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Hydrography and Hydrodynamics of Virgina Estuaries XV: Mathematical Model Studies of Water Quality of the Nansemond Estuary

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HYDROGRAPHY AND HYDRODYNAMICS OF VIRGINIA ESTUARIES

XV. Mathematical Model Studies of Water Quality of the Nansemond Estuary

by

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ABSTRACT

In Summer, 1974, an intensive field survey was conducted in the Nansemond River estuary from Suffolk to Pig Point. Temporal and spatial distributions of the parameters dissolved oxygen, salinity and temperature were obtained from the survey. Additional slack water runs were conducted in 1974 and 1975. The hydrographic and water quality data, combined with measured bathymetric profiles, were used to construct, calibrate and verify a one-dimensional, time-dependent mathematical model.

Modeling of the Nansemond River estuary is part of the continuing program of the Cooperative State Agencies (Virginia State Water Control Board and the Virginia Institute of Marine Science) to develop water quality models of Virginia's estuaries. The Nansemond River is located 14.5 kilometers (9 statute miles) from the mouth of the James River. The river receives industrial and domestic wastes from packing plants, sewage treatment plants, and housing developments. In the river reach around Suffolk, low values of dissolved oxygen (less than 4 mg/l) have been observed. The implicit numerical mathematical model predicts the intra-tidal distribution of dissolved oxygen, biochemical oxygen demand, and salinity. The model accurately predicts the region of low dissolved oxygen.

I. SUMMARY AND CONCLUSIONS

1. The Nansemond River drainage basin is small, fairly level, and low lying. The runoff from 63% of the drainage basin is impounded by a series of domestic water supply reservoirs. During the dry season, (there is no water discharged over the reservoir spillways) and the freshwater input to the river is reduced to a minimum. Tidal flushing is the principal mechanism which serves to flush the pollutants introduced into the river.

2. Development along the river is centered around its head and mouth. Meat packing is the major industry of the area. The Suffolk sewage treatment plant, located at the head of the river, is the major point source of pollutants.

3. An intensive field survey was carried out in August, 1974. Time series data on salinity, temperature and dissolved oxygen (DO) were collected at eight anchor stations. Current measurements were made at four anchor stations along the channel. Additional slack water runs were conducted in 1974 and 1975, salinity, temperature, dissolved oxygen and biochemical oxygen demand were measured at the surface and bottom at stations along the river.

4. Tidal action in the Nansemond River is strong, with the amplitude of cross-sectional average tidal currents as high as 0.61 m/sec (2 ft/sec) at some transects. The tidal amplitude increases from 0.42 m (1.4 ft) at the mouth to 0.58 m (1.9 ft) at the head.

5. During the dry season, little vertical stratification in salinity was observed. The river may be classified as a sectional homogeneous estuary. The salinity intrudes all the way to the fall line near Suffolk.

6. A critical oxygen sag has been observed in the vicinity of Suffolk with average dissolved oxygen values less than 4 mg/l and instantaneous values falling frequently below 2 mg/l.

7. Field data indicate that algal bloom is a potential water quality problem in the upper reach of the river.

8. A mathematical model of water quality was developed for the Nansemond River. The model is a real time model with implicit finite difference scheme. The variables modeled are salinity, dissolved oxygen, nitrogenous and carbonaceous biochemical oxygen demand. The model adequately reproduces the DO sag near Suffolk.

II. INTRODUCTION

The Cooperative State Agencies (CSA) program is a continuing joint project of the Virginia State Water Control Board and the Virginia Institute of Marine Science. The program is conducted to monitor water quality and develop water quality models of Virginia's estuaries. In addition to the major estuarine rivers, the CSA program also encompasses the small tributaries and coastal basins where there are actual or potential water quality problems. The Nansemond River (figures 1 and 2) is an estuary that exhibits water quality problems.

The Nansemond River is located towards the mouth of the James River in a developing area. There are currently domestic and industrial wastes being loaded into the estuary. A series of reservoirs around the Nansemond hold much of the freshwater runoff. Because of the control of the freshwater input into the Nansemond, there are pronounced seasonal changes in the salinity and dissolved oxygen distributions that are important for the water quality of the Nansemond. A modeling study of the river should render useful information on the distribution of these parameters and give insight into the capability of the Nansemond to handle waste loadings and development.

This report summarizes the hydrographic data, method of data collection, the model itself and the results of the model study. The model reported on herein is a real-time, one-dimensional, intra-tidal model of dissolved oxygen,

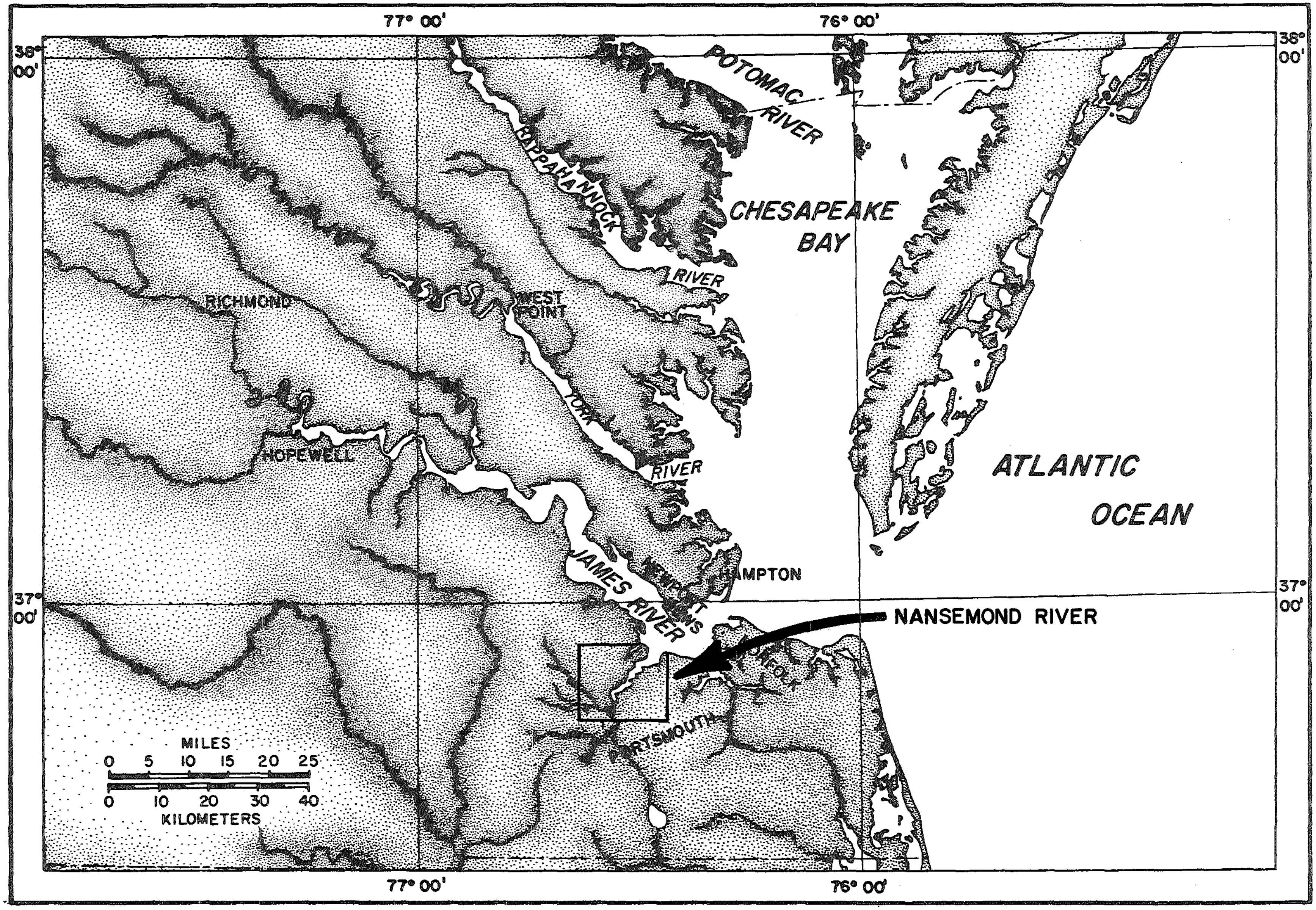

Figure 1. Map showing location of the Nansemond River.

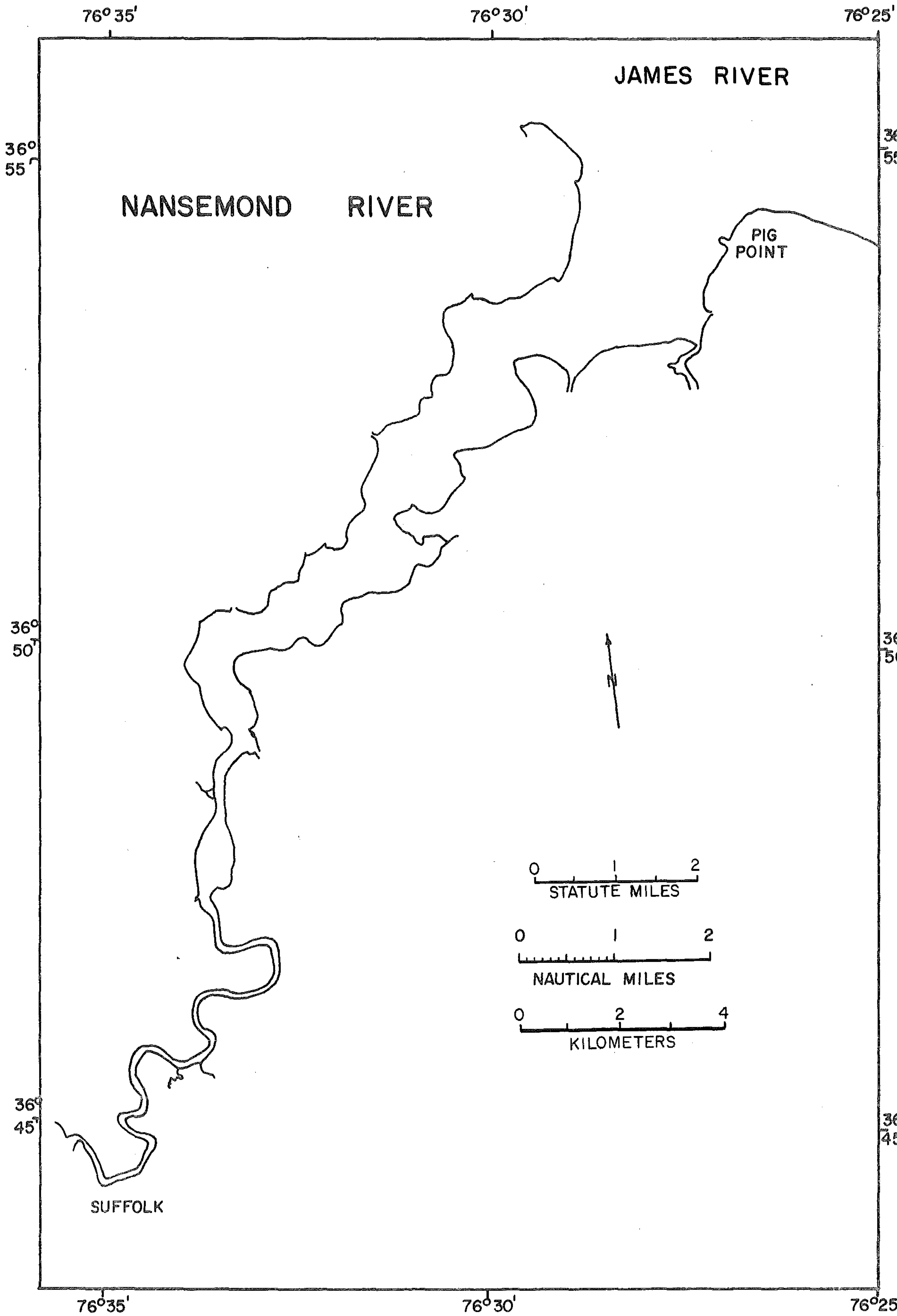

Figure 2. The Nansemond River estuary of Virginia.

carbonaceous and nitrogenous biochemical oxygen demand, and salinity. The model is based upon an implicit integration scheme.

III. DESCRIPTION OF STUDY AREA

The Nansemond River is a tributary of the James River estuary located on the south bank near the mouth (see figures 1 and 2). The river rapidly converges from its mouth to a narrow sinuous channel that is bordered by marshes. The drainage basin is small, fairly level and low lying. Of the total drainage area of 507 km^2 (195 mi^2), only 185.6 km^2 (71.4 mi^2) drains directly into the river. The freshwater runoff from the rest of the drainage basin is controlled by a series of domestic water supply reservoirs. The reservoirs above head water on the main stream impounds 161 km^2 (62 mi^2) of drainage area, while those on the Western Branch impound 160 km^2 (61.6 mi^2) (S.E.P.P.). The water withdrawn from these impoundments is utilized by the cities of Suffolk, Portsmouth, Norfolk and Virginia Beach, and all but a small percentage is discharged as wastewater into other water sheds.

The climate is humid subtropical. Solar radiation is an important factor in the seasonal regimes of the river. During the summer there is extensive warming of the river corresponding with low freshwater input due to evapotranspiration and reservoir control. This results in greater vertical homogeneity and higher salinity in the river. The salt water intrudes all the way to the head of the river. At the opposite end of the hydrologic cycle, the heavy spring rains result in great freshwater inflow from the land drainage and reservoir discharge. The net result is a more stratified river with lower salinity. The upper portion of the river becomes a freshwater tidal river.

Because of the reflection at the head of the river, the tidal wave has mixed characteristics of both progressive wave and standing wave. The tidal range increases from 0.85 m (2.8 ft) at the mouth to 1.16 m (3.8 ft) at the head, partially due to the superposition of reflected wave and partially due to the convergence of the cross-section. The tidal phase has a lag of about one hour between the head and mouth of the river. Tidal current has an amplitude of about 0.5 m/sec (1.5 ft/sec) throughout most part of the river.

Development along the river is centered around the city of Suffolk and Pig Point. Suffolk is the major town on the river and is located at the head. Meat packing plants are the major industries of the area. The major point source of waste water is the Suffolk Sewage Treatment Plant, with five other point sources in the vicinity of Suffolk. Since the major point sources are located at the head of the river, the resulting flushing of the waste materials is far from satisfactory. Dissolved oxygen concentrations have been observed to be less than 4 mg/l in the summer.

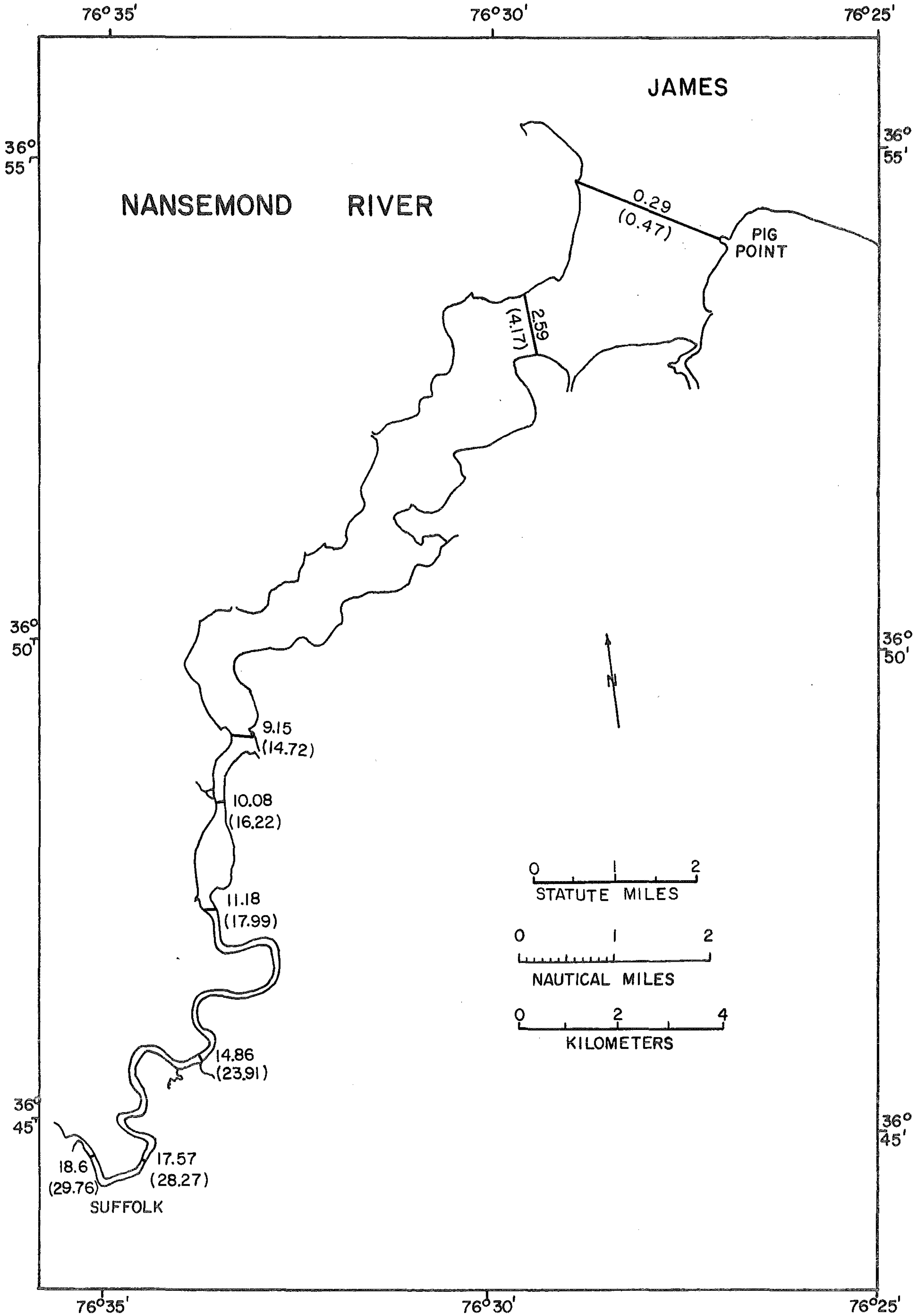

Figure 3. Location of intensive field survey stations. The numbers indicate the distance from mouth in statute miles (kilometers).

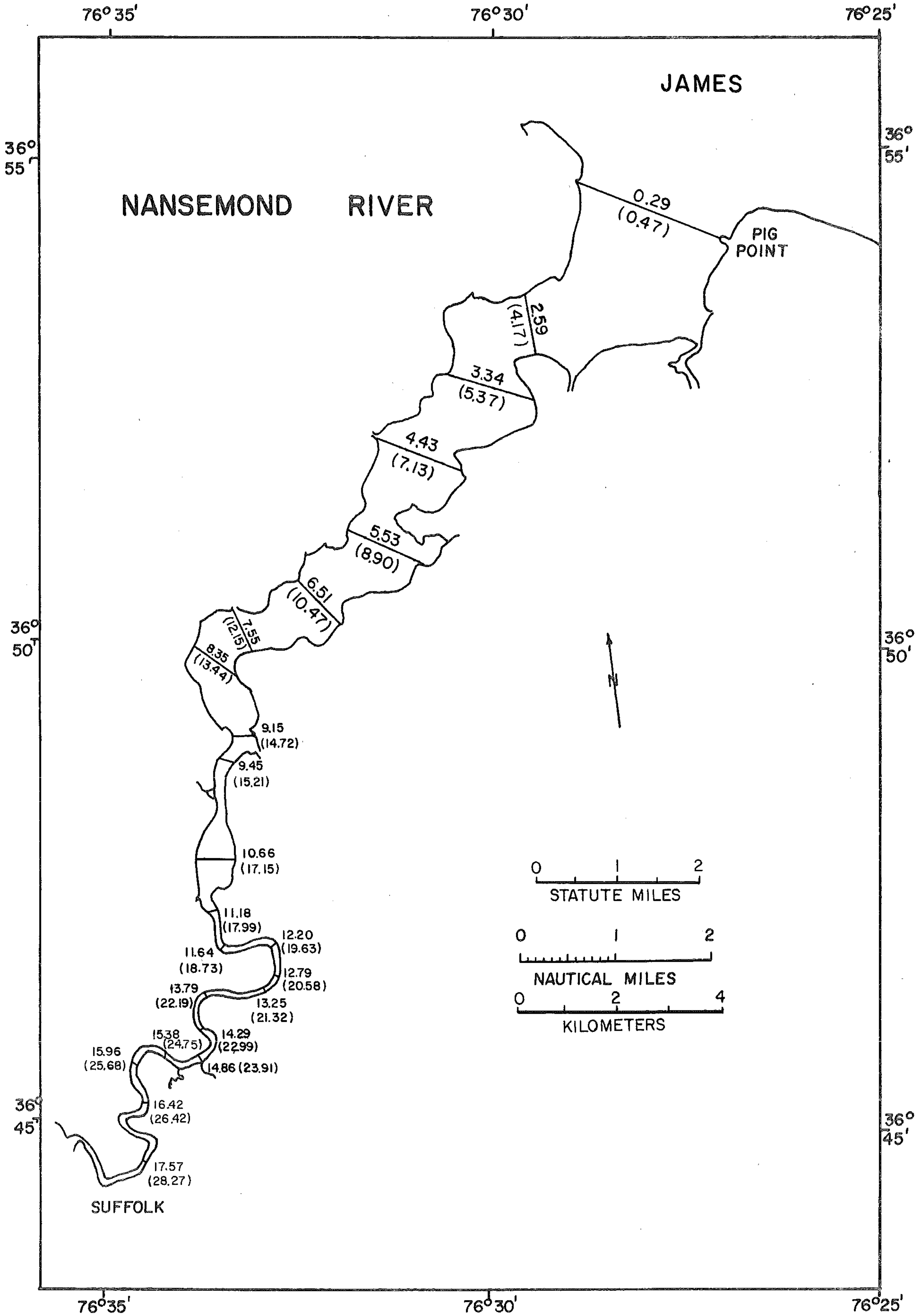

Figure 4. Location of bathymetric profile stations. The numbers indicate the distance from mouth in statute miles (kilometers).

IV. HYDROGRAPHIC SURVEY

1. Description of Field Survey

To provide the necessary data for the calibration and verification of the mathematical model, a number of field surveys were conducted. In August 1974, an intensive survey was conducted when eight transects were occupied between Pig Point and Suffolk. Twenty-three bathymetric profiles were taken to provide geometrical input for the model in the spring of 1976. The locations of the transects for the intensive field survey and bathymetric profiles, respectively, are shown in Figures 3 and 4.

The eight intensive survey stations were occupied at hourly intervals for 13 hours during the daylight period for two successive days. Stations JN4 and JN7, located at miles 10.08 and 17.57, respectively, were continuously occupied and sampled at hourly intervals for 36 hours. Conductivity and temperature measurements and dissolved oxygen samples were taken at 2 meter intervals from surface to bottom. Concurrently, current meters were in place at 4 locations (kilometer 0.47, 4.17, 16.22 and 29.76 or mile 0.29, 2.59, 10.08, and 18.60) in vertical strings taking twenty minute averages of water speed and direction.

Slack water runs were made 12 times during 1974 for the lower reaches of the river. The 5 stations occupied were sampled for dissolved oxygen, temperature and conductivity measurements in all the studies. CBOD and NBOD measurements were also made in the first nine slack water studies. During

1975, slack water runs were made at 13 stations. Salinity, temperature, dissolved oxygen and BOD were measured in these slack water runs.

2. Instruments and Analyses

Dissolved oxygen samples were collected with a Frautschy bottle and stored in 125 ml glass sample bottles. The samples were "pickled" in the field, and the dissolved oxygen concentration determined later in the laboratory by means of titration using the Winkler Method (Azide modification). The accuracy of this method is 0.1 mg/l. Biochemical oxygen demand (BOD) samples were collected in Fratschy bottles and transferred to 500 ml dark bottles. The samples were stored on ice and then incubated for 5 days at 20°C. They were then analyzed for the DO content using the modified Winkler method to determine the carbonaceous BOD.

Temperature and conductivity were measured in the field by use of an Inter Ocean Model 513 CTD. Temperature is accurate to 0.1°C; salinity is accurate to 0.1 parts per thousand (ppt). Salinity was calculated from conductivity and temperature according to a regression formula based on laboratory calibration. During the intensive surveys, salinity samples were taken every 3 hours and stored in 125 ml sample bottles. These were analyzed in the laboratory using a Beckman RS-7A salinometer. This was done for quality control of the temperature and conductivity measurements.

Cross-sectional areas were determined by planimetry of the bottom profile data and adjusted to mean water level.

Channel widths were determined from the bathymetric survey and Geological Survey 25 minute quadrangles. The reach lengths were found from Coast and Geodetic Survey navigation charts. The Raytheon Model RE719 fathometer was used for bottom profiling. The accuracy of the depth sounding is 15 cm (0.5 ft).

3. Results and Discussion

The water quality and current meter data were compiled, edited, keypunched and stored in the VIMS data file on a magnetic disk. The water quality data are summarized in Appendix A.

The Nansemond River is a well-mixed estuary during the dry seasons. This is shown by the salinity data for the intensive survey period (see Appendix A). At stations near the river mouth, there is some degree of stratification imposed by the salinity structure in the James. The vertical variation of salinity decreases upstream due to the tidal mixing in the river. The data show that the river reach upstream of kilometer 22.5 (mile 14) is essentially homogeneous. The temporal variation in salinity is large and exhibits a tidal periodicity. The extent of salt intrusion is highly dependent on the seasonal hydrologic cycle as shown by the reduced salinities during the slack water run of March, 1975, representing a period of high freshwater runoff. The extent of the oligohaline waters has retreated out of the mouth of the river.

Both the 1974 intensive survey data and the March 1975 slack water run data show a distinctive DO sag at or downstream of Suffolk (Figures 9 and 10). The average (both vertical and temporal average) dissolved oxygen fell below 4 mg/l at kilometer 28.3 (mile 17.6) in August 1974. The dissolved oxygen data of the intensive survey exhibit large vertical and temporal variations in the upper reach where the salinity data have the least variations. The maximum DO stratification occurs during the afternoon hours when the surface DO reaches its maximum value of the day and supersaturation occurs. A possible reason for the large temporal variation, high stratification add supersaturation is the existence of high algal concentrations, which might be the result of nutrient enrichment by the waste discharge. In fact, a planned dye dispersion study was called off because of the high background fluorescent level measured in the river prior to the intensive survey. The background fluorescent level detected was much higher in the upper reaches than in the lower reaches of the river. In the lower reaches of the river, the temporal and spatial variations of dissolved oxygen are much smaller.

The importance of the seasonal hydrologic cycle is shown by the slack water run of March 1975. The consistently higher dissolved oxygen values are representative of the colder water during that period. The higher dissolved oxygen concentrations are also influenced by the large freshwater inflow, resulting in better flushing of the river. The rainy cold period also means that the productivity of the Nansemond River is decreased such that the oxygen demand is lower, therefore, the waters are oxygen rich (Brehmer, et al., 1967).

The cross-sectional profiles obtained from the bathymetric survey are shown in Appendix B. The profiles were constructed from the bathymetric data (Figure 4 shows these bathymetric stations) and plotted on a Hewlett Packard Calculator 9810A after the data was corrected to mean tide level according to the tide tables and time of sounding. Longitudinal distance from the mouth of the river was determined from a National Ocean Survey (NOS) navigation chart.

V. MATHEMATICAL MODEL STUDY

A one-dimensional water quality model was applied to the Nansemond River. This model was developed under the CSA program and has been used to investigate the water quality in other Virginia estuaries. The model is a real-time, intra-tidal model representing the parameters salinity, dissolved oxygen, and carbonaceous and nitrogenous biochemical oxygen demand. The model is based on the conservation of a dissolved or suspended substance in a water body. The equation for mass balance is solved for different segments of the river where a concentration of a substance is described by an average value in the volume element. A complete description of the model with uses and application is presented in detail by Kuo, et al. (1975).

1. Segmentation of the River

The Nansemond River was divided into 34 reaches with 35 transects (Figure 5). The transects for the first 4.83 km (3 mi) of the river (upstream of kilometer 24.7 or mile 15.35) were located 0.4 km (0.25 mi) apart, the transects from kilometer 24.7 (mile 15.35) to kilometer 15.86 (mile 9.85) were located 0.8 km (0.5 mi) apart and the transects in the lower reaches were located 1.61 km (1.0 mi) apart (Figure 5). The geometric parameters were obtained through interpolating the bathymetric profiles to smooth the data. Cross-sectional area of the transects as a function of distance from the river mouth are shown in Figure 6. The direct drainage area (excluding impounded area) used for calculating lateral

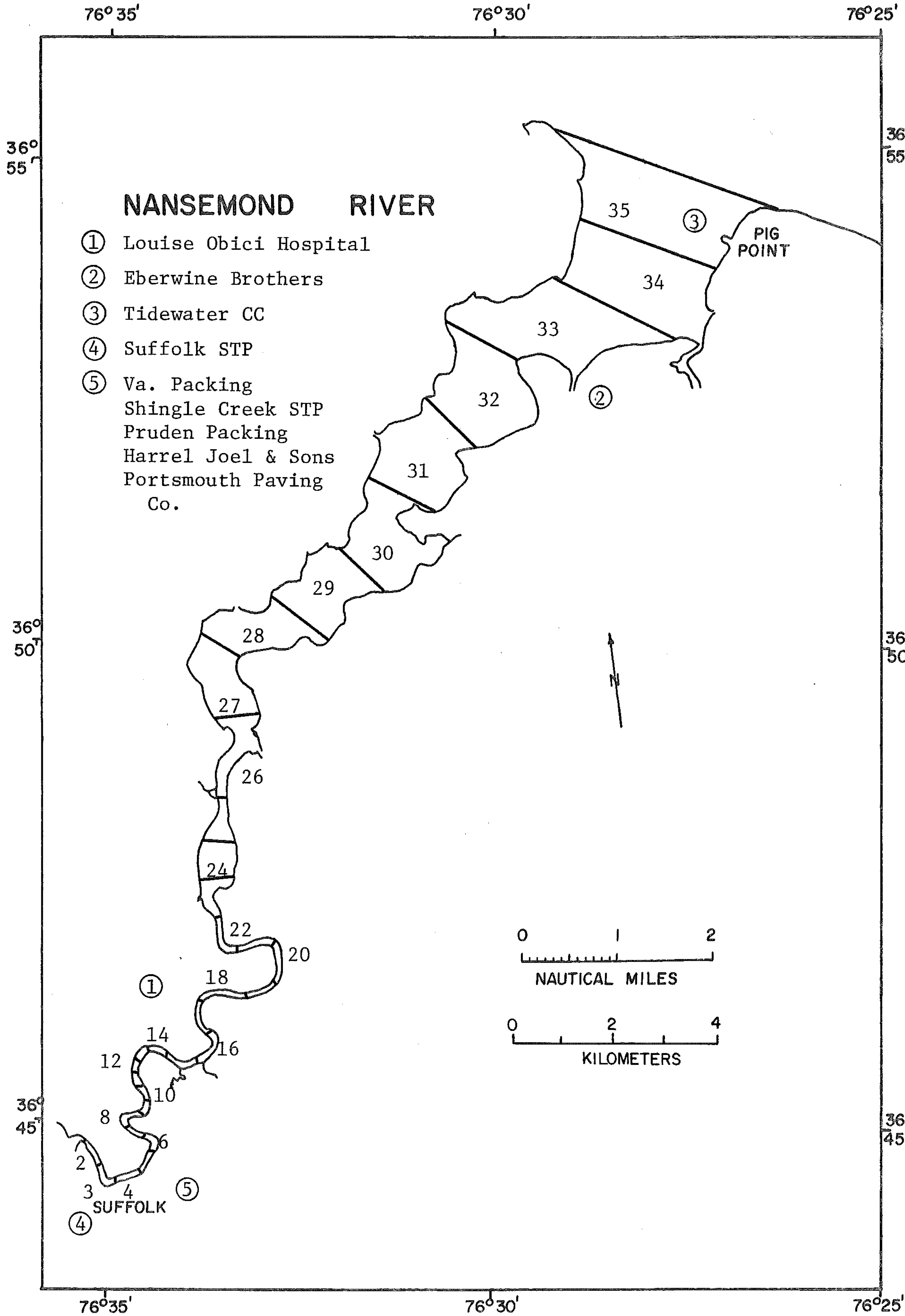

Figure 5. Location of model reaches and point sources of the Nansemond River.

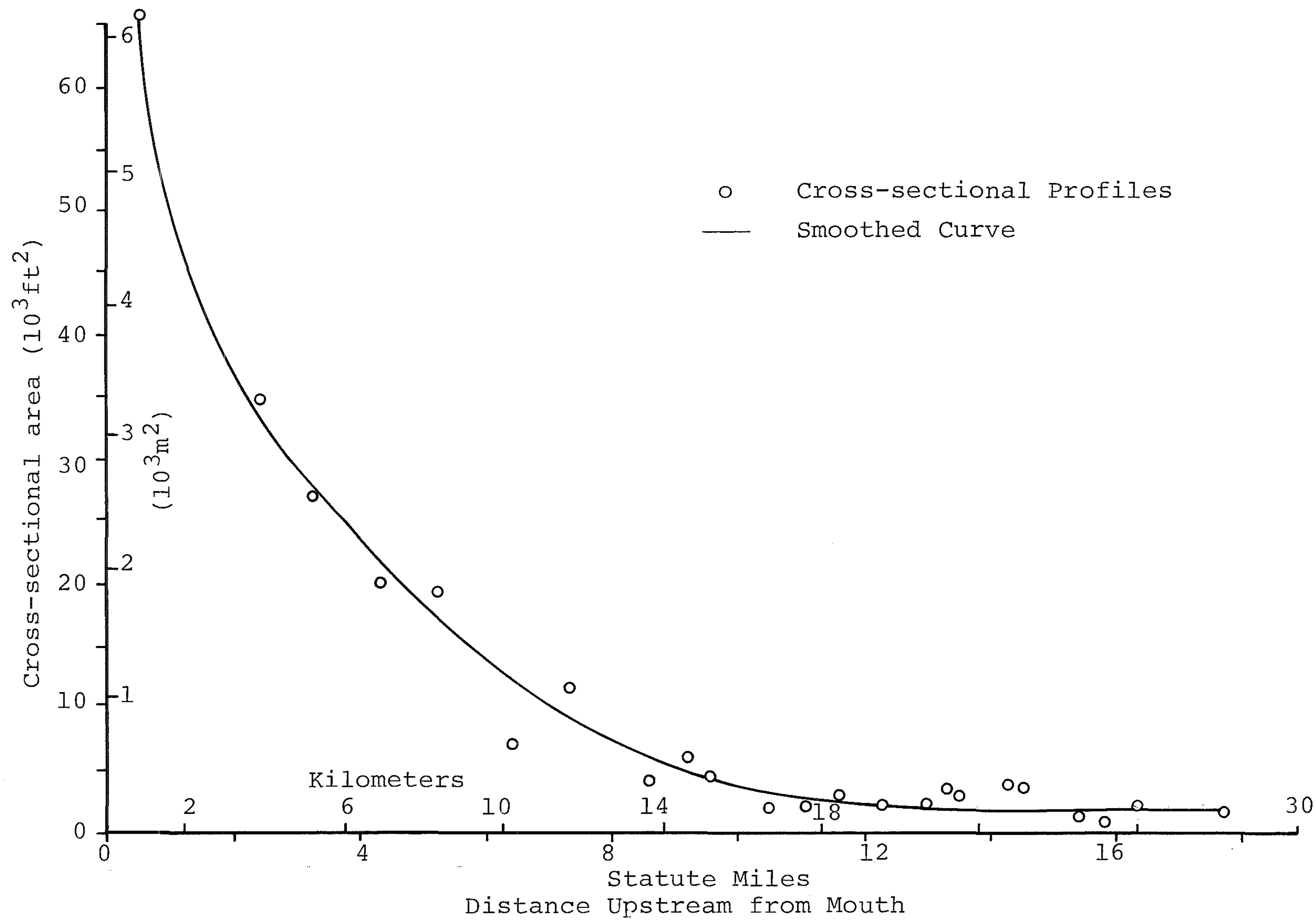

Figure 6. Cross-sectional areas versus distance along the river (1 statute mile = 1.61 kilometers).

freshwater input in the model is represented as accumulated drainage area versus distance from mouth in Figure 7.

2. Point Sources of Pollutants

There are seven point sources discharging into the Nahsemond River (Figure 5). These are listed in Table 1 with relevant data. Harrel Joel and Sons and Portsmouth Paving now, respectively, are discharging into the Shingle Creek STP and stopped discharging as of June 1975. Future water quality tests should include this aspect by the elimination of these two industrial point sources from the model. Kennedy High School was not considered because its seasonal discharge rate did not affect the ambient dissolved oxygen concentration at critical times in the summer. The model reach number indicates the reach into which the sources discharge in the numerical segmentation of the river. The locations of these discharges are shown in Figure 5.

All data for the discharge rates for the period April 1974 to June 1975 were obtained through the State Water Control Board in the municipal and industrial waste sections. The most important source of BOD_5 is from the Suffolk STP. A high of 1068 mg/l was discharged in April 1974. The waste water from all point sources are assumed to be of the characteristics of the primary treated sewage effluent. The CBOD concentration is assumed to be 1.5 times the BOD_5 concentration, and NBOD concentration is assumed to be 1.21 times the CBOD concentration.

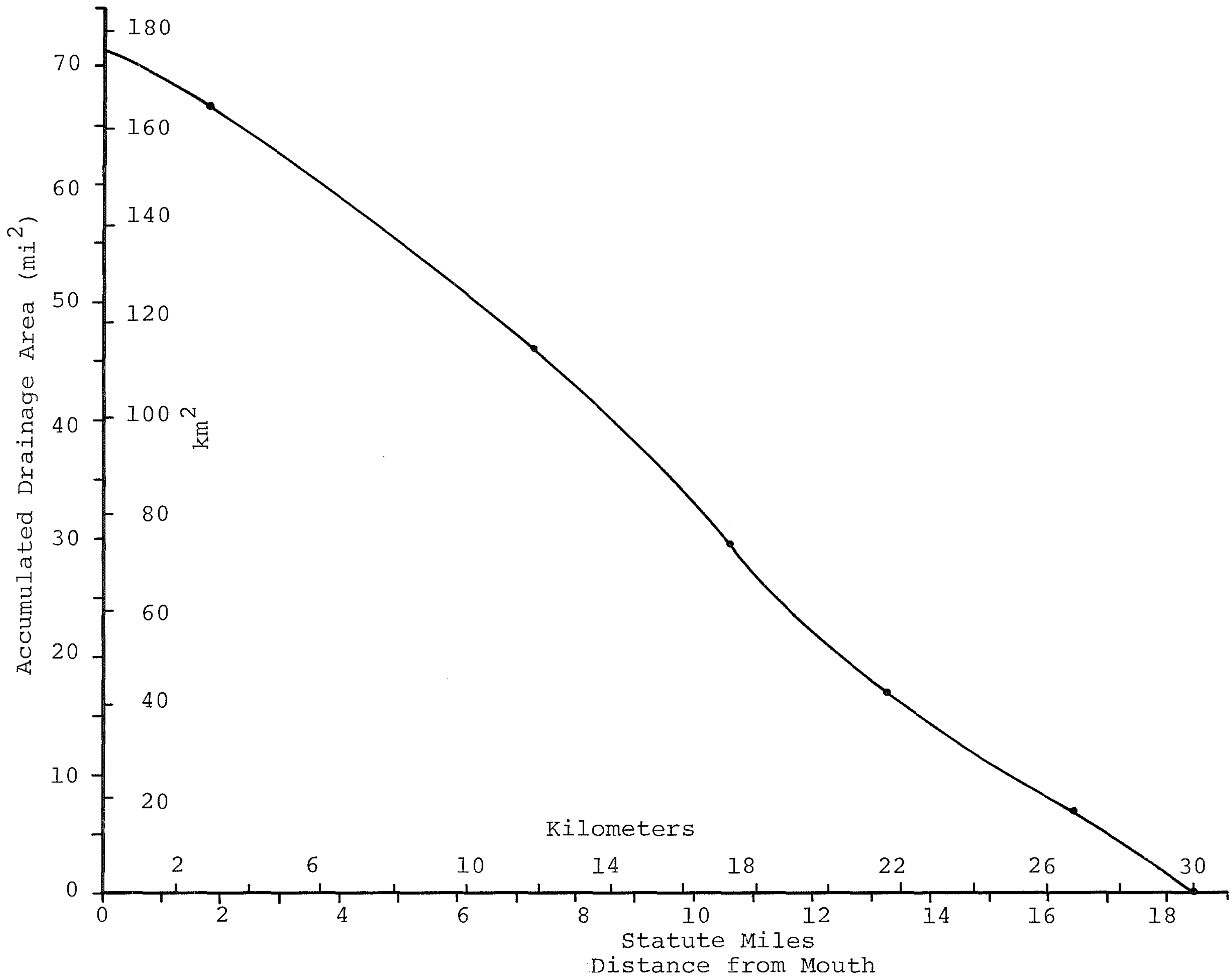

Figure 7. Accumulated drainage area versus distance along the river (1 statute mile = 1.61 kilometers).

Table 1. Major Point Sources

Source	Distance from River Mouth	Model Reach Number	Flow Rate (MDG)	Waste Discharge Rate Aug., 1974 BOD_5 (lbs/day)
Louise Obici Hospital	14.1	17	.086	21
Eberwine Brothers	2.6	33	.02	132
Tidewater Community College	.8	35	.043	5
Suffolk STP	18.1	3	.866	377
Va. Packing	17.7	5	.068	35
Pruden Packing	17.7	5	.0001	5
Shingle Creek STP	17.7	5	.17	9
Harrel Joel and Son[1]	17.7	5	.144	5
Portsmouth Paving[2]	17.7	5	.06	2

1 Now discharging in Shingle Creek STP.

2 Stopped discharging, June, 1975.

3. Model Calibration and Results

The freshwater runoff into the Nansemond River is primarily controlled by the flows over the spillways of the water supply reservoirs. The spillway overflows are transient events because they occur only during heavy rainfall. However, the only record existing for the spillway overflow is the total monthly discharge which is inadequate for the purpose of model simulation. Because of the lack of adequate freshwater runoff data, the salinity data were used to determine the freshwater discharge for each of the model simulations. Figures 8 and 9 show the comparisons of salinity data with model results after the freshwater discharges are properly adjusted.

Instead of calibrating the dispersion coefficient with salinity data, the empirical constant for the dispersion coefficient obtained from the Rappahannock River simulation (Kuo, et al., 1975) was adopted. Since the model results are rather insensitive to the dispersion coeffieicnt, the error introduced by the inaccuracy of the dispersion coefficient is negligible.

The CBOD and DO data collected on the slack water run of March 28, 1975 were used to calibrate the decay rates. No NBOD data were collected at this slack water run. The CDOD decay rate was determined to be 0.15 /day at 20°C by matching the model results with field data of CBOD distribution (figure 10). The NBOD decay rate was adjusted until the model predicted a DO distribution which agreed with field data (figure 11). The NBOD distribution predicted by the model is

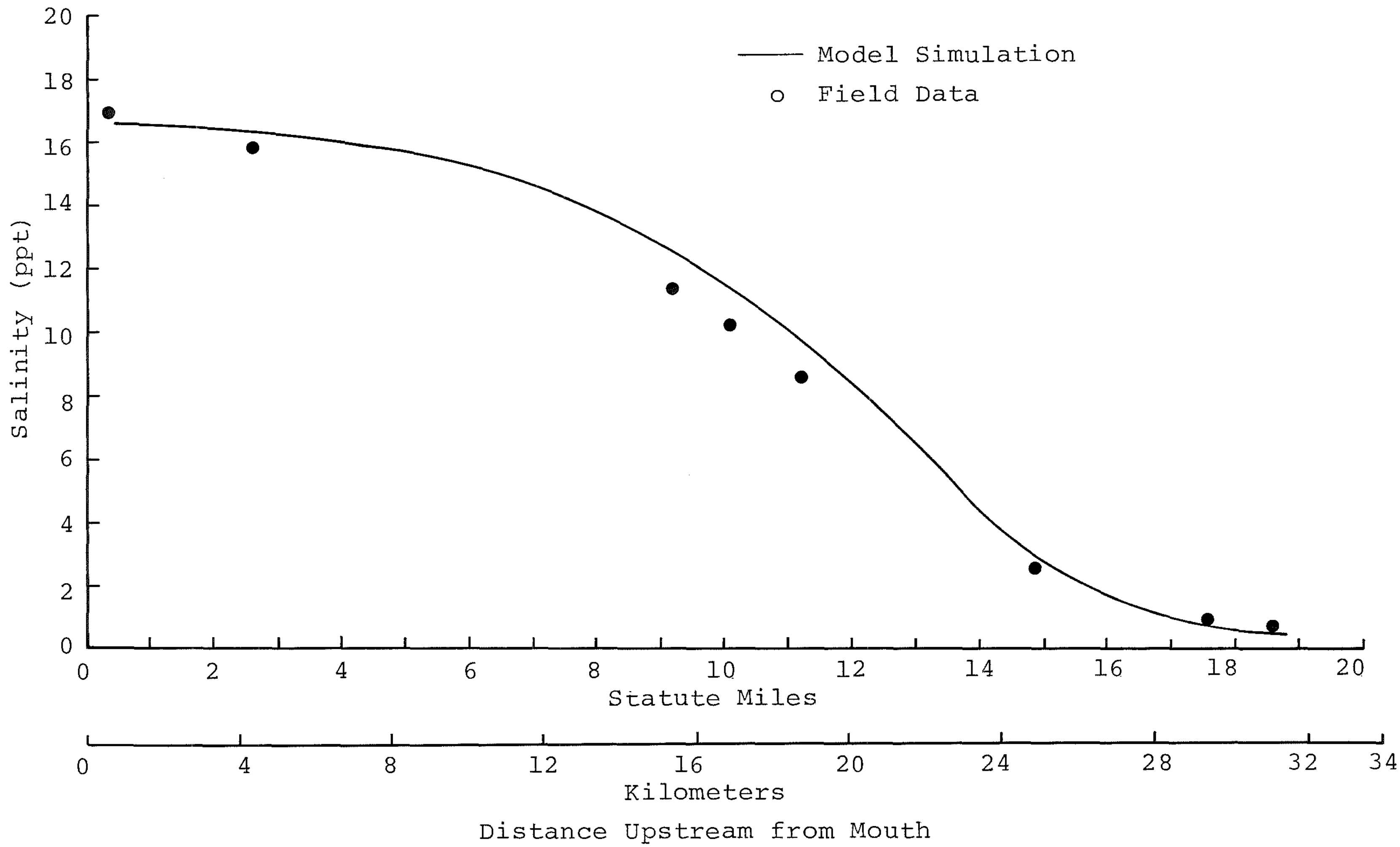

Figure 8. Longitudinal salinity distribution, August 14-15, 1974.

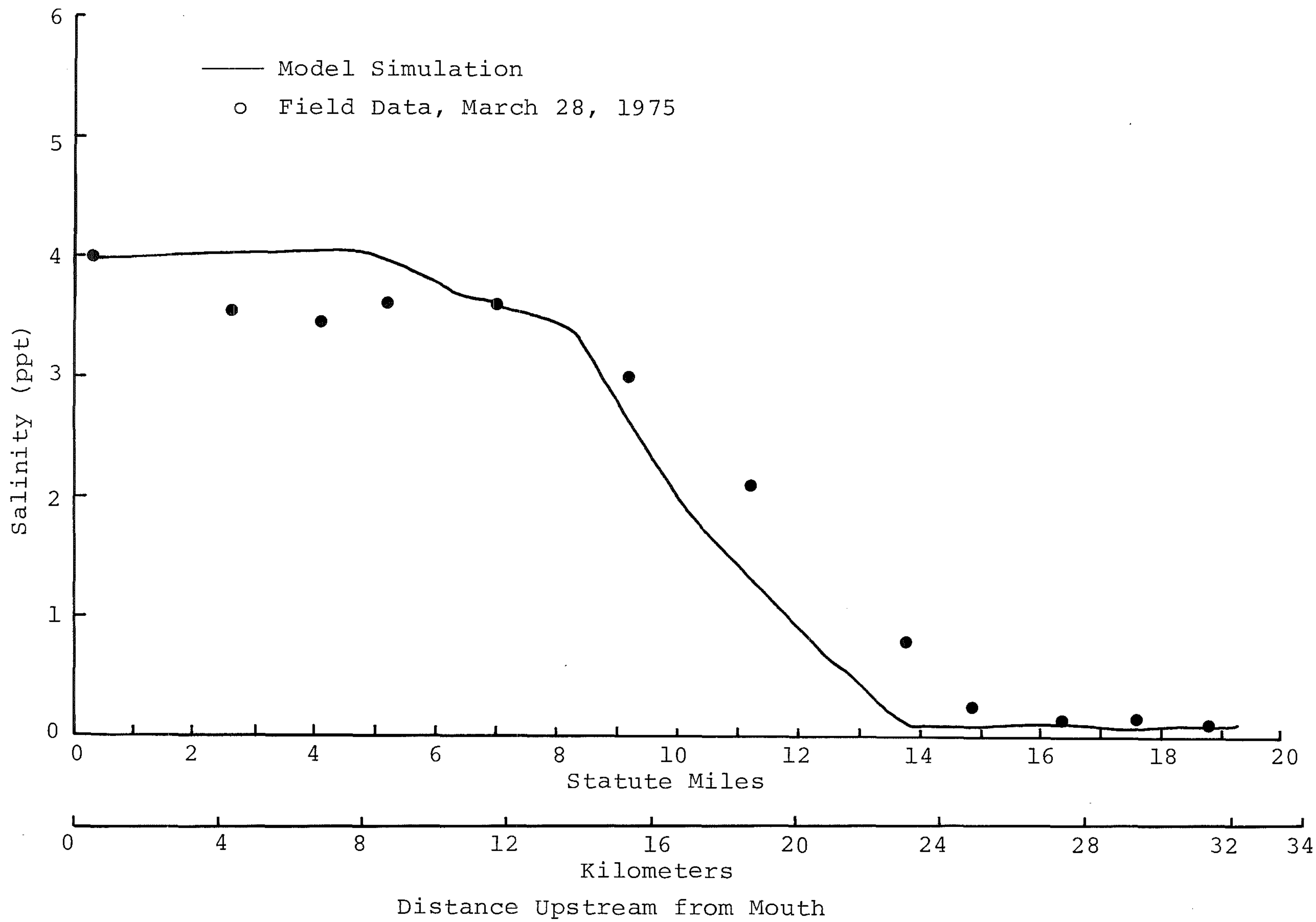

Figure 9. Longitudinal salinity distribution, March 28, 1975.

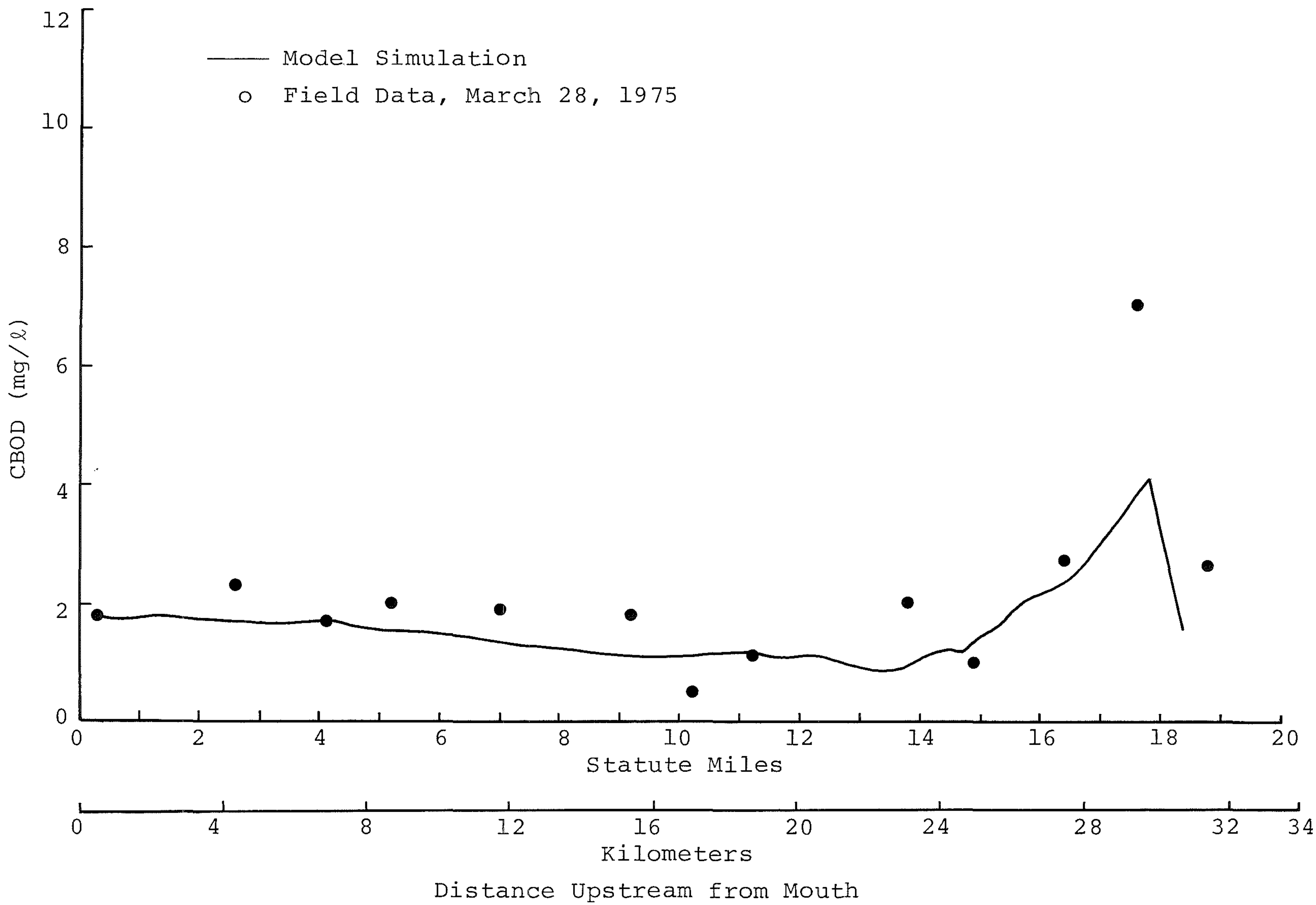

Figure 10. Longitudinal distribution of carbonaceous oxygen demand, March 28, 1975.

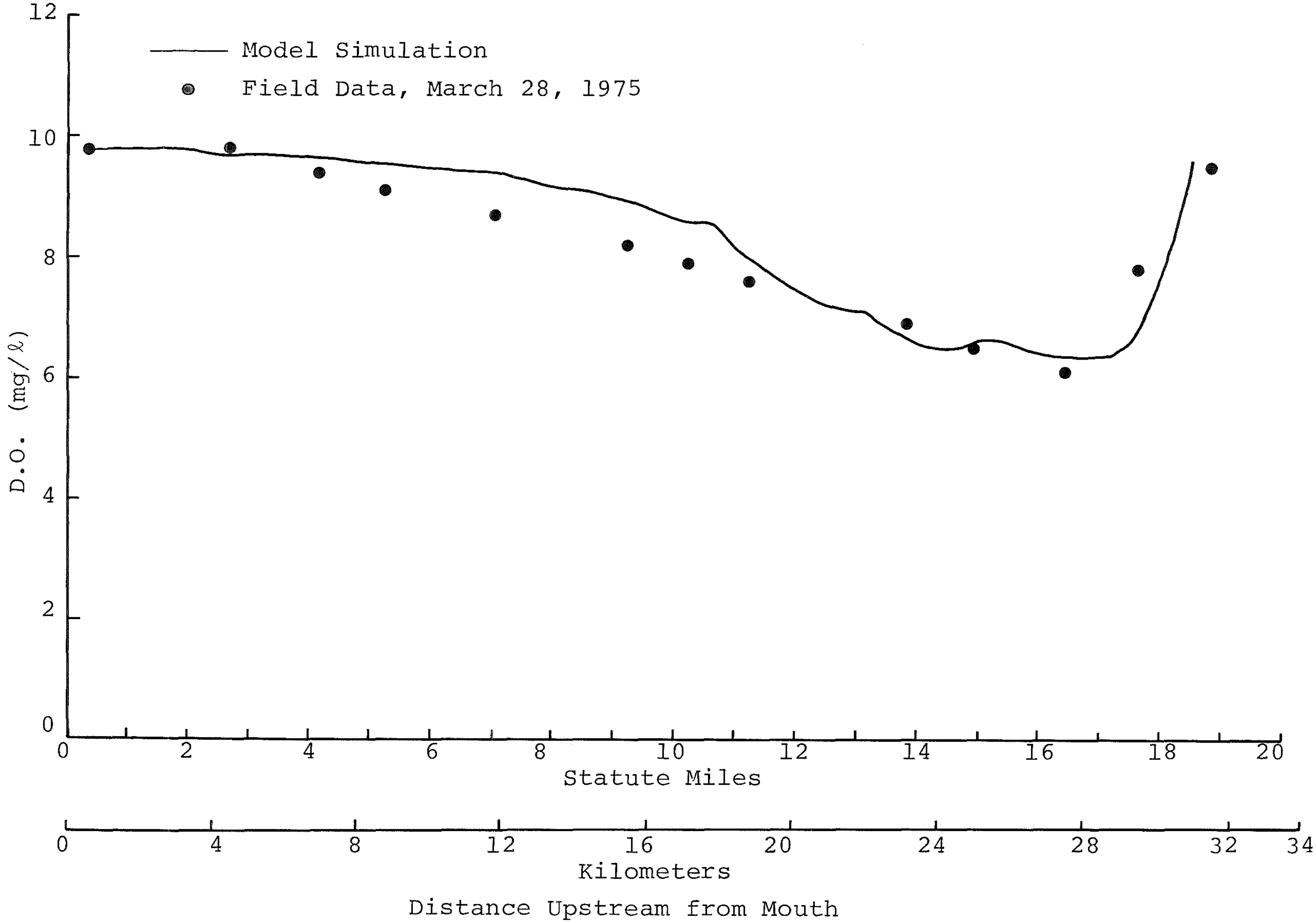

Figure 11. Longitudinal distribution of dissolved oxygen, March 28, 1975.

presented in figure 12. A decay rate of 0.08/day at 20°C was determined to be optimal. Figures 10 and 12 both show a peak concentration at kilometer 28.6 (mile 17.75) which clearly demonstrates the waste discharge from Suffolk Sewage Treatment Plant.

The DO data of August 1974 intensive survey were used to verify the model. With CBOD and NBOD decay rates unchanged, the model result is compared with field data in figure 13. Both figures 11 and 13 show a DO sag around or downstream of the Suffolk STP. The minimum DO of March 1975 is higher and located further downstream than that of August 1974 because of the lower temperature and higher freshwater discharge in March.

4. Sensitivity Analysis

Sensitivity analysis of the model is employed to demonstrate the effects of varying the input rate constants on model results. For each rate, a significantly higher and a significantly lower rate than the calibrated rate were substituted. All of the model runs simulated the March 1975 loading conditions that had been previously calibrated. Two sensitivity analyses were made by independently varying the CBOD and NBOD decay rates or the dispersion coefficient while maintaining all other input data unchanged.

The effects of different BOD decay rates on simulated CBOD, NBOD and DO profiles are shown in figures 14, 15 and 16, respectively. Figure 16 illustrates the effect of different decay rates on the dissolved oxygen distribution.

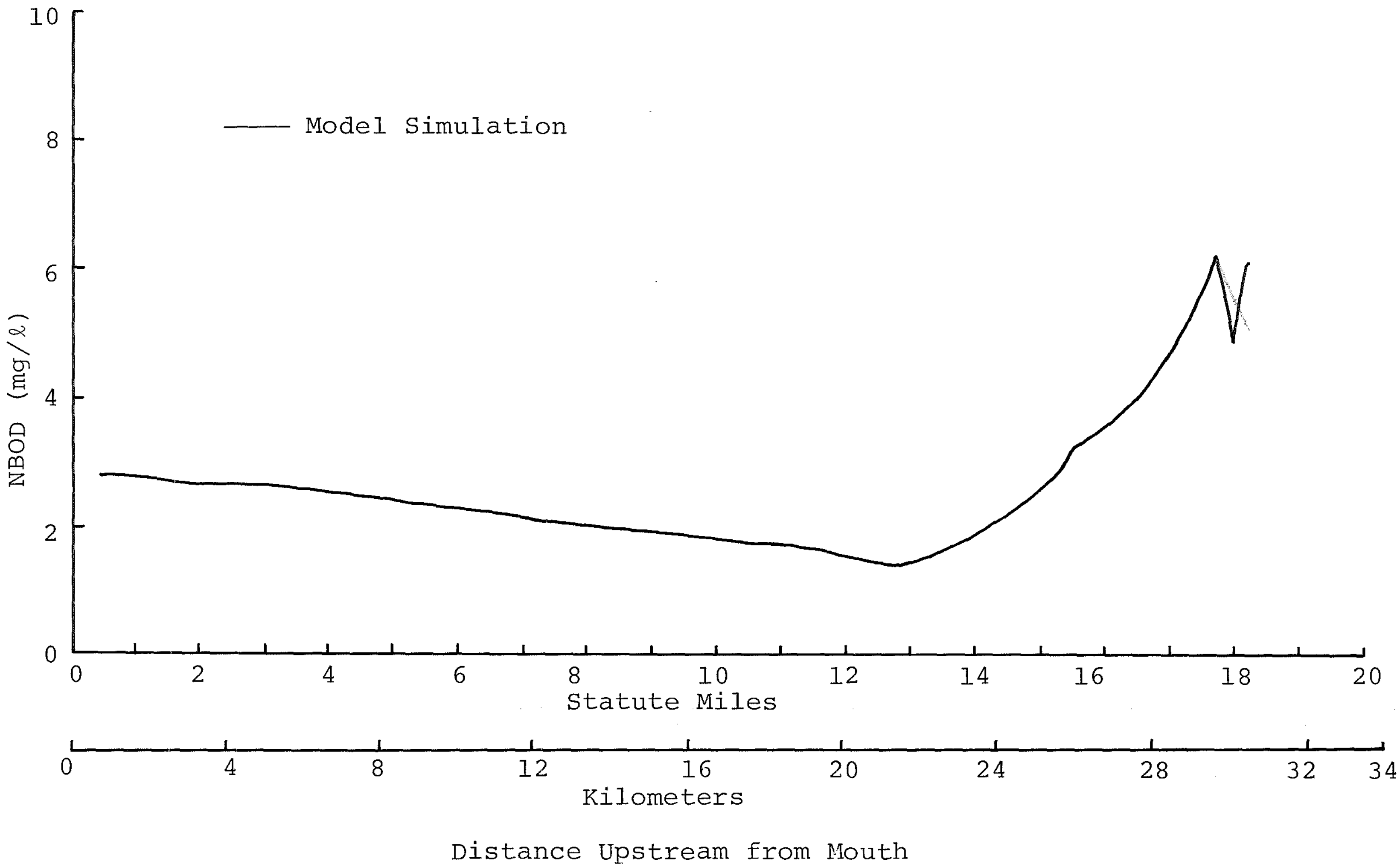

Figure 12. Longitudinal distribution of nitrogenous oxygen demand, March 28, 1975.

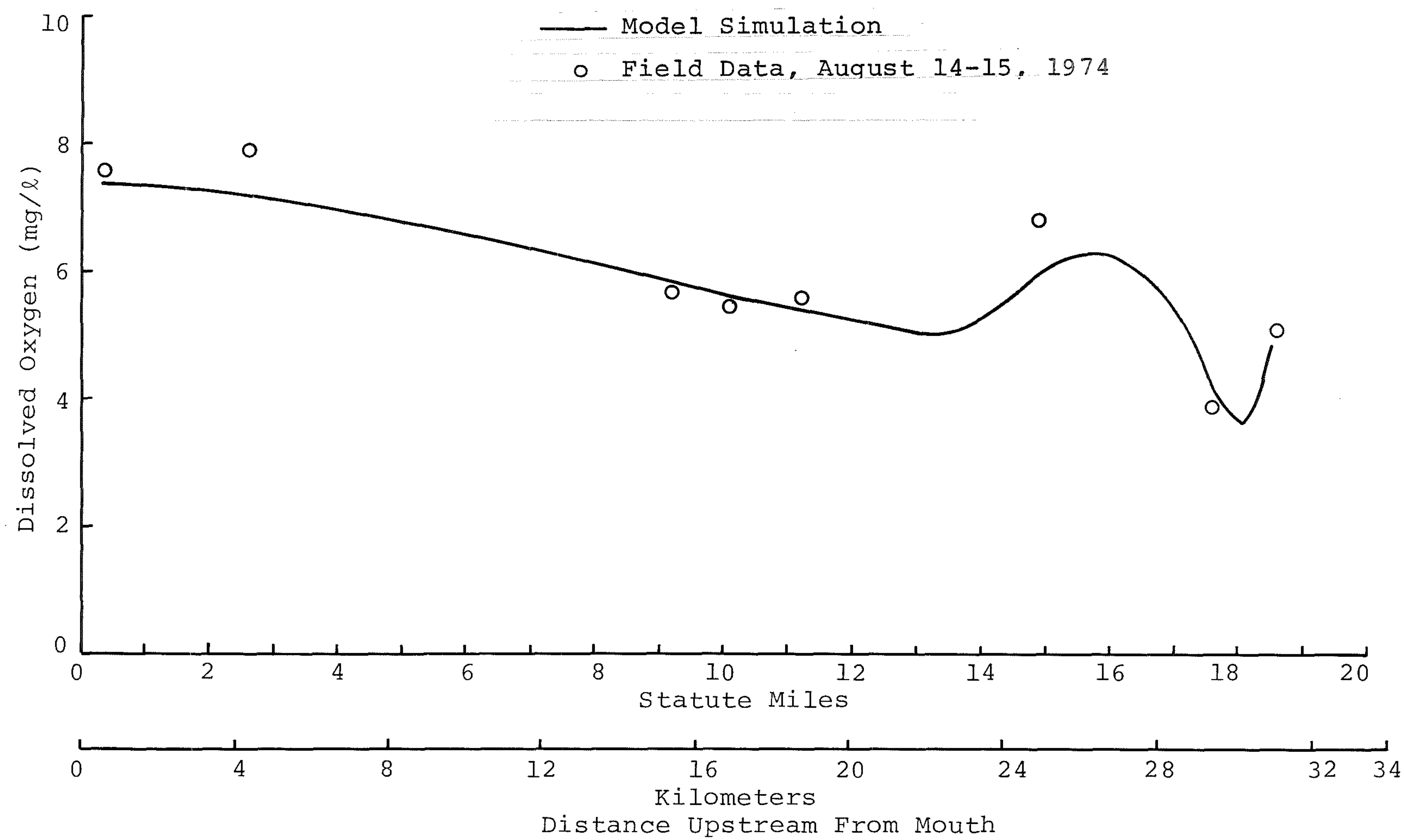

Figure 13. Longitudinal distribution of dissolved oxygen, August 14-15, 1974.

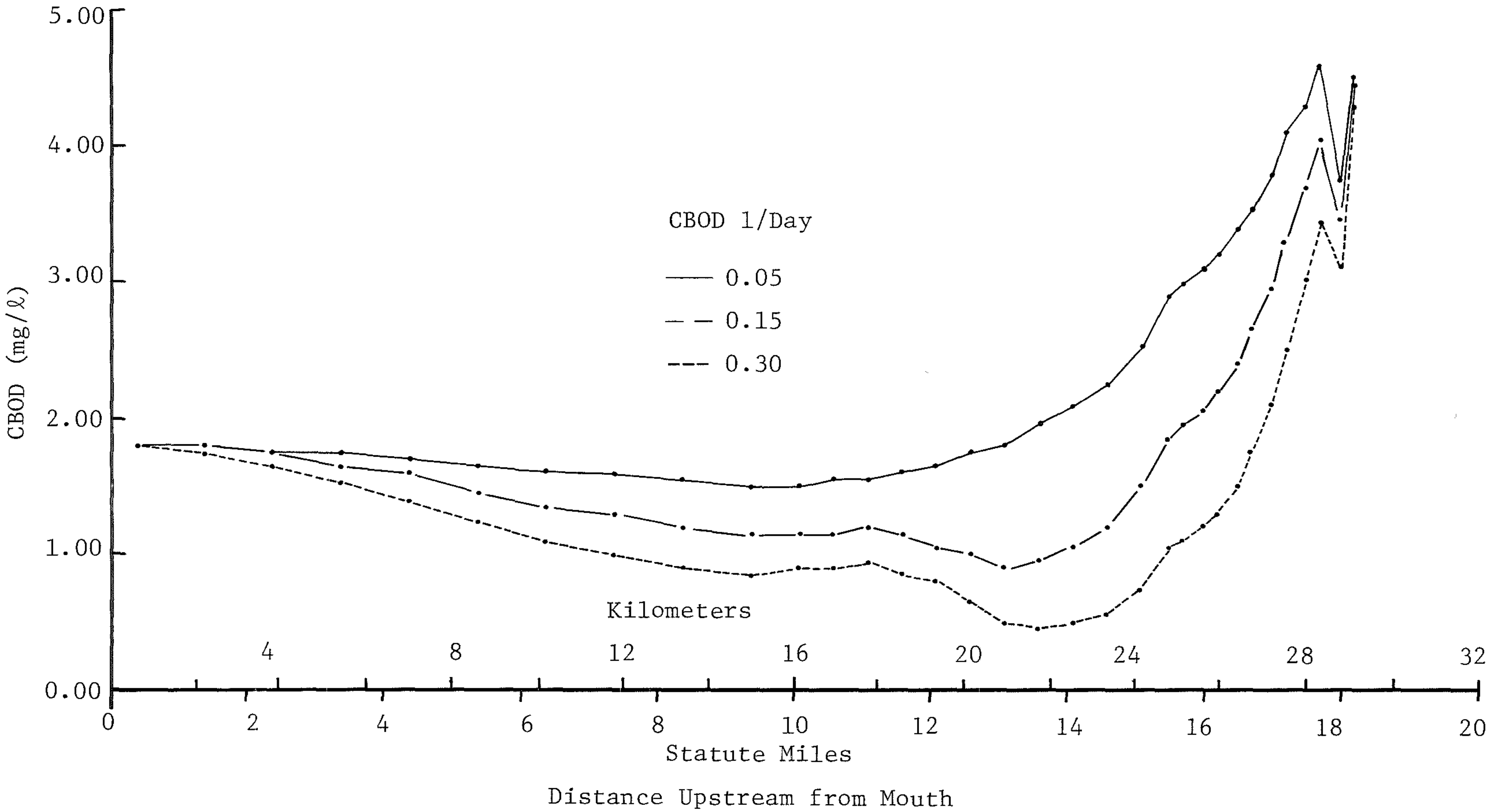

Figure 14. Effects of CBOD and NBOD decay rates on DO profiles.

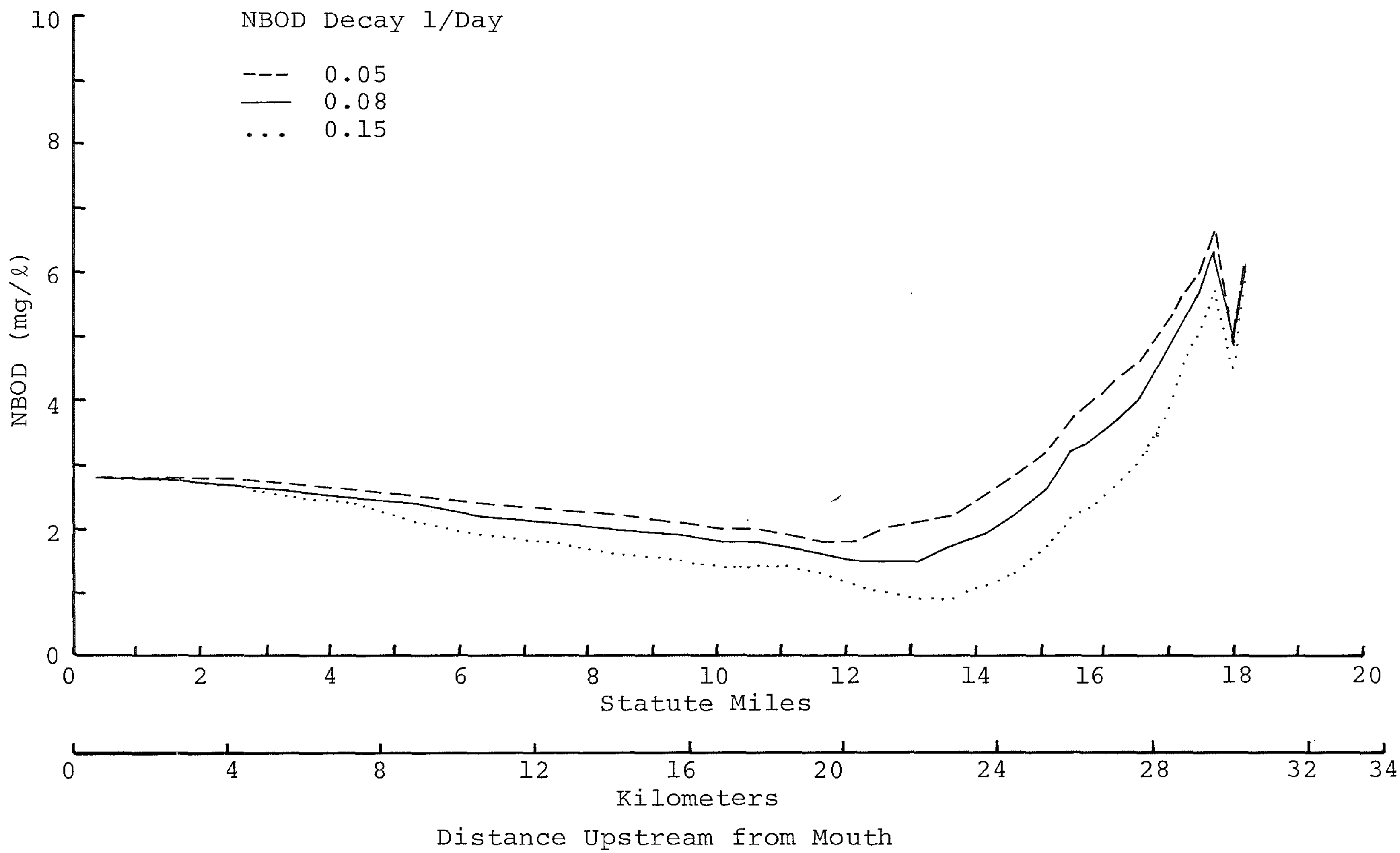

Figure 15. Effect of decay rate on CBOD distribution.

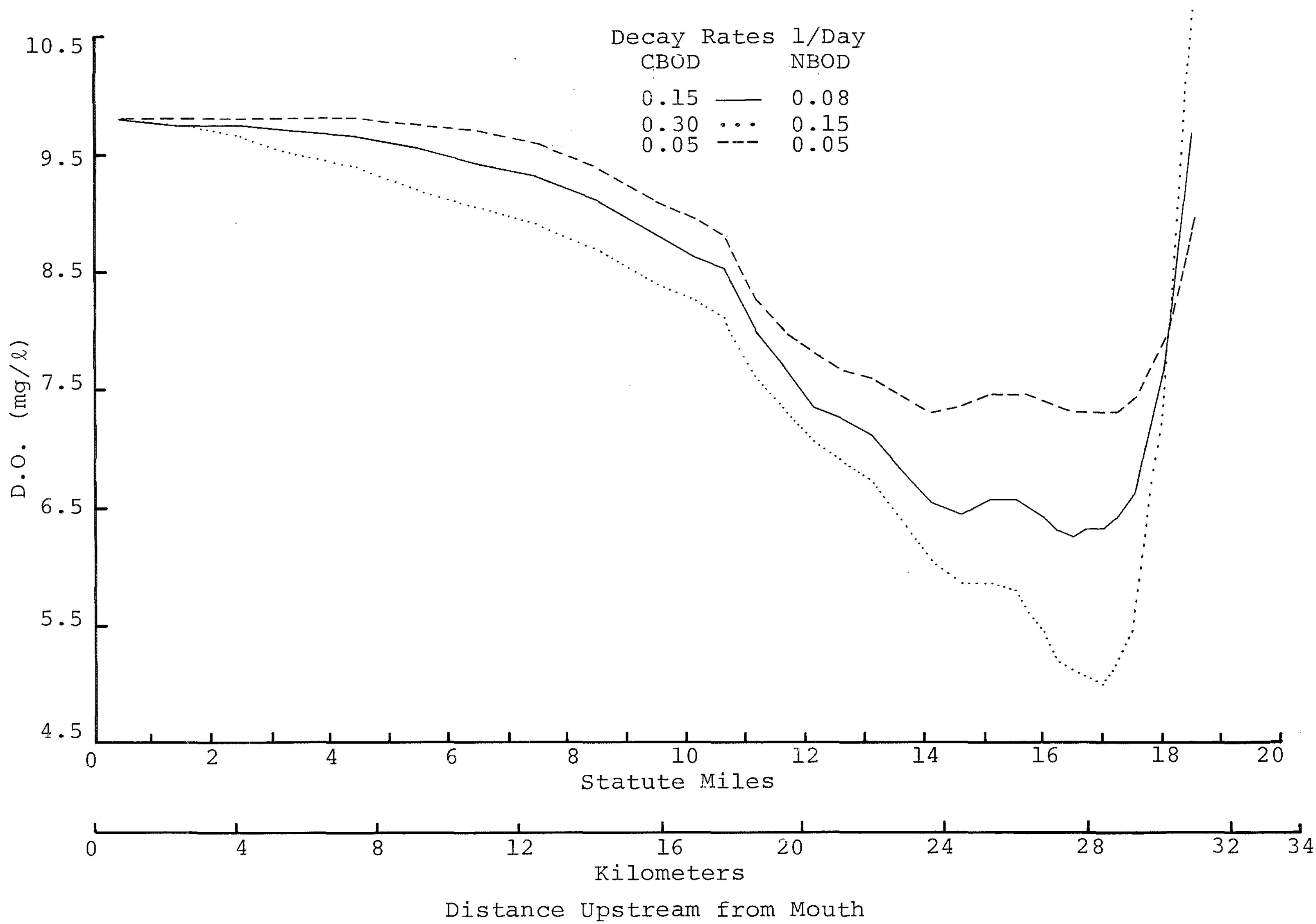

Figure 16. Effect of decay rate on NBOD distribution.

Doubling the decay rates results in a minimum DO level of 5.0 mg/l. Decreasing both the NBOD and CBOD recay rates by approximately two-thirds increases the minimum DO to 7.3 mg/l. The minimum DO value in the calibrated model is 6.25 mg/l.

The effects of the dispersion coefficient on the salinity, CBOD, NBOD, and DO are shown in figures 17, 18, 19 and 20, respectively. It is noted from figure 17 that the numerical calculation tends to become unstable when the dispersion coefficient is too low. Figures 18, 19 and 20 show that the CBOD, NBOD and DO distributions are rather insensitive to the dispersion coefficient.

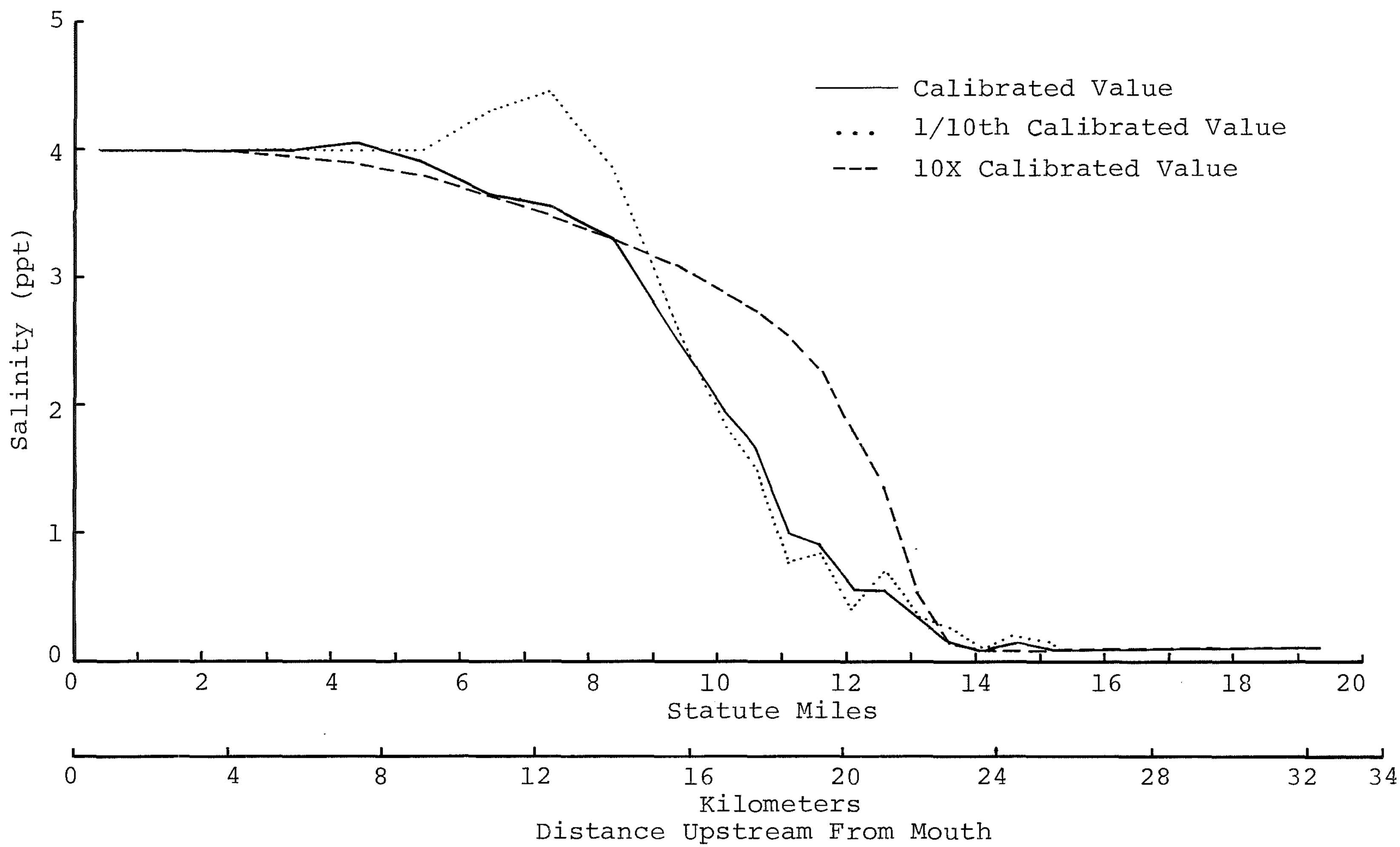

Figure 17. Effects of dispersion coefficient on salinity distributions.

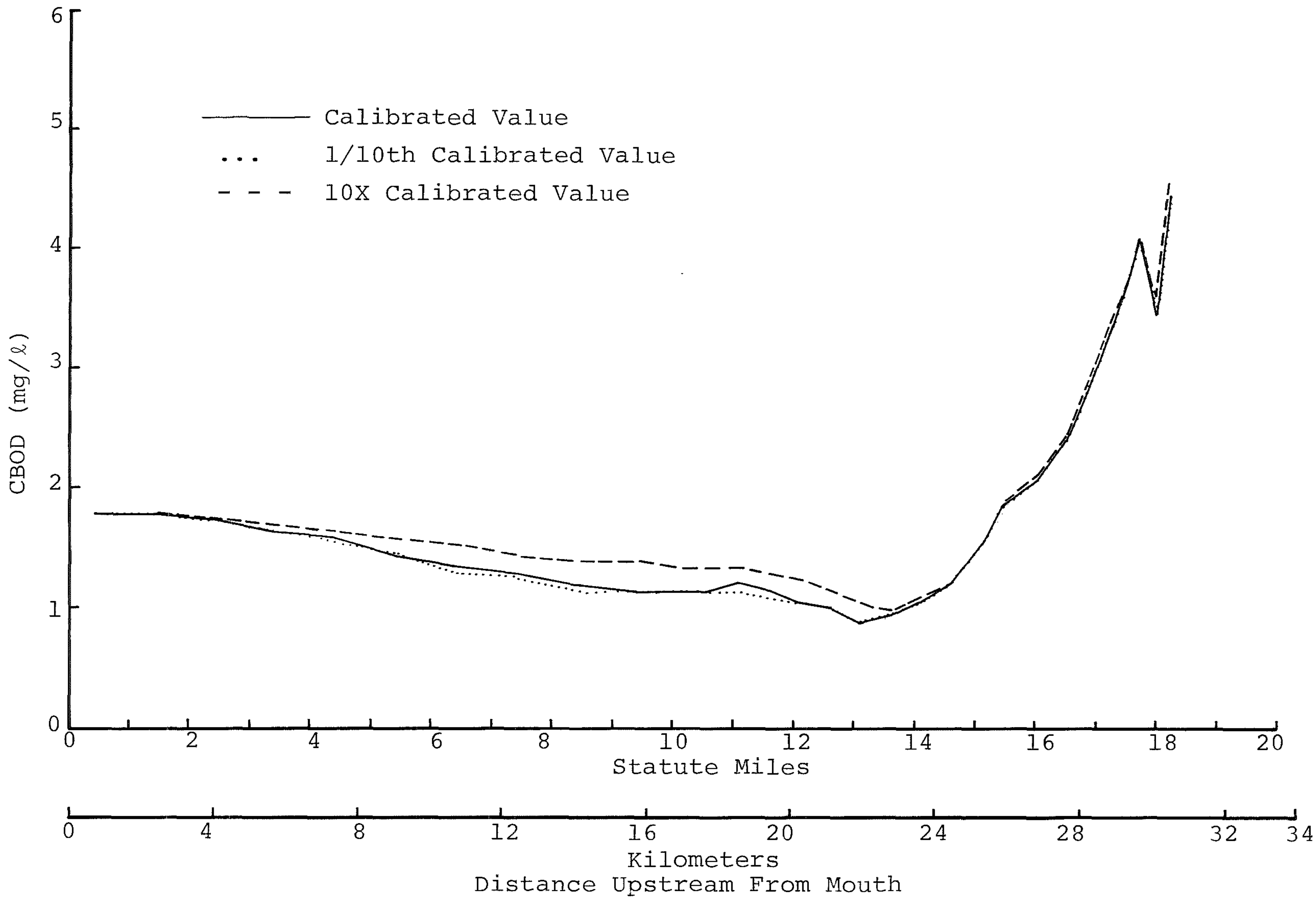

Figure 18. Effects of dispersion coefficient on CBOD distribution.

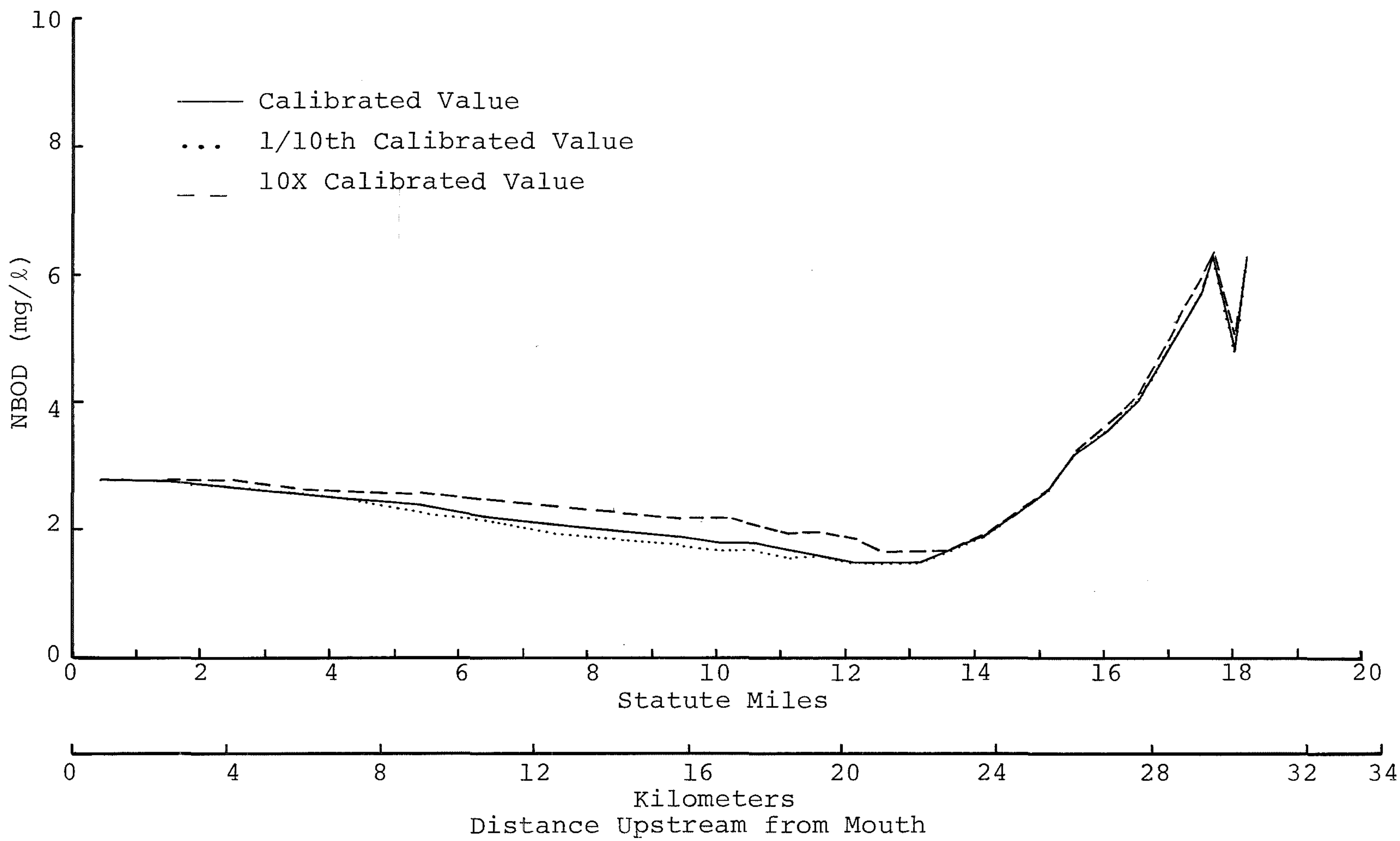

Figure 19. Effects of dispersion coefficient on NBOD distributions.

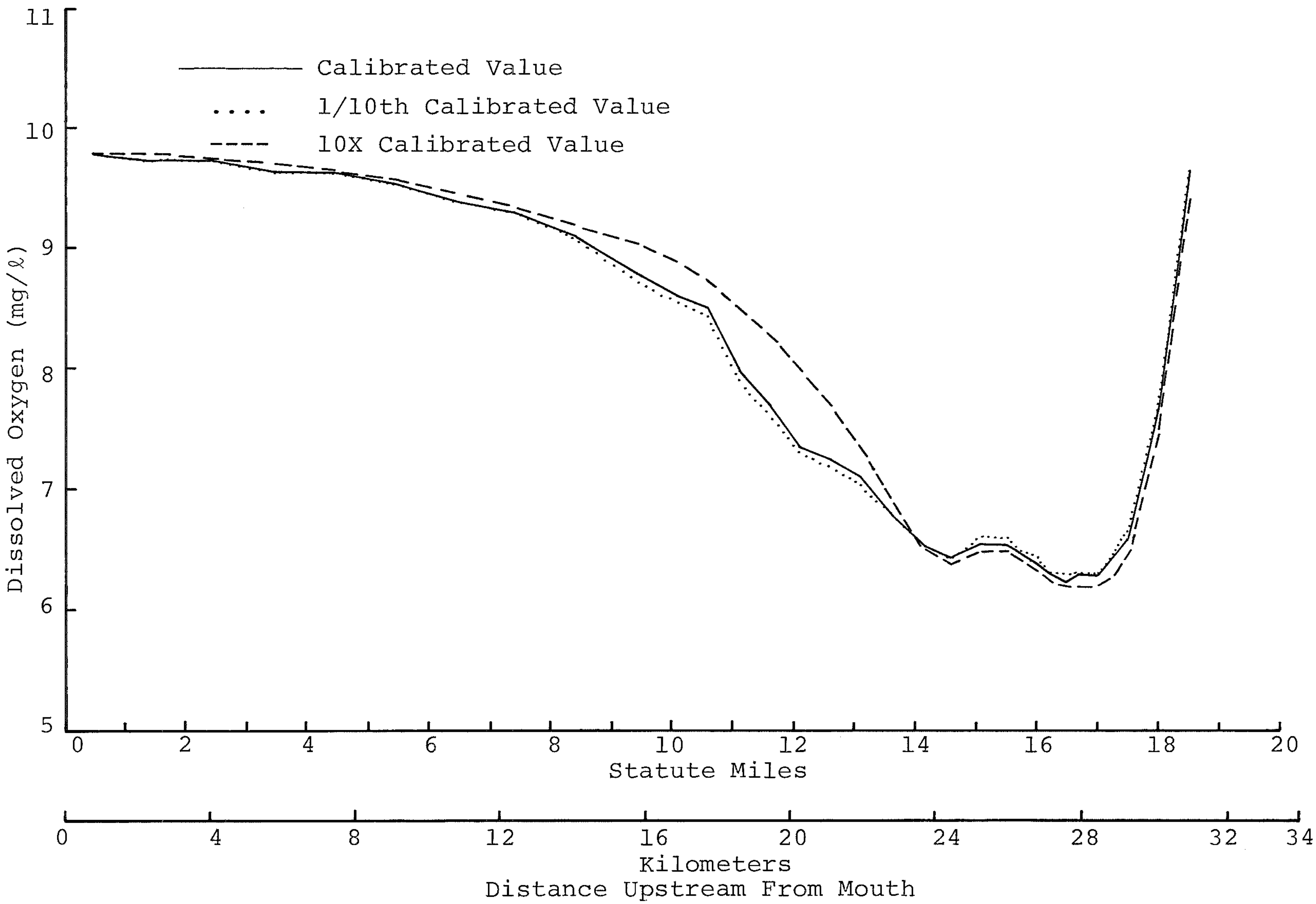

Figure 20. Effects of dispersion coefficient on DO profiles.

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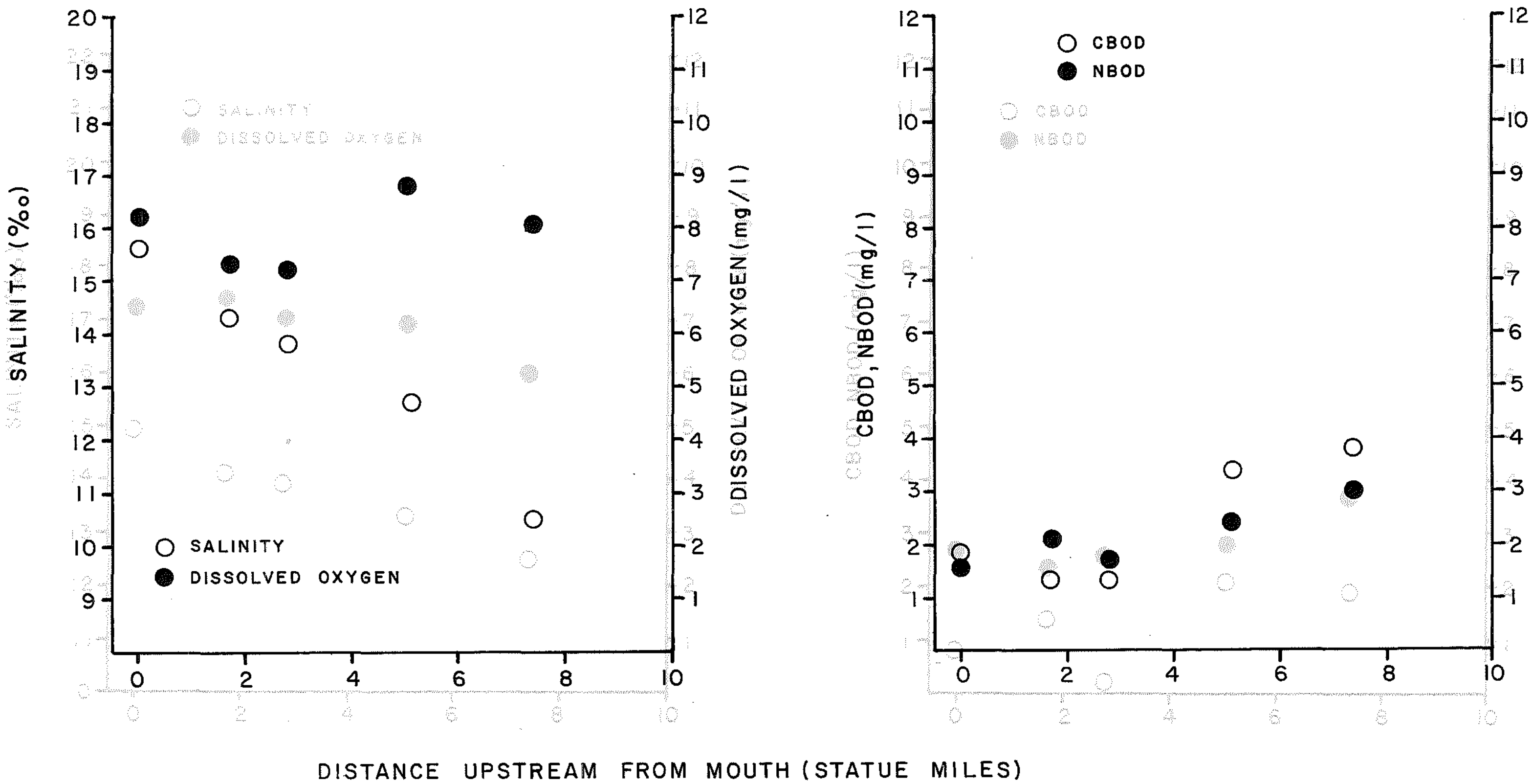
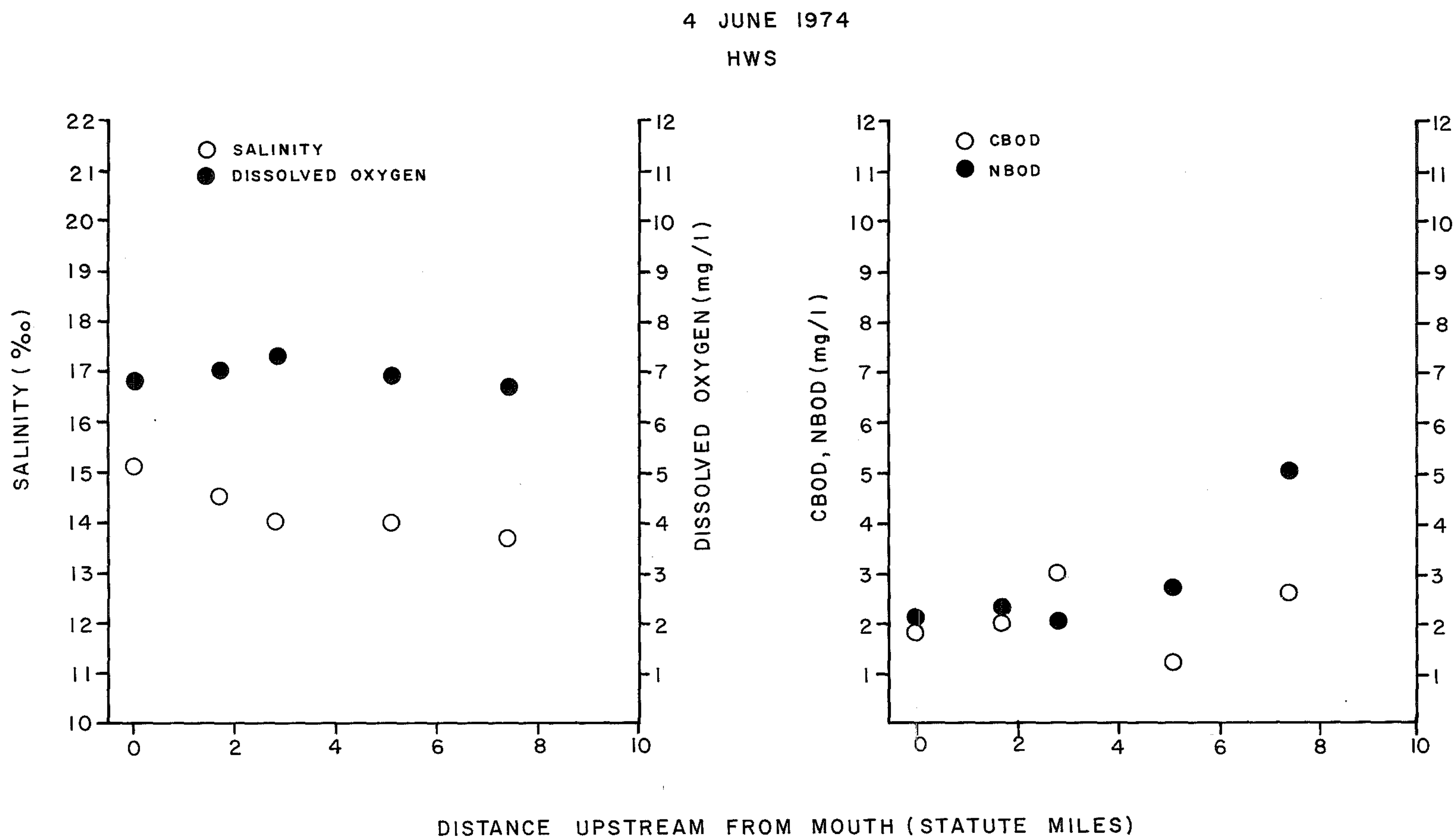
APPENDIX A

Graphical Summary of Water Quality Data

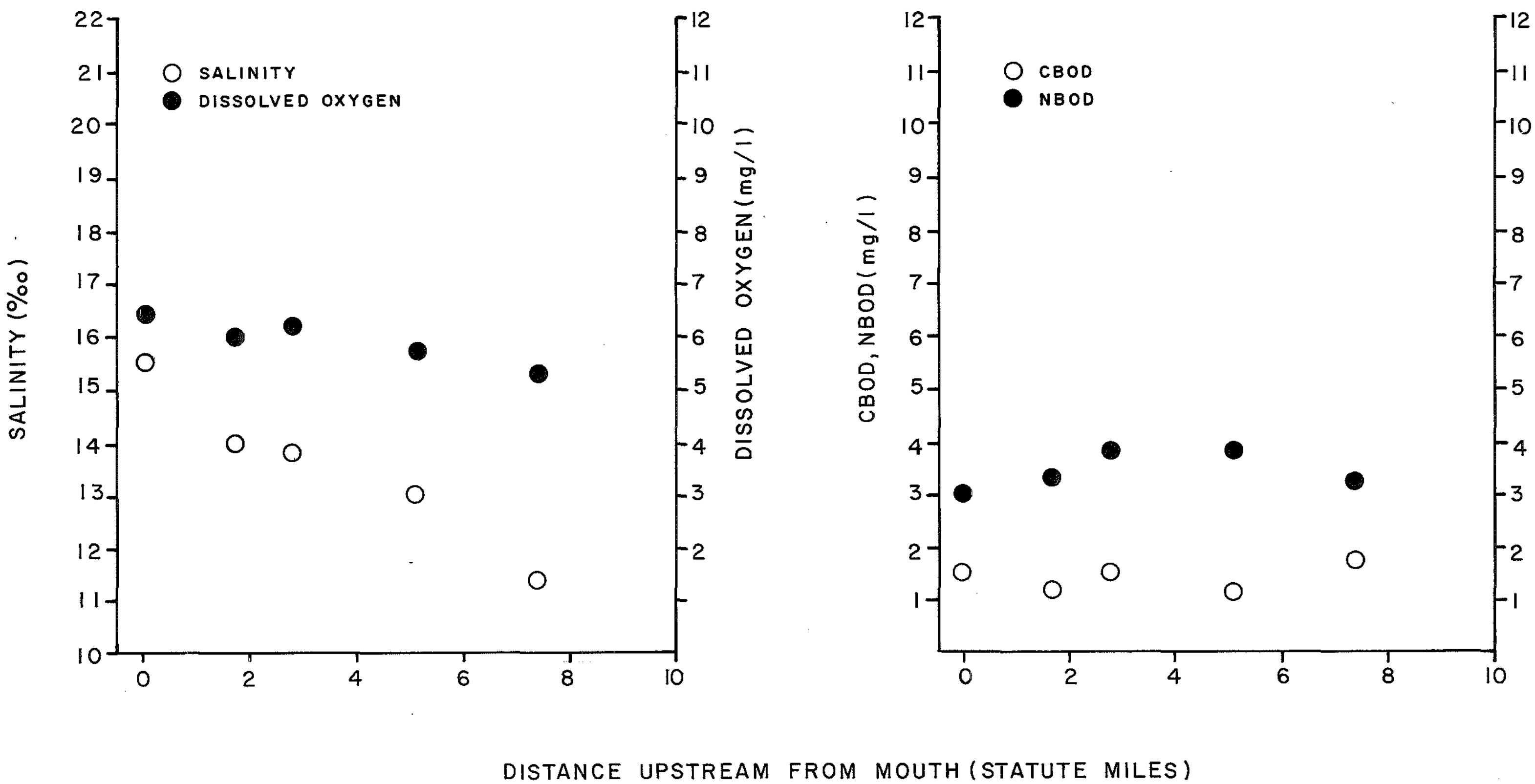
14 MAY 1974
LWS



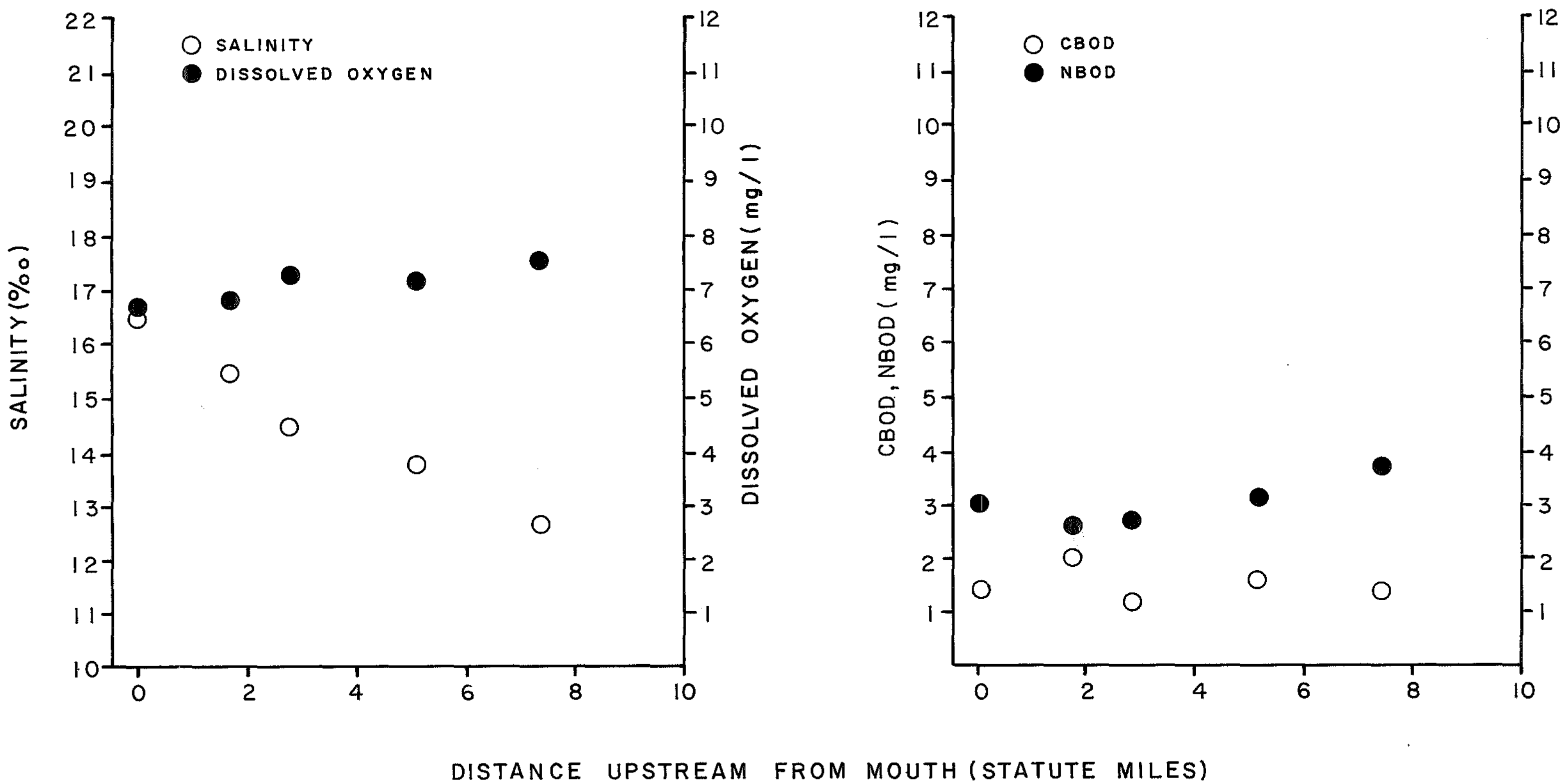

4 JUNE 1974
HWS
SALINITY
DISSOLVED OXYGEN
SALINITY (‰)
DISSOLVED OXYGEN (mg/l)
22
21
20
19
18
17
16
15
14
13
12
11
10
12
11
10
9
8
7
6
5
4
3
2
1
0
2
4
6
8
10
CBOD
NBOD
CBOD, NBOD (mg/l)
DISTANCE UPSTREAM FROM MOUTH (STATUTE MILES)

25 JUNE 1974

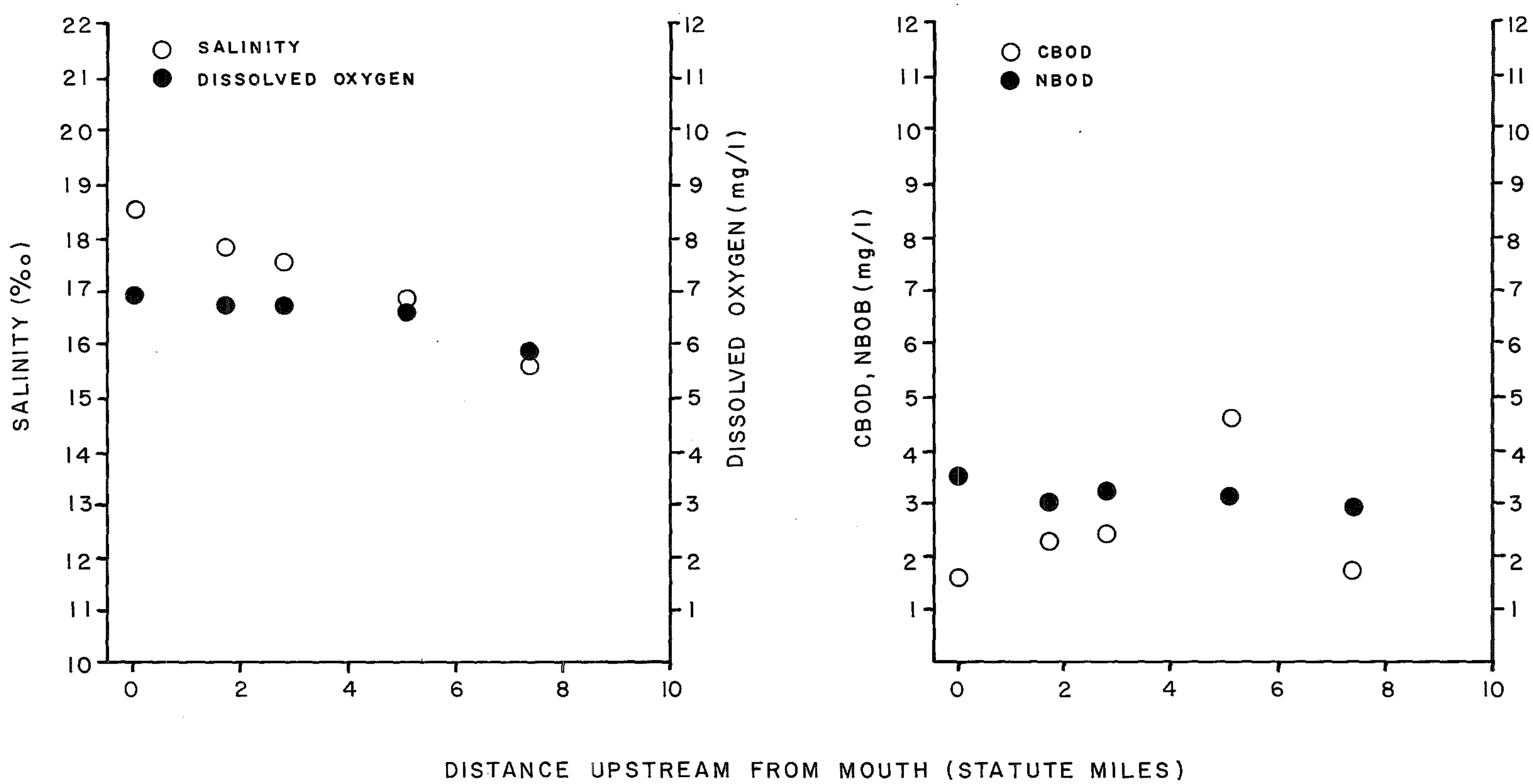
LWS



2 JULY 1974
HWS

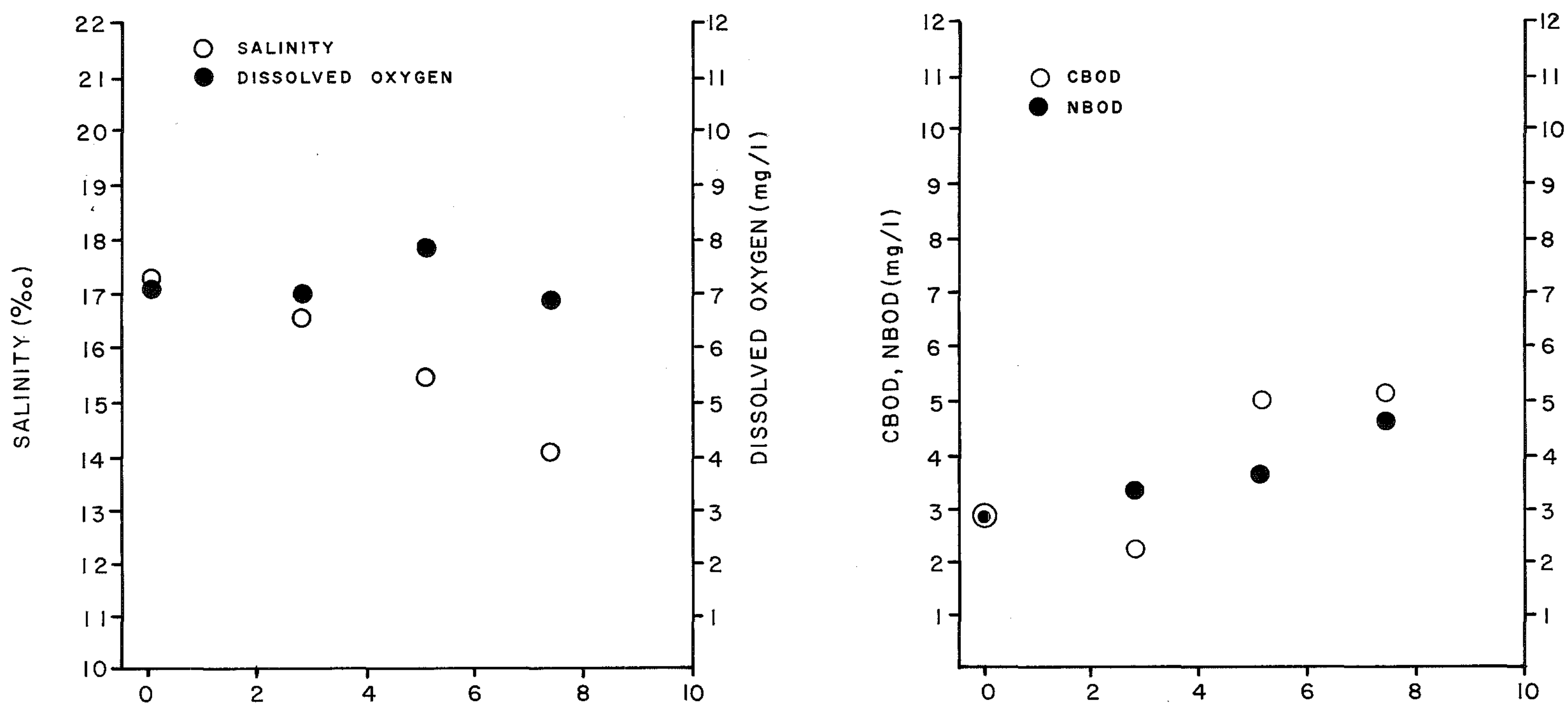


25 JULY 1974
LWS



8 AUGUST 1974

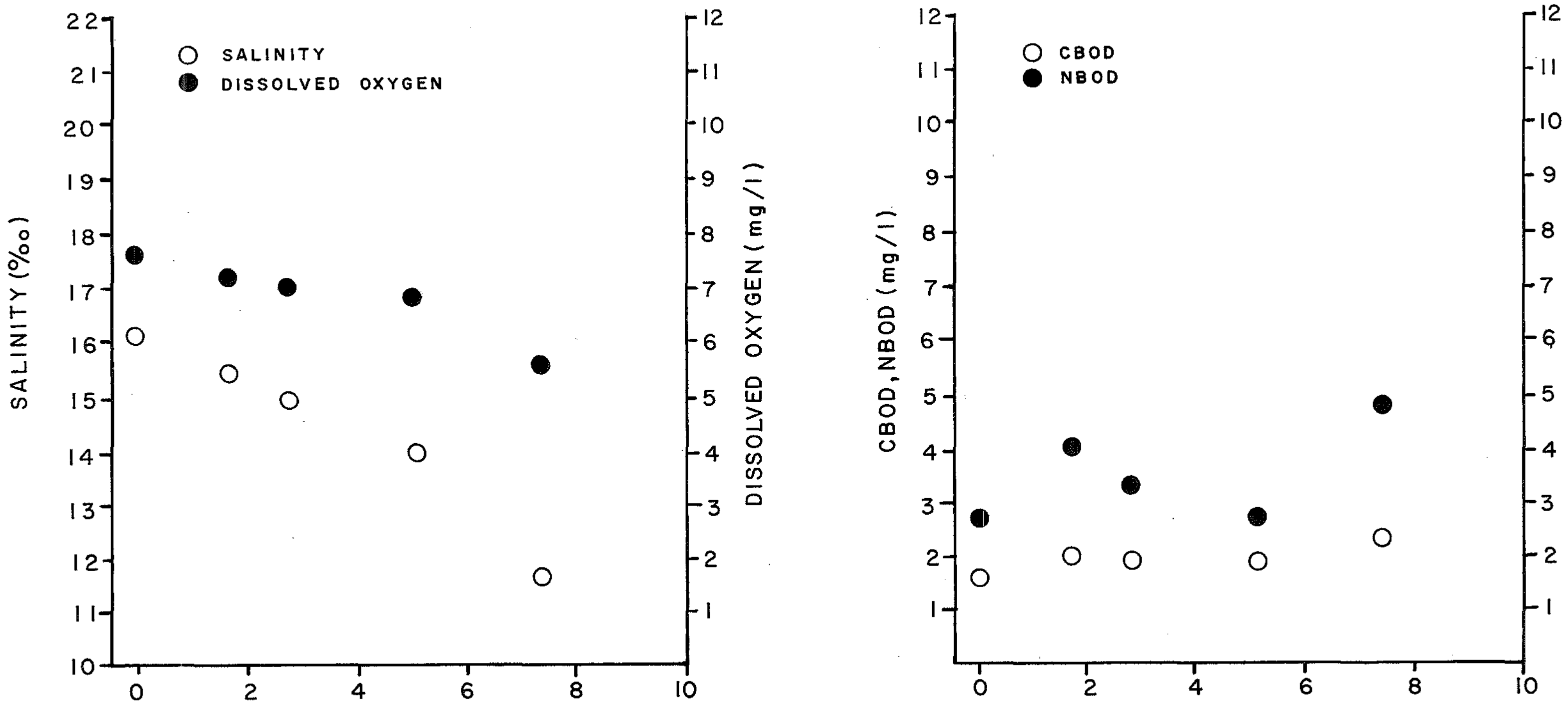
HWS



DISTANCE UPSTREAM FROM MOUTH (STATUTE MILES)

13 AUGUST 1974

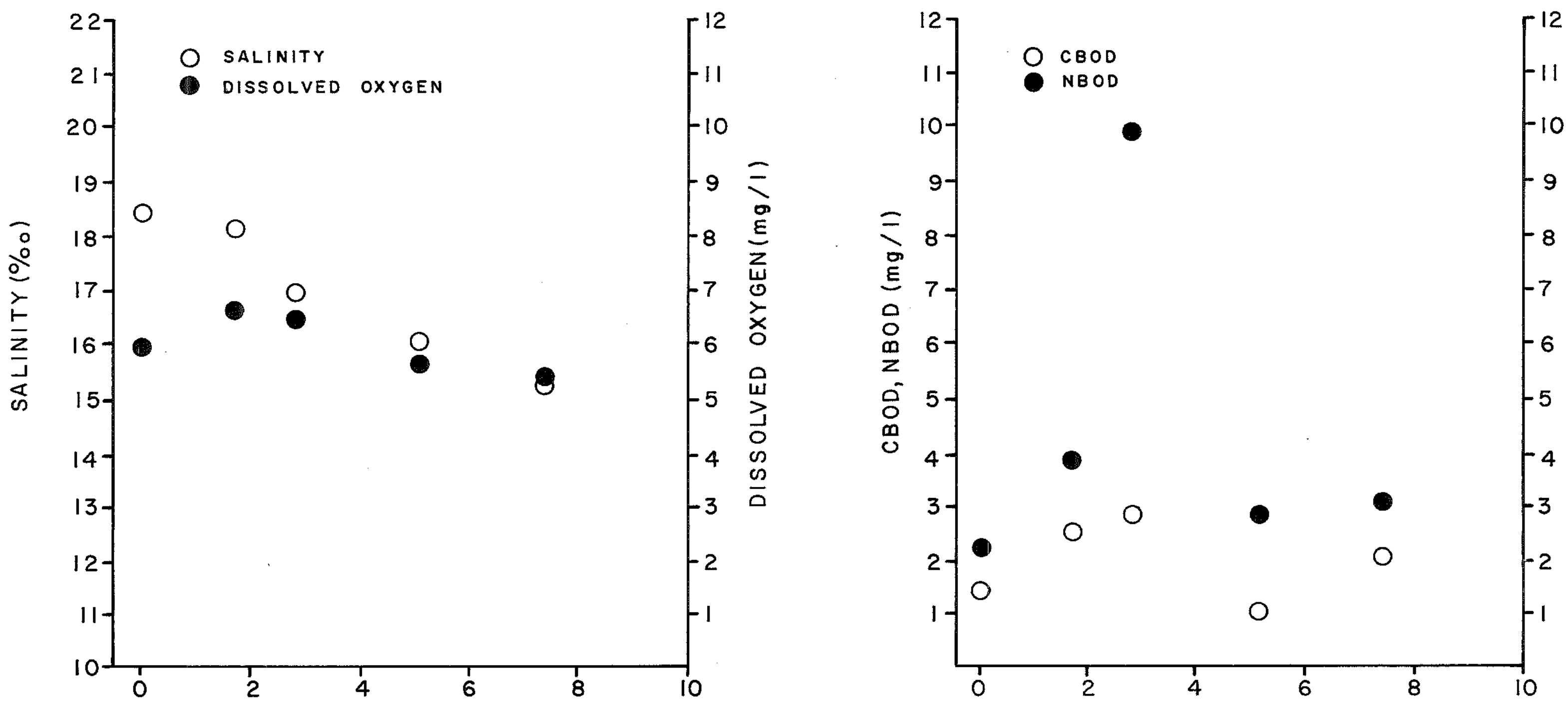
LWS



DISTANCE UPSTREAM FROM MOUTH (STATUTE MILES)

19 AUGUST 1974

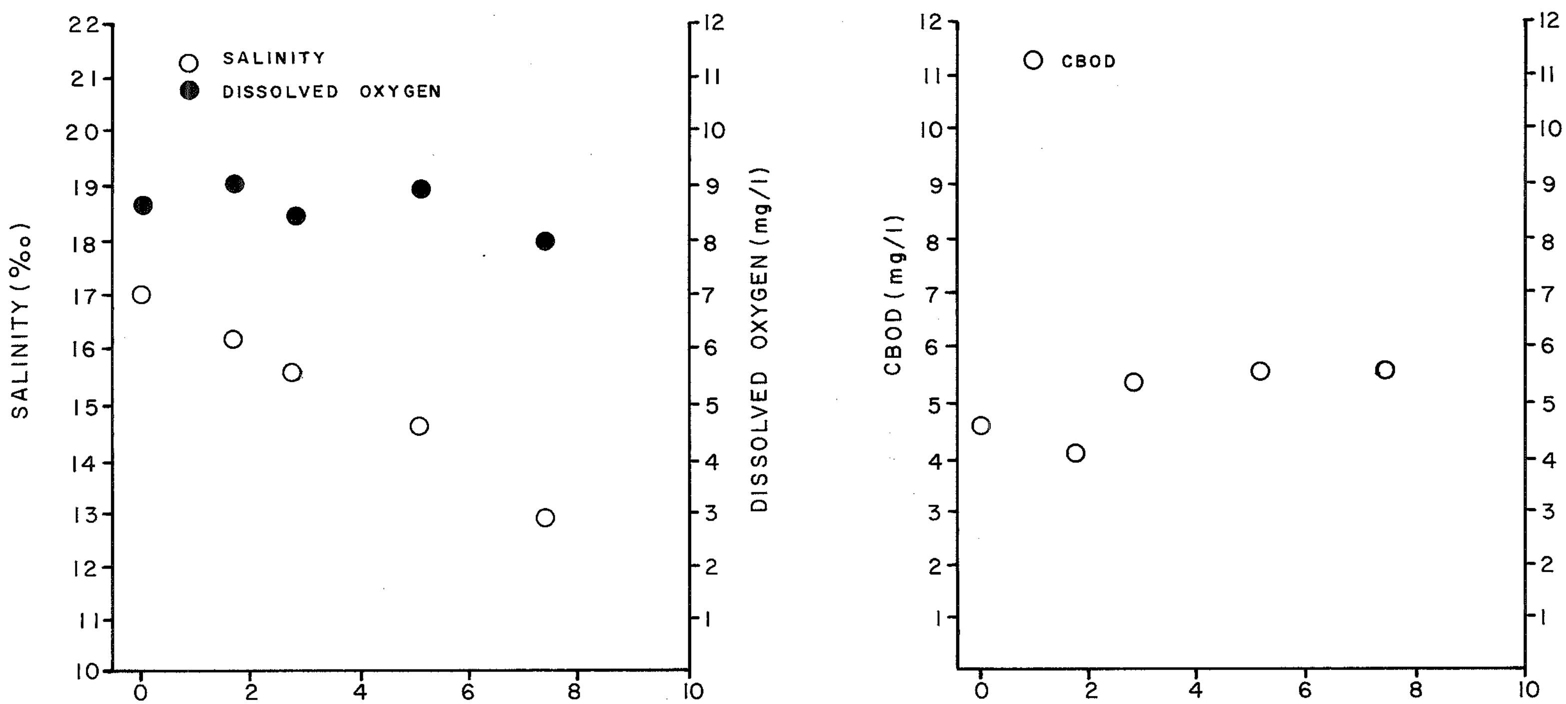
HWS



DISTANCE UPSTREAM FROM MOUTH (STATUTE MILES)

29 AUGUST 1974

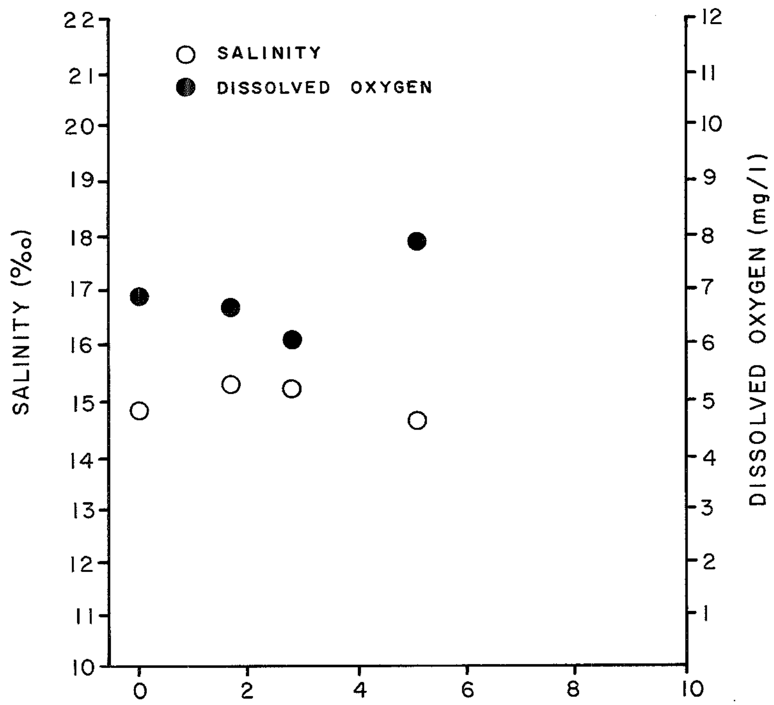
LWS

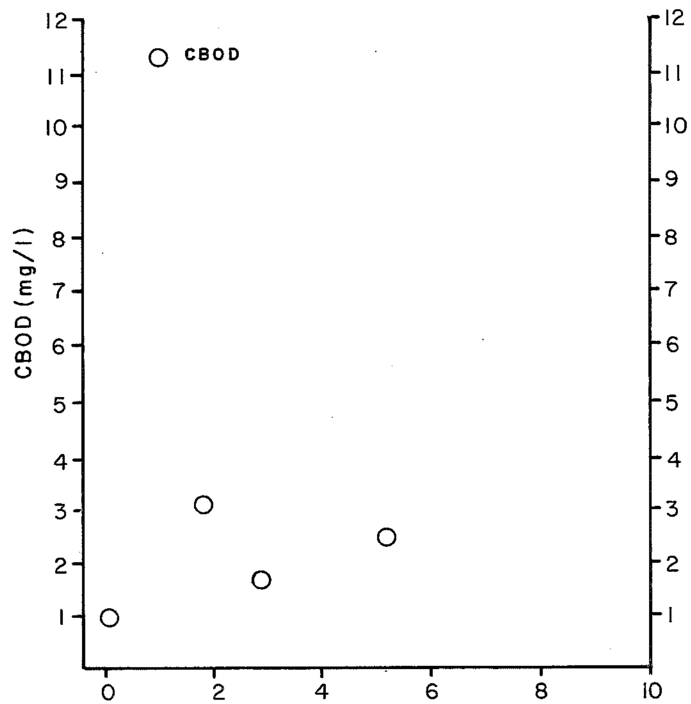


DISTANCE UPSTREAM FROM MOUTH (STATUTE MILES)

10 SEPTEMBER 1974

LWS

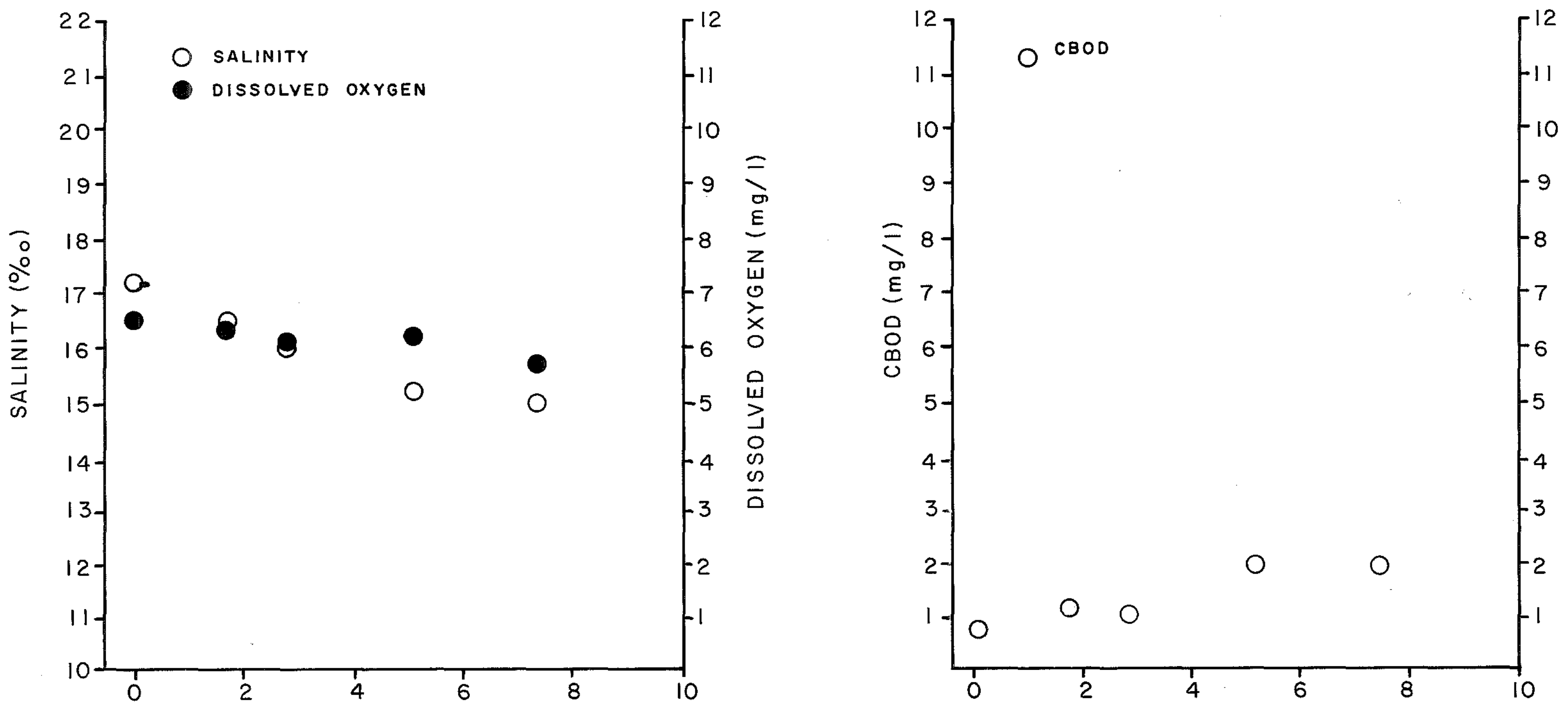




DISTANCE UPSTREAM FROM MOUTH (STATUTE MILES)

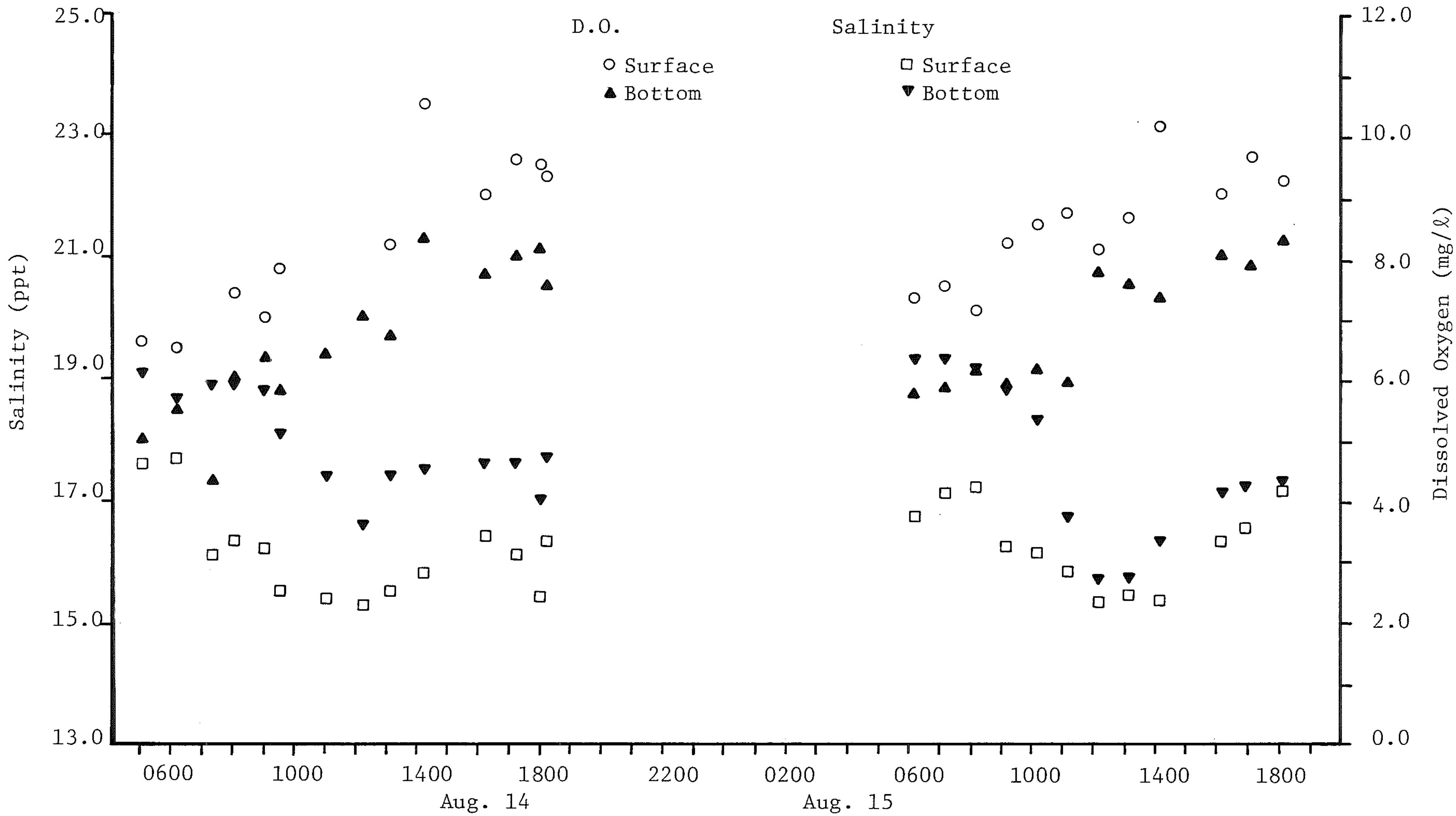
17 SEPTEMBER 1974

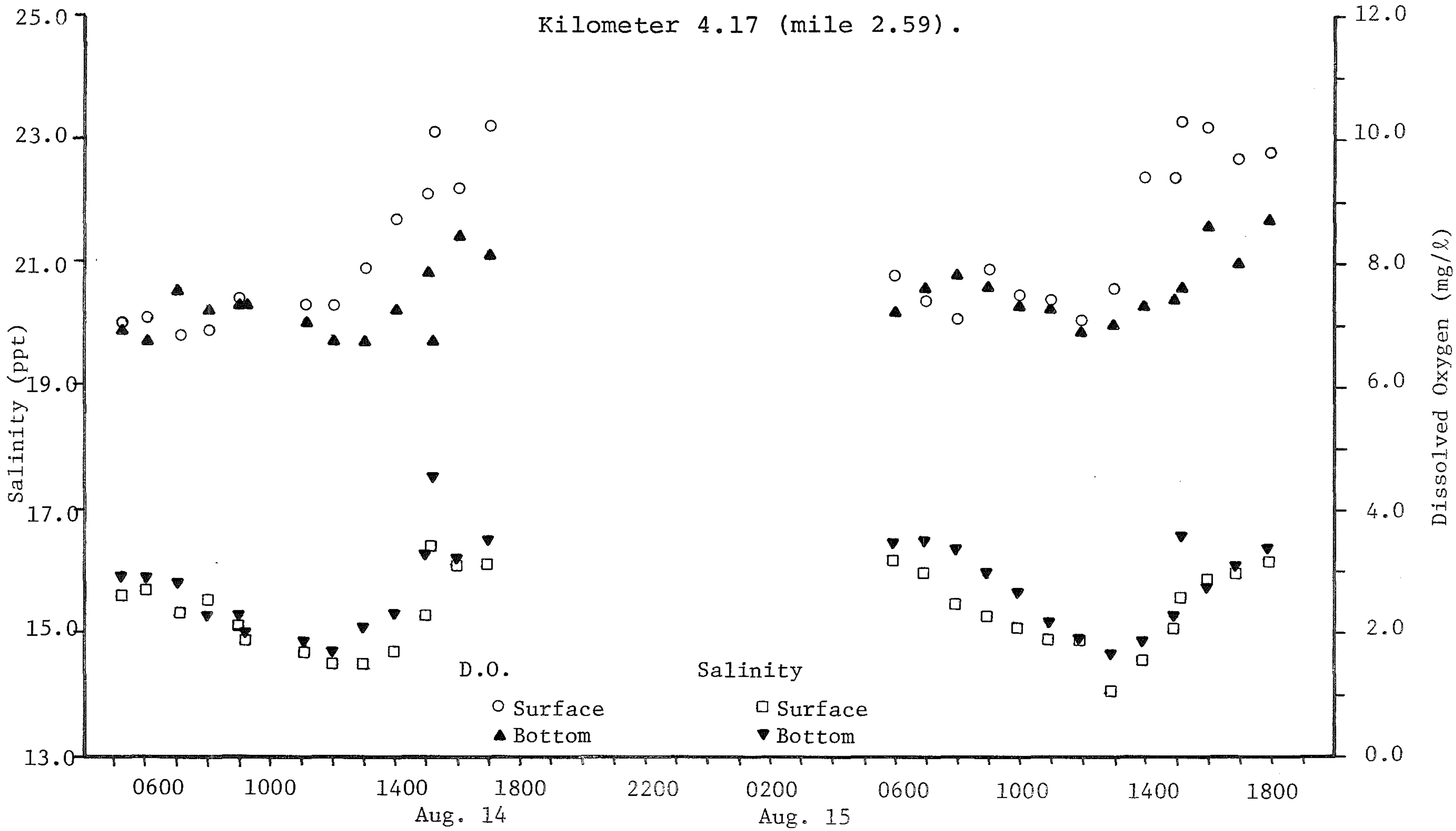
HWS



DISTANCE UPSTREAM FROM MOUTH (STATUTE MILES)

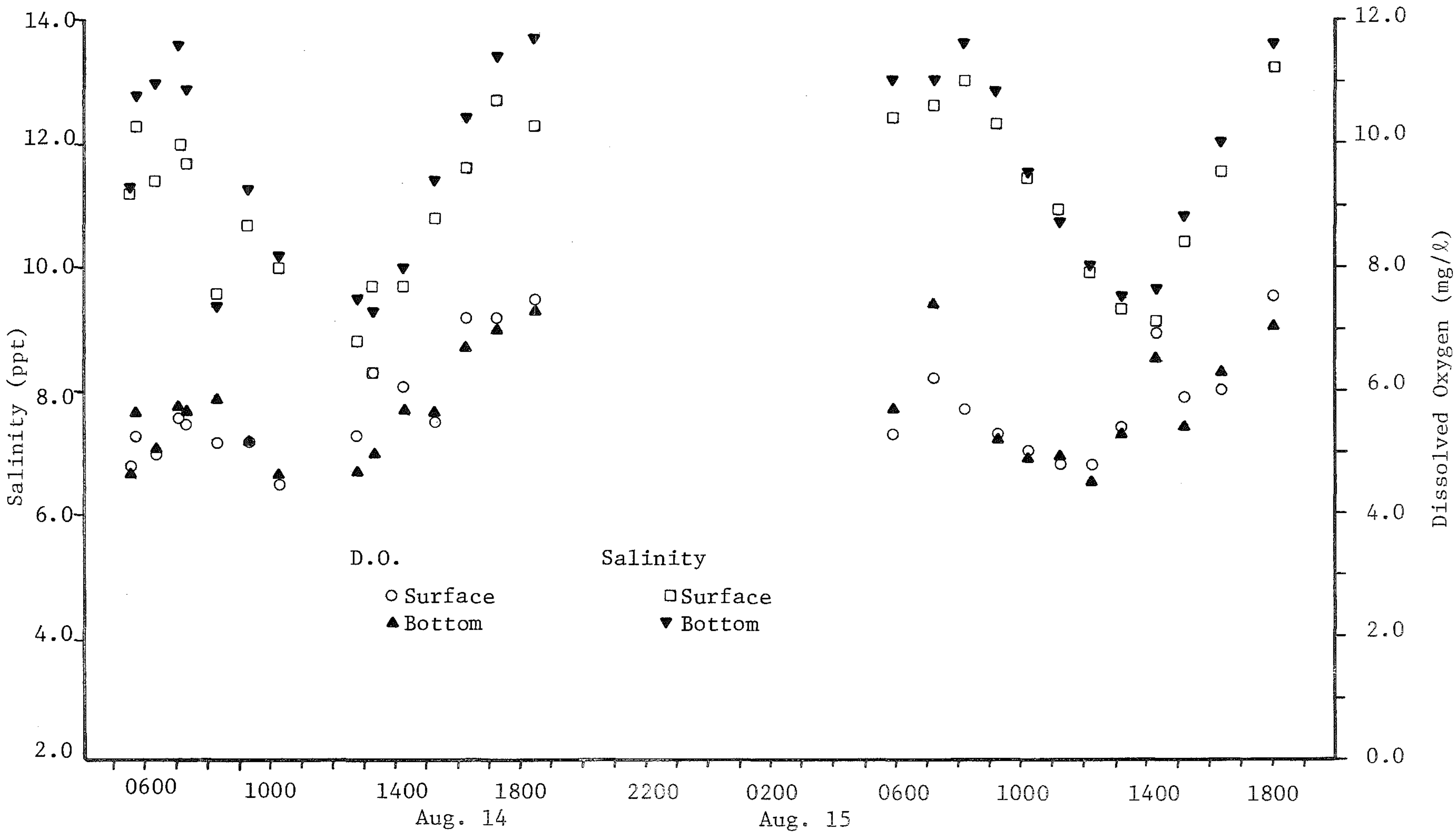
Kilometer 0.47 (mile 0.29).



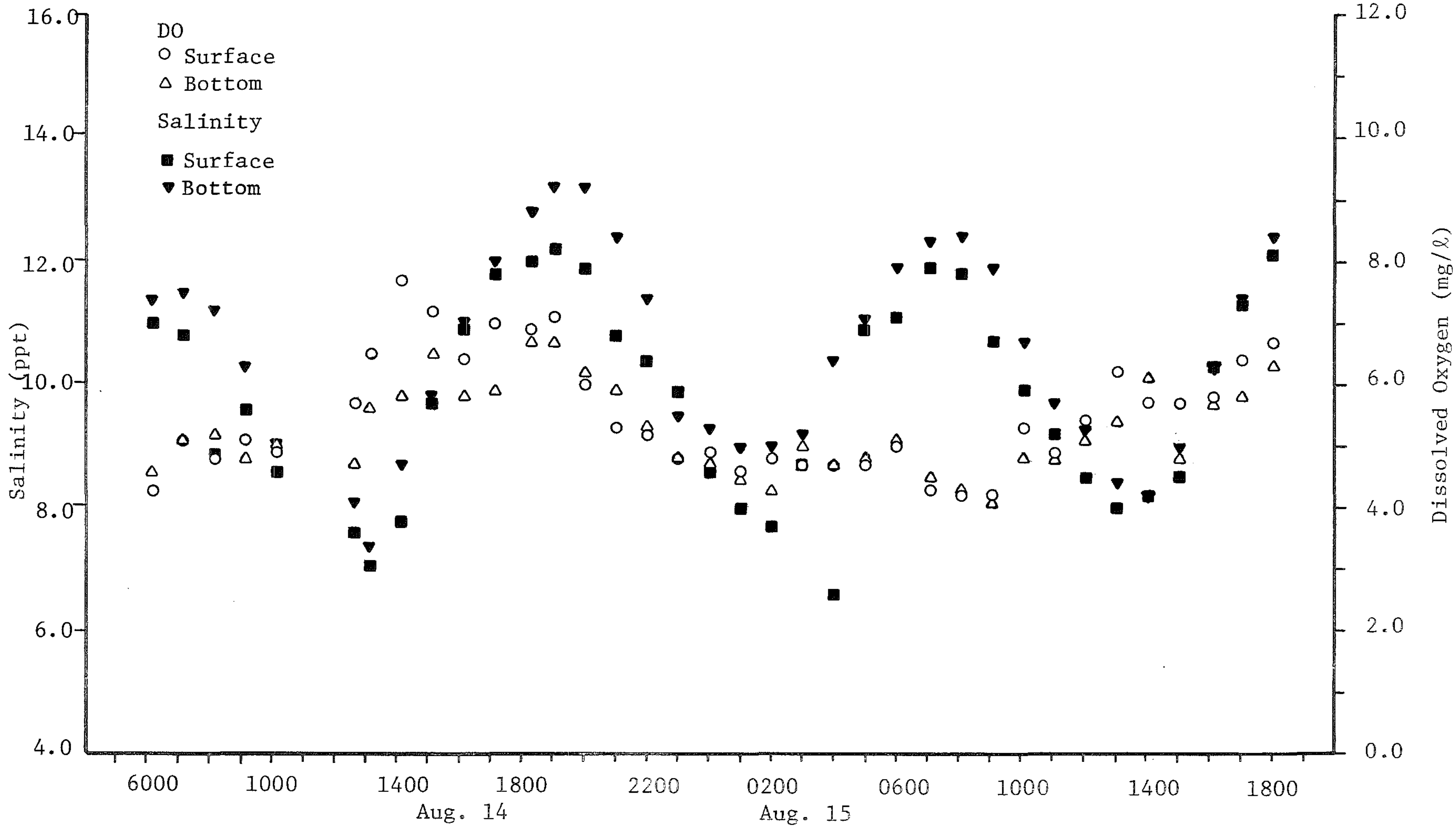


Kilometer 4.17 (mile 2.59).
25.0
23.0
21.0
19.0
17.0
15.0
13.0
Salinity (ppt)
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Dissolved Oxygen (mg/ℓ)
D.O.
○ Surface
▲ Bottom
Salinity
□ Surface
▼ Bottom
0600
1000
1400
1800
2200
0200
0600
1000
1400
1800
Aug. 14
Aug. 15

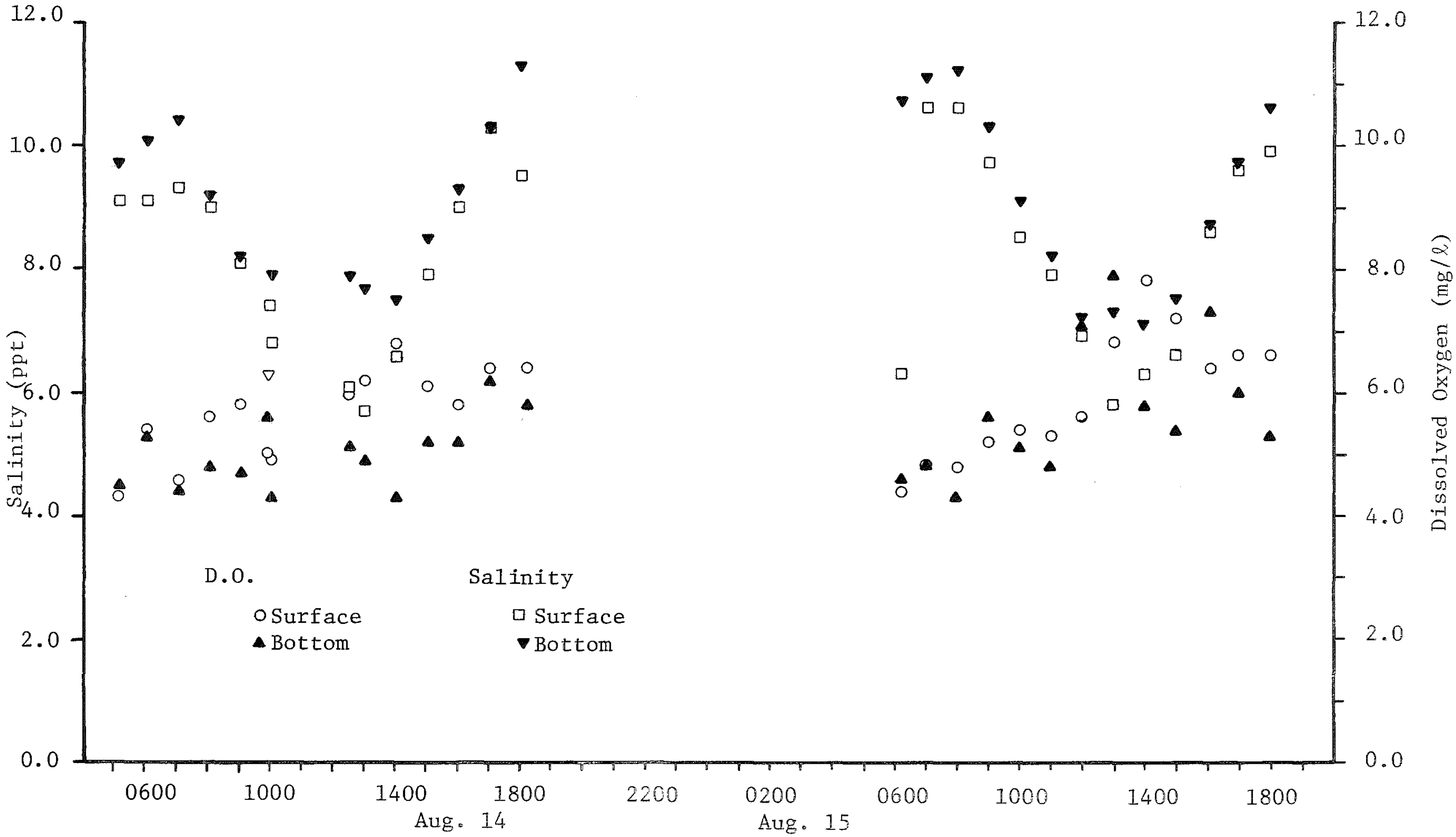
Kilometer 14.72 (mile 9.15).



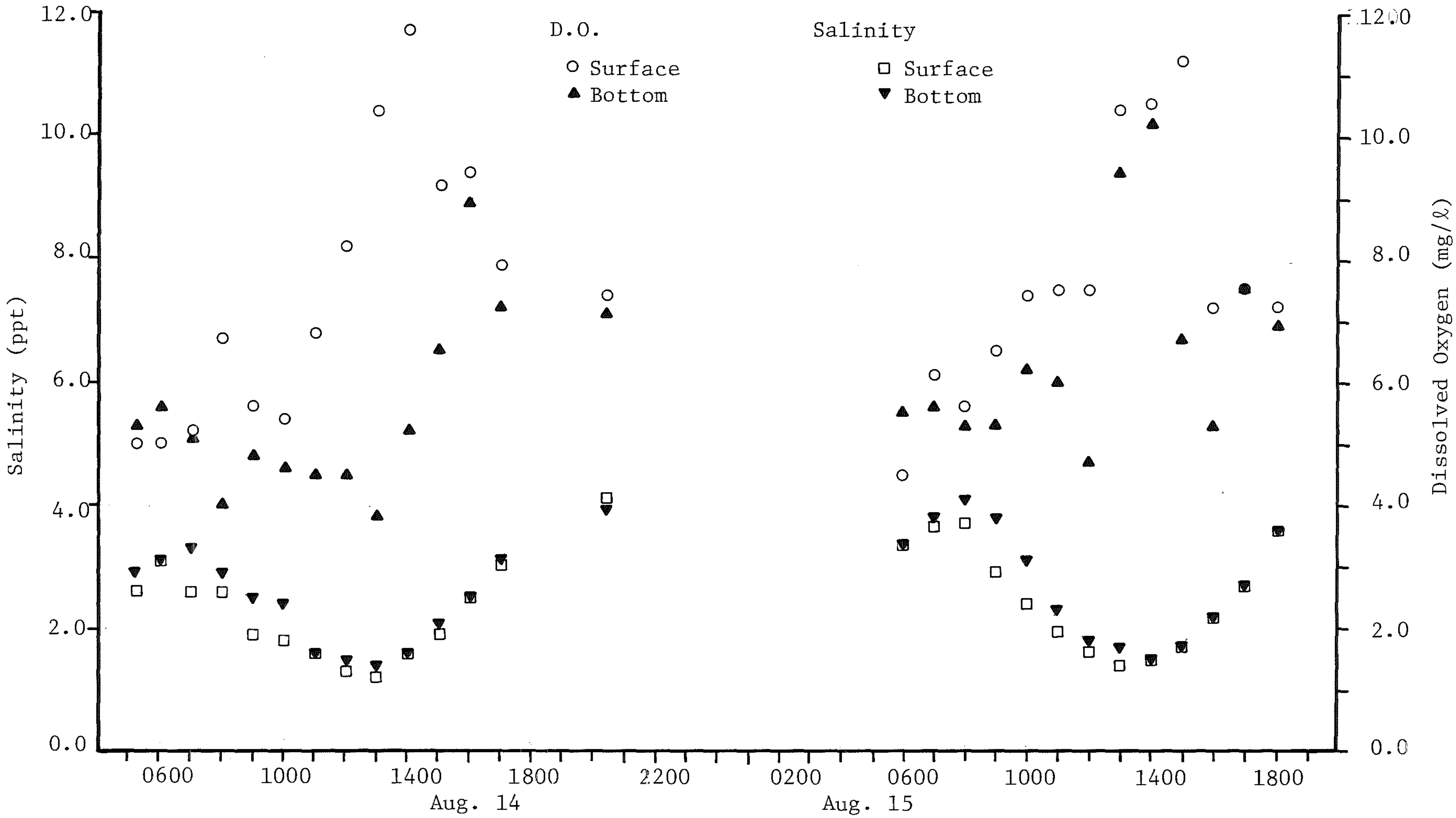
Kilometer 16.22 (mile 10.08).



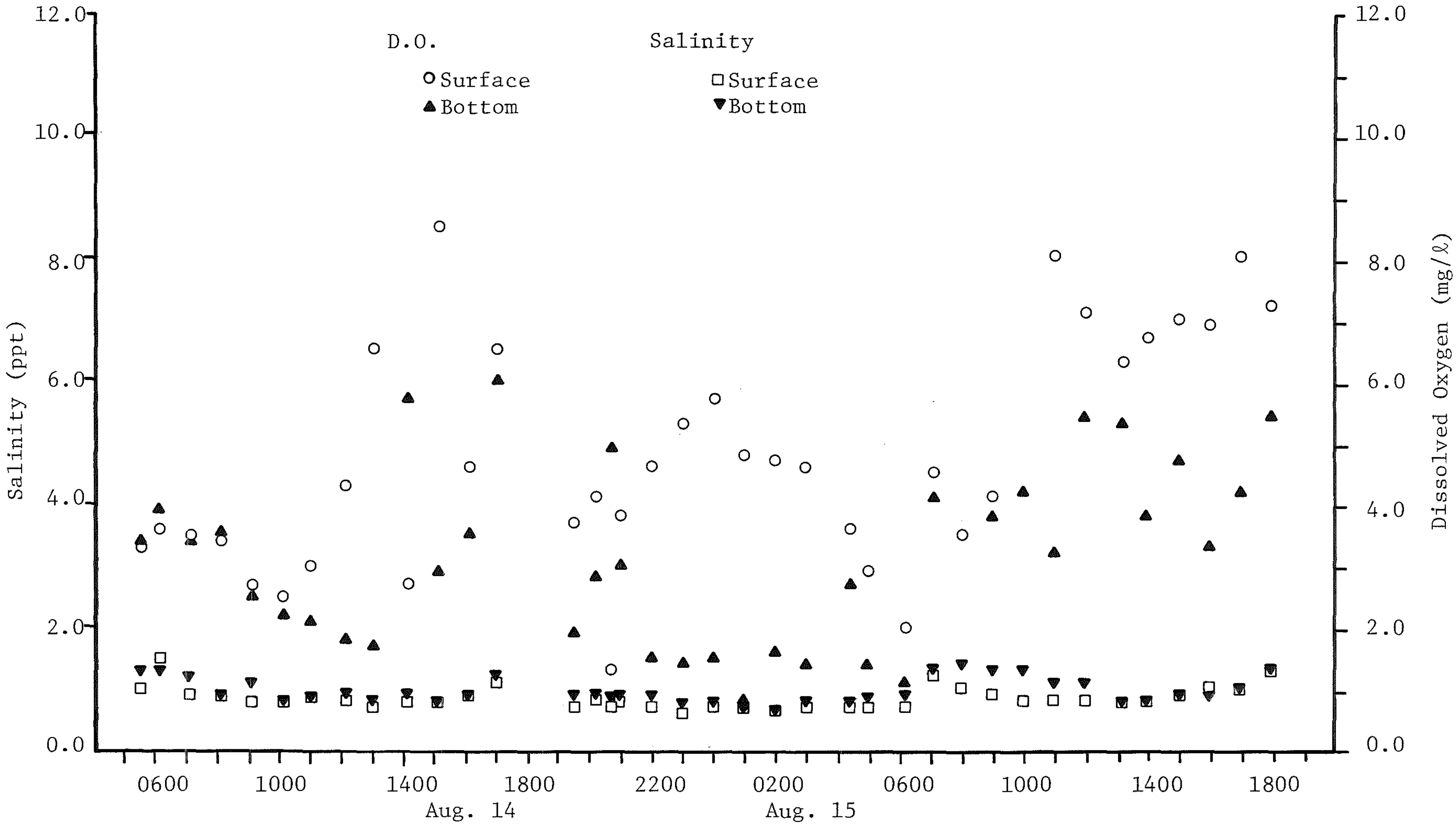
Kilometer 17.99 (mile 11.18).



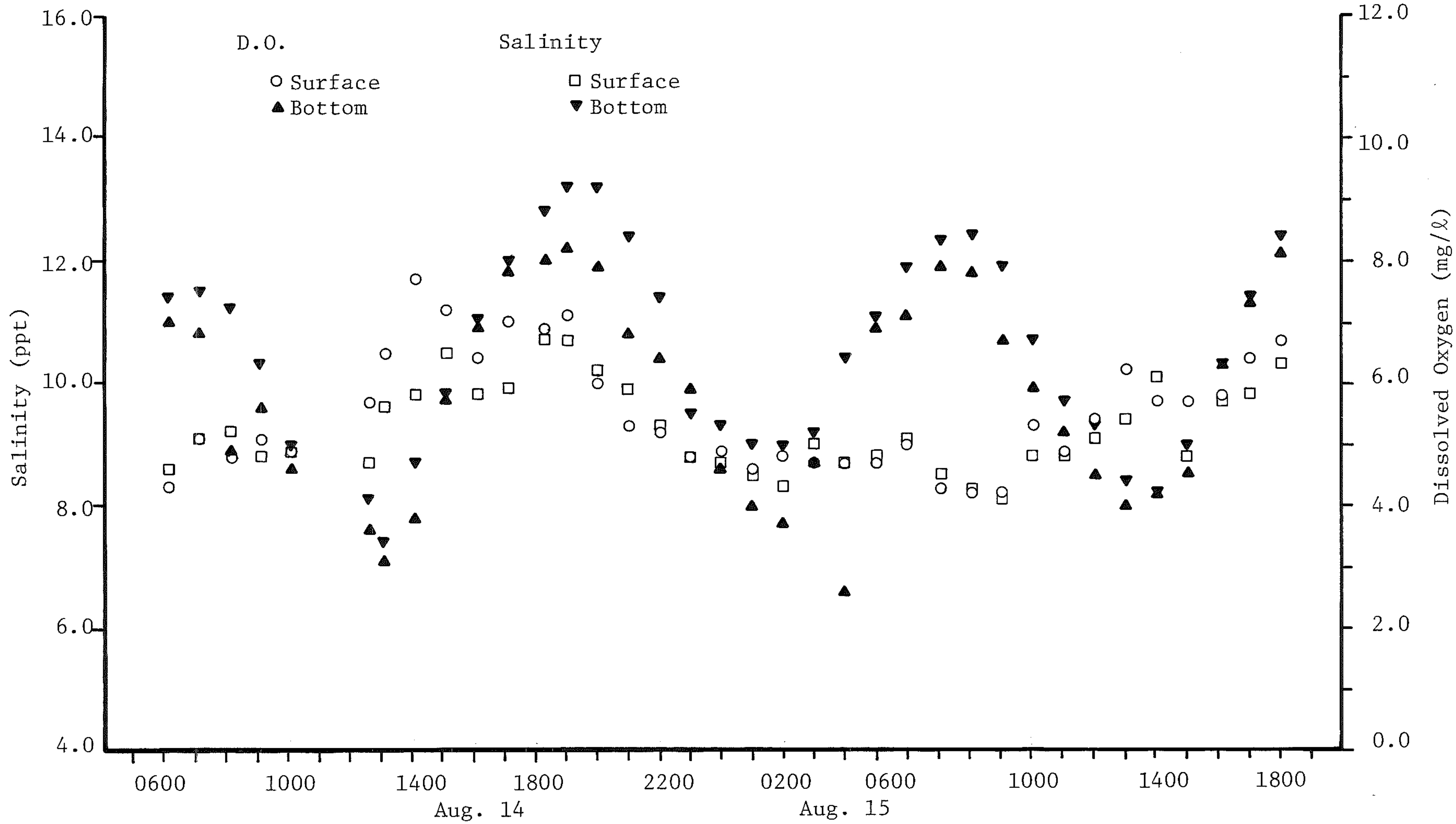
Kilometer 23.91 (mile 14.86).



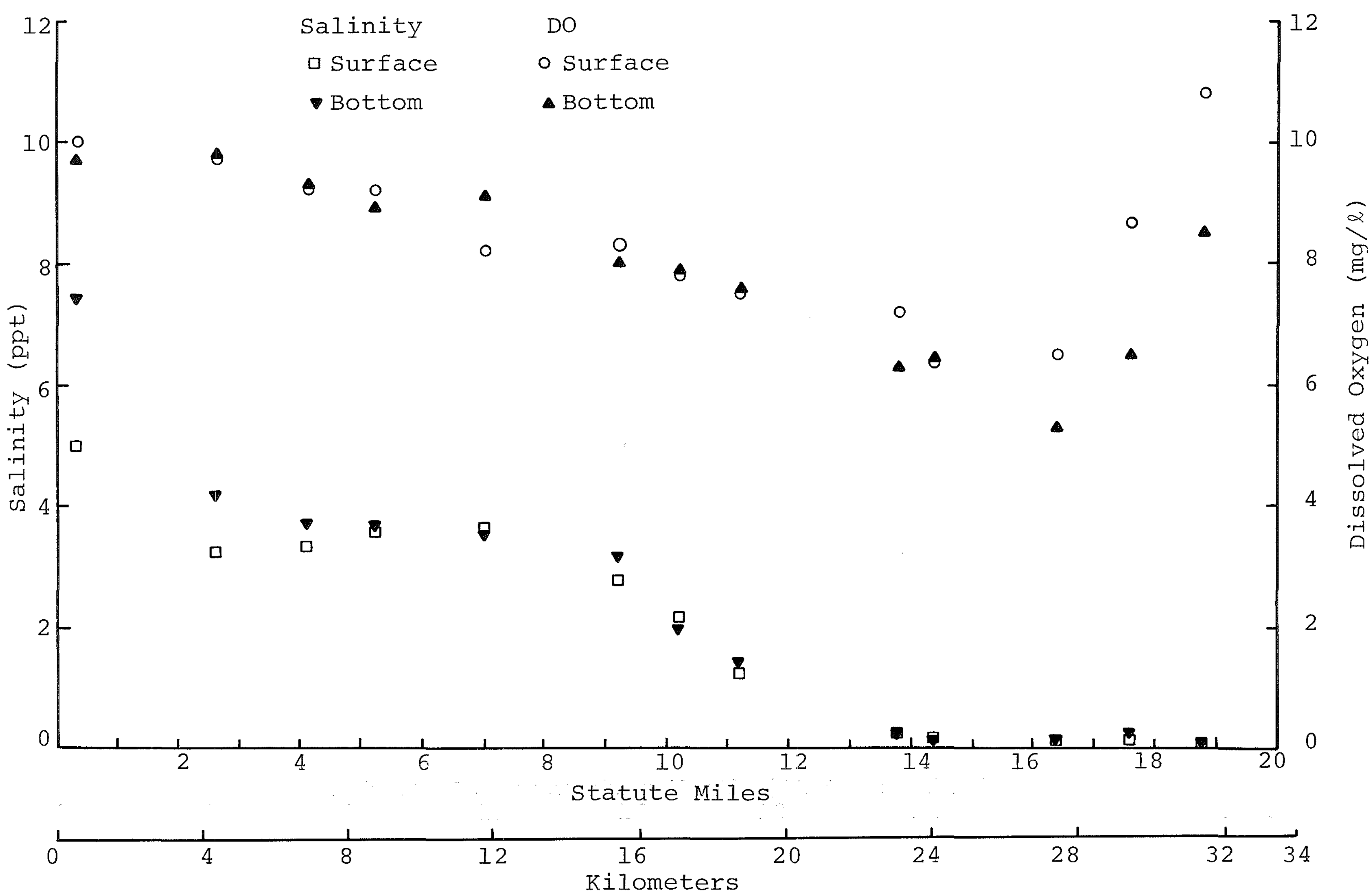
Kilometer 28.27 (mile 17.57).



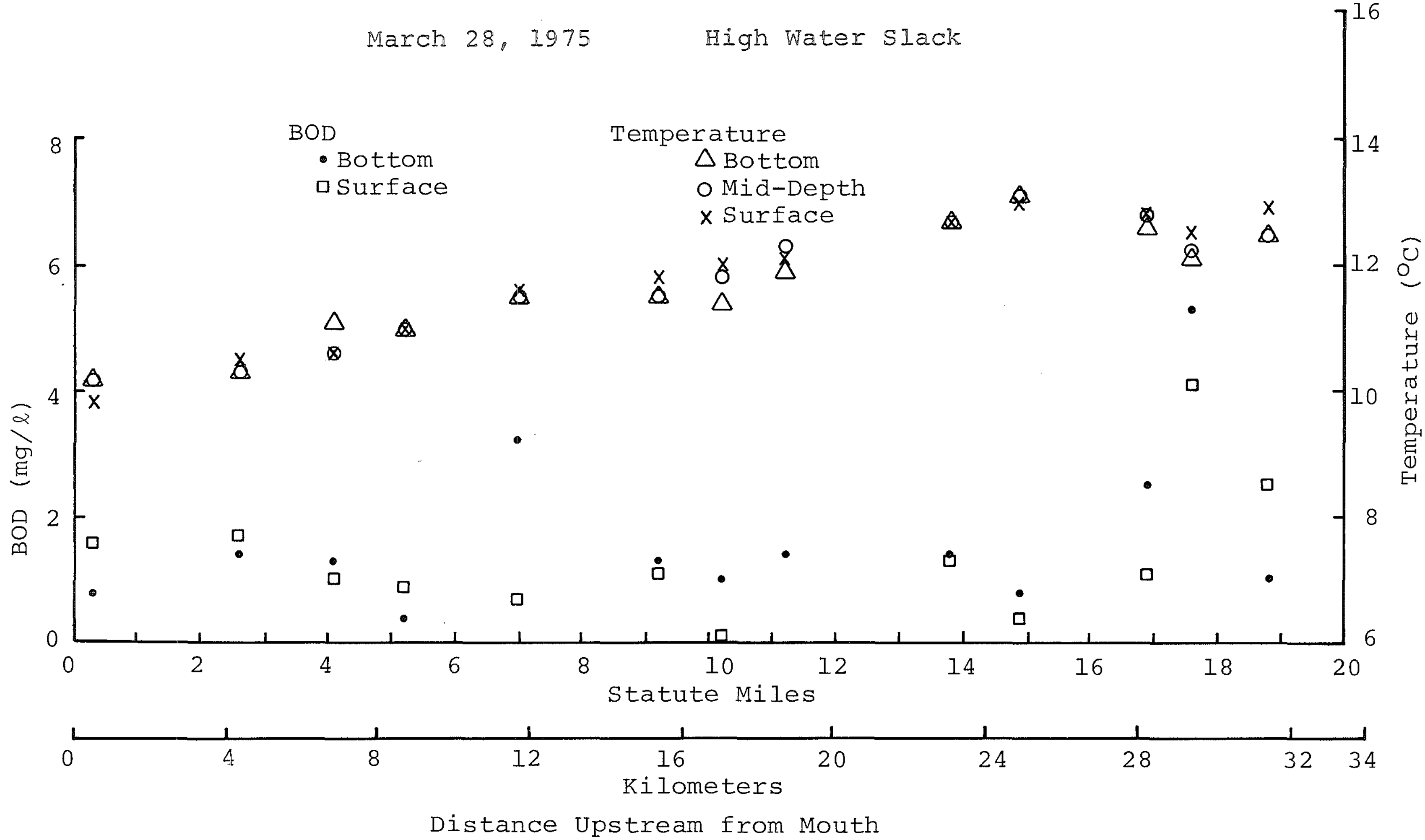
Kilometer 29.76 (mile 18.6).



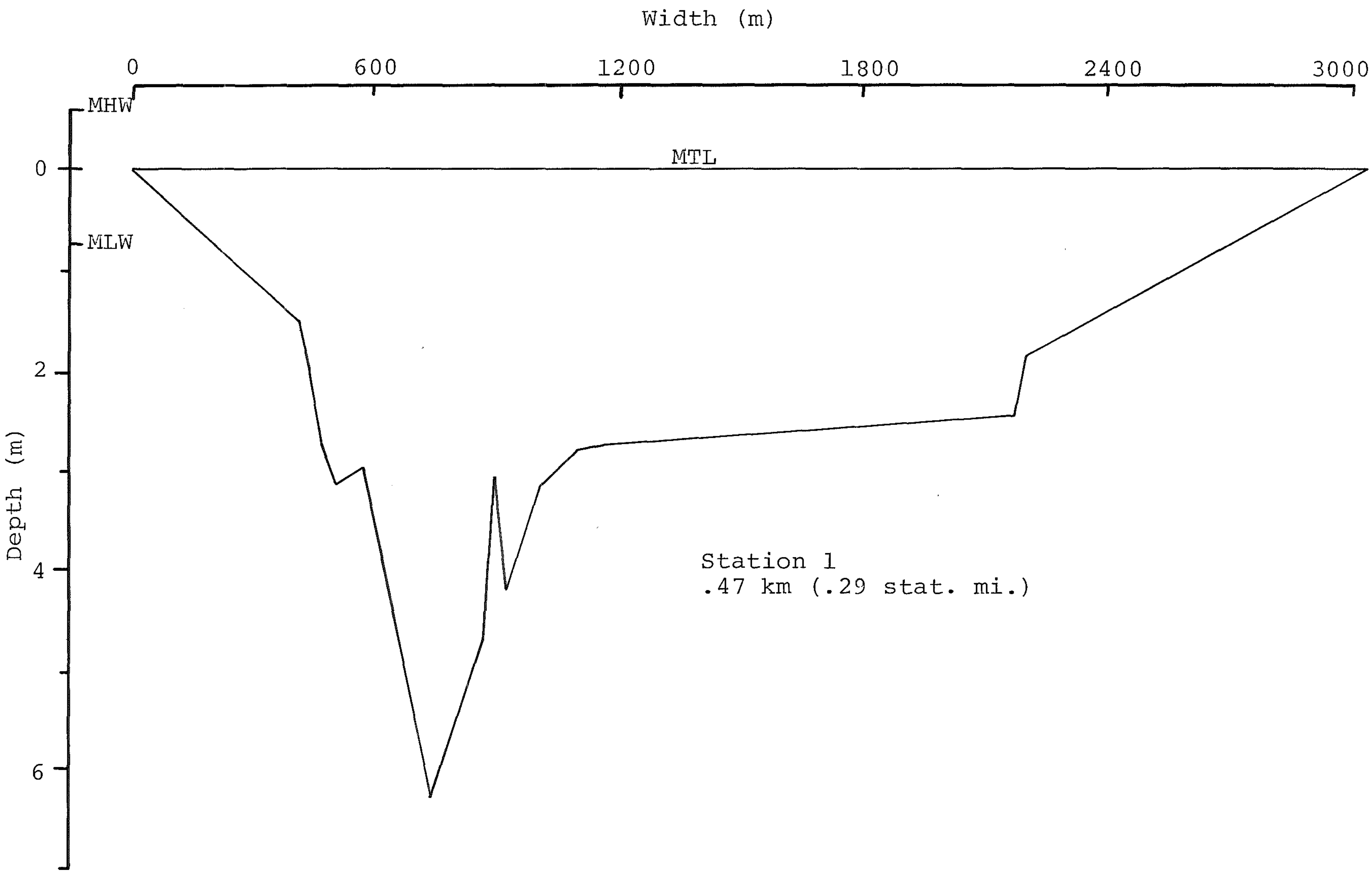
March 28, 1975 High Water Slack



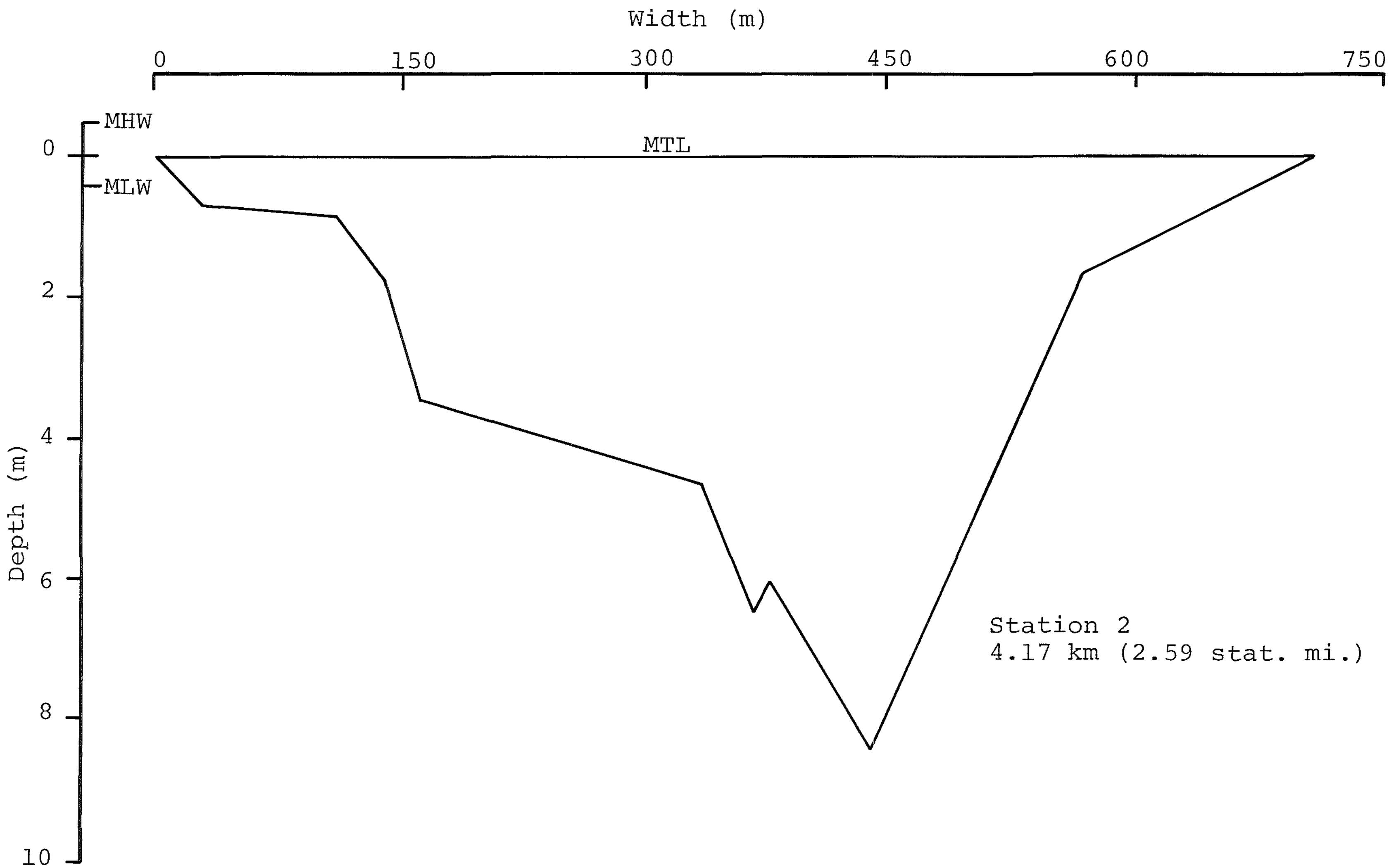
Distance Upstream from Mouth



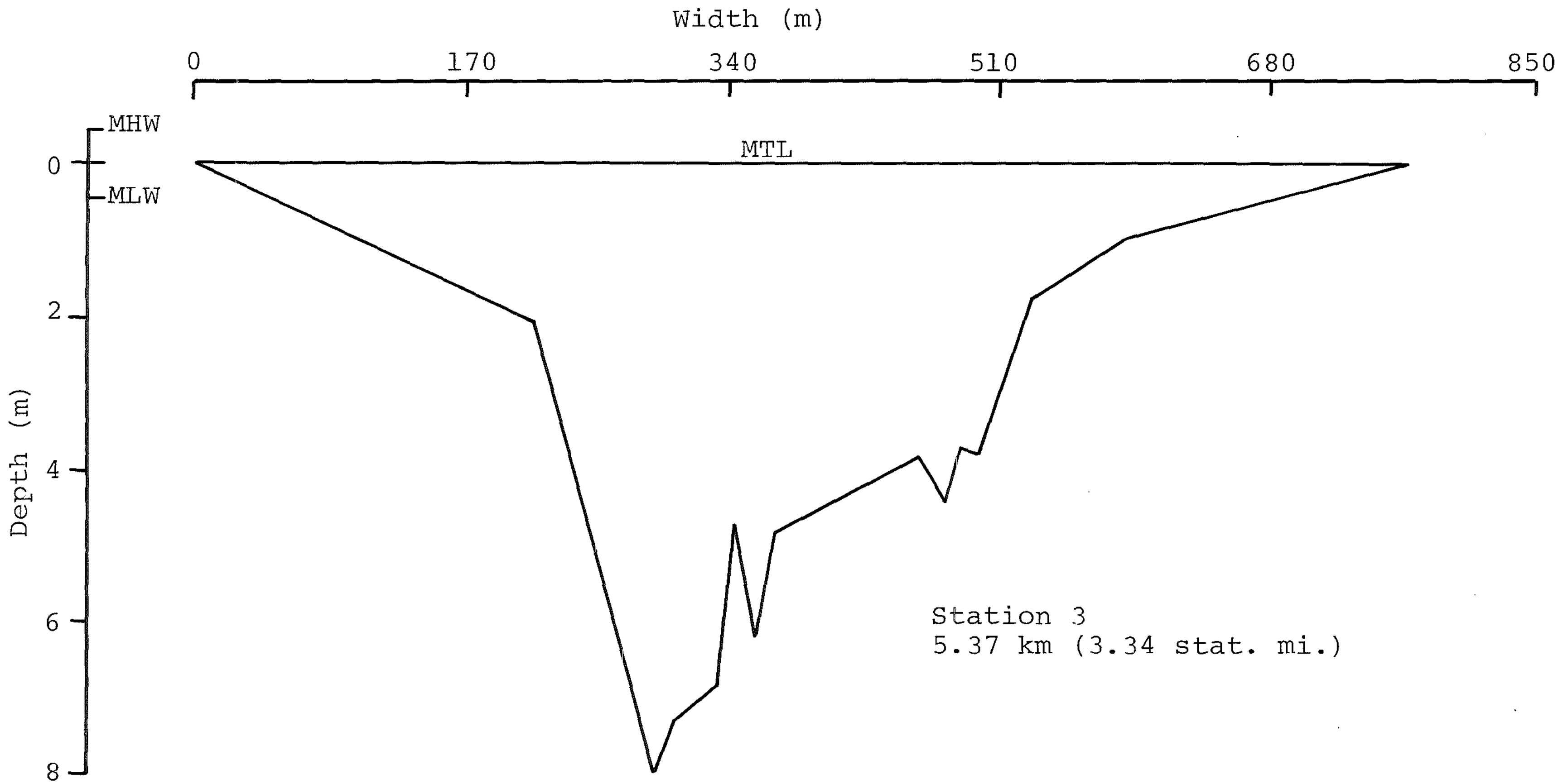
March 28, 1975
High Water Slack
BOD
Bottom
Surface
Temperature
Bottom
Mid-Depth
Surface
BOD (mg/ℓ)
Temperature (°C)
0
2
4
6
8
6
8
10
12
14
16
0
2
4
6
8
10
12
14
16
18
20
Statute Miles
0
4
8
12
16
20
24
28
32
34
Kilometers
Distance Upstream from Mouth

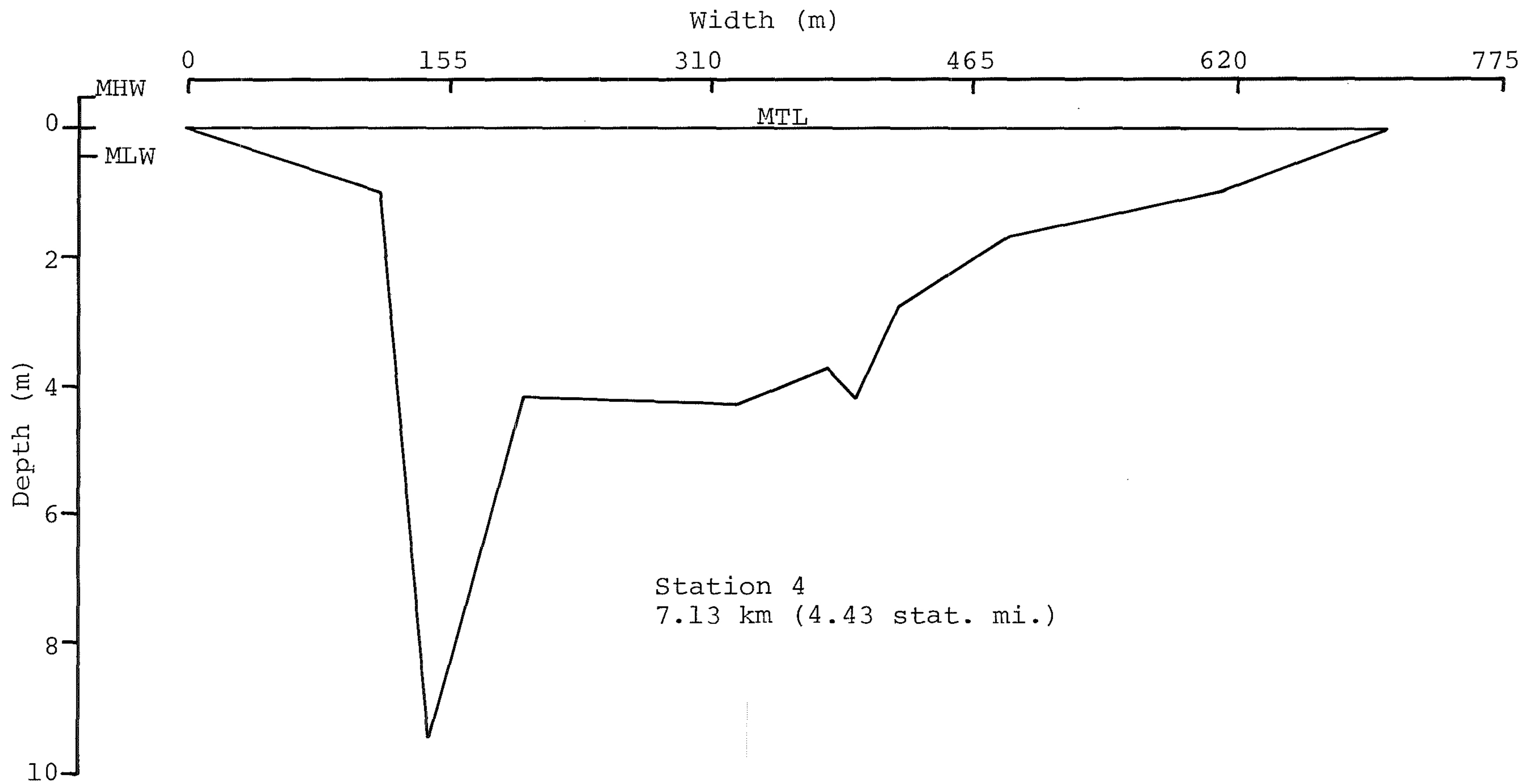


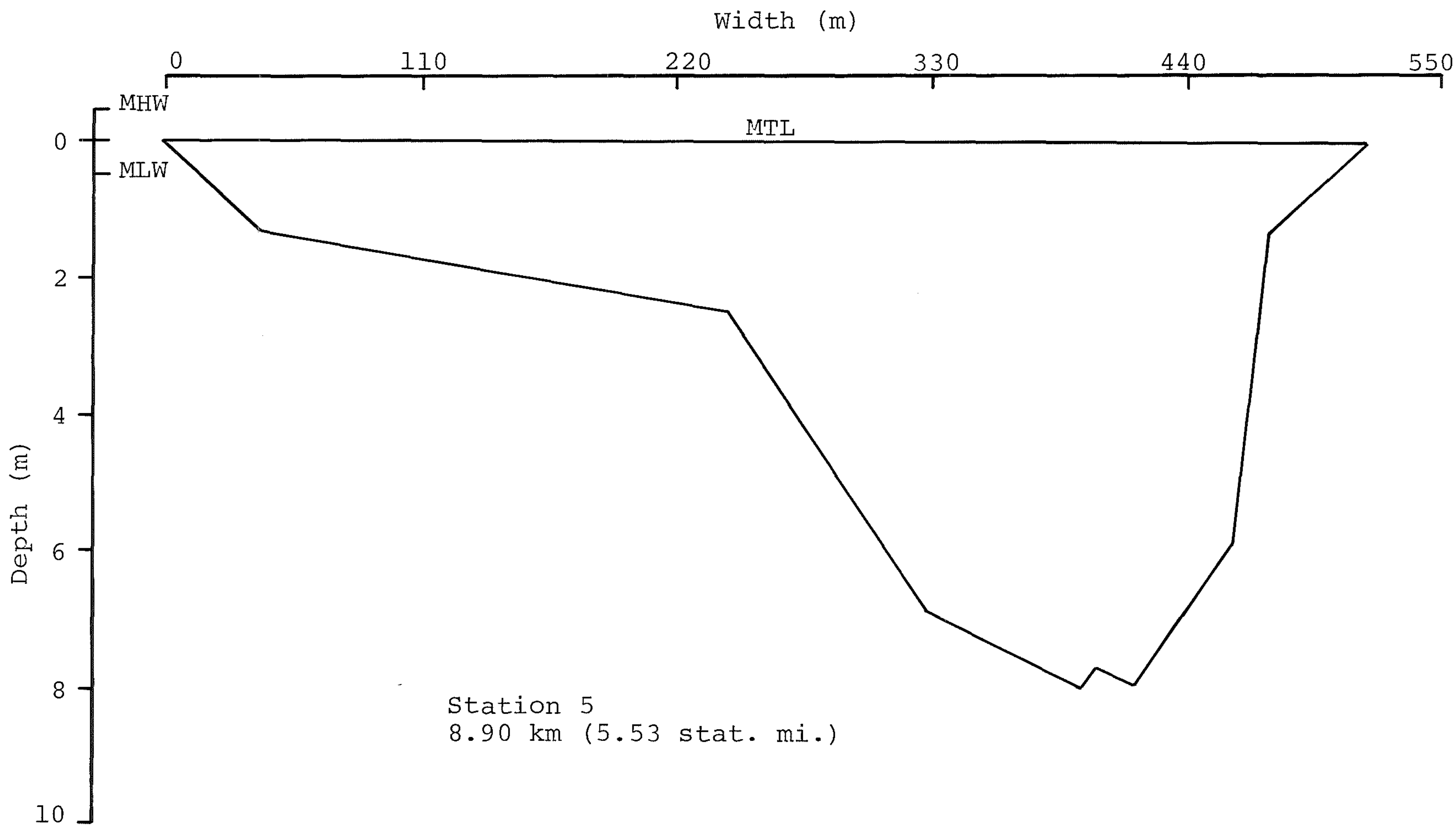
Width (m)
0
600
1200
1800
2400
3000
MHW
MTL
0
MLW
2
Depth (m)
4
6
Station 1
.47 km (.29 stat. mi.)



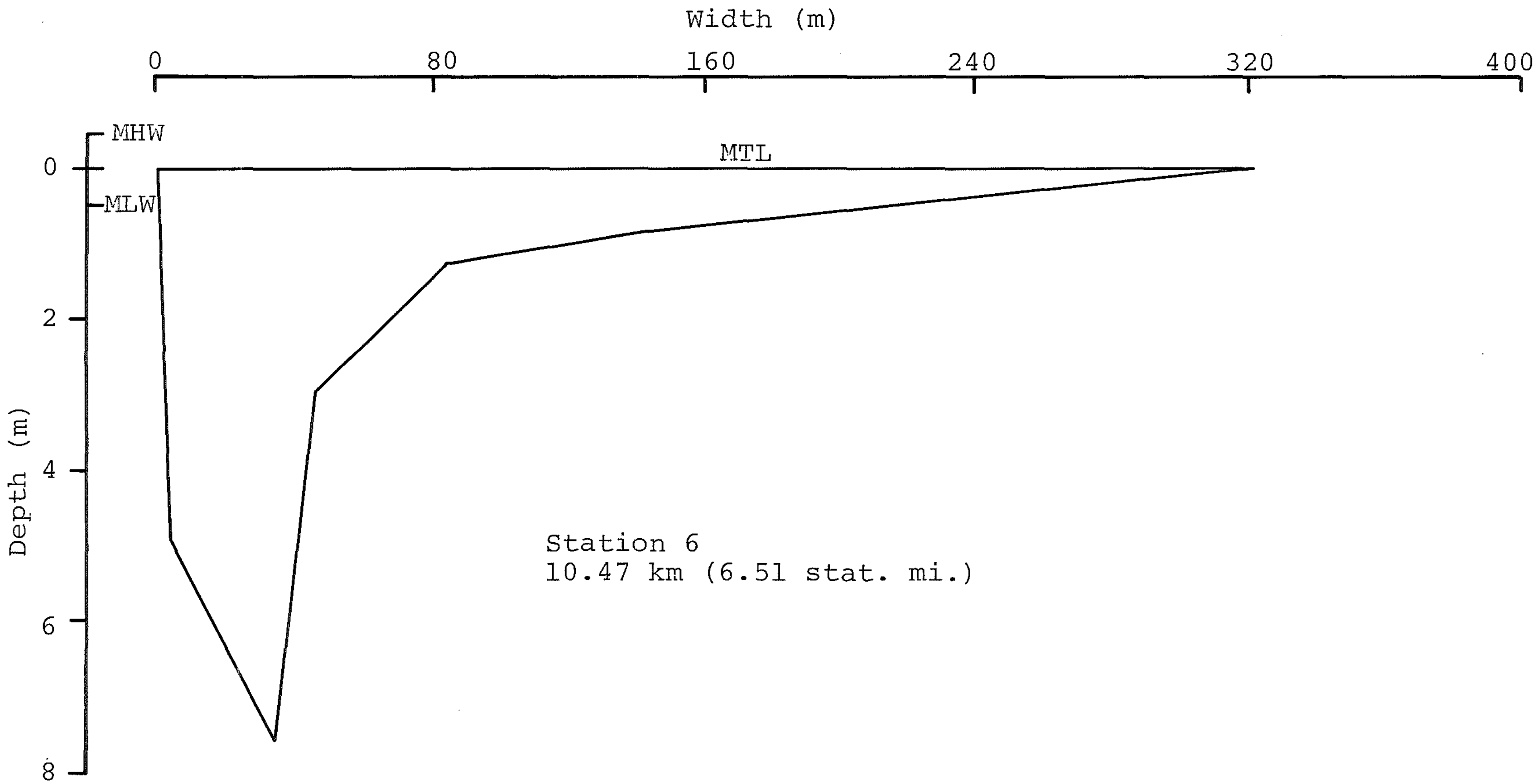
Width (m)
0
150
300
450
600
750
MHW
MTL
MLW
0
2
4
6
8
10
Depth (m)
Station 2
4.17 km (2.59 stat. mi.)

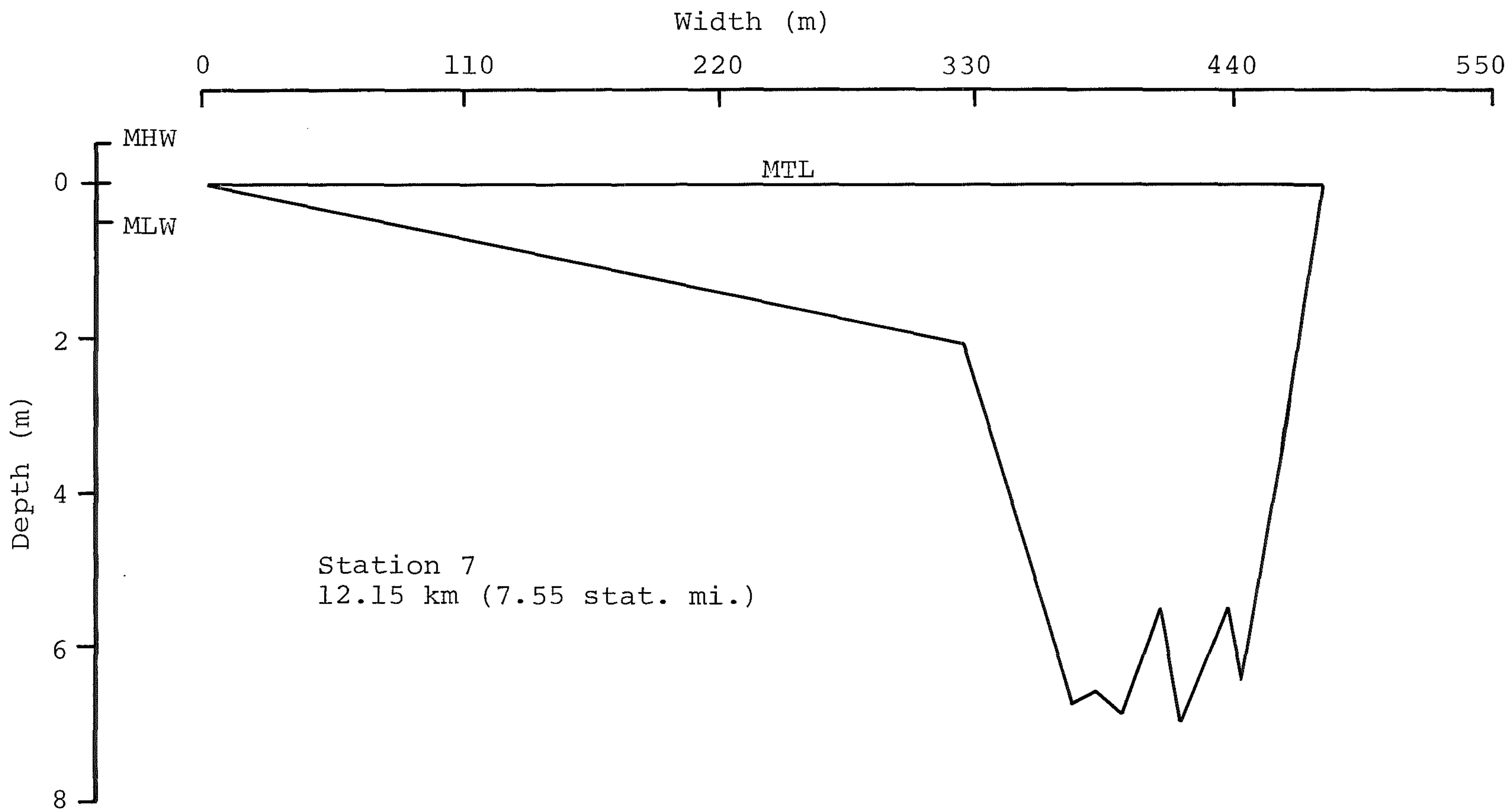

Width (m)
0
170
340
510
680
850
MHW
0
MLW
MTL
2
Depth (m)
4
6
8
Station 3
5.37 km (3.34 stat. mi.)

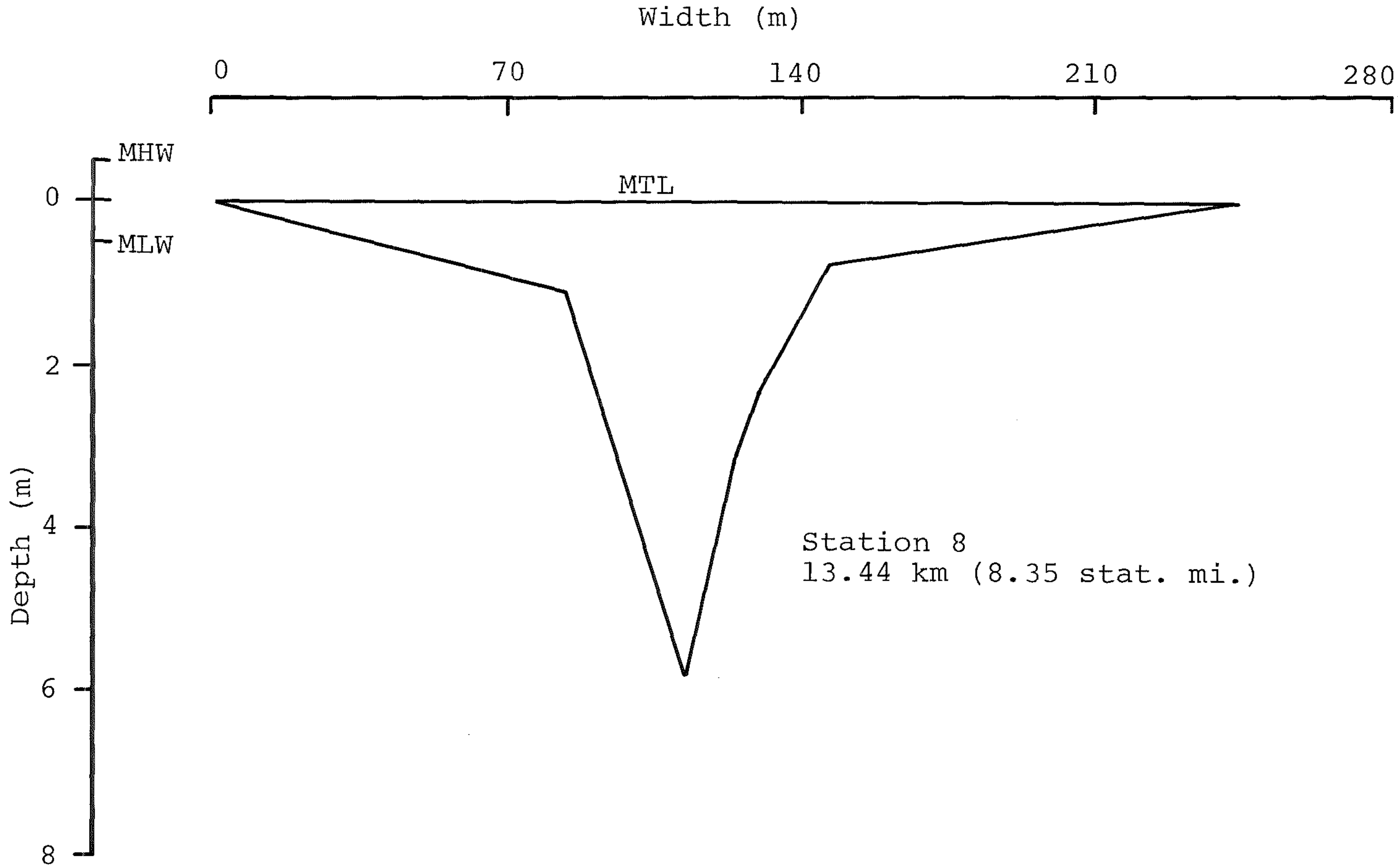

Width (m)
0
155
310
465
620
775
MHW
0
MLW
MTL
2
4
6
8
10
Depth (m)
Station 4
7.13 km (4.43 stat. mi.)

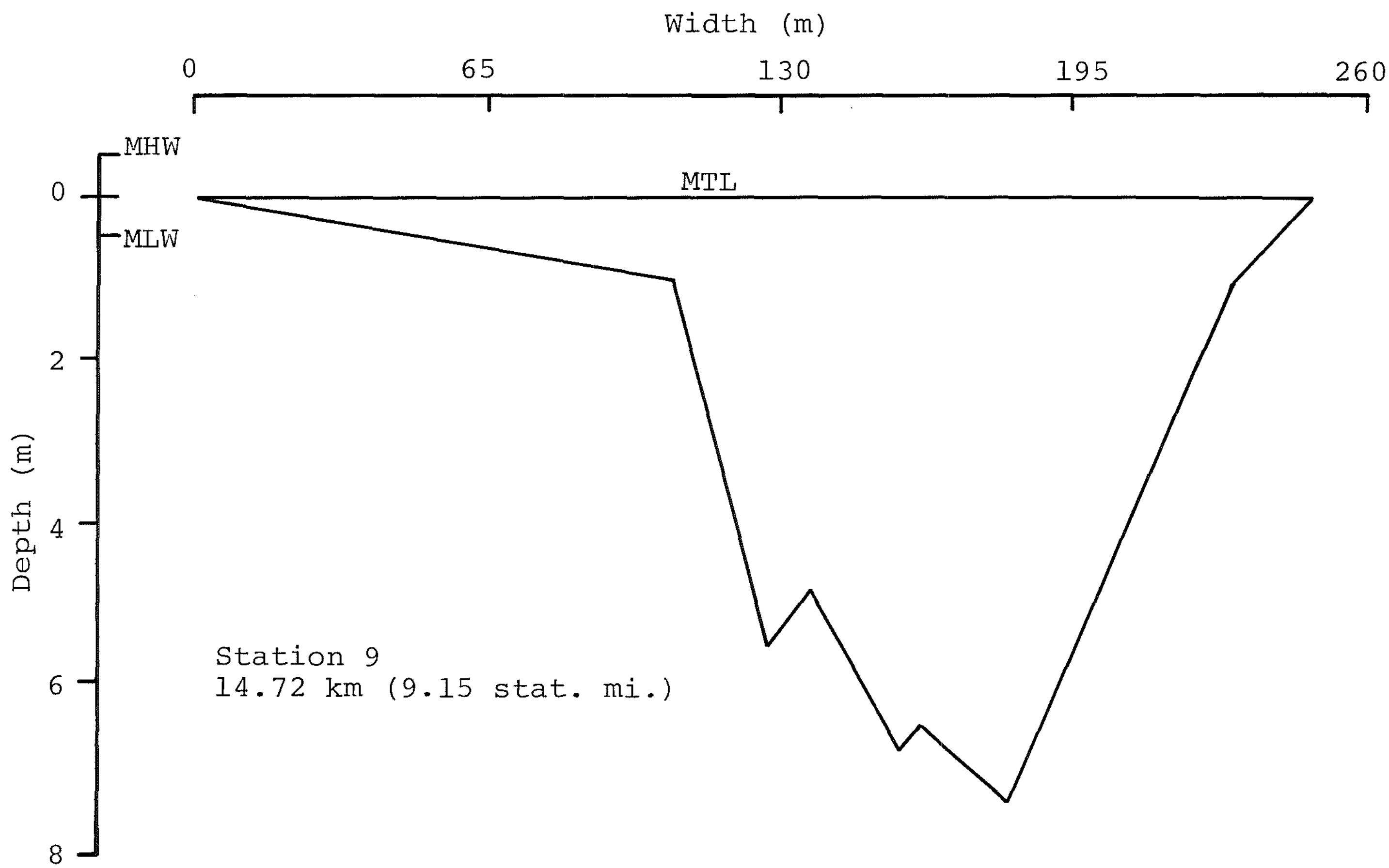


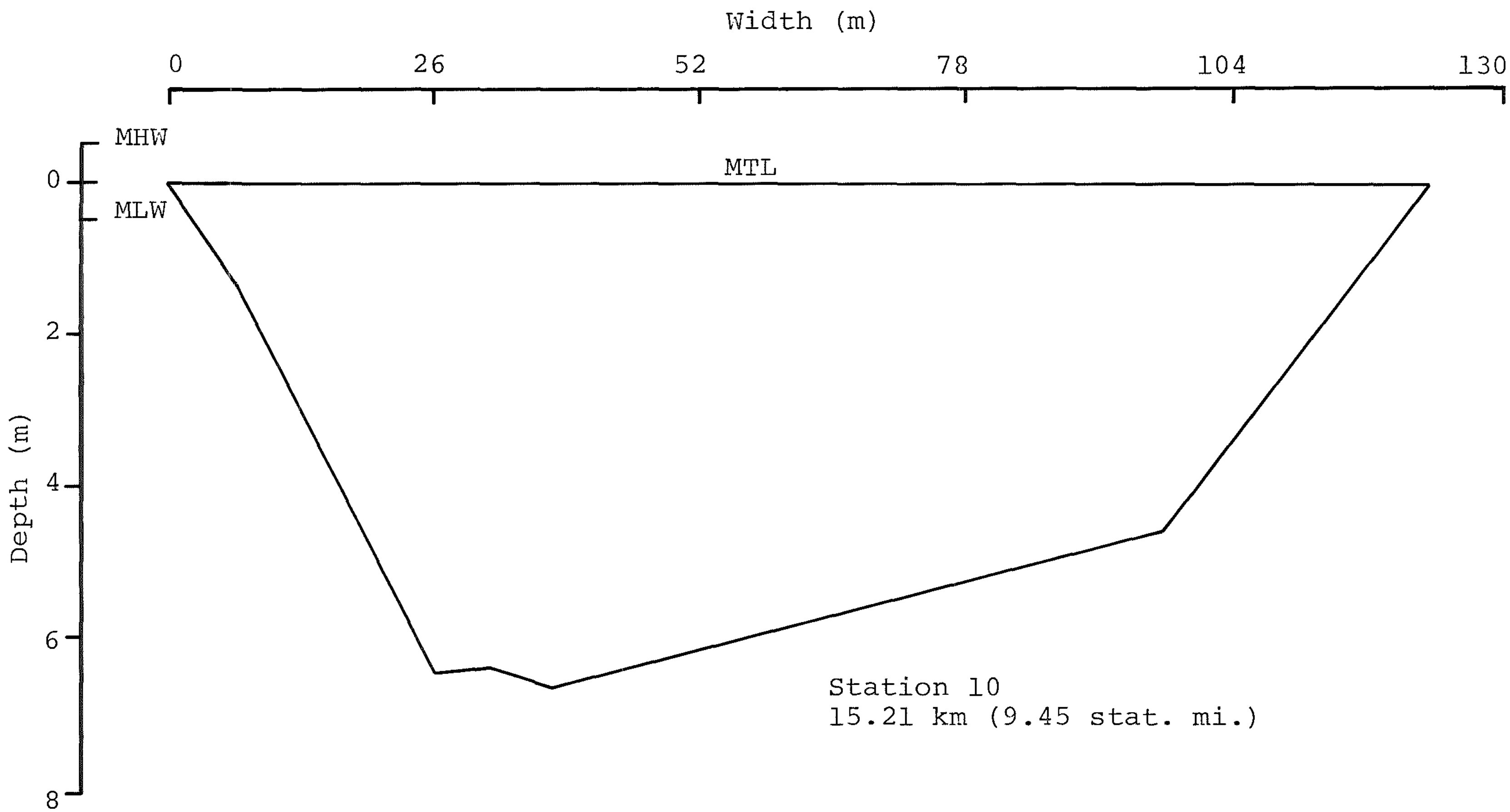
Station 5
8.90 km (5.53 stat. mi.)

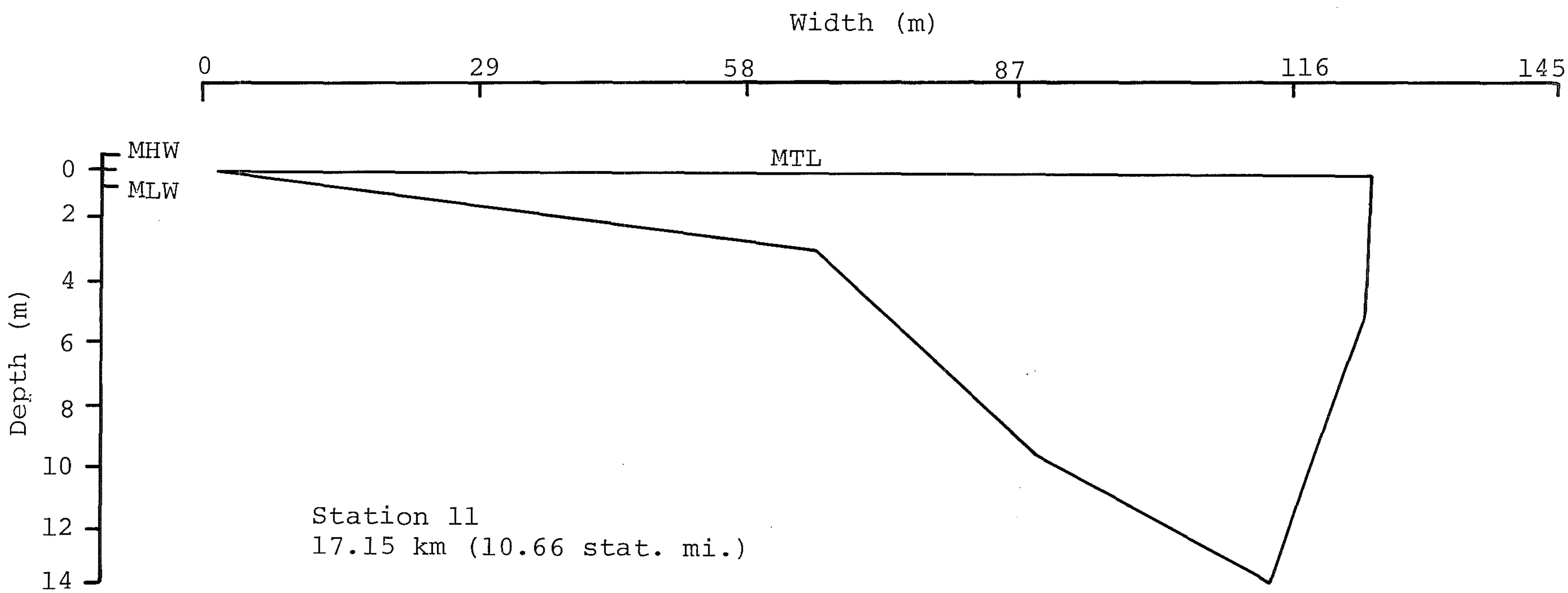

Width (m)
0
80
160
240
320
400
MHW
MTL
0
MLW
2
4
6
8
Depth (m)
Station 6
10.47 km (6.51 stat. mi.)

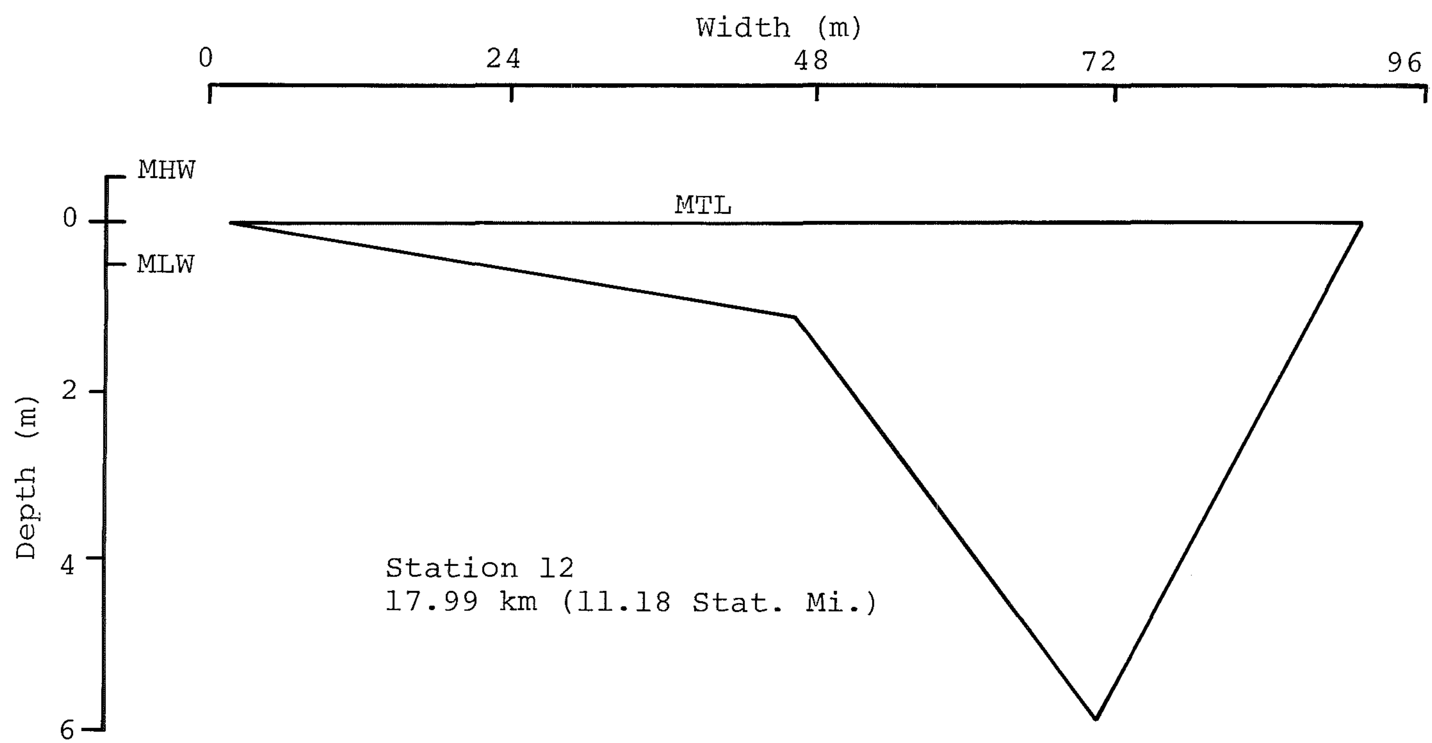

Width (m)
0
110
220
330
440
550
MHW
0
MLW
MTL
2
4
6
8
Depth (m)
Station 7
12.15 km (7.55 stat. mi.)


Width (m)
0
70
140
210
280
MHW
0
MTL
MLW
2
Depth (m)
4
6
8
Station 8
13.44 km (8.35 stat. mi.)

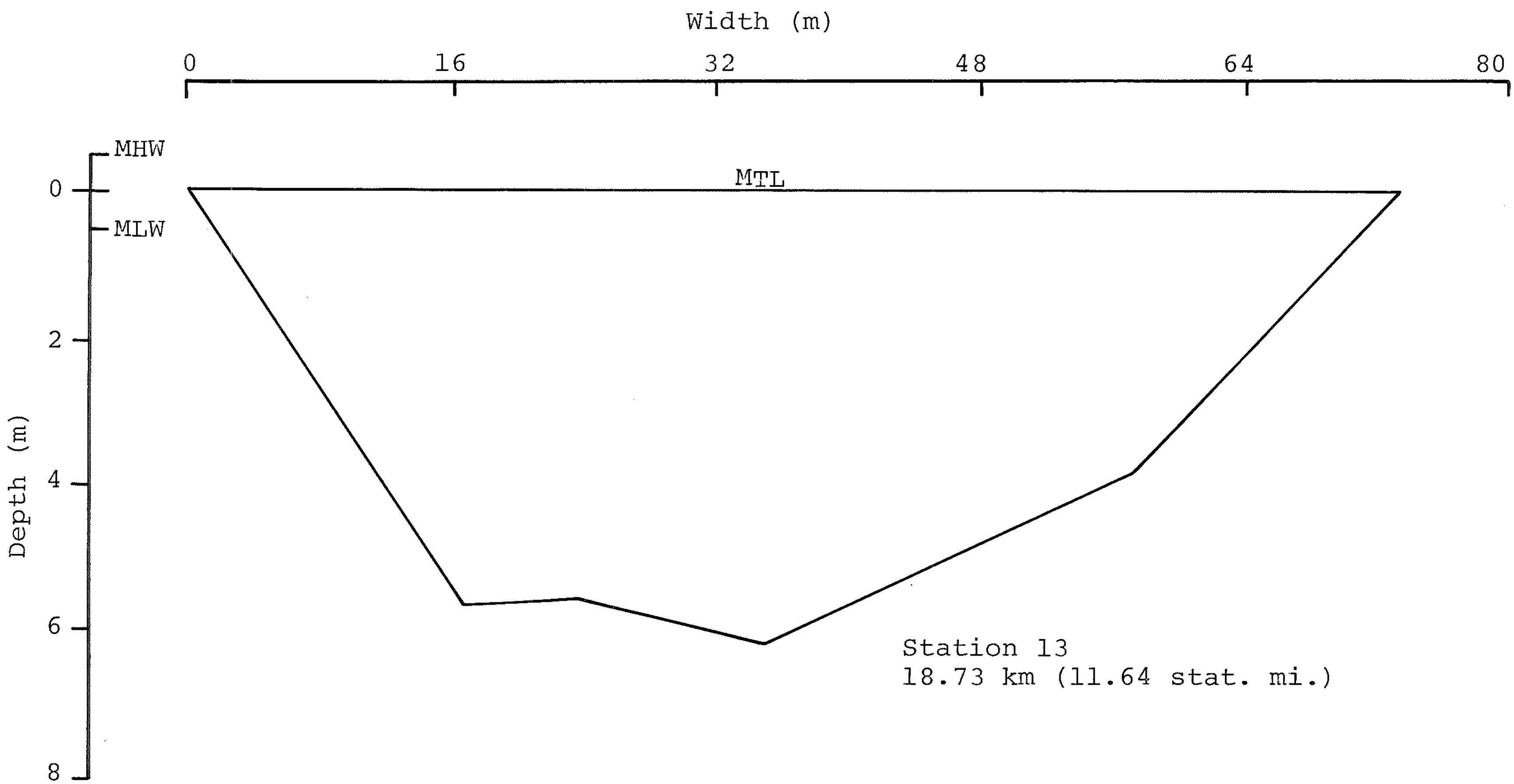

Width (m)
0
65
130
195
260
MHW
0
MTL
MLW
2
Depth (m)
4
6
8
Station 9
14.72 km (9.15 stat. mi.)


Width (m)
0
26
52
78
104
130
MHW
MTL
0
MLW
2
4
6
8
Depth (m)
Station 10
15.21 km (9.45 stat. mi.)

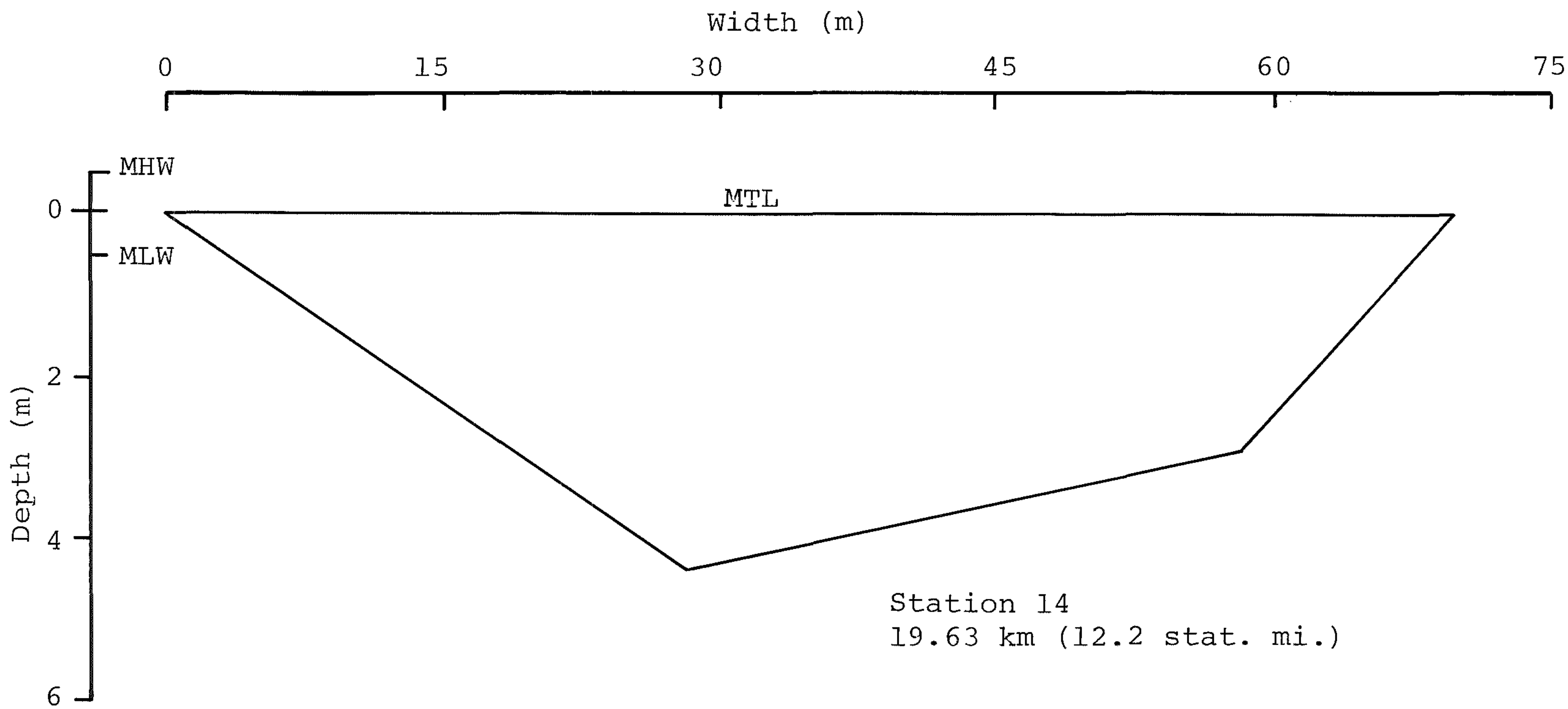

Width (m)
0
29
58
87
116
145
MHW
MLW
MTL
Depth (m)
0
2
4
6
8
10
12
14
Station 11
17.15 km (10.66 stat. mi.)

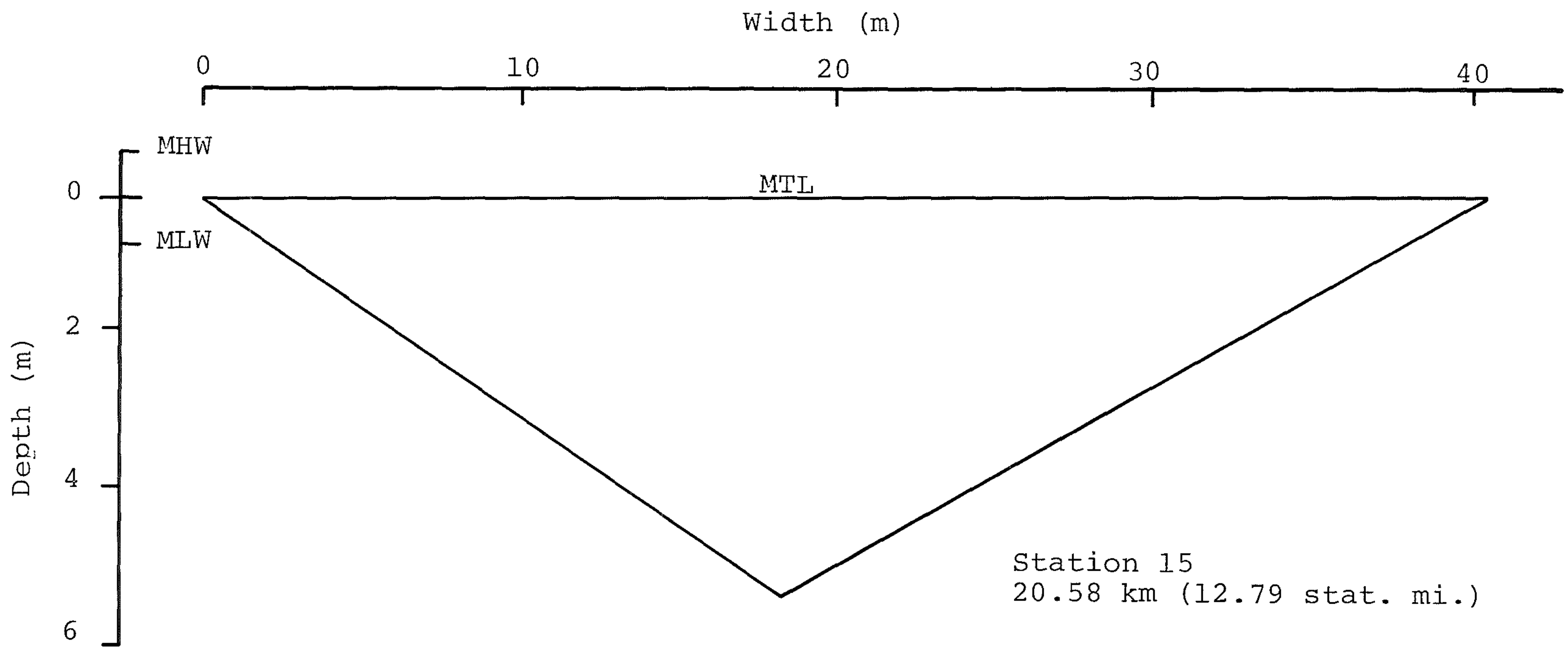


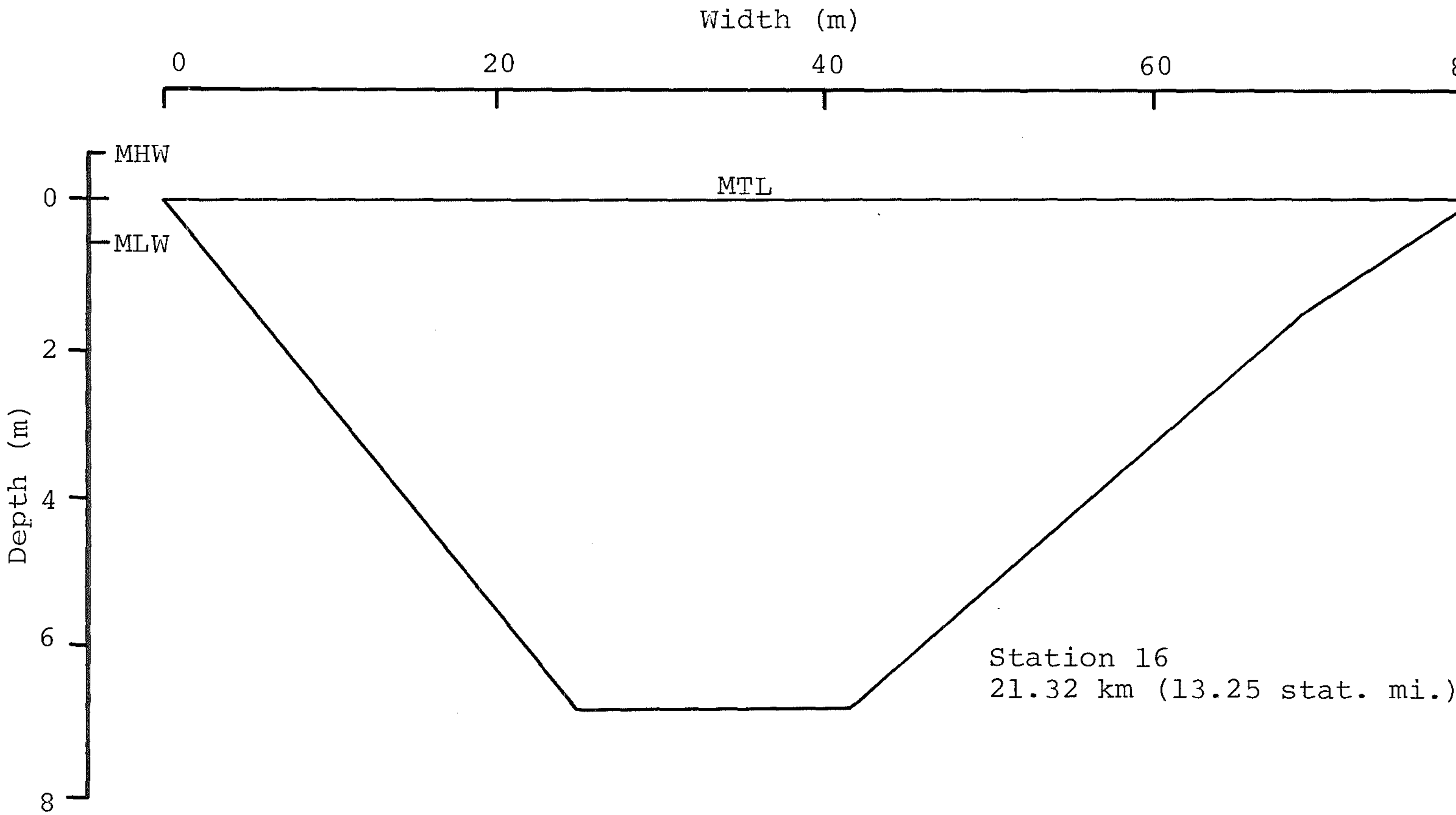
Width (m)
0
24
48
72
96
MHW
0
MTL
MLW
2
Depth (m)
4
6
Station 12
17.99 km (11.18 Stat. Mi.)



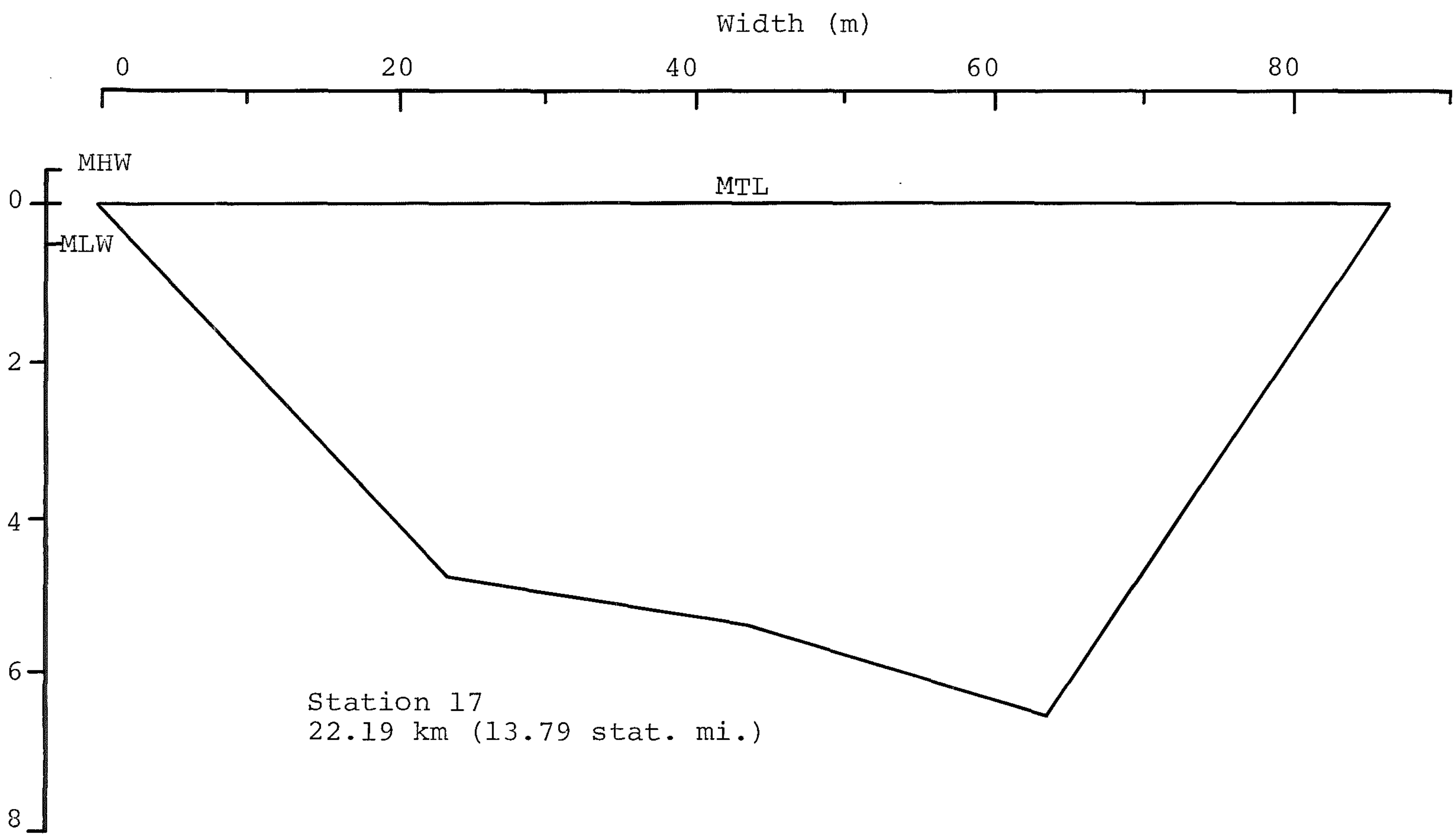
Width (m)
0
16
32
48
64
80
MHW
0
MLW
MTL
2
Depth (m)
4
6
8
Station 13
18.73 km (11.64 stat. mi.)

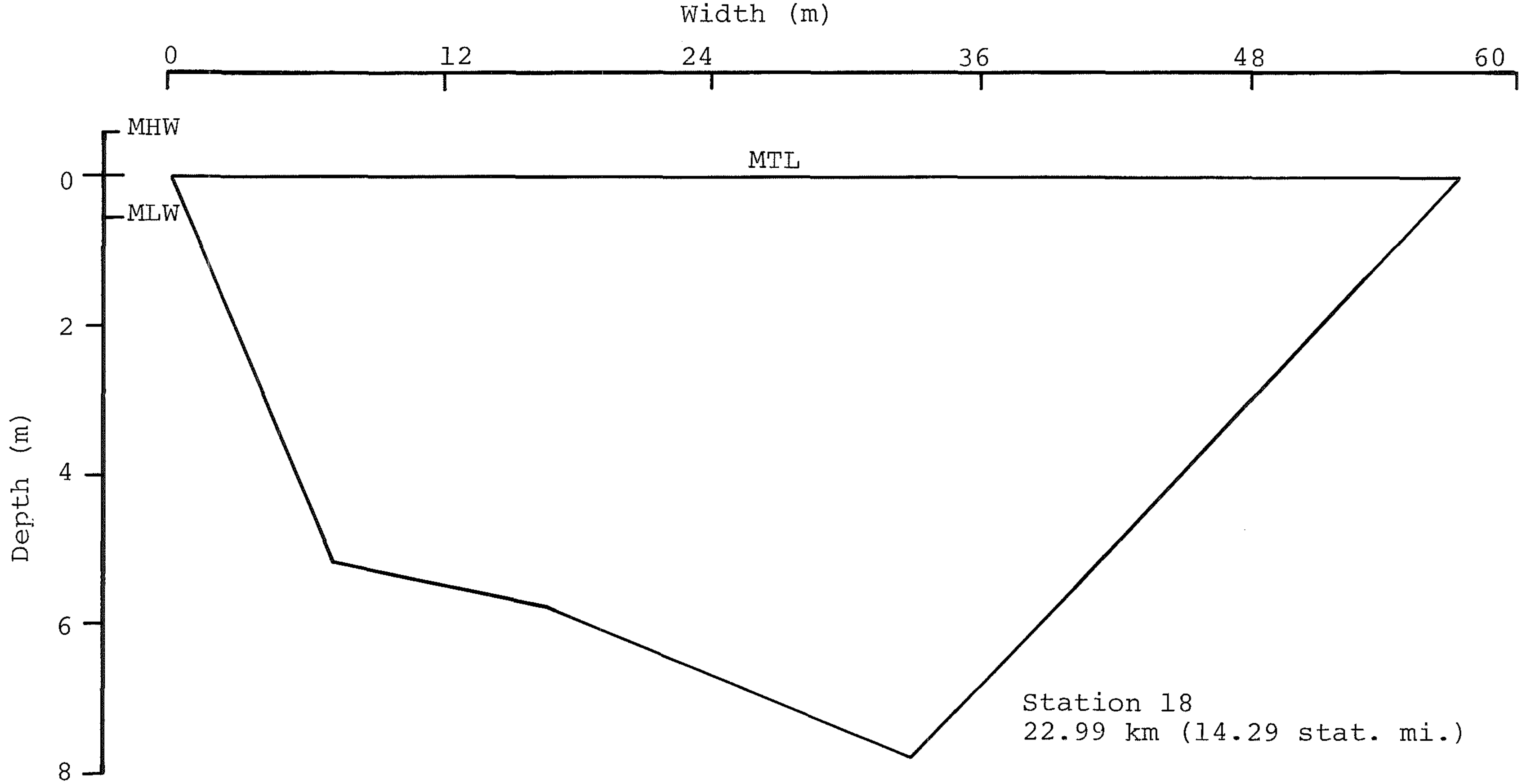

Width (m)
0
15
30
45
60
75
MHW
0
MTL
MLW
2
Depth (m)
4
6
Station 14
19.63 km (12.2 stat. mi.)

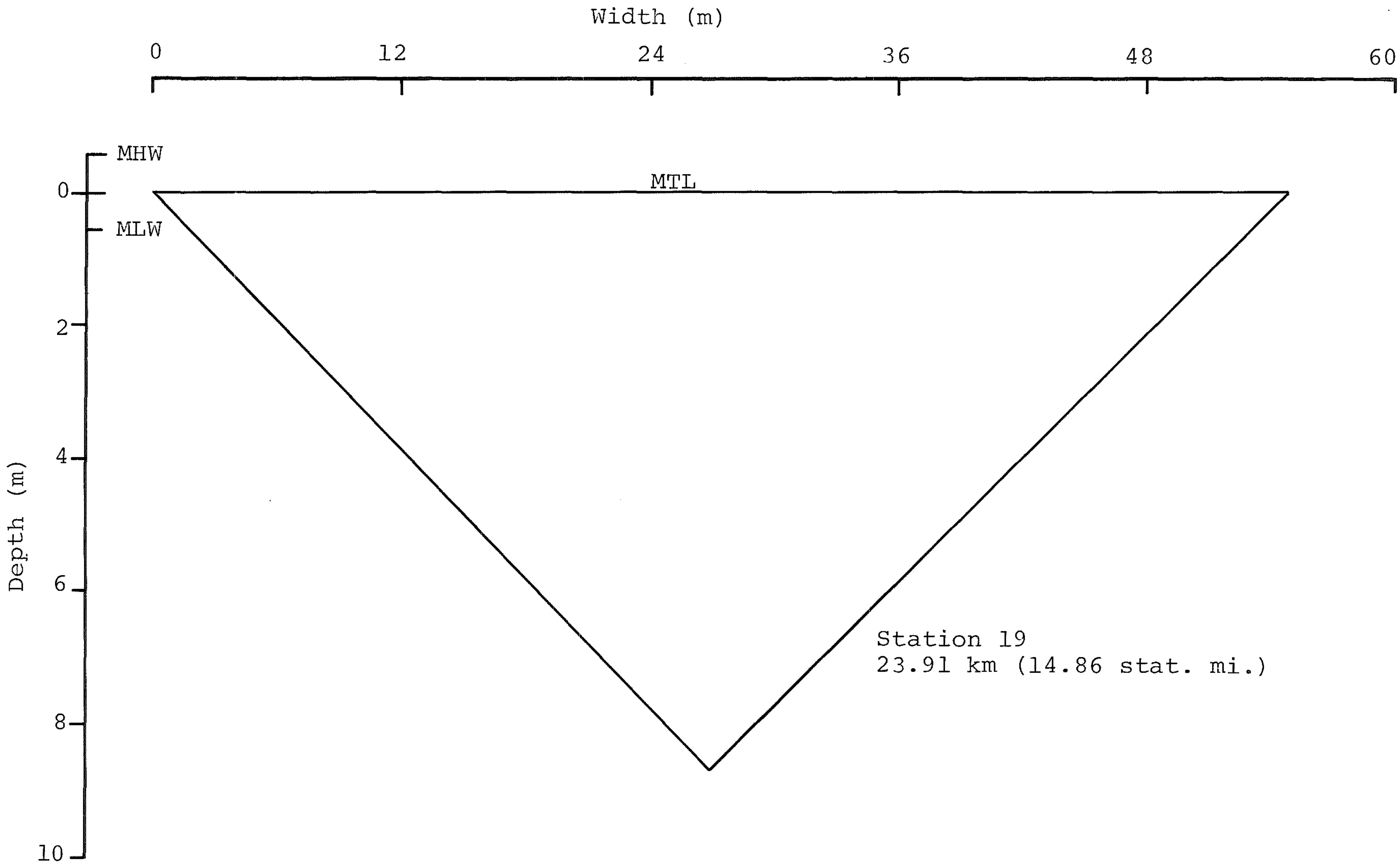

Width (m)
0
10
20
30
40
MHW
0
MTL
MLW
2
Depth (m)
4
6
Station 15
20.58 km (12.79 stat. mi.)



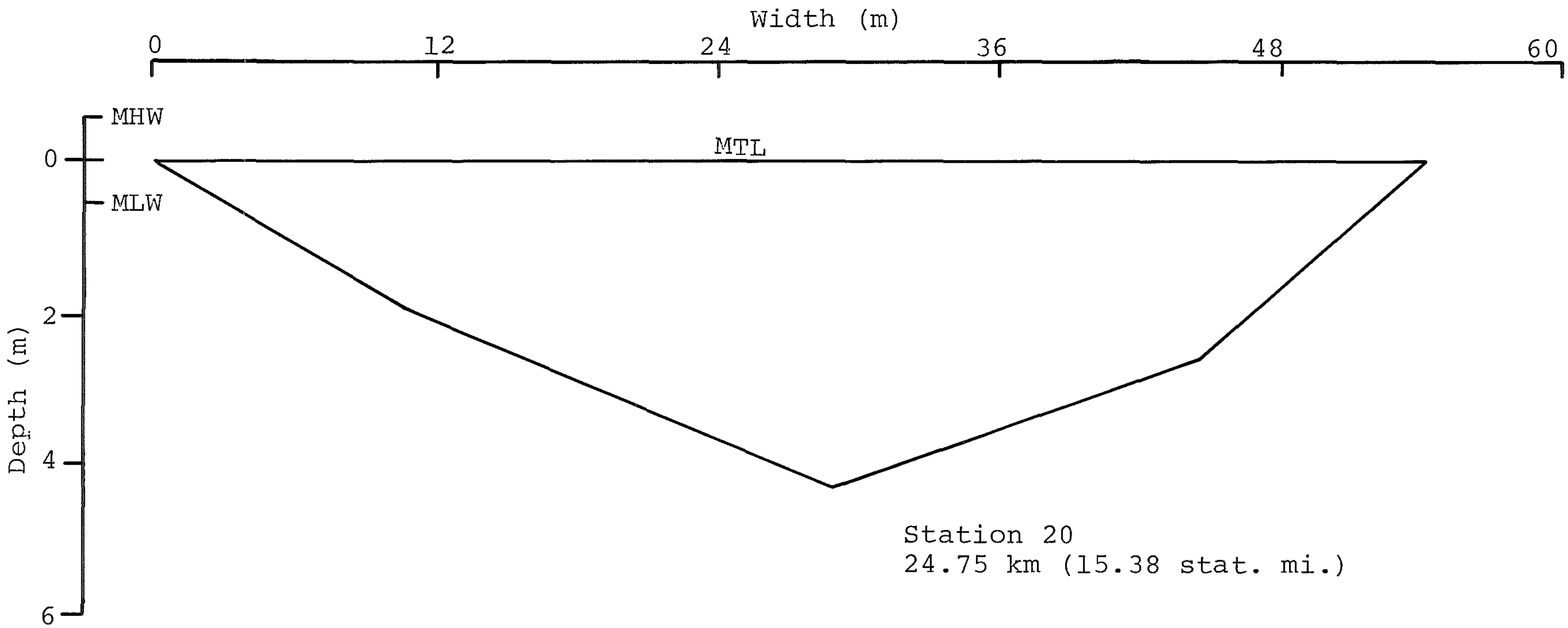
Width (m)
0
20
40
60
80
MHW
0
MTL
MLW
2
Depth (m)
4
6
8
Station 16
21.32 km (13.25 stat. mi.)


Width (m)
0
20
40
60
80
MHW
MTL
MLW
0
2
4
6
8
Station 17
22.19 km (13.79 stat. mi.)

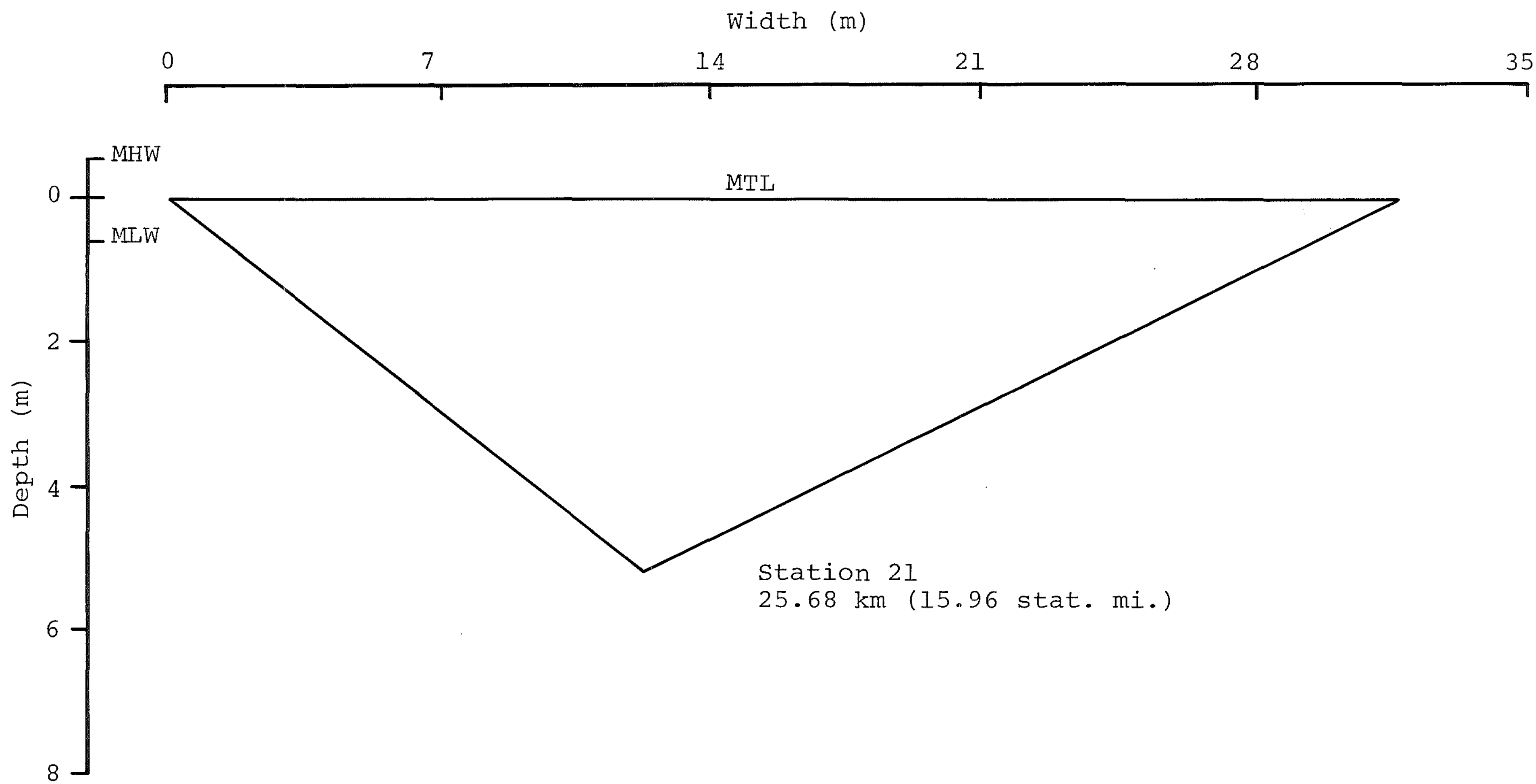

Width (m)
0
12
24
36
48
60
MHW
MTL
MLW
Depth (m)
0
2
4
6
8
Station 18
22.99 km (14.29 stat. mi.)

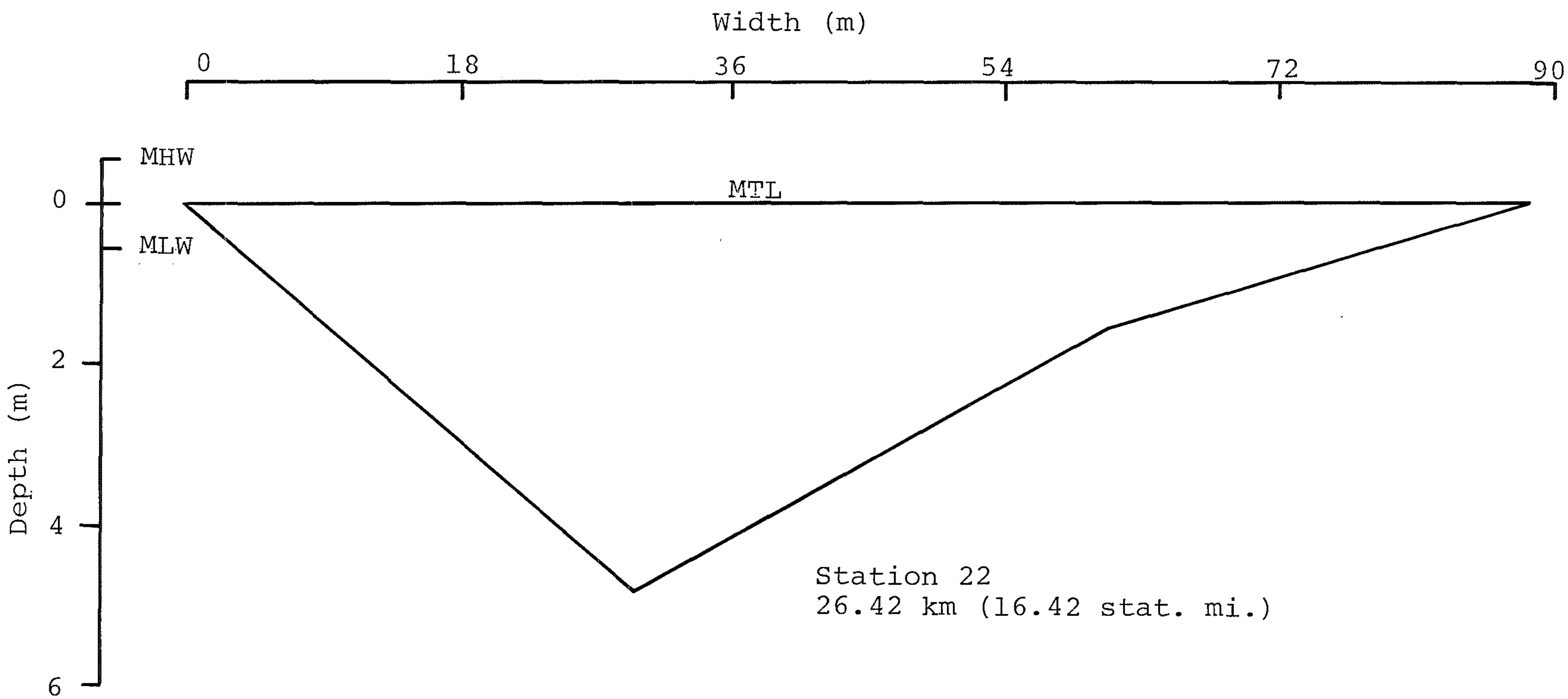


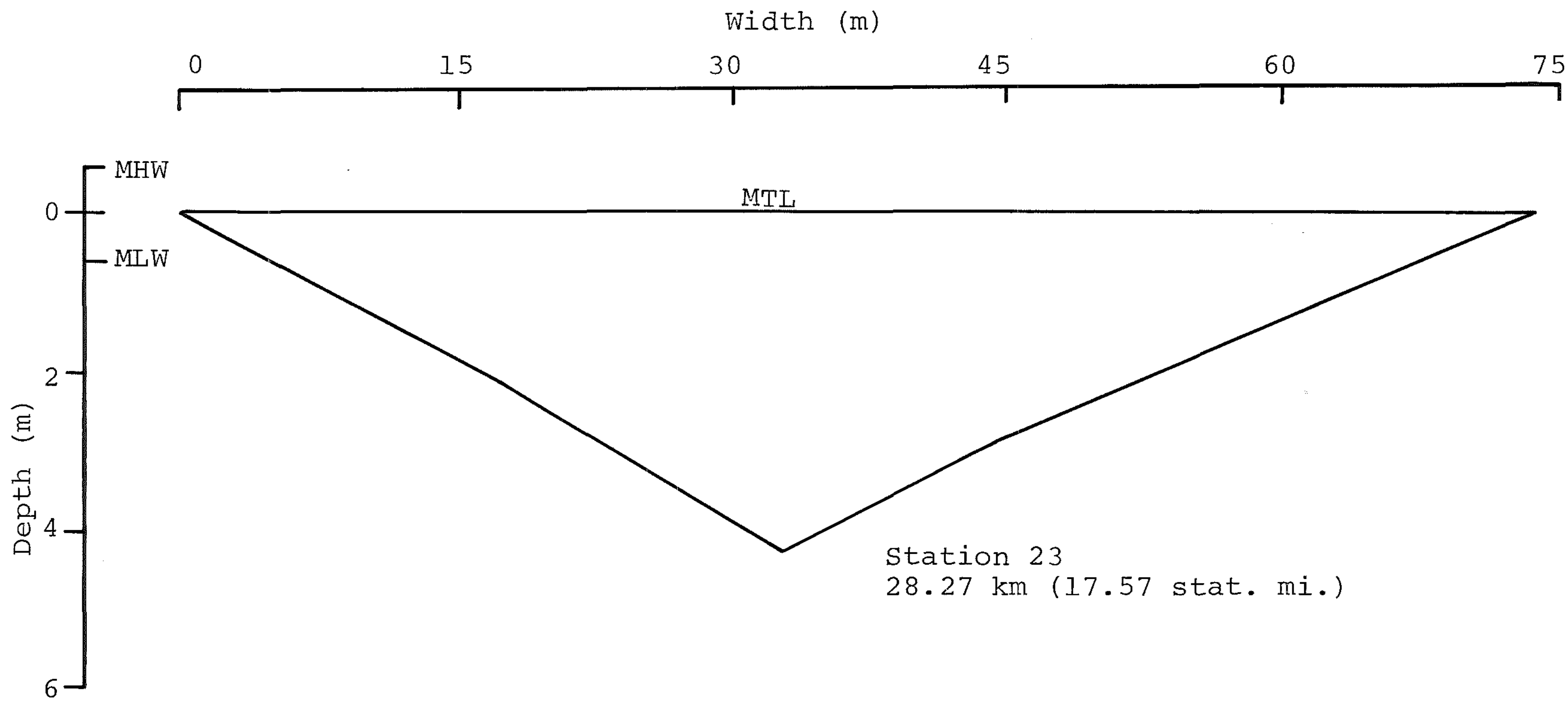
Width (m)
0
12
24
36
48
60
MHW
MTL
MLW
Depth (m)
0
2
4
6
8
10
Station 19
23.91 km (14.86 stat. mi.)



Station 20
24.75 km (15.38 stat. mi.)


Width (m)
0
7
14
21
28
35
MHW
0
MTL
MLW
2
Depth (m)
4
6
8
Station 21
25.68 km (15.96 stat. mi.)


Width (m)
0
18
36
54
72
90
MHW
0
MTL
MLW
2
Depth (m)
4
6
Station 22
26.42 km (16.42 stat. mi.)


Width (m)
0
15
30
45
60
75
MHW
MTL
0
MLW
2
Depth (m)
4
6
Station 23
28.27 km (17.57 stat. mi.)