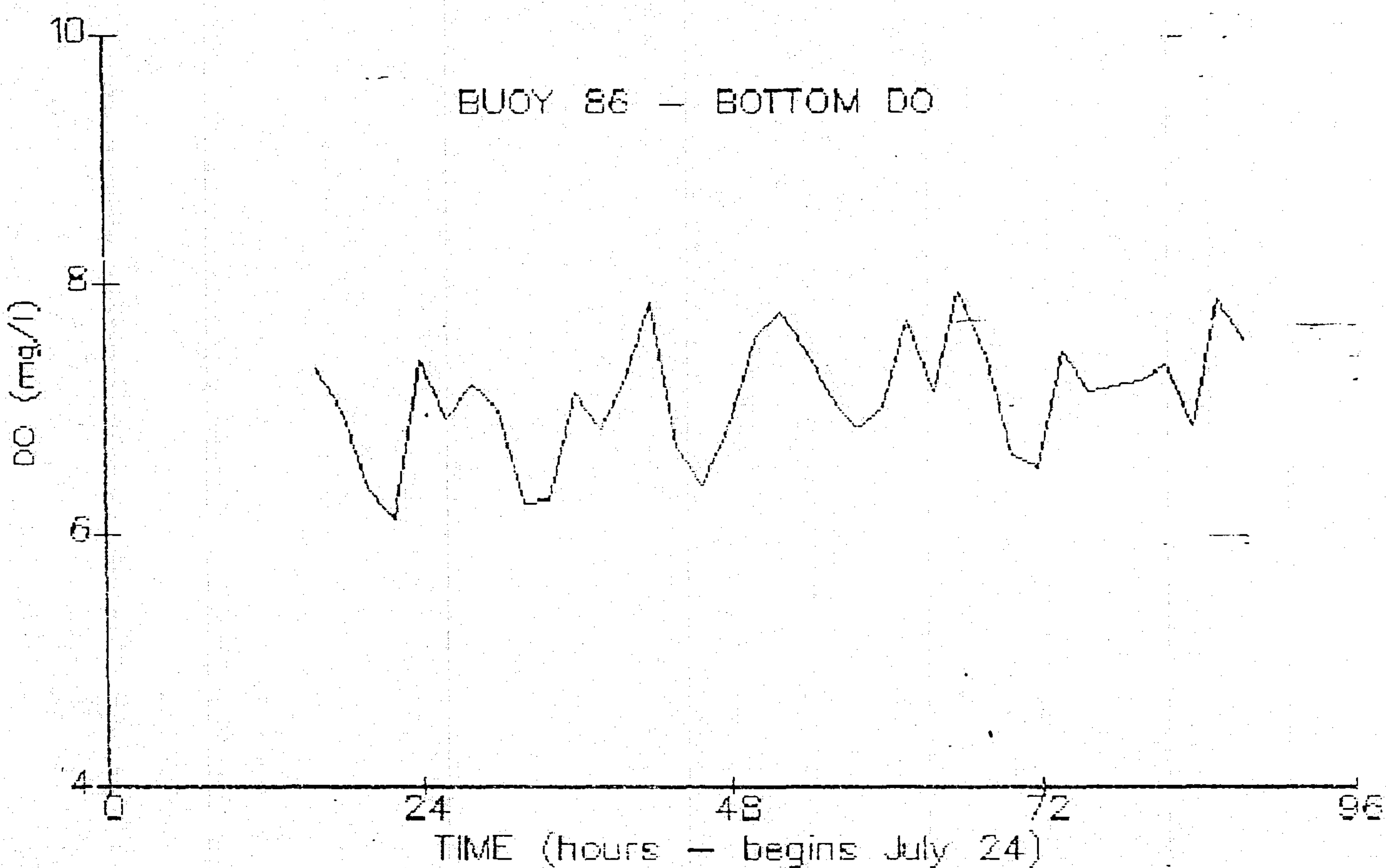


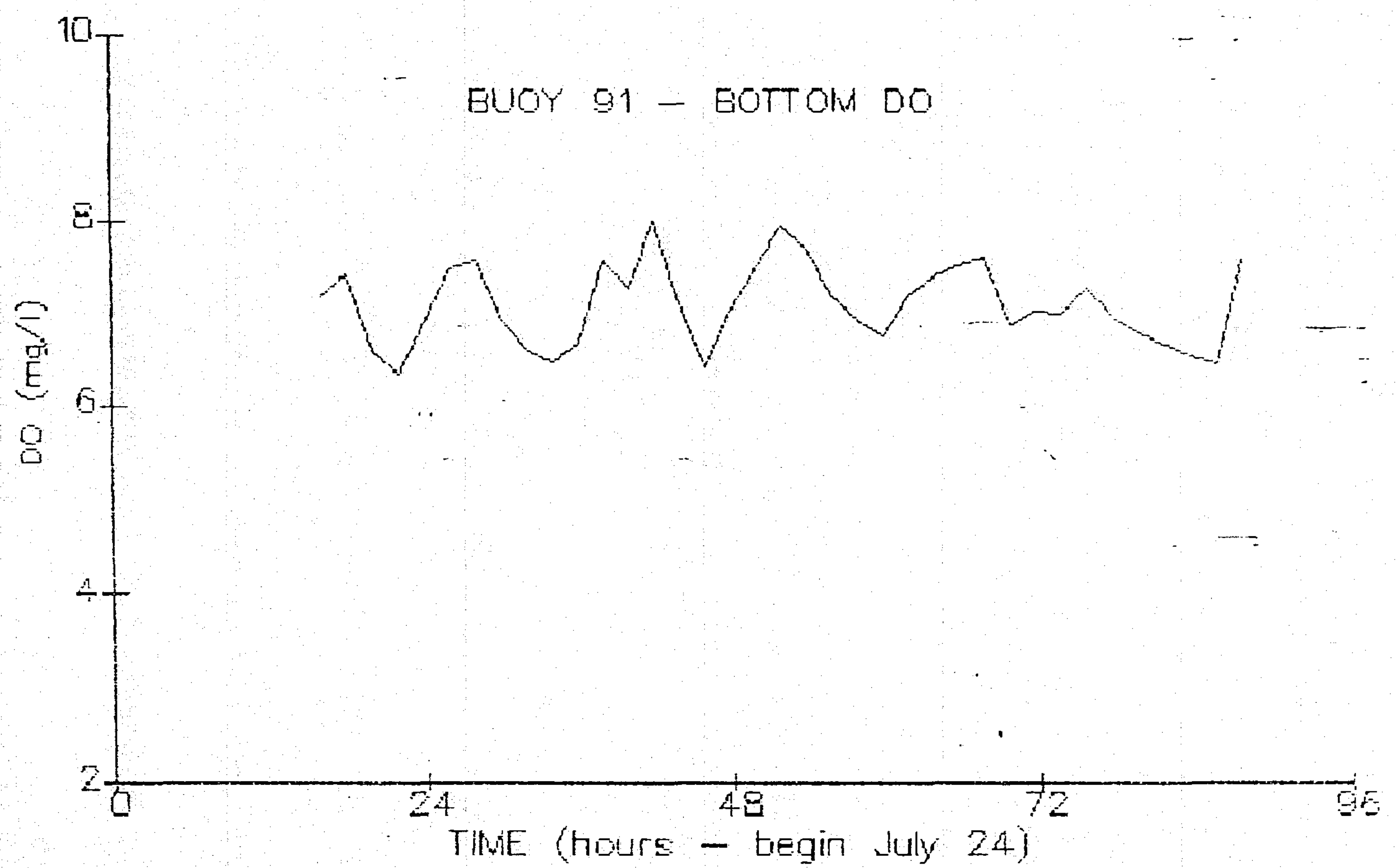
BUOY 107 — BOTTOM DO
DO (mg/l)
10
8
6
4
0
24
48
72
96
120
144
168
192
TIME (hours — begins July 14)

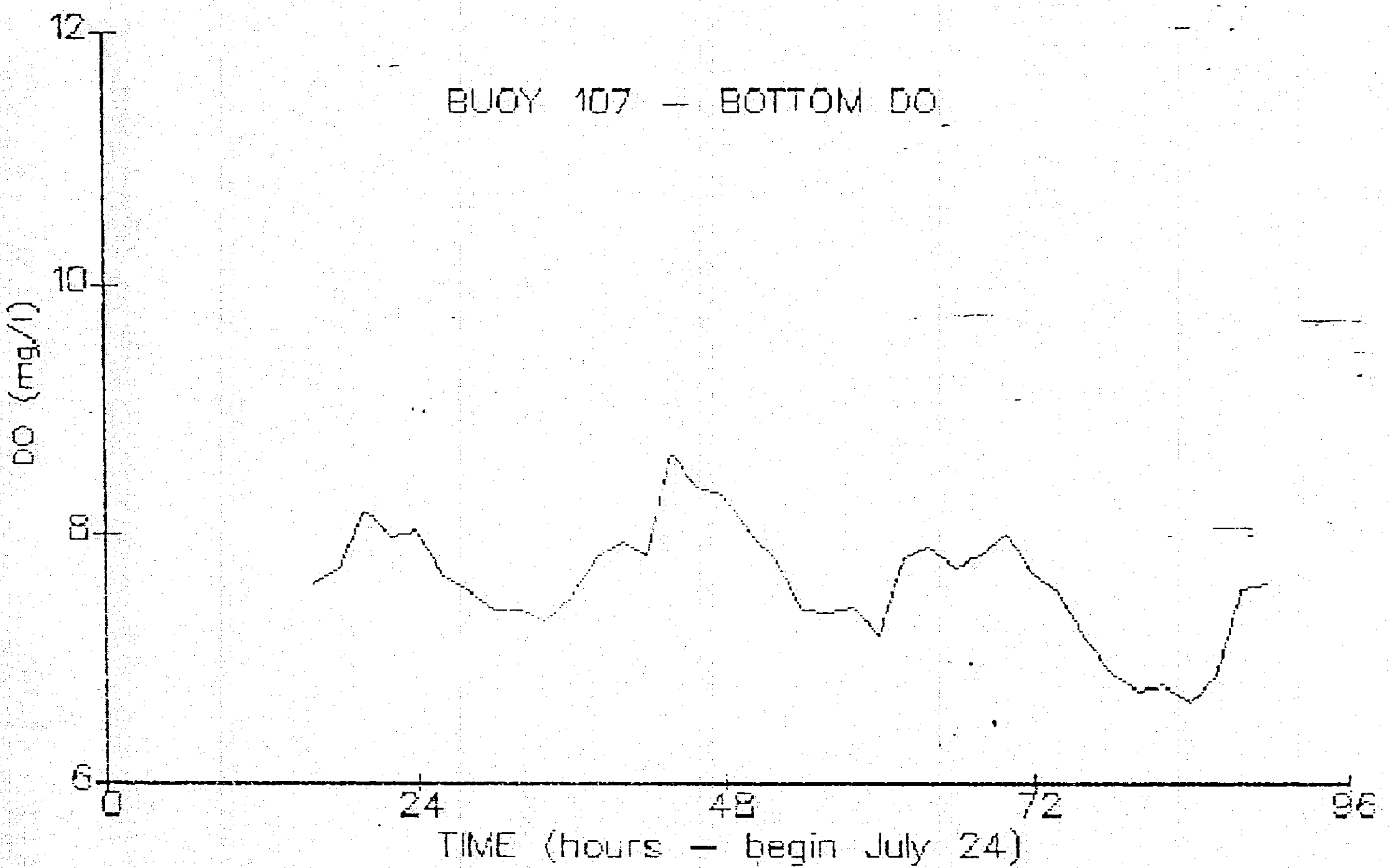

BUOY 69 — BOTTOM DO
10
8
6
4
DO (mg/l)
0
24
48
72
96
TIME (hours — begins July 24)

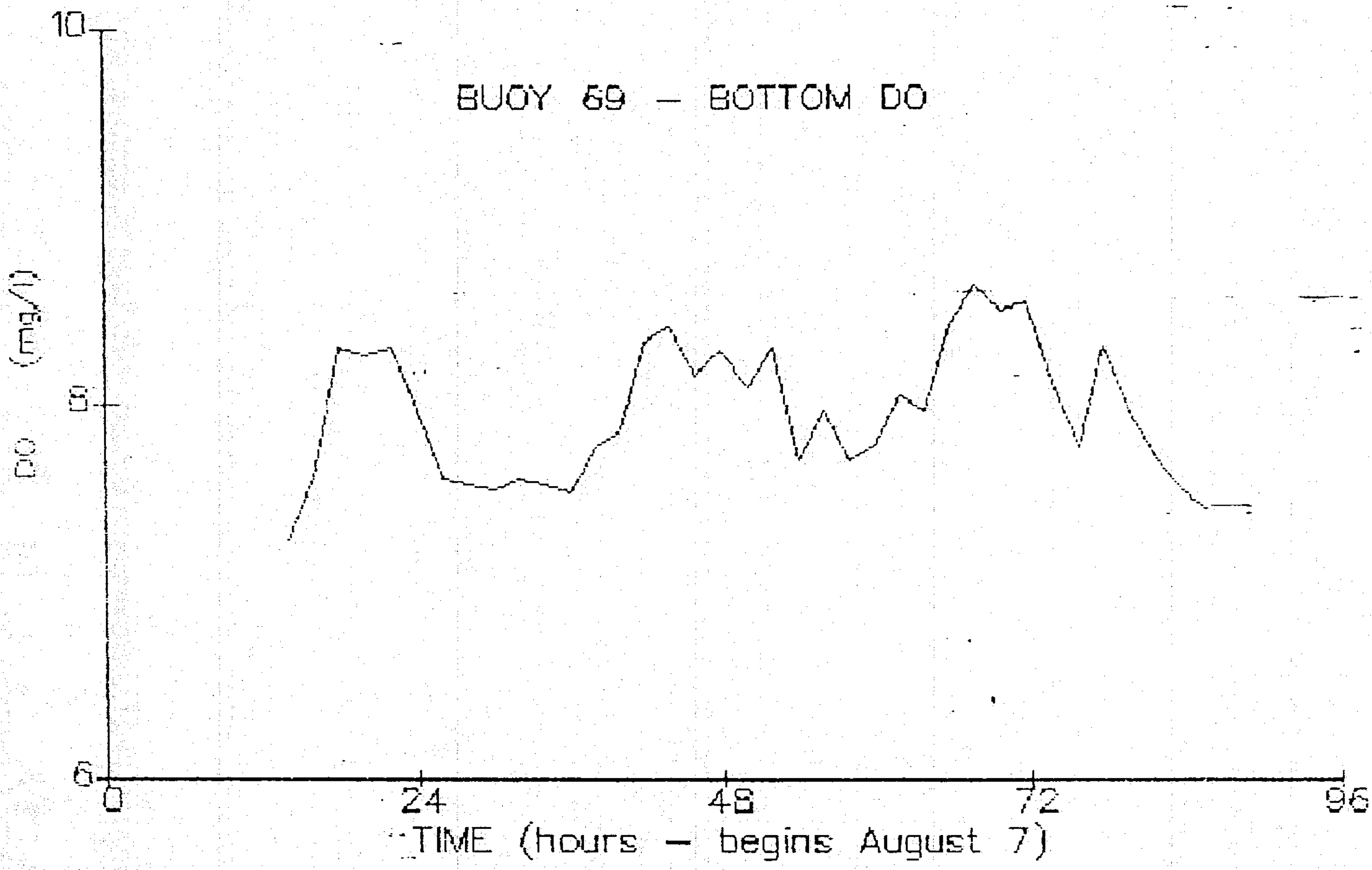

BUOY 74 — BOTTOM DO
DO (mg/l)
8
6
4
2
0
24
48
72
96
TIME (hours — begins July 24)

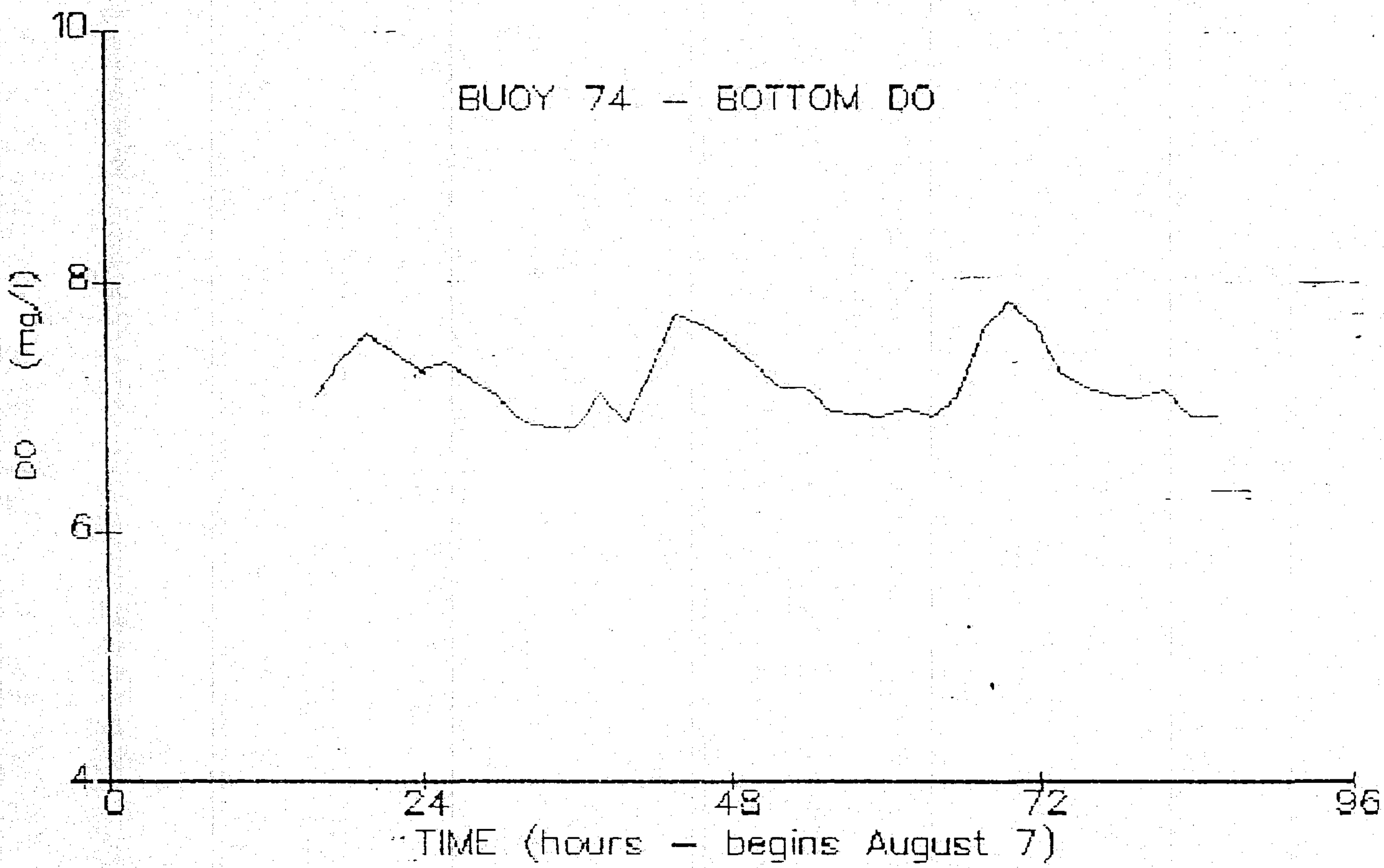

BUOY 76 — BOTTOM DO
10
8
6
4
DO (mg/l)
0
24
48
72
96
TIME (hours — begins July 24)

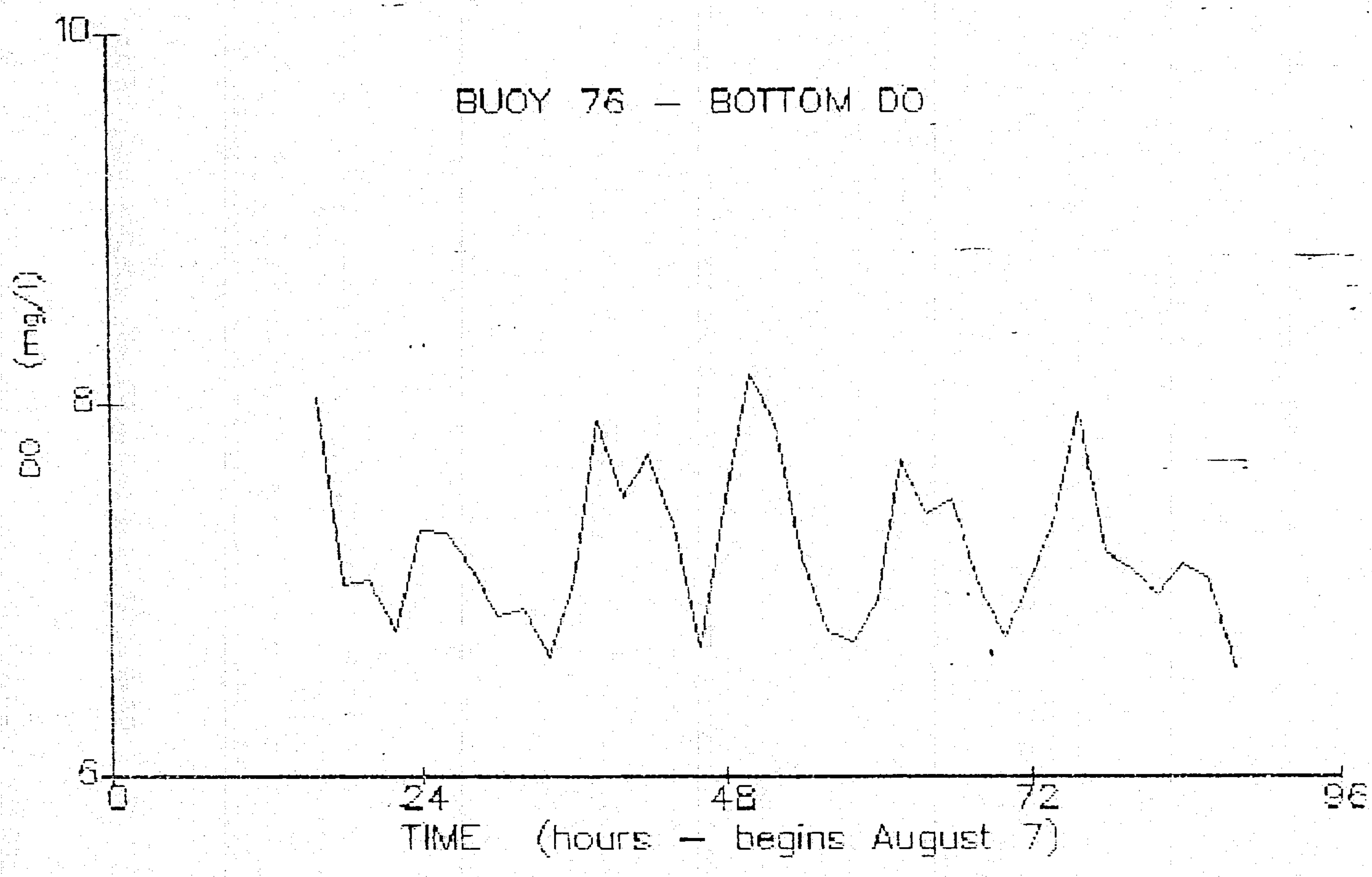

BUOY 86 — BOTTOM DO
DO (mg/l)
10
8
6
4
0
24
48
72
96
TIME (hours — begins July 24)

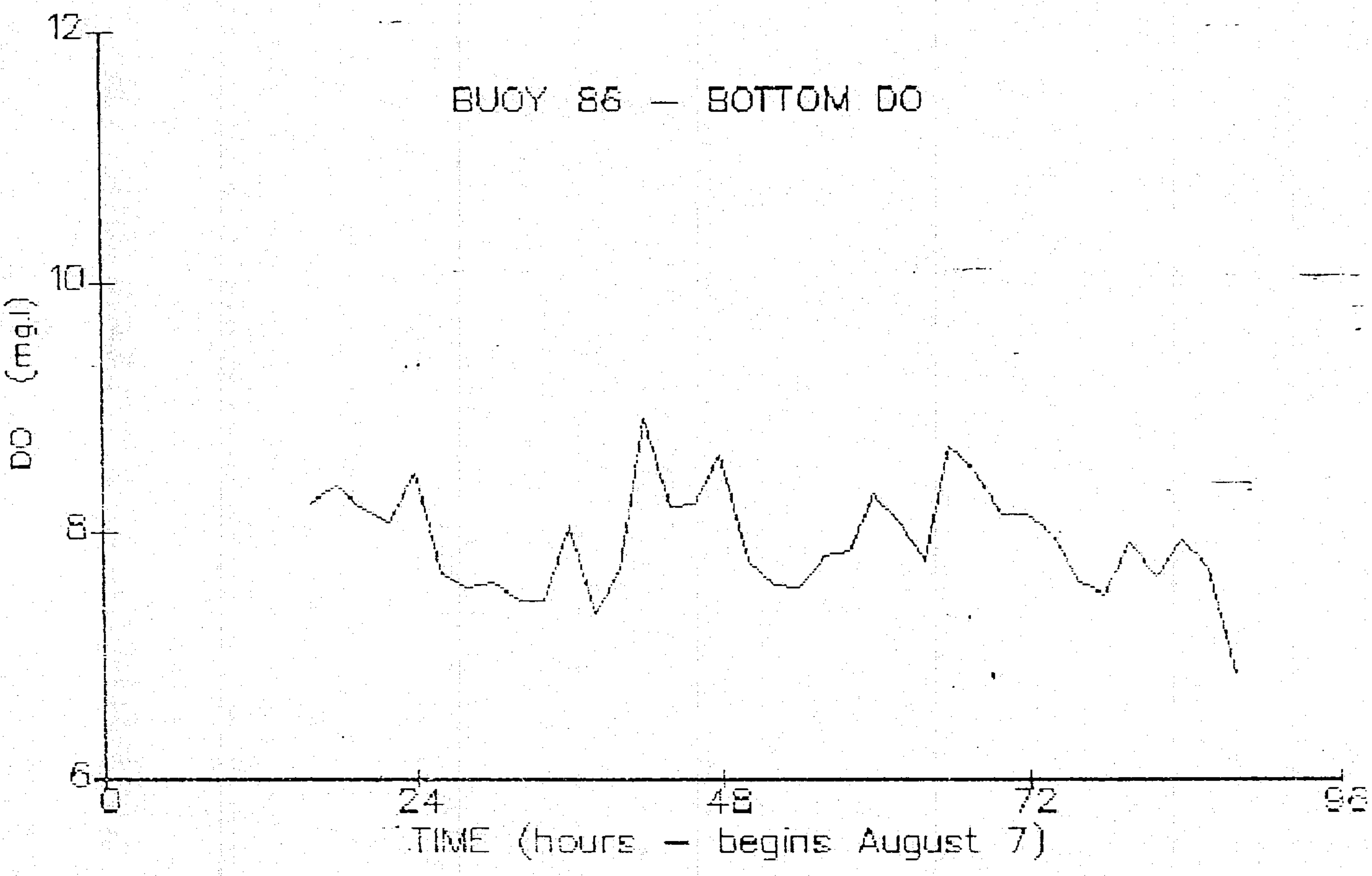

BUOY 91 — BOTTOM DO
DO (mg/l)
10
8
6
4
2
0
24
48
72
96
TIME (hours — begin July 24)

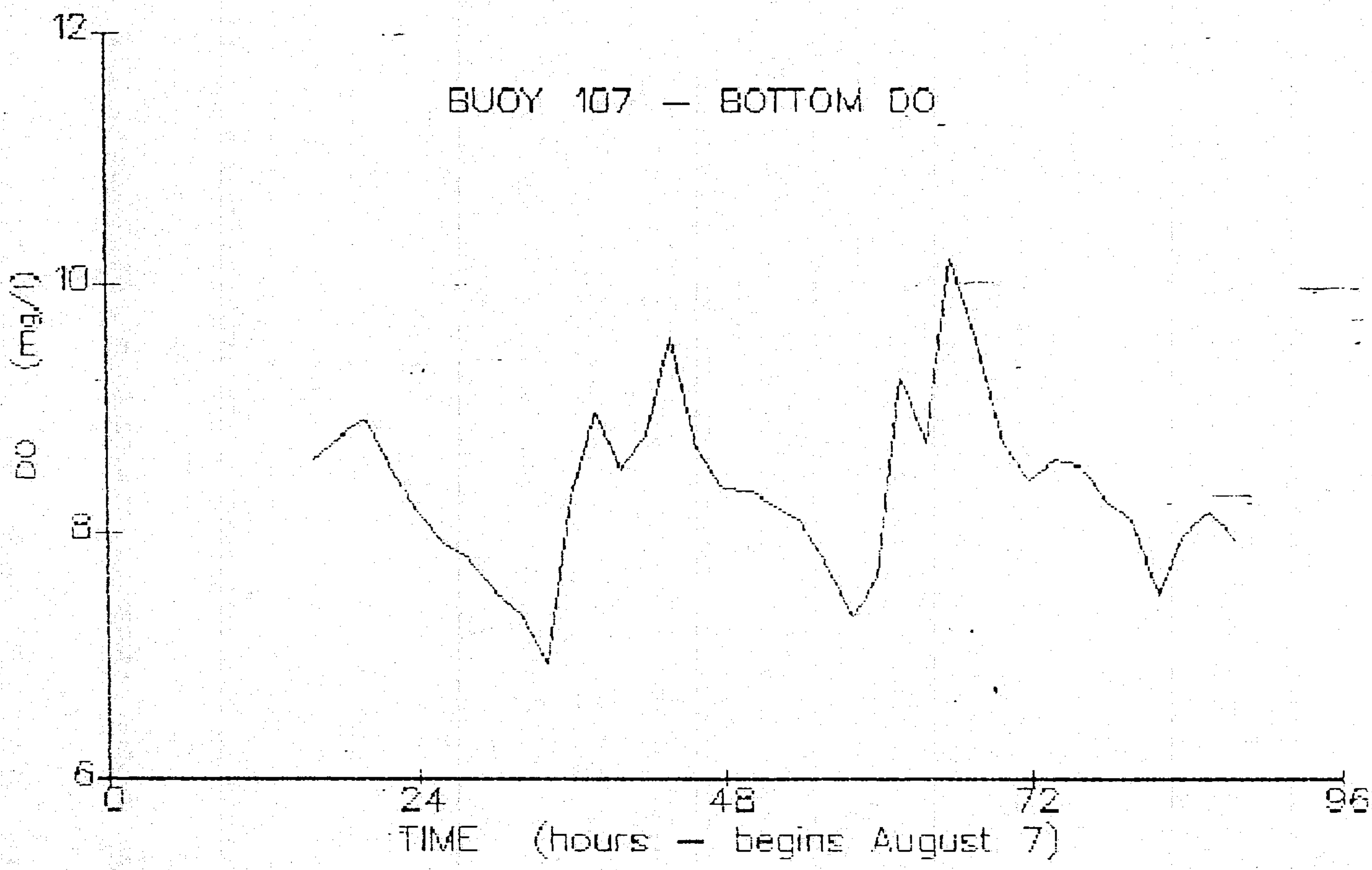

BUOY 107 — BOTTOM DO
DO (mg/l)
12
10
8
6
0
24
48
72
96
TIME (hours — begin July 24)

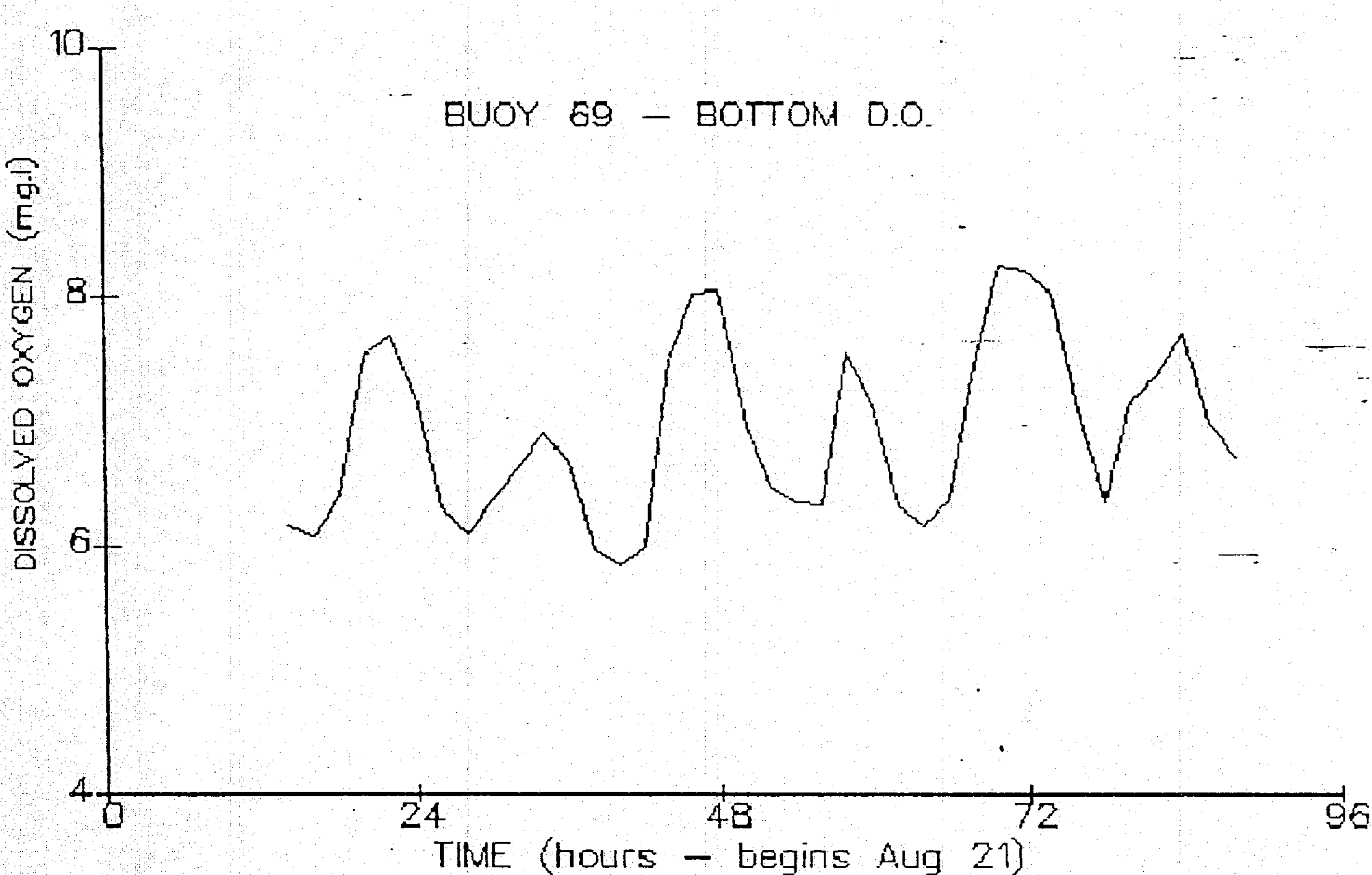

BUOY 69 — BOTTOM DO
10
8
6
DO (mg/l)
0
24
48
72
96
TIME (hours — begins August 7)

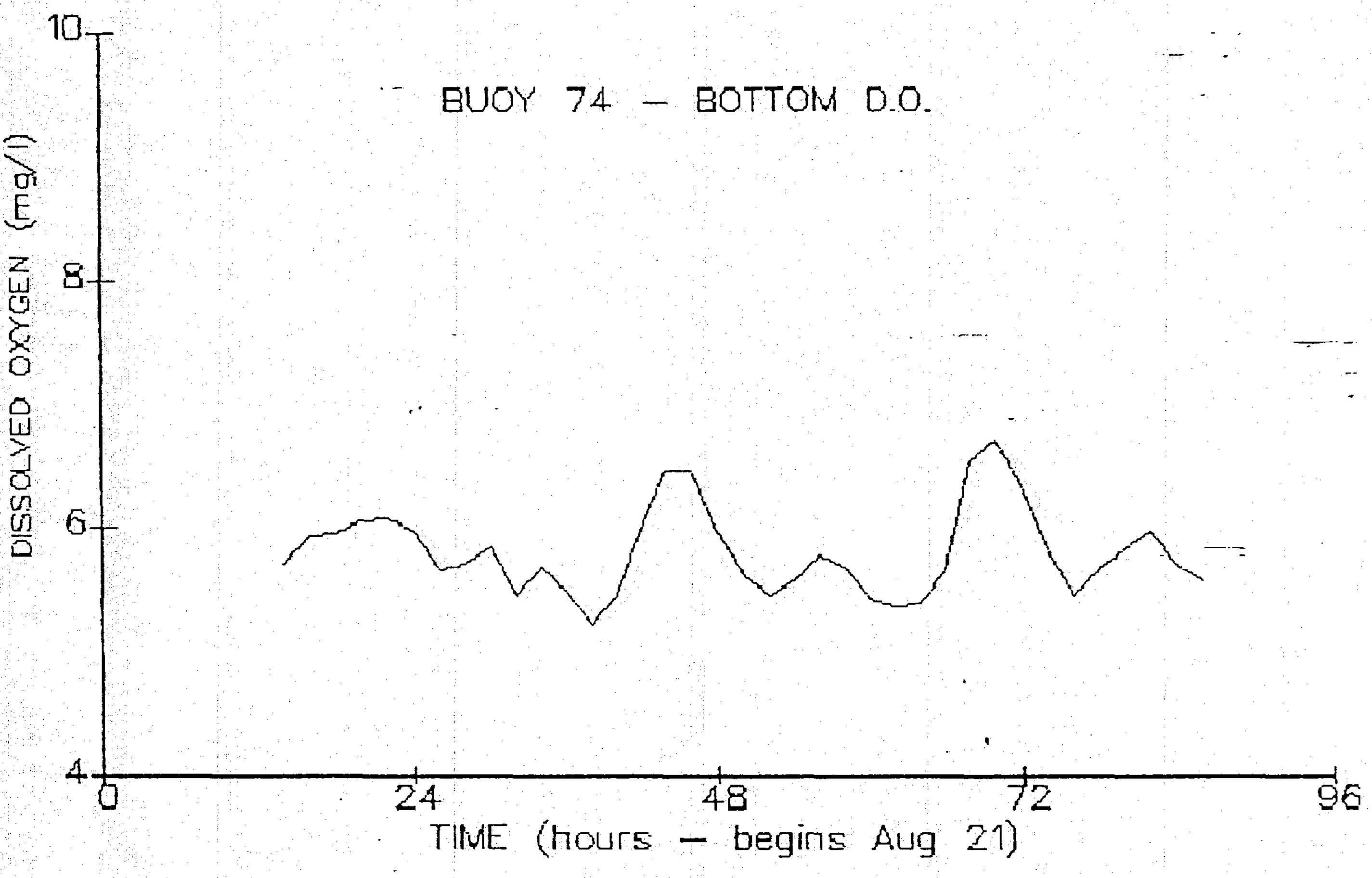

BUOY 74 — BOTTOM DO
10
8
6
4
DO (mg/l)
0
24
48
72
96
TIME (hours — begins August 7)

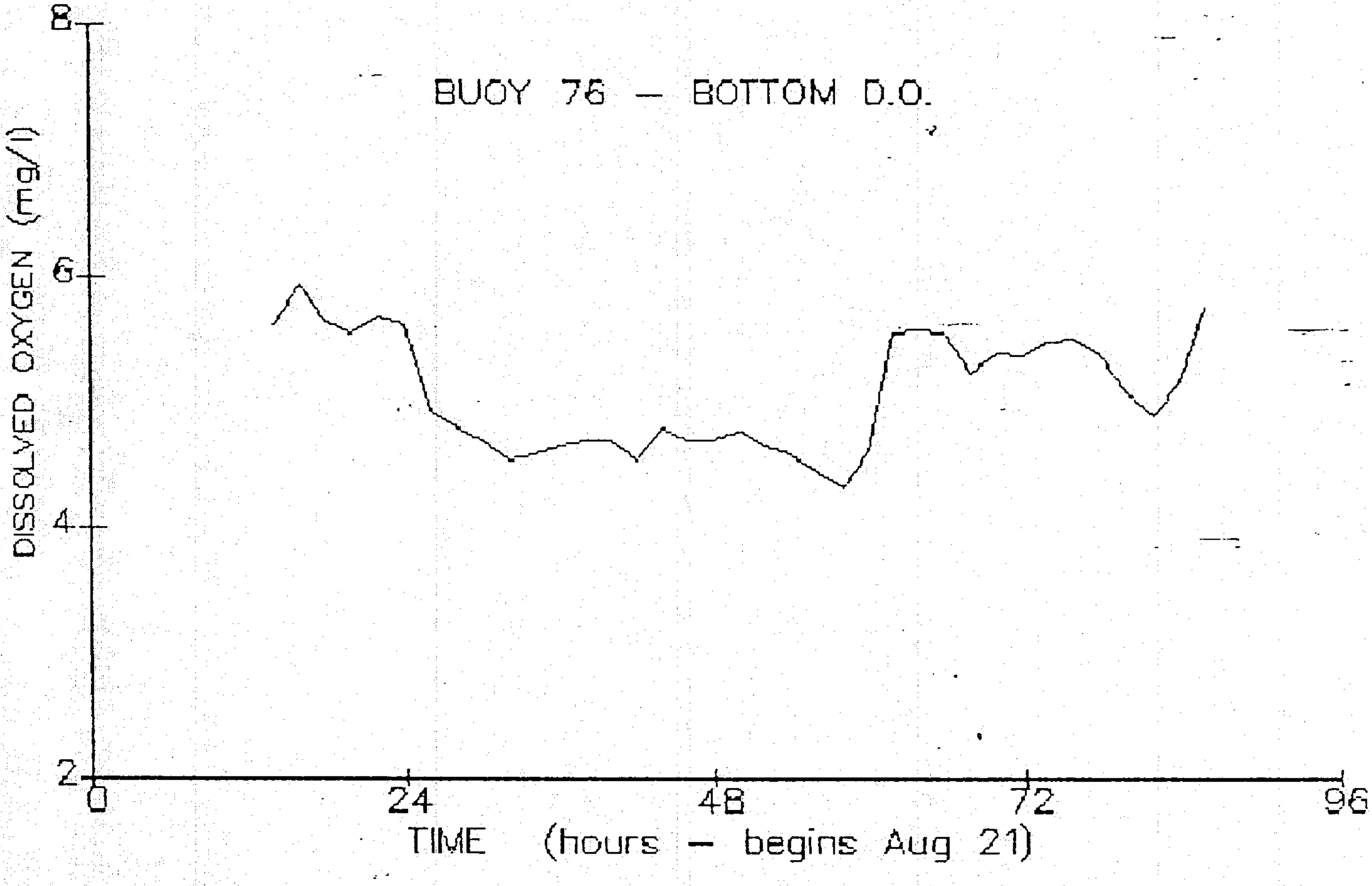

BUOY 76 — BOTTOM DO
DO (mg/l)
10
8
6
0
24
48
72
96
TIME (hours — begins August 7)

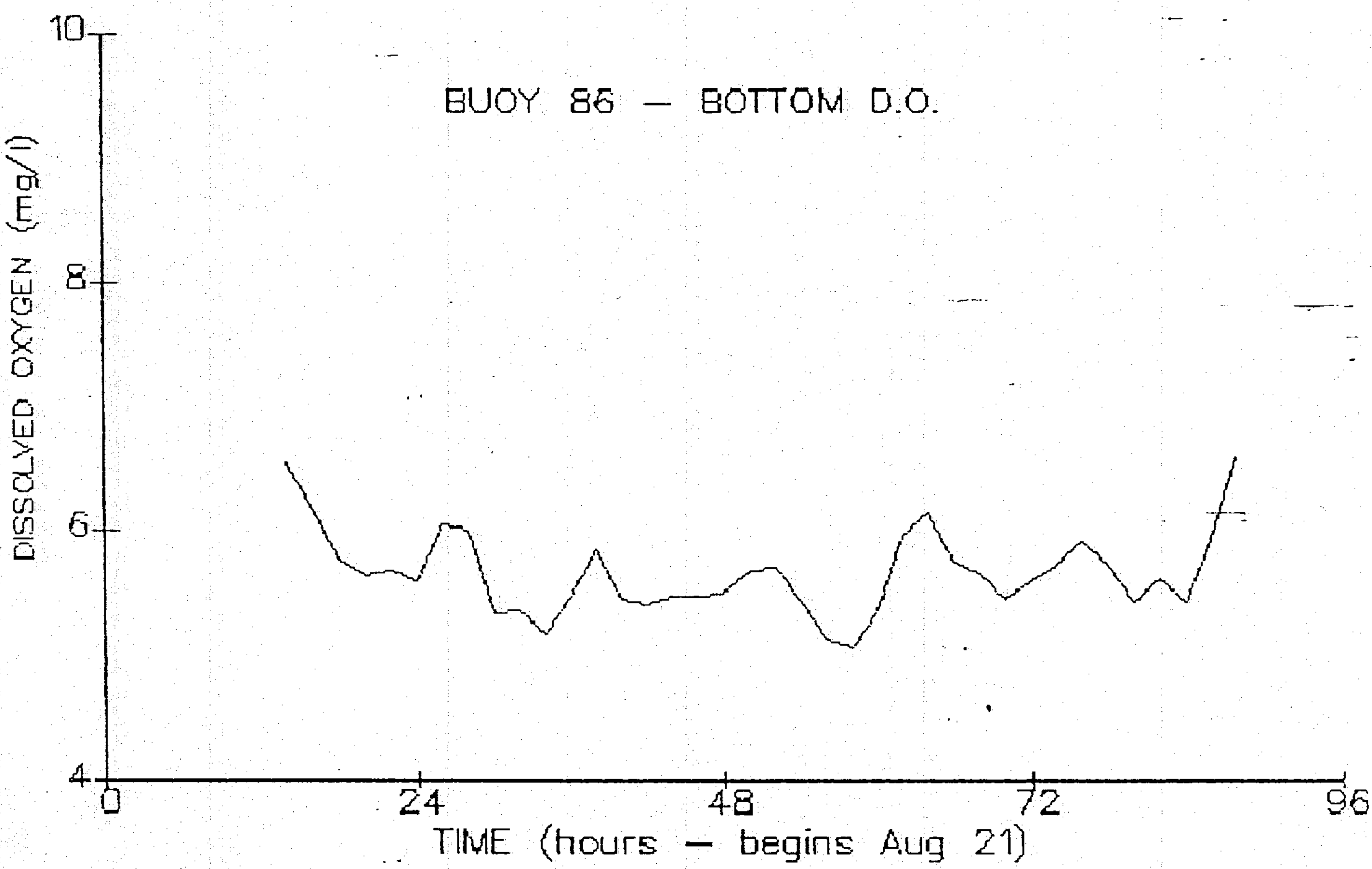

BUOY 86 — BOTTOM DO
DO (mg/l)
12
10
8
6
0
24
48
72
96
TIME (hours — begins August 7)

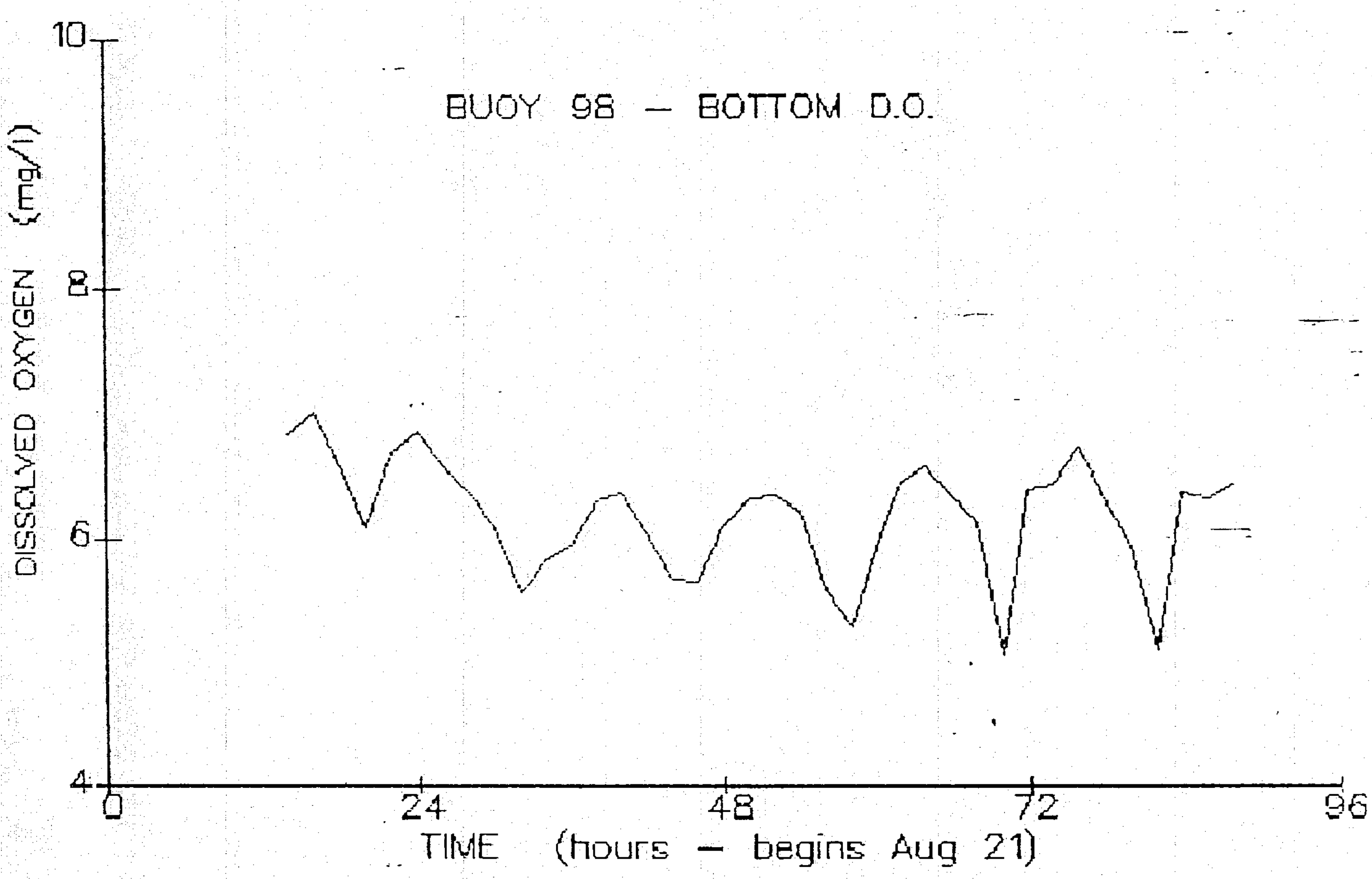

BUOY 107 — BOTTOM DO
DO (mg/l)
12
10
8
6
0
24
48
72
96
TIME (hours — begins August 7)

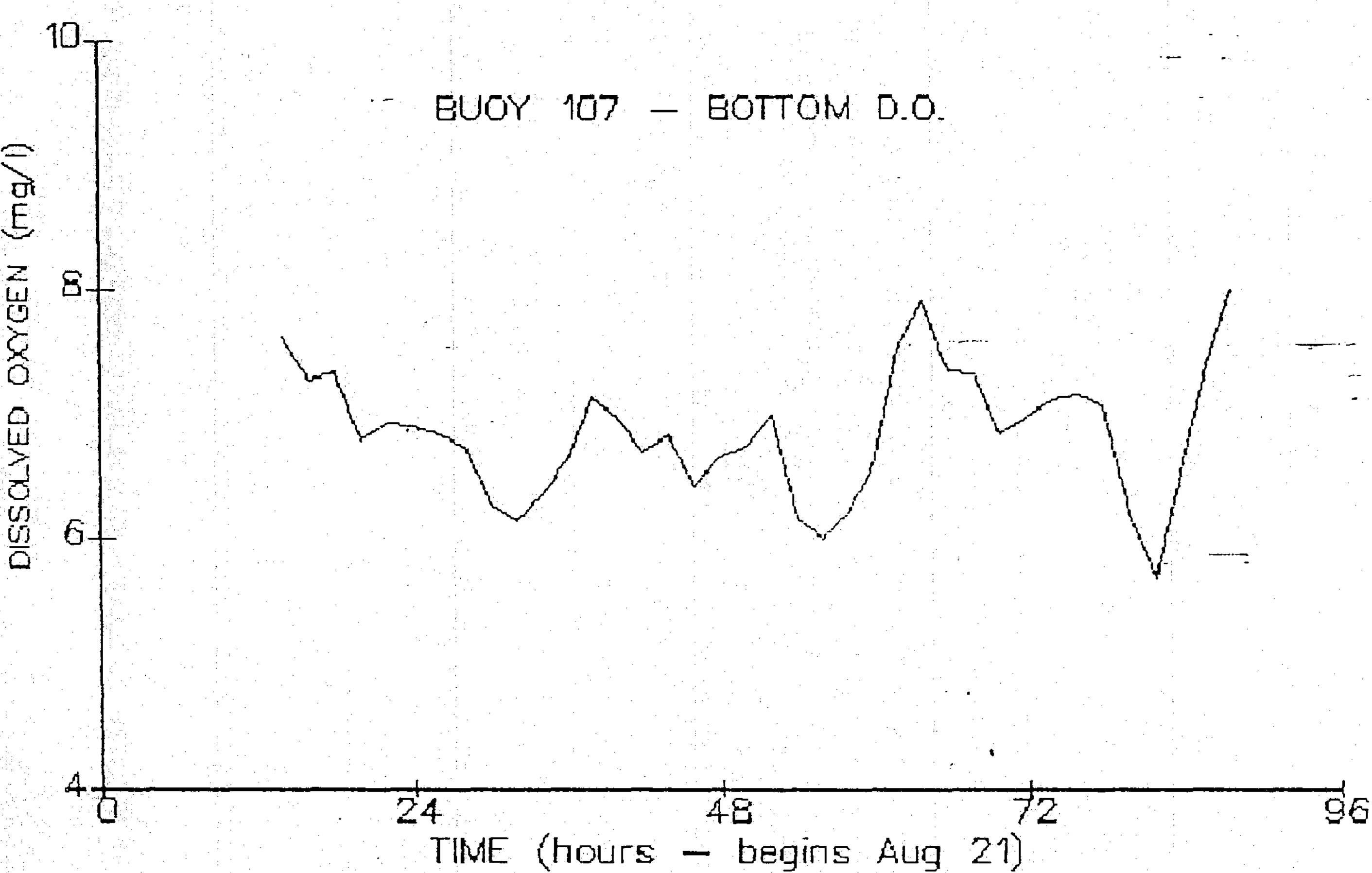

BUOY 69 — BOTTOM D.O.
DISSOLVED OXYGEN (mg/l)
10
8
6
4
0
24
48
72
96
TIME (hours — begins Aug 21)

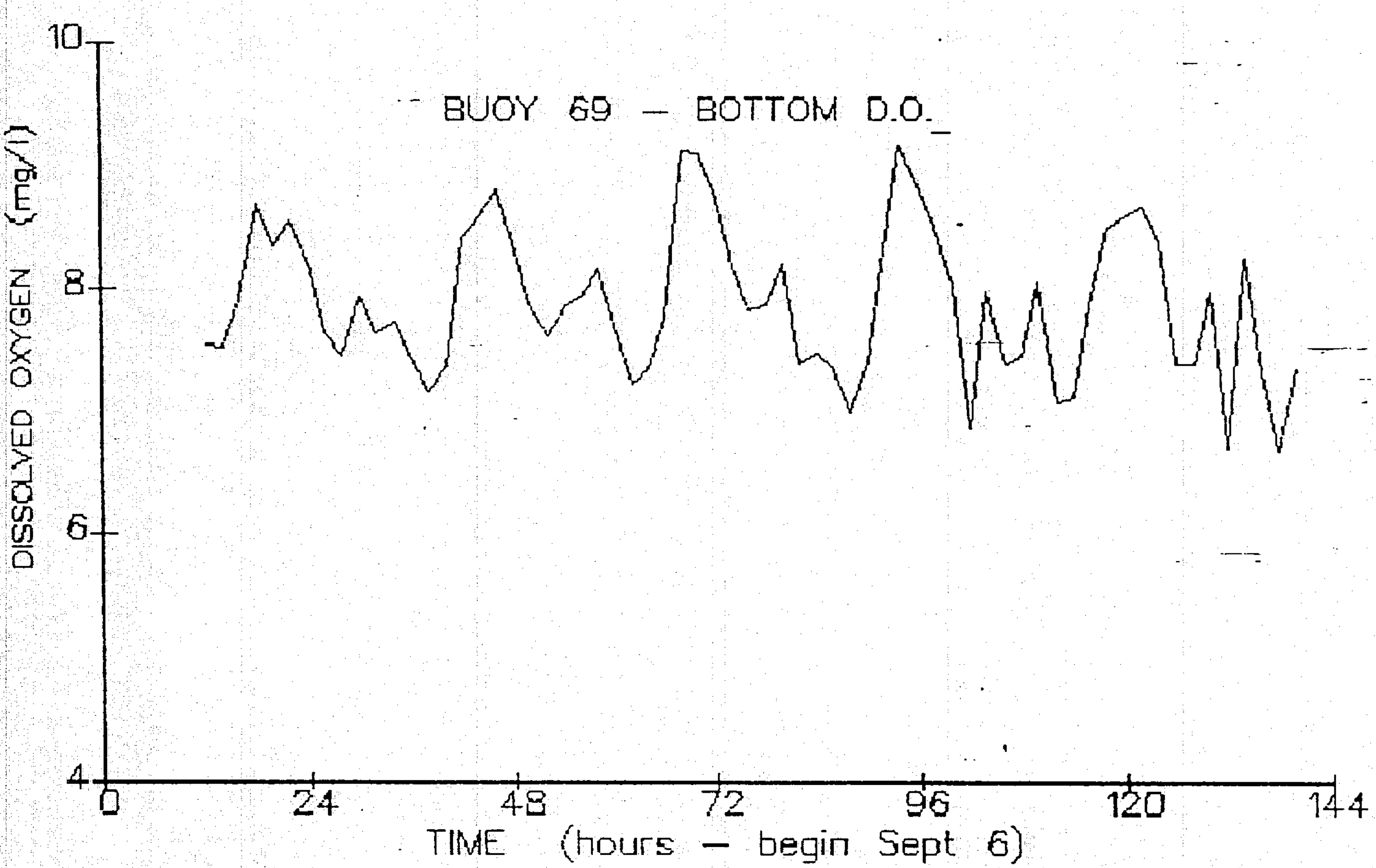

BUOY 74 — BOTTOM D.O.
10
8
6
4
DISSOLVED OXYGEN (mg/l)
0
24
48
72
96
TIME (hours — begins Aug 21)

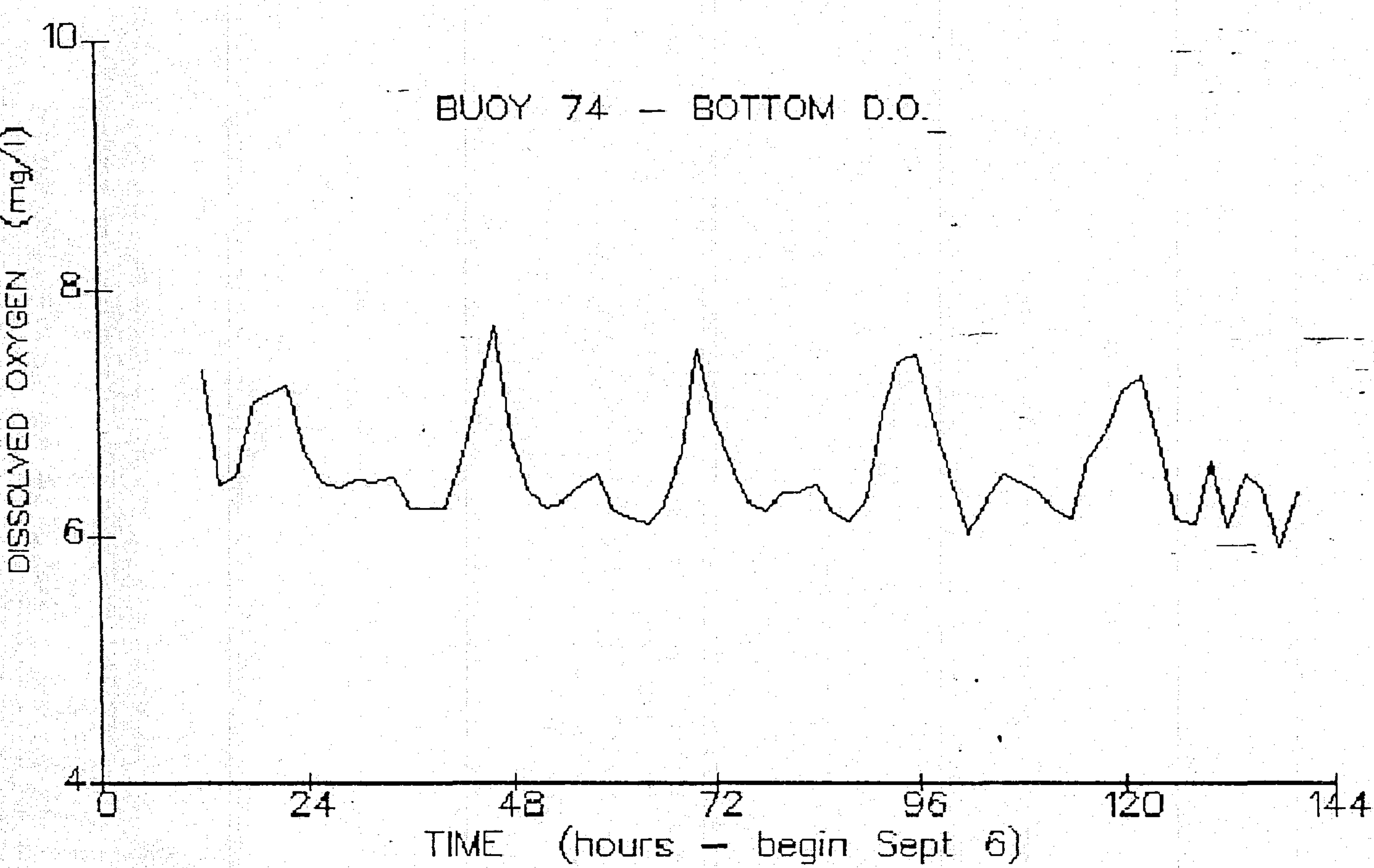

BUOY 76 — BOTTOM D.O.
DISSOLVED OXYGEN (mg/l)
8
6
4
2
0
24
48
72
96
TIME (hours — begins Aug 21)

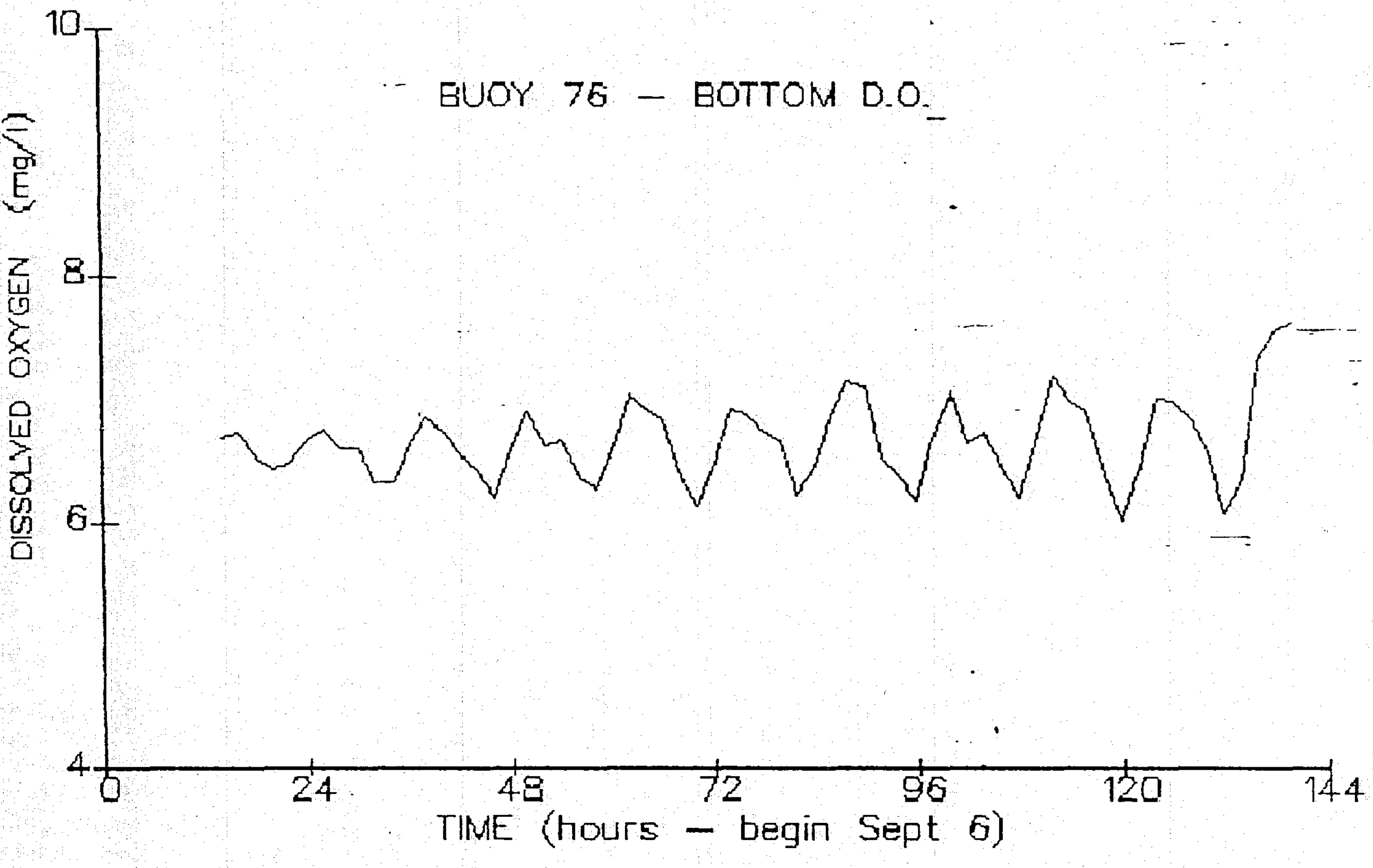

BUOY 86 — BOTTOM D.O.
DISSOLVED OXYGEN (mg/l)
10
8
6
4
0
24
48
72
96
TIME (hours — begins Aug 21)

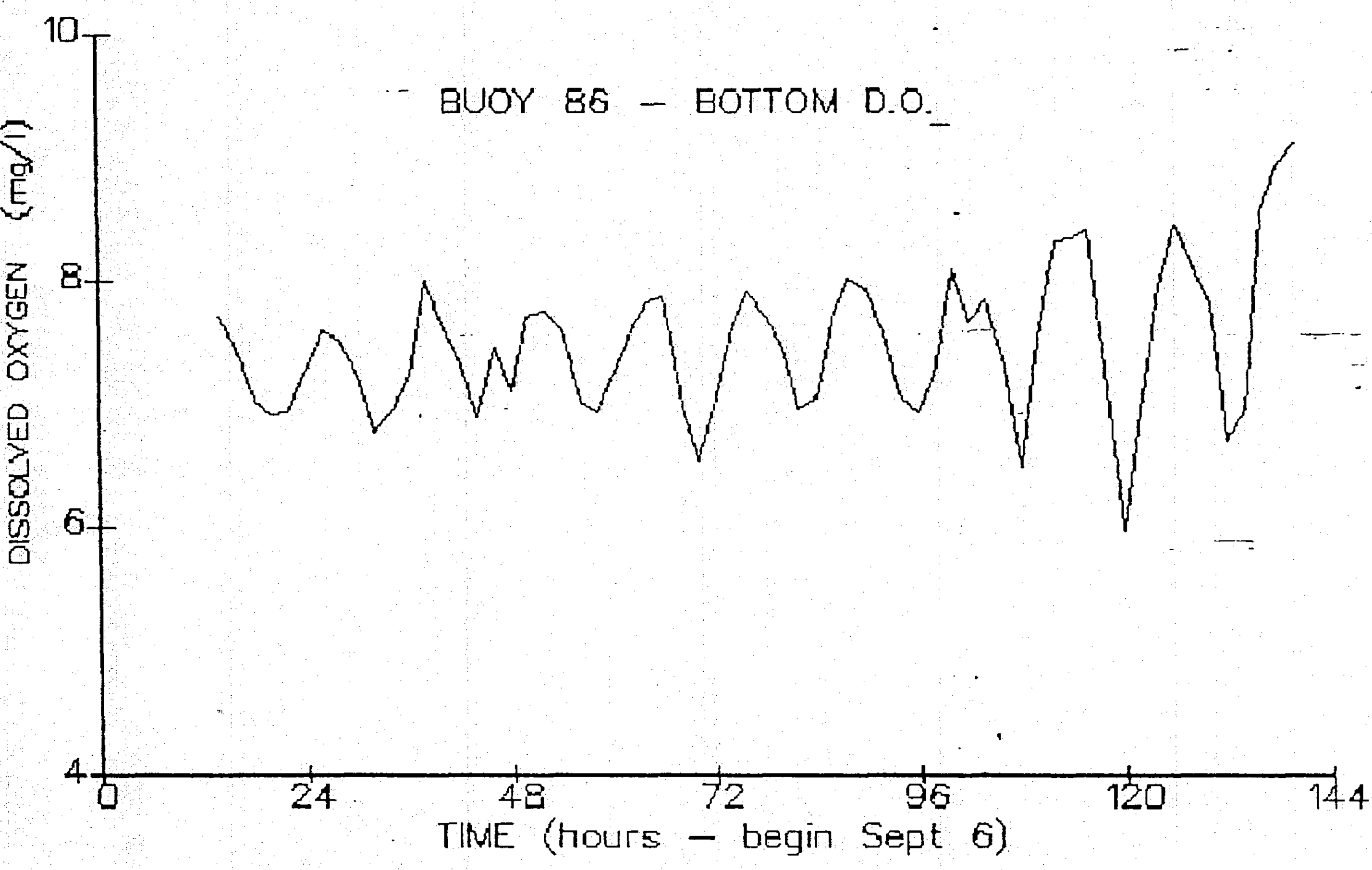

BUOY 98 — BOTTOM D.O.
DISSOLVED OXYGEN (mg/l)
10
8
6
4
0
24
48
72
96
TIME (hours — begins Aug 21)


BUOY 107 — BOTTOM D.O.
DISSOLVED OXYGEN (mg/l)
10
8
6
4
0
24
48
72
96
TIME (hours — begins Aug 21)

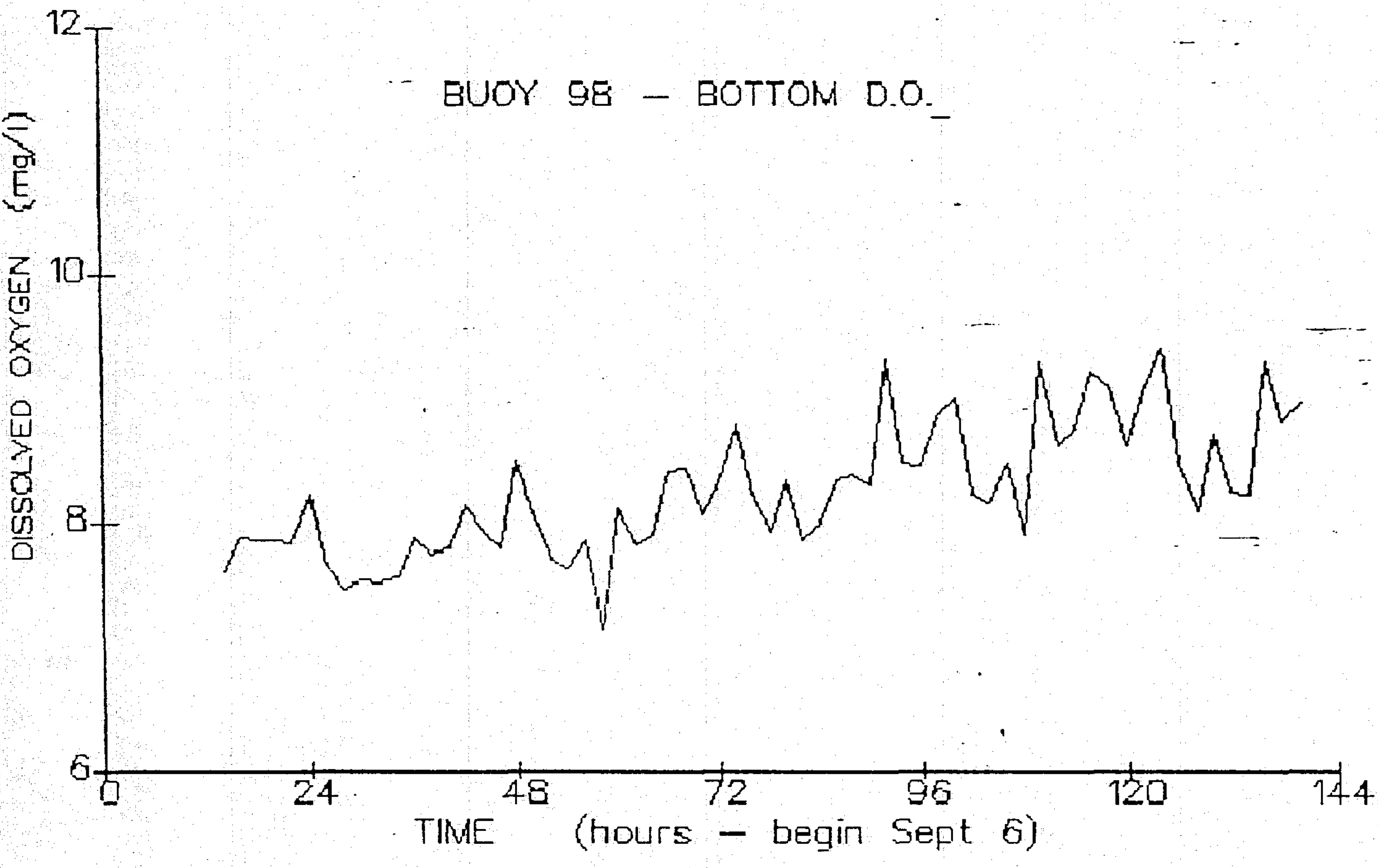

BUOY 69 — BOTTOM D.O.
DISSOLVED OXYGEN (mg/l)
10
8
6
4
0
24
48
72
96
120
144
TIME (hours — begin Sept 6)

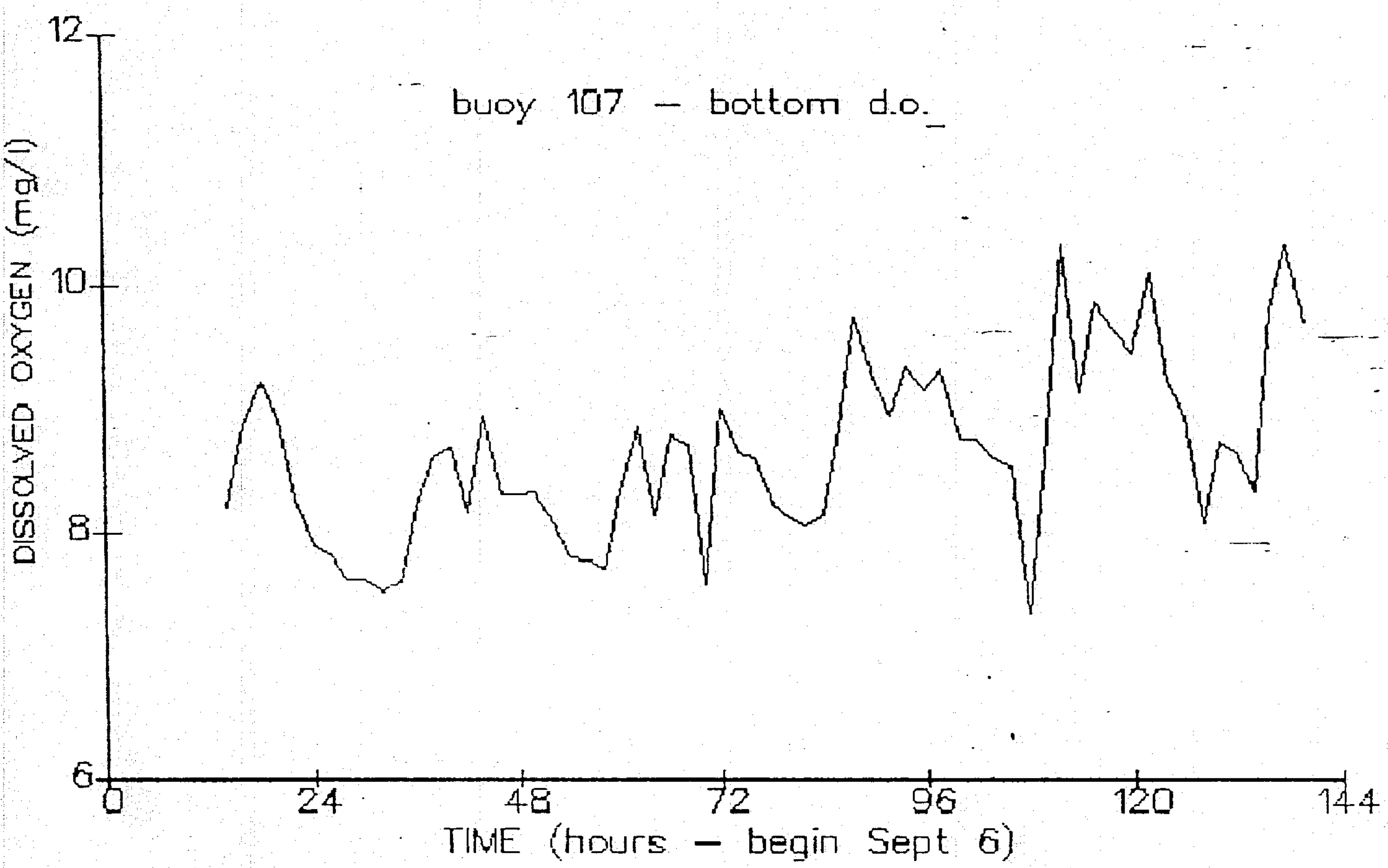

BUOY 74 — BOTTOM D.O.
DISSOLVED OXYGEN (mg/l)
10
8
6
4
0
24
48
72
96
120
144
TIME (hours — begin Sept 6)


BUOY 76 — BOTTOM D.O.
DISSOLVED OXYGEN (mg/l)
10
8
6
4
0
24
48
72
96
120
144
TIME (hours — begin Sept 6)



BUOY 86 — BOTTOM D.O.
DISSOLVED OXYGEN (mg/l)
10
8
6
4
0
24
48
72
96
120
144
TIME (hours — begin Sept 6)


BUOY 98 — BOTTOM D.O.
DISSOLVED OXYGEN (mg/l)
12
10
8
6
0
24
48
72
96
120
144
TIME (hours — begin Sept 6)


buoy 107 — bottom d.o.
DISSOLVED OXYGEN (mg/l)
12
10
8
6
0
24
48
72
96
120
144
TIME (hours — begin Sept 6)

DATE DUE

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